# THE STAR FORMATION NEWSLETTER

*An electronic publication dedicated to early stellar/planetary evolution and molecular clouds*

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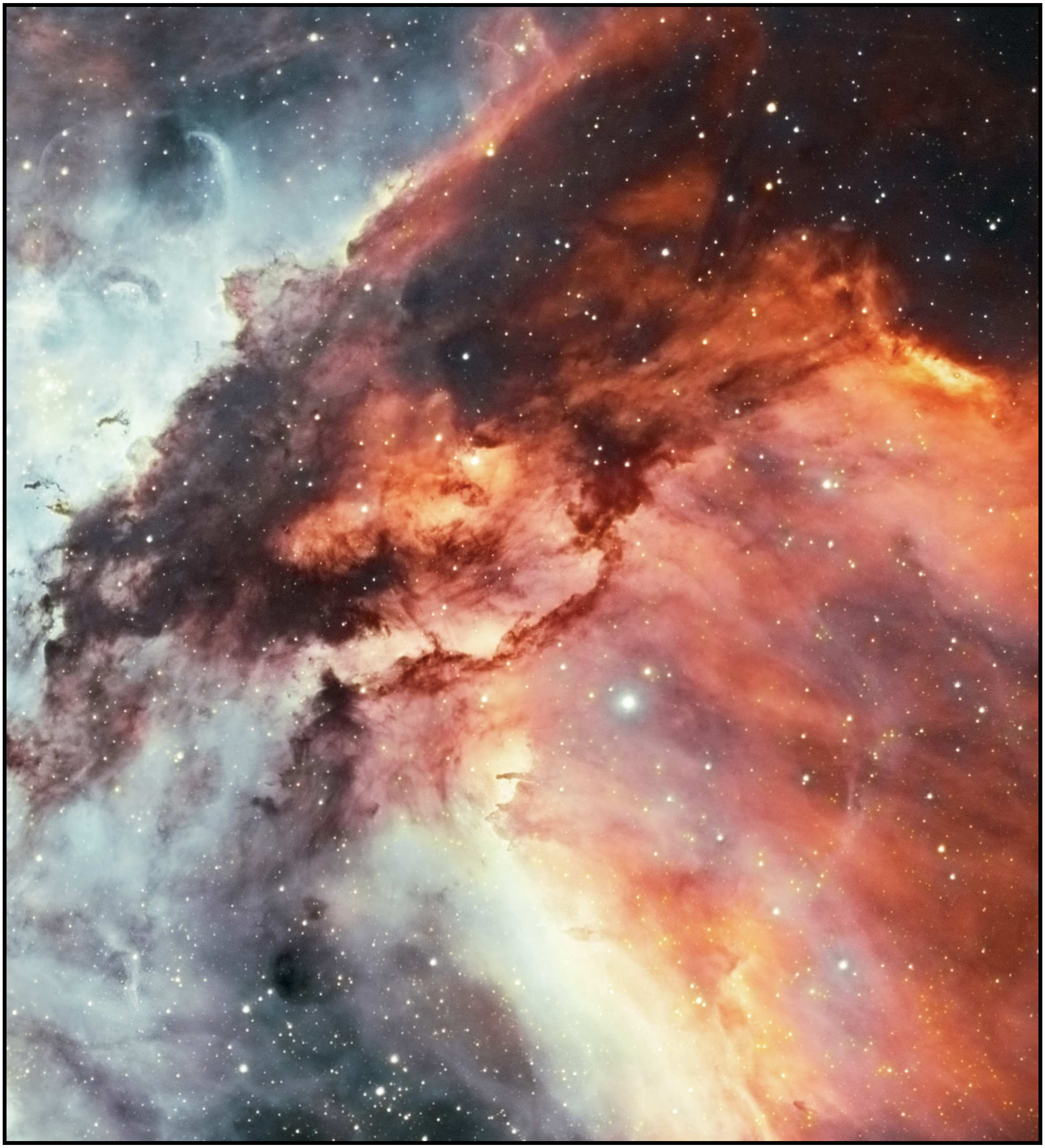

# The Star Formation Newsletter

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The Star Formation Newsletter is a vehicle for fast distribution of information of interest for astronomers working on star and planet formation and molecular clouds. You can submit material for the following sections: *Abstracts of recently accepted papers* (only for papers sent to refereed journals), *Abstracts of recently accepted major reviews* (not standard conference contributions), *Dissertation Abstracts* (presenting abstracts of new Ph.D dissertations), *Meetings* (announcing meetings broadly of interest to the star and planet formation and early solar system community), *New Jobs* (advertising jobs specifically aimed towards persons within the areas of the Newsletter), and *Short Announcements* (where you can inform or request information from the community). Additionally, the Newsletter brings short overview articles on objects of special interest, physical processes or theoretical results, the early solar system, as well as occasional interviews.

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## Cover Picture

The Carina Nebula is a rich star forming region at a distance of about 2.3 kpc with about 65 O-stars distributed in several clusters and producing powerful UV radiation that sculpts the surrounding molecular clouds. The image shows the dominant northwestern cloud. Eta Carinae is outside the left edge of the image. The Trumpler 14 cluster containing 10 O-stars is seen in the upper left part of the image.

Image courtesy Bastien Foucher (http://www.bastienfoucher.com).

## Submitting your abstracts

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## Bo Reipurth

*in conversation with Hans Zinnecker*

**Q**: *With the present issue #300 of the Star Formation Newsletter you have edited the Newsletter for 25 years. How did it start?*

**A:** When I was a student in Copenhagen in the 1970s it was not so easy to follow the latest developments in astronomy as it is today. The major libraries exchanged preprints, which were especially important because publication times were much longer in those days. Only the largest institutes were reasonably well covered, otherwise if one had been lucky enough to hear about a new interesting preprint, one had to write the author and receive a copy by postal mail. So by the early 1990s when email had become universal, I one day had the epiphany that one could make a newsletter with abstracts distributed by email, and so I created what was the first electronic newsletter in astronomy, every month calling for and collating abstracts of newly accepted papers on Galactic star formation and young stars. With time, the Newsletter has evolved, bringing additional information relevant for our community. Still, the Newsletter is not as indispensable as it was once, and every month when I have to find time to assemble another issue I think about shutting it down. But I regularly get nice emails from people who like their monthly issue and thank me for the effort, so I continue.

**Q**: *Your earliest work was on Bok globules.*

**A:** I actually started doing a thesis on eclipsing binaries, which was the main focus of Danish astronomers in the 60s and 70s. But my heart was really beating for star formation, and I read all the papers on the subject (which was possible back then, but certainly not today). I was fascinated by Bok globules, which in the early days were seen as an intermediate stage in the contraction of the interstellar medium into stars. I had some - what seemed to me - simple ideas about their formation, which I assumed had to be wrong since nobody else had pursued them. Then in 1978 I met Bart Bok, who enthusiastically supported me and gave me the courage to pursue these ideas. I went to my eclipsing binary advisor who expected me to come with my finished thesis, and instead I told him I quit. This caused much consternation but I stuck to my decision, and then with Bart Bok and a Danish expert on the interstellar medium, Jens Knude, as dual advisors I instead completed a thesis on Bok globules, and showed that they were remnants of dense cloud cores escavated from more tenuous molecular clouds by the presence of closeby massive stars. I showed that globules indeed do form stars, but that they are only contributing a tiny fraction of all newborn stars. Today that's widely accepted and pretty self-evident, but it made quite a splash then.

**Q**: *Soon you switched your interest to Herbig-Haro jets.*

**A:** As a teenager I read an article in Sky and Telescope on mysterious semi-stellar objects found in dark clouds that might be related to the birth of stars. I was mesmerized and dreamt about one day studying such Herbig-Haro objects. As soon as the Danish 1.5m telescope at La Silla was equipped with a CCD in 1982 I started to image HH objects. My first scoop occurred on 20 December 1982 when I was imaging the HH 34 object. In those days the readout and display was painfully slow, so while I was looking at the image of HH 34 itself, slowly this major finely collimated jet rolled up above it, one knot at a time. I almost fell from my chair, I had never seen anything like that. So I embarked on a detailed multi-wavelength study of this object, and soon others.

**Q**: *You have made many surveys for new Herbig-Haro objects. Do you have any favorites?*

**A:** When I was young I was frequently observing at La Silla, and whenever the weather was bad, I would spend the night poring over the large sky atlas films which were at that time being produced at the ESO and Siding Spring Schmidt telescopes. It was an excellent way to become familiar with the known star forming regions, but to my surprise I kept finding objects that were not described anywhere, so of course I started studying them. That way I found numerous new HH objects, I have lost count. But one object stands out, namely the HH 111 jet which I found later after I in 1986 moved to Chile to become a staff astronomer at La Silla, a position I held for 11 years. I was curious about a little-studied region of Orion, and requested a deep photographic plate of that area. I saw on the plate a little streak in a dark cloud, and the same evening I got very excited when my CCD images revealed a beautiful and perfectly collimated bipolar jet emerging from a dense cloud core. I have spent several years studying this object with many techniques and at many wavelengths, and the object has generated much interest and is in many ways a benchmark for jet studies. By now well over 50 papers have been devoted to it by many groups.

Later I noted two large HH shocks far from and symmetric around the HH 111 source, and I realized that HH 111 formed a giant bipolar HH complex almost 8 parsec in extent. From this emerged a major study of giant parsec-scale HH flows that I wrote with John Bally and his student Dave Devine. Giant flows have dynamical ages comparable to the duration of the main accretion phase of the sources, and thus provide a fossil record of their mass loss and accretion history. Such giant flows have burst out of their cloud cores, dissociating molecules and injecting momentum and kinetic energy into the interclump medium of the host clouds. They may contribute to the chemical rejuvenation of clouds, the generation of turbulent motions, and perhaps even the self-regulation of star formation.

**Q**: *You also studied the driving sources of these HH flows.*

**A:** Infrared astronomy was in its infancy in the 1970s, and we had little idea what was inside most molecular clouds, so already as a student in the late 1970s I started groping around in the clouds surrounding HH objects, trying to identify their energy sources. This was with single-pixel InSb detectors with which one made manual raster scans across the selected regions, a laborious process which is hard to imagine now that we have widefield near-infrared imagers and various all-sky infrared catalogs. Such surveys, together with later surveys that Rolf Chini and I did in the early 1990s at submm wavelengths, identified a number of the flow sources known today, and revealed that HH flows can take place at all evolutionary phases from Class 0 to Class III.

**Q**: *What about jets from massive stars?*

Herbig-Haro flows are rarely found in association with massive stars. And in the few cases known, they tend to be poorly collimated, not jets. One spectacular exception is the HH 80/81 flow. In the early 1980s I was interested in objective prism surveys in the grand tradition of Guillermo Haro and George Herbig. I used the Curtis Schmidt at Cerro Tololo, which required guiding at the eyepiece for 4-hour exposures, and ending the night in the dark room developing the plates. I remember one morning holding a wet plate up to the light and seeing the spectra of a pair of bright HH objects in Sagittarius. These were the now famous HH 80/81 objects, the most luminous known HH objects. The driving source is the $10^4$ $L_\odot$ embedded IRAS source 18162–2048. Subsequently, Josep Martí, Luis Felipe Rodríguez, and I used the VLA to detect a finely collimated radio continuum jet emanating from this newborn massive star. The rarity of such jets from massive stars suggests that the collimation mechanism, presumably by magnetic fields anchored in a circumstellar disk, does not survive the intense radiation for very long.

**Q**: *30 years ago you wrote an early review on pre-main sequence binaries, an interest you have maintained during all those years. How did that start?*

**A:** Well, as I mentioned earlier, I started out working on eclipsing binaries, and it was therefore natural to ponder the formation of binaries. The first step was to identify and characterize a large population of young low-mass binaries. So I embarked on a massive imaging survey of more than 200 T Tauri stars, doing 1 $\mu$m CCD imaging at the NTT in sub-arcsec seeing, and that was the genesis of the large paper that you and I published in 1993. Within a month the speckle interferometric studies of Leinert et al. and Ghez et al. appeared, and all three studies showed a clear excess of binaries in star forming regions compared to the field, pointing to powerful dynamical processes shaping the early separation distribution function.

**Q**: *In 2001 you and Cathie Clarke suggested that brown dwarfs may be ejected stellar embryos from disintegrating triple systems. What was the origin of that idea?*

**A:** This was a corollary to a study I had done the year before where I pointed out the very high fraction of higher-order multiples among the driving sources of HH flows. I found that the structure of giant HH flows could be understood in terms of the orbital evolution of a binary newly formed in a triple disintegration event. Such breakups of T Tauri stars had been previously studied numerically, especially by Michael Sterzik, and it was clear that the lowest mass objects were most likely to be ejected. Cathie and I turned that around and pointed out that brown dwarfs are of low mass precisely because they are ejected. In other words, when a stellar embryo is evicted from its nascent cloud core, it is deprived of the mass that it needs to eventually be able to burn hydrogen. It has come as a surprise to me that it has taken the community a while to embrace this simple idea. After all, there is no voodoo physics involved, just straight dynamics. The question to ask is not whether this mechanism operates, because it is inevitable, but rather what fraction of brown dwarfs are formed this way, compared to other processes that also will lead to very low mass objects.

**Q**: *You introduced the concept of 'Orphaned Protostars'.*

**A:** In recent years I have mainly focused on studying small multiple systems of 3 or 4 young stars, both observationally as well as numerically. It was Richard Larson who, from an angular momentum point of view, in 1972 first stressed that it is likely that most stars are born in such systems, only to subsequently break apart. If this is so, and the evidence increasingly points in that direction, then dynamics plays a much more important role than is recognized now. Three-body interactions can both trigger accretion as well as truncate some of the circumstellar gas reservoirs, so dynamics is a stochastic parameter that can influence the accretion history of young stars and affect the shape of the initial mass function. I am convinced that until we fully appreciate the importance of early dynamical evolution of such small-N systems, we are missing an essential element in early stellar evolution.

My former student and current colleague, Mike Connelley, did a major study of binarity among Class I sources for his thesis, and found a population of distant low-mass companions that is not observed for more evolved young stars, and therefore must be lost. Subsequently, Seppo Mikkola and I have been doing very detailed numerical simulations of triple systems, including the gravitational potential of a massive cloud core, which show that the majority of such systems early on have a distant tenuously bound low-mass companion, precisely as observed. But by the end of the embedded phase half of the simulated systems have disintegrated, thus releasing the distant companions, again as observed. Some of these systems break up very early, and sometimes so violently that the remaining object (single or binary) also recoils out of the core. These objects are structurally protostars, belonging high up on their Hayashi tracks, but they have lost their infalling envelopes and part of their disks, so they can be observed at near-infrared and sometimes even at optical wavelengths. So I dubbed them orphaned protostars.

**Q**: *In 2012 you and Seppo Mikkola proposed a new formation mechanism for ultrawide binaries. What is the idea?*

**A:** Yes, that was an unexpected by-product of our numerical simulations of unstable triple systems. Sometimes two stars dynamically control the center of an infalling envelope, ejecting the third star, and sometimes a single star dominates the center, pushing a low-mass binary out. We realized that since 90% of the triples eventually break up with energy enough for an escape, there would be a number of disintegrations that have *almost* enough energy for an escape, and hence can reach enormous separations, up to several parsec, yet remain tenuously bound. Such highly eccentric systems will spend most of their time near apastron, interspersed with rare and brief periastron passages, until Galactic tides and passing stars nudge them loose on a Gyr timescale. In this scenario such ultrawide binaries are not born wide, but gradually unfold as they drift away. Their compact size as they leave their dense birth sites help them survive this perilous phase. Such ultrawide systems will at closer examination be triple systems. Of course there are other ways that Nature can make very wide binaries, and all are likely to contribute to the observed population.

**Q**: *You have edited and written many books on star formation, including the 'Protostars and Planets V' book, the two-volume 'Handbook of Star Forming Regions' covering both the northern and southern sky, and most recently a biography of George Herbig.*

**A:** I enjoy writing. The new book about George Herbig was a labor of love, since I knew George very well, personally and scientifically, and I was always amazed at how he had almost singlehandedly opened the field of early stellar evolution with instrumentation that we would sneer at today. He was truly a remarkable person. I wanted the young generation to know how our field started, and that's also why the book is freely available to download (http://www.ifa.hawaii.edu/SP1). As for organizing PPV, I am glad I did it, and glad that I don't have to do it again. I am proud of the proceedings, because all the chapters were on the internet less than 6 months after the meeting, although it took much longer to get the book printed. The Handbook originated because I realized that too many people do not know all the wonderful objects that are littered across the sky. The Handbook is a one-stop resource of information on all important star forming regions within 2 kpc, and although it is soon ten years old, I think it still gives a useful overview of what is out there.

**Q**: *You have had a life-long interest in meteorites.*

I find it amazing that while we make increasingly detailed observations of circumstellar material around newborn stars, here on Earth we can at the same time in great detail study rocks that are left over from the formation of our planetary system. A major hurdle in bringing the fields of star formation and the early solar system together is the technical vocabulary that each topic employs. Hopefully some day students will choose to combine studies of astronomy and geology, and I suspect such cross-disciplinary efforts would yield rich rewards. On the practical side I have been leading meteorite expeditions to the ice cap in Greenland, and have spent much time searching, successfully, for meteorites in Chile and Brazil.

**Q**: *What are your current interests?*

**A:** Too many subjects and too little time! I am trying to finish a large observational study of the properties of young triple and quadruple systems. And for the past ten years I am operating several small robotic telescopes at the Mauna Loa Observatory with my colleague Josh Walawender. Every clear night the telescopes monitor up to 100 star forming regions and the goals are to characterize and quantify the irregular accretion events at different evolutionary stages; to better understand the angular momentum evolution at different ages by studying sinusoidal variability of young spotted stars; to find and analyze pre-main sequence eclipsing binaries; and to detect new FUors. FUors are complex, because there are many ways that a disk can be disturbed resulting in a major flare-up, the in-spiraling of a binary on its way to become a spectroscopic binary is just one, and other triggering mechanisms may lead to different light curves. Observing in detail the onset and early phases of FUor eruptions is to my mind the Holy Grail of early stellar evolution.

*Perspective*

# Accretion onto young stars: the key to disk evolution

*Carlo F. Manara*

## 1 Introduction

The early stages of the pre-Main-Sequence (PMS) evolution of young stars are characterized by a substantial interaction between the central star and the surrounding disk. Among the processes that take place, the accretion of material from the disk onto the star is a crucial one, as it traces the disk evolution and, in turn, affects how planets are formed and evolve in disks. Even if accretion has been studied for many years, it is still the focus of a large body of work, as we do not fully understand how it happens (see e.g., Hartmann et al. 2016 for an extended review).

The current paradigm describing how the material is accreted from the disk onto the star is the magnetospheric accretion scenario. In this scenario the material is accreted onto the central star along the stellar magnetic field lines, assumed to be mostly dipolar. This paradigm was proposed almost 30 years ago to explain the ultraviolet excess and strong emission lines observed in the spectra of young stars (e.g., Camenzind 1990, Königl 1991, Calvet & Hartmann 1992). From then on, the comparison of more advanced observations with modeling of the process has confirmed magnetospheric accretion to be the way material is accreted onto young stars (e.g., Calvet & Gullbring 1998, Muzerolle et al. 2003), at least in objects with stellar mass ($M_\star$) smaller than $\sim 2M_\odot$, but also in some Herbig Ae/Be stars (e.g., Calvet et al. 2004, Mendigutia et al. 2011). Studies of the variability pattern of young stars are also in line with this paradigm (e.g., Venuti et al. 2015, Costigan et al. 2014). A significant effort is going into measuring the strengths and large-scale topologies of magnetic fields at the surfaces of young stars (e.g., Donati et al. 2007, 2010a, 2013; Hussain et al. 2009, future: CFHT/SPIRou). These studies report strong (kG) multipolar components of the magnetic field but cannot exclude even stronger fields, particularly on small scales (e.g., Chen & Johns-Krull 2013, Hussain & Alecian 2014).

Overall, it is now considered fair to assume that, in young stars, the excess continuum and line emission with respect to the photospheric and chromospheric one is (mainly) due to accretion. This excess emission can be converted into accretion luminosity ($L_{\rm acc}$), and then mass accretion rates ($\dot{M}_{\rm acc}$) by knowing $M_\star$ and the stellar radius ($R_\star$). Blue spectra of young stars, ideally near-ultraviolet (NUV) spectra taken with the Hubble Space Telescope (HST, e.g., Herczeg & Hillenbrand 2008, Ingleby et al. 2013) are ideal to trace excess continuum emission. Optical and near-infrared spectra are also used to measure the fluxes of hydrogen, helium, and calcium emission lines produced by accretion (e.g., Calvet & Hartmann 1992, Natta et al. 2004, 2006, Mohanty et al. 2005, Antoniucci et al. 2011, Fang et al. 2013). Photometry in the $U$-band (e.g., Gullbring et al. 1998, Robberto et al. 2004, Sicilia-Aguilar et al. 2010, Rigliaco et al. 2011, Manara et al. 2012, Venuti et al. 2014) or in narrow band filters, such as filters centered on the H$\alpha$ line (e.g., De Marchi et al. 2010, Kalari et al. 2015), is also a powerful way to measure $L_{\rm acc}$. While photometry provides access to large samples with a limited telescope time effort, spectroscopy allows us to firmly determine the accretion and stellar properties.

One big elephant in the room in this context is which process allows the material to lose angular momentum and therefore accrete *through* the disk. This issue is key to determine how disks evolve and how planets form. Indeed, the processes proposed to explain the evolution of disks and the transport of material through the disk predict very different surface density distributions at a given time. These differences strongly impact how and where planets are formed in the disk, and how they migrate (e.g., Thommes et al. 2008, Mordasini et al. 2012, Bitsch et al. 2015, Morbidelli & Raymond 2016). The historically favored process to describe the redistribution of material and angular momentum in disks is viscous accretion (e.g., Lynden-Bell & Pringle 1974, Hartmann et al. 1998), usually coupled to processes such as internal photoevaporation driven by high-energy UV- and/or X-ray radiation, crucial to explain disk dispersal (e.g., Alexander et al. 2014, Gorti et al. 2016, Ercolano & Pascucci 2017). Recently, more interest is being devoted to study magnetic disk winds (e.g., Armitage et al. 2013, Bai 2016, Ercolano & Pascucci 2017) and low viscosity hydrodynamic turbulence (e.g., Hartmann et al. 2017), which are other ways

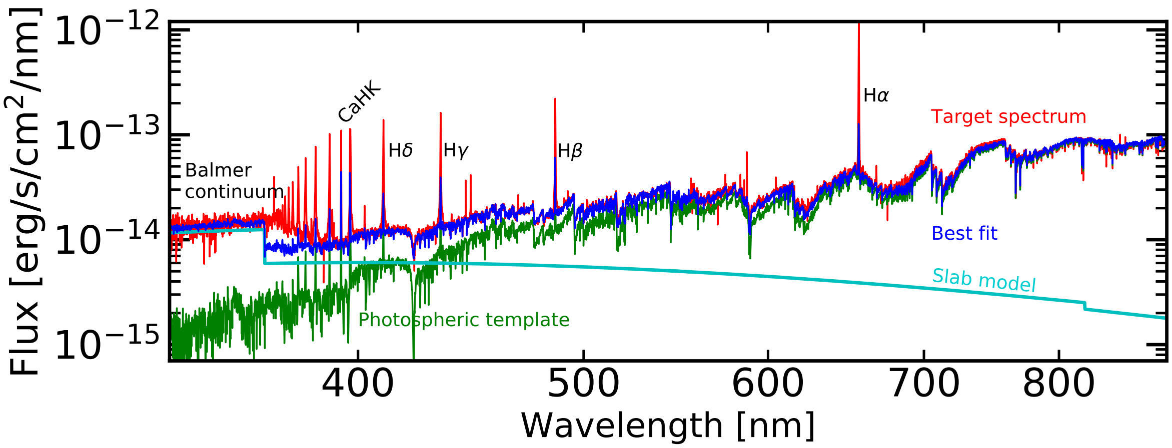


Figure 1: Fit of the target Ass Cha T 2-10 (adapted from Manara et al. 2017a). The target spectrum, corrected for extinction ($A_V$=1.1 mag), is shown in red. The best fit of the continuum emission is shown in blue, and it is the sum of the photospheric template (green) and of the accretion shock model (slab model, cyan).

to explain the removal of angular momentum. These processes predict how the mass accretion rate scales with age, with stellar mass (see Sect. 3), and with the disk mass (see Sect. 4). Therefore, determining stellar, accretion, and disk properties in large samples of young stellar objects (see Sect. 2) is key to determine which process regulates disk evolution, hence constraining planet formation.

