The Star Formation Newsletter

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

Newsletter Archive

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Cover Picture

The 4 Myr old Herbig Ae star, located at a Gaia2 distance of 101.51.2 pc, has been studied with ALMA, and evidence has been found in its disk for deviations from Keplerian velocity which are consistent with the presence of three newborn Jupiter-mass planets at orbital radii of about 83, 137, and 260 AU. The image, showing ^{12}CO emission in a channel map at +1 km/s from the systemic velocity, reveals a distinct kink in the emission, which is interpreted as the perturbing influence of a newly born planet. For details, see the abstracts by Pinte et al. and Teague et al. in this issue.

Courtesy ESO, ALMA (ESO/NAOJ/NRAO), and Pinte et al.

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

Richard Crutcher

in conversation with Bo Reipurth

Q: *Your PhD in 1972 was about 'Observations of Hydroxyl Molecules in Interstellar Clouds'. What motivated this choice of subject, and who was your advisor?*

A: I had heard George Abell give a talk at an AAS meeting at the University of Kentucky (my undergraduate institution) on using the luminosity function of clusters of galaxies as a cosmological distance indicator; I got excited about that and went to graduate school at UCLA to work with him. But it turned out the project was mainly scanning Palomar Sky Survey plates, and I wanted to do more hands-on observational astronomy. A young assistant professor at UCLA, Kurt Riegel, had started to use the Caltech Owens Valley Radio Observatory, and he invited me to join that research program. Caltech had built a 40-m radio antenna as a prototype for a large interferometer, but lost out to NRAO when the VLA was selected instead. NRAO donated an older autocorrelation spectrometer, so the 40-m telescope was available with lots of observing time for single-dish radio spectroscopy. I worked with an Owens Valley digital engineer to test and fix some non-functional circuit boards and wrote some software to get the system working. The 18-cm OH lines had just been detected in dark clouds by Carl Heiles at Hat Creek Observatory, so using those lines to survey dark clouds and study their kinematics, densities, and conditions for star formation became my PhD thesis. It seemed that OH would continue to play a leading role in such studies, but the discovery of the 3-mm CO line near the end of my PhD work meant that CO became the leading tracer of conditions in molecular clouds.

Q: *A few years later you and your collaborators turned your attention to the diffuse interstellar medium in the solar neighborhood.*

A: After I received my PhD from UCLA in 1972, Caltech offered me a postdoc position. I continued my radio astronomy work at Owens Valley, but Professor Guido Münch asked me to go with him to use the Mt Wilson 100-in telescope. Its Coudé spectrograph had been used decades earlier for pioneering observations of optical interstellar lines, and photographic plates had been replaced by an electronic detector. One thing I did was to use optical interstellar Na I D-lines for distance determination. My first research project in graduate school was a study of a very extensive (10s of degrees) cold cloud observed in 21-cm H I self-absorption in the general direction of the Galactic center; this cloud is sometimes now referred to as the "Riegel-Crutcher" cloud. I found mainly B stars at various photometric distances toward this cloud and looked for the D-lines. They suddenly "turned on" in the spectra of stars about 150 pc away, establishing the distance and enabling better understanding of the nature of the cold cloud. At about this time, Lew Hobbs had obtained very high resolution spectra of Na I D interstellar lines that showed flat bottoms indicative of very high optical depth, making it difficult to obtain accurate column densities. But there are much weaker Na I lines at $\lambda 3302$, so I had the idea of observing those lines at Mt Wilson to obtain accurate Na I diffuse cloud column densities. In addition, at Mt Wilson I obtained the first detections of the OH $\lambda 3078$ line in the diffuse ISM. These near-UV OH absorption lines had very accurate column densities. Combined with radio-wavelength studies, I showed that the common assumption that the 18-cm OH lines in dark clouds were in LTE and moderately optically thick was incorrect, and obtained more accurate estimates of the OH/H ratio. Also, during my study of optical interstellar lines toward relatively nearby stars, I noticed a pattern of interstellar radial velocities over a very large area of sky. I found that I could fit these velocities by assuming a local stream of interstellar material toward the Sun, with the observed radial velocites depending on position in the sky and hence projection onto the lines of sight to the stars. I called this paper "The Local Interstellar Medium"; although this idea was initially met with much skepticism, the basic idea is now widely accepted.

Q: *In the middle of the 1980s you studied the sightline to a B-star behind the Taurus clouds, combining optical and mm data. What were the key results?*

A: This was a continuation of my effort to combine radio and optical interstellar line results to study physical and chemical conditions, taking advantage of the complementary information. I searched star catalogs looking for nearby early-type stars with large interstellar extinctions and found HD29647, which is behind a thin part of the Taurus Molecular Cloud complex, with $A_V \approx 3.7$. The sight line sampled a dark cloud rather than the diffuse clouds usually sampled by optical interstellar lines. Optical lines of CN, C_2, CH and K I were detected while CH^+, NH_2, SiH, MgH, C_3, and CO^+ were not. Millimeter-

wavelength lines of CO, ^{13}CO, C^{18}O, HCN, HCO$^+$, and CN were detected, while HC$_3$N, C$_2$H, and DCO$^+$ were not. All these data made it possible to infer a detailed physical and chemical model, with $n(H_2) \approx 800$ cm^{-3}, $T_K \approx 10$ K, and $n_e/n_H \approx 10^{-6}$ (derived both from ionization equilibrium of atomic potassium and from the ion-molecule chemistry of HCO$^+$). Molecular abundances were in approximate accord with the calculations of gas-phase chemistry. The temperature of the microwave background was found from the CN excitation to be 2.82 ± 0.08 K.

Q: *In a very highly cited paper from 1999, you discussed the magnetic fields in molecular clouds, and confronted theory with observations.*

A: I actually started observational study of interstellar magnetic fields and their role in star formation as a postdoc at Caltech. Together with collaborators, I used the Owens Valley 40-m telescope to carry out deep (for the time) Zeeman observations of the OH emission from several dark clouds. Although we did not achieve any detections, this work formed the basis for much of my subsequent research. In 1982 I spent 8 weeks at the Nançay (France) radio telescope working with Ilya Kazès. I developed a technique to overcome an important instrumental polarization effect and achieved the first detection of the OH Zeeman effect in distributed (non-maser) molecular gas, toward the NGC2024 molecular cloud. Later, usually in collaboration with Tom Troland, I continued OH Zeeman observing and mapping with the Nançay, Arecibo, Green Bank, and VLA telescopes, obtaining a number of detections and sensitive upper limits. Then, in order to probe denser molecular material, I made several trips to Grenoble to persuade IRAM to equip their 30-m telescope in Spain for CN Zeeman observations and worked with them on the design of the polarimeter. In 1999 we published the first detections. All these data were the basis for the "confrontation" paper you ask about. I found that in molecular clouds internal motions are likely MHD Alfvén waves, that magnetic pressure dominates thermal pressure, that magnetic and turbulent energies are approximately equal and together about equal to gravity, and that magnetic field strengths scale as a power law with molecular densities. My conclusion was that magnetic fields are a crucial component of the physics governing cloud evolution and star formation, a result that remains valid today.

Q: *More recently you have reviewed the role of magnetic fields in molecular cloud physics in an Annual Reviews article. Is this now a well understood subject, or do you see areas where we can improve our understanding?*

A: This 2012 Annual Reviews article was an update and extension (to all observational methods, such as polarized emission from interstellar dust) of the 1999 paper. It is certain that our understanding of the role of magnetic fields in star formation has improved significantly, but it is still controversial. Although everyone acknowledges the existence of magnetic fields in diffuse and molecular clouds, some believe that they play a minor role in molecular cloud formation and evolution and that turbulence dominates the process. Others believe that magnetic fields dominate and control the star formation process. I think the data argue for an intermediate position – both turbulence and magnetic fields are important. Recent facilities such as the Planck satellite and SOFIA have added enormously to the data set of polarized emission from dust. ALMA offers the hope of making it possible to greatly extend observations of magnetic fields in molecular clouds, but to date ALMA has strong instrumental polarization problems that do not yet allow its tremendous power to be fully exploited. Longer term, the Square Kilometer Array may greatly extend our knowledge through H I and OH Zeeman mapping. I think the future will increasingly involve detailed computer simulations of the structure and evolution of molecular clouds that make specific predictions of polarization observations of dust and spectral lines.

Q: *You've been involved in the founding and construction of several major telescopes. Could you tell about those?*

A: In the 1980s Berkeley was trying to expand their three-antenna Hat Creek millimeter-wave array but had been unable to obtain funding. I had become familiar with the array while on a sabbatical at Berkeley, and conceived the idea of the University of Illinois partnering with Berkeley and contributing funds for the expansion. Together with Lew Snyder, I persuaded Illinois administrators to come up with about \$2M and founded a laboratory at Illinois to run our part of the construction and science project. The MIRIAD software was initially developed at this Illinois lab for the project. Later the University of Maryland joined, and BIMA (Berkeley-Illinois-Maryland Array) came into being. After many successful years, BIMA was combined with the Caltech millimeter-wave array to form CARMA (Combined ARray for Millimeter-wave Astronomy). As part of the Illinois role in computing and data management for these arrays, I eventually became Senior Associate Director at NCSA (National Center for Supercomputing Applications). In this role I helped lead NCSA to become computing partners with the Dark Energy Survey and the Large Synoptic Survey Telescope, and served for a while as a Board member of the LSST.

