THE STAR FORMATION NEWSLETTER

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

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The Star Formation Newsletter

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 NGC 2023 reflection nebula is located close to the iconic Horsehead Nebula, and is illuminated by the B1.5V star HD 37903 partly embedded in the southern part of L1630 cloud. A small cluster of embedded young stars is found there, and one drives the little Herbig-Haro flow HH 247 discovered by Malin, Ogura, & Walsh (1987). The image shows part of the HH 247 flow in an ACS/HST image. North is to the upper left, east to the lower left.

Color mosaic based on the filters F625W, F658N, and F850LP.
Image processing by Roberto Colombari (http://www.astrobin.com/users/rob77/).

Submitting your abstracts

Latex macros for submitting abstracts and dissertation abstracts (by e-mail to reipurth@ifa.hawaii.edu) are appended to each Call for Abstracts. You can also submit via the Newsletter web interface at http://www2.ifa.hawaii.edu/star-formation/index.cfm

Thomas Henning

in conversation with Bo Reipurth

Q: *What was your PhD about?*

A: I wrote my PhD thesis about radiative transfer in circumstellar dust shells to explain the physical properties of massive young stellar objects. This remained a topic of great interest to me and we later designed one of the first Monte Carlo radiative transfer codes. During the time of my PhD thesis I realized the importance of fundamental dust properties and learned a lot from the members of the Jena school of interstellar medium studies.

Q: *You grew up in what was at that time East Germany. What were the strengths and weaknesses of higher education in this part of the world?*

A: I had the great privilege to grow up in a very liberal family environment where classical education in literature and music was highly valued. I learned early that natural sciences allow one to be more independent from ideology and that knowledge is an important achievement. I was very much interested in mathematics, chemistry and physics where education was excellent. The main threat was my tendency to speak openly about the things I did not like. In addition, the rather limited "public opportunities" led to self-driven curiosity: I established my own chemical laboratory in the basement of our house and later became heavily interested in non-linear dynamics. As a student I had a great time because I could participate very early in active research.

Q: *Your most cited paper is the study that Ossenkopf and you did in 1994 on dust opacities for protostellar cores. What were the key new insights that made this paper so recognized?*

A: The mass of an astronomical object, being it a star, a galaxy, a molecular cloud or a protoplanetary disk, is one of the most fundamental quantities. During one of the runs at the SEST telescope in La Silla I realized that we can rather precisely measure the millimetre flux of optically thin configurations, but that the derived masses strongly depend on the selected dust model. We then developed a rather comprehensive physical model of dust evolution in molecular cloud cores and calculated the relevant dust opacities over a wide wavelength range. It turned out that these opacities survived many observational tests and are of high value for the derivation of dust masses.

Q: *How has this field moved forward in the intervening twenty years?*

A: The interest moved both to more global scales, dust evolution in galaxies and the high-z universe, and the more local environments of protoplanetary disks. In protoplanetary disks the situation is more complex than in molecular clouds because dust properties change strongly with time and position in these disks and dust and gas evolution are coupled via complicated physics. Meanwhile we developed very detailed models of dust evolution in disks, taking into account experimental results provided by laboratory groups. I am very excited that I laid the foundation for some of these groups and was able to build a network of laboratory facilities in Germany.

Q: *Have observations of grains in young circumstellar disks reached the point when meaningful comparisons with carbonaceous chondrites can be made?*

A: This is actually a topic of great interest to me. The carbon budget in disks and the relation to oxygen-rich materials drive the composition of exoplanets and their atmospheres. We are presently developing a model combining planet formation, evolution, and atmosphere composition. What we really do not know is the C/O ratio in these disks. In the solar system we have a deficit of carbonaceous material compared with the interstellar medium and we have not fully understood what the reason is. Spitzer spectroscopy has revelaed a wealth of information about silicates in disks, and with Herschel we could even detect molecular water ice. However, we know very little about the carbonaceous component of dust in these disks.

Q: *Another influential paper was your 1998 review in Science with Salama on carbon in the universe. Today does this field advance mainly through observations or through laboratory studies?*

A: Today many astronomers discuss PAHs as part of the life cycle of matter and as an important component for the heating of the ISM. This is mostly driven by the enormous amount of data ranging from local molecular clouds and HII regions to distant galaxies. At the same time, laboratory experiments are starting to provide key answers as to how this material is formed and evolves under interstellar conditions.

Q: *What do you see as the most significant results from Herschel in the study of dust in star forming regions?*

A: Dust remains a great tracer of molecular cloud structure. The high dynamic range and large mapping speed of Herschel allowed the mapping of molecular clouds in our and other galaxies and revealed the filamentary structure of these clouds. The combination of Herschel data with Spitzer and submillimeter data is presently providing better constraint of dust properties. For the first time, we were able to determine the amount of cold dust in supernova remnants with sensitive Herschel observations.

Q: *When you became director of the MPIA in Heidelberg, what was the vision you developed for the institute?*

A: In order to make progress in star and planet formation one has to combine strong observational programs with theoretical studies and instrumentation programs. MPIA is providing a unique environment to develop such a program. I am very proud that we have been heavily involved in the PACS instrument for Herschel, the MIRI instrument for JWST and we are just celebrating the very successful commissioning of the planet finder instrument SPHERE for ESO's VLT. Our theory group is very strong and we are able to contribute to solving the puzzle how massive stars form.

In addition, one of my visions has been always to provide a very inspiring and open atmosphere for students and postdocs from all over the world and together with my co-director Hans-Walter Rix we have made the MPIA to an international center in our research fields. Many of my former students, postdocs and collaborators are now Professors at leading research institutions which may - at some point - be the greatest achievement.

At the moment, I am very eager to establish an "Origins of Life Center" in Heidelberg and we made the first steps in this direction.

Q: *What are currently the main focus and challenges of the study of planet and star formation?*

A: In planet formation we really need to make a connection between disk structure and chemical content of disks with the structure of planetary systems and exoplanet atmospheres. I am extremely excited by the discovery of asymmetric structures in disks with high-contrast AO-assisted imaging and submillimetre interferometry, especially with ALMA. We are now talking about the discovery of dust traps, something we predicted many years ago based on theoretical studies. In star formation the questions remain to find a predictive recipe for the rate of star formation in molecular clouds and to connect our tremendous knowledge on local star formation with star formation on galactic scales. The various galactic surveys from the near-infrared to centimeter wavelengths provide a unique multi-wavelength dataset to explore star formation in our and other galaxies. The discovery of giant molecular filaments is just the beginning of a larger endeavour to reveal the star formation potential of galaxies.

Q: *What are the next big projects for your department?*

We are heavily involved in the search for young exoplanets in disks with the VLT and LBT and the discovery of transiting planets with the Hat-South network. These studies will provide the best targets for observations with JWST, especially with the MIRI instrument. For the VLT Interferometer we are part of the Matisse and Gravity consortia - instruments which will allow the imaging of disks at near- and mid-infrared wavelengths. In Europe we are all working together to make the E-ELT a reality and I am eager to collect photons from exoplanets with this machine.

My Favorite Object

TW Hya - an accreting T Tauri star

Andrea Dupree

1 Introduction

The cool young star, TW Hya resembles our young Sun in a critical stage of evolution. TW Hya is fortunately placed close by, oriented well, undergoing accretion from a circumstellar disk, disk dispersal, and perhaps planet formation before our very eyes! What else could an astronomer wish for?! Let's review the basic facts.

TW Hya appears to be the closest accreting T Tauri star (54 pc [*1*]) with an age of 7-10 Myr [*2, 3*]. It is surrounded by a circumstellar disk of gas and dust which has been imaged directly and studied with interferometric techniques in the infrared and submillimeter/millimeter regions (see Fig. 1). The disk is essentially 'face-on', with inclination $\sim 7° \pm 1°$ [*4*] – an orientation which means that the process of accretion of material from the surrounding disk onto the star can be observed directly. These two conditions: its brightness and its orientation make TW Hya a perfect target to understand the physics of accretion in detail. The power of spectroscopy from X-rays, ultraviolet, optical, through the infrared allows a probe of the different facets of the accretion process. These capabilities have been available now for almost a decade, and exploitation of both simultaneity and the time domain has enabled new discoveries to complement other snapshot studies.

TW Hya has been a favorite target since Henize [*7*] first remarked on its 'extreme intensity of H-alpha emission.' Herbig [*8*] conjectured that it might be a "post-T Tauri star" since it did not appear associated with a dark cloud. Five years later, photometry and spectra suggested to Rucinski and Krautter [*9*] that TW Hya exhibited properties of a T Tauri star, albeit a lonely one - far from any dark cloud. Since this early attention, almost 1000 papers citing TW Hya have flooded the refereed literature.

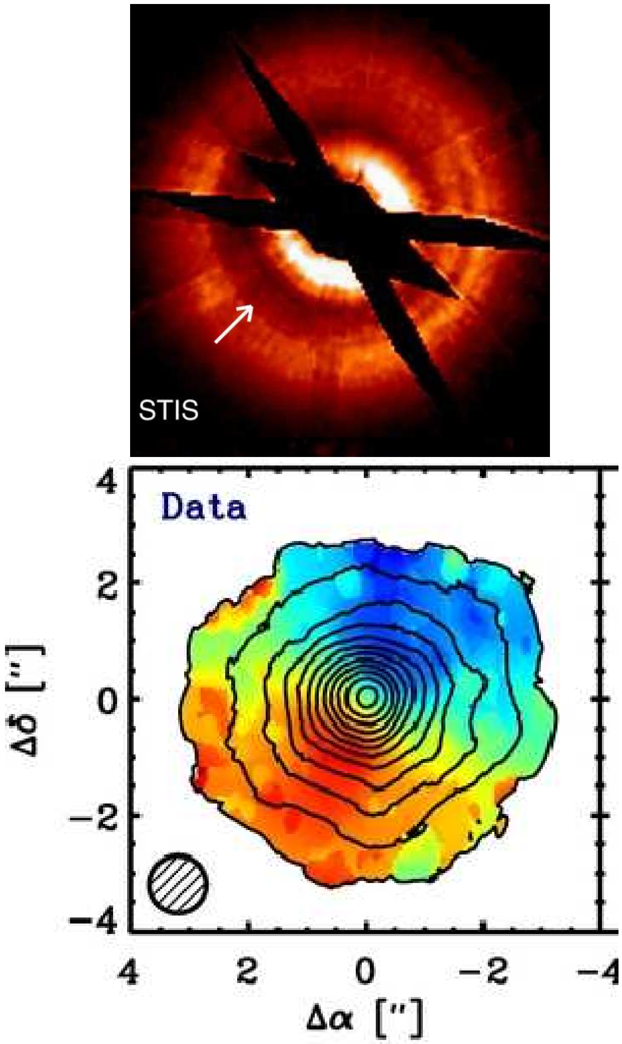

Figure 1: Optical and CO images demonstrate that the disk surrounding TW Hya is effectively face-on. *Top panel:* Surface brightness of visible scattered light in the STIS image of the TW Hya disk which has been scaled by the distance from the central star. The arrow points to the position where a decrease in brightness occurs $\sim$ 80AU from the star and is thought to signal a gap in the disk. Black regions mask the star itself or diffraction spikes. The figure spans about 8.8 arcsec on a side [*5*]. *Lower panel:* Moment maps of the the CO J=3-2 emission from the disk of TW Hya. Contours mark the velocity-integrated CO intensities and the color scale indicates intensity weighted line velocities showing rotation from the northwest (*blue-shift*) to the south east (*red-shift*) [*6*].

With apologies to the authors of these many papers, in this brief discussion, I want to focus on recent results that benefit from wide wavelength coverage and time-domain spectroscopy. These capabilities are leading to a better understanding of the accretion process in low mass stars, and point to future studies.

The process of building a low mass star culminates in its later stages when the magnetic field field from the star cuts the surrounding circumstellar disk. Such a disk has been dubbed 'transitional', marking the disk phase between an embedded protostar and an evolved planetary system [*10*]. Material from the disk is channeled along the stellar field lines, and accelerates towards the star. Approaching the surface, gas in the accretion column reaches free fall velocity, forming a shock discontinuity, a post-shock cooling zone, and penetrates to the stellar surface where a hot spot or ring is formed. Zeeman-Doppler imaging and spectropolarimetry vividly demonstrate the effects of accretion on the polar regions of TW Hya (Fig. 2). Our understanding of the disk accretion process has been developed extensively since the original suggestion [*12*] that the evolution of viscous disks could account for the properties of T Tauri stars. The circumstellar disk of TW Hya itself is also intriguing because it possesses a 'gap' – a low density region – which may result from planet-clearing although no confirmed planet has been detected around the star [*13, 14*].

High-resolution spectroscopy across multiple wavelength regions allows us to probe this accretion process in detail. Additionally, reliable plasma diagnostics available in the X-ray spectrum place meaningful constraints on densities and temperatures [*15*]. A long set of observations in X-rays with the CHANDRA satellite [*15*] was accompanied by simultaneous and contemporaneous optical and infrared spectroscopy [*16*]. Substantial time-domain spectroscopy over a decade [*17*] allows a comprehensive picture of the accretion process and its consequences in TW Hya. How is accretion detected? And what have we learned?

2 Accretion Signatures

Multi-spectral and sequential observations reveal critical details both of accretion and wind variability. X-ray spectra contain numerous high-temperature emission lines, some arising from the stellar corona at a temperature of $\sim 10^7$K, and others from the accretion shock characteristic of a temperature of 3×10^6K [*15*]. Emission lines formed in the accretion shock show that a major accretion event occurred during the long observation with the CHANDRA satellite. The flux of X-ray accretion lines reached the largest value observed during the 500ks pointing (Fig. 3), and it lasted for one hour. This enhancement was followed by sequential changes in the optical line profiles observed simultaneously. This event offered a rich opportunity to probe the accretion process. The behavior of Hα and Hβ in Fig. 4 is illustrative. The Hα total flux does not change,

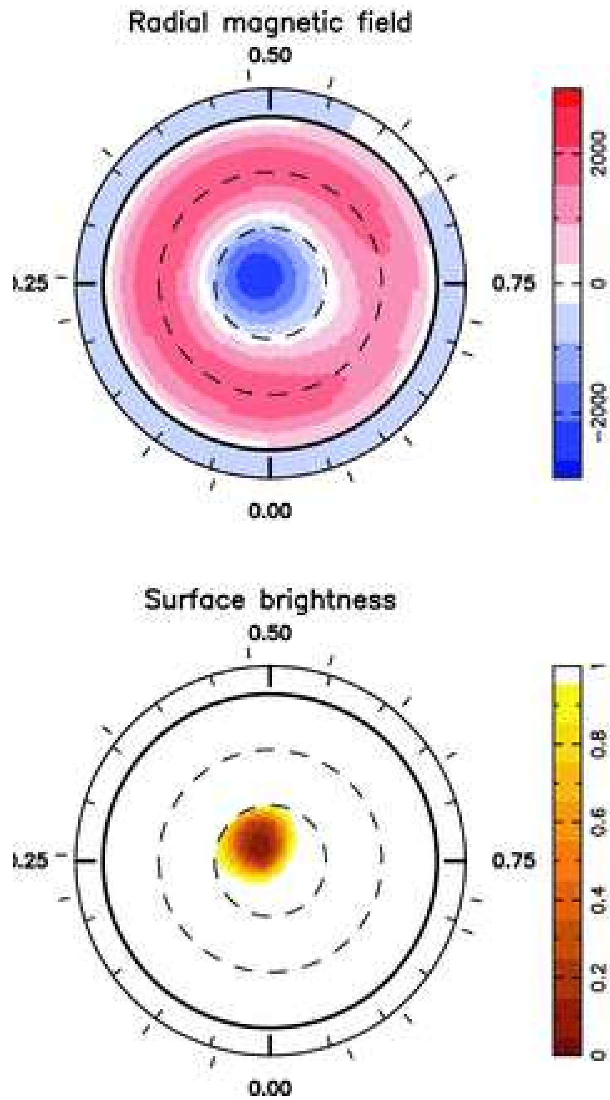

Figure 2: Note the concentration of magnetic flux and brightness at the pole of TW Hya. The radial magnetic field B (*top panel*) and the photospheric brightness (*lower panel*) of TW Hya in March 2010. The magnetic flux is labeled in Gauss, and the local photospheric brightness is normalized to the quiet photosphere. The display is a flattened polar projection to a latitude of −30°; the stellar equator is marked as a bold circle. Observation phases are denoted by radial tick marks. This figure is reproduced from [*11*] which includes extensive spectropolarimetric observations with ESPaDOnS at the CFHT.

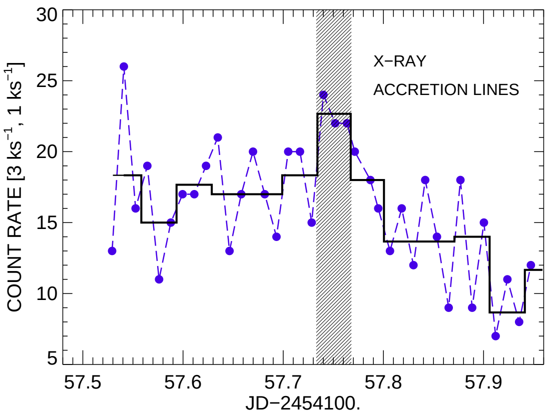

Figure 3: Accretion lines (N VII, O VIII, Ne IX, Fe XVII, Mg XI) binned over 1 ks (*filled circles*) or 3 ks and divided by 3 for display (*solid line*). The hatched region marks the accretion event. [*18*]

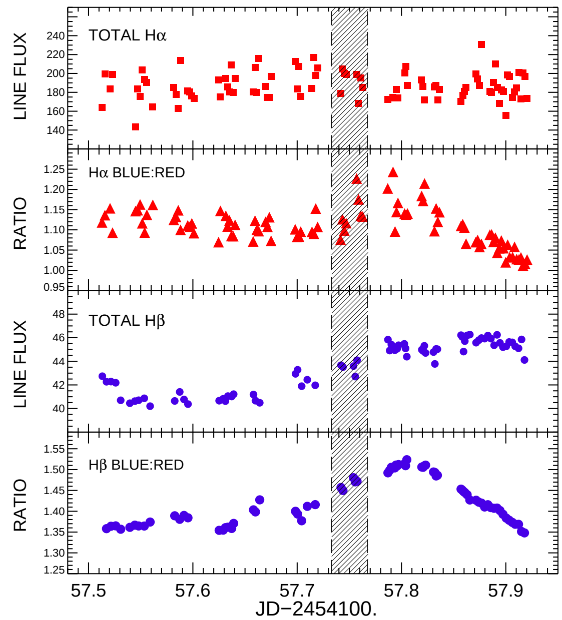

Figure 4: Balmer lines showing the effect of the accretion event (Fig. 3) on the Hα and Hβ line profiles. The change in asymmetry, indicated by the increased ratio of flux on the blue side to red-side flux signals an increase of infalling material onto the star. The behavior of the optical emission lines follows an accretion burst signaled by the accretion diagnostics in the X-ray spectrum.[*18*]

not surprising for such a strong optically thick line. However there is an abrupt change in the line asymmetries: the long wavelength side of the profile becomes weaker – in both Hα and Hβ – signaling material infalling towards the star. The total flux in Hβ also increases. This sequence gives an important clue to the formation of the broad optical emission lines. It suggests that they arise subsequent to the accretion shock event and an increase of inflowing material appears. The post-shock cooling volume is expected to be turbulent, offering a natural explanation of the observed broad line widths, both in optical and ultraviolet spectra. Extraction of the amount of veiling or 'weakening' of absorption lines in the optical spectrum due to a continuum and possibly line emission [*19*] showed an increase with a delay of about 2 hours after the X-ray accretion event. And the coronal X-ray spectrum responded to the increase in veiling about 2 hours later as signaled by increased coronal line flux [*16*]. The delayed coronal response points to coronal heating as another consequence of accretion.