## 2 Accretion rate estimates in the VLT/X-Shooter era

The spectral type of a star determines the overall shape of its spectrum and the appearance and strength of absorption lines and molecular bands. However, the presence of usually non-negligible interstellar extinction, different from object to object, makes the overall shape of the spectrum redder. In contrast, the emission due to accretion gives rise to a strong blue continuum excess. One needs to take into account all these aspects simultaneously to be able to overcome the degeneracies and derive the stellar and accretion parameters of a young star. This is possible only by combining good quality broad-band flux-calibrated spectra (e.g., Manara et al. 2013b, Herczeg & Hillenbrand 2014), with a modeling of the various components. In Manara et al. (2013b) we showed how to overcome degeneracies between the parameters with the method I will describe in this section. We analyzed two objects in the Orion Nebula Cluster, previously considered to be older than 30 Myr based on their location on the HR Diagram. Our analysis method showed that they have stellar parameters typical of ~2-3 Myr old objects, much more in line with the rest of the population of the cluster. The previous estimates were affected by a degeneration between $A_V$ and $L_{\rm acc}$.

A key ingredient in the development of our new analysis method has been the advent of the spectrograph X-Shooter (Vernet et al. 2011), a second generation instrument on the ESO Very Large Telescope (VLT). This instrument allows one to obtain flux-calibrated spectra covering simultaneously the wavelength interval from ~300 nm to ~2.5 $\mu$m with a resolution $R \sim$ 5000-18000. This implies covering simultaneously the spectral region of the Balmer continuum, particularly sensitive to excesses due to accretion, several emission lines tracing both accretion and winds, and multiple absorption features needed to determine the stellar properties of the target and the veiling due to accretion. Given these great potentials, a significant fraction of the Italian X-Shooter guaranteed time (GTO) was devoted to collect spectra for a large sample of young stars both with and without disks to determine their stellar and accretion properties (Alcalá et al. 2011).

During my PhD I used these GTO spectra and I developed with my colleagues a self-consistent method to obtain the spectral type and stellar luminosity, reddening, and the accretion luminosity of young stars (Manara et al. 2013b). The method is based on finding the best fit model in a grid by minimizing a $\chi^2_{\rm like}$ distribution computed in various continuum regions of the spectra from the Balmer continuum ($\lambda \sim$ 330 nm) to the red part of the optical spectrum ($\lambda \sim$ 720 nm). The grid of models spans a set of photospheric templates of young stars observed by us with X-Shooter, a number of extinction ($A_V$) values, and models of the continuum excess due to accretion (a hydrogen slab model, as done by, e.g., Valenti et al. 1993 and Herczeg & Hillenbrand 2008). The photospheric templates we use are observed X-Shooter spectra of non accreting young stars with spectral types between G5 and M9.5 (Manara et al. 2013a, 2017b), the best possible templates to reproduce the expected photospheric emission of young stars. Our modeling allows us to reproduce the continuum emission from the target spectra of young stars from $\lambda \sim 300$ nm up to $\lambda \sim 900$ nm (Fig. 1), and to derive stellar parameters and mass accretion rates with typical uncertainties of <0.45 dex in $\dot{M}_{\rm acc}$ (e.g., Alcalá et al. 2014).

More recently we have collected larger samples of VLT/X-Shooter spectra of young stars in different star forming regions in addition to the GTO data. We aimed at covering objects with a large range of $M_\star$ and located in different regions. By analyzing the spectra with the method described above we have been able to study how the mass accretion rates scale with the stellar mass, and, combining these surveys with the results from ALMA surveys, how $\dot{M}_{\rm acc}$ scales with the disk mass, as I describe in the following sections. I only mention that these spectra are useful for many other goals, including calibrating the relation between emission lines and accretion luminosity (Alcalá et al. 2014, 2017), studies of winds and jets in young stars (Natta et al. 2014, Nisini et al. 2017), of photospheric properties (Stelzer et al. 2013, Frasca et al. 2017) and of metallicity of young stars (Biazzo et al. 2017). We used our spectra of non-accreting young stars to determine how chromospheric emission makes the detection of low $\dot{M}_{\rm acc}$ challenging (Manara et al. 2013a, 2017b), giving a quantitative value in line with previous studies (e.g., Sicilia-Aguilar et al. 2010, Ingleby et al. 2011). We have studied individual objects, for example DR Tau, to determine the impact of accretion variability on the chemical evolution of its disk (Banzatti et al. 2014). We have also studied the accretion properties of transition disks, finding that they have in many cases accretion rates as high as those of full disks (e.g., Manara et al. 2014), in line with e.g., Espaillat et al. (2014) or Najita et al. (2015). Finally, I would like to stress that the method described here is also applicable to other broad-band flux-calibrated spectra, such as LBT/MODS spectra, as we showed in the analysis of the EXor V1118 Ori (Giannini et al. 2017).

# 3 The relation between stellar and accretion properties

Our first large sample of stars with disks in a single star forming region, Lupus, was collected during the GTO observations. The analysis of this incomplete sample showed a simple power-law relation between $\dot{M}_{\rm acc}$ and $M_\star$ with a spread <1 dex, much narrower than in previous studies (Alcalá et al. 2014). The other initial and still incomplete samples of X-Shooter spectra of young stars with disks in the $\sigma$-Orionis and $\rho$-Ophiuchus regions were analyzed by Rigliaco et al. (2012) and Manara et al. (2015), respectively. These datasets supported the idea that the power-law relation between $\dot{M}_{\rm acc}$ and $M_\star$ found in the first sample of targets in the Lupus region is valid from brown dwarfs up to $\sim$1 $M_\odot$ with a scatter smaller than $\sim$1 dex.

However, when we recently collected and analyzed the almost complete samples of X-Shooter spectra of young stars with disks in the Chamaeleon I and Lupus star forming regions (Fig. 2, Manara et al. 2016a, 2017a; Alcala et al. 2017), a more elaborate picture emerged: the $\dot{M}_{\rm acc}$-$M_\star$ relation in each of the two regions is better represented with a slightly higher statistical confidence by a double power-law fit, with a steeper relation at low $M_\star$, than by a simple power-law. This double power-law behaviour, tentatively already observed also by Fang et al. (2013) and Venuti et al. (2014) in other complete samples in other regions, is quantitatively similar to what Vorobyov & Basu (2009) suggested as a result of two different accretion regimes at different $M_\star$. However, it could also result from a faster evolution of the accretion rates for lower mass stars, as proposed by Rigliaco et al. (2011), Manara et al. (2012), or Fang et al. (2013). On the other hand, the data can also be fitted with a single power-law with exponent $\sim$2. This single power-law is possibly explainable by different theories, such as the result of particular initial conditions (Alexander & Armitage 2006; Dullemond et al. 2006), of Bondi-Hoyle driven accretion (Padoan et al. 2005), or, if

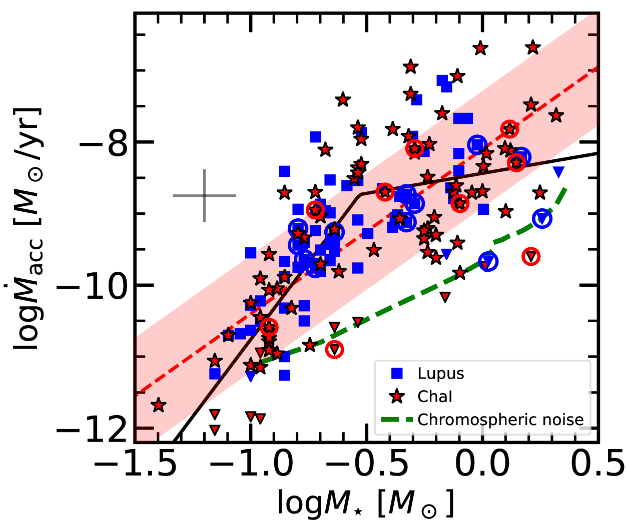


Figure 2: Mass accretion rates vs stellar mass for the samples of stars with disks in the Lupus and Chamaleon I regions (Alcalá et al. 2014, 2017; Manara et al. 2016a, 2017a). Transition disk objects are circled, downwards triangles are targets with accretion rates compatible with chromospheric emission, which is expected to be at about the location of the dashed green line at this age (Manara et al. 2013a, 2017b). The fits for the Chamaeleon I sample are shown with a red dashed line (single power-law) and a black solid line (double power-law).

the slope is ∼1.7, of an evolution driven by X-ray photoevaporation (Ercolano et al. 2014). An intriguing feature of these sets of data is the lack of low accretors at $M_\star$∼0.3 $M_\odot$ (Manara et al. 2017a). This could be a consequence of the fast dispersal of disks due to photoevaporation (see also Sicilia-Aguilar et al. 2010). Finally, the objects with a transition disk are well mixed in this plot with objects hosting a full disk, although none of the strongly accreting objects hosts a transition disk, and some transition disk objects appear to be very low accretors, or non-accretors.

One still open question, from an observational point of view, is how this picture evolves with time. The two regions we have been studying with X-Shooter, Lupus and Chamaeleon I, have similar ages, and the age differences of targets within these regions are subject to large uncertainties (e.g., Soderblom et al. 2014). It is therefore mandatory to explore this relation in younger and older regions to further constrain the theoretical scenarios.

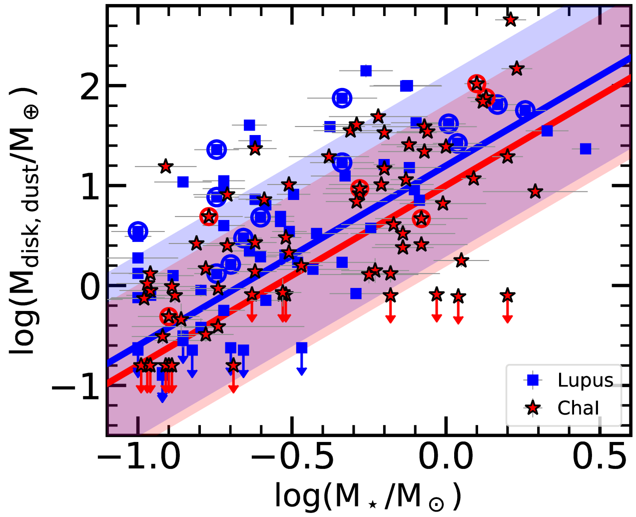


Figure 3: Disk mass vs stellar mass for the samples in the Lupus and Chamaeleon I regions (Ansdell et al. 2016, Pascucci et al. 2016). Symbols as in Fig. 2. The stellar masses are derived from the stellar parameters derived using the X-Shooter spectra by Manara et al. (2016a, 2017a) and Alcalá et al. (2014, 2017).

## 4 Combining stellar, accretion, and disk properties

The combination of precise values of $M_\star$ and $\dot{M}_{\rm acc}$ with the measurements of disk masses from ongoing ALMA surveys in the Lupus (Ansdell et al. 2016) and Chamaeleon I (Pascucci et al. 2016) star forming regions has allowed us for the first time to properly assess how the stellar and accretion properties of young stars scale with the disk masses. The relation between disk dust masses and stellar masses is found to be steeper than linear (Fig. 3), in line with the higher number of massive planets found around more massive stars, and it becomes steeper with time (e.g., Ansdell et al. 2016, 2017, Pascucci et al. 2016, Barenfeld et al. 2016). It is worth noting that the transition disks happen to be among the most massive disks in the sample at all stellar masses, as noted by several authors (e.g., Van der Marel et al., subm.).

The other important relation, the one between $\dot{M}_{\rm acc}$ and $M_{\rm disk}$, is observed to be slightly shallower than linear in the Lupus and in the Chamaeleon I samples (Fig. 4, Manara et al. 2016b, Mulders et al. 2017). Furthermore, the ratio $M_{\rm disk}/\dot{M}_{\rm acc}$, expected for viscously evolving disks to be approximately the age of the surrounding region (e.g., Jones et al. 2012, Rosotti et al. 2017), is found to be ∼1-3 Myr for several disks in Lupus, as expected, when assuming a gas-to-dust ratio of 100. A very surprising finding is the fact that the correlation is present when considering disk masses obtained from (sub-)mm continuum measurements, thus tracing the dust content in disks, and not when using disk gas masses from CO isotopologues (from Ansdell et al. 2016 and Miotello et al. 2017). The lack of a correlation between $\dot{M}_{\rm acc}$ and the gas masses from CO observations, as well as the short inferred ratios $M_{\rm disk}/\dot{M}_{\rm acc}$ using CO gas masses, are further hints to the fact that CO gas masses are underestimated due to carbon depletion, as claimed by several independent studies (e.g., Bergin et al. 2014, Du et al. 2015, Kama et al. 2016, Miotello et al. 2017, Long et al. 2017).

Our finding of an almost linear correlation between $\dot{M}_{\rm acc}$ and the disk (dust) mass is being used as a powerful test of our current theories of disk evolution. Both Lodato et al. (2017) and Mulders et al. (2017) have shown how the only way to reconcile the observed slope and scatter around a linear relation with the predictions of viscous evolution is to assume that the viscous timescale is as long as ∼1 Myr, thus of the order of the age of the surrounding region. Mulders et al. (2017) have explored a simple toy model of disks in which the mass accretion rate is independent of the disk mass, as expected if magnetic disk winds drive the evolution of disks. Such a model would lead to a distribution of $\dot{M}_{\rm acc}$ vs $M_{\rm disk}$ very similar to the observed one. This is a very interesting result, but more realistic models of disk wind driven evolution are needed.

Rosotti et al. (2017) expanded the work of Jones et al. (2012) to explore the effect of several disk evolution processes on the $\dot{M}_{\rm acc}$-$M_{\rm disk}$ relation. This work shows that external photoevaporation (Clarke et al. 2007, Anderson et al. 2013) affects the disk mass so that the ratio $M_{\rm disk}/\dot{M}_{\rm acc}$ becomes much smaller than the age of the

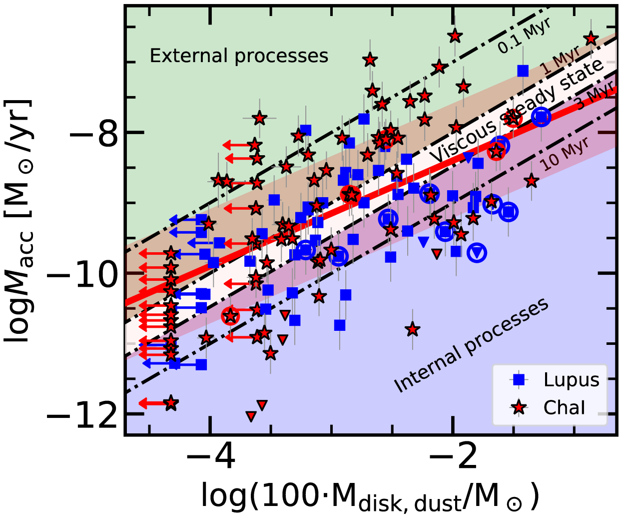


Figure 4: Mass accretion rate vs disk mass for the samples in the Lupus and Chamaeleon I regions (Manara et al. 2016b, Mulders et al. 2017). Symbols as in Fig. 2. The disk dust masses (Ansdell et al. 2016, Pascucci et al. 2016), are converted to total disk masses with a gas-to-dust-ratio of 100. Mass accretion rates are from Manara et al. (2016a, 2017a) and Alcalá et al. (2014, 2017). The red solid line is the best fit by Mulders et al. (2017). The black dot-dashed lines are values of $M_{\rm disk}/\dot{M}_{\rm acc}$ from 0.1 to 10 Myr. Colored regions are from Rosotti et al. (2017).

region. In contrast, internal processes, such as internal photoevaporation, planet formation, or dead zones, tend to produce ratios $M_{\rm disk}/\dot{M}_{\rm acc}$ larger than the age of the region. We combined ALMA measurements of disk masses and photometric estimates of $\dot{M}_{\rm acc}$ in the Orion Nebula Cluster (Mann et al. 2014, Eisner et al. 2016; Manara et al. 2012) and in the $\sigma$-Orionis cluster (Ansdell et al. 2017; Rigliaco et al. 2011), and we showed that the observed ratios of $M_{\rm disk}/\dot{M}_{\rm acc}$ are very small, confirming that these disks are experiencing external photoevaporation (Rosotti et al. 2017, Ansdell et al. 2017). Interestingly, the transition disk objects appear to be in the lower part of the distribution, meaning their ratios of $M_{\rm disk}/\dot{M}_{\rm acc}$ are in general larger than the age of the region, in line with previous results (e.g., Najita et al. 2015). In the theoretical framework discussed by Rosotti et al. (2017), this is in line with the fact that transition disk objects are experiencing internal processes, either planet formation or internal photoevaporation (e.g., Espaillat et al. 2014, Ercolano & Pascucci 2017).

Current observations thus imply that either disks evolve viscously but on a very long timescale and are dispersed by other mechanisms, or that several disks are already experiencing other processes than viscous evolution that are affecting their evolution.

# 5 What's next

Our works based on VLT/X-Shooter spectra proved how crucial the use of broad-band flux-calibrated spectra is to overcome the degeneracies between stellar parameters, extinction, and the effect of accretion (e.g., Manara et al. 2013b), in particular when veiling due to accretion is substantial. We have also shown how the use of multiple emission line fluxes leads to estimates of the accretion luminosity consistent with that from the UV-excess (e.g., Alcalá et al. 2014). Again, this latter way to derive accretion rates relies on the availability of broad-band flux-calibrated spectra. Thus, it is crucial to continue to have access to instruments such as the VLT/X-Shooter, and in particular to cover the NUV Balmer continuum region to properly estimate the contribution of veiling in strongly accreting objects. Also HST (or its successor) is a key telescope, especially because it allows one to observe the FUV molecular and atomic gas lines emitted in the accretion shock and inner disk region (e.g., Ardila et al. 2013, France et al. 2014, Booth & Clarke 2018).

Furthermore, we have shown how important it is to survey complete samples of young stars in the targeted regions, as incomplete samples can lead to erroneous or only partially correct results in the same way as inappropriate analysis methodologies. The combination of spectroscopic studies with surveys of disks is key to test disk evolution mechanisms. The relation between $\dot{M}_{\rm acc}$ and $M_{\rm disk}$, in particular, seems to be the most promising way to test models of angular momentum dispersal in disks.

Finally, the big question to address is the evolution of $\dot{M}_{\rm acc}$ with time. While Gaia will help us to lower our uncertainties on the ages of the regions (and maybe of individual objects?) by providing more stringent constraints on their distances and dynamical state (e.g., Voirin et al. 2017, Manara et al. 2017c), more effort should be put into covering all the stages of evolution of young stars. Obviously, it would be crucial to study older regions, where the disk evolution processes have shaped the disk properties. Moreover, the advent of JWST will allow us to finally be able to properly probe the earliest stages of disk evolution by measuring $\dot{M}_{\rm acc}$ in embedded objects, using the promising proxies of the mid-infrared emission lines (Salyk et al. 2013, Rigliaco et al. 2015). On this point, the still open question is how to determine the properties of the central forming star. Once this is sorted out, we will be able to finally determine how $\dot{M}_{\rm acc}$ evolves with time and constrain theories of disk evolution.

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## Abstracts of recently accepted papers

### A Green Bank Telescope Survey of Large Galactic HII Regions

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As part of our ongoing HII Region Discovery Survey (HRDS), we report the Green Bank Telescope detection of 148 new angularly-large Galactic HII regions in radio recombination line (RRL) emission. Our targets are located at a declination $\delta > -45°$, which corresponds to $266° > \ell > -20°$ at $b = 0°$. All sources were selected from the *WISE* Catalog of Galactic HII Regions, and have infrared angular diameters $\geq 260$ *arcsec*. The Galactic distribution of these "large" HII regions is similar to that of the previously-known sample of Galactic HII regions. The large HII region RRL line width and peak line intensity distributions are skewed toward lower values compared with that of previous HRDS surveys. We discover 7 sources with extremely narrow RRLs $< 10\ \mathrm{km\,s^{-1}}$. If half the line width is due to turbulence, these 7 sources have thermal plasma temperatures $< 1100$ K. These temperatures are lower than any measured for Galactic HII regions, and the narrow line components may arise instead from partially ionized zones in the HII region photo-dissociation regions. We discover G039.515+00.511, one of the most luminous HII regions in the Galaxy. We also detect the RRL emission from three HII regions with diameters $> 100$ pc, making them some of the physically largest known HII regions in the Galaxy. This survey completes the HRDS HII region census in the Northern sky, where we have discovered 887 HII regions and more than doubled the previously-known census of Galactic HII regions.

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### ALMA Discovery of Dust Belts around Proxima Centauri

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Proxima Centauri, the star closest to our Sun, is known to host at least one terrestrial planet candidate in a temperate orbit. Here we report the Atacama Large Millimeter/submillimeter Array (ALMA) detection of the star at 1.3 mm wavelength and the discovery of a belt of dust orbiting around it at distances ranging between 1 and 4 au, approximately. Given the low luminosity of the Proxima Centauri star, we estimate a characteristic temperature of about 40 K for this dust, which might constitute the dust component of a small-scale analog to our solar system's Kuiper Belt. The estimated total mass, including dust and bodies up to 50 km in size, is of the order of 0.01 Earth masses, which is similar to that of the solar Kuiper Belt. Our data also show a hint of warmer dust closer to the star. We also find signs of two additional features that might be associated with the Proxima Centauri system that still require further observations to be confirmed: an outer extremely cold (about 10 K) belt around the star at about 30 au, with an orbital plane that is tilted about 45 degrees with respect to the plane of the sky; additionally, we marginally detect a compact 1.3 mm emission source at a projected distance of about 1.2 arcsec from the star, the nature of which is still unknown.