Q: *What are your current interests?*

A: I'm now retired, but I remain active in magnetic field observations, including as yet not fully analyzed CARMA CN 2-1 Zeeman mapping, SOFIA observations (I had the pleasure of being on a SOFIA flight last summer for polarization observations), and attempts at ALMA polarization mapping. I'm also now working on trying to finish a book on "Observations of Magnetic Fields in Molecular Clouds – Implications for Star Formation".

My Favorite Object

Westerlund 2 - Revealing the secrets of a Galactic young massive star cluster

Peter Zeidler

1 Introduction

The young massive star cluster Westerlund 2 (Wd2) was discovered by (and named after) Bengt Westerlund (Westerlund 1961). He identified it as a "fairly strong HII region", which is excited by an association of young stars including a WN6 Wolf-Rayet star (nowadays known as: WR20a). According to his analysis, Wd2 is about 6 kpc away with a varying extinction of $A_V = 1-6$ mag. In this summary we will see that, despite the limited technical capabilities, the original assessment of Westerlund (1961) is not far from modern knowledge.

Wd2 is the the central ionizing star cluster of the giant HII region RCW 49 (Rodgers et al. 1960), that comprises an estimated molecular cloud mass of $(1.7 - 7.5) \times 10^5 \, \mathrm{M}_\odot$ (Dame 2007; Furukawa et al 2009). It is located about 4 kpc away from us in the Carina-Sagittarius spiral arm, has an age of 1–2 Myr (Vargas Álvares et al., 2013; Zeidler et al., 2015), and a total stellar mass of $(3.6 \pm 0.3) \times 10^4 \, \mathrm{M}_\odot$ (Zeidler et al. 2017). These properties make Wd2 the second most massive young star cluster in the Milky Way after Westerlund 1 ($4.9 \times 10^4 \, \mathrm{M}_\odot$, Gennaro et al. 2011). The young age, close proximity to the Sun, and the many O-type stars (~ 80 expected by Moffat et al. 1991) make Wd2 a perfect testbed to study young massive star clusters (YMCs) close to their initial conditions and its stellar population down to the hydrogen burning limit. The far-ultra-violet (FUV) flux of the many OB-stars allow us to study feedback on the remainders of the surrounding HII region including possible triggered star formation.

Even with modern telescopes, observing Wd2 is challenging due to its location in the Galactic disk causing high extinction and crowding by many field stars. In 2012 we obtained high-resolution, multi-band observations of Wd2 (P.I.: A. Nota) in the optical and near-infrared using the *Hubble* Space Telescope (HST). These observations provided us with the necessary spatial resolution and depth to study the prominent pre-main-sequence (PMS) population down to sub-solar masses (see Fig. 1). The data was obtained using the Advance Camera for Surveys (ACS, Avila et al. 2017) using the $F555W$, $F814W$, and $F658N$ filters (representing V, I, and Hα) and the Wide Field Camera 3/IR (WFC3/IR, Dressel, 2018) using the $F125W$, $F160W$, and $F128N$ filters (representing J, H, and Paβ). The photometric catalog comprises a total of 17121 objects, of which 2236 were detected in all 6 filters.

2 The stellar population

In Zeidler et al. (2015) we analyzed the properties of the stellar population of Wd2. Due to its location in the Galactic disk a large fraction of the stars are foreground stars and the interstellar medium (ISM) and the remaining gas of the parental HII region significantly extincts the stellar photometry. The high extinction toward Wd2 leads to a much more reddened cluster population compared to the foreground field stars, which in turn leads to well separated populations in color-space. We used this to separate the field stars from the cluster members.

We used the Hα/Paβ flux ratio, in combination with the Cardelli et al. (1989) extinction law, to determine the $E(B-V)$ color excess of the gas. This procedure provided us with a pixel-to-pixel color excess map of the gas (see Fig. 2), with a mean stellar color excess of $E(B - V) = 1.55$ mag.

We used 13 O and B stars with a known spectral type and existing U-band photometry (Rauw et al., 2007, 2011, Vargas Álvarez et al., 2013) to transform the color excess of the gas to a color excess of the stars. Using the color-excess map, we now are able to deredden the individual stellar photometry of the cluster members, for which we show the $(F814W - F160W)_0$ vs. $F814W_0$ color-magnitude diagram (CMD, see Fig. 3) as an example. We over-plotted the MESA Isochrones & Stellar Tracks (MIST, Dotter et al 2016, Choi et al. 2016) including the zero-age main-sequence (ZAMS) for Solar metallicity ($Z = 0.0152$) and the stellar masses for the 1 Myr isochrone. By fitting multiple isochrones to various two-color diagrams (TCDs) and CMDs we determined that a combination of a total-to selective extinction of $R = 3.95$, larger than the Milky Way average of $R = 3.1$, and a distance of 4 kpc are the best
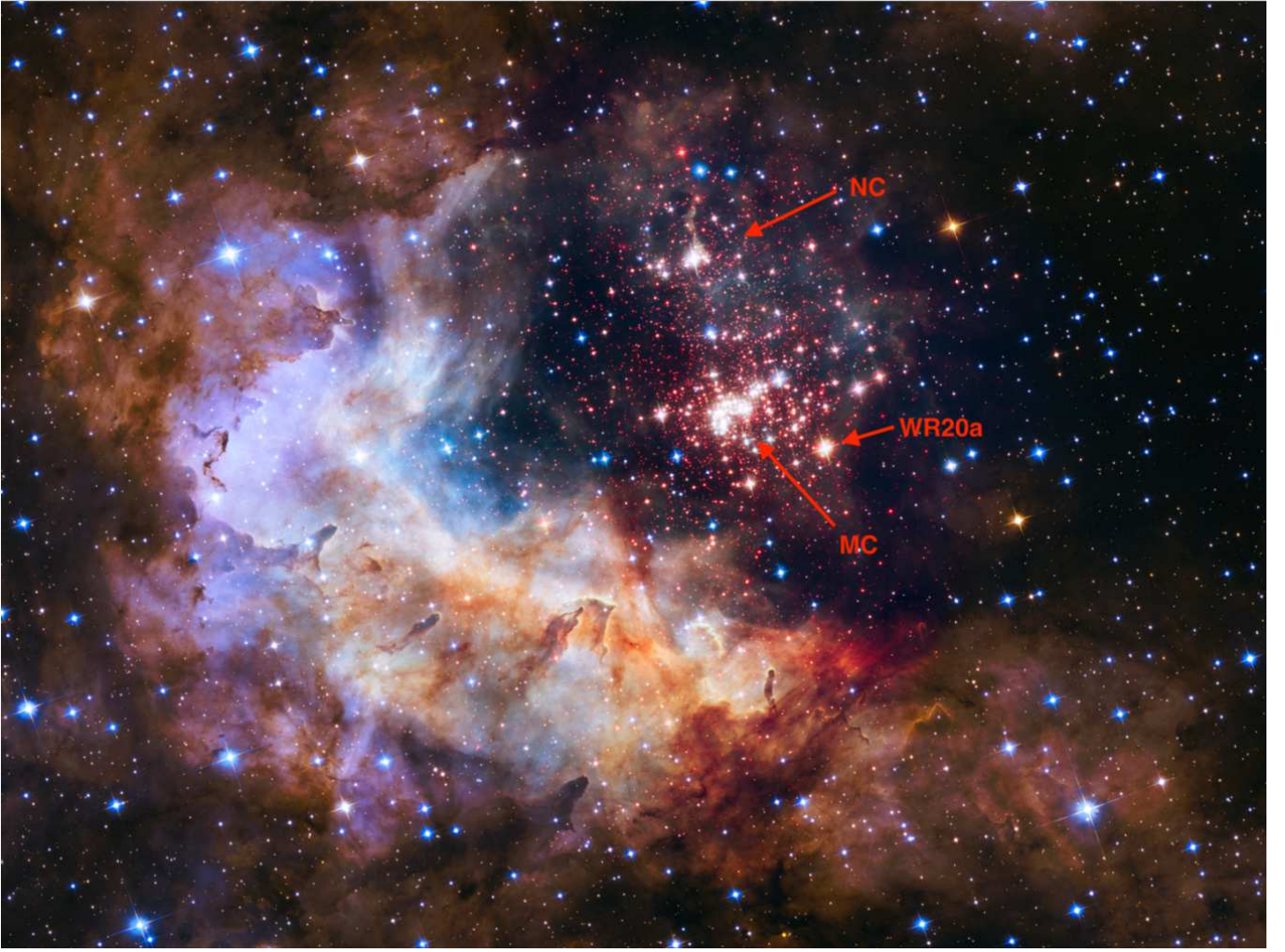
Figure 1: Color-composite image of Wd2, including the F125W (red), F814W (green), and F555W (blue) filters. North is up, East is to the left. The FOV is $4\,\text{arcmin} \times 4\,\text{arcmin}$. This image was chosen to be the official *Hubble* 25th anniversary image. *Credit: NASA, ESA, the Hubble Heritage Team (STScI/AURA), A. Nota (ESA/STScI), and the Westerlund 2 Science Team.*

fitting parameter combination. Therefore, we adopted the spectroscopically determined distance (Vargas Álvares et al. 2013) of 4.16 kpc. The mean total extinction in the visual toward Wd2 is $A_V = 6.12$ mag spanning more than 5 mag. This shows that an individual extinction correction for the photometry of the cluster stars is crucial for their detailed analysis.