3 Stellar Wind Variability

Sequential spectra reveal systematic changes in the wind from TW Hya. One example of many is shown in Fig. 5 where the Hα line became increasingly more wind-absorbed over successive nights. This line is usually centered on the stellar photospheric velocity, and the negative velocity side of the profile exhibits scattering in the stellar wind. The near-IR helium line (1.08μ) is a valuable diagnostic of winds as well (see Fig. 6). Because of the metastable nature of the lower energy level of the transition, the level population is maintained in the chromosphere and can scatter the photospheric continuum in an expanding wind. The terminal velocities are easy to measure. Emission is also strong from the extended chromosphere, forming a P Cygni profile. And at times there is subcontinuum absorption on the positive velocity side of the helium line ('inverse' P Cygni). Based on the temporal variation of X-rays and the optical spectrum, it appears that the broad emission arises from the post-shock region

What is striking from the many years of near-IR helium line observations is the variation in speed and opacity structure of the wind. In fact, such variability makes it difficult to identify systematic trends in wind parameters from snapshots [*21, 22, 23*] of accreting systems.

Parameters of the helium line profiles are especially interesting because they are in harmony with a simple model of accretion. To model the accretion, Cranmer [*24, 25*] considers a dipole field aligned with the rotation axis of the star. Material originates from the disk, following the magnetic field lines, and the accretion stream free-falls towards the star, shocking near the stellar surface. More than 10^5 models were calculated by varying the accretion rate, the

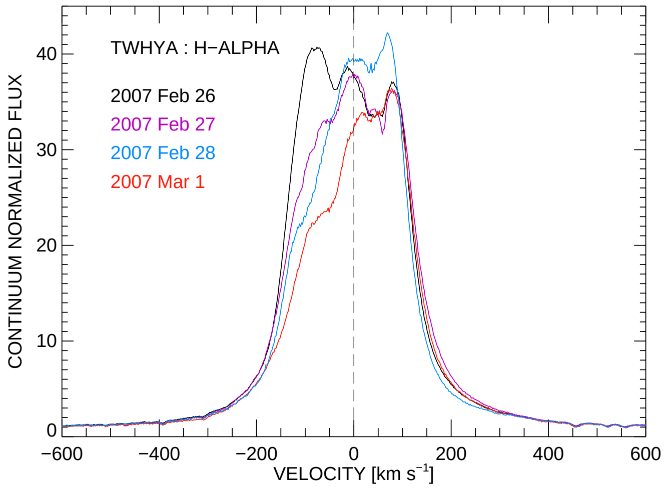

Figure 5: Changes in the Hα profile revealing the onset of a wind by the absorption at negative velocities. [*17*]

magnetic field strength, and the shock surface filling factor to select models that agree with physical parameters indicated by the X-ray spectrum [*20*]. Acceptable models (Fig. 7) demonstrate a relationship between the mass accretion rate and the terminal free-fall velocity such that the accretion rate increases as the terminal velocity decreases. The distance of the accreting material from the star controls the terminal velocity. When the accreting material originates from the disk closer to the star, the infalling terminal velocity is lower, the filling factor increases, and the mass accretion rate also increases. Such a relation is confirmed from the parameters of the helium line profile. The emission in helium, believed to arise from the post-shock cooling zone increases when the mass accretion rate increases and this is associated with a lower terminal inflow velocity - the latter measured directly from the helium line profile (Fig. 8).

4 Shadowing by Accretion Funnels?

The Hα line has long been known to exhibit kinks or absorption features in the emission profile [*16*]. Time-domain spectroscopy reveals (Fig. 9 and Fig. 10) two new features of these absorptions: (1) the absorption features are constant in velocity over a night; (2) the features have been observed to 'jump' abruptly from one velocity to another. Absorption at a constant velocity is unlike 'stellar prominences' found in rapidly rotating stars where the absorption feature – thought to be similar to a solar prominence – moves rapidly in velocity as it traverses the stellar disk [*27, 28*]. The profiles of the absorption features (shown in Fig. 10) over a span of 8 hours demonstrate absorption at -50 km s^{-1} in the profile that weakens and another absorption appears at -175 km s^{-1}. It seems likely that

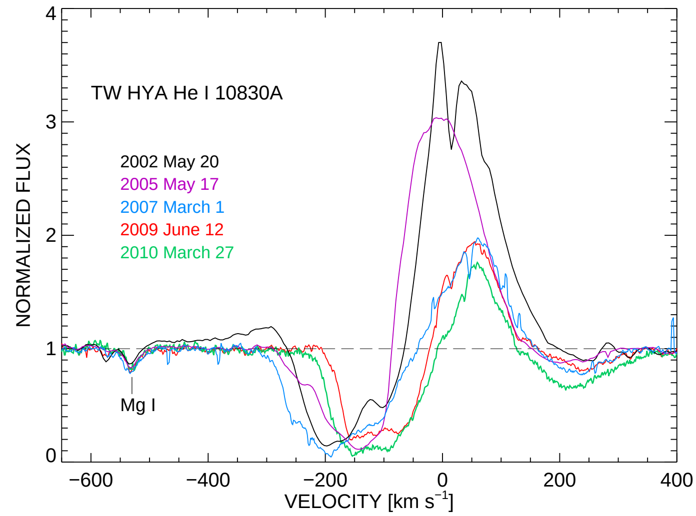

Figure 6: Helium line observations spanning 8 years. This diagnostic shows both variable warm wind opacity and signs of variable amounts of infalling material. [*17*]

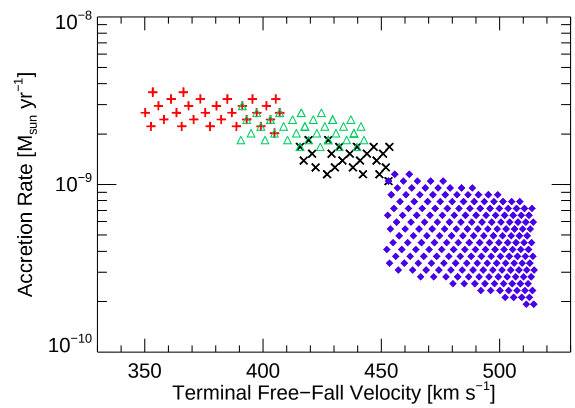

Figure 7: The magnetic dipole accretion model predicts the relationship between the accretion rate and the terminal free-fall velocity. Parameter ranges of the models are constrained by values of the shock parameters (T_e, n_e) and the absorption column density (N_H) derived from diagnostics in the X-ray spectrum. The $\times$ symbols denote parameter constraints from the average Chandra spectrum. Other symbols mark parameter constraints from 3 individual Chandra pointings. [*17, 20*]

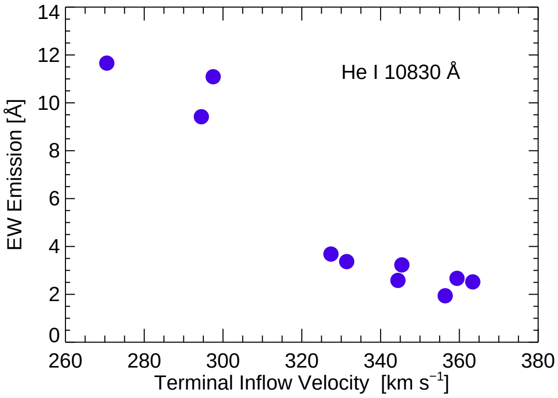

Figure 8: Relations between line parameters measured from the near-IR helium line profile. [*17*]

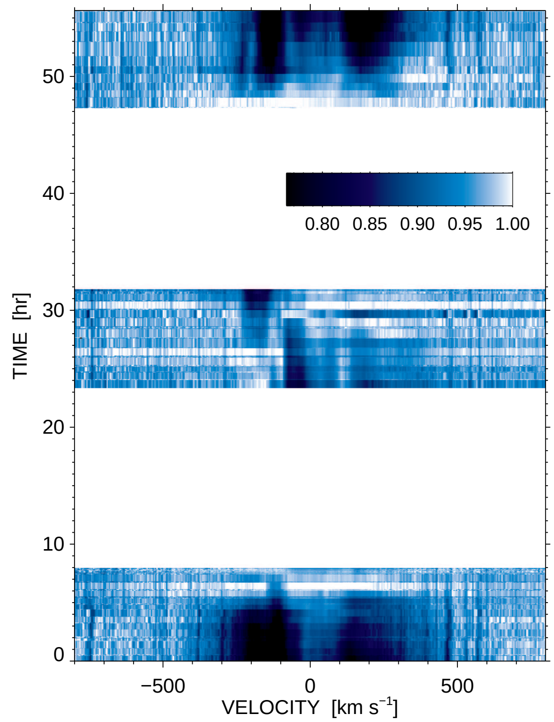

Figure 9: Gray scale showing Hα absorption over 3 consecutive nights of observation. Each spectrum has been divided by the maximum flux at each wavelength in order to display absorption features. Note the abrupt change in absorption during the second night near a velocity of -200 km s^{-1}. [*17*]

these relatively narrow absorptions could arise from a stable cool structure located in the wind itself at a distance of $\sim$1.2$-$1.3 R$_\star$ that is silhouetted in the hydrogen line profile. The amount of absorption is consistent with our understanding of the temperature and density structure in the accretion funnels.

Intensive photometric monitoring by the MOST satellite recently revealed 'mysterious' brightness dips from TW Hya lasting 10 to 20 minutes that might arise from the occultation of photospheric hot spots by 'clumps' related somehow with the accretion process or free-floating condensations [*29*]. This phenomenon appears transitory as compared to the stable structures visible in the Hα profile, and emphasizes the complex activity associated with accretion.

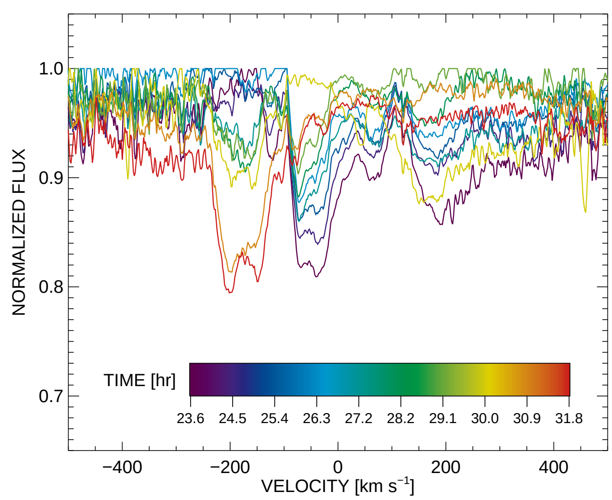

Figure 10: Line plot of the absorption over a span of 8 hours during the 'second night' of Fig. 9. Absorption at $\sim$50 km s^{-1}weakens, and a new absorption feature emerges at ~ -200 km s^{-1}. [*17*]

5 A Model and the Future

The 'image' we have of the accretion process in TW Hya is diagrammed in Fig. 11. Accreting material free-falls forming a shock, and subsequently billows out to form a large post-shock turbulent plasma. Consequences of this plasma include broad emission lines and a hot spot in the photosphere, followed by coronal heating, and an increased wind opacity. This star shows many variations in accretion, activity, and wind structure. The results from spectroscopy described above create a tension when confronting current models of the accretion process. The new spectroscopic measurements indicate that a comprehensive picture of accretion must include not only the accretion 'funnels' themselves but the substantial, likely overwhelming, contribution of the post-shock volume. Formation of the broad optical and ultraviolet lines appears easily explained as arising in the turbulent post-shock volume. MHD modeling suggests [*30*] that under some con-

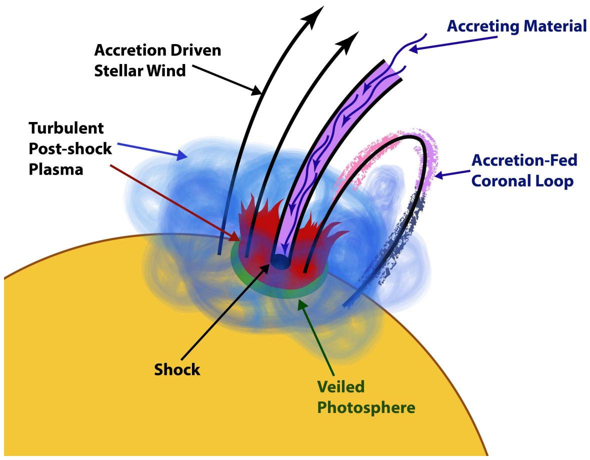

Figure 11: Cartoon illustrating the various components of the accretion scenario. [*Courtesy of A. Szentgyorgi.*]

ditions the post-shock region can undergo chaotic plasma motions in harmony with the spectroscopic results. Moreover, line profiles are modified in a hot stellar wind [*31*] that scatters the negative velocity side of the profile. This wind can be detected in many emission lines ranging from Hα, He I, to ultraviolet transitions of C II, C III, N V, and O VI with temperatures reaching 3×10^5K. The relations between the near-IR helium emission, the inflow velocity, and the wind velocity are consistent [*17*] with an accretion-driven wind.

A remaining puzzle is the difference in width between wide ultraviolet emission lines formed at high-temperatures (>80,000K) as compared to lower temperature lines such as C II (T$\sim$10,000K) [*17,32*] which are narrow. Perhaps the turbulent material never reaches low temperatures. Material at $\sim$10,000K may be more widely distributed over the stellar chromosphere, and the relative contribution to the profile from accretion effects is diminished.

The well-studied target TW Hya provides evidence of spectroscopic variability and we might expect similar variations in other accreting stars. Accreting systems merit intensive time-domain study, to assess the effects of age, of higher accretion rates, and inclination of the source relative to the surrounding disk. To investigate the mass outflow rates and wind structures, we need to carry out detailed non-LTE modeling of the line profiles. Future models must consider the whole system, including details of the post-shock cooling conditions and resulting spectrum. Wonderful opportunities exist to confront models with observations given the rich store of spectroscopic measurements of TW Hya.

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Perspective

Distances to Star Forming Regions

Laurent Loinard

A historical perspective on astronomical distance measurements

The problem of accurate distance measurements has been a central theme of astronomy ever since the Antiquity (see de Grijs 2011 for a comprehensive contemporary discussion). For instance, Aristarchus of Samos is credited with the first reliable measurement of the distance to the Moon in the 4^{th} century B.C.; remarkably, but somewhat fortuitously, his estimate was accurate to better than 1.5% (e.g. Guillot 2001). Throughout the following centuries and up to this day, many ingenious methods have been devised to estimate distances to celestial bodies (a very important recent example is the determination of cosmological distances based on type Ia Supernovae; Riess et al. 1998, Perlmutter et al. 1999). It was clear from the beginning, however, that parallax techniques (i.e. those based on triangulation) were the most reliable, and this remains as true as ever.

The Merriam-Webster dictionary defines parallax as *"the apparent displacement or the difference in apparent direction of an object as seen from two different points not on a straight line with the object."* In principle, the two different points do not have to be very separated: Aficionados of the *Big Bang Theory* TV series (Season 1, Episode 1) may recall that Sheldon pick his "spot" in part because *"it faces television at an angle that is (...) not so far wide as to create a parallax distortion"*. In the context of astronomy, parallaxes are used to estimate distances by measuring the angular difference in the apparent position on the celestial sphere of a given source observed from two different (widely separated, in this case) perspectives.[1] This was successfully realized for the Moon in 1751 by the French abbot and astronomer Nicolas Louis de La Caille (see Hirshfeld 2001) using simultaneous observations collected in Europe and the Cape of Good Hope (a baseline larger than 9,000 km). Similar observations were carried out in 1672 from Paris and Cayenne by Cassini and Richer to estimate the parallax of the planet Mars (see Hirshfeld 2001 and Ferguson 1999 for a discussion of the conclusiveness and accuracy of these results). At about the same time, Flamsteed obtained a similar value for Mars' parallax using a clever variant originally devised by Tycho Brahe. Rather than using two points on the Earth to define a long baseline, the same point can be used provided the observations are carried out several hours apart. Over such a time period, the rotation of the Earth on its axis carries the observer through space at a rate of about 1,000 km per hour (the displacement is of order of the Earth diameter for a timespan of 12 hours). A practical difficulty of this *diurnal parallax* method is that it requires fairly accurate time keeping, not easily achieved in the 16^{th} and 17^{th} centuries.

For objects outside of the Solar System, longer baselines are required to measure accurate parallaxes, and the solution comes from extending further Tycho's idea. Over the course of one year, the motion of the Earth about the Sun carries any point on the surface of the Earth through millions of kilometers. The resulting *trigonometric parallax* permits direct astronomical distance measurements provided the location of the Earth relative to the Sun is accurately known as a function of time. It is important to point out that at the level of accuracy reached by modern parallax measurements such as those that we will describe below, the requirement on the Earth-Sun separation can only be met by considering sophisticated Solar System dynamical models. Thus, although trigonometric parallaxes are commonly considered the first step of the cosmic distance ladder, they themselves rests on an accurate description of the Solar System dynamics.

Returning to our historical development, we note that the first impetus to detect stellar trigonometric parallaxes came more from the desire to confirm the heliocentric Copernican view of the Universe, than from an interest about the distance to stars. The reasoning was that if the Earth were at the center of the Solar System (i.e. in the geocentric model of Ptolemy) distant stars would not exhibit any trigonometric parallax, whereas they would in the heliocentric Copernican model. The existence of stellar parallaxes thus became of prime importance to the

[1] Thus, terms like *spectroscopic parallax* or *expansion parallax* are outright misnomers, since such methods involve no apparent displacement whatsoever. Their common use reflects the fact that astronomers have come to use "parallax" as a synonym for "distance measurement method."

development of astronomy during the Renaissance, and many astronomers (including Tycho, Galileo, and William Herschel) tried to measure them throughout the years. It was not until the 1830s, however, that Friedrich Bessel, Thomas Henderson, and Friedrich von Struve successfully measured the trigonometric parallax of 61 Cygni, α Centauri, and Vega, respectively. The trigonometric parallaxes that they measured were only a fraction of an arcsecond (modern values are $0''.29$, $0''.75$, and $0''.13$ for 61 Cyg, α Cen, and Vega, respectively; van Leeuwen 2007), demonstrating that even the nearest stars are at considerable distances. This explained the lack of earlier detection, and implies that parallax measurements are indeed technically challenging: to measure the parallax of even the nearest star with 1% accuracy requires angle measurements more accurate than 10 milli-arcseconds (mas)!

Because of these technical requirements, less than 100 stars had trigonometric parallax measurements by the end of the 19^{th} century, and many of them turned out to be very approximate. The situation steadily improved over the course of the 20^{th} century, but the real breakthrough came with the Hipparcos mission (Perryman et al. 1997) of the European Space Agency (ESA), which measured the trigonometric parallax of over 100,000 stars with an average accuracy of about 1 mas. This translates into an accuracy on the distance better than 1% for stars within 10 pc and 10% for stars within 100 pc. ESA has just launched a second astrometry mission (GAIA; de Bruijne 2012) that will provide trigonometric parallaxes for millions of stars. The full results are expected to be published in about 5 years, and the astrometric accuracy is anticipated to be of order 20 to 30 micro-arcseconds (μas) with some dependence on the stellar magnitude (de Bruijne 2012). This would result in distances accurate to better than 1% for objects within 400 pc.