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## On the Formation of Multiple Concentric Rings and Gaps in Protoplanetary Disks

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As spiral waves driven by a planet in a gaseous disk steepen into a shock, they deposit angular momentum, opening a gap in the disk. This has been well studied using both linear theory and numerical simulations, but so far, only for the primary spiral arm – the one directly attached to the planet. Using two-dimensional hydrodynamic simulations, we show that the secondary and tertiary arms driven by a planet can also open gaps as they steepen into shocks. The depths of the secondary/tertiary gaps in surface density grow with time in a low viscosity disk ($\alpha = 5 \times 10^{-5}$), so even low-mass planets (e.g., super-Earth or mini-Neptune-mass) embedded in the disk can open multiple observable gaps, provided that sufficient time has passed. Applying our results to the HL Tau disk, we show that a single 30 Earth-mass planet embedded in the ring at 68.8 au (B5) can reasonably well reproduce the positions of the two major gaps at 13.2 and 32.3 au (D1 and D2), and roughly reproduce two other major gaps at 64.2 and 74.7 au (D5 and D6) seen in the mm continuum. The positions of secondary/tertiary gaps are found to be sensitive to the planetary mass and the disk temperature profile, so with accurate observational measurements of the temperature structure the positions of multiple gaps can be used to constrain the mass of the planet. We also comment on the gaps seen in the TW Hya and HD 163296 disk.

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## Observing the linked depletion of dust and CO gas at 0.1-10 au in disks of intermediate-mass stars

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We report on the discovery of correlations between dust and CO gas tracers of the 0.1-10 au region in planet-forming disks around young intermediate-mass stars. The abundance of refractory elements on stellar photospheres decreases as the location of hot CO gas emission recedes to larger disk radii, and as the near-infrared excess emission from hot dust in the inner disk decreases. The linked behavior between these observables demonstrates that the recession of infrared CO emission to larger disk radii traces an inner disk region where dust is being depleted. We also find that Herbig disk cavities have either low ($\sim$ 5-10 %) or high ($\sim$ 20-35 %) near-infrared excess, a dichotomy that has not been captured by the classic definition of "pre-transitional" disks.

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## Measurement of Circumstellar Disk Sizes in the Upper Scorpius OB Association with ALMA

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We present detailed modeling of the spatial distributions of gas and dust in 57 circumstellar disks in the Upper Scorpius OB Association observed with ALMA at sub-millimeter wavelengths. We fit power-law models to the dust surface density and CO $J = 3$–$2$ surface brightness to measure the radial extent of dust and gas in these disks. We found that these disks are extremely compact: the 25 highest signal-to-noise disks have a median dust outer radius of 21 au, assuming an $R^{-1}$ dust surface density profile. Our lack of CO detections in the majority of our sample is consistent with these small disk sizes assuming the dust and CO share the same spatial distribution. Of seven disks in our sample with well-constrained dust and CO radii, four appear to be more extended in CO, although this may simply be due to higher optical depth of the CO. Comparison of the Upper Sco results with recent analyses of disks in Taurus, Ophiuchus, and Lupus suggests that the dust disks in Upper Sco may be $\sim$3 times smaller in size than their younger counterparts, although we caution that a more uniform analysis of the data across all regions is needed. We discuss the implications of these results for disk evolution.

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## New massive members of Cygnus OB2

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The Cygnus complex is one of the most powerful star forming regions at a close distance from the Sun ($\sim$1.4 kpc). Its richest OB association Cygnus OB2 is known to harbor many tens of O-type stars and hundreds of B-type stars, providing a large homogeneous population of OB stars that can be analyzed. Many studies of its massive population

have been developed in the last decades, although the total number of OB stars is still incomplete. Our aim is to increase the sample of O and B members of Cygnus OB2 and its surroundings by spectroscopically classifying 61 candidates as possible OB-type members of Cygnus OB2. We have obtained new blue intermediate-resolution spectra suitable for spectral classification of the 61 candidates in Cygnus OB2 and surroundings. We thus performed a spectral classification of the sample using He I-II and metal lines rates, as well as the Marxist Ghost Buster (MGB) software for O-type stars and the IACOB standards catalog for B-type stars. Out of the 61 candidates, we have classified 42 stars as new massive OB-type stars, earlier than B3, in Cygnus OB2 and surroundings, including 11 O-type stars. The other candidates are discarded as they display later spectral types inconsistent with membership in the association. However, the magnitude cutoff and dust extinction introduce an incompleteness. Many O and early B stars at $B > 16$ mag are still undiscovered in the region. Finally, we have studied the age and extinction distribution of our sample within the region, placing them in the Hertzsprung-Russell Diagram using different stellar models in order to assess age uncertainties. Massive star formation in Cygnus OB2 seems to have proceeded from lower to higher Galactic longitudes, regardless of the details of the models used. The correlation between age and Galactic longitude previously found in the region is now confirmed.

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## HD 169142 in the eyes of ZIMPOL/SPHERE

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We present new data of the protoplanetary disc surrounding the Herbig Ae/Be star HD 169142 obtained in the very broad-band (VBB) with the Zurich imaging polarimeter (ZIMPOL), a sub-system of the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE) at the Very Large Telescope (VLT). Our Polarimetric Differential Imaging (PDI) observations probe the disc as close as 0.03" (3.5au) to the star and are able to trace the disc out to 1.08" ( 126au). We find an inner hole, a bright ring bearing substructures around 0.18" (21au), and an elliptically shaped gap stretching from 0.25" to 0.47" (29-55au). Outside of 0.47", the surface brightness drops off, discontinued only by a narrow annular brightness minimum at 0.63"-0.74" (74-87au). These observations confirm features found in less-well resolved data as well as reveal yet undetected indications for planet-disc interactions, such as small-scale structures, star-disk offsets, and potentially moving shadows.

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## On the fragmentation of filaments in a molecular cloud simulation

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*Context.* The fragmentation of filaments in molecular clouds has attracted a lot of attention recently as there seems to be a close relation between the evolution of filaments and star formation. The study of the fragmentation process has been motivated by simple analytical models. However, only a few comprehensive studies have analysed the evolution of filaments using numerical simulations where the filaments form self-consistently as part of large-scale molecular cloud evolution.
*Aims.* We address the early evolution of parsec-scale filaments that form within individual clouds. In particular, we focus on three questions: How do the line masses of filaments evolve? How and when do the filaments fragment? How does the fragmentation relate to the line masses of the filaments?
*Methods.* We examine three simulated molecular clouds formed in kiloparsec-scale numerical simulations performed with the FLASH adaptive mesh refinement magnetohydrodynamic code. The simulations model a self-gravitating, magnetised, stratified, supernova-driven interstellar medium, including photoelectric heating and radiative cooling. We follow the evolution of the clouds for 6 Myr from the time self-gravity starts to act. We identify filaments using the `DisPerSe` algorithm, and compare the results to other filament-finding algorithms. We determine the properties of the identified filaments and compare them with the predictions of analytic filament stability models.
*Results.* The average line masses of the identified filaments, as well as the fraction of mass in filamentary structures, increases fairly continuously after the onset of self-gravity. The filaments show fragmentation starting relatively early: the first fragments appear when the line masses lie well below the critical line mass of Ostriker's isolated hydrostatic equilibrium solution ($\sim$16 M$_\odot$ pc$^{-1}$), commonly used as a fragmentation criterion. The average line masses of filaments identified in three-dimensional volume density cubes increases far more quickly than those identified in two-dimensional column density maps.
*Conclusions.* Our results suggest that hydrostatic or dynamic compression from the surrounding cloud has a significant impact on the early dynamical evolution of filaments. A simple model of an isolated, isothermal cylinder may not provide a good approach for fragmentation analysis. Caution must be exercised in interpreting distributions of properties of filaments identified in column density maps, especially in the case of low-mass filaments. Comparing or combining results from studies that use different filament finding techniques is strongly discouraged.

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## The ALMA early science view of FUor/EXor objects - V: continuum disc masses and sizes

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Low-mass stars build a significant fraction of their total mass during short outbursts of enhanced accretion known as FUor and EXor outbursts. FUor objects are characterized by a sudden brightening of ∼5 magnitudes at visible wavelengths within one year and remain bright for decades. EXor objects have lower amplitude outbursts on shorter timescales. Here we discuss a 1.3 mm ALMA mini-survey of eight outbursting sources (three FUor, four EXor, and the borderline object V1647 Ori) in the Orion Molecular Cloud. While previous papers in this series discuss the remarkable molecular outflows observed in the three FUor objects and V1647 Ori, here we focus on the continuum data and the differences and similarities between the FUor and EXor populations. We find that FUor discs are significantly more massive (∼80-600 $M_{JUP}$) than the EXor objects (∼0.5-40 $M_{JUP}$). We also report that the EXor sources lack the prominent outflows seen in the FUor population. Even though our sample is small, the large differences in disc masses and outflow activity suggest that the two types of objects represent different evolutionary stages.The FUor sources seem to be rather compact ($R_c$ < 20-40 au) and to have a smaller characteristic radius for a given disc mass when compared to T Tauri stars. V1118 Ori, the only known close binary system in our sample, is shown to host a disc around each one of the stellar components. The disc around HBC 494 is asymmetric, hinting at a structure in the outer disc or the presence of a second disc.

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## ALMA observations of Elias 2-24: a protoplanetary disk with multiple gaps in the Ophiuchus Molecular Cloud

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We present ALMA 1.3 mm continuum observations at 0.2″ (25 au) resolution of Elias 2-24, one of the largest and brightest protoplanetary disks in the Ophiuchus Molecular Cloud, and report the presence of three partially resolved concentric gaps located at ∼20, 52, and 87 au from the star. We perform radiative transfer modeling of the disk to constrain its surface density and temperature radial profile and place the disk structure in the context of mechanisms capable of forming narrow gaps such as condensation fronts and dynamical clearing by actively forming planets. In particular, we estimate the disk temperature at the locations of the gaps to be 23, 15, and 12 K (at 20, 52, and 87 au respectively), very close to the expected snow-lines of CO (12-15 K). Similarly, by assuming that the widths of the gaps correspond to 4–8 × the Hill radii of forming planets (as suggested by numerical simulations), we estimate planet masses in the range of 0.2–1.5 $M_{\rm Jup}$, 1.0–8.0 $M_{\rm Jup}$, and 0.02–0.15 $M_{\rm Jup}$ for the inner, middle, and outer gap, respectively. Given the surface density profile of the disk, the amount of "missing mass" at the location of each one of these gaps (between 4 and 20 $M_{\rm Jup}$) is more than sufficient to account for the formation of such planets.

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## Very Low-mass Stars and Brown Dwarfs in Upper Scorpius Using Gaia DR1: Mass Function, Disks, and Kinematics

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Our understanding of the brown dwarf population in star-forming regions is dependent on knowing distances and proper motions and therefore will be improved through the Gaia space mission. In this paper, we select new samples of very low-mass objects (VLMOs) in Upper Scorpius using UKIDSS colors and optimized proper motions calculated using Gaia DR1. The scatter in proper motions from VLMOs in Upper Scorpius is now (for the first time) dominated by the kinematic spread of the region itself, not by the positional uncertainties. With age and mass estimates updated using Gaia parallaxes for early-type stars in the same region, we determine masses for all VLMOs. Our final most complete sample includes 453 VLMOs of which  125 are expected to be brown dwarfs. The cleanest sample is comprised of 131 VLMOs, with  105 brown dwarfs. We also compile a joint sample from the literature that includes 415 VLMOs, out of which 152 are likely brown dwarfs. The disk fraction among low-mass brown dwarfs ($M < 0.05 M_\odot$) is substantially higher than in more massive objects, indicating that disks around low-mass brown dwarfs survive longer than in low-mass stars overall. The mass function for $0.01 < M < 0.1 M_\odot$ is consistent with the Kroupa Initial Mass Function. We investigate the possibility that some "proper motion outliers" have undergone a dynamical ejection early in their evolution. Our analysis shows that the colormagnitude cuts used when selecting samples introduce strong bias into the population statistics due to varying levels of contamination and completeness.

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http://arxiv.org/pdf/1710.11625
http://iopscience.iop.org/article/10.3847/1538-3881/aa9751

## Widespread SiO and $CH_3OH$ Emission in Filamentary Infrared-Dark Clouds

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Infrared-Dark Clouds (IRDCs) are cold, dense regions of high (optical and infrared) extinction, believed to be the birthplace of high-mass stars and stellar clusters. The physical mechanisms leading to the formation of these IRDCs are not completely understood and it is thus important to study their molecular gas kinematics and chemical content to search for any signature of the IRDCs formation process. Using the 30m-diameter antenna at the Instituto de Radioastronomía Milimétrica, we have obtained emission maps of dense gas tracers ($H^{13}CO^+$ and $HN^{13}C$) and typical shock tracers (SiO and $CH_3OH$) toward three IRDCs, G028.37+00.07, G034.43+00.24 and G034.77-00.55 (clouds C, F and G, respectively). We have studied the molecular gas kinematics in these clouds and, consistent with previous works toward other IRDCs, the clouds show complex gas kinematics with several velocity-coherent sub-structures separated in velocity space by a few km $s^{-1}$. Correlated with these complex kinematic structures, widespread (parsec-scale) emission of SiO and $CH_3OH$ is present in all the three clouds. For clouds C and F, known to be actively forming stars, widespread SiO and $CH_3OH$ is likely associated with on-going star formation activity. However, for cloud G, which lacks either 8 $\mu$m or 24 $\mu$m sources and 4.5 $\mu$m $H_2$ shock-excited emission, the detected widespread SiO and $CH_3OH$ emission may have originated in a large-scale shock interaction, although a scenario involving a population of low-mass stars driving molecular outflows cannot be fully ruled out.

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## Protoplanetary Disks in $\rho$ Ophiuchus as Seen From ALMA

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We present a high angular resolution ($\sim$0''.2), high sensitivity ($\sigma \sim 0.2$ mJy) survey of the 870 $\mu$m continuum emission from the circumstellar material around 49 pre-main sequence stars in the $\rho$ Ophiuchus molecular cloud. Because most millimeter instruments have resided in the northern hemisphere, this represents the largest high-resolution, millimeter-wave survey of the circumstellar disk content of this cloud. Our survey of 49 systems comprises 63 stars; we detect disks associated with 29 single sources, 11 binaries, 3 triple systems and 4 transition disks. We present flux and radius distributions for these systems; in particular, this is the first presentation of a reasonably complete probability distribution of disk radii at millimeter-wavelengths. We also compare the flux distribution of these protoplanetary disks with that of the disk population of the Taurus-Auriga molecular cloud. We find that disks in binaries are both significantly smaller and have much less flux than their counterparts around isolated stars. We compute truncation calculations on our binary sources and find that these disks are too small to have been affected by tidal truncation and posit some explanations for this. Lastly, our survey found 3 candidate gapped disks, one of which is a newly identified transition disk with no signature of a dip in infrared excess in extant observations.

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## Probing the origin of UX Ori-type variability in the YSO binary CO Ori with VLTI/GRAVITY

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The primary star in the young stellar object (YSO) binary CO Ori displays UX Ori-type variability: irregular, high amplitude optical and near-infrared photometric fluctuations where flux minima coincide with polarization maxima. This is attributed to changes in local opacity. In CO Ori A, these variations exhibit a 12.4 yr cycle. Here, we investigate the physical origin of the fluctuating opacity and its periodicity using interferometric observations of CO Ori obtained using VLTI/GRAVITY. Continuum K-band circum-primary and circum-secondary emission are marginally spatially resolved for the first time while Br$\gamma$ emission is detected in the spectrum of the secondary. We estimate a spectral type range for CO Ori B of K2-K5 assuming visual extinction, $A_{\rm V} = 2$ and a distance of 430 pc. From geometric modelling of the continuum visibilities, the circum-primary emission is consistent with a central point source plus a Gaussian component with a full-width-half-maximum of 2.31$\pm$0.04 milliarcseconds (mas), inclined at 30.2$\pm$2.2° and with a major axis position angle of 40$\pm$6°. This inclination is lower than that reported for the discs of other UX Ori-type stars, providing a first indication that the UX Ori phenomena may arise through fluctuations in circumstellar material exterior to a disc, e.g. in a dusty outflow. An additional wide, symmetric Gaussian component is required to fit the visibilities of CO Ori B, signifying a contribution from scattered light. Finally, closure phases of CO Ori A were used to investigate whether the 12.4 yr periodicity is associated with an undetected third component, as has been previously suggested. We rule out any additional companions contributing more than 3.6

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## New insights in the mid-infrared bubble N49 site: a clue of collision of filamentary molecular clouds

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We investigate the star formation processes operating in a mid-infrared bubble N49 site, which harbors an O-type star in its interior, an ultracompact H II region, and a 6.7 GHz methanol maser at its edges. The $^{13}$CO line data reveal two velocity components (at velocity peaks $\sim$88 and $\sim$95 km s$^{-1}$) in the direction of the bubble. An elongated filamentary feature (length >15 pc) is investigated in each molecular cloud component, and the bubble is found at the interface of these two filamentary molecular clouds. The *Herschel* temperature map traces all these structures in a temperature range of $\sim$16–24 K. In the velocity space of $^{13}$CO, the two molecular clouds are separated by $\sim$7 km s$^{-1}$, and are interconnected by a lower intensity intermediate velocity emission (i.e. a broad bridge feature). A possible complementary molecular pair at [87, 88] km s$^{-1}$ and [95, 96] km s$^{-1}$ is also observed in the velocity channel maps. These observational signatures are in agreement with the outcomes of simulations of the cloud-cloud collision process. There are also noticeable embedded protostars and *Herschel* clumps distributed toward the filamentary features including the intersection zone of the two molecular clouds. In the bubble site, different early evolutionary stages of massive star formation are also present. Together, these observational results suggest that in the bubble N49 site, the collision of the filamentary molecular clouds appears to be operated about 0.7 Myr ago, and may have triggered the formation of embedded protostars and massive stars.

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## ALMA continuum observations of the protoplanetary disk AS 209. Evidence of multiple gaps opened by a single planet

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The paper presents new high angular resolution ALMA 1.3 mm dust continuum observations of the protoplanetary system AS 209 in the Ophiuchus star forming region. The dust continuum emission is characterized by a main central core and two prominent rings at $r = 75$ au and $r = 130$ au intervaled by two gaps at at $r = 62$ au and $r = 103$ au. The two gaps have different widths and depths, with the inner one being narrower and shallower. We determined the surface density of the millimeter dust grains using the 3D radiative transfer disk code DALI. According to our fiducial model the inner gap is partially filled with millimeter grains while the outer gap is largely devoid of dust. The inferred surface density is compared to 3D hydrodynamical simulations (FARGO-3D) of planet-disk interaction. The outer dust gap is consistent with the presence of a giant planet ($M_{\rm planet} \sim 0.8\ M_{\rm Staturn}$); the planet is responsible for the gap opening and for the pile-up of dust at the outer edge of the planet orbit. The simulations also show that the same planet can give origin to the inner gap at $r = 62$ au. The relative position of the two dust gaps is close to the 2:1 resonance and we have investigated the possibility of a second planet inside the inner gap. The resulting surface density (including location, width and depth of the two dust gaps) are in agreement with the observations. The properties of the inner gap pose a strong constraint to the mass of the inner planet ($M_{\rm planet} < 0.1\ M_{\rm J}$). In both scenarios (single or pair of planets), the hydrodynamical simulations suggest a very low disk viscosity ($\alpha < 10^{-4}$). Given the young age of the system (0.5–1 Myr), this result implies that the formation of giant planets occurs on a timescale of $\lesssim$1 Myr.

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## The evolution of surface magnetic fields in young solar-type stars II: The early main sequence (250–650 Myr)

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There is a large change in surface rotation rates of sun-like stars on the pre-main sequence and early main sequence. Since these stars have dynamo driven magnetic fields, this implies a strong evolution of their magnetic properties over this time period. The spin-down of these stars is controlled by interactions between stellar winds and magnetic fields, thus magnetic evolution in turn plays an important role in rotational evolution. We present here the second part of a study investigating the evolution of large-scale surface magnetic fields in this critical time period. We observed stars in open clusters and stellar associations with known ages between 120 and 650 Myr, and used spectropolarimetry and Zeeman Doppler Imaging to characterize their large-scale magnetic field strength and geometry. We report 15 stars with magnetic detections here. These stars have masses from 0.8 to 0.95 $M_\odot$, rotation periods from 0.326 to 10.6 days, and we find large-scale magnetic field strengths from 8.5 to 195 G with a wide range of geometries. We find a clear

trend towards decreasing magnetic field strength with age, and a power-law decrease in magnetic field strength with Rossby number. There is some tentative evidence for saturation of the large-scale magnetic field strength at Rossby numbers below 0.1, although the saturation point is not yet well defined. Comparing to younger classical T Tauri stars, we support the hypothesis that differences in internal structure produce large differences in observed magnetic fields, however for weak lined T Tauri stars this is less clear.

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## Twelve Years of Spectroscopic Monitoring in the Galactic Center: The Closest Look at S-stars near the Black Hole

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We study the young S-stars within a distance of 0.04 pc from the supermassive black hole in the center of our Galaxy. Given how inhospitable the region is for star formation, their presence is more puzzling the younger we estimate their ages. In this study, we analyze the result of 12 years of high-resolution spectroscopy within the central arcsecond of the Galactic Center (GC). By co-adding between 55 and 105 hr of spectra we have obtained high signal-to-noise H- and K-band spectra of eight stars orbiting the central supermassive black hole. Using deep H-band spectra, we show that these stars must be high surface gravity (dwarf) stars. We compare these deep spectra to detailed model atmospheres and stellar evolution models to infer the stellar parameters. Our analysis reveals an effective temperature of 21,000–28,500 K, a rotational velocity of 60–170 km $s^{-1}$, and a surface gravity of 4.1–4.2. These parameters imply a spectral type of B0–B3V for these stars. The inferred masses lie within 8–14 $M_{\odot}$. We derive an age of $6.6^{+3.4}_{-4.7}$ Myr for the star S2, which is compatible with the age of the clockwise-rotating young stellar disk in the GC. We estimate the ages of all other studied S-stars to be less than 15 Myr, which is compatible with the age of S2 within the uncertainties. The relatively low ages for these S-stars favor a scenario in which the stars formed in a local disk rather than a field binary-disruption scenario that occurred over a longer period of time.