Analyzing the spatial distribution of the stellar population revealed that Wd2 is built from two sub clumps, which we call the "Main Cluster" (MC) and the "Northern Clump" (NC). While the NC appears to be much sparser populated than the MC in terms of stellar density, they appear to be coeval, meaning they have the same age. The clumps are separated by about 1 pc. This leads to the conclu-

sion that they actually formed at the same time and none triggered the formation of the other. This supports hierarchical cluster formation as a possible scenario for the formation of Wd2.

Rauw et al. (2004) and Bonanos et al. (2004) took and analyzed a series of spectra from the Wolf-Rayet star WR20a. They revealed that WR20a is in fact an eclipsing binary of two O-type stars with a component mass of $83.0 \pm 3.8\,\text{M}_\odot$ and $82.0 \pm 5.0\,\text{M}_\odot$ and an orbital period of 3.675 ± 0.030 days. The spectral types of both components are WN6ha, which is close to the predicted spectral type by Westerlund (1961).
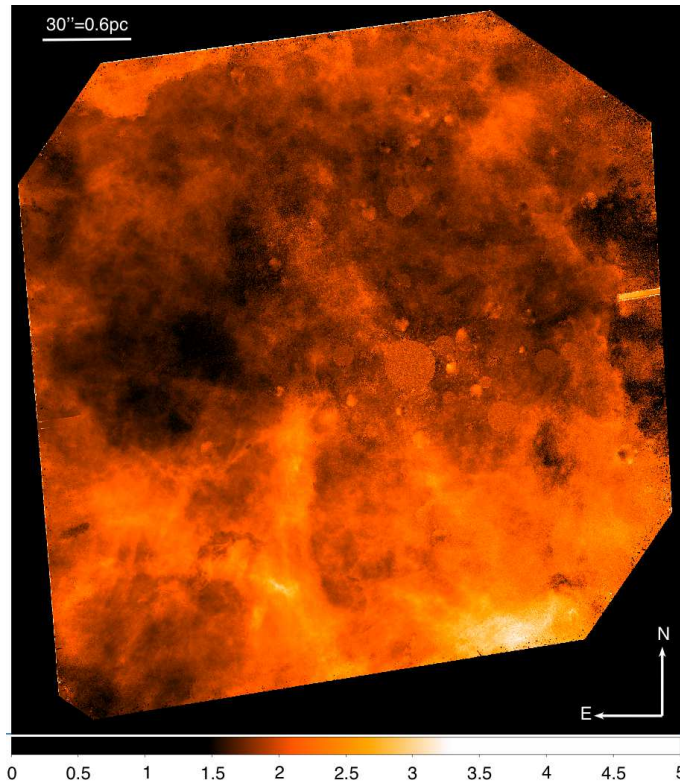
Figure 2: The pixel-to-pixel color excess map of the gas. The colorbar shows the color excess in magnitudes. This figure was published as Fig. 8 in Zeidler et al. (2015).

3 The mass function and mass segregation

One of the crucial properties of a star cluster that highly influences its evolution and its capability to be long-lived is its gravitational potential, which is defined by its total mass. To estimate the total stellar mass of Wd2 we derived its mass function (MF), which represents the completeness-corrected logarithmic number of stars per logarithmic mass bin (see Fig. 4). The only published MF that has ever been determined for Wd2 was based on ground-based photometry resulting in a slope of $\Gamma = -1.20 \pm 0.16$ and a total stellar mass of $> 10^4 \, \mathrm{M_\odot}$ (Ascenso et al. 2007). The analysis was limited by the spatial resolution of ground-based photometry and only uses stars between 8–25 $\mathrm{M_\odot}$.

To properly determine a Wd2's total stellar mass, we corrected the number of stars for observational incompleteness and assigned a mass to each star using stellar evolution tracks. Besides the photometric uncertainties for each star various other uncertainties have to be taken into account when assigning masses: the color-excess map, the distance modulus (0.175 mag), and the statistical uncer-
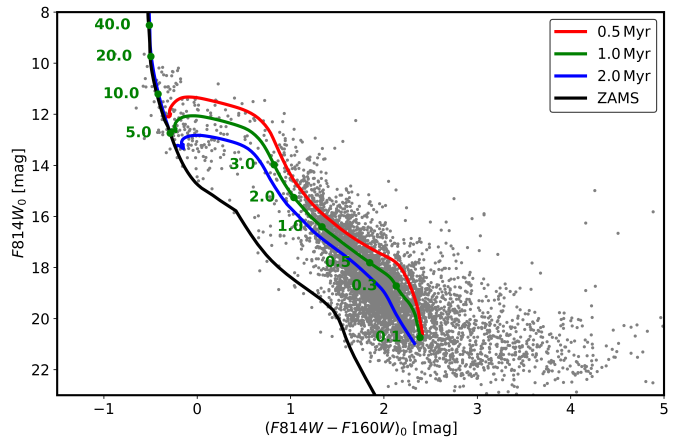

Figure 3: The color-magnitude diagram of the Wd2 cluster members. Over-plotted are various isochrones, as well as the ZAMS including the stellar masses for a 1 Myr old star.

tainty on the number of stars per mass bin (Poisson statistics) when counting the stars. Additionally, the majority of high-mass stars are in binary systems (e.g., Sana et al. 2012, 2013). For some of these stars the binary components are known from previous works (see Vargas Álvares et al., 2013, and reference therein) and we adopted them. For all other stars above 8 $\mathrm{M_\odot}$ we introduced mass uncertainties based on the two extreme cases: 1) a single star and 2) the star is an equal-mass binary. Other uncertainties that cannot be addressed directly are stellar rotation and photometric variability due to mass accretion and different, unknown circumstellar disk sizes and inclination angles.

To fit the high-mass slope of the MF we used two mass ranges ($0.65-2.0 \, \mathrm{M_\odot}$ and $6.0-100 \, \mathrm{M_\odot}$, blue shaded area in Fig. 4) excluding the turn-on (TOn) region ($2.0-6.0 \, \mathrm{M_\odot}$). This results in a slope of $\Gamma = -1.46 \pm 0.06$, steeper than the canonical Salpeter (1955) slope of $\Gamma = -1.35$. This slope agrees very well with other YMCs, such as Westerlund 1 ($\Gamma = -1.44^{+0.56}_{-0.08}$, Gennaro et al. 2011), NGC 602 ($\Gamma = -1.25 \pm 0.22$, Cignoni et al. 2009), or NGC 346 ($\Gamma = -1.87 \pm 0.41$, Sabbi et al. 2008). To calculate the total mass of Wd2 we summed the masses of all mass bins up to a 50% completeness limit (0.65 $\mathrm{M_\odot}$). For the stars with lower masses and the brown dwarf regime, we adopted and integrated over a Chabrier (2003) IMF after fitting it to the data. This leads to a total stellar mass of ($3.6 \pm 0.3) \times 10^4 \, \mathrm{M_\odot}$, which makes Wd2 the second most massive YMC in the Milky Way after Westerlund 1 ($4.9 \times 10^4 \, \mathrm{M_\odot}$, Gennaro et al. 2011).