Radio interferometry

All the parallax measurements mentioned thus far were obtained from observations in the optical part of the electromagnetic spectrum. With the advent of radio-astronomy during the second half of the 20^{th} century, and particularly with the development of radio-interferometry (Thompson et al. 2001), new astrometric tools became available. Indeed, it was rapidly clear that radio-interferometry was a powerful technique for astrometric measurement thanks to the relatively smaller effect of the Earth atmosphere on radio waves, and to the ease with which radio signals can be manipulated. The combination of these two factors enabled, in particular, the development of Very Long Baseline Interferometry (VLBI), a technique through which telescopes separated from one another by thousands of kilometers are operated as a single instrument[2] to provide high angular resolution. At a wavelength of a few centimeters, the angular resolution achieved is of the order of a few mas. Concomitant with the high angular resolution of VLBI arrays comes their astrometric accuracy which –if all systematics can be controlled– is given by θ/SNR, where θ is the angular resolution and SNR the signal-to-noise with which the source is detected. Thus, with a signal-to-noise of a few hundred, an astrometric accuracy of order 10 μas can be achieved with VLBI arrays – this is comparable with the accuracy expected of GAIA.

In principle, any set of radio telescopes operating at a common frequency can be tied up to form a VLBI array. For instance, the European VLBI Network (EVN; http://www.evlbi.org/intro/intro.html) operates by linking together up to two dozen radio telescopes distributed over Europe, Asia, and Africa. These telescopes are all different and are used most of the time as stand-alone "single-dish" telescopes; they are combined into a VLBI array only for a few weeks every year. This is very much like the situation with ESO's Very Large Telescope (VLT) where the Unit Telescopes (UT) are normally used by themselves, but can be linked with the Auxiliary Telescopes (AT) to form the VLTI. The National Radio Astronomy Observatory (NRAO) adopted a different strategy when it designed and built the Very Long Baseline Array (VLBA; http://www.vlba.nrao.edu) in the early 1990s. The VLBA is an array of 10 identical radio telescopes distributed over the US territory and operated solely as a VLBI array (i.e. they are never used as stand-alone telescopes). This has the great advantage of providing a VLBI array that can operate all year long (rather than only a few weeks every year), offering much greater scheduling flexibility. There is a common (and understandable) confusion outside of the radio community between VLBI and the VLBA. We hope it is now clear that VLBI is a technique, whereas the VLBA is a specific instrument using that technique: the VLBA is to VLBI what the VLTI is to optical interferometry.

The astrometric quality of VLBI instruments was used, in particular, to define the International Celestial Reference Frame (ICRF). The ICRF provides the closest approximation to date of an inertial reference frame and is materialized by precise equatorial coordinates for about 600 quasars distributed across the entire sky (Ma et al. 1998). VLBI arrays can also be used to measure trigonometric parallaxes to stars if they are sufficiently radio-bright. This was first achieved by Lestrade et al. (1999) who reached a typical accuracy of about 0.5 mas. Thanks to the improvement both in the sensitivity and in the calibration of VLBI observations over the past two decades, trigonometric parallaxes can now be measured with an ac-

[2] VLBI instruments can be constructed only because the signal can be adequately manipulated and recorded at each telescope, and sense can be made of the resulting interferences only because of the limited effect of the atmosphere.

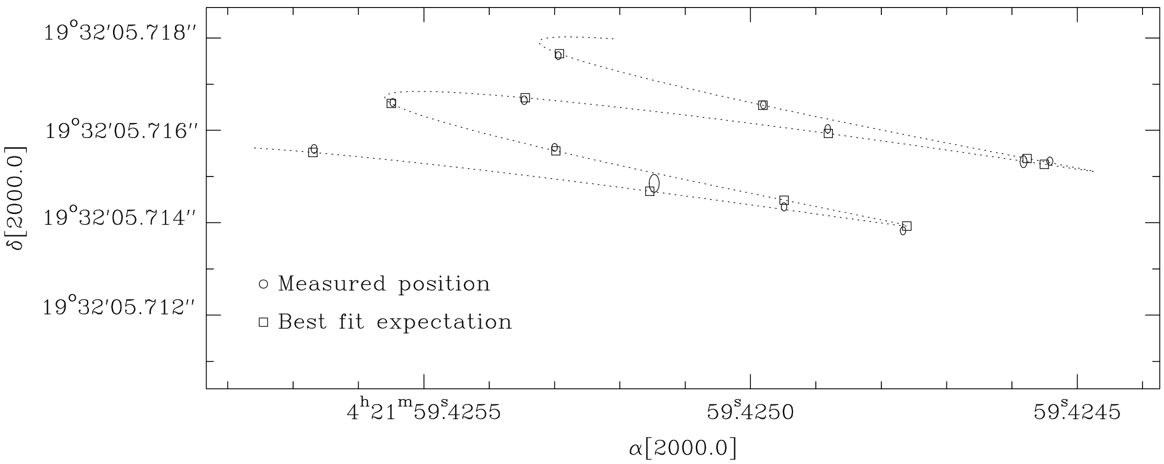

Figure 1: Trajectory of T Tau Sb on the plane of the sky as measured by multi-epoch VLBA observations. The data were collected at 12 epochs from September 2003 to July 2005, and are shown as ellipses whose sizes represent the error bars. The dotted curve shows the best fit with a combination of parallax and proper motion. The squares are the positions predicted by the best fit at the twelve epochs (see Loinard et al. 2007 for details).

curacy of order 10 μas with VLBI arrays (Reid & Honma 2014).

Previous distances to star-forming regions

Given the technical difficulty involved in obtaining accurate trigonometric parallaxes, distances to star-forming regions have traditionally been estimated from indirect techniques such as the convergent point method (e.g. Bertout & Genova 2006; Galli et al. 2012) or "spectroscopic parallaxes" and isochrone fitting –both of which can be quite uncertain for young associations given the uncertainties of pre-main sequence evolutionary models and the substantial amount of dust that normally exists along the line of sight toward young stars. These indirect methods typically yield errors of 30% or worse on the distance estimates of star-forming regions, and only provide a *mean distance* for each region. This is quite an unsatisfactory situation as a 30% distance error propagates to uncertainties larger than 50% on derived luminosities ($L \propto d^2$) and errors larger than 100% on masses derived from Kepler's law ($M \propto a^3$). In addition, star-forming regions often exhibit internal structure, and in many cases, it is unclear whether a single mean distance is appropriate for the entire region, or if different sub-structures might be at different distances.

Unfortunately, the Hipparcos satellite did not significantly improve our knowledge of the distances to star-forming regions (e.g. Bertout et al. 1999). This is because Hipparcos operated at optical wavelengths, and young stars are usually dim in the optical due to dust extinction. Indirect distances that incorporate Hipparcos results have enabled refinements in the distance determination of several star-forming regions (e.g. Knude & Høg 1998; Mamajek 2008), but with resulting uncertainties that remain substantial.

VLBI distances to star-forming regions

The situation started to change about 10 years ago thanks to VLBI measurements (see Loinard et al. 2005). As we mentioned earlier, VLBI observations provide an astrometric accuracy similar to that expected from GAIA. Additionally, they have the distinct advantage that they are not affected by dust extinction. Thus, they can be used even for sources that are either deeply embedded within dusty regions, or located behind a large column of line-of-sight dust (or both). Star-forming regions are clearly in this situation, and are therefore prime targets for VLBI astrometric observations.

In star-forming regions, there are two classes of sources that are sufficiently bright at radio wavelengths to be detectable with VLBI arrays: masers and chromospherically active young stars. Masers (hydroxyl, water, or methanol) are commonly found in high-mass star-forming regions (Bartkiewicz & van Langevelde 2012) and can be extremely bright. This makes them ideal tracers to map the distribution of high-mass star-forming regions across the Milky Way (Reid et al. 2014). Chromospherically active young stars, on the other hand, are often radio sources thanks to the gyration of electrons in their strong superficial magnetic fields (Dulk 1985). This results in continuum cyclotron, gyrosynchrotron, or synchrotron emission depending on the energy of the gyrating electrons. This emission is normally confined to regions extending only a few stellar radii around the stars, and therefore remains very compact even in the nearest star-forming regions (for instance, 4 $R_\odot \equiv 50$ μas at 300 pc).

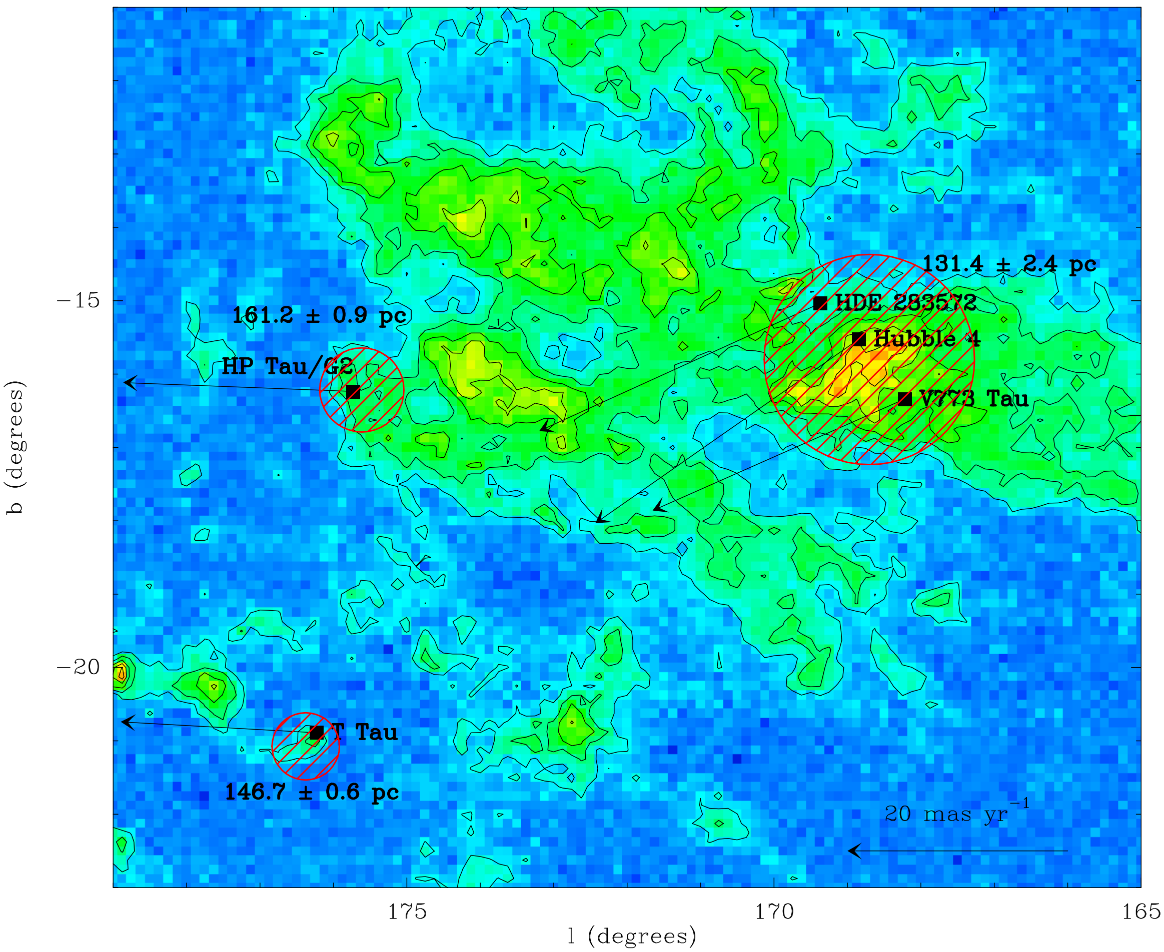

Figure 2: Positions, distances, and proper motions of Hubble 4, HDE 283572, V773 Tau, T Tau, and HP Tau/G2 superposed on the CO(1-0) map of Taurus from Dame et al. (2001). Adapted from Loinard et al. (2007) and Torres et al. (2007, 2009, 2012).

To appreciate the astrometric quality of VLBI observations, consider the case of T Tau Sb (Figure 1), one of the southern companions of the famous object T Tauri (e.g. Duchêne et al. 2002). T Tau Sb was observed with the Very Long Baseline Array (VLBA) at 12 epochs between 2003 September and 2005 July with a cadence of two months (see Loinard et al. 2007 for details). The position of the radio source associated with T Tau Sb was measured at each of these epochs and modeled as a combination of trigonometric parallax and proper motion. The best fit (shown as a dotted curve on Figure 1) yields a parallax of 6.82 ± 0.03 mas, corresponding to a distance $d = 146.7 \pm 0.6$ pc. Note that the resulting uncertainty on the distance is about 0.4% which represents an improvement over the Hipparcos uncertainty of about two orders of magnitude.

Limiting ourselves to regions within 1 kpc of the Sun, similar observations have now been performed for a total of 5 young stars in Taurus (Torres et al. 2007, 2009, 2012), 2 young stars in Ophiuchus (Loinard et al. 2008), 2 young stars in Perseus (Hirota et al. 2008, 2011), 1 young star in Serpens (Dzib et al. 2010), 5 objects in the Orion Nebula Cluster (Hirota et al. 2007; Sandstrom et al. 2007; Menten et al. 2007; Kim et al. 2008), and 2 objects in Cepheus (Moscadelli et al. 2009; Dzib et al. 2011). The results are summarized in Table 1, and we consider them to be the most accurate distance estimates to date; note that we were careful to specify the sub-region in each case. Roughly 75% of these distances are based on observations of the continuum emission emitted by chromospherically active young stars, whereas the other 25% are from maser observations. In addition to these results for nearby regions ($d < 1$ kpc), roughly 100 parallaxes of similar accuracy (a few tens of μas) have been measured using VLBI observations of masers associated with high-mass star-forming regions distributed across the disk of the Milky Way (Reid et al. 2014; their Table 1).

Table 1: VLBI distances to star-forming regions within 1 kpc of the Sun.

Region	Distance	References
Ophiuchus (L1688)	120 ± 4 pc	Loinard et al. (2008)
Taurus-west	131.4 ± 2.4 pc	Torres et al. (2007, 2012)
Taurus-east	161.2 ± 0.9 pc	Torres et al. (2009)
Taurus-south	146.7 ± 0.6 pc	Loinard et al. (2005, 2007)
Perseus (NGC 1333)	235 ± 18 pc	Hirota et al. (2008)
Perseus (L 1448)	232 ± 18 pc	Hirota et al. (2011)
Serpens core	415 ± 25 pc	Dzib et al. (2010)
Orion (ONC)	416 ± 5 pc	Menten et al. (2007); Kim et al. (2008)
Cepheus	700 ± 30 pc	Moscadelli et al. (2009); Dzib et al. (2011)

VLBI tomography of star-forming regions

As shown earlier, VLBI measurements can provide distances accurate to about 1 pc in the nearest star-forming regions. Such regions are typically a few tens of pc across, and are expected to be about as deep. Thus, VLBI observations should easily resolve their depth, and could be used to perform *tomographic studies* of nearby regions. This has recently been demonstrated in the case of the Taurus star-forming region thanks to multi-source VLBA observations. As Figure 2 shows, the young stars located to the west of the Taurus region are at a common distance of about 130 pc, and share similar proper motions. Measurements from the literature show that they also have similar radial velocities. The stars to the east and south of the complex, on the other hand, are significantly farther (145-160 pc) and have different proper motions and radial velocities (from those to the west). Although based on a very limited number of targets, this example demonstrates that multi-source VLBI observations do enable *tomography* of individual star-forming regions.

Such a possibility is fundamental to implement accurate astrophysics: Consider again the Taurus region, it appears to be at a mean distance of order 145 pc (the average of the near side at 130 pc and the far side at 160 pc), but to be 30 pc deep. Since 30 pc corresponds to 20% of 145 pc, *using the mean distance indiscriminately for all stars in the complex results in a typical error of 20%.* Accurate trigonometric parallaxes have eliminated any systematic errors on the mean distance, but statistical errors remain due to the intrinsic depth of the region. To eliminate them, the 3D structure of the region must be taken into account. We are currently in the process of measuring the trigonometric parallax of tens of young stars distributed across the star-forming regions of Table 1 with the VLBA . This large project, called *The Gould's Belt Distances Survey* is described in detail in Loinard et al. (2011) and will start to provide results in the coming two years. Meanwhile, we encourage the community to use the best available distances not just for their favorite region, but also for their favorite sub-region. For instance, when considering stars on the western side of Taurus, 131.4 pc should be used rather than 140 or 145 pc.

Conclusions and prospects

Ours are exciting times to consider star-forming region distances and structure. The VLBI results briefly described above have enabled a significant improvement in our best distance estimates and have shown that the internal structure of individual regions can be reconstructed. Interestingly, the internal kinematics can also be constrained by combining the high accuracy proper motions delivered by VLBI astrometry with radial velocity measurements. This type of results will be significantly expanded when the results of *The Gould's Belt Distances Survey* currently underway at the VLBA are available.

Of course, GAIA will soon provide results with an accuracy similar to those delivered by VLBI observations.The two sets of data will be extremely complementary. First they will be useful to discard any systematic effects in either data sets (see Melis et al. 2014 for a discussion of the "Pleiades Controversy", a case where Hipparcos and VLBI results are in disagreement). In addition, their combination will be a powerful probe of the structure of nearby regions: GAIA will deliver a large number of parallaxes but will be limited to regions of moderate extinction. This could induce systematic errors: If we assume that a typical star-forming region contains clumps with an $A_V \sim 10$, then GAIA will be biased to stars located in front (or at least on the near side) of such clumps. VLBI experiments are not affected by dust extinction and will identify regions where GAIA results might be biased and correct the distances appropriately.

Two final points are worth mentioning. First, that even higher astrometric accuracy (5 μas or better) should be achievable through VLBI experiments incorporating the Square Kilometer Array (SKA; Loinard et al. 2015). This would correspond to a breathtaking 0.06% accuracy (less than a tenth of a pc) on individual distances in Ophiuchus. SKA-VLBI experiments would also enable tomography mappings similar to those shown here for Taurus for regions at a few kpc. Second, that for highly obscured regions, a GAIA-like mission with near-infrared detectors might be useful. The situation is not so clear, however, as discussed by Høg & Knude (2014).

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Abstracts of recently accepted papers

Multimolecular studies of Galactic star-forming regions

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Molecular emission line observations of isolated Galactic star-forming regions are used to model the physical properties of the molecular interstellar medium in these systems. Observed line ratios are compared with the results predicted by models that incorporate gas-phase chemistry and the heating by stellar radiation and non-radiative feedback processes. The line ratios of characteristic tracer molecules may be interpreted using the contributions of two distinct components: a cold (40-50 K) and high-density (10^5-$10^{5.5}$ cm^{-3}) Photon Dominated Region (PDR) with a nominal UV-flux density and a warm ($\sim$300 K) Mechanical Heating Dominated region (MHDR) with a slightly lower density ($10^{4.5}$-10^5 cm^{-3}). The relative contribution of these structural components are used to model the observed line ratios. Ionised species may be better modelled by adopting an increase of the cosmic ray flux towards the Galactic Center and the sulphur abundance should depleted by a factor of 200 to 400 relative to solar values.
The line ratios of the Galactic sample are found to be very similar to those of the integrated signature of prominent (Ultra-)Luminous IR Galaxies. The PDRs and MHDRs in the isolated Galactic regions may be modelled with slightly higher mean densities than in extra-galactic systems and a higher MHDR temperature resulting from non-radiative mechanical heating. Multi-molecular studies are effective in determining the physical and chemical properties of star-formation regions by using characteristic line ratios to diagnose their environment. The addition of more molecular species will reduce the existing modelling redundancy.