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## The Evolution of Supermassive Population III Stars

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Supermassive primordial stars forming in atomically-cooled halos at $z \sim 15-20$ are currently thought to be the progenitors of the earliest quasars in the Universe. In this picture, the star evolves under accretion rates of 0.1 – 1 $M_{\odot}\,yr^{-1}$ until the general relativistic instability triggers its collapse to a black hole at masses of $\sim 10^5$ $M_{\odot}$. However, the ability of the accretion flow to sustain such high rates depends crucially on the photospheric properties of the accreting star, because its ionising radiation could reduce or even halt accretion. Here we present new models of supermassive Population III protostars accreting at rates 0.001 – 10 $M_{\odot}\,yr^{-1}$, computed with the GENEVA stellar

evolution code including general relativistic corrections to the internal structure. We compute for the first time evolutionary tracks in the mass range $M > 10^5\,M_\odot$. We use the polytropic stability criterion to estimate the mass at which the collapse occurs, which has been shown to give a lower limit of the actual mass at collapse in recent hydrodynamic simulations. We find that at accretion rates higher than 0.01 $M_\odot\,yr^{-1}$ the stars evolve as red, cool supergiants with surface temperatures below $10^4$ K towards masses $> 10^5$ $M_\odot$. Moreover, even with the lower rates 0.001 $M_\odot\,yr^{-1} < dm < 0.01$ $M_\odot\,yr^{-1}$, the surface temperature is substantially reduced from $10^5$ K to $10^4$ K for $M > 600$ $M_\odot$. Compared to previous studies, our results extend the range of masses and accretion rates at which the ionising feedback remains weak, reinforcing the case for direct collapse as the origin of the first quasars. We provide numerical tables for the surface properties of our models.

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## A likely planet-induced gap in the disk around T Cha

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We present high resolution (0.″11×0.″06) 3mm ALMA observations of the highly inclined transition disk around the star T Cha. Our continuum image reveals multiple dust structures: an inner disk, a spatially resolved dust gap, and an outer ring. When fitting sky-brightness models to the real component of the 3mm visibilities, we infer that the inner emission is compact (≤1 au in radius), the gap width is between 18–28 au, and the emission from the outer ring peaks at ∼36 au. We compare our ALMA image with previously published 1.6 $\mu$m VLT/SPHERE imagery. This comparison reveals that the location of the outer ring is wavelength dependent. More specifically, the peak emission of the 3mm ring is at a larger radial distance than that of the 1.6 $\mu$m ring, suggesting that millimeter-sized grains in the outer disk are located further away from the central star than micron-sized grains. We discuss different scenarios to explain our findings, including dead zones, star-driven photoevaporation, and planet-disk interactions. We find that the most likely origin of the dust gap is from an embedded planet, and estimate — for a single planet scenario — that T Cha's gap is carved by a 1.2 $M_{\rm jup}$ planet.

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## The Power of SOFIA/FORCAST in Estimating Internal Luminosities of Low Mass Class 0/I Protostars

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With the Stratospheric Observatory for Infrared Astronomy (SOFIA) routinely operating science flights, we demonstrate that observations with the Faint Object infraRed CAmera for the SOFIA Telescope (FORCAST) can provide reliable estimates of the internal luminosities, $L_{\rm int}$, of protostars. We have developed a technique to estimate $L_{\rm int}$ using

a pair of FORCAST filters: one "short-wavelength" filter centered within 19.7–25.3 $\mu$m, and one "long-wavelength" filter within 31.5–37.1 $\mu$m. These $L_{\rm int}$ estimates are reliable to within 30–40% for 67% of protostars and to within a factor of 2.3–2.6 for 99% of protostars. The filter pair comprised of F25.3$\mu$m and F37.1$\mu$m achieves the best sensitivity and most constrained results. We evaluate several assumptions that could lead to systematic uncertainties. The OH5 dust opacity matches observational constraints for protostellar environments best, though not perfectly; we find that any improved dust model will have a small impact of 5–10% on the $L_{\rm int}$ estimates. For protostellar envelopes, the TSC84 model yields masses that are twice those of the Ulrich model, but we conclude this mass difference does not significantly impact results at the mid-infrared wavelengths probed by FORCAST. Thus, FORCAST is a powerful instrument for luminosity studies targeting newly discovered protostars or suspected protostars lacking detections longward of 24 $\mu$m. Furthermore, with its dynamic range and greater angular resolution, FORCAST may be used to characterize protostars that were either saturated or merged with other sources in previous surveys using the Spitzer Space Telescope or Herschel Space Observatory.

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## IN-SYNC. VII. Evidence for a decreasing spectroscopic binary fraction from 1 to 100 Myr within the IN-SYNC sample

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We study the occurrence of spectroscopic binaries in young star-forming regions using the INfrared Spectroscopy of Young Nebulous Clusters (IN-SYNC) survey, carried out in SDSS III with the APOGEE spectrograph. Multi-epoch observations of thousands of low-mass stars in Orion A, NGC 2264, NGC 1333, IC 348, and the Pleiades have been carried out, yielding H-band spectra with a nominal resolution of R=22,500 for sources with H<12 mag. Radial velocity precisions of $\sim$0.3 km s$^{-1}$ were achieved, which we use to identify radial velocity variations indicative of undetected companions. We use Monte Carlo simulations to assess the types of spectroscopic binaries to which we are sensitive, finding sensitivity to binaries with orbital periods $\lesssim 10^{3.5}$ d, for stars with 2500 K $\leq T_{\rm eff} \leq$ 6000 K and $v \sin i$<100 km s$^{-1}$. Using Bayesian inference, we find evidence for a decline in the spectroscopic binary fraction, by a factor of 3–4 from the age of our pre–main-sequence sample to the Pleiades age . The significance of this decline is weakened if spot-induced radial-velocity jitter is strong in the sample, and is only marginally significant when comparing any one of the pre–main-sequence clusters against the Pleiades. However, the same decline in both sense and magnitude is found for each of the five pre–main-sequence clusters, and the decline reaches statistical significance of greater than 95% confidence when considering the pre–main-sequence clusters jointly. Our results suggest that dynamical processes disrupt the widest spectroscopic binaries ($P_{\rm orb} \approx 10^3 - 10^4$ d) as clusters age, indicating that this occurs early in the stars' evolution, while they still reside within their nascent clusters.

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## Spiral arms in thermally stratified protoplanetary discs

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Spiral arms have been observed in nearly a dozen protoplanetary discs in near-infrared scattered light and recently also in the sub-millimetre continuum. While one of the most compelling explanations is that they are driven by planetary

or stellar companions, in all but one cases such companions have not yet been detected and there is even ambiguity on whether the planet should be located inside or outside the spirals. Here we use 3D hydrodynamic simulations to study the morphology of spiral density waves launched by embedded planets taking into account the vertical temperature gradient, a natural consequence of stellar irradiation. Our simulations show that the pitch angle of the spirals in thermally stratified discs is the lowest in the disc mid-plane and increases towards the disc surface. We combine the hydrodynamic simulations with 3D radiative transfer calculations to predict that the pitch-angle of planetary spirals observed in the near-infrared is higher than in the sub-millimetre. We also find that in both cases the spirals converge towards the planet. This provides a new powerful observational method to determine if the perturbing planet is inside our outside the spirals, as well as map the thermal stratification of the disc.

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## Relationship between turbulence energy and density variance in the Solar neighbourhood molecular clouds

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The relationship between turbulence energy and gas density variance is a fundamental prediction for turbulence-dominated media and it is commonly used in analytic models of star formation. We determine this relationship for 15 molecular clouds in the Solar neighbourhood. We use the linewidths of the CO molecule as the probe of the turbulence energy (sonic Mach number, $\mathcal{M}_{\rm s}$) and three-dimensional models to reconstruct the density probability distribution function ($\rho$-PDF) of the clouds, derived using near-infrared extinction and *Herschel* dust emission data, as the probe of the density variance ($\sigma_{\rm s}$). We find no significant correlation between $\mathcal{M}_{\rm s}$ and $\sigma_{\rm s}$ among the studied clouds, however, we also cannot rule out a weak correlation. In the context of turbulence-dominated gas, the range of the $\mathcal{M}_{\rm s}$ and $\sigma_{\rm s}$ values corresponds with the model predictions. The data cannot constrain whether the turbulence driving parameter, $b$, and/or thermal-to-magnetic pressure ratio, $\beta$, vary among the sample clouds. Most clouds are not in agreement with field strengths stronger than given by $\beta < 0.05$. A model with $b^2\beta/(\beta+1) = 0.30 \pm 0.06$ provides an adequate fit to the cloud sample as a whole. When considering the average behaviour of the sample, we can rule out three regimes: (i) strong compression combined with a weak magnetic field ($b > 0.7$ and $\beta > 3$), (ii) weak compression ($b < 0.35$), and (iii) strong magnetic field ($\beta < 0.1$). Including independent magnetic field strength estimates to the analysis, the data rule out solenoidal driving ($b < 0.4$) for the majority of the Solar neighbourhood clouds. However, most clouds have $b$ parameters larger than unity, which indicates a discrepancy with the turbulence-dominated picture; we discuss the possible reasons for this.

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## Pillars of creation amongst destruction: Star formation in molecular clouds near R 136 in 30 Doradus

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New sensitive CO (2-1) observations of the 30 Doradus region in the Large Magellanic Cloud are presented. We identify a chain of three newly discovered molecular clouds we name KN1, KN2 and KN3 lying within 2–14 pc in projection from the young massive cluster R 136 in 30 Doradus. Excited $H_2$ 2.12$\mu$m emission is spatially coincident with the molecular clouds, but ionized Br$\gamma$ emission is not. We interpret these observations as the tails of pillar-like structures whose ionized heads are pointing towards R 136. Based on infrared photometry, we identify a new generation of stars forming within this structure.

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http://www.das.uchile.cl/~vkalari/staplervk.pdf

## Molecular gas in high-mass filament WB673

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We studied the distribution of dense gas in a filamentary molecular cloud containing several dense clumps. The center of the filament is given by the dense clump WB673. The clumps are high-mass and intermediate-mass star-forming regions. We observed CS(2-1), 13CO(1-0), C18O(1-0) and methanol lines at 96GHz toward WB673 with the Onsala Space Observatory 20-m telescope. We found CS(2-1) emission in the inter-clump medium so the clumps are physically connected and the whole cloud is indeed a filament. Its total mass is 104 solar masses, and mass-to-length ratio is 360 solar masses per parsec from 13CO(1-0) data. Mass-to-length ratio for the dense gas is 3.4?34 solar masses per parsec from CS(2-1) data. The PV-diagram of the filament is V-shaped. We estimated physical conditions in the molecular gas using methanol lines. Location of the filament on the sky between extended shells suggests that it could be a good example to test theoretical models of formation of the filaments via multiple compression of interstellar gas by supersonic waves.

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## Gas-Phase Spectra of MgO Molecules: A Possible Connection from Gas-Phase Molecules to Planet Formation

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A more fine-tuned method for probing planet-forming regions, such as protoplanetary discs, could be rovibrational molecular spectroscopy observation of particular premineral molecules instead of more common but ultimately less related volatile organic compounds. Planets are created when grains aggregate, but how molecules form grains is an ongoing topic of discussion in astrophysics and planetary science. Using the spectroscopic data of molecules specifically involved in mineral formation could help to map regions where planet formation is believed to be occurring in order to examine the interplay between gas and dust. Four atoms are frequently associated with planetary formation: Fe, Si, Mg, and O. Magnesium, in particular, has been shown to be in higher relative abundance in planet-hosting stars. Magnesium oxide crystals comprise the mineral periclase making it the chemically simplest magnesium-bearing mineral and a natural choice for analysis. The monomer, dimer, and trimer forms of $(MgO)_n$ with $n = 1$–3 are analyzed in this work using high-level quantum chemical computations known to produce accurate results. Strong vibrational transitions at 12.5 $\mu$m, 15.0 $\mu$m, and 16.5 $\mu$m are indicative of magnesium oxide monomer, dimer, and trimer making

these wavelengths of particular interest for the observation of protoplanetary discs and even potentially planet-forming regions around stars. If such transitions are observed in emission from the accretion discs or absorptions from stellar spectra, the beginning stages of mineral and, subsequently, rocky body formation could be indicated.

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## Debris Disc Constraints on Planetesimal Formation

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Two basic routes for planetesimal formation have been proposed over the last few decades. One is a classical "slow-growth" scenario. Another one is particle concentration models, in which small pebbles are concentrated locally and then collapse gravitationally to form planetesimals. Both types of models make certain predictions for the size spectrum and internal structure of newly-born planetesimals. We use these predictions as input to simulate collisional evolution of debris discs left after the gas dispersal. The debris disc emission as a function of a system's age computed in these simulations is compared with several Spitzer and Herschel debris disc surveys around A-type stars. We confirm that the observed brightness evolution for the majority of discs can be reproduced by classical models. Further, we find that it is equally consistent with the size distribution of planetesimals predicted by particle concentration models - provided the objects are loosely bound "pebble piles" as these models also predict. Regardless of the assumed planetesimal formation mechanism, explaining the brightest debris discs in the samples uncovers a "disc mass problem." To reproduce such discs by collisional simulations, a total mass of planetesimals of up to $\sim$1000 Earth masses is required, which exceeds the total mass of solids available in the protoplanetary progenitors of debris discs. This may indicate that stirring was delayed in some of the bright discs, that giant impacts occurred recently in some of them, that some systems may be younger than previously thought, or that non-collisional processes contribute significantly to the dust production.

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## Magnetic fields of intermediate mass T Tauri stars

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*Aims.* In this paper, we aim to measure the strength of the surface magnetic fields for a sample of five intermediate mass T Tauri stars and one low mass T Tauri star from late-F to mid-K spectral types. While magnetic fields of T Tauri stars at the low mass range have been extensively characterized, our work complements previous studies towards the intermediate mass range; this complementary study is key to evaluate how magnetic fields evolve during the transition from a convective to a radiative core.
*Methods.* We studied the Zeeman broadening of magnetically sensitive spectral lines in the *H*-band spectra obtained with the CRIRES high-resolution near-infrared spectrometer. These data are modelled using magnetic spectral syn-

thesis and model atmospheres. Additional constraints on non-magnetic line broadening mechanisms are obtained from modelling molecular lines in the $K$ band or atomic lines in the optical wavelength region.
*Results.* We detect and measure mean surface magnetic fields for five of the six stars in our sample: CHXR 28, COUP 107, V2062 Oph, V1149 Sco, and Par 2441. Magnetic field strengths inferred from the most magnetically sensitive diagnostic line range from 0.8 to 1.8 kG. We also estimate a magnetic field strength of 1.9 kG for COUP 107 from an alternative diagnostic. The magnetic field on YLW 19 is the weakest in our sample and is marginally detected, with a strength of 0.8 kG.
*Conclusions.* We populate an uncharted area of the pre-main-sequence HR diagram with mean magnetic field measurements from high-resolution near-infrared spectra. Our sample of intermediate mass T Tauri stars in general exhibits weaker magnetic fields than their lower mass counterparts. Our measurements will be used in combination with other spectropolarimetric studies of intermediate mass and lower mass T Tauri stars to provide input into pre-main-sequence stellar evolutionary models.

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## An SMA Continuum Survey of Circumstellar Disks in the Serpens Star-Forming Region

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We present observations with the Submillimeter Array of the continuum emission at $\lambda = 1.3$ mm from 62 young stars surrounded by a protoplanetary disk in the Serpens star-forming region. The typical angular resolution for the survey in terms of beam size is $3\farcs5 \times 2\farcs5$ with a median rms noise level of 1.6 mJy beam$^{-1}$. These data are used to infer the dust content in disks around low-mass stars (0.1–2.5 $M_\odot$) at a median stellar age of 1–3 Myr. Thirteen sources were detected in the 1.3 mm dust continuum with inferred dust masses of ≈10–260 $M_\oplus$ and an upper limit to the median dust mass of $5.1^{+6.1}_{-4.3}$ $M_\oplus$, derived using survival analysis. Comparing the protoplanetary disk population in Serpens to those of other nearby star-forming regions, we find that the populations of dust disks in Serpens and Taurus, which have a similar age, are statistically indistinguishable. This is potentially surprising since Serpens has a stellar surface density two orders of magnitude in excess of Taurus. Hence, we find no evidence that dust disks in Serpens have been dispersed as a result of more frequent and/or stronger tidal interactions due its elevated stellar density. We also report that the fraction of Serpens disks with $M_{\rm dust} \geq 10$ $M_\oplus$ is less than 20%, which supports the notion that the formation of giant planets is likely inherently rare or has substantially progressed by a few Myrs.

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## Stellar mass spectrum within massive collapsing clumps II. Thermodynamics and tidal forces of the first Larson core

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We investigate the dependence of the peak of the IMF on the physics of the so-called first Larson core, which corresponds to the point where the dust becomes opaque to its own radiation. We perform numerical simulations of collapsing clouds of 1000 $M_\odot$ for various gas equation of state (eos), paying great attention to the numerical resolution and convergence. The initial conditions of these numerical experiments are varied in the companion paper. We also develop analytical models that we confront to our numerical results. If an isothermal eos is used, we show that the

peak of the IMF shifts to lower masses with improved numerical resolution. When an adiabatic eos is employed, numerical convergence is obtained. The peak position varies with the eos and we find that the peak position is about ten times the mass of the first Larson core. By analyzing the stability of non-linear density fluctuations in the vicinity of a point mass and then summing over a reasonable density distribution, we find that tidal forces exert a strong stabilizing effect and likely lead to a preferential mass several times larger than that of the first Larson core. We propose that in a sufficiently massive and cold cloud, the peak of the IMF is determined by the thermodynamics of the high density adiabatic gas as well as the stabilizing influence of tidal forces. The resulting characteristic mass is about ten times the mass of the first Larson core, which altogether leads to a few tenths of solar masses. Since these processes are not related to the large scale physical conditions and to the environment, our results suggest a possible explanation for the apparent universality of the peak of the IMF.

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## Quantifying the interplay between gravity and magnetic field in molecular clouds - a possible multi-scale energy equipartition in NGC6334

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The interplay between gravity, turbulence and the magnetic field determines the evolution of the molecular ISM and the formation of the stars. In spite of growing interests, there remains a lack of understanding of the importance of magnetic field over multiple scales. We derive the magnetic energy spectrum – a measure that constraints the multi-scale distribution of the magnetic energy, and compare it with the gravitational energy spectrum derived in Li & Burkert (2016). In our formalism, the gravitational energy spectrum is purely determined by the surface density PDF, and the magnetic energy spectrum is determined by both the surface density PDF and the magnetic-field-density relation. If regions have density PDFs close to $P(\Sigma) \sim \Sigma^{-2}$ and a universal magnetic field-density relation $B \sim \rho^{1/2}$, we expect a multi-scale near equipartition between gravity and the magnetic fields. This equipartition is found to be true in NGC6334 where estimates of magnetic fields over multiple scales (from 0.1 pc to a few parsec) are available. However, the current observations are still limited in sample size. In the future, it is necessary to obtain multi-scale measurements of magnetic fields from different clouds with different surface density PDFs and apply our formalism to further study the gravity-magnetic field interplay.

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## Impact splash chondrule formation during planetesimal recycling

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Chondrules, mm-sized igneous-textured spherules, are the dominant bulk silicate constituent of chon- dritic meteorites and originate from highly energetic, local processes during the first million years af- ter the birth of the Sun. So far, an astrophysically consistent chondrule formation scenario explaining major chemical, isotopic and textural features, in particular Fe,Ni metal abundances, bulk Fe/Mg ratios and intra-chondrite chemical and isotopic diversity, remains

elusive. Here, we examine the prospect of forming chondrules from impact splashes among planetesimals heated by radioactive decay of short- lived radionuclides using thermomechanical models of their interior evolution. We show that intensely melted planetesimals with interior magma oceans became rapidly chemically equilibrated and physically differentiated. Therefore, collisional interactions among such bodies would have resulted in chondrule- like but basaltic spherules, which are not observed in the meteoritic record. This inconsistency with the expected dynamical interactions hints at an incomplete understanding of the planetary growth regime during the lifetime of the solar protoplanetary disk. To resolve this conundrum, we examine how the observed chemical and isotopic features of chondrules constrain the dynamical environment of accret- ing chondrite parent bodies by interpreting the meteoritic record as an impact-generated proxy of early solar system planetesimals that underwent repeated collision and reaccretion cycles. Using a coupled evolution-collision model we demonstrate that the vast majority of collisional debris feeding the asteroid main belt must be derived from planetesimals which were partially molten at maximum. Therefore, the precursors of chondrite parent bodies either formed primarily small, from sub-canonical aluminum-26 reservoirs, or collisional destruction mechanisms were efficient enough to shatter planetesimals before they reached the magma ocean phase. Finally, we outline the window in parameter space for which chondrule formation from planetesimal collisions can be reconciled with the meteoritic record and how our results can be used to further constrain early solar system dynamics.

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## Synthetic observations of protostellar multiple systems

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Observations of protostars are often compared with synthetic observations of models in order to infer the underlying physical properties of the protostars. The majority of these models have a single protostar, attended by a disc and an envelope. However, observational and numerical evidence suggests that a large fraction of protostars form as multiple systems. This means that fitting models of single protostars to observations may be inappropriate. We produce synthetic observations of protostellar multiple systems undergoing realistic, non-continuous accretion. These systems consist of multiple protostars with episodic luminosities, embedded self-consistently in discs and envelopes. We model the gas dynamics of these systems using smoothed particle hydrodynamics and we generate synthetic observations by post-processing the snapshots using the SPAMCART Monte Carlo radiative transfer code. We present simulation results of three model protostellar multiple systems. For each of these, we generate $4 \times 10^4$ synthetic spectra at different points in time and from different viewing angles. We propose a Bayesian method, using similar calculations to those presented here, but in greater numbers, to infer the physical properties of protostellar multiple systems from observations.

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## A clustered origin for isolated massive stars

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High-mass stars are commonly found in stellar clusters promoting the idea that their formation occurs due to the physical processes linked with a young stellar cluster. It has recently been reported that isolated high-mass stars are present in the Large Magellanic Cloud. Due to their low velocities it has been argued that these are high-mass stars which formed without a surrounding stellar cluster. In this paper we present an alternative explanation for the origin of these stars in which they formed in a cluster environment but are subsequently dispersed into the field as their natal

cluster is tidally disrupted in a merger with a higher-mass cluster. They escape the merged cluster with relatively low velocities typical of the cluster interaction and thus of the larger scale velocity dispersion, similarly to the observed stars. $N$-body simulations of cluster mergers predict a sizeable population of low velocity ($\leq 20\,\mathrm{km\,s^{-1}}$), high-mass stars at distances of $> 20$ pc from the cluster. High-mass clusters in which gas poor mergers are frequent would be expected to commonly have halos of young stars, including high-mass stars, that were actually formed in a cluster environment.

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## Massive Outflows Driven by Magnetic Effects II: Comparison with Observations

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The driving mechanism of massive outflows observed in high-mass star-forming regions is investigated using three-dimensional magnetohydrodynamics (MHD) and protostellar evolution calculations. In our previous paper, we showed that the mass outflow rate depends strongly on the mass accretion rate onto the circumstellar disk around a high-mass protostar, and massive outflows may be driven by the magnetic effect in high-mass star-forming cores. In the present study, in order to verify that the MHD disk wind is the primary driving mechanism of massive outflows, we quantitatively compare outflow properties obtained through simulations and observations. Since the outflows obtained through simulations are slightly younger than those obtained through observations, the time-integrated quantities of outflow mass, momentum, and kinetic energy are slightly smaller than those obtained through observations. On the other hand, time-derivative quantities of mass ejection rate, outflow momentum flux, and kinetic luminosity obtained through simulations are in very good agreement with those obtained through observations. This indicates that the MHD disk wind greatly contributes to the massive outflow driving from high-mass protostars, and the magnetic field might significantly control the high-mass star formation process.