We further analyzed the spatial dependence of the MF by dividing the cluster into 5 equally-spaced, elliptical annuli, oriented along the MC – NC axis, using the cluster's center
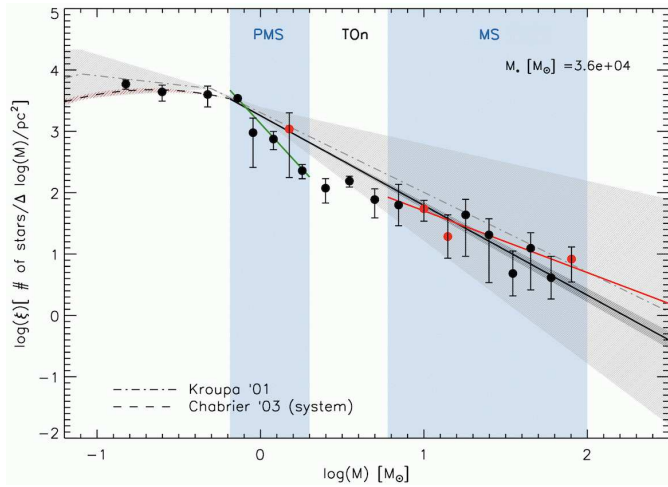
Figure 4: The mass function of Wd2. The black filled circles represent the completeness-corrected, normalized number of stars per logarithmic mass bin. The red filled circles indicate that at least on star's mass was adopted from the literature. The black solid line represents the error-weighted fit of the overall MF with the uncertainty marked as the shaded area. The dasheddotted line is the Kroupa (2001) IMF with the associated uncertainty as the gray area. The dashed line is the Chabrier (2003) IMF. The green and red solid lines indicate the PMS and main-sequence MF, respectively.

as origin. We determined the MF slope for each of these annuli with the result of an increasing slope from $\Gamma = -1.09 \pm 0.07$ in the cluster center to $\Gamma = -2.70 \pm 0.29$ in the outer periphery. A steeper MF slope means that this region contains more low-mass stars relative to high-mass stars compared to regions with a shallower slope. Conclusively, a steepening of the MF slope while moving outwards from the cluster's center means that the cluster contains more high-mass stars in the center than further outwards compared to the number of lower mass stars. This phenomenon is called mass segregation and is seen in many YMCs, such as NGC 3603 (Pang et al. 2013) or NGC 346 (Sabbi et al. 2008). Mass-segregation plays an important role for the fate of star clusters since a larger number of massive stars in the cluster center will lead to more violent feedback onto the other stars and a more drastic change in the gravitational potential as soon as the first stars will go supernovae. Ultimately, this can lead to the cluster's destruction.

Although many YMCs show mass segregation, it is still a matter of debate whether mass segregation in such young clusters is primordial, meaning that the more massive stars formed originally in the central regions of the cluster, or whether it is dynamical, implying that they formed equally

throughout the region and moved inwards due to dynamical interactions. Due to its young age the probable scenario is primordial mass segregation, since Wd2 has probably not had time to become dynamically relaxed, and the massive stars would not have had time to migrate to the center. A thorough analysis based on stellar motions will determine the dynamical state of Wd2 (see Sect. 5 for an outlook).

4 The mass-accreting PMS stars

Another aspect of YMCs is its on-going (or not completely finished) star formation process, which mainly concerns the low-mass stellar population. For Wd2 we discussed this in Zeidler et al. (2016), studying the mass accretion rates of 240 bona-fide Hα-excess emitters.

During their PMS phase, low-mass stars grow in mass by slowly accreting matter from their circumstellar disks (e.g., Lynden-Bell & Pringle 1974), which formed because of the conservation of angular momentum during the collapse of the protostellar cloud. While disk material gets accreted onto the star through the magnetic field lines connecting the inner edge of the disk and the stellar surface, this process creates strong excess emission in contrast to a normal blackbody. For classical T-Tauri stars, accretion rates ($\dot{M}_{acc}$) can be inferred from the excess emission strength of the Hα and Paβ lines (e.g., Muzerolle et al. 1998a, 1998b). The standard way of quantifying the accretion processes is through spectroscopy. To measure the line profiles and intensities medium to high-resolution spectra are needed, whose long integration times limit the number of observed stars for reasonable telescope times. Another approach is to use a narrow-band Hα filter in combination with broad-band filters such as R, V, or I, to measure the continuum (see e.g., Grebel et al. 1993 or DeMarchi et al. 2010).

DeMarchi et al. (2010) showed that the HST ACS $F555W$ and $F814W$ photometry can be combined to an R-band filter, which is a good estimate for the Hα continuum emission. Subsequently, in combination with our $E(B - V)$ extinction map, we can use the extinction-corrected $(F555W - F814W)_0$ vs. $(R - F658)_0$ TCD to select 240 bona-fide Hα excess emitters since only a fraction of PMS stars shows excess emission due to periodic mass accretion. The remaining stars are used as baseline. The measured median mass accretion rate of the 240 bona-fide stars is $\dot{M}_{acc} = (4.43 \pm 1.77) \times 10^{-8} \, M_\odot \mathrm{yr}^{-1}$.

Analyzing the mass accretion rate as a function of age showed that it decreases with age, and is therefore consistent with viscous disk evolution models (e.g., Hartmann et al. 1998). We also analyzed the dependence of the mass accretion rate on the locus of the star within the star clus-

ter. We found that the mass accretion rate increases by $\sim 68\%$ with an increasing distance to the cluster center, where most of the OB-stars are located. These stars emit a high far-ultraviolet (FUV) flux, which leads to an accelerated disk dispersal. Theoretical studies (e.g. Clarke 2007) showed that, depending on the viscosity, most disks disperse within the first 3 Myr of the star's life, which is consistent with the estimated age of 1–2 Myr for Wd2.

This knowledge is important for modeling and searching for exoplanets, since a faster dispersing disk means that planets have less time to form. Furthermore, the FUV radiation provides a harsher environment to form a planet.

5 Outlook - A 3D picture of Westerlund 2

The photometric analysis of Wd2 revealed many different properties, such as its distance and the total stellar mass. However, to determine its fate, a dynamical analysis of the stellar content is necessary. Knowing the velocity dispersion of the stars will provide information, to determine whether it will disperse in the future due to abrupt changes in the gravitational potential and violent gas expulsion caused by supernova explosions of the massive OB stars, or if it remains gravitationally bound and will be long-lived.

Our group (Antonella Nota, Elena Sabbi, Peter Zeidler, and many other collaborators) is leading two successful proposals, which are both in the process of being observed and analyzed. One is a multi-epoch follow-up HST observation (P.I.: Elena Sabbi) to measure the proper motions of the cluster members and reveal the binary fraction of the stellar population down to $1\,M_\odot$ including orbital solutions. The other proposal covers ground-based observations with the integral field unit (IFU) MUSE mounted on the Very Large Telescope (P.I.: P. Zeidler). MUSE is an optical ($4650\,\text{Å}$–$9300\,\text{Å}$) instrument with a field-of-view (FOV) of $1\,\text{arcmin}^2$ and a medium spectral resolution of $R = 2000$–4000. The large FOV has made it possible for the first time to completely map Galactic YMCs spectroscopically with a reasonable amount of telescope time. A combination of short and long exposures provides the dynamic range to measure stellar radial velocities from the most massive OB-stars down to 1–$2\,M_\odot$. Using IFUs also has the advantage that we observe not only the spectra of the stars but also of the surrounding gas and, especially, the interaction between a central ionizing star cluster and the gas.

With the proper motions and radial velocities we will determine 3D motions of the stellar population of Wd2 to accuracy of a few km/s. Knowing the binary population will help to accurately determine Wd2's velocity dispersion to estimate the long-term survivability of this cluster and whether it is a possible progenitor of a massive globular cluster. With the MUSE data we will obtain a catalog of the spectral types of PMS stars and their spectral-energy distributions. We will also analyze the feedback of the stars, especially the high ionizing flux of the massive OB-stars on the surrounding gas cloud to see whether there is triggered active star formation.

Combining the high-precision multi-epoch HST photometry with the MUSE IFU spectroscopy of Wd2 will give us, for the first time, the full multi-phase 3D information needed to push forward the observational knowledge about the evolution of resolved YMCs, which will provide information to interpret more massive yet spatially unresolved YMCs in the more distant Universe.

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Perspective

Massive Star Formation

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1   Introduction

Massive stars shine bright across the Galaxy and the Universe, yet have enigmatic beginnings. Astrophysicists have long realized that these stars, i.e., with $\gtrsim 8\,M_\odot$ that eventually explode as supernovae, have crucial radiative, mechanical and chemical feedback on the cosmos. Thus it is surprising that the massive star formation mechanism remains so much debated, with consensus not yet reached on the relative importance of *Core Accretion*, *Competitive Accretion* and *Protostellar Collision* models. However, with improving theoretical and observational techniques, rapid progress is being made to literally resolve the process.

Here I describe theoretical and observational studies of local, Galactic massive star formation, giving a brief historical overview and then concentrating on developments since the reviews of Tan et al. (2014 [T14]) and offering a somewhat different perspective compared to the review of Motte et al. (2017). Interested readers can also refer to Tan (2017), which presents a more extensive discussion, including a focus on astrochemical aspects.

We use the term *clump* for a self-gravitating molecular cloud that fragments into a star cluster, perhaps via a population of self-gravitating prestellar *cores* (PSCs). These cores are defined to be structures that collapse to a central, rotationally-supported disk leading to single stars or small-N multiples formed by disk fragmentation. As massive stars tend to form in clusters (e.g., de Wit et al. 2005), massive star formation and cluster formation are connected processes that need to be understood together.