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Accretion Outbursts in Self-gravitating Protoplanetary Disks

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We improve on our previous treatments of long-term evolution of protostellar disks by explicitly solving disk self-gravity in two dimensions. The current model is an extension of the one-dimensional layered accretion disk model of Bae et al. We find that gravitational instability (GI)-induced spiral density waves heat disks via compressional heating (i.e. PdV work), and can trigger accretion outbursts by activating the magnetorotational instability (MRI) in the magnetically inert disk dead-zone. The GI-induced spiral waves propagate well inside of gravitationally unstable region before they trigger outbursts at $R < 1$ AU where GI cannot be sustained. This long-range propagation of waves cannot be reproduced with the previously used local α treatments for GI. In our standard model where zero dead-zone residual viscosity ($\alpha_{\rm rd}$) is assumed, the GI-induced stress measured at the onset of outbursts is locally as large as 0.01 in terms of the generic α parameter. However, as suggested in our previous one-dimensional calculations, we confirm that the presence of a small but finite $\alpha_{\rm rd}$ triggers thermally-driven bursts of accretion instead of the GI + MRI-driven outbursts that are observed when $\alpha_{\rm rd} = 0$. The inclusion of non-zero residual viscosity in the dead-zone decreases the importance of GI soon after mass feeding from the envelope cloud ceases. During the infall phase while the central protostar is still embedded, our models stay in a "quiescent" accretion phase with $\dot{M}_{\rm acc} \sim 10^{-8} - 10^{-7}\ M_\odot\,{\rm yr}^{-1}$ over 60 % of the time and spend less than 15 % of the infall phase in accretion outbursts. While our models indicate

that episodic mass accretion during protostellar evolution can qualitatively help explain the low accretion luminosities seen in most low-mass protostars, detailed tests of the mechanism will require model calculations for a range of protostellar masses with some constraint on the initial core angular momentum, which affects the length of time spent in a quasi-steady disk accretion phase.

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Color Variability of HBC 722 in the Post-Outburst Phases

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We carried out photometric observations for HBC 722 in SDSS r, i and z bands from 2011 April to 2013 May with a Camera for Quasars in Early uNiverse attached to the 2.1m Otto Struve telescope at McDonald Observatory. The post-outburst phenomena were classified into five phases according to not only brightness but also color variations, which might be caused by physical changes in the emitting regions of optical and near-infrared bands. A series of spectral energy distribution (SED) is presented to support color variations and track the time evolution of SED in optical/near-infrared bands after the outburst. Given two years of data, possible periodicities of r, i and z bands were checked. We found out three families of signals around ∼6, ∼10 and ∼1 days in three bands, which is broadly consistent with Green et al. (2013). We also examined short term variability (intra-day and day scales) to search for evidences of flickering by using the micro-variability method. We found clear signs of day scale variability and weak indications of intra-day scale fluctuations, which implies that the flickering event occurs in HBC 722 after outburst.

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Outflows, Dusty Cores, and a Burst of Star Formation in the North America and Pelican Nebulae

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We present observations of near-infrared 2.12 μm molecular hydrogen outflows emerging from 1.1 mm dust continuum clumps in the North America and Pelican Nebula (NAP) complex selected from the Bolocam Galactic Plane Survey (BGPS). Hundreds of individual shocks powered by over 50 outflows from young stars are identified, indicating that the dusty molecular clumps surrounding the NGC 7000 / IC 5070 / W80 HII region are among the most active sites of on-going star formation in the Solar vicinity. A spectacular X-shaped outflow, MHO 3400, emerges from a young star system embedded in a dense clump more than a parsec from the ionization front associated with the Pelican Nebula (IC 5070). Suspected to be a binary, the source drives a pair of outflows with orientations differing by 80°. Each flow exhibits S-shaped symmetry and multiple shocks indicating a pulsed and precessing jet. The 'Gulf of Mexico' located south of the North America Nebula (NGC 7000), contains a dense cluster of molecular hydrogen objects

(MHOs), Herbig-Haro (HH) objects, and over 300 YSOs, indicating a recent burst of star formation. The largest outflow detected thus far in the North America and Pelican Nebula complex, the 1.6 parsec long MHO 3417 flow, emerges from a 500 $M_\odot$ BGPS clump and may be powered by a forming massive star. Several prominent outflows such as MHO 3427 appear to be powered by highly embedded YSOs only visible at $\lambda > 70$ μm. An 'activity index' formed by dividing the number of shocks by the mass of the cloud containing their source stars is used to estimate the relative evolutionary states of Bolocam clumps. Outflows can be used as indicators of the evolutionary state of clumps detected in mm and sub-mm dust continuum surveys.

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Absorption Filaments Towards the Massive Clump G0.253+0.016

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ALMA HCO^+ observations of the infrared dark cloud G0.253+0.016 located in the Central Molecular Zone of the Galaxy are presented. The 89 GHz emission is area-filling, optically thick, and sub-thermally excited. Two types of filaments are seen in absorption against the HCO^+ emission. *Broad-line absorption filaments* (BLAs) have widths of less than a few arcseconds (0.07 − 0.14 pc), lengths of 30 to 50 arcseconds (1.2 −1.8 pc), and absorption profiles extending over a velocity range larger than 20 km s^{-1} . The BLAs are nearly parallel to the nearby G0.18 non-thermal filaments and may trace HCO^+ molecules gyrating about highly ordered magnetic fields located in front of G0.253+0.016 or edge-on sheets formed behind supersonic shocks propagating orthogonal to our line-of-sight in the foreground. *Narrow-line absorption filaments* (NLAs) have line-widths less than 20 km s^{-1} . Some NLAs are also seen in absorption in other species with high optical depth such as HCN and occasionally in emission where the background is faint. The NLAs, which also trace low-density, sub-thermally excited HCO^+ molecules, are mostly seen on the blueshifted side of the emission from G0.253+0.016. If associated with the surface of G0.253+0.016, the kinematics of the NLAs indicate that the cloud surface is expanding. The decompression of entrained, milli-Gauss magnetic fields may be responsible for the re-expansion of the surface layers of G0.253+0.016 as it recedes from the Galactic center following a close encounter with Sgr A.

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Pre-main-sequence isochrones – III. The Cluster Collaboration isochrone server

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We present an isochrone server for semi-empirical pre-main-sequence model isochrones in the following systems: Johnson-Cousins, Sloan Digital Sky Survey, Two-Micron All-Sky Survey, Isaac Newton Telescope (INT) Wide-Field Camera, and INT Photometric Hα Survey (IPHAS)/UV-Excess Survey (UVEX). The server can be accessed via the Cluster Collaboration webpage http://www.astro.ex.ac.uk/people/timn/isochrones/. To achieve this we have used the observed colours of member stars in young clusters with well-established age, distance and reddening to create fiducial loci in the colour-magnitude diagram. These empirical sequences have been used to quantify the discrepancy between the models and data arising from uncertainties in both the interior and atmospheric models, resulting in tables of semi-empirical bolometric corrections (BCs) in the various photometric systems. The model isochrones made available through the server are based on existing stellar interior models coupled with our newly derived semi-empirical BCs.
As part of this analysis we also present new cluster parameters for both the Pleiades and Praesepe, yielding ages of 135^{+20}_{-11} and 665^{+14}_{-7} Myr as well as distances of 132 ± 2 and 184 ± 2 pc respectively (statistical uncertainty only).

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Detection of a branched alkyl molecule in the interstellar medium: *iso*-propyl cyanide

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The largest noncyclic molecules detected in the interstellar medium (ISM) are organic with a straight-chain carbon backbone. We report an interstellar detection of a branched alkyl molecule, *iso*-propyl cyanide (i-C_3H_7CN), with an abundance 0.4 times that of its straight-chain structural isomer. This detection suggests that branched carbon-chain molecules may be generally abundant in the ISM. Our astrochemical model indicates that both isomers are produced within or upon dust grain ice mantles through the addition of molecular radicals, albeit via differing reaction pathways. The production of *iso*-propyl cyanide appears to require the addition of a functional group to a non-terminal carbon in the chain. Its detection therefore bodes well for the presence in the ISM of amino acids, for which such side-chain structure is a key characteristic.

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Carbon in different phases ([CII], [CI], and CO) in infrared dark clouds: Cloud formation signatures and carbon gas fractions

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Context. How molecular clouds form out of the atomic phase and what the relative fractions of carbon are in the ionized, atomic, and molecular phase are questions at the heart of cloud and star formation.
Aims. We want to understand the kinematic processes of gas flows during the formation of molecular clouds. In addition to that, we aim at determining the abundance ratios of carbon in its various gas phases from the ionized to

the molecular form.
Methods. Using multiple observatories from Herschel and SOFIA to APEX and the IRAM 30 m telescope, we mapped the ionized and atomic carbon as well as carbon monoxide ([CII] at 1900 GHz, [CI] at 492 GHz, and $C^{18}O(2–1)$ at 220 GHz) at high spatial resolution ($12'' - 25''$) in four young massive infrared dark clouds (IRDCs).
Results. The three carbon phases were successfully mapped in all four regions, only in one source does the [CII] line remain a non-detection. With these data, we dissect the spatial and kinematic structure of the four IRDCs and determine the abundances of gas phase carbon in its ionized, atomic, and most abundant molecular form (CO). Both the molecular and atomic phases trace the dense structures well, with [CI] also tracing material at lower column densities. [CII] exhibits diverse morphologies in our sample from compact to diffuse structures, probing the cloud environment. In at least two out of the four regions, we find kinematic signatures strongly indicating that the dense gas filaments have formed out of a dynamically active and turbulent atomic and molecular cloud, potentially from converging gas flows. The atomic carbon-to-CO gas mass ratios are low between 7% and 12% with the lowest values found toward the most quiescent region. In the three regions where [CII] is detected, its mass is always higher by a factor of a few than that of the atomic carbon. While the ionized carbon emission depends on the radiation field, we also find additional signatures that indicate that other processes, for example, energetic gas flows can contribute to the [CII] excitation as well.
Conclusions. Combining high-resolution maps in the different carbon phases reveals the dynamic interplay of the various phases of the interstellar medium during cloud formation. Extending these studies to more evolved stages and combining the observations with molecular cloud formation simulations including the chemistry and radiative transfer will significantly improve our understanding of the general interstellar medium, cloud and star formation processes.

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http://www.mpia.de/homes/beuther/papers.html
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On the accretion properties of young stellar objects in the L1615/L1616 cometary cloud

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We present the results of FLAMES/UVES and FLAMES/GIRAFFE spectroscopic observations of 23 low-mass stars in the L1615/L1616 cometary cloud, complemented with FORS2 and VIMOS spectroscopy of 31 additional stars in the same cloud. L1615/L1616 is a cometary cloud where the star formation was triggered by the impact of the massive stars in the Orion OB association. From the measurements of the lithium abundance and radial velocity, we confirm the membership of our sample to the cloud. We use the equivalent widths of the Hα, Hβ, and the HeI λ5876, λ6678, λ7065 Å emission lines to calculate the accretion luminosities, $L_{\rm acc}$, and the mass accretion rates, $\dot{M}_{\rm acc}$. We find in L1615/L1616 a fraction of accreting objects ($\sim$ 30%), which is consistent with the typical fraction of accretors in T associations of similar age ($\sim$ 3 Myr). The mass accretion rate for these stars shows a trend with the mass of the central object similar to that found for other star-forming regions, with a spread at a given mass which depends on the evolutionary model used to derive the stellar mass. Moreover, the behavior of the $2MASS/WISE$ colors with $\dot{M}_{\rm acc}$ indicates that strong accretors with $\log \dot{M}_{\rm acc} \gtrsim -8.5$ dex show large excesses in the JHKs bands, as in previous studies. We also conclude that the accretion properties of the L1615/L1616 members are similar to those of young stellar objects in T associations, like Lupus.

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Resolving the shocked gas in HH 54 with *Herschel*: CO line mapping at high spatial and spectral resolution

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The HH 54 shock is a Herbig-Haro object, located in the nearby Chamaeleon II cloud. Observed CO line profiles are due to a complex distribution in density, temperature, velocity, and geometry. Resolving the HH 54 shock wave in the far-infrared cooling lines of CO constrain the kinematics, morphology, and physical conditions of the shocked region. We used the PACS and SPIRE instruments on board the *Herschel* space observatory to map the full FIR spectrum in a region covering the HH 54 shock wave. Complementary *Herschel*-HIFI, APEX, and *Spitzer* data are used in the analysis as well. The observed features in the line profiles are reproduced using a 3D radiative transfer model of a bow-shock, constructed with the Line Modeling Engine code (LIME). The FIR emission is confined to the HH 54 region and a coherent displacement of the location of the emission maximum of CO with increasing J is observed. The peak positions of the high-J CO lines are shifted upstream from the lower J CO lines and coincide with the position of the spectral feature identified previously in CO (10−9) profiles with HIFI. This indicates a hotter molecular component in the upstream gas with distinct dynamics. The coherent displacement with increasing J for CO is consistent with a scenario where IRAS12500 − 7658 is the exciting source of the flow, and the 180 K bow-shock is accompanied by a hot (800 K) molecular component located upstream from the apex of the shock and blueshifted by -7 km s^{-1}. The spatial proximity of this knot to the peaks of the atomic fine-structure emission lines observed with *Spitzer* and PACS ([O I]63, 145μm) suggests that it may be associated with the dissociative shock as the jet impacts slower moving gas in the HH 54 bow-shock.

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Variations of the stellar initial mass function in the progenitors of massive early-type galaxies and in extreme starburst environments

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We examine variations of the stellar initial mass function (IMF) in extreme environments within the formalism derived by Hennebelle & Chabrier. We focus on conditions encountered in progenitors of massive early type galaxies and starburst regions. We show that, when applying the concept of turbulent Jeans mass as the characteristic mass for fragmentation in a turbulent medium, instead of the standard thermal Jeans mass for purely gravitational fragmentation, the peak of the IMF in such environments is shifted towards smaller masses, leading to a bottom-heavy IMF, as suggested by various observations. In very dense and turbulent environments, we predict that the high-mass tail of the IMF can even become steeper than the standard Salpeter IMF, with a limit for the power law exponent $\alpha \simeq -2.7$, in agreement with recent observational determinations. This steepening is a direct consequence of the high densities and Mach values in such regions but also of the time dependence of the fragmentation process, as incorporated in

the Hennebelle-Chabrier theory. We provide analytical parametrizations of the IMF, to be used in galaxy evolution calculations. We also calculate the star formation rates and the mass-to-light ratios expected under such extreme conditions and show that they agree well with the values inferred in starburst environments and massive high-redshift galaxies. This reinforces the paradigm of star formation as being a universal process, i.e. the direct outcome of gravitationally unstable fluctuations in a density field initially generated by large scale shock-dominated turbulence. This globally enables us to infer the variations of the stellar IMF and related properties for atypical galactic conditions.

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Exclusion of Cosmic Rays in Protoplanetary Disks. II. Chemical Gradients and Observational Signatures

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The chemical properties of protoplanetary disks are especially sensitive to their ionization environment. Sources of molecular gas ionization include cosmic rays, stellar X-rays and short-lived radionuclides, each of which varies with location in the disk. This behavior leads to a significant amount of chemical structure, especially in molecular ion abundances, which is imprinted in their submillimeter rotational line emission. Using an observationally motivated disk model, we make predictions for the dependence of chemical abundances on the assumed properties of the ionizing field. We calculate the emergent line intensity for abundant molecular ions and simulate sensitive observations with the Atacama Large Millimeter/Sub-millimeter Array (ALMA) for a disk at D=100 pc. The models readily distinguish between high ionization rates ($\zeta \geq 10^{-17}$ s^{-1} per H_2) and below, but it becomes difficult to distinguish between low ionization models when $\zeta \leq 10^{-19}$ s^{-1}. We find that H_2D^+ emission is not detectable for sub-interstellar CR rates with ALMA (6h integration), and that N_2D^+ emission may be a more sensitive tracer of midplane ionization. HCO^+ traces X-rays and high CR rates ($\zeta_{\rm CR} \geq 10^{-17}$ s^{-1}), and provides a handle on the warm molecular ionization properties where CO is present in the gas. Furthermore, species like HCO^+, which emits from a wide radial region and samples a large gradient in temperature, can exhibit ring-like emission as a consequence of low-lying rotational level de-excitation near the star. This finding highlights a scenario where rings are not necessarily structural or chemical in nature, but simply a result of the underlying line excitation properties.

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The Structure, Dynamics and Star Formation Rate of the Orion Nebula Cluster

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The spatial morphology and dynamical status of a young, still-forming stellar cluster provide valuable clues on the conditions during the star formation event and the processes that regulated it. We analyze the Orion Nebula Cluster (ONC), utilizing the latest censuses of its stellar content and membership estimates over a large wavelength range. We determine the center of mass of the ONC, and study the radial dependence of angular substructure. The core appears rounder and smoother than the outskirts, consistent with a higher degree of dynamical processing. At larger distances the departure from circular symmetry is mostly driven by the elongation of the system, with very little additional substructure, indicating a somewhat evolved spatial morphology or an expanding halo. We determine the mass density profile of the cluster, which is well fitted by a power law that is slightly steeper than a singular isothermal sphere. Together with the ISM density, estimated from average stellar extinction, the mass content of the ONC is insufficient by a factor ~ 1.8 to reproduce the observed velocity dispersion from virialized motions, in agreement with

previous assessments that the ONC is moderately supervirial. This may indicate recent gas dispersal. Based on the latest estimates for the age spread in the system and our density profiles, we find that, at the half-mass radius, 90% of the stellar population formed within $\sim$ 5–8 free-fall times ($t_{\rm ff}$). This implies a star formation efficiency per $t_{\rm ff}$ of $\epsilon_{\rm ff} \sim 0.04$–0.07, i.e., relatively slow and inefficient star formation rates during star cluster formation.

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Macroscopic Dust in Protoplanetary Disks - From Growth to Destruction

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The collision dynamics of dusty bodies are crucial for planetesimal formation. Especially decimeter agglomerates are important in the different formation models. Therefore, in continuation of our experiments on mutual decimeter collisions, we investigate collisions of centimeter onto decimeter dust agglomerates in a small drop tower under vacuum conditions ($p < 5 \times 10^{-1}$ mbar) at a mean collision velocity of 6.68±0.67 m s^{-1}. We use quartz dust with irregularly shaped micrometer grains. Centimeter projectiles with different diameters, masses and heights are used, their typical volume filling factor is $\Phi_{p,m} = 0.466 \pm 0.02$. The decimeter agglomerates have a mass of about 1.5 kg, a diameter and height of 12 cm and a mean filling factor of $\Phi_{t,m} = 0.44 \pm 0.004$. At lower collision energies only the projectile gets destroyed and mass is transferred to the target. The accretion efficiency decreases with increasing obliquity and increasing difference in filling factor, if the projectile is more compact than the target. The accretion efficiency increases with increasing collision energy for collision energies under a certain threshold. Beyond this threshold at 298±25 mJ catastrophic disruption of the target can be observed. This corresponds to a critical fragmentation strength $Q^* = 190 \pm 16$ mJ kg^{-1}, which is a factor of four larger than expected. Analyses of the projectile fragments show a power law size distribution with average exponent of -3.8 ± 0.3. The mass distributions suggest that the fraction of smallest fragments increases for higher collision energies. This is interesting for impacts of small particle on large target bodies within protoplanetary disks, as smaller fragments couple better to the surrounding gas and re-accretion by gas drag is more likely.