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## The protoplanetary system HD 100546 in H$\alpha$ polarized light from SPHERE/ZIMPOL. A bar-like structure across the disk gap?

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*Context:* HD 100546 is one of the few known pre-main-sequence stars that may host a planetary system in its disk.
Aims: This work aims to contribute to our understanding of HD 100546 by analyzing new polarimetric images with high spatial resolution.
*Methods:* Using VLT/SPHERE/ZIMPOL with two filters in H$\alpha$ and the adjacent continuum, we have probed the disk gap and the surface layers of the outer disk, covering a region $< 500$ *mas* ($< 55$ *au* at 109 pc) from the central star,

at an angular resolution of $\sim 20$ $mas$.
*Results:* Our data show an asymmetry: the SE and NW regions of the outer disk are more polarized than the SW and NE regions. This asymmetry can be explained from a preferential scattering angle close to $90^o$ and is consistent with previous polarization images. The outer disk in our observations extends from $13 \pm 2$ to $45 \pm 9$ $au$, with a position angle and inclination of $137 \pm 5^o$ and $44 \pm 8^o$, respectively. The comparison with previous estimates suggests that the disk inclination could increase with the stellocentric distance, although the different measurements are still consistent within the error bars. In addition, no direct signature of the innermost candidate companion is detected from the polarimetric data, confirming recent results that were based on intensity imagery. We set an upper limit to its mass accretion rate $< 10^{-8}$ $M_\odot$ yr$^{-1}$ for a substellar mass of $15M_{Jup}$. Finally, we report the first detection ($> 3\sigma$) of a $\sim$ 20 $au$ bar-like structure that crosses the gap through the central region of HD 100546.
*Conclusions:* In the absence of additional data, it is tentatively suggested that the bar could be dust dragged by infalling gas that radially flows from the outer disk to the inner region. This could represent an exceptional case in which a small-scale radial inflow is observed in a single system. If this scenario is confirmed, it could explain the presence of atomic gas in the inner disk that would otherwise accrete on to the central star on a timescale of a few months/years, as previously indicated from spectro-interferometric data, and could be related with additional (undetected) planets.

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## Near-infrared spectroscopic observations of massive young stellar object candidates in the Central Molecular Zone

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We present a spectroscopic follow-up of photometrically-selected young stellar object (YSO) candidates in the Central Molecular Zone of the Galactic center. Our goal is to quantify the contamination of this YSO sample by reddened giant stars with circumstellar envelopes and to determine the star formation rate in the CMZ. We obtained KMOS low-resolution near-infrared spectra ($R \sim 4000$) between 2.0 and 2.5 $\mu$m of sources, many of them previously identified, by mid-infrared photometric criteria, as massive YSOs in the Galactic center. Our final sample consists of 91 stars with good signal-to-noise ratio. We separate YSOs from cool late-type stars based on spectral features of CO and $Br_\gamma$ at 2.3 $\mu$m and 2.16 $\mu$m respectively. We make use of SED model fits to the observed photometric data points from 1.25 to 24 $\mu$m in order to estimate approximate masses for the YSOs. Using the spectroscopically identified YSOs in our sample, we confirm that existing colour-colour diagrams and colour-magnitude diagrams are unable to efficiently separate YSOs and cool late-type stars. In addition, we define a new colour-colour criterion that separates YSOs from cool late-type stars in the $H - K_s$ vs $H - [8.0]$ diagram. We use this new criterion to identify YSO candidates in the $|l| < 1.5$, $|b| < 0.5$ degree region and use model SED fits to estimate their approximate masses. By assuming an appropriate initial mass function (IMF) and extrapolating the stellar IMF down to lower masses, we determine a star formation rate (SFR) of $\sim$0.046$\pm$0.026 Msun yr$^{-1}$ assuming an average age of 0.75$\pm$0.25 Myr for the YSOs. This

value is lower than estimates found using the YSO counting method in the literature. Our SFR estimate in the CMZ agrees with the previous estimates from different methods and reaffirms that star formation in the CMZ is proceeding at a lower rate than predicted by various star forming models.

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## Young cluster Berkeley 59 : Properties, evolution and star formation

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Berkeley 59 is a nearby (∼1 kpc) young cluster associated with the Sh2-171 HII region. We present deep optical observations of the central $\sim 2.5 \times 2.5$ pc$^2$ area of the cluster, obtained with the 3.58-m Telescopio Nazionale Galileo. The $V/(V-I)$ color-magnitude diagram manifests a clear pre-main-sequence (PMS) population down to ∼0.2 $M_\odot$. Using the near-infrared and optical colors of the low-mass PMS members we derive a global extinction of $A_V = 4$ mag and a mean age of ∼1.8 Myr, respectively, for the cluster. We constructed the initial mass function and found that its global slopes in the mass ranges of 0.2–28 $M_\odot$ and 0.2–1.5 $M_\odot$ are −1.33 and −1.23, respectively, in good agreement with the Salpeter value in the solar neighborhood. We looked for the radial variation of the mass function and found that the slope is flatter in the inner region than in the outer region, indicating mass segregation. The dynamical status of the cluster suggests that the mass segregation is likely primordial. The age distribution of the PMS sources reveals that the younger sources appear to concentrate close to the inner region compared to the outer region of the cluster, a phenomenon possibly linked to the time evolution of star-forming clouds is discussed. Within the observed area, we derive a total mass of $\sim 10^3$ $M_\odot$ for the cluster. Comparing the properties of Berkeley 59 with other young clusters, we suggest it resembles more to the Trapezium cluster.

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## The ALMA-PILS survey: Formaldehyde deuteration in warm gas on small scales toward IRAS 16293-2422 B

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[abridged] The enhanced degrees of deuterium fractionation observed in envelopes around protostars demonstrate the importance of chemistry at low temperatures, relevant in pre- and protostellar cores. Formaldehyde is an important species in the formation of methanol and more complex molecules. Here, we present the first study of formaldehyde deuteration on small scales around the prototypical low-mass protostar IRAS 16293-2422 using high spatial and spectral resolution Atacama Large Millimeter/submillimeter Array (ALMA) observations. Numerous isotopologues of formaldehyde are detected, among them $H_2C^{17}O$, and $D_2^{13}CO$ for the first time in the ISM. The large range of upper energy levels covered by the HDCO lines help constrain the excitation temperature to 106±13 K. Using the derived column densities, formaldehyde shows a deuterium fractionation of $HDCO/H_2CO$=6.5±1%, $D_2CO/HDCO=12.8^{+3.3}_{-4.1}$%, and $D_2CO/H_2CO$=0.6(4)±0.1%. The isotopic ratios derived are $^{16}O/^{18}O$=805, $^{18}O/^{17}O$=3.2 and $^{12}C/^{13}C$=56. The $HDCO/H_2CO$ ratio is lower than found in previous studies, highlighting the uncertainties involved in interpreting single dish observations of the inner warm regions. The $D_2CO/HDCO$ ratio is only slightly larger than the $HDCO/H_2CO$ ratio. This is consistent with formaldehyde forming in the ice as soon as CO has frozen onto the grains, with most of the deuteration happening towards the end of the prestellar core phase. A comparison with available time-dependent chemical models indicates that the source is in the early Class 0 stage.

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## Did a stellar fly-by shape the planetary system around Pr0211 in the cluster M44?

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Out of the ∼3000 exoplanets detected so far, only fourteen planets are members of open clusters: among them an exoplanet system around Pr0211 in the cluster M44 which consists of at least two planets with the outer planet moving on a highly eccentric orbit at 5.5 AU. One hypothesis is that a close fly-by of a neighbouring star was responsible for the eccentric orbit. We test this hypothesis.First we determine the type of fly-by that would lead to the observed parameters and then use this result to determine the history of such fly-bys in simulations of the early dynamics in an M44-like environment. We find that although very close fly-bys are required to obtain the observed properties of Pr0211c, such fly-bys are relatively common due to the high stellar density and longevity of the cluster. Such close fly-bys are most frequent during the first 1-2 Myr after cluster formation, corresponding to a cluster age ≤ 3 Myr. During the first 2-3 Myr about 6.5% of stars experience a fly-by that would lead to such a small system-size as observed for Pr0211 or even smaller. It is unclear whether planets generally form on such short timescales. However, afterwards the close fly-by rate is still 0.2-0.5 $Myr^{-1}$, which means extrapolating this to the age of M44 12%-20% of stars would experience such close fly-bys over this timespan. Our simulations show that the fly-by scenario is a realistic option for the formation of eccentricity orbits of the planets in M44. The occurrence of such events is relatively high leading to the expectation that similar systems are likely common in open clusters in general.

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## XMM-Newton imaging of V1818 Ori: a young stellar group on the eastern edge of the $\kappa$ Ori ring

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We present the results of a 40 ks XMM-Newton observation centered on the variable star V1818 Ori. Using a combination of the XMM-Newton and AllWISE catalog data, we identify a group of about 31 young stellar objects around V1818 Ori. This group is coincident with the eastern edge of the dust ring surrounding $\kappa$ Ori. Previously, we concluded that the young stellar objects on the western side of ring were formed in an episode of star formation that started 3–5 Myr ago, and are at a distance similar to that of $\kappa$ Ori (250–280 pc) and in the foreground to the Orion A cloud. Here we use the XMM-Newton observation to calculate X-ray fluxes and luminosities of the young stars around V1818 Ori. We find that their X-ray luminosity function (XLF), calculated for a distance of $\sim$270 pc, matches the XLF of the YSOs west of $\kappa$ Ori. We rule out that this group of young stars is associated to Mon R2 as assumed in the literature, but rather they are part of the same Kappa Ori's ring stellar population.

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## Orbital Solution for the Spectroscopic Binary in the GW Ori Hierarchical Triple

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We present the first double-lined orbital solution for the close binary in the GW Ori triple system. Using 12 epochs of infrared spectroscopy, we detected the lines of both stars in the inner pair, previously known as single-lined only. Our preliminary infrared orbital solution has an eccentricity of $e = 0.21 \pm 0.10$, a period of $P = 241.15 \pm 0.72$ days, and a mass ratio of $q = 0.66 \pm 0.13$. We find a larger semi-amplitude for the primary star, $K1 = 6.57 \pm 1.00$ km s$^{-1}$, with an infrared-only solution compared to $K1 = 4.41 \pm 0.33$ km s$^{-1}$ with optical data from the literature, likely the result of line blending and veiling in the optical. The component spectral types correspond to G3 and K0 stars, with $v \sin i$ values of 43 km s$^{-1}$ and 50 km s$^{-1}$, respectively. We obtained a flux ratio of $\alpha = 0.58 \pm 0.14$ in the $H$-band, allowing us to estimate individual masses of 3.2 and 2.7 $M_{\odot}$ for the primary and secondary, respectively, using evolutionary tracks. The tracks also yield a coeval age of 1 Myr for both components to within $1\sigma$. GW Ori is surrounded by a circumbinary/circumtriple disk. A tertiary component has been detected in previous studies; however, we did not detect this component in our near-infrared spectra, probably the result of its relative faintness and blending in the absorption lines of these rapidly rotating stars. With these results, GW Ori joins the small number of classical T Tauri, double-lined spectroscopic binaries.

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## Chemical modelling of complex organic molecules with peptide-like bonds in star-forming regions

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Peptide bonds (N-C=O) play a key role in metabolic processes since they link amino acids into peptide chains or proteins. Recently, several molecules containing peptide-like bonds have been detected across multiple environments in the interstellar medium (ISM), growing the need to fully understand their chemistry and their role in forming larger pre-biotic molecules. We present a comprehensive study of the chemistry of three molecules containing peptide-like bonds: HNCO, $NH_2CHO$, and $CH_3NCO$. We also included other CHNO isomers (HCNO, HOCN), and $C_2H_3NO$ isomers ($CH_3OCN$, $CH_3CNO$) to the study. We have used the uclchem gas-grain chemical code and included in our chemical network all possible formation/destruction pathways of these peptide-like molecules recently investigated either by theoretical calculations or in laboratory experiments. Our predictions are compared to observations obtained toward

the proto-star IRAS16293–2422 and the L1544 pre-stellar core. Our results show that some key reactions involving the CHNO and $C_2H_3NO$ isomers need to be modified to match the observations. Consistently with recent laboratory findings, hydrogenation is unlikely to produce $NH_2CHO$ on grain surfaces, while a combination of radical-radical surface reactions and gas-phase reactions is a better alternative. In addition, better results are obtained for $NH_2CHO$ when a slightly higher activation energy of 25 K is considered for the gas-phase reaction $NH_2 + H_2CO \rightarrow NH_2CHO + H$. Finally, our modelling shows that the observed correlation between $NH_2CHO$ and HNCO in star-forming regions may come from the fact that HNCO and $NH_2CHO$ react to temperature in the same manner rather than from a direct chemical link between the two species.

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## X-ray radiative transfer in protoplanetary disks - The role of dust and X-ray background fields

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The X-ray luminosities of T Tauri stars are about two to four orders of magnitude higher than the luminosity of the contemporary Sun. As these stars are born in clusters, their disks are not only irradiated by their parent star but also by an X-ray background field produced by the cluster members.
We aim to quantify the impact of X-ray background fields produced by young embedded clusters on the chemical structure of disks. Further, we want to investigate the importance of the dust for X-ray radiative transfer in disks.
We present a new X-ray radiative transfer module for the radiation thermo-chemical disk code ProDiMo (PROtoplanetary DIsk MOdel), which includes X-ray scattering and absorption by both the gas and dust component. The X-ray dust opacities can be calculated for various dust compositions and dust size distributions. For the X-ray radiative transfer, we consider irradiation by the star and by X-ray background fields. To study the impact of X-rays on the chemical structure of disks we use the well-established disk ionization tracers $N_2H^+$ and $HCO^+$.
For evolved dust populations (e.g. grain growth), X-ray opacities are mostly dominated by the gas; only for photon energies $E \gtrsim 5 - 10\,\mathrm{keV}$, dust opacities become relevant. Consequently, the local disk X-ray radiation field is only affected in dense regions close to the disk midplane. X-ray background fields can dominate the local X-ray disk ionization rate for disk radii $r \gtrsim 20\,\mathrm{au}$. However, the $N_2H^+$ and $HCO^+$ column densities are only significantly affected in case of low cosmic-ray ionization rates ($\lesssim 10^{-19}\,\mathrm{s}^{-1}$), or if the background flux is at least a factor of ten higher than the flux level of $\approx 10^{-5}\,\mathrm{erg\,cm^{-2}s^{-1}}$ expected for clusters typical for the solar vicinity.
Observable signatures of X-ray background fields in low-mass star-formation regions, like Taurus, are only expected for cluster members experiencing a strong X-ray background field (e.g. due to their location within the cluster). For the majority of the cluster members, the X-ray background field has only little impact on the disk chemical structure.

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## Streaming Motions and Kinematic Distances to Molecular Clouds

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We present high-resolution smoothed particle hydrodynamics simulations of a region of gas flowing in a spiral arm and identify dense gas clouds to investigate their kinematics with respect to a Milky Way model. We find that, on average, the gas in the arms can have a net radial streaming motion of $v_{\rm R} \approx -9$ km s$^{-1}$ and rotate $\approx 6$ km s$^{-1}$ slower than the circular velocity. This translates to average peculiar motions towards the Galaxy centre and opposite to Galactic rotation. These results may be sensitive to the assumed spiral arm perturbation, which is $\approx 3\%$ of the disc potential in our model. We compare the actual distance and the kinematic estimate and we find that streaming motions introduce systematic offsets of $\approx$1 kpc. We find that the distance error can be as large as $\pm$2 kpc and the recovered cloud positions have distributions that can extend significantly into the inter-arm regions. We conclude that this poses a difficulty in tracing spiral arm structure in molecular cloud surveys.

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## Line-depending veiling in very active classical T Tauri stars

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The T Tauri stars with active accretion discs show veiled photospheric spectra. This is supposedly due to non-photospheric continuum radiated by hot spots beneath the accretion shocks at stellar surface and/or chromospheric emission lines radiated by the post-shocked gas. The amount of veiling is often considered as a measure of the mass-accretion rate. We analysed high-resolution photospheric spectra of accreting T Tauri stars LkH$\alpha$ 321, V1331 Cyg and AS 353 A with the aim to clarify the nature of the *line-dependent* veiling. Each of these objects shows strong emission line spectrum and powerful wind features indicating high rates of accretion and mass-loss. Equivalent widths of hundred of weak photospheric lines were measured in the observed spectra of high quality and compared with those in synthetic spectra of appropriate models of stellar atmospheres. The photospheric spectra of the three objects are highly veiled. We found that the veiling is strongly line-dependent: larger in stronger photospheric lines and is weak or absent in the weakest ones. No dependence of veiling on excitation potential within 0 to 5 eV was found. Different physical processes, responsible for these unusual veiling effects are discussed in the framework of the magnetospheric accretion model. The observed veiling have two origins: 1) an abnormal structure of stellar atmosphere heated up by the accreting matter, and 2) non-photospheric continuum radiated by a hot spot with temperature lower than 10000 K. The true level of the veiling continuum can be derived by measuring the weakest photospheric lines with equivalent widths down to $\approx$10 mÅ. A limited spectral resolution and/or low signal-to-noise ratio results in overestimation of the veiling continuum. In the three very active stars, the veiling continuum is a minor contributor to the observed veiling, while the major contribution comes from the line-dependent veiling.

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## Linking Signatures of Accretion with Magnetic Field Measurements - Line Profiles are not Significantly Different in Magnetic and Non-Magnetic Herbig Ae/Be Stars

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Herbig Ae/Be stars are young, pre-main-sequence stars that sample the transition in structure and evolution between low- and high-mass stars, providing a key test of accretion processes in higher-mass stars. Few Herbig Ae/Be stars have detected magnetic fields, calling into question whether the magnetospheric accretion paradigm developed for low-mass stars can be scaled to higher masses. We present He I 10830 Å line profiles for 64 Herbig Ae/Be stars with a magnetic field measurement in order to test magnetospheric accretion in the physical regime where its efficacy remains uncertain. Of the 5 stars with a magnetic field detection, 1 shows redshifted absorption, indicative of infall, and 2 show blueshifted absorption, tracing mass outflow. The fraction of redshifted and blueshifted absorption profiles in the non-magnetic Herbig Ae/Be stars is remarkably similar, suggesting that the stellar magnetic field does not affect gas kinematics traced by He I 10830 Å. Line profile morphology does not correlate with the luminosity, rotation rate, mass accretion rate, or disk inclination. Only the detection of a magnetic field and a nearly face-on disk inclination show a correlation (albeit for few sources). This provides further evidence for weaker dipoles and more complex field topologies as stars develop a radiative envelope. The small number of magnetic Herbig Ae/Be stars has already called into question whether magnetospheric accretion can be scaled to higher masses; accretion signatures are not substantially different in magnetic Herbig Ae/Be stars, casting further doubt that they accrete in the same manner as classical T Tauri stars.

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## The Highly Collimated Radio Jet of HH 80-81: Structure and Non-Thermal Emission

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Radio emission from protostellar jets is usually dominated by free-free emission from thermal electrons. However, in some cases, it has been proposed that non-thermal emission could also be present. This additional contribution from non-thermal emission has been inferred through negative spectral indices at centimeter wavelengths in some regions of the radio jets. In the case of HH 80-81, one of the most powerful protostellar jets known, linearly polarized emission has also been detected, revealing that the non-thermal emission is of synchrotron nature from a population of relativistic particles in the jet. This result implies that an acceleration mechanism should be taking place in some parts of the jet. Here, we present new high sensitivity and high angular resolution radio observations at several wavelengths (in the 3–20 cm range) of the HH80-81 radio jet. These new observations represent an improvement in sensitivity and angular resolution by a factor of $\sim$10 with respect to previous observations. This allows us to resolve the morphology of the radio jet, and to study the different emission mechanisms involved through spectral index maps. We conclude that synchrotron emission in this jet arises from an extended component detected at low frequencies and from the termination points of the jet, where strong shocks against the ambient medium can produce efficient particle acceleration.

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## Large Interstellar Polarisation Survey II. UV/optical study of cloud-to-cloud variations of dust in the diffuse ISM

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It is well known that the dust properties of the diffuse interstellar medium exhibit variations towards different sight-lines on a large scale. We have investigated the variability of the dust characteristics on a small scale, and from cloud-to-cloud. We used low-resolution spectro-polarimetric data obtained in the context of the Large Interstellar Polarisation Survey (LIPS) towards 59 sight-lines in the southern hemisphere, and we fitted these data using a dust model composed of silicate and carbon particles with sizes from the molecular to the sub-micrometre domain. Large ($\geq 6$ nm) silicates of prolate shape account for the observed polarisation. For 32 sight-lines we complemented our data set with UVES archive high-resolution spectra, which enable us to establish the presence of single-cloud or multiple-clouds towards individual sight-lines. We find that the majority of these 32 sight-lines intersect two or more clouds, while eight of them are dominated by a single absorbing cloud. We confirm several correlations between extinction and parameters of the Serkowski law with dust parameters, but we also find previously undetected correlations between these parameters that are valid only in single-cloud sight-lines. We find that interstellar polarisation from multiple-clouds is smaller than from single-cloud sight-lines, showing that the presence of a second or more clouds depolarises the incoming radiation. We find large variations of the dust characteristics from cloud-to-cloud. However, when we average a sufficiently large number of clouds in single-cloud or multiple-cloud sight-lines, we always retrieve similar mean dust parameters. The typical dust abundances of the single-cloud cases are [C]/[H] = 92 ppm and [Si]/[H] = 20 ppm

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## Dust Concentration and Emission in Protoplanetary Disks Vortices

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We study the dust concentration and emission in protoplanetary disks vortices. We extend the Lyra-Lin solution for the dust concentration of a single grain size to a power-law distribution of grain sizes $n(a) \propto a^{-p}$. Assuming dust conservation in the disk, we find an analytic dust surface density as a function of the grain radius. We calculate the increase of the dust to gas mass ratio $\epsilon$ and the slope $p$ of the dust size distribution due to grain segregation within the vortex. We apply this model to a numerical simulation of a disk containing a persistent vortex. Due to the accumulation of large grains towards the vortex center, $\epsilon$ increases by a factor of 10 from the background disk value, and $p$ decreases from 3.5 to 3.0. We find the disk emission at millimeter wavelengths corresponding to synthetic observations with ALMA and VLA. The simulated maps at 7 mm and 1 cm show a strong azimuthal asymmetry. This happens because, at these wavelengths, the disk becomes optically thin while the vortex remains optically thick. The large vortex opacity is mainly due to an increase in the dust to gas mass ratio. In addition, the change in the slope of

the dust size distribution increases the opacity by a factor of 2. We also show that the inclusion of the dust scattering opacity substantially changes the disks images.