2   Theoretical Models

The most basic, conservative way to understand massive star formation is to generalize *Core Accretion* models of low-mass star formation (e.g., Shu, Adams & Lizano 1987). This approach was adopted by many groups: e.g., Myers & Fuller (1992); Caselli & Myers (1995); Bernasconi & Maeder (1996); McLaughlin & Pudritz (1997); Osorio et al. (1999); Nakano et al. (2000); Behrend & Maeder (2001). However, these models involved a huge range of accretion rates, $\dot{m}_* \sim 10^{-5}$ to $10^{-2}\,M_\odot\,\mathrm{yr}^{-1}$. The smallest of these implied very long formation times, incompatible with massive stellar evolution timescales. Other potential problems for Core Accretion included whether radiation pressure feedback could be overcome, how massive PSCs resist fragmentation and how such cores exist in crowded centers of protocluster clumps (Stahler et al. 2000).

These perceived difficulties led to radical proposed alternatives. *Protostellar Collisions* were invoked as a way to build up the most massive stars in dense regions (Bonnell, Bate & Zinnecker 1998), with this mechanism immune to feedback given the optically thick nature of the protostars. While a merger has been proposed to explain the closest massive protostar in Orion KL, due to its "explosive" outflow (Bally & Zinnecker 2005), collisions are not thought to be of general importance as $\gtrsim 10^8\,\mathrm{pc}^{-3}$ stellar densities are needed for efficient growth in $\sim 1\,\mathrm{Myr}$ timescales.

Competitive Accretion was proposed as a means of naturally producing the entire stellar mass spectrum, with prediction that massive stars require the presence of a cluster of lower-mass stars to form (Bonnell et al. 2001; Bate 2012). After initial fragmentation at the thermal Bonnor-Ebert scale, typically $\ll 1\,M_\odot$ in dense clumps, low-mass protostellar seeds gather more mass by Bondi-Hoyle accretion, mostly in the clump center that is fed by global collapse from larger scales. There are no massive prestellar cores and the accretion process is more chaotic, leading to smaller disks and less ordered outflows. Simulations that included magnetic fields and outflow feedback that stabilized the protocluster clump in quasi-virial equilibrium with relatively low (few %) star formation efficiencies per free-fall time (Wang et al. 2010), also formed massive stars via Competitive Accretion. Here the overall time to form the most massive, i.e., $\sim 50\,M_\odot$, star was $\sim 1\,\mathrm{Myr}$, thus having an average accretion rate of $5 \times 10^{-5}\,M_\odot\,\mathrm{yr}^{-1}$.

Following an original proposal by Chris McKee and building on ideas already discussed by Stahler, Shu & Taam (1980), the *Turbulent Core Model* (TCM) for massive star formation was presented as a way to overcome the apparent difficulties facing Core Accretion models (McKee & Tan 2002, 2003 [MT03]). The basic assumption is that massive PSCs exist and can be approximated as virialized pressure-bounded polytropic spheres, with surface pres-

sure set by the self-gravitating weight of the surrounding clump gas, i.e., $P \sim G\Sigma_{\rm cl}^2$. In the high pressure environments relevant to observed regions of massive star formation, i.e., with mass surface densities $\Sigma_{\rm cl} \sim 1\,{\rm g\,cm^{-2}}$ (Plume et al. 1997; Shirley et al. 2003), massive cores and clumps would need to be supported against collapse by nonthermal means, i.e., some combination of turbulence and B-fields. High pressures cause the cores to be small, thus mitigating the crowding problem. Cores are also dense, leading to short formation times ($\sim 10^5\,{\rm yr}$) and high accretion rates ($\gtrsim 10^{-4}\,M_\odot\,{\rm yr^{-1}}$) that help overcome feedback, especially via an optically thick accretion disk (Jijina & Adams 1996; Yorke & Sonnhalter 2002). During collapse to a massive star, cores interact with, and possibly accrete, an amount of clump gas similar to their initial PSC mass. Cores have some turbulence-induced substructure, but fragmentation is expected to be suppressed either by chance conditions in the turbulent clump (as massive stars are, after all, rare objects and most protocluster mass does end up fragmenting into lower-mass stars) and/or via magnetic support. Once a massive protostar develops, its local heating of its infall envelope, along with its tidal field, would also act to suppress fragmentation. Later numerical simulations validated these proposed effects of radiative feedback (e.g., Krumholz et al. 2009) and magnetic fields (e.g., Seifried et al. 2011; Myers et al. 2013).

Further theoretical work on the TCM has included study of the deuteration astrochemistry relevant to the formation of PSCs (Kong et al. 2015), together with coupling of these models to MHD simulations of early core evolution (Goodman et al. 2016; see also Körtgen et al. 2017). The time needed to form massive PSCs and how this occurs from the clump (e.g., top-down fragmentation or bottom-up growth by mergers of smaller PSCs) are open questions.

For the protostellar core stage, there has been development of semi-analytic treatments of the density structures of the infall envelope, accretion disk and magnetocentrifugal (disk wind) outflows, which, together with protostellar evolution modeling, are then coupled to radiative transfer simulations treating continuum opacities of gas & dust (Zhang & Tan 2011; Zhang, Tan & McKee 2013a; Zhang, Tan & Hosokawa 2014). A model grid that can be used to fit observed spectral energy distributions (SEDs) has been released (Zhang & Tan 2018), exploring the two main parameters of TCM initial conditions, i.e., core mass (M_c) and clump environment mass surface density ($\Sigma_{\rm cl}$), so far sampled from 10 to 480 $M_\odot$ and 0.1 to 3 ${\rm g\,cm^{-2}}$, respectively, along with the variable of protostellar mass (m_*) for each of these cores, i.e., at 0.5, 1, 2, 4 $M_\odot$, ... etc., tracing evolutionary state until the core is exhausted or expelled by disk wind feedback. This feedback clears outflow cavities that widen as the protostar grows in mass, with final star formation efficiencies from the core of ~ 0.5,

with modest dependencies on M_c & $\Sigma_{\rm cl}$. Tanaka et al. (2017a) considered the combined effects of radiative and mechanical (outflow & stellar wind) feedback, concluding disk wind driven outflows are dominant even into the high-mass regime. Photoionization in these models, i.e., initially of disk wind "outflow-confined HII regions" (Tan & McKee 2003), that leads to the appearance of radio "jets" has been calculated by Tanaka et al (2016, 2017b). Other Core Accretion studies include axisymmetric, 2D simulations of mechanical & radiative feedback from massive protostars (Kuiper et al. 2015, 2016) and 3D radiative feedback only simulations (Rosen et al. 2016; Harries et al. 2017). Note that, as in low-mass star formation (e.g., Zhao et al. 2016), theoretical prediction of disk sizes and properties depends on the uncertain initial magnetic field strength and structure in the core, along with uncertain modeling of the ionization fractions of gas and dust.

3 Observational Tests

3.1 The Hunt for Massive Prestellar Cores

Although traditionally viewed as a "low-mass" PSC, L1544 is actually relatively massive, i.e., $\sim 8\,M_\odot$ (Caselli & Ceccarelli 2012). Importantly, it appears to have very slow, subsonic infall at speeds $< 10\%$ of free-fall, which requires presence of dynamically strong B-fields (Keto et al. 2015). From studies of nearby examples like L1544, PSCs are known to be very cold, e.g., reaching down to ~ 6 K in their centers. Thus detecting PSCs in mm/sub-mm continuum may be very challenging. With this point in mind, a focus was made on using MIR extinction (MIREX) maps to find the densest, coldest structures in Infrared Dark Clouds (IRDCs) (Butler & Tan 2009, 2012 [BT12]). Using *Spitzer*-IRAC 8 μm images with 2" resolution, "cores" with radii of ~ 0.1 pc could be characterized in IRDCs out to ~ 5 kpc. However, with typical *Spitzer*-GLIMPSE (Churchwell et al. 2009) sensitivities, the MIREX maps "saturate" at $\Sigma \sim 0.5\,{\rm g\,cm^{-2}}$, i.e., such regions become too optically thick, so the estimated Σ is a lower limit. MIREX and FIR extinction maps at longer wavelengths can in principle probe to higher Σ's (Lim & Tan 2014), but images from *Spitzer*-MIPS at 24 μm and *Herschel*-PACS at 70 μm have relatively poor 6" resolution.