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The extinction law inside the 30 Doradus nebula

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We have studied the interstellar extinction in a field of $\sim 3' \times 3'$ at the core of the 30 Doradus nebula, including the central R 136 cluster, in the Large Magellanic Cloud. Observations at optical and near-infrared wavelengths, obtained with the WFC 3 camera on board the *Hubble Space Telescope*, show that the stars belonging to the red giant clump are spread across the colour–magnitude diagrams because of the considerable and uneven levels of extinction in this region. Since these stars share very similar physical properties and are all at the same distance, they allow us to derive the absolute extinction in a straightforward and reliable way. Thus we have measured the extinction towards about 180 objects and the extinction law in the range $0.3 - 1.6\,\mu$m. At optical wavelengths, the extinction curve is almost parallel to that of the diffuse Galactic interstellar medium. Taking the latter as a template, the value of $R_V = 4.5 \pm 0.2$ that we measure indicates that in the optical there is an extra grey component due to a larger fraction of large grains. At wavelengths longer than $\sim 1\,\mu$m, the contribution of this additional component tapers off as $\lambda^{-1.5}$, like in the Milky Way, suggesting that the nature of the grains is otherwise similar to those in our Galaxy, but with a ~ 2.2 times higher fraction of large grains. These results are consistent with the addition of "fresh" large grains by supernova explosions, as recently revealed by *Herschel* and *ALMA* observations of SN 1987A.

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How to Detect the Signatures of Self-Gravitating Circumstellar Discs with the Atacama Large Millimetre/sub-millimetre Array

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In this paper we present simulated Atacama Large Millimetre/sub-millimetre Array (ALMA) observations of self-gravitating circumstellar discs with different properties in size, mass and inclination, located in four of the most extensively studied and surveyed star-forming regions. Starting from a Smoothed Particle Hydrodynamics (SPH) simulation and representative dust opacities, we have initially constructed maps of the expected emission at sub-mm wavelengths of a large sample of discs with different properties. We have then simulated realistic observations of discs as they may appear with ALMA using the Common Astronomy Software Application ALMA simulator. We find that, with a proper combination of antenna configuration and integration time, the spiral structure characteristic of self-gravitating discs is readily detectable by ALMA over a wide range of wavelengths at distances comparable to TW Hydrae (∼50 pc), Taurus - Auriga and Ophiucus (∼140 pc) star-forming regions. However, for discs located in Orion complex (∼400 pc) only the largest discs in our sample (outer radius of 100 AU) show a spatially resolved structure while the smaller ones (outer radius of 25 AU) are characterized by a spiral structure that is not conclusively detectable with ALMA.

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Methanol Along the Path from Envelope to Protoplanetary Disc

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Interstellar methanol is considered to be a parent species of larger, more complex organic molecules. A physicochemical simulation of infalling parcels of matter is performed for a low-mass star-forming system to trace the chemical evolution from cloud to disc. An axisymmetric 2D semi-analytic model generates the time-dependent density and velocity distributions, and full continuum radiative transfer is performed to calculate the dust temperature and the UV radiation field at each position as a function of time. A comprehensive gas-grain chemical network is employed to compute the chemical abundances along infall trajectories. Two physical scenarios are studied, one in which the dominant disc growth mechanism is viscous spreading, and another in which continuous infall of matter prevails. The results show that the infall path influences the abundance of methanol entering each type of disc, ranging from complete loss of methanol to an enhancement by a factor of >1 relative to the prestellar phase. Critical chemical processes and parameters for the methanol chemistry under different physical conditions are identified. The exact abundance and distribution of methanol is important for the budget of complex organic molecules in discs, which will be incorporated into forming planetary system objects such as protoplanets and comets. These simulations show that the comet-forming zone contains less methanol than in the precollapse phase, which is dominantly of prestellar origin, but also with additional layers built up in the envelope during infall. Such intriguing links will soon be tested by upcoming data from the Rosetta mission.

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CO/H_2 Abundance Ratio $\sim 10^{-4}$ in a Protoplanetary Disk

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The relative abundances of atomic and molecular species in planet-forming disks around young stars provide important constraints on photochemical disk models and provide a baseline for calculating disk masses from measurements of trace species. A knowledge of absolute abundances, those relative to molecular hydrogen (H_2), are challenging because of the weak rovibrational transition ladder of H_2 and the inability to spatially resolve different emission components within the circumstellar environment. To address both of these issues, we present new contemporaneous measurements of CO and H_2 absorption through the "warm molecular layer" of the protoplanetary disk around the Classical T Tauri Star RW Aurigae A. We use a newly commissioned observing mode of the Hubble Space Telescope-Cosmic Origins Spectrograph to detect warm H_2 absorption in this region for the first time. An analysis of the emission and absorption spectrum of RW Aur shows components from the accretion region near the stellar photosphere, the molecular disk, and several outflow components. The warm H_2 and CO absorption lines are consistent with a disk origin. We model the 1092–1117 Å spectrum of RW Aur to derive $\log_{10} N(H_2) = 19.90^{+0.33}_{-0.22}$ cm^{-2} at $T_{\rm rot}(H_2) = 440 \pm 39$ K. The CO A–X bands observed from 1410–1520 Å are best fit by $\log_{10} N({\rm CO}) = 16.1^{+0.3}_{-0.5}$ cm^{-2} at $T_{\rm rot}({\rm CO}) = 200^{+650}_{-125}$ K. Combining direct measurements of the HI, H_2, and CO column densities, we find a molecular fraction in the warm disk surface of $f_{H_2} \geq 0.47$ and derive a molecular abundance ratio of $CO/H_2 = 1.6^{+4.7}_{-1.3} \times 10^{-4}$, both consistent with canonical interstellar dense cloud values.

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Constraints on photoevaporation models from (lack of) radio emission in the Corona Australis protoplanetary disks

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Photoevaporation due to high-energy stellar photons is thought to be one of the main drivers of protoplanetary disk dispersal. The fully or partially ionized disk surface is expected to produce free-free continuum emission at centimeter (cm) wavelengths that can be routinely detected with interferometers such as the upgraded Very Large Array (VLA). We use deep (rms noise down to 8 μJy beam^{-1} in the field of view center) 3.5 cm maps of the nearby (130 pc) Corona Australis (CrA) star formation (SF) region to constrain disk photoevaporation models. We find that the radio emission from disk sources in CrA is surprisingly faint. Only 3 out of 10 sources within the field of view are detected, with flux densities of order 10^2 μJy. However, a significant fraction of their emission is non-thermal. Typical upper limits for non-detections are $3\sigma \sim 60$ μJy beam^{-1}. Assuming analytic expressions for the free-free emission from extreme-UV (EUV) irradiation, we derive stringent upper limits to the ionizing photon luminosity impinging on the disk surface $\Phi_{\rm EUV} < 1 - 4 \times 10^{41}$ s^{-1}. These limits constrain $\Phi_{\rm EUV}$ to the low end of the values needed by EUV-driven photoevaporation models to clear protoplanetary disks in the observed few Myr timescale. Therefore, at least in CrA, EUV-driven photoevaporation is not likely to be the main agent of disk dispersal. We also compare the observed X-ray luminosities L_X of disk sources with models in which photoevaporation is driven by such photons. Although predictions are less specific than for the EUV case, most of the observed fluxes (upper limits) are roughly consistent with the (scaled) predictions. Deeper observations, as well as predictions spanning a wider parameter space, are needed to properly test X-ray driven photoevaporation.

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Astrometric follow-up observations of directly imaged sub-stellar companions to young stars and brown dwarfs

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The formation of massive planetary or brown dwarf companions at large projected separations from their host star is not yet well understood. In order to put constraints on formation scenarios we search for signatures in the orbit dynamics of the systems. We are specifically interested in the eccentricities and inclinations since those parameters might tell us about the dynamic history of the systems and where to look for additional low-mass sub-stellar companions. For this purpose we utilized VLT/NACO to take several well calibrated high resolution images of 6 target systems and analyze them together with available literature data points of those systems as well as Hubble Space Telescope archival data. We used a statistical Least-Squares Monte-Carlo approach to constrain the orbit elements of all systems that showed significant differential motion of the primary star and companion. We show for the first time that the GQ Lup system shows significant change in both separation and position angle. Our analysis yields best fitting orbits for this system, which are eccentric (e between 0.21 and 0.69), but can not rule out circular orbits at high inclinations. Given our astrometry we discuss formation scenarios of the GQ Lup system. In addition, we detected an even fainter new companion candidate to GQ Lup, which is most likely a background object. We also updated the orbit constraints of the PZ Tel system, confirming that the companion is on a highly eccentric orbit with $e > 0.62$. Finally we show with a high significance, that there is no orbital motion observed in the cases of the DH Tau, HD 203030 and 1RXS J160929.1−210524 systems and give the most precise relative astrometric measurement of the UScoCTIO 108 system to date.

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On the filtering and processing of dust by planetesimals 1. Derivation of collision probabilities for non-drifting planetesimals

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Context. Circumstellar disks are known to contain a significant mass in dust ranging from micron to centimeter size.

Meteorites are evidence that individual grains of those sizes were collected and assembled into planetesimals in the young solar system.
Aims. We assess the efficiency of dust collection of a swarm of non-drifting planetesimals with radii ranging from 1 to 10^3 km and beyond.
Methods. We calculate the collision probability of dust drifting in the disk due to gas drag by planetesimal accounting for several regimes depending on the size of the planetesimal, dust, and orbital distance: the geometric, Safronov, settling, and three-body regimes. We also include a hydrodynamical regime to account for the fact that small grains tend to be carried by the gas flow around planetesimals.
Results. We provide expressions for the collision probability of dust by planetesimals and for the filtering efficiency by a swarm of planetesimals. For standard turbulence conditions (i.e., a turbulence parameter $\alpha = 10^{-2}$), filtering is found to be inefficient, meaning that when crossing a minimum-mass solar nebula (MMSN) belt of planetesimals extending between 0.1 AU and 35 AU most dust particles are eventually accreted by the central star rather than colliding with planetesimals. However, if the disk is weakly turbulent ($\alpha = 10^{-4}$) filtering becomes efficient in two regimes: (i) when planetesimals are all smaller than about 10 km in size, in which case collisions mostly take place in the geometric regime; and (ii) when planetary embryos larger than about 1000 km in size dominate the distribution, have a scale height smaller than one tenth of the gas scale height, and dust is of millimeter size or larger in which case most collisions take place in the settling regime. These two regimes have very different properties: we find that the local filtering efficiency $x_{\rm filter,MMSN}$ scales with $r^{-7/4}$ (where r is the orbital distance) in the geometric regime, but with $r^{-1/4}$ to $r^{1/4}$ in the settling regime. This implies that the filtering of dust by small planetesimals should occur close to the central star and with a short spread in orbital distances. On the other hand, the filtering by embryos in the settling regime is expected to be more gradual and determined by the extent of the disk of embryos. Dust particles much smaller than millimeter size tend only to be captured by the smallest planetesimals because they otherwise move on gas streamlines and their collisions take place in the hydrodynamical regime.
Conclusions. Our results hint at an inside-out formation of planetesimals in the infant solar system because small planetesimals in the geometrical limit can filter dust much more efficiently close to the central star. However, even a fully-formed belt of planetesimals such as the MMSN only marginally captures inward-drifting dust and this seems to imply that dust in the protosolar disk has been filtered by planetesimals even smaller than 1 km (not included in this study) or that it has been assembled into planetesimals by other mechanisms (e.g., orderly growth, capture into vortexes). Further refinement of our work concerns, among other things: a quantitative description of the transition region between the hydro and settling regimes; an assessment of the role of disk turbulence for collisions, in particular in the hydro regime; and the coupling of our model to a planetesimal formation model.

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Slow ionized wind and rotating disklike system associated with the high-mass young stellar object G345.4938+01.4677

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We report the detection, made using ALMA, of the 92 GHz continuum and hydrogen recombination lines (HRLs) H40α, H42α, and H50β emission toward the ionized wind associated with the high-mass young stellar object G345.4938+01.4677. This is the luminous central dominating source located in the massive and dense molecular clump associated with IRAS 16562−3959. The HRLs exhibit Voigt profiles, a strong signature of Stark broadening. We successfully reproduce the observed continuum and HRLs simultaneously using a simple model of a slow ionized wind in local thermody-

namic equilibrium, with no need a high-velocity component. The Lorentzian line wings imply electron densities of 5×10^7 cm^{-3} on average. In addition, we detect SO and SO_2 emission arising from a compact ($\sim$ 3000 AU) molecular core associated with the central young star. The molecular core exhibits a velocity gradient perpendicular to the jet-axis, which we interpret as evidence of rotation. The set of observations toward G345.4938+01.4677 are consistent with it being a young high-mass star associated with a slow photo-ionized wind.

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Investigating the inner discs of Herbig Ae/Be stars with CO bandhead and Br γ emission

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Herbig Ae/Be stars lie in the mass range between low and high mass young stars, and therefore offer a unique opportunity to observe any changes in the formation processes that may occur across this boundary. This paper presents medium resolution VLT/X-Shooter spectra of six Herbig Ae/Be stars, drawn from a sample of 91 targets, and high resolution VLT/CRIRES spectra of five Herbig Ae/Be stars, chosen based on the presence of CO first overtone bandhead emission in their spectra. The X-Shooter survey reveals a low detection rate of CO first overtone emission (7 per cent), consisting of objects mainly of spectral type B. A positive correlation is found between the strength of the CO $v = 2$–0 and Br γ emission lines, despite their intrinsic linewidths suggesting a separate kinematic origin. The high resolution CRIRES spectra are modelled, and are well fitted under the assumption that the emission originates from small scale Keplerian discs, interior to the dust sublimation radius, but outside the co-rotation radius of the central stars. In addition, our findings are in very good agreement for the one object where spatially resolved near-infrared interferometric studies have also been performed. These results suggest that the Herbig Ae/Be stars in question are in the process of gaining mass via disc accretion, and that modelling of high spectral resolution spectra is able to provide a reliable probe into the process of stellar accretion in young stars of intermediate to high masses.

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Diversity of chemistry and excitation conditions in the high-mass star forming complex W33

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The object W33 is a giant molecular cloud that contains star forming regions at various evolutionary stages from quiescent clumps to developed HII regions. Since its star forming regions are located at the same distance and the primary material of the birth clouds is probably similar, we conducted a comparative chemical study to trace the chemical footprint of the different phases of evolution. We observed six clumps in W33 with the Atacama Pathfinder Experiment (APEX) telescope at 280 GHz and the Submillimeter Array (SMA) at 230 GHz. We detected 27 transitions of 10 different molecules in the APEX data and 52 transitions of 16 different molecules in the SMA data. The chemistry on scales larger than ∼0.2 pc, which are traced by the APEX data, becomes more complex and diverse the more evolved the star forming region is. On smaller scales traced by the SMA data, the chemical complexity and diversity increase up to the hot core stage. In the HII region phase, the SMA spectra resemble the spectra of the protostellar phase. Either these more complex molecules are destroyed or their emission is not compact enough to be detected with the SMA. Synthetic spectra modelling of the H_2CO transitions, as detected with the APEX telescope, shows that both a warm and a cold component are needed to obtain a good fit to the emission for all sources except for W33 Main1. The temperatures and column densities of the two components increase during the evolution of the star forming regions. The integrated intensity ratios $N_2H^+(3-2)/CS(6-5)$ and $N_2H^+(3-2)/H_2CO(4_{2,2}-3_{2,1})$ show clear trends as a function of evolutionary stage, luminosity, luminosity-to-mass ratio, and H_2 peak column density of the clumps and might be usable as chemical clocks.

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An Improved Determination of the Lithium Depletion Boundary Age of Blanco 1 and a First Look on the Effects of Magnetic Activity

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The Lithium Depletion Boundary (LDB) is a robust method for accurately determining the ages of young clusters, but most pre-main-sequence models used to derive LDB ages do not include the effects of magnetic activity on stellar properties. In light of this, we present results from our spectroscopic study of the very low-mass members of the southern open cluster Blanco 1 using the Gemini-North telescope, program IDs: GN-2009B-Q-53 and GN-2010B-Q-96. We obtained GMOS spectra at intermediate resolution for cluster candidate members with $I \approx$ 13–20 mag. From our sample of 43 spectra, we find 14 probable cluster members by considering proximity to the cluster sequence in an $I/I{-}K_s$ color-magnitude diagram, agreement with the cluster's systemic radial velocity, and magnetic activity as a youth indicator. We systematically analyze the Hα and Li features and update the LDB age of Blanco 1 to be 126^{+13}_{-14} Myr. Our new LDB age for Blanco 1 shows remarkable coevality with the benchmark Pleiades open cluster. Using available empirical activity corrections, we investigate the effects of magnetic activity on the LDB age of Blanco 1. Accounting for activity, we infer a corrected LDB age of 114^{+9}_{-10} Myr. This work demonstrates the importance of accounting for magnetic activity on LDB inferred stellar ages, suggesting the need to re-investigate previous LDB age determinations.

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Shockingly low water abundances in *Herschel* / PACS observations of low-mass protostars in Perseus

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Context Protostars interact with their surroundings through jets and winds impinging on the envelope and creating shocks, but the nature of these shocks is still poorly understood.
Aims Our aim is to survey far-infrared molecular line emission from a uniform and significant sample of deeply-embedded low-mass young stellar objects (YSOs) in order to characterize shocks and the possible role of ultraviolet radiation in the immediate protostellar environment.
Methods Herschel/PACS spectral maps of 22 objects in the Perseus molecular cloud were obtained as part of the William Herschel Line Legacy (WILL) survey. Line emission from H_2O, CO, and OH is tested against shock models from the literature.
Results Observed line ratios are remarkably similar and do not show variations with physical parameters of the sources (luminosity, envelope mass). Most ratios are also comparable to those found at off-source outflow positions. Observations show good agreement with the shock models when line ratios of the same species are compared. Ratios of various H_2O lines provide a particularly good diagnostic of pre-shock gas densities, $n_{\rm H} \sim 10^5$ cm^{-3}, in agreement with typical densities obtained from observations of the post-shock gas when a compression factor on the order of 10 is applied (for non-dissociative shocks). The corresponding shock velocities, obtained from comparison with CO line ratios, are above 20 km s^{-1}. However, the observations consistently show H_2O-to-CO and H_2O-to-OH line ratios that are one to two orders of magnitude lower than predicted by the existing shock models.
Conclusions The overestimated model H_2O fluxes are most likely caused by an overabundance of H_2O in the models since the excitation is well-reproduced. Illumination of the shocked material by ultraviolet photons produced either in the star-disk system or, more locally, in the shock, would decrease the H_2O abundances and reconcile the models with observations. Detections of hot H_2O and strong OH lines support this scenario.

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How does a low-mass cut-off in the stellar IMF affect the evolution of young star clusters?