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## ALMA Reveals Transition of Polarization Pattern with Wavelength in HL Tau's Disk

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The mechanism for producing polarized emission from protostellar disks at (sub)millimeter wave- lengths is currently uncertain. Classically, polarization is expected from non-spherical grains aligned with the magnetic field. Recently, two alternatives have been suggested. One polarization mechanism is caused by self-scattering from dust grains of sizes comparable to the wavelength while the other mechanism is due to grains aligned with their short axes along the direction of radiation anisotropy. The latter has recently been shown as a likely mechanism for causing the dust polarization detected in HL Tau at 3.1 mm. In this paper, we present ALMA polarization observations of HL Tau for two more wavelengths: 870 $\mu$m and 1.3 mm. The morphology at 870 $\mu$m matches the expectation for self-scattering, while that at 1.3 mm shows a mix between self-scattering and grains aligned with the radiation anisotropy. The observations cast doubt on the ability of (sub)millimeter continuum polarization to probe disk magnetic fields for at least HL Tau. By showing two distinct polarization morphologies at 870 $\mu$m and 3.1 mm and a transition between the two at 1.3 mm, this paper pro- vides definitive evidence that the dominant (sub)millimeter polarization mechanism transitions with wavelength. In addition, if the polarization at 870 $\mu$m is due to scattering, the lack of polarization asymmetry along the minor axis of the inclined disk implies that the large grains responsible for the scattering have already settled into a geometrically thin layer, and the presence of asymmetry along the major axis indicates that the HL Tau disk is not completely axisymmetric.

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## The spatial extent of Polycyclic Aromatic Hydrocarbons emission in the Herbig star HD 179218

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We investigate, in the mid-infrared, the spatial properties of the Polycyclic Aromatic Hydrocarbons (PAHs) emission in the disk of HD 179218, an intermediate-mass Herbig star at ∼300 pc. We obtained mid-infrared images in the PAH-1, PAH-2 and Si-6 filters centered at 8.6, 11.3, and 12.5 $\mu$m, and N-band low-resolution spectra using CanariCam on the 10-m Gran Telescopio Canarias (GTC). We compared the point spread function (PSF) profiles measured in the PAH filters to the profile derived in the Si-6 filter, where the thermal continuum emission dominates. We performed radiative transfer modeling of the spectral energy distribution (SED) and produced synthetic images in the three filters to investigate different spatial scenarios. Our data show that the disk emission is spatially resolved in the PAH-1 and PAH-2 filters, while unresolved in the Si-6 filter. Thanks to very good observing conditions, an average full width at half maximum (FHWM) of 0.232″, 0.280″ and 0.293″ is measured in the three filters, respectively. Gaussian disk fitting and quadratic subtraction of the science and calibrator PSFs suggests a lower-limit characteristic angular diameter of the emission of ∼100 mas, or ∼30 au. The photometric and spectroscopic results are compatible with previous findings. Our radiative transfer (RT) modeling of the continuum suggests that the resolved emission should result from PAH molecules on the disk atmosphere being UV-excited by the central star. Simple geometrical models of the PAH component compared to the underlying continuum point to a PAH emission uniformly extended out to the physical limits of the disk model. Furthermore, our RT best model of the continuum requires a negative exponent of the surface density power-law, in contrast with earlier modeling pointing to a positive exponent. We have spatially resolved - for the first time to our knowledge - the PAHs emission in the disk of HD 179218 and set constraints on its spatial extent. Based on spatial and spectroscopic considerations as well as on qualitative comparison with IRS 48 and HD 97048, we favor a scenario in which PAHs extend out to large radii across the flared disk surface and are at the same time predominantly in an ionized charge state due to the strong UV radiation field of the 180 $L_\odot$ central star.

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## ATLASGAL-selected massive clumps in the inner Galaxy: VI. Kinetic temperature and spatial density measured with formaldehyde

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Formaldehyde ($H_2CO$) is a reliable tracer to accurately measure the physical parameters of dense gas in star forming regions. We aim to directly determine the kinetic temperature and spatial density with formaldehyde for the ∼100 brightest ATLASGAL-selected clumps (the TOP100 sample) at 870 $\mu$m representing various evolutionary stages of high-mass star formation. Ten transitions ($J = 3$–2 and 4–3) of ortho- and para-$H_2CO$ near 211, 218, 225, and 291 GHz were observed with the Atacama Pathfinder EXperiment (APEX) 12 m telescope. Using non-LTE models with

RADEX, we derive the gas kinetic temperature and spatial density using the measured para-$H_2CO$ $3_{21}$–$2_{20}$/$3_{03}$–$2_{02}$, $4_{22}$–$3_{21}$/$4_{04}$–$3_{03}$, and $4_{04}$–$3_{03}$/$3_{03}$–$2_{02}$ ratios. The gas kinetic temperatures derived from the para-$H_2CO$ $3_{21}$–$2_{20}$/$3_{03}$–$2_{02}$ and $4_{22}$–$3_{21}$/$4_{04}$–$3_{03}$ line ratios are high, ranging from 43 to >300 K with an unweighted average of $91 \pm 4$ K. Deduced $T_{\rm kin}$ values from the $J = 3$–2 and 4–3 transitions are similar. Spatial densities of the gas derived from the para-$H_2CO$ $4_{04}$–$3_{03}$/$3_{03}$–$2_{02}$ line ratios yield $0.6$–$8.3 \times 10^6$ cm$^{-3}$ with an unweighted average of $1.5\,(\pm 0.1) \times 10^6$ cm$^{-3}$. A comparison of kinetic temperatures derived from para-$H_2CO$, $NH_3$, and the dust emission indicates that para-$H_2CO$ traces a distinctly higher temperature than the $NH_3$ (2,2)/(1,1) transitions and the dust, tracing heated gas more directly associated with the star formation process. The $H_2CO$ linewidths are found to be correlated with bolometric luminosity and increase with the evolutionary stage of the clumps, which suggests that higher luminosities tend to be associated with a more turbulent molecular medium. It seems that the spatial densities measured with $H_2CO$ do not vary significantly with the evolutionary stage of the clumps. However, averaged gas kinetic temperatures derived from $H_2CO$ increase with time through the evolution of the clumps. The high temperature of the gas traced by $H_2CO$ may be mainly caused by radiation from embedded young massive stars and the interaction of outflows with the ambient medium. For $L_{\rm bol}/M_{\rm clump} \gtrsim 10\,{\rm L_\odot/M_\odot}$, we find a rough correlation between gas kinetic temperature and this ratio, which is indicative of the evolutionary stage of the individual clumps. The strong relationship between $H_2CO$ line luminosities and clump masses is apparently linear during the late evolutionary stages of the clumps, indicating that $L_{\rm H_2CO}$ does reliably trace the mass of warm dense molecular gas. In our massive clumps $H_2CO$ line luminosities are approximately linearly correlated with bolometric luminosities over about four orders of magnitude in $L_{\rm bol}$, which suggests that the mass of dense molecular gas traced by the $H_2CO$ line luminosity is well correlated with star formation.

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## Emission from magnetized accretion disks around young stars

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We calculate the emission of protoplanetary disks threaded by a poloidal magnetic field and irradiated by the central star. The radial structure of these disks was studied by Shu and collaborators and the vertical structure was studied by Lizano and collaborators. We consider disks around low mass protostars, T Tauri stars, and FU Ori stars with different mass-to-flux ratios $\lambda_{\rm sys}$. We calculate the spectral energy distribution and the antenna temperature profiles at 1 mm and 7 mm convolved with the ALMA and VLA beams. We find that disks with weaker magnetization (high values of $\lambda_{\rm sys}$) emit more than disks with stronger magnetization (low values of $\lambda_{\rm sys}$). This happens because the former are denser, hotter and have larger aspect ratios, receiving more irradiation from the central star. The level of magnetization also affects the optical depth at millimeter wavelengths, being larger for disks with high $\lambda_{\rm sys}$. In general, disks around low mass protostars and T Tauri stars are optically thin at 7 mm while disks around FU Ori are optically thick. A qualitative comparison of the emission of these magnetized disks, including heating by an external envelope, with the observed millimeter antenna temperature profiles of HL Tau indicates that large cm grains are required to increase the optical depth and reproduce the observed 7 mm emission at large radii.

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## Transient events in bright debris discs: Collisional avalanches revisited

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A collisional avalanche is set off by the breakup of a large planetesimal, releasing vast amounts of small unbound grains that enter a debris disc located further away from the star, triggering there a collisional chain reaction that

could potentially create detectable transient structures. We investigate this mechanism, using for the first time a fully self-consistent code coupling dynamical and collisional evolutions. We also quantify for the first time the photometric evolution of the system and investigate if avalanches could explain the short-term luminosity variations recently observed in some extremely bright debris discs. We use the state-of-the-art LIDT-DD code (Kral et al., 2013, 2015). We consider an avalanche-favouring A6V star, and two set-ups: a "cold disc" case, with a dust release at 10 au and an outer disc extending from 50 to 120 au, and a "warm disc" case with the release at 1 au and a 5-12 au outer disc. We explore, in addition, two key parameters, which are the density (parameterized by its optical depth $\tau$) of the main outer disc and the amount of dust released by the initial breakup. We find that avalanches could leave detectable structures on resolved images, for both "cold" and "warm" disc cases, in discs with $\tau$ of a few $10^{-3}$, provided that large dust masses ($\gtrsim 10^{20}$–$5\times10^{22}$g) are initially released. The integrated photometric excess due to an avalanche is relatively limited, less than 10% for these released dust masses, peaking in the $\lambda\sim$10–20$\mu$m domain and becoming insignificant beyond $\sim$40–50$\mu$m. Contrary to earlier studies, we do not obtain stronger avalanches when increasing $\tau$ to higher values. Likewise, we do not observe a significant luminosity deficit, as compared to the pre-avalanche level, after the passage of the avalanche. These two results concur to make avalanches an unlikely explanation for the sharp luminosity drops observed in some extremely bright debris discs. The ideal configuration for observing an avalanche would be a two-belt structure, with an inner belt (at $\sim$1 or $\sim$10au for the "warm" and "cold" disc cases, respectively) of fractional luminosity $f\geq10^{-4}$ where breakups of massive planetesimals occur, and a more massive outer belt, with $\tau$ of a few $10^{-3}$, into which the avalanche chain reaction develops and propagates.

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## Non-linear Development of Secular Gravitational Instability in Protoplanetary Disks

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We perform non-linear simulation of secular gravitational instability (GI) in protoplanetary disks that has been proposed as a mechanism of the planetesimal formation and the multiple ring formation. Since the timescale of the growth of the secular GI is much longer than the Keplerian rotation period, we develop a new numerical scheme for a long term calculation utilizing the concept of symplectic integrator. With our new scheme, we first investigate the non-linear development of the secular GI in a disk without a pressure gradient in the initial state. We find that the surface density of dust increases by more than a factor of one hundred while that of gas does not increase even by a factor of two, which results in the formation of dust-dominated rings. A line mass of the dust ring tends to be very close to the critical line mass of a self-gravitating isothermal filament. Our results indicate that the non-linear growth of the secular GI provides a powerful mechanism to concentrate the dust. We also find that the dust ring formed via the non-linear growth of the secular GI migrates inward with a low velocity, which is driven by the self-gravity of the ring. We give a semi-analytical expression for the inward migration speed of the dusty ring.

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## Implications for planetary system formation from interstellar object 1I/2017 U1 ('Oumuamua)

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The recently discovered minor body 1I/2017 U1 ('Oumuamua) is the first known object in our Solar System that is not bound by the Sun's gravity. Its hyperbolic orbit (eccentricity greater than unity) strongly suggests that it originated outside our Solar System; its red color is consistent with substantial space weathering experienced over a long interstellar journey. We carry out an simple calculation of the probability of detecting such an object. We find that the observed detection rate of 1I-like objects can be satisfied if the average mass of ejected material from nearby stars during the process of planetary formation is ∼20 Earth masses, similar to the expected value for our Solar System. The current detection rate of such interstellar interlopers is estimated to be 0.2/year, and the expected number of detections over the past few years is almost exactly one. When the Large Synoptic Survey Telescope begins its wide, fast, deep all-sky survey the detection rate will increase to 1/year. Those expected detections will provide further constraints on nearby planetary system formation through a better estimate of the number and properties of interstellar objects.

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## The VLA Nascent Disk And Multiplicity Survey of Perseus Protostars (VANDAM). III. Extended Radio Emission from Protostars in Perseus

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Centimeter continuum emission from protostars offers insight into the innermost part of the outflows, as shock-ionized gas produces free-free emission. We observed a complete population of Class 0 and I protostars in the Perseus molecular cloud at 4.1 cm and 6.4 cm with resolution and sensitivity superior to previous surveys. From a total of 71 detections, 8 sources exhibit resolved emission at 4.1 cm and/or 6.4 cm. In this paper we focus on this sub-sample, analyzing their spectral indices along the jet, and their alignment with respect to the large-scale molecular outflow. Spectral indices for fluxes integrated toward the position of the protostar are consistent with free-free thermal emission. The value of the spectral index along a radio jet decreases with distance from the protostar. For six sources, emission is well aligned with the outflow central axis, showing that we observe the ionized base of the jet. This is not the case for two sources, where we note misalignment of the emission with respect to the large-scale outflow. This might indicate that the emission does not originate in the radio jet, but rather in an ionized outflow cavity wall or disk surface. For five of the sources, the spectral indices along the jet decrease well below the thermal free-free limit of -0.1 with $> 2\sigma$ significance. This is indicative of synchrotron emission, meaning that high energy electrons are being produced in the outflows close to the disk. This result can have far-reaching implications for the chemical composition of the embedded disks.

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## High spectral resolution observations of HNC3 and HCCNC in the L1544 prestellar core

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HCCNC and $HNC_3$ are less commonly found isomers of cyanoacetylene, $HC_3N$, a molecule that is widely found in diverse astronomical sources. We want to know if $HNC_3$ is present in sources other than the dark cloud TMC-1 and how its abundance is relative to that of related molecules. We used the ASAI unbiased spectral survey at IRAM 30m towards the prototypical prestellar core L1544 to search for $HNC_3$ and HCCNC which are by-product of the $HC_3NH^+$ recombination, previously detected in this source. We performed a combined analysis of published $HNC_3$ microwave rest frequencies with thus far unpublished millimeter data because of issues with available rest frequency predictions. We determined new spectroscopic parameters for $HNC_3$, produced new predictions and detected it towards L1544. We used a gas-grain chemical modelling to predict the abundances of N-species and compare with the observations. The modelled abundances are consistent with the observations, considering a late stage of the evolution of the prestellar core. However the calculated abundance of $HNC_3$ was found 5–10 times higher than the observed one. The $HC_3N$, $HNC_3$ and HCCNC versus $HC_3NH^+$ ratios are compared in the TMC-1 dark cloud and the L1544 prestellar core.

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## Probing the massive star forming environment - a multiwavelength investigation of the filamentary IRDC G333.73+0.37

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We present a multiwavelength study of the filamentary infrared dark cloud (IRDC) G333.73+0.37. The region contains two distinct mid-infrared sources S1 and S2 connected by dark lanes of gas and dust. Cold dust emission from the IRDC is detected at seven wavelength bands and we have identified 10 high density clumps in the region. The physical properties of the clumps such as temperature: $14.3 - 22.3$ K and mass: $87 - 1530$ $M_\odot$ are determined by fitting a modified blackbody to the spectral energy distribution of each clump between 160 $\mu$m and 1.2 mm. The total mass of the IRDC is estimated to be $\sim 4700$ $M_\odot$. The molecular line emission towards S1 reveals signatures of protostellar activity. Low frequency radio emission at 1300 and 610 MHz is detected towards S1 (shell-like) and S2 (compact morphology), confirming the presence of newly formed massive stars in the IRDC. Photometric analysis of near and mid-infrared point sources unveil the young stellar object population associated with the cloud. Fragmentation analysis indicates that the filament is supercritical. We observe a velocity gradient along the filament, that is likely to be associated with accretion flows within the filament rather than rotation. Based on various age estimates obtained for objects in different evolutionary stages, we attempt to set a limit to the current age of this cloud.

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## Detection of non-thermal emission from the massive protostellar jet HH80-81 at low radio frequencies using GMRT

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Low radio frequencies are favourable for the identification of emission from non-thermal processes such as synchrotron emission. The massive protostellar jet associated with IRAS 18162–2048 (also known as the HH80-81 system) has been imaged at low radio frequencies: 325, 610 and 1300 MHz, using the Giant Metrewave Radio Telescope, India. This is the first instance of detection of non-thermal emission from a massive protostellar jet at such low radio frequencies. The central region displays an elongated structure characteristic of the jet. In addition, the associated Herbig-Haro objects such as HH80, HH81, HH80N, and other condensations along the inner regions of the jet exhibit negative spectral indices. The spectral indices of most condensations are $\sim -0.7$, higher than the value of $-0.3$ determined earlier using high frequency measurements. The magnetic field values derived using radio flux densities in the present work, under the assumption of equipartition near minimum energy condition, lie in the range $116 - 180$ $\mu$G. We probe into the hard X-ray nature of a source that has been attributed to HH80, in an attempt to reconcile the non-thermal characteristics of radio and X-ray measurements. The flux densities of condensations at 610 MHz, measured nearly 11 yrs apart, display variability that could be ascribed to the cooling of condensations, and emphasize the importance of coeval or nearly-coeval measurements for estimation of spectral indices.

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## Star formation in a high-pressure environment: An SMA view of the Galactic centre dust ridge

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The star formation rate in the Central Molecular Zone (CMZ) is an order of magnitude lower than predicted according to star formation relations that have been calibrated in the disc of our own and nearby galaxies. Understanding how and why star formation appears to be different in this region is crucial if we are to understand the environmental dependence of the star formation process. Here, we present the detection of a sample of high-mass cores in the CMZ's "dust ridge" that have been discovered with the Submillimeter Array as part of the CMZoom survey. These cores range in mass from $\sim$50–2150 $M_\odot$ within radii of 0.1–0.25 pc. All appear to be young (pre-UCHII), meaning that they are prime candidates for representing the initial conditions of high-mass stars and sub-clusters. We report that at least two of these cores ('c1' and 'e1') contain young, high-mass protostars. We compare all of the detected cores with high-mass cores in the Galactic disc and find that they are broadly similar in terms of their masses and sizes, despite being subjected to external pressures that are several orders of magnitude greater — $\sim 10^8$ K cm$^{-3}$, as opposed to $\sim 10^5$ K cm$^{-3}$. The fact that >80% of these cores do not show any signs of star-forming activity in such a high-pressure environment leads us to conclude that this is further evidence for an increased critical density threshold for star formation in the CMZ due to turbulence.

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## Carbon Monoxide Observations Toward Star Forming Regions in the Outer Scutum-Centaurus Spiral Arm

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The Outer Scutum-Centaurus arm (OSC) is the most distant molecular spiral arm known in the Milky Way. The OSC may be the very distant end of the well-known Scutum-Centaurus arm, which stretches from the end of the Galactic bar to the outer Galaxy. At this distance the OSC is seen in the first Galactic quadrant. The population of star formation tracers in the OSC remains largely uncharacterized. Extragalactic studies show a strong correlation between molecular gas and star formation, and carbon monoxide (CO) emission was recently discovered in the OSC. Here we use the Arizona Radio Observatory (ARO) 12-m telescope to observe the $^{12}$CO $J = 1$–0 and $^{13}$CO $J = 1$–0 transitions toward 78 HII region candidates chosen from the WISE Catalog of Galactic HII Regions. These targets are spatially coincident with the Galactic longitude-latitude $(l, b)$ OSC locus as defined by HI emission. We detect CO emission in $\sim$80% of our targets. In total, we detect 117 $^{12}$CO and 40 $^{13}$CO emission lines. About 2/3 of our targets have at least one emission line originating beyond the Solar orbit. Most of the detections beyond the Solar orbit are associated with the Outer Arm, but there are 17 $^{12}$CO emission lines and 8 $^{13}$CO emission lines with LSR velocities that are consistent with the velocities of the OSC. There is no apparent difference between the physical properties (e.g., molecular column density) of these OSC molecular clouds and non–OSC molecular clouds within our sample.

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## ALMA and VLA Observations of the HD 141569 System

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We present VLA 9 mm (33 GHz) observations of the HD 141569 system from semester 16A. The observations achieve a resolution of $0\farcs25$ ($\sim$28 au) and a sensitivity of 4.7 $\mu$Jy beam$^{-1}$. We find (1) a 52±5 $\mu$Jy point source at the location of HD 141569A that shows potential variability, (2) the detected flux is contained within the SED-inferred central clearing of the disc meaning the spectral index of the dust disc is steeper than previously inferred, and (3) the M dwarf companions are also detected and variable. Previous lower-resolution VLA observations (semester 14A) found a higher flux density, interpreted as solely dust emission. When combined with ALMA observations, the VLA 14A observations suggested the spectral index and grain size distribution of HD 141569's disc was shallow and an outlier among debris systems. Using archival ALMA observations of HD 141569 at 0.87 mm and 2.9 mm we find a dust spectral index of $\alpha_{\rm mm} = 1.81 \pm 0.20$. The VLA 16A flux corresponds to a brightness temperature of $\sim 5 \times 10^6$ K, suggesting strong non-disc emission is affecting the inferred grain properties. The VLA 16A flux density of the M2V companion HD 141569B is 149±9 $\mu$Jy, corresponding to a brightness temperature of $\sim 2 \times 10^8$ K and suggesting significant stellar variability when compared to the VLA14A observations, which are smaller by a factor of $\sim$6.

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## HST Scattered Light Imaging and Modeling of the Edge-on Protoplanetary Disk ESO-H$\alpha$ 569

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We present new HST ACS observations and detailed models for a recently discovered edge-on protoplanetary disk around ESO H$\alpha$ 569 (a low-mass T Tauri star in the Cha I star forming region). Using radiative transfer models we probe the distribution of the grains and overall shape of the disk (inclination, scale height, dust mass, flaring exponent and surface/volume density exponent) by model fitting to multiwavelength (F606W and F814W) HST observations together with a literature compiled spectral energy distribution. A new tool set was developed for finding optimal fits of MCFOST radiative transfer models using the MCMC code emcee to efficiently explore the high dimensional parameter space. It is able to self-consistently and simultaneously fit a wide variety of observables in order to place constraints on the physical properties of a given disk, while also rigorously assessing the uncertainties in those derived properties. We confirm that ESO H$\alpha$ 569 is an optically thick nearly edge-on protoplanetary disk. The shape of the disk is well described by a flared disk model with an exponentially tapered outer edge, consistent with models previously advocated on theoretical grounds and supported by millimeter interferometry. The scattered light images and spectral energy distribution are best fit by an unusually high total disk mass (gas+dust assuming a ratio of 100:1) with a disk-to-star mass ratio of 0.16.

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## GMC Collisions as Triggers of Star Formation. VI. Collision-Induced Turbulence

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We investigate collisions between giant molecular clouds (GMCs) as potential generators of their internal turbulence. Using magnetohydrodynamic (MHD) simulations of self-gravitating, magnetized, turbulent, GMCs, we compare kinematic and dynamic properties of dense gas structures formed when such clouds collide compared to those that form in non-colliding clouds as self-gravity overwhelms decaying turbulence. We explore the nature of turbulence in these structures via distribution functions of density, velocity dispersions, virial parameters, and momentum injection. We find that the dense clumps formed from GMC collisions have higher effective Mach number, greater overall velocity dispersions, sustain near-virial equilibrium states for longer times, and are the conduit for injection of turbulent momentum into high density gas at high rates.