Nevertheless, BT12 identified dense structures, without obvious IR sources. Being dark even at 70 μm implies they are cold ($\lesssim 15$ K). These IRDC cores/clumps have $\sim 100\,M_\odot$ on scales of ~ 0.1 pc, i.e., contain hundreds of Jeans masses. BT12 anticipated that strong B-fields (~ 1 mG) are present to limit fragmentation and allow quasi equilibrium conditions. From the high degree of relatively ordered polarization pseudo-vectors of dust continuum emission, such B-fields have since been inferred to be
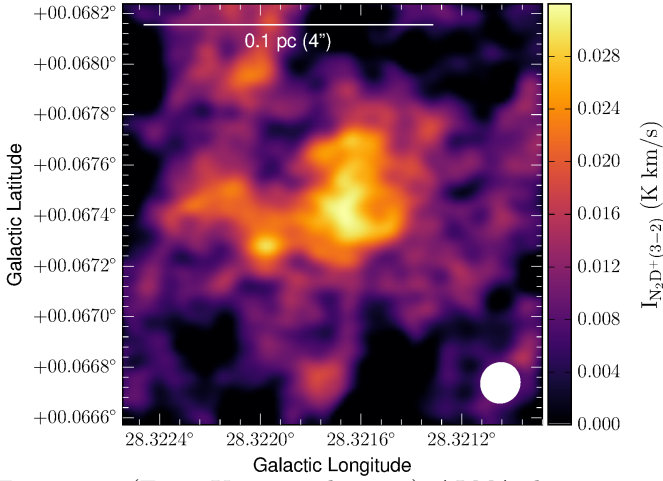
Figure 1: (From Kong et al. 2018) *ALMA* observations of integrated intensity of $N_2D^+(3-2)$ emission (0.5" resolution) from the C1-South massive PSC candidate.

present on both large (> 1 pc) (Pillai et al. 2015) and small (~ 0.1 pc) (Beuther et al. 2018) scales in IRDCs.

To search for massive PSCs at higher resolution, *ALMA* has been used to probe dust continuum and molecular line emission. Studies of nearby lower-mass PSCs show that CO freezes out rapidly onto dust in cold ($\lesssim 20$ K), dense conditions (e.g., Caselli et al. 1999). Then, if the ortho-to-para ratio of H_2 falls to low values, abundances of deuterated species H_2D^+ & N_2D^+ rise by orders of magnitude, so these molecular ions, especially N_2D^+, are promising diagnostics of PSCs. Following up four of the BT12 MIREX map peaks, Tan et al. (2013) identified six PSC candidates via $N_2D^+(3-2)$ emission. Further observations of the strongest source, C1-S, found protostellar outflows in its vicinity (Tan et al. 2016), but analysis of the highest resolution data (Kong et al. 2018) indicates that C1-S, as defined by its N_2D^+ emission, is spatially and kinematically distinct from the protostars and is thus a promising massive PSC candidate (Fig. 1). Based on mm dust continuum emission, C1-S's mass is $\sim 50\,M_\odot$ inside a radius of 0.045 pc, implying a mean density of $n_H \sim 4 \times 10^6 \mathrm{cm}^{-3}$. Note, due to systematically cooler temperatures, PSCs like C1-S do not stand out as strong continuum sources, especially compared to protostellar cores. C1-S's velocity dispersion is 0.28 km/s, $\sim 1/3$ of that expected from virial equilibrium of a fiducial TCM. To be virialized would require stronger large-scale B-fields, ~ 3 mG, so that the Alfvén Mach number is ~ 0.2. Astrochemical modeling of the observed deuteration level of C1-S (Kong et al. 2016) implies the core is at least several times older than its local free-fall time, consistent with the strong B-field scenario.

To find more PSCs, Kong et al. (2017) searched 30 IRDC clumps for $N_2D^+(3-2)$. Analysis of the 6 strongest cores,

along with the 6 cores of Tan et al. (2013), finds mean velocity dispersions that are similar, within a factor ~ 0.8, to the fiducial virial equilibrium prediction of the TCM.

Cyganowski et al. (2014) reported G11.920.61-MM2 as a massive PSC candidate. However, nondetection of molecular lines from this source is peculiar and makes it difficult to assess the reliability of the structure, e.g., via a dynamical mass measurement. The Cygnus X N53 MM2 core (Bontemps et al. 2010) and G11P6-SMA1 (Wang et al. 2014) are other potential massive PSCs based on the absence of obvious outflows (see also Motte et al. 2017). Sanhueza et al. (2017) searched IRDC G028.23-00.19 finding five PSCs with masses up to $\sim 15\,M_\odot$.

Motte et al. (2007) and Russeil et al. (2010) (see also Motte et al. 2017) estimated massive PSC and starless clump lifetimes as short as $\lesssim 1$ to 3×10^4 yr in Cygnus X and NGC6334/NGC6357 by comparing to numbers of O to B3 stars and assigning a timescale of a few Myr to these stars. In addition to the difficulty of identifying PSCs via dust continuum if they are systematically colder than protostellar cores and the ambient clump (e.g., Russeil et al. adopt 20 K for PSC mass estimates), another potential problem with this analysis is that only cores/clumps of $\geq 40\,M_\odot$ & $\geq 200\,M_\odot$ were counted in Cygnus X & NGC6334/NGC6357, respectively. In the fiducial TCM, PSCs with masses as low as $\sim 16\,M_\odot$ (and perhaps even initially as low as $\sim 8\,M_\odot$) are able to produce $\sim 8\,M_\odot$ stars, i.e., B3 stars on the zero age main sequence. These differences of temperature, i.e., 10 K vs 20 K, and minimum core mass, i.e., $16\,M_\odot$ vs $40\,M_\odot$, combine to yield a factor of 20 in demographic lifetime estimates (for Salpeter core mass distribution up to $240\,M_\odot$), so massive PSC lifetimes in these regions may be $> 10^5$ yr, perhaps by a large factor depending on sample completeness.

3.2 Dissecting Massive Protostellar Cores

Csengeri et al. (2017) studied mm dust continuum emission from 35 IR quiet clumps, finding massive, protostellar cores with limited fragmentation: $\sim 90\%$ are dominated by just one or a few cores. Presence of strong B-fields is a plausible explanation for this modest degree of fragmentation. However, Cyganowski et al. (2017) found a high degree of fragmentation in G11.92-0.61. Still, if massive stars form in an unbiased way in protoclusters, then, even for Core Accretion models, one expects that many lower-mass cores should be found in their vicinity. Ultimately, systematic studies of the core mass function (e.g., Cheng et al. 2018; Liu et al. 2018; Motte et al. 2018) and PSC mass function and their spatial & kinematic distributions near massive protostars (e.g., Fontani et al. 2008; Sánchez-Monge et al. 2013) are needed to understand how clump fragmentation impacts massive star formation.

Dynamically strong, $\sim$mG, B-fields in massive protostellar cores have been found by mm/sub-mm polarization observations (Girart et al. 2009; Zhang et al. 2014), while $\sim$ 20 mG field strengths are reported within $\sim$ 10^3 AU of Cep A HW2 (Vlemmings et al. 2010) via 6.7 GHz methanol masers. Infall has been detected in 9 sources by Wyrowski et al. (2016), who find slow infall speeds: $\sim$ 10% of free-fall. Processes that may slow infall include support from B-fields and/or maintenance of turbulence by outflows and accretion. Goddi et al. (2018) have presented high angular resolution observations of 3 massive protostars, finding "filamentary streamers" that are interpreted as structured accretion flows feeding relatively small ($\lesssim$100 AU) disks, not yet resolved in these systems.

Ilee et al. (2016) and Beuther et al. (2017) have reported massive protostellar disks via CH_3CN. Sanna et al. (2018) found evidence for a $\lesssim$3000 AU disk with accretion rate of $6\times10^{-4}M_\odot\mathrm{yr}^{-1}$ around a potential O-type star. Ginsburg et al. (2018) presented 12 AU resolution imaging of the closest massive protostar, Source I in Orion KL, inferring a Keplerian disk around a 15 $M_\odot$ protostar.

Collimated outflows are often a feature of massive protostars (e.g., Beuther et al. 2002; Duarte-Cabral et al. 2013). Hirota et al. (2017) found evidence of rotation near the base of the outflow of Orion Source I, consistent with disk wind models. During the later stages of formation and for more massive systems, outflows are expected to become photoionized by the protostar. Ionized, collimated outflows traced as radio continuum "jets" have been seen in many sources (e.g., Gibb et al. 2003; Guzmán et al. 2014; Sanna et al. 2018), although the relative importance of shock- vs photoionization remains to be established. Cm continuum emission from ionized gas is the most useful method to identify locations of massive protostars over a range of evolutionary stages (e.g., Rosero et al. 2016). A growing sample of massive protostars now have IR to mm SEDs well-characterized and fit to predictions of the TCM (De Buizer et al. 2017). Elongation in 10 to $40\,\mu$m images is expected along the outflow cavity and this information helps to test radiative transfer models. One goal of such studies is to see to what extent axisymmetric protostellar models can explain observed dust continuum and, eventually, spectral line morphologies.