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We investigate how different stellar initial mass functions (IMFs) can affect the mass loss and survival of star clusters. We find that IMFs with radically different low-mass cut-offs (between 0.1 and 2 $M_{\odot}$) do not change cluster destruction time-scales as much as might be expected. Unsurprisingly, we find that clusters with more high-mass stars lose relatively more mass through stellar evolution, but the response to this mass loss is to expand and hence significantly slow their dynamical evolution. We also argue that it is very difficult, if not impossible, to have clusters with different IMFs that are initially "the same", since the mass, radius and relaxation times depend on each other and on the IMF in a complex way. We conclude that changing the IMF to be biased towards more massive stars does speed up mass loss and dissolution, but that it is not as dramatic as might be thought.

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Signatures of massive collisions in debris discs

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Violent stochastic collisional events have been invoked as a possible explanation for some debris discs displaying pronounced azimuthal asymmetries or having a luminosity excess exceeding that expected for systems at collisional steady-state. So far, no thorough modelling of the consequences of such stochastic events has been carried out, mainly because of the extreme numerical challenge of coupling the dynamical and collisional evolution of the released dust.
We perform the first fully self-consistent modelling of the aftermath of massive breakups in debris discs. We follow the collisional and dynamical evolution of dust released after the breakup of a Ceres-sized body at 6 AU from its central star. We investigate the duration, magnitude and spatial structure of the signature left by such a violent event, as well as its observational detectability.
We use the recently developed LIDT-DD code (Kral et al., 2013), which handles the coupled collisional and dynamical evolution of debris discs. The main focus is placed on the complex interplay between destructive collisions, Keplerian dynamics and radiation pressure forces. We use the GRaTer package to estimate the system's luminosity at different wavelengths.
The breakup of a Ceres-sized body at 6 AU creates an asymmetric dust disc that is homogenized, by the coupled action of collisions and dynamics, on a timescale of a few 10^5 years. The particle size distribution in the system, after a transient period where it is very steep, relaxes to a collisional steady-state law after $\sim 10^4$ years. The luminosity excess in the breakup's aftermath should be detectable by mid-IR photometry, from a 30 pc distance, over a period of $\sim 10^6$ years that exceeds the duration of the asymmetric phase of the disc (a few 10^5 years). As for the asymmetric structures, we derive synthetic images for the SPHERE/VLT and MIRI/JWST instruments, showing that they should be clearly visible and resolved from a 10 pc distance. Images at 1.6μm (marginally), 11.4 and 15.5μm would show the inner disc structures while 23μm images would display the outer disc asymmetries.

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Challenges in Forming the Solar System's Giant Planet Cores via Pebble Accretion

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Though $\sim$10 $M_{\oplus}$ rocky/icy cores are commonly held as a prerequisite for the formation of gas giants, theoretical models still struggle to explain how these embryos can form within the lifetimes of gaseous circumstellar disks. In recent years, aerodynamic-aided accretion of "pebbles", objects ranging from centimeters to meters in size, has been

suggested as a potential solution to this long-standing problem. While pebble accretion has been demonstrated to be extremely effective in local simulations that look at the detailed behavior of these pebbles in the vicinity of a single planetary embryo, to date there have been no global simulations demonstrating the effectiveness of pebble accretion in a more complicated, multi-planet environment. Therefore, we have incorporated the aerodynamic-aided accretion physics into LIPAD, a Lagrangian code which can follow the collisional / accretional / dynamical evolution of a protoplanetary system, to investigate the how pebble accretion manifests itself in the larger planet formation picture. We find that under generic circumstances, pebble accretion naturally leads to a "oligarchic" type of growth in which a large population of planetesimals grow to similar sized planets. In particular, our simulations tend to form hundreds of Mars and Earth mass objects between 4 and 10 AU. While merging of some oligarchs may grow massive enough to form giant planet cores, left-over oligarchs lead to planetary systems that cannot be consistent with our own Solar System. We investigate various ideas presented in the literature (including evaporation fronts and planet traps) and find that none easily overcomes this tendency towards oligarchic growth.

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SiO excitation from dense shocks in the earliest stages of massive star formation

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Molecular outflows are a direct consequence of accretion, and therefore they represent one of the best tracers of accretion processes in the still poorly understood early phases of high-mass star formation. Previous studies suggested that the SiO abundance decreases with the evolution of a massive young stellar object probably because of a decay of jet activity, as witnessed in low-mass star-forming regions. We investigate the SiO excitation conditions and its abundance in outflows from a sample of massive young stellar objects through observations of the SiO(8–7) and CO(4–3) lines with the APEX telescope. Through a non-LTE analysis, we find that the excitation conditions of SiO increase with the velocity of the emitting gas. We also compute the SiO abundance through the SiO and CO integrated intensities at high velocities. For the sources in our sample we find no significant variation of the SiO abundance with evolution for a bolometric luminosity-to-mass ratio of between 4 and 50 $L_\odot/M_\odot$. We also find a weak increase of the SiO(8–7) luminosity with the bolometric luminosity-to-mass ratio. We speculate that this might be explained with an increase of density in the gas traced by SiO. We find that the densities constrained by the SiO observations require the use of shock models that include grain-grain processing. For the first time, such models are compared and found to be compatible with SiO observations. A pre-shock density of 10^5 cm^{-3} is globally inferred from these comparisons. Shocks with a velocity higher than 25 km s^{-1} are invoked for the objects in our sample where the SiO is observed with a corresponding velocity dispersion. Our comparison of shock models with observations suggests that sputtering of silicon-bearing material (corresponding to less than 10% of the total silicon abundance) from the grain mantles is occurring.

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The Immediate Environments of Two Herbig Be Stars: MWC 1080 and HD 259431

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Deep mid-infrared (10–20 μm) images with sub-arcsec resolution were obtained for two Herbig Be stars, MWC 1080 and HD 259431, to probe their immediate environments. Our goal is to understand the origin of the diffuse nebulosities observed around these two very young objects. By analyzing our new mid-IR images and comparing them to published data at other wavelengths, we demonstrate that the well extended emission around MWC 1080 traces neither a disk nor an envelope, but rather the surfaces of a cavity created by the outflow from MWC 1080A, the primary star of the MWC 1080 system. In the N-band images, the filamentary nebulosities trace the hourglass-shaped gas cavity wall out to ∼0.15 pc. This scenario reconciles the properties of the MWC 1080 system revealed by a wide range of observations. Our finding confirms that the environment around MWC 1080, where a small cluster is forming, is strongly affected by the outflow from the central Herbig Be star. Similarities observed between the two subjects of this study suggest that the filamentary emission around HD 259431 may arise from a similar outflow cavity structure, too.

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X-ray emission from an FU Ori star in early outburst: HBC 722

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Aims: We conducted the first X-ray observations of the newly erupting FU Ori-type outburst in HBC 722 (V2493 Cyg) with the aim to characterize its X-ray behavior and near-stellar environment during early outburst.
Methods: We used data from the XMM-Newton and Chandra X-ray observatories to measure X-ray source temperatures and luminosities as well as the gas column densities along the line of sight toward the source.
Results: We report a Chandra X-ray detection of HBC 722 with an X-ray luminosity of LX 4E30 erg s-1. The gas column density exceeds values expected from optical extinction and standard gas-to-dust ratios. We conclude that dust-free gas masses are present around the star, such as strong winds launched from the inner disk, or massive accretion columns. A tentative detection obtained by XMM-Newton two years earlier after an initial optical peak revealed a fainter X-ray source with only weak absorption.

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On the age of the β Pictoris moving group

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Jeffries & Binks (2014) and Malo et al. (2014) have recently reported Li depletion boundary (LDB) ages for the β Pictoris moving group (BPMG) which are twice as old as the oft-cited kinematic age of ~ 12 Myr. In this study we present (1) a new evaluation of the internal kinematics of the BPMG using the revised *Hipparcos* astrometry and best available published radial velocities, and assess whether a useful kinematic age can be derived, and (2) derive an isochronal age based on the placement of the A-, F- and G-type stars in the colour-magnitude diagram (CMD). We explore the kinematics of the BPMG looking at velocity trends along Galactic axes, and conducting traceback analyses assuming linear trajectories, epicyclic orbit approximation, and orbit integration using a realistic gravitational potential. None of the methodologies yield a kinematic age with small uncertainties using modern velocity data. Expansion in the Galactic X and Y directions is significant only at the 1.7σ and 2.7σ levels, and together yields an overall kinematic age with a wide range ($13-58$ Myr; 95 per cent CL). The A-type members are all on the zero age-main-sequence, suggestive of an age of > 20 Myr, and the loci of the CMD positions for the late-F- and G-type pre-main-sequence BPMG members have a median isochronal age of 22 Myr ($\pm$ 3 Myr stat., $\pm$ 1 Myr sys.) when considering four sets of modern theoretical isochrones. The results from recent LDB and isochronal age analyses are now in agreement with a median BPMG age of 23 ± 3 Myr (overall 1σ uncertainty, including ± 2 Myr statistical

and ±2 Myr systematic uncertainties).

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The Kozai-Lidov Mechanism in Hydrodynamical Disks

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We use three dimensional hydrodynamical simulations to show that a highly misaligned accretion disk around one component of a binary system can exhibit global Kozai-Lidov cycles, where the inclination and eccentricity of the disk are interchanged periodically. This has important implications for accreting systems on all scales, for example, the formation of planets and satellites in circumstellar and circumplanetary disks, outbursts in X-ray binary systems and accretion on to supermassive black holes.

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Water in star-forming regions with Herschel (WISH) V. The physical conditions in low-mass protostellar outflows revealed by multi-transition water observations

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Context: Outflows are an important part of the star formation process as both the result of ongoing active accretion and one of the main sources of mechanical feedback on small scales. Water is the ideal tracer of these effects because it is present in high abundance for the conditions expected in various parts of the protostar, particularly the outflow.
Aims: To constrain and quantify the physical conditions probed by water in the outflow-jet system for Class 0 and I sources.
Methods: We present velocity-resolved *Herschel* HIFI spectra of multiple water-transitions observed towards 29 nearby Class 0/I protostars as part of the WISH Guaranteed Time Key Programme. The lines are decomposed into different Gaussian components, with each component related to one of three parts of the protostellar system; quiescent envelope, cavity shock and spot shocks in the jet and at the base of the outflow. We then use non-LTE RADEX models to constrain the excitation conditions present in the two outflow-related components.
Results: Water emission at the source position is optically thick but effectively thin, with line ratios that do not vary with velocity, in contrast to CO. The physical conditions of the cavity and spot shocks are similar, with post-shock H_2 densities of order $10^5–10^8\,cm^{-3}$ and H_2O column densities of order $10^{16}–10^{18}\,cm^{-2}$. H_2O emission originates in compact emitting regions: for the spot shocks these correspond to point sources with radii of order 10-200 AU, while for the cavity shocks these come from a thin layer along the outflow cavity wall with thickness of order 1-30 AU.
Conclusions: Water emission at the source position traces two distinct kinematic components in the outflow; J shocks at the base of the outflow or in the jet, and C shocks in a thin layer in the cavity wall. The similarity of the physical conditions is in contrast to off-source determinations which show similar densities but lower column densities and larger filling factors. We propose that this is due to the differences in shock properties and geometry between these positions. Class I sources have similar excitation conditions to Class 0 sources, but generally smaller line-widths and emitting region sizes. We suggest that it is the velocity of the wind driving the outflow, rather than the decrease in envelope density or mass, that is the cause of the decrease in H_2O intensity between Class 0 and I sources.

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Revisiting Jovian-Resonance Induced Chondrule Formation

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It is proposed that planetesimals perturbed by Jovian mean-motion resonances are the source of shock waves that form chondrules. It is considered that this shock-induced chondrule formation requires the velocity of the planetesimal relative to the gas disk to be on the order of > 7 km s^{-1} at 1 AU. In previous studies on planetesimal excitation, the effects of Jovian mean-motion resonance together with the gas drag were investigated, but the velocities obtained were at most 8 km s^{-1} in the asteroid belt, which is insufficient to account for the ubiquitous existence of chondrules. In this paper, we reexamine the effect of Jovian resonances and take into account the secular resonance in the asteroid belt caused by the gravity of the gas disk. We find that the velocities relative to the gas disk of planetesimals a few hundred kilometers in size exceed 12 km s^{-1}, and that this is achieved around the 3:1 mean-motion resonance. The heating region is restricted to a relatively narrow band between 1.5 AU and 3.5 AU. Our results suggest that chondrules were produced effectively in the asteroid region after Jovian formation. We also find that many planetesimals are scattered far beyond Neptune. Our findings can explain the presence of crystalline silicate in comets if the scattered planetesimals include silicate dust processed by shock heating.

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The Mass Budget of Planet Forming Discs: Isolating the Epoch of Planetesimal Formation

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The high rate of planet detection among solar-type stars argues that planet formation is common. It is also generally assumed that planets form in protoplanetary discs like those observed in nearby star forming regions. On what timescale does the transformation from discs to planets occur? Here we show that current inventories of planets and protoplanetary discs are sensitive enough to place basic constraints on the timescale and efficiency of the planet formation process. A comparison of planet detection statistics and the measured solid reservoirs in T Tauri discs suggests that planet formation is likely already underway at the few Myr age of the discs in Taurus-Auriga, with a large fraction of solids having been converted into large objects with low millimeter opacity and/or sequestered at small disc radii where they are difficult to detect at millimeter wavelengths.

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Formation of a Keplerian disk in the infalling envelope around L1527 IRS: transformation from infalling motions to Kepler motions

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We report Atacama Large Millimeter/submillimeter Array (ALMA) cycle 0 observations of $C^{18}O$ ($J = 2-1$), SO ($J_N = 6_5 - 5_4$) and 1.3 mm dust continuum toward L1527 IRS, a class 0 solar-type protostar surrounded by an infalling and rotating envelope. $C^{18}O$ emission shows strong redshifted absorption against the bright continuum emission associated with L1527 IRS, strongly suggesting infall motions in the $C^{18}O$ envelope. The $C^{18}O$ envelope also rotates with a velocity mostly proportional to r^{-1}, where r is the radius, while the rotation profile at the innermost radius (∼54 AU) may be shallower than r^{-1}, suggestive of formation of a Keplerian disk around the central protostar of $\sim 0.3\ M_\odot$ in dynamical mass. SO emission arising from the inner part of the $C^{18}O$ envelope also shows rotation in the same direction as the $C^{18}O$ envelope. The rotation is, however, rigid-body like which is very different from the differential rotation shown by $C^{18}O$. In order to explain the line profiles and the position-velocity (PV) diagrams of $C^{18}O$ and SO observed, simple models composed of an infalling envelope surrounding a Keplerian disk of 54 AU in radius orbiting a star of 0.3 $M_\odot$ are examined. It is found that in order to reproduce characteristic features of the observed line profiles and PV diagrams, the infall velocity in the model has to be smaller than the free-fall velocity yielded by a star of 0.3 $M_\odot$. Possible reasons for the reduced infall velocities are discussed.

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Dynamics versus structure: breaking the density degeneracy in star formation

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The initial density of individual star-forming regions (and by extension the birth environment of planetary systems) is difficult to constrain due to the "density degeneracy problem": an initially dense region expands faster than a more quiescent region due to two-body relaxation and so two regions with the same observed present-day density may have had very different initial densities. We constrain the initial densities of seven nearby star-forming regions by folding in information on their spatial structure from the $\mathcal{Q}$-parameter and comparing the structure and present-day density to the results of N-body simulations. This in turn places strong constraints on the possible effects of dynamical interactions and radiation fields from massive stars on multiple systems and protoplanetary discs.
We apply our method to constrain the initial binary population in each of these seven regions and show that the populations in only three – the Orion Nebula Cluster, ρ Oph and Corona Australis – are consistent with having evolved from the Kroupa universal initial period distribution and a binary fraction of unity.

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Modeling and predicting the shape of the far-infrared to submillimeter emission in ultra-compact HII regions and cold clumps

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Dust properties are very likely affected by the environment in which dust grains evolve. For instance, some analyses of cold clumps (7–17 K) indicate that the aggregation process is favored in dense environments. However, studying warm (30–40 K) dust emission at long wavelength ($\lambda > 300$ μm) has been limited because it is difficult to combine far infared-to-millimeter (FIR-to-mm) spectral coverage and high angular resolution for observations of warm dust grains. Using Herschel data from 70 to 500 μm, which are part of the Herschel infrared Galactic (Hi-GAL) survey combined with 1.1 mm data from the Bolocam Galactic Plane Survey (BGPS), we compared emission in two types of environments: ultra-compact HII (UCHII) regions, and cold molecular clumps (denoted as cold clumps). With this comparison we tested dust emission models in the FIR-to-mm domain that reproduce emission in the diffuse medium, in these two environments (UCHII regions and cold clumps). We also investigated their ability to predict the dust emission in our Galaxy. We determined the emission spectra in twelve UCHII regions and twelve cold clumps, and derived the dust temperature (T) using the recent two-level system (TLS) model with three sets of parameters and the so-called T-β (temperature-dust emissvity index) phenomenological models, with β set to 1.5, 2 and 2.5. We tested the applicability of the TLS model in warm regions for the first time. This analysis indicates distinct trends in the dust emission between cold and warm environments that are visible through changes in the dust emissivity index. However, with the use of standard parameters, the TLS model is able to reproduce the spectral behavior observed in cold and warm regions, from the change of the dust temperature alone, whereas a T-β model requires β to be known.

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Local-Density-Driven Clustered Star Formation: Model and (Some) Implications

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A positive power-law trend between the local surface densities of molecular gas, Σ_{gas}, and young stellar objects, Σ_{stars}, in molecular clouds of the solar neighbourhood has recently been identified. How it relates to the properties of embedded clusters has so far not been investigated. To that purpose, we model the development of the stellar component of molecular clumps as a function of time and local volume density. Specifically, we associate the observed volume density gradient of molecular clumps to the density-dependent free-fall time and we obtain the molecular clump star formation history by applying a constant star formation efficiency per free-fall time, ϵ_{ff}. The model reproduces naturally the observed (Σ_{gas}, Σ_{stars}) relation quoted above.

The consequences of our model in terms of cluster survivability after residual star-forming gas expulsion and in terms of star age distribution in young gas-free clusters are discussed.

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Stellar age spreads in clusters as imprints of cluster-parent clump densities

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It has recently been suggested that high-density star clusters have stellar age distributions much narrower than that of the Orion Nebula Cluster, indicating a possible trend of narrower age distributions for denser clusters. We show this effect to likely arise from star formation being faster in gas with a higher density. We model the star formation history of molecular clumps in equilibrium by associating a star formation efficiency per free-fall time, ϵ_{ff}, to their volume density profile. We focus on the case of isothermal spheres and we obtain the evolution with time of their star formation rate. Our model predicts a steady decline of the star formation rate, which we quantify with its half-life time, namely, the time needed for the star formation rate to drop to half its initial value.
Given the uncertainties affecting the star formation efficiency per free-fall time, we consider two distinct values: $\epsilon_{ff} = 0.1$ and $\epsilon_{ff} = 0.01$. When $\epsilon_{ff} = 0.1$, the half-life time is of the order of the clump free-fall time, τ_{ff}. As a result, the age distributions of stars formed in high-density clumps have smaller full-widths at half-maximum than those of stars formed in low-density clumps. When the star formation efficiency per free-fall time is 0.01, the half-life time is 10 times longer, i.e. 10 clump free-fall times. We explore what happens if the duration of star formation is shorter than $10\tau_{ff}$, that is, if the half-life time of the star formation rate cannot be defined. There, we build on the invariance of the shape of the young cluster mass function to show that an anti-correlation between the clump density and the duration of star formation is expected. We therefore conclude that, regardless of whether the duration of star formation is longer than the star formation rate half-life time, denser molecular clumps yield narrower star age distributions in clusters. Published densities and stellar age spreads of young clusters and star-forming regions actually suggest that the time-scale for star formation is of order 1-4τ_{ff}.
We also discuss how the age-bin size and uncertainties in stellar ages affect our results. We conclude that there is no need to invoke the existence of multiple cluster formation mechanisms to explain the observed range of stellar age spreads in clusters.