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## Formation of Super-Earths by Tidally-Forced Turbulence

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The Kepler observations indicate that many exoplanets are super-Earths, which brings about a puzzle for the core-accretion scenario. Since observed super-Earths are in the range of critical mass, they would accrete gas efficiently and become gas giants. Theoretically, super-Earths are predicted to be rare in the core-accretion framework. To resolve this contradiction, we propose that the tidally-forced turbulent diffusion may affect the heat transport inside the planet. Thermal feedback induced by turbulent diffusion is investigated. We find that the tidally-forced turbulence would generate pseudo-adiabatic regions within radiative zones, which pushes the radiative-convective boundaries (RCBs) inwards. This would decrease the cooling luminosity and enhance the Kelvin–Helmholtz (KH) timescale. For a given lifetime of protoplanetary disks (PPDs), there exists a critical threshold for the turbulent diffusivity, $\nu_{\rm critical}$. If $\nu_{\rm turb} > \nu_{\rm critical}$, the KH timescale is longer than the disk lifetime and the planet would become a super-Earth rather than a gas giant. We find that even a small value of turbulent diffusion has influential effects on evolutions of super-Earths. $\nu_{\rm critical}$ increases with the core mass. We further ascertain that, within the minimum mass extrasolar nebula (MMEN), $\nu_{\rm critical}$ increases with the semi-major axis. This may explain the feature that super-Earths are common in inner PPD regions, while gas giants are common in the outer PPD regions. The predicted envelope mass fraction (EMF) is not fully consistent with observations. We discuss physical processes, such as late core assembly and mass loss mechanisms, that may be operating during super-Earth formation.

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## High-mass Star Formation through Filamentary Collapse and Clump-fed Accretion in G22

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How mass is accumulated from cloud-scale down to individual stars is a key open question in understanding high-mass star formation. Here, we present the mass accumulation process in a hub-filament cloud G22 which is composed of four supercritical filaments. Velocity gradients detected along three filaments indicate that they are collapsing with a total mass infall rate of about 440 $M_\odot$ Myr$^{-1}$, suggesting the hub mass would be doubled in six free-fall times, adding up to $\sim 2$ Myr. A fraction of the masses in the central clumps C1 and C2 can be accounted for through large-scale filamentary collapse. Ubiquitous blue profiles in HCO$^+$ $(3-2)$ and $^{13}$CO $(3-2)$ spectra suggest a clump-scale collapse scenario in the most massive and densest clump C1. The estimated infall velocity and mass infall rate are 0.31 km s$^{-1}$ and $7.2\times10^{-4}$ $M_\odot$ yr$^{-1}$, respectively. In clump C1, a hot molecular core (SMA1) is revealed by the SMA observations and an outflow-driving high-mass protostar is located at the center of SMA1. The mass of the protostar is estimated to be $11-15$ $M_\odot$ and it is still growing with an accretion rate of $7\times10^{-5}$ $M_\odot$ yr$^{-1}$. The coexistent infall in filaments, clump C1, and the central hot core in G22 suggests that pre-assembled mass reservoirs (i.e., high-mass starless cores) may not be required to form high-mass stars. In the course of high-mass star formation, the central protostar, the core, and the clump can simultaneously grow in mass via core-fed/disk accretion, clump-fed accretion, and filamentary/cloud collapse.

Accepted by the Astrophysical Journal

https://arxiv.org/pdf/1711.08951

## ALMA Detection of Bipolar Outflows: Evidence for Low Mass Star Formation within 1 pc of Sgr A*

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We report the discovery of 11 bipolar outflows within a projected distance of 1 pc from Sgr A* based on deep ALMA observations of $^{13}$CO, H30$\alpha$ and SiO (5–4) lines with sub-arcsecond and $\sim$1.3 km s$^{-1}$, resolutions. These unambiguous signatures of young protostars manifest as approaching and receding lobes of dense gas swept up by the jets created during the formation and early evolution of stars. The lobe masses and momentum transfer rates are consistent with young protostellar outflows found throughout the disk of the Galaxy. The mean dynamical age of the outflow population is estimated to be $6.5^{+8.1}_{-3.6}\times10^3$ years. The rate of star formation is $\sim 5\times10^{-4}$ $M_\odot$ yr$^{-1}$ assuming a mean stellar mass of $\sim$0.3 $M_\odot$. This discovery provides evidence that star formation is taking place within clouds surprisingly close to Sgr A*, perhaps due to events that compress the host cloud, creating condensations with sufficient self-gravity to resist tidal disruption by Sgr A*. Low-mass star formation over the past few billion years at this level would contribute significantly to the stellar mass budget in the central few pc of the Galaxy. The presence of many dense clumps of molecular material within 1 pc of Sgr A* suggests that star formation could take place in the immediate vicinity of supermassive black holes in the nuclei of external galaxies

Accepted by ApJL

http://arxiv.org/pdf/1711.10573

## Mapping young stellar populations towards Orion with Gaia DR1

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We use the first data release of the Gaia mission to explore the three dimensional arrangement and the age ordering of the many stellar groups towards the Orion OB association, aiming at a new classification and characterization of the stellar population. We make use of the parallaxes and proper motions provided in the Tycho Gaia Astrometric Solution (TGAS) sub-set of the Gaia catalogue, and of the combination of Gaia and 2MASS photometry. In TGAS we find evidence for the presence of a young population, at a parallax $\varpi \sim 2.65$ mas, loosely distributed around some known clusters: 25 Ori, $\epsilon$ Ori and $\sigma$ Ori, and NGC 1980 ($\iota$ Ori). The low mass counterpart of this population is visible in the color-magnitude diagrams constructed by combining Gaia and 2MASS photometry. We study the density distribution of the young sources in the sky. We find the same groups as in TGAS, and also some other density enhancements that might be related to the recently discovered Orion X group, the Orion dust ring, and to the $\lambda$ Ori complex. We estimate the ages of this population and we infer the presence of an age gradient going from 25 Ori (13–15 Myr) to the ONC (1–2 Myr). We confirm this age ordering by repeating the Bayesian fit using the Pan-STARRS1 data. The estimated ages towards the NGC 1980 cluster span a broad range of values. This can either be due to the presence of two populations coming from two different episodes of star formation or to a large spread along the line of sight of the same population. Our results form the first step towards using the Gaia data to unravel the complex star formation history of the Orion region in terms of the different star formation episodes, their duration, and their effects on the surrounding interstellar medium.

Accepted by A&A

http://arxiv.org/pdf/1711.03815

*Abstracts of recently accepted major reviews*

## Synthetic observations of star formation and the interstellar medium

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Synthetic observations are playing an increasingly important role across astrophysics, both for interpreting real observations and also for making meaningful predictions from models. In this review, we provide an overview of methods and tools used for generating, manipulating and analysing synthetic observations and their application to problems involving star formation and the interstellar medium. We also discuss some possible directions for future research using synthetic observations

Accepted by New Astronomy Reviews

https://arxiv.org/pdf/1711.05275.pdf

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# Multiple star formation: Chemistry, physics and coevality

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Ph.D dissertation directed by: Ewine F. van Dishoeck

Ph.D degree awarded: November 2017

Multiple stars are common in the universe, with multiplicity increasing proportionally with mass. These systems are excellent laboratories for stellar physics, and produce interesting phenomena in evolved stars, for example dust and gas shells of evolved stars, type Ia supernovae, and one of the mechanisms to form binary black holes. It is then of interest to understand how multiple stellar systems are formed. Infra-red and radio surveys of star forming regions in recent decades have detected multiplicity from pre-main sequence stars down to the embedded stage of star formation. This thesis takes a look into a few of the open questions in the formation of multiple stellar systems, focusing on the early deeply embedded phase of star formation. The questions of disk formation, physico-chemical structure of embedded protostars and the factors that influence multiple star formation are addressed using radio and infrared observations coupled with physical and chemical models. A detailed introduction of the picture of star formation, including current knowledge on multiple star formation, is given in Chapter 1.

Chapter 2 takes a look into the formation of rotationally supported disks. For this purpose, the prototypical Class 0 system VLA 1623-2417, a triple protostellar system located in $\rho$ Ophiuchus (d$\sim$120 pc), is studied. The components show different characteristics, most likely product of different evolutionary stages. One of the components, VLA 1623-2417 A, presents a flattened disk-like structure both in dust and molecular line emission. Studying the kinematics traced by $C^{18}O$ with a simple thin-disk model indicates that the emission is indeed tracing a rotating disk, with a radius of about 150 AU. Given that VLA 1623-2417 A is a very young, deeply embedded, protostar, finding a rotating disk around this source evidences that these structures can form very early in the star formation process.

The impact of rotating disks in the early stages of star formation is addressed in Chapter 3 by studying the material surrounding the rotating disk of VLA 1623-2417 A. For this purpose, molecules typically associated with the cold material in the cloud core of protostars are studied. $DCO^+$ is used to trace the cold material of VLA 1623-2417 A, since this molecule is mainly formed at temperatures of 20 K or below. Combining the observations with a simple chemical model can help to analyze the $DCO^+$ emission. The position of the observed $DCO^+$ emission is found to be closer to the source than expected from a spherically symmetric density and temperature structure. Instead, the $DCO^+$ emission is observed to be closer to the protostar along the rotating disk, but not along the direction of the outflow. The reason for this is that the disk causes a drop in temperature at its edge because it is shadowing the envelope from heating by the protostar. This indicates that the presence of a disk has a significant impact on the surrounding material, by altering both its temperature and chemical structure.

The physico-chemical structure of embedded protostars is further studied in Chapter 4. Two deeply embedded multiple protostellar systems in $\rho$ Ophiuchus, IRAS 16293-2422 and VLA 1623-2422, are studied using molecules that trace the cold and warm gas. IRAS 16293-2422 is a very bright protostellar binary, while VLA 1623-2417 is a dimmer triple protostellar system. VLA 1623-2417 A has been found to have a rotating disk, while IRAS 16293-2422 A presents a large, flattened disk-like structure with a radius of about 200 AU. The other sources in each system have no confirmed disk(-like) structure. The cold gas is traced by $DCO^+$, $N_2H^+$ and $N_2D^+$, which form at temperatures below 20 K. For warm environments with temperature of 50 to 100 K or UV-irradiated by the central protostar, c-$C_3H_2$ and $C_2H$ are good tracers. The cold molecules are found to be located closer to the source in both systems due to the presence of the disk(-like) structure, but not along any other direction. For VLA 1623-2417, $N_2H^+$ or $N_2D^+$ are not detected, most likely due to its low luminosity and low temperatures (<10 K) caused by the disk shadowing the envelope. c-$C_3H_2$ traces the outflow cavity in both systems, consistent with the presence of this molecule in warm and UV-irradiated environments. In previous work a tendency for c-$C_3H_2$ and $C_2H$ trace the same region has been observed. While this is true for VLA 1623-2417, it is not for IRAS 16293-2422. It is interesting to note that the multiplicity of these systems does not seem to have a significant impact in the chemical structure, however this needs to be explored further.

Chapter 5 examines the question if all components in a multiple stellar system form at the same time. In order to answer this question, embedded protostars are studied, rather than pre-main sequence protostars. This is because embedded protostars have the conditions of formation almost intact, while pre-main sequence protostars have undergone considerable evolution. Since ages are difficult to determine with certainty for embedded protostars, the evolutionary stages of the components in a multiple protostellar system are determined through the spectral energy distribution (SED). The relative evolutionary stages within the multiple protostellar system then determine if all the components formed at the same time or not. The SEDs for all the identified protostellar systems in the Perseus molecular cloud (d$\sim$235 pc) are constructed using data from literature and Herschel Space Observatory PACS photometric maps. For multiple protostellar systems, the SEDs of the individual components can only be disentangled for separations of 1600 AU, due to the resolution of Herschel. The geometry of the protostar can impact the constructed SED, thus to determine whether the protostars within multiple systems are formed simultaneously or not, the orientation of the protostar, its physical structure and the SED are taken into consideration. The results of this study find that one-third of the time, the components of multiple protostellar systems are not formed simultaneously. In other words, some cloud cores continue forming protostars even after one or two have formed, while others do not. This provides important information for theory and models of multiple star formation, and at the same time, leads to the question of what factors cause some multiple protostellar systems to continue forming protostars.

Chapter 6 examines the relation between temperature and multiplicity. Simulations including radiative feedback suggest that once a protostar is formed, the heated gas and dust does not fragment further. However, the results from Chapter 5 suggest that there are other factors that influence fragmentation and the formation of multiple stars. To address whether there is a temperature-fragmentation relation or not, the gas and dust at scales of 1000 AU are investigated. Single-dish observations with APEX are used to observe molecules that are good thermometers, (e.g., $DCO^+$ and $H_2CO$), as well as molecules that trace regions irradiated by the protostar, (e.g., c-$C_3H_2$ and $C_2H$). These molecules are observed toward a selected sample of single and multiple protostellar systems in Perseus. Including both types of systems allows the comparison of conditions in single and multiple stars, which can help determine whether temperature is a key element in multiple star formation. The observations, and derived temperature measurements from the observed molecules, show that there is no clear relation between temperature and multiple or single stars. In fact, the only observed difference is that multiple stellar systems have large cold gas reservoirs compared to single protostars. These findings suggest that mass and density, rather than temperature, play a role in fragmentation, and consequently, the formation of multiple protostellar systems.

This thesis can be summarized as follows. Large disks can form in the early stages of star formation, and they impact the physicochemical structure of protostars. This is important for star formation in general, since it changes our view of the process of protostellar evolution. In addition, both of these factors, disks and the physicochemical structure, can influence the formation of multiple protostellar systems, since they provide ingredients for fragmentation. Not all protostars in a multiple protostellar system form at the same time. This indicates that in some cases, the conditions in the cloud core are appropriate for further fragmentation. These conditions, however, do not seem to be associated with temperature and instead could be related to mass and density. The results from this thesis contribute useful pieces to the puzzle of multiple star formation, but further work is needed to fully understand multiple star formation.

Digital version of this thesis can be found at: https://multiple.starformation.space

*New Jobs*

## Postdoctoral Position in Computational Astrophysics

The Research School of Astronomy and Astrophysics (RSAA) at the Australian National University (ANU) invites applications for a 3-year postdoctoral position in Dr. Christoph Federrath's computational astrophysics research group.

Federrath's group is developing innovative techniques for star and cluster formation, molecular cloud evolution, and turbulent plasmas, with applications to star, planet and galaxy formation and evolution, first stars, interstellar medium, and cosmic structure formation. For this postdoctoral position we are especially looking for excellent early career researchers. The position is open to excellent applicants from all fields, and applicants with previous experience in computational hydrodynamics (grid-based and/or SPH), galaxy, star or planet formation, and first stars, are especially encouraged to apply.

RSAA has a long history of world-class research at the forefront of astronomy and astrophysics and is Australia's top astrophysics research institution. Federrath's group is embedded in a stimulating and vibrant environment consisting of a large number of faculty, postdocs, and PhD/Master/Undergrad students working on related topics. Our Distinguished Visitor Program attracts world-class astronomers for long-term visits every year. Astronomers at RSAA have access to Australia's top supercomputing facilities at ANU. Federrath's group has additional access to world-class international supercomputing facilities and to observational data through established collaborations.

This 3-year position has a negotiable starting date around mid 2018. The starting salary is $75,297–$86,646 p.a., depending on experience, plus superannuation contribution of 17%.

In order to apply please upload the following documents submitted through
http://jobs.anu.edu.au/cw/en/job/518436/postdoctoral-fellow-in-computational-astrophysics :

1. A cover letter.
2. A current curriculum vitae (CV) with an up-to-date publication list.
3. A two (2) page description of your previous research.
4. A three (3) page statement describing your future research plan.
5. A statement addressing the selection criteria.
6. Applicants should arrange for three (3) letters of recommendation to be sent directly to Christoph Federrath (christoph.federrath@anu.edu.au).

Application deadline is **15 December 2017 (AEDT)**.

Included Benefits: We offer a competitive remuneration and benefits package, a friendly and collaborative work environment, generous leave entitlements, flexible working arrangements, a relocation allowance, generous superannuation, salary packaging arrangements including child care, and the potential to support dual-career arrangements.

## Research Fellow in ALMA Studies of Protoplanetary Disks

The School of Physics and Astronomy at the University of Leeds invites applications for a 2-year fixed-term postdoctoral research fellow in ALMA Studies of Protoplanetary Disks. The post involves working on an STFC-funded project in collaboration with Dr Catherine Walsh in the Astrophysics Group investigating the chemistry of complex organic molecules (COMs) in disks around nearby young stars.

You will carry out a research programme to search for emission from COMs in nearby protoplanetary disks using the Atacama Large Millimeter/submillimeter Array (ALMA). You will conduct analyses of the data to derive the distribution and abundance of COMs using molecular line radiative transfer methods. In addition, you will aid interpretation of the data by running astrochemical models to determine the chemical origin of COMs in protoplanetary disks.

With a PhD in Astrophysics or a related field (or if you will have submitted your thesis prior to tak- ing up the appointment), you will have experience in the reduction and analysis of observational data at (sub)millimeter or radio wavelengths and a developing track record of peer reviewed publications in international journals.

The application deadline is 15th January 2018 and the starting date will be 1st April 2018 or as soon as possible thereafter. For more information and to apply, please follow the link:
https://jobs.leeds.ac.uk/Vacancy.aspx?ref=MAPPA1049. For more information on the project, you can also contact Dr Catherine Walsh: c.walsh1@leeds.ac.uk.

## Two ERC-funded postdoctoral positions in star formation at IPAG, Grenoble.

IPAG (Institut de Plantologie et d'Astrophysique de Grenoble) invites applications for 2 post-doctoral research positions in the framework of the European Research Council Project "Star-Planet(s)-Inner Disk Interactions (SPIDI): unveiling the formation and evolution of inner planetary systems ".

The successful candidates will work on the development of numerical models of the interaction between the magnetosphere of a young forming star, its surrounding accretion disk, and planet(s) embedded in the innermost disk region. The aim of these models is to understand the impact of inner planets on the dynamics of the magnetospheric star-disk interaction and to derive observational signatures that could unveil their presence.

**Postdoc I. MHD simulations of star-planet(s)-inner disk interactions.**

A solid experience in numerical magnetohydrodynamics (MHD) and the use of numerical codes for MHD are strongly sought-after. The successful applicant will work with Jérôme Bouvier and his research group at IPAG and will closely collaborate with Claudio Zanni and the PLUTO code development team at INAF - Osservatorio Astrofisico di Torino Italy, to develop 3D numerical MHD simulations of star-planet(s)-inner disk interactions. The outcome of these simulations will be used as an input for radiative transfer calculations (Postdoc II) to extract synthetic observables. Long-term visits to Turin, Italy, are foreseen to work directly with C. Zanni on the development of the MHD models with the PLUTO code.

**Postdoc II. Radiative transfer models of star-planet(s)-inner disk interactions.**

Demonstrated experience in the development and/or use of radiative transfer (RT) codes, in particular applied to atomic lines, will be a strong asset. The successful applicant will work with Jérôme Bouvier and his research group at IPAG and will closely collaborate with Christophe Pinte at Monash University, Australia, on the development of the MCFOST RT code applied to atomic lines. Long-term visits to Monash, Australia, are foreseen to work directly with C. Pinte. At IPAG, extensive RT calculations will be run in collaboration with F. Ménard to compare the results of MHD simulations (Postdoc I) to observations (line profiles, photometric light curves, interferometric images).

**IPAG** is a world-leading institute in astronomy and astrophysics. It hosts 5 research groups working on stellar and planetary formation, from pre-stellar core collapse to the physics and chemistry of circumstellar disks, and the initial phases of planet formation, on exoplanetary systems detection and characterization, and on planetary science. IPAG is also involved in cutting edge instrumental development (e.g. ESO/VLT(I) SPHERE, PIONIER, AMBER, E-ELT/MAORY), and benefits from the proximity of the IRAM/ALMA node and the Grenoble University environment. The current position offers the opportunity for astronomers to work in a world-class research environment and pursue their career in a very dynamic and competitive field of research.

The candidates applying for the position should have a PhD in physics or astronomy, or in a related field. Interested candidates should send their curriculum vitae, bibliography, a brief statement of research interests outlining their suitability and motivation for one of the positions above, and arrange for three letters of reference. Applications received before January 15, 2018 will be given full consideration, but will continue to be accepted until the positions are filled. Please send all applications and reference letters to: Jerome.bouvier@univ-grenoble-alpes.fr

The appointment is for three years and may start as early as March 2018. Funds are available for computing, publications, travel, and other needs. The gross salary is in the range 30-42 kEuros per annum, depending on qualifications and experience. IPAG welcomes applicants with diverse backgrounds and experiences. We regard gender equality and diversity as a strength and an asset.

ERC SPIDI: http://cordis.europa.eu/project/rcn/210985_en.html.

IPAG: http://ipag.osug.fr/

Selective bibliography related to the positions I) and II):

I) Bouvier, J., Matt, S. P., Mohanty, S., Scholz, A., Stassun, K. G., Zanni, C. 2014. Angular Momentum Evolution of Young Low-Mass Stars and Brown Dwarfs: Observations and Theory. Protostars and Planets VI 433-450.

I) Romanova, M. M., Owocki, S. P. 2015. Accretion, Outflows, and Winds of Magnetized Stars. Space Science Reviews 191, 339-389.

I) Zanni, C., Ferreira, J. 2013. MHD simulations of accretion onto a dipolar magnetosphere. II. Magnetospheric ejections and stellar spin-down. Astronomy and Astrophysics 550, A99.

II) Pinte, C., Harries, T. J., Min, M., Watson, A. M., Dullemond, C. P., Woitke, P., Mnard, F., Durn-Rojas, M. C. 2009. Benchmark problems for continuum radiative transfer. High optical depths, anisotropic scattering, and polarisation. Astronomy and Astrophysics 498, 967-980.

II) Pinte, C., Menard, F., Duchene, G., Bastien, P. 2006. Monte Carlo radiative transfer in protoplanetary disks. Astronomy and Astrophysics 459, 797-804.

**First Announcement**

# Magnetic fields along the star-formation sequence: bridging polarization-sensitive views

## Focus Meeting 4 at the IAU General Assembly, Vienna (Austria), August 30-31, 2018

Dear colleagues,

We invite you to join us at the 2018 IAU General Assembly for a Focus Meeting dedicated to the role of magnetic fields in the star-formation process.

In this Focus Meeting we wish to gather the different communities working with magnetized models and polarimetric observations of the various stages and objects along the star formation sequence, from molecular clouds to young stars reaching the main sequence.

The goal is to discuss how to compare constraints on magnetic fields at different evolutionary stages and physical scales in order to establish a coherent view of their role in the multi-scale process of star formation. Combining observational results and theoretical expectations from different communities is complex, so we especially welcome contributions that will emphasize how different measurements of magnetic fields can be compared and interpreted in a coherent way, despite the widely varying observing techniques, objects, and physical scales that are involved in studies across the star-formation sequence.