One example of a massive protostar that exhibits several features expected in Core Accretion models is G328.3-0.5 (Csengeri et al. 2018, Fig. 2). A protostar with 1.3×10^4 $L_\odot$, i.e., $m_* \sim$ 11 to 16 $M_\odot$, is observed as an isolated mm continuum peak, with CH_3OH emission potentially tracing a centrifugal barrier around a disk that is several hundred AU in radius. The protostar drives a collimated, symmetric bipolar outflow. The full extent of the redshifted lobe appears contained within the field of view, indicating that the orientation of the outflow has remained
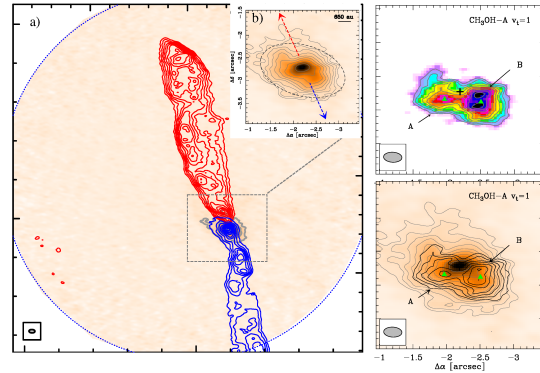

Figure 2: (Adapted from Csengeri et al. 2018) *ALMA* observations of G328.3-0.5, a massive protostar driving a collimated bipolar outflow (left: fast blue- & redshifted CO(3-2); color scale & contour show 345 GHz dust continuum), with limited fragmentation (inset: zoom-in of 345 GHz continuum), and kinematic evidence for a centrifugal barrier around a 15 $M_\odot$ protostar (top right: integrated intensity of $v_t = 1$ CH_3OH at 334.4 GHz; black cross is dust continuum peak; green triangles local CH_3OH peaks showing $\sim \pm 4.5$ km/s offsets from source radial velocity; bottom right: as top, but color scale shows dust continuum & CH_3OH emission as black contours).

approximately constant over the entire accretion history. An example of a much larger ($\gtrsim$10 pc) massive protostellar outflow with apparently stable orientation has been reported in the LMC (McLeod et al. 2018).

Such order & symmetry in core/outflow features, especially maintained over large scales in space and time, along with limited source multiplicity on $\sim$ 0.1 pc scales, is not expected in Competitive Accretion & Protostellar Collision models. Core Accretion models may also show spatial asymmetries, e.g., due to low-order multiplicity arising from disk fragmentation and/or disk axis precession due to turbulent infall, as well as time variability, e.g., due to disk instabilities. Accretion bursts found by luminosity variations are reported by Caratti o Garatti et al. (2017) and Hunter et al. (2017). There are relatively few examples of more disordered outflows around massive protostars: the Orion KL outflow, likely driven by Source I (Bally et al. 2017); and an older example of such an outflow in DR21 (Zapata et al. 2013). Occasional dynamical interaction among protostars and young stellar objects, some of which are then ejected as fast-moving "runaway" stars (Luhman et al. 2017; Farias & Tan 2018), and with tidally-enhanced accretion from pre-existing disks, is one potential way of creating these types of "explosive" outflows.

4 Summary and Outlook

Theoretical models of massive star formation are advancing rapidly. Still, care is needed on adopting realistic initial conditions, including cases with strong B-fields and following non-ideal MHD processes (e.g., Higuchi et al. 2018). At later stages, it remains challenging to resolve these processes in disks that extend all the way in to the protostar and self-consistently launch outflows (e.g., Matsushita et al. 2018), while also treating radiative feedback.

Observationally, the search for massive PSCs continues. They are likely to be faint in sub-mm continuum emission, so deuterated species may be key for identification. Demographic studies can be subject to large systematic uncertainties, including mass estimates and choice of threshold masses to define the populations. The sample of massive protostars with high resolution IR to cm observations is growing rapidly, so statistically significant tests of different accretion models are now possible, including effects of environment. Initial results indicate that Core Accretion models are valid descriptions in some cases. Across the evolutionary sequence, B-fields may have dynamical importance in limiting fragmentation, regulating disk sizes and driving outflows that set core to star formation efficiencies, and so improved methods of observing B-field strengths and morphologies are crucial.

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Magnetic field in a circumbinary disk around a Class I YSO

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We use polarization observations of a circumbinary disk to investigate how the polarization properties change at distinct frequency bands. Our goal is to discern the main mechanism responsible for the polarization through comparison between our observations and model predictions. We used ALMA to perform full polarization observations at 97.5 GHz, 233 GHz and 343.5 GHz. The target is the Class I object BHB07-11, which is the youngest object in the Barnard 59 protocluster. Complementary VLA observations at 34.5 GHz revealed a binary system within the disk. We detect an extended and structured polarization pattern remarkably consistent among all three bands. The distribution of polarized intensity resembles a horseshoe shape with polarization angles following this morphology. From the spectral index between bands 3 and 7, we derive a dust opacity index $\beta \sim 1$ consistent with maximum grain sizes larger than expected to produce self-scattering polarization in each band. The polarization morphology do not match predictions from self-scattering. On the other hand, marginal correspondence is seen between our maps and predictions from radiation field assuming the brightest binary component as main radiation source. Molecular line data from BHB07-11 indicates disk rotation. We produced synthetic polarization maps from a rotating magnetized disk model assuming combined poloidal and toroidal magnetic field components. The magnetic field vectors (i.e., the polarization vectors rotated by 90°) are better represented by a model with poloidal magnetic field strength about 3 times the toroidal one. The similarity of our polarization patterns among the three bands provides a strong evidence against self-scattering and radiation fields. On the other hand, our data are reasonably well reproduced by a model of disk with toroidal magnetic field components slightly smaller than poloidal ones.

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Planet-driven spiral arms in protoplanetary disks: I. Formation mechanism

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Protoplanetary disk simulations show that a single planet can excite more than one spiral arm, possibly explaining recent observations of multiple spiral arms in some systems. In this paper, we explain the mechanism by which a planet excites multiple spiral arms in a protoplanetary disk. Contrary to previous speculations, the formation of both primary and additional arms can be understood as a linear process when the planet mass is sufficiently small. A planet resonantly interacts with epicyclic oscillations in the disk, launching spiral wave modes around the Lindblad resonances. When a set of wave modes is in phase, they can constructively interfere with each other and create a spiral

arm. More than one spiral arm can form because such constructive interference can occur for different sets of wave modes, with the exact number and launching position of spiral arms dependent on the planet mass as well as the disk temperature profile. Non-linear effects become increasingly important as the planet mass increases, resulting in spiral arms with stronger shocks and thus larger pitch angles. This is found in common for both primary and additional arms. When a planet has a sufficiently large mass ($\gtrsim 3$ thermal masses for $(h/r)_p = 0.1$), only two spiral arms form interior to its orbit. The wave modes that would form a tertiary arm for smaller mass planets merge with the primary arm. Improvements in our understanding of the formation of spiral arms can provide crucial insights into the origin of observed spiral arms in protoplanetary disks.

Planet-driven spiral arms in protoplanetary disks: II. Implications

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We examine whether various characteristics of planet-driven spiral arms can be used to constrain the masses of unseen planets and their positions within their disks. By carrying out two-dimensional hydrodynamic simulations varying planet mass and disk gas temperature, we find that a larger number of spiral arms form with a smaller planet mass and a lower disk temperature. A planet excites two or more spiral arms interior to its orbit for a range of disk temperature characterized by the disk aspect ratio $0.04 \leq (h/r)_p \leq 0.15$, whereas exterior to a planet's orbit multiple spiral arms can form only in cold disks with $(h/r)_p \lesssim 0.06$. Constraining the planet mass with the pitch angle of spiral arms requires accurate disk temperature measurements that might be challenging even with ALMA. However, the property that the pitch angle of planet-driven spiral arms decreases away from the planet can be a powerful diagnostic to determine whether the planet is located interior or exterior to the observed spirals. The arm-to-arm separations increase as a function of planet mass, consistent with previous studies; however, the exact slope depends on disk temperature as well as the radial location where the arm-to-arm separations are measured. We apply these diagnostics to the spiral arms seen in MWC 758 and Elias 2-27. As shown in Bae et al., planet-driven spiral arms can create concentric rings and gaps, which can produce more dominant observable signature than spiral arms under certain circumstances. We discuss the observability of planet-driven spiral arms versus rings and gaps.