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Kompaneets model fitting of the Orion-Eridanus superbubble

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Winds and supernovae from OB associations create large cavities in the interstellar medium referred to as superbubbles. The Orion molecular clouds are the nearest high-mass star-forming region and have created a highly elongated, 20° x 45°, superbubble. We fit Kompaneets models to the Orion–Eridanus superbubble and find that a model where the Eridanus side of the superbubble is oriented away from the Sun provides a marginal fit. Because this model requires an unusually small scaleheight of 40 pc and has the superbubble inclined 35° from the normal to the Galactic plane, we propose that this model should be treated as a general framework for modelling the Orion–Eridanus superbubble, with a secondary physical mechanism not included in the Kompaneets model required to fully account for the orientation and elongation of the superbubble.

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Mid-J CO observations of Perseus B1-East 5: evidence for turbulent dissipation via low-velocity shocks

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Giant molecular clouds contain supersonic turbulence and magnetohydrodynamic simulations predict that this turbulence should decay rapidly. Such turbulent dissipation has the potential to create a warm ($T\sim$100 K) gas component within a molecular cloud. We present observations of the CO J = 5–4 and 6–5 transitions, taken with the Herschel Space Observatory, towards the Perseus B1-East 5 region. We combine these new observations with archival measurements of lower rotational transitions and fit photodissociation region models to the data. We show that Perseus B1-E5 has an anomalously large CO J = 6–5 integrated intensity, consistent with a warm gas component existing within the region. This excess emission is consistent with predictions for shock heating due to the dissipation of turbulence in low velocity shocks with the shocks having a volume filling factor of 0.15%. We find that B1-E has a turbulent energy dissipation rate of 3.5×10^{32} erg s^{-1} and a dissipation time-scale that is only a factor of 3 larger than the flow crossing time-scale.

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Submillimeter Array Observations of Magnetic Fields in G240.31+0.07: an Hourglass in a Massive Cluster-forming Core

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We report the first detection of an hourglass magnetic field aligned with a well-defined outflow-rotation system in a high-mass star-forming region. The observations were performed with Submillimeter Array toward G240.31+0.07, which harbors a massive, flattened, and fragmenting molecular cloud core and a wide-angle bipolar outflow. The polarized dust emission at 0.88 mm reveals a clear hourglass-shaped magnetic field aligned within 20° of the outflow axis. Maps of high-density tracing spectral lines, e.g., $H^{13}CO^+$ (4–3), show that the core is rotating about its minor axis, which is also aligned with the magnetic field axis. Therefore, both the magnetic field and kinematic properties observed in this region are surprisingly consistent with the theoretical predictions of the classic paradigm of isolated low-mass star formation. The strength of the magnetic field in the plane of sky is estimated to be about 1.1 mG, resulting in a mass-to-magnetic flux ratio of 1.4 times the critical value and a turbulent to ordered magnetic energy ratio of 0.4. We also find that the specific angular momentum almost linearly decreases from $r\sim0.6$ pc to 0.03 pc scales, which is most likely attributed to magnetic braking.

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A Spitzer View of Mon OB1 East/NGC 2264

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We present Spitzer 3.6, 4.5, 5.8, 8.0, and 24 μm images of the Mon OB1 East giant molecular cloud, which contains the young star forming region NGC 2264, as well as more extended star formation. With Spitzer data and 2MASS photometry, we identify and classify young stellar objects (YSOs) with dusty circumstellar disks and/or envelopes in Mon OB1 East by their infrared-excess emission and study their distribution with respect to cloud material. We find a correlation between the local surface density of YSOs and column density of molecular gas as traced by dust extinction that is roughly described as a power law in these quantities. NGC 2264 follows a power law index of $\sim$2.7, exhibiting a large YSO surface density for a given gas column density. Outside of NGC 2264 where the surface density of YSOs is lower, the power law is shallower and the region exhibits a larger gas column density for a YSO surface density, suggesting the star formation is more recent. In order to measure the fraction of cloud members with circumstellar disks/envelopes, we estimate the number of diskless pre-main sequence stars by statistical removal of background star detections. We find that the disk fraction of the NGC 2264 region is 45%, while the surrounding more distributed regions show a disk fraction of 19%. This may be explained by the presence an older, more dispersed population of stars. In total, the Spitzer observations provide evidence for heterogenous, non-coeval star formation throughout the

Mon OB1 cloud.

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Young Stellar Object Variability (YSOVAR): Long Timescale Variations in the Mid-Infrared

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The YSOVAR (Young Stellar Object VARiability) Spitzer Space Telescope observing program obtained the first extensive mid-infrared (3.6 and 4.5 μm) time-series photometry of the Orion Nebula Cluster plus smaller footprints in eleven other star-forming cores (AFGL 490, NGC 1333, Mon R2, GGD 12-15, NGC 2264, L1688, Serpens Main,

Serpens South, IRAS 20050+2720, IC 1396A, and Ceph C). There are ∼29,000 unique objects with light curves in either or both IRAC channels in the YSOVAR data set. We present the data collection and reduction for the Spitzer and ancillary data, and define the "standard sample" on which we calculate statistics, consisting of fast cadence data, with epochs very roughly twice per day for ∼40d. We also define a "standard sample of members", consisting of all the IR-selected members and X-ray selected members. We characterize the standard sample in terms of other properties, such as spectral energy distribution shape. We use three mechanisms to identify variables in the fast cadence data – the Stetson index, a χ^2 fit to a flat light curve, and significant periodicity. We also identified variables on the longest timescales possible of 6-7 years, by comparing measurements taken early in the Spitzer mission with the mean from our YSOVAR campaign. The fraction of members in each cluster that are variable on these longest timescales is a function of the ratio of Class I/total members in each cluster, such that clusters with a higher fraction of Class I objects also have a higher fraction of long-term variables. For objects with a YSOVAR-determined period and a [3.6]−[8] color, we find that a star with a longer period is more likely than those with shorter periods to have an IR excess. We do not find any evidence for variability that causes [3.6]−[4.5] excesses to appear or vanish within our dataset; out of members and field objects combined, at most 0.02% may have transient IR excesses.

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Southern Massive Stars at High Angular Resolution: Observational Campaign and Companion Detection

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Multiplicity is one of the most fundamental observable properties of massive O-type stars and offers a promising way to discriminate between massive star formation theories. Nevertheless, companions at separations between 1 and 100 milli-arcsec (mas) remain mostly unknown due to intrinsic observational limitations. At a typical distance of 2 kpc, this corresponds to projected physical separations of 2-200 AU. The Southern MAssive Stars at High angular resolution survey (SMaSH+) was designed to fill this gap by providing the first systematic interferometric survey of Galactic massive stars. We observed 117 O-type stars with VLTI/PIONIER and 162 O-type stars with NACO/SAM, respectively probing the separation ranges 1-45 and 30-250 mas and brightness contrasts of $\Delta H < 4$ and $\Delta H < 5$. Taking advantage of NACO's field-of-view, we further uniformly searched for visual companions in an 8 arcsec-radius down to $\Delta H = 8$. This paper describes the observations and data analysis, reports the discovery of almost 200 new companions in the separation range from 1 mas to 8 arcsec and presents the catalog of detections, including the first resolved measurements of over a dozen known long-period spectroscopic binaries.
Excluding known runaway stars for which no companions are detected, 96 objects in our main sample ($\delta < 0$deg; $H < 7.5$) were observed both with PIONIER and NACO/SAM. The fraction of these stars with at least one resolved companion within 200 mas is 0.53. Accounting for known but unresolved spectroscopic or eclipsing companions, the multiplicity fraction at separation $\rho < 8$ arcsec increases to $f_{\rm m} = 0.91 \pm 0.03$. The fraction of luminosity class V stars that have a bound companion reaches 100% at 30 mas while their average number of physically connected companions within 8 arcsec is $f_{\rm c} = 2.2 \pm 0.3$. This demonstrates that massive stars form nearly exclusively in multiple systems. The nine non-thermal radio emitters observed by are all resolved, including the newly discovered pairs HD 168112 and CPD−47°2963. This lends strong support to the universality of the wind-wind collision scenario to explain the non-thermal emission from O-type stars.

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First spectrally-resolved H_2 observations towards HH 54. Low H_2O abundance in shocks

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Context. Herschel observations suggest that the H_2O distribution in outflows from low-mass stars resembles the H_2 emission. It is still unclear which of the different excitation components that characterise the mid- and near-IR H_2 distribution is associated with H_2O.
Aims. The aim is to spectrally resolve the different excitation components observed in the H_2 emission. This will allow us to identify the H_2 counterpart associated with H_2O and finally derive directly an H_2O abundance estimate with respect to H_2.
Methods. We present new high spectral resolution observations of H_2 0-0 S(4), 0-0 S(9), and 1-0 S(1) towards HH 54, a bright nearby shock region in the southern sky. In addition, new *Herschel*-HIFI H_2O ($2_{12}-1_{01}$) observations at 1670 GHz are presented.
Results. Our observations show for the first time a clear separation in velocity of the different H_2 lines: the 0-0 S(4) line at the lowest excitation peaks at -7 km s^{-1}, while the more excited 0-0 S(9) and 1-0 S(1) lines peak at -15 km s^{-1}. H_2O and high-J CO appear to be associated with the H_2 0-0 S(4) emission, which traces a gas component with a temperature of 700$-$1000 K. The H_2O abundance with respect to H_2 0-0 S(4) is estimated to be $X(H_2O)<1.4\times10^{-5}$ in the shocked gas over an area of 13″.
Conclusions. We resolve two distinct gas components associated with the HH 54 shock region at different velocities and excitations. This allows us to constrain the temperature of the H_2O emitting gas ($\leq$1000 K) and to derive correct estimates of H_2O abundance in the shocked gas, which is lower than what is expected from shock model predictions.

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Water in Low-Mass Star-Forming Regions with Herschel: The Link Between Water Gas and Ice in Protostellar Envelopes

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Aims: Our aim is to determine the critical parameters in water chemistry and the contribution of water to the oxygen budget by observing and modelling water gas and ice for a sample of eleven low-mass protostars, for which both forms

of water have been observed.
Methods: A simplified chemistry network, which is benchmarked against more sophisticated chemical networks, is developed that includes the necessary ingredients to determine the water vapour and ice abundance profiles in the cold, outer envelope in which the temperature increases towards the protostar. Comparing the results from this chemical network to observations of water emission lines and previously published water ice column densities, allows us to probe the influence of various agents (e.g., FUV field, initial abundances, timescales, and kinematics).
Results: The observed water ice abundances with respect to hydrogen nuclei in our sample are 30-80ppm, and therefore contain only 10–30% of the volatile oxygen budget of 320 ppm. The keys to reproduce this result are a low initial water ice abundance after the pre-collapse phase together with the fact that atomic oxygen cannot freeze-out and form water ice in regions with $T(\mathrm{dust}) > 15$ K. This requires short prestellar core lifetimes of less than about 0.1 Myr. The water vapour profile is shaped through the interplay of FUV photodesorption, photodissociation, and freeze-out. The water vapour line profiles are an invaluable tracer for the FUV photon flux and envelope kinematics.
Conclusions: The finding that only a fraction of the oxygen budget is locked in water ice can be explained either by a short pre-collapse time of less than 0.1 Myr at densities of $n(\mathrm{H}) \sim 10^4$ cm^{-3}, or by some other process that resets the initial water ice abundance for the post-collapse phase. A key for the understanding of the water ice abundance is the binding energy of atomic oxygen on ice.

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Spatially Resolved Magnetic Field Structure in the Disk of a T Tauri Star

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Magnetic fields in accretion disks play a dominant role during the star formation process but have hitherto been observationally poorly constrained. Field strengths have been inferred on T Tauri stars themselves and possibly in the innermost part of the accretion disk, but the strength and morphology of the field in the bulk of the disk have not been observed. Unresolved measurements of polarized emission (arising from elongated dust grains aligned perpendicular to the field) imply average fields aligned with the disks. Theoretically, the fields are expected to be largely toroidal, poloidal, or a mixture of the two, which imply different mechanisms for transporting angular momentum in the disks of actively accreting young stars such as HL Tau. Here we report resolved measurements of the polarized 1.25 mm continuum emission from HL Tau's disk. The magnetic field on a scale of 80 AU is coincident with the major axis (∼210 AU diameter) of the disk. From this we conclude that the magnetic field inside the disk at this scale cannot be dominated by a vertical component, though a purely toroidal field does not fit the data well either. The unexpected morphology suggests that the magnetic field's role for the accretion of a T Tauri star is more complex than the current theoretical understanding.

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CARMA Large Area Star Formation Survey: Project Overview with Analysis of Dense Gas Structure and Kinematics in Barnard 1

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We present details of the CARMA Large Area Star Formation Survey (CLASSy), while focusing on observations of Barnard 1. CLASSy is a CARMA Key Project that spectrally imaged N_2H^+, HCO^+, and HCN (J=1–0 transitions) across over 800 square arcminutes of the Perseus and Serpens Molecular Clouds. The observations have angular resolution near 7″ and spectral resolution near 0.16 km s^{-1}. We imaged ∼150 square arcminutes of Barnard 1, focusing on the main core, and the B1 Ridge and clumps to its southwest. N_2H^+ shows the strongest emission, with morphology similar to cool dust in the region, while HCO^+ and HCN trace several molecular outflows from a collection of protostars in the main core. We identify a range of kinematic complexity, with N_2H^+ velocity dispersions ranging from ∼0.05–0.50 km s^{-1} across the field. Simultaneous continuum mapping at 3 mm reveals six compact object detections, three of which are new detections. A new non-binary dendrogram algorithm is used to analyze dense gas structures in the N_2H^+ position-position-velocity (PPV) cube. The projected sizes of dendrogram-identified structures range from about 0.01–0.34 pc. Size-linewidth relations using those structures show that non-thermal line-of-sight velocity dispersion varies weakly with projected size, while rms variation in the centroid velocity rises steeply with projected size. Comparing these relations, we propose that all dense gas structures in Barnard 1 have comparable depths into the sky, around 0.1–0.2 pc; this suggests that over-dense, parsec-scale regions within molecular clouds are better described as flattened structures rather than spherical collections of gas. Science-ready PPV cubes for Barnard 1 molecular emission are available for download.

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Angular Momentum Exchange by Gravitational Torques and Infall in the Circumbinary Disk of the Protostellar System L1551 NE

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We report the ALMA observation of the Class I binary protostellar system L1551 NE in the 0.9-mm continuum, $C^{18}O$ (3-2), and ^{13}CO (3-2) lines at a ∼1.6 times higher resolution and a ∼6 times higher sensitivity than those of our previous SMA observations, which revealed a r ∼300 AU-scale circumbinary disk in Keplerian rotation. The 0.9-mm continuum shows two opposing U-shaped brightenings in the circumbinary disk, and exhibits a depression between the circumbinary disk and the circumstellar disk of the primary protostar. The molecular lines trace non-axisymmetric deviations from Keplerian rotation in the circumbinary disk at higher velocities relative to the systemic velocity, where our previous SMA observations could not detect the lines. In addition, we detect inward motion along the minor axis of the circumbinary disk. To explain the newly-observed features, we performed a numerical simulation of gas orbits in a Roche potential tailored to the inferred properties of L1551 NE. The observed U-shaped dust features coincide with locations where gravitational torques from the central binary system are predicted to impart angular momentum to the circumbinary disk, producing shocks and hence density enhancements seen as a pair of spiral arms. The observed inward gas motion coincides with locations where angular momentum is predicted to be lowered by the gravitational torques. The good agreement between our observation and model indicates that gravitational torques from the binary stars constitute the primary driver for exchanging angular momentum so as to permit infall through the circumbinary disk of L1551 NE.

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http://arxiv.org/pdf/1409.4903

Surface Geometry of Protoplanetary Disks Inferred From Near-Infrared Imaging Polarimetry

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We present a new method of analysis for determining the surface geometry of five protoplanetary disks observed with near-infrared imaging polarimetry using Subaru-HiCIAO. Using as inputs the observed distribution of polarized intensity (PI), disk inclination, assumed properties for dust scattering, and other reasonable approximations, we calculate a differential equation to derive the surface geometry. This equation is numerically integrated along the distance from the star at a given position angle. We show that, using these approximations, the local maxima in the PI distribution of spiral arms (SAO 206462, MWC 758) and rings (2MASS J16042165–2130284, PDS 70) is associated with local concave-up structures on the disk surface. We also show that the observed presence of an inner gap in scattered light still allows the possibility of a disk surface that is parallel to the light path from the star, or a disk that is shadowed by structures in the inner radii. Our analysis for rings does not show the presence of a vertical inner wall as often assumed in studies of disks with an inner gap. Finally, we summarize the implications of spiral and ring structures as potential signatures of ongoing planet formation.

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Effect of OH depletion on measurements of the mass-to-flux ratio in molecular cloud cores

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The ratio of mass and magnetic flux determines the relative importance of magnetic and gravitational forces in the evolution of molecular clouds and their cores. Its measurement is thus central in discriminating between different theories of core formation and evolution. Here we discuss the effect of chemical depletion on measurements of the mass

to-flux ratio using the same molecule (OH) both for Zeeman measurements of the magnetic field and the determination of the mass of the region. The uncertain- ties entering through the OH abundance in determining separately the magnetic field and the mass of a region have been recognized in the literature. It has been proposed however that, when comparing two regions of the same cloud, the abundance will in both cases be the same. We show that this assumption is invalid. We demonstrate that when comparing regions with different densities, the effect of OH depletion in measuring changes of the mass-to-flux ratio between different parts of the same cloud can even reverse the direction of the underlying trends (for example, the mass-to-flux ratio may appear to decrease as we move to higher density regions). The systematic errors enter primarily through the inadequate estimation of the mass of the region.

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The origin of complex organic molecules in prestellar cores

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Complex organic molecules (COMs) have been detected in a variety of environments, including cold prestellar cores. Given the low temperature of these objects, these last detections challenge existing models. We report here new observations towards the prestellar core L1544. They are based on an unbiased spectral survey of the 3 mm band at the IRAM-30m telescope, as part of the Large Program ASAI. The observations allow us to provide the full census of the oxygen bearing COMs in this source. We detected tricarbon monoxide, methanol, acetaldehyde, formic acid, ketene, and propyne with abundances varying from 5×10^{-11} to 6×10^{-9}. The non-LTE analysis of the methanol lines shows that they are likely emitted at the border of the core, at a radius of ∼8000 AU where $T \sim 10$ K and $n_{\mathrm{H_2}} \sim 2 \times 10^4$ cm^{-3}. Previous works have shown that water vapour is enhanced in the same region because of the photodesorption of water ices. We propose that a non-thermal desorption mechanism is also responsible for the observed emission of methanol and COMs from the same layer. The desorbed oxygen and a tiny amount of desorbed methanol and ethene are enough to reproduce the abundances of tricarbon monoxide, methanol, acetaldehyde and ketene measured in L1544. These new findings open the possibility that COMs in prestellar cores originate in a similar outer layer rather than in the dense inner cores, as previously assumed, and that their formation is driven by the non-thermally desorbed species.