If you would like to receive updates about the organization of the Focus Meeting, please register your contact information on our webpage: https://escience.aip.de/iau30-fm4/registration/

Note that registration for IAU GA 2018 and payment of the corresponding fees will be handled by the IAU General Assembly organizers and are mandatory to participate in the event! Abstract submission is possible once registration is completed on the IAU XXX GA webpage (early-bird rate before Jan. 31, 2018):

https://astronomy2018.univie.ac.at/registration/online-registration/

Any inquiry about the scientific program of Focus Meeting 4 can be directed to: iau2018.fm4@gmail.com

We look forward to seeing you in Vienna in August, 2018!

The SOC: Anaelle Maury, Swetlana Hubrig, and Chat Hull (co-chairs), Silvia Alencar, Andrea Bracco, Edith Falgarone, Josep Miquel Girart, Martin Houde, Jungmi Kwon, Hiro Takami, Helmut Wiesemeyer, Qizhou Zhang.

# Cloudy workshop at NARIT in Chiang Mai, Thailand

## May 14 - 25, 2018

The next Cloudy workshop will be at the National Astronomical Research Institute of Thailand (NARIT), in Chiang Mai, Thailand, May 14-25, 2018. The workshop will be patterned after the very successful program at INAOE, Tonantzintla, Mexico, lasting two weeks with three speakers. For more details visit the workshop website at NARIT: http://cloud9.pa.uky.edu.

# The Cosmic Cycle of Dust and Gas in the Galaxy: from Old to Young Stars

## July 9 - 13, 2018, Quy Nhon, Vietnam

The registration for the conference "The Cosmic Cycle of Dust and Gas in the Galaxy: from Old to Young Stars  is now open. This conference will take place at the International Centre for Interdisciplinary Science and Education (ICISE) located in the beautiful coastal city Quy Nhon in central Vietnam (July 9th to July 13th, 2018).

Organized in the framework of "Rencontres du Vietnam", a conference on the evolution of gas and dust from evolved to young stars will bring astronomers working on the circumstellar environment of evolved stars and star (and planet) forming regions together with planetologists working on the origin of the solar system. In July 2016, in the same cycle of conferences, Blowing In the Wind had addressed issues related to the relevant dynamics. In July 2017, another conference of the same cycle, 'Star Formation in Different Environments' focused on how stars form. The July 2018 conference will be dedicated to the physico-chemistry and evolution of gas and dust. It will review state-of-the-art knowledge of the molecular and dust components of envelopes and shells surrounding Supernovae, AGB stars and planetary nebulae as well as diffuse, cold and giant molecular clouds. Special sessions will be dedicated to the origin and evolution of matter in the solar system: meteorites, Rosetta, etc. Recent observations, in particular using ALMA, are the source of major progress in the study of the cosmic cycle of the Galaxy, making such a conference very timely.

An updated list of confirmed invited speakers can be found at:
https://cosmiccycle2018.sciencesconf.org/resource/page/id/6

Researchers are invited to submit contributed talks and posters.

Key dates

Call for contributed talks: November: 20th 2017

End of early-bird registration May: 8th 2018

Oral contribution submission deadline: May 8th

Poster contribution submission deadline: June 1st

Regular registration deadline: June 15th

Conference starts: July 9th

https://cosmiccycle2018.sciencesconf.org/

# IAU Symposium 345 on "Origins: From the Protosun to the First Steps of Life"

## held August 20 - 23, 2018 at the IAU General Assembly in Vienna

IAU Symposium 345 will take place at the General Assembly of the IAU in Vienna Austria from August 20-23, 2018. Major topics include: star formation in the solar neighborhood and cloud cores, early environment of the pre-solar nebula, formation and evolution of protoplanetary disks, physical and chemical properties of protoplanetary disks, formation of Earth and Earth-like planets, early planetary atmospheres and surfaces, early conditions on the Earth, Earth-like planets, and early life on Earth. Registration is now open.

The deadline for early registration is 31 January 2018, for abstracts and grant requests, February 28th, and for regular registration, June 30.

Registration is here: http://astronomy2018.univie.ac.at/registration/

The IAUS345 website on the General Assembly page is here: http://astronomy2018.univie.ac.at/symposia/symposium345/

The local IAUS345 website with invited speaker names is here: http://ninlil.elte.hu/IAUS345/

# COSPAR 2018 sessions on Planet Formation and Exoplanets

## 2018 July 14-22, Pasadena, USA

The 42nd Committee on Space Research (COSPAR) Scientific Assembly will be held at Caltech (Pasadena, California) between July 14 and 22, 2018. COSPAR assemblies typically attract a large audience of about 4000 participants, where the focus is on research conducted from space. We would like to advertise the following sessions related to planet formation and exoplanet science:

### Session E4.2: "Planet Formation at High Resolution

The discovery that many stars have planetary systems drastically different from our own has upended our ideas about the origins of planets. Learning how these diverse planets formed from protostellar gas and dust disks requires measurements with enough spatial and/or spectral resolution to reveal signatures of processes such as gas accretion, gravitational instability, orbital migration, planet-planet scattering, and many others. Finding such signatures will both advance our knowledge of our own origins, and help in the hunt for other planets like Earth. This COSPAR session will cover the birth of planets in protostellar disks, and searches for and characterization of exoplanets around young and mature stars. We will review some of the recent breakthroughs achieved with ground-based instrumentation and discuss the exciting new questions that can soon be tackled with JWST, and further ahead with WFIRST. Finally we will explore concepts for future spectroscopy or imaging missions that might employ interferometry and advanced coronagraphy/nulling techniques in order to achieve the high resolution and high contrast needed for detecting planets and protostellar disk features within a few astronomical unit of the host stars.

**Solicited Speakers:** Ilsedore Cleeves (CfA), Michael Ireland (ANU), Hannah Jang-Condell (Wyoming), Stephanie Sallum (Arizona)

**Organisers:** Stefan Kraus (Exeter), Gautam Vasisht (JPL); **SOC:** Richard Alexander (Leicester), Francesca Altieri (INAF), Myriam Benisty (IPAG), Simon Casassus (U. de Chile), Denis Defrere (Liege), Misato Fukagawa (Nagoya U.), Lee Hartmann (Michigan), Thomas Henning (MPIA), Andrea Isella (Rice U.), John Monnier (Michigan), Ilaria Pascucci (Arizona), Stephen Rinehardt (NASA Goddard), Rens Waters (SRON), Alycia Weinberger (Carnegie DTM)

**Website:** https://www.cospar-assembly.org/admin/sessioninfo.php?session=744

### Session E4.1: "Current and Future Projects for Exoplanets Detections and Characterisation"

Thanks to synergies between ground and space-based observations, we have learned that planets orbiting other stars are quite common and we have been able to perform statistical surveys of their occurrence, masses, sizes and eccentricities. At the same time, we have discovered that the architecture of exoplanetary systems shows a remarkable diversity and that exoplanet properties can be very different, indeed, from what we can expect based on the knowledge of our Solar System. Spectra of increasing quality and resolution enable us to investigate their rotation, atmospheric chemical composition, the presence of clouds and day to night side differences. These more detailed observations require more sophisticated modeling efforts. In the near future, CHEOPS, TESS, JWST and PLATO missions are going to open a new era in the exoplanet studies and revolutionize our picture. In view of the outcomes from the next exoplanet missions, this COSPAR event aims to put together the broad community interested in the field to review major results, discuss models and present new projects.

**Solicited Speakers:** Charles Beichman (NExScI), Christopher Broeg (Bern), George Ricker (MIT Kavli)

**Organisers:** Francesca Altieri (INAF), Rens Waters (SRON); **SOC:** Daniel Angerhausen (Bern), Tom Greene (NASA Ames), Stefan Kraus (Exeter), Avi Mandell (NASA Goddard), Giusi Micela (INAF), Motohide Tamura (Tokyo), Diego Turrini (INAF-IAPS), Stephane Udry (Geneva), Gautam Vasisht (JPL)

**Website:** https://www.cospar-assembly.org/admin/sessioninfo.php?session=743

Abstracts for talks and posters are accepted until **February 9, 2018,** and might present recent results (obtained either from the ground or space), outline science opportunities, explore enabling technologies, or highlight current/upcoming/potential future missions related to these science areas. Please submit your abstract on the following website: https://www.cospar-assembly.org/user/mypapers.php?log=1

## Formation of substellar objects: theory and observations
### 21-23 May 2018, ESAC, Madrid, Spain

On behalf of Local and Scientific Organizing Committees, we are pleased to announce a three days workshop devoted to brown dwarfs and their formation mechanism/s. More than 20 years have passed since the discovery of the first confirmed substellar objects. However, there are still many problems concerning brown dwarf formation and evolution.

During the last years, a large number of works have been focused on explaining the origin of brown dwarfs. Thanks to Spitzer, Herschel and lately ALMA, there are now evidences of a starlike scenario to explain the formation of these substellar objects. However, there are still open questions, like the role of turbulence, and the efficiency of other mechanisms (e.g. photoevaporation, disk fragmentation) to produce BDs. On the other hand, the study of young clusters is producing more and more spectroscopically confirmed substellar IMFs, which are fundamental to understand BD formation and evolution.

The scope of this workshop is to gather experts on BD formation, both theoreticians and observational astronomers, to discuss about the results of the last decade. We plan to compare the theoretical expectations with the results from observations to understand which questions have been answered, and which ones are still open. Moreover, experts from other fields, such as exoplanets and chemical modeling, are welcome since one of the goals is to study the phenomena from a comprehensive perspective and to produce new synergies and projects. In addition, we will discuss about the advances that can be done in this field with the advent of new facilities like e.g. JWST or Euclid.

All relevant information can be found at:

http://www.laeff.cab.inta-csic.es/projects/ws18/main/index.php

Regards,

David Barrado, Maria Morales, Nuria Huelamo and Carlos Eiroa, on behalf of the SOC and LOC

## Take a Closer Look - The Innermost Region of Protoplanetary Discs and its Connection to the Origin of Planets
### ESO Headquarters, Garching, Germany, 15 - 19 October 2018

Recent discoveries of close-in planets around main sequence and even pre-main sequence stars raise a number of questions about the formation of planetary systems. Their formation and migration history must be directly linked to the conditions within the inner regions of their progenitor protoplanetary discs. These sites also play a key role in star-disc interactions. Studies probing this important region require the use of innovative techniques and a wide range of instruments.

This workshop will address a number of topics related to the inner disc, including the morphology and composition of the innermost disc regions, star-disc interaction, and theories that describe the evolution of the innermost disc regions and the formation of close-in planets.

This workshop will cover the following themes:

Observations of the innermost regions of discs (<0.1-1 au, with near-IR interferometry, adaptive optics, spectroscopic techniques, space-based diffraction limited telescopes such as HST and JWST in the future). Modeling of the inner disc (structure of the inner gas disc, disc walls, effects of magnetic fields). Observations and theoretical predictions of processes happening at the inner disc-star interface (e.g., magnetic fields, accretion, jets). Observations of exo-planets close to the central star (hot Jupiters, transits...). Theoretical predictions to explain the origin of planets detected close to the stars.

Please see the workshop webpage for more details or contact the organisers by email.

The deadline for talk abstracts is 19 May 2018 and the registration deadline is 29 June 2018.

http://www.eso.org/sci/publications/announcements/sciann17072.html

# The Laws of Star Formation: From the Cosmic Dawn to the Present Universe

## 2 - 6 July 2018, Cambridge, Umited Kingdom

This is a conference in honour of Prof. Robert Kennicutt. It will be held at the Institute of Astronomy and the adjoining Kavli Institute for Cosmology at the University of Cambridge (UK) from Monday July 2th to Friday July 6th, 2018.

Registration is now open.

Scientific rationale:

The coming of age of many facilities and new instrumental capabilities, including ALMA, JWST, VLT/MUSE, etc., and the continuous stream of ground-breaking results from HST, Spitzer, Herschel, and others, has ushered a new era for the investigation of star formation in galaxies. As we inch our way into the formulation of a predictive theory of star formation, we are now in a position to relate the newly formed stars to their natal gas at all scales, from giant molecular clouds up to entire galaxy populations, in present-day galaxies back to the dawn of cosmic time. Observational studies linking molecular gas mass to star formation activity are crucial to shape our understanding of the physical processes that drive the conversion of gas into stars, and to identify the dominant positive/negative feedback processes that trigger and quench star formation in a wide variety of galactic environments. Balancing these physical processes over time, galactic disks self-regulate their level of star formation and become galactic ecosystems, in analogy to many other ecosystems observed on earth. This conference will bring together experts on all aspects of star formation to assess the progress made so far, compare achievements in different areas, and lay the ground for future directions. Among the goals is to bring together different communities and to discuss the role of planned and future facilities in unraveling the link between star formation and gas in galaxies.

The major themes of this meeting are:

* The star formation law in different gas phases (LSB, HSB, atomic or molecular gas). (Non-)linearity of the star formation law.

* Triggering (dynamics, environment, instabilities) and quenching mechanism of star formation (morphology, AGN, stabilizing bulges, environment effects in gas stripping, or starvation)

* Self-regulation of star formation through positive/negative feedback processes (SN, AGN, ...)

* Star formation at small scales: What drives the small-scale substructure of star formation in galaxies? What threshold holds for SF in different regimes?

* Cosmic evolution of star formation: starbursts census with redshifts

Confirmed invited speakers:
Angela Adamo (Stockholm University), Joao Alves (University of Vienna), Frdéric Bournaud (Laboratoire AIM Paris-Saclay), Clare Dobbs (University of Exeter), Bruce Elmegreen (IBM T.J Watson Research Center), Neal Evans (University of Texas), Natasha Förster Schreiber (Max-Planck-Institut fr extraterrestrische Physik), Diederik Kruijssen (Universität Heidelberg), Mark Krumholz (Australian National University), Adam Leroy (Ohio State University), Margaret Meixner (Space Telescope Science Institute), Sally Oey (University of Michigan), Ying-jie Peng (Peking University), Amelie Saintonge (University College London), Eva Schinnerer (Max Planck Institute for Astronomy, Heidelberg), Stefanie Walch (University of Cologne), Fabian Walter (Max Planck Institute for Astronomy, Heidelberg)

SOC:
Daniela Calzetti (co-Chair), Ilse De Looze (co-Chair), Maud Galametz (co-Chair), Monica Relao-Pastor (co-Chair), Gustavo Bruzual, Francoise Combes, Andy Fabian, Timothy Heckman, Linda Tacconi, Serena Viti, Anthony Whitworth

We look forward to welcoming you to Cambridge to an exciting and vibrant meeting full of discussions and new ideas.

http://www.ast.cam.ac.uk/meetings/2018/sf.law2018.cambridge

# Circumplanetary Disks and Satellite Formation
## March 26 - 30, 2018, Nagoya, Japan

Dear Colleague,

We are pleased to announce the meeting "Circumplanetary Disks and Satellite Formation" to be held in Nagoya March 26-30, 2018.

The aim of the meeting is to have active discussion on origin of satellites among theorists and observers. In this meeting, we will cover the formation environments and processes of moons, gas and particle dynamics around terrestrial and giant planets, observation of circumplanetary disks and exomoons including candidates, and constraints that we can obtain from the observations including space probes to Solar System bodies. The deadline of the registration is January 15, but we will close the registration as soon as the number of the participants reaches 55.

Confirmed Invited Speakers (alphabetical):
Sebastien Charnoz (Institut de Physique du Globe de Paris), Aurélien Crida (Observatoire de Côte d'Azur), Oliver Gressel (Niels Bohr Institute), Andrea Isella (Rice University), David Kipping (Columbia University), Hiroyuki Kurokawa (Earth-Life Science Institute), Satoshi Okuzumi (Tokyo Institute of Technology), Judit Szulágyi (ETH Zürich), Takayuki Tanigawa (National Institute of Technology, Ichinoseki College), Tomohiro Usui (Earth-Life Science Institute)

Scientific Organizing Committee (alphabetical):
Yuri Fujii, Hidenori Genda, Tristan Guillot, Shigeru Ida, Shu-ichiro Inutsuka, Jun Kimura, Neal Turener

Local Organizing Committee (alphabetical):
Yuri Fujii, Ryuki Hyodo, Shu-ichiro Inutsuka, Kenji Kurosaki

We are looking forward to meet you in Nagoya.

Best wishes,
Yuri Fujii (on behalf of the SOC and LOC)

https://cpdsf2018.wixsite.com/home

# *Summary of Upcoming Meetings*

**Star Formation and Young Stars in Cygnus**
31 Jan - 2 Feb 2018, Keele, UK
http://www.astro.keele.ac.uk/cygnus

**Magnetic Fields or Turbulence: Which is the critical factor for the formation of stars and planetary disks?**
6 - 9 February 2018, Hsinchu, Taiwan
http://events.asiaa.sinica.edu.tw/workshop/20180206/index.php

**Water during planet formation and evolution 2018**
12-16 February 2018, Zürich, Switzerland
https://waterzurich.github.io/

**Star and Planet Formation in the Southwest 2 (SPF2)**
12 - 16 March 2018, Oracle, Arizona, USA
http://tinyurl.com/spf2018

**Circumplanetary Disks and Satellite Formation**
26 - 30 March 2018
https://cpdsf2018.wixsite.com/home

**Complex Organic Molecules in the Universe: Current Understanding and Perspective**
4 April 2018, Liverpool, UK
http://eas.unige.ch/EWASS2018/session.jsp?id=SS5

**Cosmic Rays: the salt of the star formation recipe**
2 - 4 May 2018, Florence, Italy
http://www.arcetri.astro.it/cosmicrays

**EPoS 2018 The Early Phase of Star Formation - Archetypes**
13 - 18 May 2018, Ringberg Castle, Tegernsee, Germany
http://www.mpia.de/homes/stein/EPoS/epos.php

**Interstellar: The Matter**
14 - 18 May 2018, Cozumel, Mexico
http://bigbang.nucleares.unam.mx/astroplasmas/interstellar-the-matter

**Cloudy workshop**
14 - 25 Mauy 2018, Chiang Mai, Thailand
http://cloud9.pa.uky.edu

**From Prestellar Cores to Solar Nebulae**
14 May - 22 June 2018, Paris-Saclay, France
https://www.ias.u-psud.fr/core2disk/

**Formation of substellar objects: theory and observation**
21-23 May 2018, ESAC, Madrid, Spain
http://www.laeff.cab.inta-csic.es/projects/ws18/main/index.php

**The Olympian Symposium 2018: Gas and stars from milli- to mega- parsecs**
28 May - 1 June 2018, Mt. Olympus, Greece
http://www.olympiansymposium.org

**Tracing the Flow: Galactic Environments and the Formation of Massive Stars**
2 - 6 July 2018, Lake Windermere, UK
http://almaost.jb.man.ac.uk/meetings/TtF

**The Laws of Star Formation: from the Cosmic Dawn to the Present Universe**
2 - 6 July 2018, Cambridge, UK
http://www.ast.cam.ac.uk/meetings/2018/sf.law2018.cambridge

**The Cosmic Cycle of Dust and Gas in the Galaxy: from Old to Young Stars**
9 - 13 July 2018, Quy Nhon, Vietnam
https://cosmiccycle2018.sciencesconf.org

**Astrochemistry: Past, Present, and Future**
10 - 13 July, 2018, Pasadena, USA
http://www.cfa.harvard.edu/events/2018/astrochem18

**COSPAR 2018 sessions on Planet Formation and Exoplanets**
14 - 22 July 2018, Pasadena, USA
https://www.cospar-assembly.org/admin/sessioninfo.php?session=744

**Cool Stars 20: Cambridge Workshop on Cool Stars, Stellar Systems and the Sun**
29 July - 3 August 2018, Cambridge/Boston, USA
http://www.coolstars20.com

**Origins: From the Protosun to the First Steps of Life**
20 - 23 August 2018, Vienna, Austria
http://ninlil.elte.hu/IAUS345/

**Magnetic fields along the star-formation sequence: bridging polarization-sensitive views**
30-31 August 2018, Vienna, Austria
http://escience.aip.de/iau30-fm4/

**The Wonders of Star Formation**
3 - 7 September 2018, Edinburgh, Scotland
http://events.ph.ed.ac.uk/star-formation

**Take a Closer Look - The Innermost Region of Protoplanetary Discs and its Connection to the Origin of Planets**
15 - 19 October 2018, ESO Headquarters, Garching, Germany
http://www.eso.org/sci/publications/announcements/sciann17072.html

## Abstract submission deadline

The deadline for submitting abstracts and other submissions is the first day of the month.

*New Books*

## Star Formation

### Mark R Krumholz

This new textbook, written by a leading theoretician, is based on lectures given over a number of years and is primarily directed towards graduate students. The basic theoretical and observational aspects of star formation is covered, with an emphasis on theory, up until the transition to planet formation. References to the key literature is interspersed through the book, and include recent papers. The book additionally contains 5 problem sets and their solutions and three appendices. The following lists the chapters and subsections of the book:

**9 The Star Formation Rate at Galactic Scales: Observations**
9.1 The Star Formation Rate Integrated Over Whole Galaxies
9.2 The Spatially-Resolved Star Formation Rate
9.3 Star Formation in Dense Gas

**10 The Star Formation Rate at Galactic Scales: Theory**
10.1 The Top-Down Approach
10.2 The Bottom-Up Approach

**11 Stellar Clustering**
11.1 Observations of Clustering
11.2 Theory of Stellar Clustering

**12 The Initial Mass Function: Observations**
12.1 Resolved Stellar Populations
12.2 Unresolved Stellar Populations
12.3 Binaries

**13 The Initial Mass Function: Theory**
13.1 The Power-Law Tail
13.2 The Peak of the IMF

**14 Protostellar Disks and Outflows: Observations**
14.1 Observing Disks
14.2 Observations of Outflows

**15 Protostellar Disks and Outflows: Theory**
15.1 Disk Formation
15.2 Disk Evolution
15.3 Outflow Launching

**16 Protostar Formation**
16.1 Thermodynamics of a Collapsing Core
16.2 The Protostellar Envelope

**17 Protostellar Evolution**
17.1 Fundamental Theory
17.2 Evolutionary Phases for Protostars
17.3 Observable Evolution of Protostars

**18 Massive Star Formation**
18.1 Observational Phenomenology
18.2 Fragmentation
18.3 Barriers to Accretion

**19 The First Stars**
19.1 Cosmological Context
19.2 Chemistry and Thermodynamics of Primordial Gas
19.3 The IMF of the First Stars
19.4 The Transition to Modern Star Formation

**20 Late-Stage Stars and Disks**
20.1 Stars Near the End of Star Formation
20.2 Disk Dispersal: Observation
20.3 Disk Dispersal: Theory

**21 The Transition to Planet Formation**
21.1 Dynamics of Solid Particles in a Disk
21.2 From Pebbles to Planetesimals

World Scientific 2017, ISBN 9813142030
507 pages, softcover US$88.00, hardcover US$128.00
Available from http://www.worldscientific.com/worldscibooks/10.1142/10091