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The effect of external environment on the evolution of protostellar disks

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Using numerical hydrodynamics simulations we studied the gravitational collapse of pre-stellar cores of sub-solar mass embedded into a low-density external environment. Four models with different magnitude and direction of rotation of the external environment with respect to the central core were studied and compared with an isolated model. We found that the infall of matter from the external environment can significantly alter the disk properties as compared to those seen in the isolated model. Depending on the magnitude and direction of rotation of the external environment, a variety of disks can form including compact (≤ 200 AU) ones shrinking in size due to infall of external matter with low angular momentum, as well as extended disks forming due to infall of external matter with high angular momentum. The former are usually stable against gravitational fragmentation, while the latter are

prone to fragmentation and formation of stellar systems with sub-stellar/very-low-mass companions. In the case of counterrotating external environment, very compact (< 5 AU) and short-lived ($\lesssim$a few 10^5 yr) disks can form when infalling material has low angular momentum. The most interesting case is found for the infall of counterrotating external material with high angular momentum, leading to the formation of counterrotating inner and outer disks separated by a deep gap at a few tens AU. The gap migrates inward due to accretion of the inner disk onto the protostar, turns into a central hole, and finally disappears giving way to the outer strongly gravitationally unstable disk. This model may lead to the emergence of a transient stellar system with sub-stellar/very-low-mass components counterrotating with respect to that of the star.

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Evolving Molecular Cloud Structure and the Column Density Probability Distribution Function

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The structure of molecular clouds can be characterized with the probability distribution function (PDF) of the mass surface density. In particular, the properties of the distribution can reveal the nature of the turbulence and star formation present inside the molecular cloud. In this paper, we explore how these structural characteristics evolve with time and also how they relate to various cloud properties as measured from a sample of synthetic column density maps of molecular clouds. We find that, as a cloud evolves, the peak of its column density PDF will shift to surface densities below the observational threshold for detection, resulting in an underlying lognormal distribution which has been effectively lost at late times. Our results explain why certain observations of actively star-forming, dynamically older clouds, such as the Orion molecular cloud, do not appear to have any evidence of a lognormal distribution in their column density PDFs. We also study the evolution of the slope and deviation point of the power-law tails for our sample of simulated clouds and show that both properties trend towards constant values, thus linking the column density structure of the molecular cloud to the surface density threshold for star formation.

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ALMA Observations of the IRDC Clump G34.43+00.24 MM3: 278 GHz Class I Methanol Masers

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We have observed a molecular clump (MM3) associated with the infrared dark cloud G34.43+00.24 in the CH_3OH J_K=9_{-1}–8_0 E, 5_0–4_0 E, and 5_{-1}–4_{-1} E lines at sub-arcsecond resolution by using the Atacama Large Millimeter/submillimeter Array. By comparing the CH_3OH J_K=9_{-1}–8_0 E emission with the CH_3OH 5_0–4_0 E and 5_{-1}–4_{-1} E emission, we have found that the CH_3OH J_K=9_{-1}–8_0 E emission is masing. We have clearly shown that the CH_3OH J_K=9_{-1}–8_0 masers arise from the post shocked gas in the interacting regions between the outflows and ambient dense gas. Toward the strongest peak of the CH_3OH maser emission, SiO J=6–5 emission is very weak. This indicates that

the CH_3OH maser emission traces relatively old shocks or weak shocks.

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Spitzer IRAC Color Diagnostics for Extended Emission in Star Forming Regions

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The infrared data from the Spitzer Space Telescope has provided an invaluable tool for identifying physical processes in star formation. In this study we calculate the IRAC color space of UV fluorescent molecular hydrogen (H_2) and Polycyclic Aromatic Hydrocarbon (PAH) emission in photodissociation regions (PDRs) using the Cloudy code with PAH opacities from Draine & Li 2007. We create a set of color diagnostics that can be applied to study the structure of PDRs and to distinguish between FUV excited and shock excited H_2 emission. To test this method we apply these diagnostics to Spitzer IRAC data of NGC 2316. Our analysis of the structure of the PDR is consistent with previous studies of the region. In addition to UV excited emission, we identify shocked gas that may be part of an outflow originating from the cluster.

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The physics of the accretion process in the formation and evolution of Young Stellar Objects

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Ph.D dissertation directed by: Leonardo Testi, Barbara Ercolano

Ph.D degree awarded: July 2014

The formation of planets is thought to happen in protoplanetary disks surrounding young stars during the first few Myrs of their pre-main-sequence evolution. In order to understand planet formation a detailed knowledge of the disk evolution process is needed. By studying the interaction of the disk with the central star, which includes accretion of matter due to viscous processes in the disk, we can constrain the physical conditions of the inner gaseous disk in which planet formation takes place. With the recent advent of the X-Shooter spectrograph, a second generation instrument of the ESO/VLT, the excess emission due to accretion in the ultraviolet can be studied simultaneously with the accretion signatures in the visible and in the near-infrared, finally giving a complete view of this phenomenon.

In this Thesis I have studied various X-Shooter datasets of young stars to determine the intensity and the properties of the accretion process at various phases of disk evolution and as a function of the central star mass and age. To fully exploit the potential of the X-Shooter spectra, I have developed an innovative method of analysis to derive accretion and stellar parameters with an automatic algorithm. This is based on a set of models, composed of a set of photospheric templates of young stars that I gathered and characterized, a set of slab models, that I have coded, to reproduce the emission due to the accretion shock, and a reddening law to take into account extinction effects. This method allows to accurately determine for the first time the stellar and accretion parameters of the targets self-consistently and with no prior assumptions, a significant improvement with respect to previous studies. I have applied this methodology to determine the correct stellar parameters of two objects in the Orion Nebula Cluster that were reported in the literature to have an anomalous old age. My analysis has shown why previous investigations could not resolve the degeneracy between various parameters, while the methodology developed in this Thesis could.

I have applied my methodology to a relatively large sample of transitional disks, which are thought to be evolved disks with a large gap in the dusty disk between the outer disk and the central star. I showed that, when accretion is present, their properties are similar to those of less evolved disks. Under steady-state assumptions this implies the presence of an efficient mechanism to transport gas from the outer disk to the inner regions of the system through the dust depleted gap. In order to investigate the evolution of accretion, I have then used a combined sample of all the ∼90 X-Shooter spectra I have studied of young stars with disks. My sample covers a range of environments and stellar masses, and my accurate analysis method allows for a much better determination of the accretion versus stellar mass

relation. The slope of this relation is in good agreement with the predictions of X-ray photoevaporation models. On the other hand, the significantly smaller spread in values that I find compared to previous works can be explained as a small spread of initial conditions, such as initial core rotation rates. By removing the dependence of the accretion rates with the stellar mass I have been able to search for a purely evolutionary trend of accretion. In general, viscous evolution models can reproduce the observed trend with small variations of the fiducial disk parameters.

To follow the path marked by this Thesis, future accretion studies should focus on complete samples in various star forming regions. These will be then coupled with on-going surveys with other observational tools, such as ALMA in the sub-mm wavelength range, targeting other properties of protoplanetary disks, for example disk masses.

Electronic copies of this PhD thesis are available upon request to the author.

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New Jobs

Postdoctoral fellowship and PhD positions in Star- and planet formation, astrochemistry

A 3 year postdoctoral fellowship and two 4-year PhD positions are available within the Molecular Astrophysics group of Ewine van Dishoeck located at Leiden Observatory (the Netherlands) and the Max Planck Institute for Extraterrestrial Physics (MPE, Garching, Germany). The postdoc and PhD students will be part of an international team studying the physical and chemical evolution from collapsing cores to planet-forming disks and exoplanets centered around ALMA data. A wide range of complementary data from Herschel as well as ground-based infrared and submillimeter spectroscopy is available. See `www.strw.leidenuniv.nl/~ewine` for more details.

The PhD students will be located at Leiden Observatory, whereas the postdoc can be located at either MPE, Leiden or a combination. The postdoc is expected to co-supervise PhD or MSc students and is encouraged to also pursue a personal research program. The postdoc appointment is initially for two years, with the possibility of renewal of 1 year. It can start anytime in 2014.

Candidates with an observational and/or modeling background in astrochemistry, star formation (from small to galactic scales), circumstellar disks, submillimeter spectroscopy, planet formation and planet population synthesis models are encouraged to apply.

Both Leiden Observatory and MPE carry out observational, interpretative and theoretical research in the fields of the star and planet formation, astrochemistry, laboratory astrophysics, galactic structure, the formation, dynamics and evolution of (high-redshift) galaxies and their nuclei, and cosmology.

Applications should include a curriculum vitae, publication list, and a brief statement of research experience and interests, and arrange for at least three letters of reference to be uploaded on the websites listed below. Review of applications for the postdoc position will start on November 15 2014. Deadline for the PhD positions is December 1 2014.

Web sites for submission:

Postdoc: http://jobs.strw.leidenuniv.nl/2015/dishoeckPD

PhD: http://www.strw.leidenuniv.nl/phd/apply.php

Postdoctoral Fellowship in Exo-Planets, Brown Dwarfs and Young Stars - York University

Applications are invited for a postdoctoral fellowship at York University in Toronto. The successful candidate will work with Prof. Ray Jayawardhana and his collaborators on observational and analytical studies of extra-solar planets, brown dwarfs and young stars, and will be encouraged to pursue independent research on related topics. On-going and recent projects include photometric and spectroscopic studies of extra-solar planets, high-contrast imaging searches for sub-stellar companions around young stars, investigations of brown dwarf variability and multiplicity, and the SONYC (Substellar Objects in Nearby Young Clusters) ultra-deep survey, using data from VLT, Subaru, Gemini, Keck, CFHT, Kepler, and other major observatories. The position is for two years, with extension to a third year possible, and comes with a competitive salary and funds for research expenses. Applicants should send their curriculum vitae, a description of research interests and plans and a list of publications, and should arrange for three letters of recommendation to be sent directly to marlene@yorku.ca All materials should be submitted electronically. Applications received before 2014 December 1 will receive full consideration. Early expressions of interest and inquiries to rayjay@yorku.ca are welcome.

Postdoctoral Position: Binary star formation and death with JWST

The California Institute of Technology (Caltech), Postdoctoral Scholars Program at the Jet Propulsion Laboratory (JPL) invites applications for a postdoctoral research position in JPL's Evolution of Galaxies Group.

The research will involve collaborating on composing an observing plan for Guaranteed Time Observations with the James Webb Space Telescope. Specific topics under consideration involve studies of very young binary stars and their interaction with their natal environment on the one extreme and planetary nebula formation and shaping with binary central stars on the other. Dr. Michael Ressler, Principal Scientist, in JPL's Astrophysics and Space Sciences Section and JPL's JWST/MIRI Project Scientist, will serve as JPL postdoctoral advisor to the selected candidate. The appointee will carry out research in collaboration with the JPL advisor, resulting in publications in the open literature.

Candidates should have a recent PhD in Astronomy or Physics with a strong background in infrared observations and analysis in either of the fields of star formation or planetary nebulae. Experience in space-borne observations and the use of their planning and data processing tools is highly desirable. Candidates who have received their PhD within the past five years since the date of their application are eligible. Postdoctoral Scholar positions are awarded for a minimum of one-year period and may be renewed up to a maximum of three years.

Please send a letter describing your research interests, a curriculum vitae, a list of three references (with telephone numbers, postal and email address) and arrange the reference letters to be sent to:

Name: Michael Ressler Address: Jet Propulsion Laboratory, M/S 79-5 4800 Oak Grove Drive, Pasadena, CA 91109 Telephone: 8183545576 E-Mail: ressler@jpl.nasa.gov

Additional informal information is available upon request to Dr. Ressler.

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http://postdocs.jpl.nasa.gov/researchapplicants/jobpostings/index.cfm?FuseAction=ShowJobPosting&JobPostingID=

Meetings

FIRST ANNOUNCEMENT:

Young Stars & Planets Near the Sun

IAU Symposium 314 May 11-15, 2015, Atlanta, GA, USA

http://youngstars.gsu.edu

youngstars@astro.gsu.edu

SYNOPSIS:
In the past two decades, research by many astronomers has revealed an abundance of late-stage and post-T Tauri stars and early type stars of comparable age within 100 pc of Earth. Many of these stars have been classified as members of (10) identified kinematic moving groups, whose ages range from 8 Myr up to 200 Myr. Because these stellar groups are so close to Earth, they provide some of the best samples available to astronomy to investigate the early evolution of low- to intermediate-mass stars. While these nearby, youthful stars are themselves of great interest to stellar astronomy, they also represent the most readily accessible targets for direct imaging (and other measurements) of dusty circumstellar debris disks and young, substellar objects – i.e., newly formed brown dwarfs and, especially, planets. Indeed, $<$200 Myr-old stars within $\sim$100 pc represent the best laboratories to study the conditions and timescales associated with protoplanetary disk evolution and the formation and early physical and dynamical evolution of planetary systems.

This potential for progress in understanding the early evolution of stars and planetary systems constitutes the motivation for IAU Symposium #314, "Young Stars & Planets Near the Sun," to be held in Atlanta, GA (USA) the week of May 11-15, 2015. The 4.5-day symposium will focus on the study of nearby young stars and planets from a variety of fundamental observational and theoretical perspectives: the identification, ages, and origins of local young moving groups; the early evolution of low- to intermediate-mass stars; the dispersal of protoplanetary disks and the nature of debris disks, including planet-disk interactions; the origins and properties of young planets; and likely future directions for the study of nearby young stars and planets in the near and longer term.

INVITED SPEAKERS:
K. Allers, C. Bell, B. Biller, T. Birnstiel, G. Chabrier, G. Chauvin, L. Cieza, K. Covey, G. De Silva, G. Feiden, U. Gorti, J. Greaves, G. Hussain, A. Kospal, A. Kraus, C. Lada, L. Malo, E. Mamajek, M. Marley, C. Marois, S. Martell, S. Matt, C. Melis, C. Mordasini, E. Nielsen, K. Oberg, J. Patience, M. Pecaut, A. Pierens, M. Pinsonneault, J. Robrade, E. Shkolnik, A. Sozzetti, A. Youdin

CONTRIBUTED TALKS and POSTERS:
There is time reserved in the science program for a limited number of contributed oral presentations, and ample space will be provided for poster presentations at the GSU meeting site. All posters will be on display for the duration of the meeting. Submission details and deadlines will be available soon at http://youngstars.gsu.edu.

REGISTRATION:
Registration will open in January 2015. Early registration fees are expected to be $315, and will include (among other things) the Symposium opening reception on Sunday May 10, daily breakfast, several lunches, and local public transportaion passes. See http://youngstars.gsu.edu/registration for details.

LOCATION:
The meeting will be held at the facilities of Georgia State University in downtown Atlanta. The Atlanta airport, an easy (direct) metro ride from downtown Atlanta, is a major airline hub that is accessible via nonstop flights from major international airports. The downtown and greater Atlanta areas boast vibrant cultural and culinary scenes and warm spring weather. Information concerning local attractions & activities can be found athttp://youngstars.gsu.edu/atlanta.

LODGING:
The LOC has reserved a block of rooms at the Hyatt Regency Atlanta, which is very near GSU, at a group rate of

$129/night; see http://youngstars.gsu.edu/accommodations for additional information.

TRAVEL SUPPORT:
A limited amount of travel support will be available to facilitate meeting attendance by students and young researchers. Instructions on how to apply for travel support can be obtained by sending an email toyoungstars@astro.gsu.edu. The deadline to request support is Nov. 15.

SCIENTIFIC ORGANIZING COMMITTEE:
Joel Kastner (co-Chair), Anne-Marie Lagrange (co-Chair), Isabelle Baraffe, Mike Bessell, Rene Doyon, Greg Herczeg, Michael Ireland, Moira Jardine, Rob Jeffries, Michael Liu, Stan Metchev, David Rodriguez, Beate Stelzer, Motohide Tamura, Carlos Torres, Ben Zuckerman

LOCAL ORGANIZING COMMITTEE:
Sebastien Lepine, Inseok Song, Russel White

The Kinematics of Star Formation: Theory and Observation in the Gaia Era

Venue: Burlington House, London

Date: Friday 9th January, 2015

Website: http://www.star.herts.ac.uk/kinematics

Organisers: Nick Wright, Richard Parker, Rowan Smith

With the advent of recent large-scale radial velocity surveys and the launch of ESA's astrometric Gaia satellite, studies of the kinematics of young stars have become increasingly prominent over the last few years. They are the key to our understanding of both the star formation process and the formation and early evolution of star clusters, allowing us to test the results of hydrodynamic simulations of the star formation process and N-body models of the dynamical evolution of star clusters. This specialist discussion meeting will focus on recent observations and models of the kinematics of young stars and star clusters, and will also discuss the upcoming wealth of kinematic data expected from the Gaia mission and how the community can best prepare for it.

Confirmed invited speakers:

- Paul Clark (Cardiff)

- Simon Goodwin (Sheffield)

- Estelle Moraux (Grenoble)

For more details, including the registration and abstract submission process, please visit the website or contact nick.nwright@gmail.com.

Summary of Upcoming Meetings

MIRA Conference on Circumstellar Disks and Planet Formation
12 - 14 October 2014 Ann Arbor, USA
http://www.lsa.umich.edu/mira/workshopsconferences/circumstellardisksandplanetformationconference

The Early Life of Stellar Clusters: Formation and Dynamics
3 - 7 November 2014, Copenhagen, Denmark
http://www.nbia.dk/nbia-clusters-2014

Star Formation Across Space and Time
11-14 November 2014 Noordwijk, The Netherlands
http://congrexprojects.com/14a09/

Triple Evolution & Dynamics in Stellar and Planetary Systems
15 - 21 November 2014 Haifa, Israel
http://trendy-triple.weebly.com

The Kinematics of Star Formation: Theory and Observation in the Gaia Era
9 January 2015 London, UK
http://www.star.herts.ac.uk/kinematics

45th "Saas-Fee Advanced Course":
From Protoplanetary Disks to Planet Formation
15-20 March 2015, Switzerland
http://isdc.unige.ch/sf2015

The Soul of Massive Star Formation
15 - 20 March 2015 Puerto Varas, Chile
http://www.das.uchile.cl/msf2015/

Star and Planet Formation in the Southwest
23 - 27 March 2015 Oracle, Arizona, USA
https://lavinia.as.arizona.edu/~kkratter/SPF1/Home.html

Triple Evolution & Dynamics in Stellar and Planetary Systems
31 May - 5 June 2015 Haifa, Israel
http://trendy-triple.weebly.com

Workshop on the Formation of the Solar System II
2 - 4 June 2015 Berlin, Germany
https://indico.mpifr-bonn.mpg/FormationOfTheSolarSystem2

IGM@50: is the Intergalactic medium driving Star Formation?
8 - 12 June 2015 Abbazia di Spineto, Italy
http://www.arcetri.astro.it/igm50

30 Years of Photodissociation regions - A Symposium to honor David Hollenbach's lifetime in science
28 June - 3 July 2015
http://pdr30.strw.leidenuniv.nl

Disc dynamics and planet formation
29 June - 3 July 2015 Larnaka, Cyprus
http://www.star.uclan.ac.uk/discs2015

Cosmic Dust
17 - 21 August 2015 Tokyo, Japan
https://www.cps-jp.org/~dust/

Extreme Solar Systems III
29 November - 4 December 2015 Hawaii, USA
http://ciera.northwestern.edu/Hawaii2015.php

The 19th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun
6 - 10 June 2016 Uppsala, Sweden
http://www.coolstars19.com

Other meetings: http://www1.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/meetings/