The Galactic Census of High- and Medium-mass Protostars. IV. Molecular Clump Radiative Transfer, Mass Distributions, Kinematics, and Dynamical Evolution

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We present ^{12}CO, ^{13}CO, & C^{18}O data as the next major release for the CHaMP project, an unbiased sample of Galactic molecular clouds in $l = 280°$–$300°$. From a radiative transfer analysis, we self-consistently compute 3D cubes of optical depth, excitation temperature, and column density for $\sim$300 massive clumps, and update the $I_{^{12}CO}$-dependent CO$\rightarrow$H$_2$ conversion law of Barnes et al. (2015). For $N \propto I^p$, we find $p = 1.92\pm0.05$ for the velocity-resolved conversion law aggregated over all clumps. A practical, integrated conversion law is $N_{^{12}CO} = (4.0\pm0.3)\times10^{19}\mathrm{m}^{-2} I_{^{12}CO}{}^{1.27\pm0.02}$, confirming an overall 2$\times$ higher total molecular mass for Milky Way clouds, compared to the standard X factor.
We use these laws to compare the kinematics of clump interiors with their foreground ^{12}CO envelopes, and find

evidence that most clumps are not dynamically uniform: irregular portions seem to be either slowly accreting onto the interiors, or dispersing from them. We compute the spatially-resolved mass accretion/dispersal rate across all clumps, and map the local flow timescale. While these flows are not clearly correlated with clump structures, the inferred accretion rate is a statistically strong function of the local mass surface density Σ, suggesting near-exponential growth or loss of mass over effective timescales $\sim$30–50 Myr. At high enough Σ, accretion dominates, suggesting gravity plays an important role in both processes. If confirmed by numerical simulations, this sedimentation picture would support arguments for long clump lifetimes mediated by pressure confinement, with a terminal crescendo of star formation, suggesting a resolution to the 40-yr-old puzzle of the dynamical state of molecular clouds and their low star formation efficiency.

The body of the paper is at http://www.astro.ufl.edu/~pjb/research/champ/papers/champIV.pdf
Four large Appendices (approx. 80–160 Mb each) are also available, at
http://www.astro.ufl.edu/∼pjb/research/champ/papers/champIV-appxA.pdf
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Fragmentation and disk formation during high-mass star formation: The IRAM NOEMA (Northern Extended Millimeter Array) large program CORE

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Context: High-mass stars form in clusters, but neither the early fragmentation processes nor the detailed physical processes leading to the most massive stars are well understood.
Aims: We aim to understand the fragmentation as well as the disk formation, outflow generation and chemical processes during high-mass star formation on spatial scales of individual cores.
Methods: Using the IRAM Northern Extended Millimeter Array (NOEMA) in combination with the 30 m telescope, we have observed in the IRAM large program CORE the 1.37 mm continuum and spectral line emission at high angular resolution ($\sim$0.4$''$) for a sample of 20 well-known high-mass star-forming regions with distances below 5.5 kpc and luminosities larger than $10^4 \, L_\odot$.
Results: We present the overall survey scope, the selected sample, the observational setup and the main goals of CORE. Scientifically, we concentrate on the mm continuum emission on scales on the order of 1000 AU. We detect strong mm

continuum emission from all regions, mostly due to the emission from cold dust. The fragmentation properties of the sample are diverse. We see extremes where some regions are dominated by a single high-mass core whereas others fragment into as many as 20 cores. A minimum-spanning-tree analysis finds fragmentation at scales on the order of the thermal Jeans length or smaller suggesting that turbulent fragmentation is less important than thermal gravitational fragmentation. The diversity of highly fragmented versus singular regions can be explained by varying initial density structures and/or different initial magnetic field strengths.

Conclusions: A large sample of high-mass star-forming regions at high spatial resolution allows us to study the fragmentation properties of young cluster-forming regions. The smallest observed separations between cores are found around the angular resolution limit which indicates that further fragmentation likely takes place on even smaller spatial scales. The CORE project with its numerous spectral line detections will address a diverse set of important physical and chemical questions in the field of high-mass star formation.

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Spectroastrometric Study of Ro-vibrational CO Emission from the Herbig Ae star HD 179218 with iSHELL on the NASA Infrared Telescope Facility

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We present analysis of commissioning $M-$band data acquired with the infrared echelle spectrograph (iSHELL) on *NASA's Infrared Telescope Facility*. In this paper we describe the delivered performance of the instrument for these $M-$band observations and the data reduction process. The feasibility of using iSHELL for spectro-astrometry is tested on the Herbig Ae/Be star HD 179218 and we show that sub-milliarcsecond fidelity is achievable.

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Dusty disc-planet interaction with dust-free simulations

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Protoplanets may be born into dust-rich environments if planetesimals formed through streaming or gravitational instabilities, or if the protoplanetary disc is undergoing mass loss due to disc winds or photoevaporation. Motivated by this possibility, we explore the interaction between low mass planets and dusty protoplanetary discs with focus on disc-planet torques. We implement Lin & Youdin's newly developed, purely hydrodynamic model of dusty gas into the PLUTO code to simulate dusty protoplanetary discs with an embedded planet. We find that for imperfectly coupled dust and high metallicity, e.g., Stokes number 10^{-3} and dust-to-gas ratio $\Sigma_{\rm d}/\Sigma_{\rm g} = 0.5$, a 'bubble' develops inside the planet's co-orbital region, which introduces unsteadiness in the flow. The resulting disc-planet torques sustain large amplitude oscillations that persists well beyond that in simulations with perfectly coupled dust or low dust-loading, where co-rotation torques are always damped. We show that the desaturation of the co-rotation torques by finite-sized particles is related to potential vorticity generation from the misalignment of dust and gas densities. We briefly discuss possible implications for the orbital evolution of protoplanets in dust-rich discs. We also demonstrate Lin & Youdin's dust-free framework reproduces previous results pertaining to dusty protoplanetary discs, including dust-trapping by pressure bumps, dust settling, and the streaming instability.

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Infall Signatures in a Prestellar Core embedded in the High-Mass 70 μm Dark IRDC G331.372-00.116

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Using Galactic Plane surveys, we have selected a massive (1200 $M_\odot$), cold (14 K) 3.6-70 μm dark IRDC G331.372-00.116. This IRDC has the potential to form high-mass stars and, given the absence of current star formation signatures, it seems to represent the earliest stages of high-mass star formation. We have mapped the whole IRDC with the Atacama Large Millimeter/submillimeter Array (ALMA) at 1.1 and 1.3 mm in dust continuum and line emission. The dust continuum reveals 22 cores distributed across the IRDC. In this work, we analyze the physical properties of the most massive core, ALMA1, which has no molecular outflows detected in the CO (2-1), SiO (5-4), and H_2CO (3-2) lines. This core is relatively massive ($M = 17.6$ $M_\odot$), subvirialized (virial parameter $\alpha_{vir} = M_{vir}/M = 0.14$), and is barely affected by turbulence (transonic Mach number of 1.2). Using the HCO$^+$ (3-2) line, we find the first detection of infall signatures in a relatively massive, prestellar core (ALMA1) with the potential to form a high-mass star. We estimate an infall speed of 1.54 km s^{-1} and a high accretion rate of 1.96×10^{-3} $M_\odot$ yr^{-1}. ALMA1 is rapidly collapsing, out of virial equilibrium, more consistent with competitive accretion scenarios rather than the turbulent core accretion model. On the other hand, ALMA1 has a mass $\sim$6 times larger than the clumps Jeans mass, being in an intermediate mass regime ($M_J = 2.7 < M \lesssim 30$ $M_\odot$), contrary to what both the competitive accretion and turbulent core accretion theories predict.

Ionised gas kinematics in bipolar H II regions

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Stellar feedback plays a fundamental role in shaping the evolution of galaxies. Here we explore the use of ionised gas kinematics in young, bipolar HII regions as a probe of early feedback in these star-forming environments. We have undertaken a multi-wavelength study of a young, bipolar HII region in the Galactic disc, G316.81–0.06, which lies at the centre of a massive ($\sim 10^3$ $M_\odot$) infrared-dark cloud filament. It is still accreting molecular gas as well as driving a $\sim$ 0.2 pc ionised gas outflow perpendicular to the filament. Intriguingly, we observe a large velocity gradient (47.81 ± 3.21 km s^{-1} pc^{-1}) across the ionised gas in a direction perpendicular to the outflow. This kinematic

signature of the ionised gas shows a reasonable correspondence with the simulations of young HII regions. Based on a qualitative comparison between our observations and these simulations, we put forward a possible explanation for the velocity gradients observed in G316.81–0.06. If the velocity gradient perpendicular to the outflow is caused by rotation of the ionised gas, then we infer that this rotation is a direct result of the initial net angular momentum in the natal molecular cloud. If this explanation is correct, this kinematic signature should be common in other young (bipolar) HII regions. We suggest that further quantitative analysis of the ionised gas kinematics of young HII regions, combined with additional simulations, should improve our understanding of feedback at these early stages.

Cloud-Cloud collision induced star formation in IRAS 18223-1243

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In the direction of $l = 17.6$ deg – 19 deg, the star-forming sites Sh 2-53 and IRAS 18223-1243 are prominently observed, and seem to be physically detached from each other. Sh 2-53 has been investigated at the junction of the molecular filaments, while a larger-scale environment of IRAS 18223-1243 remains unexplored. The goal of this paper is to investigate the star formation processes in the IRAS site (area $\sim$0.4 deg $\times$ 0.4 deg). Based on the GRS ^{13}CO line data, two molecular clouds, peaking at velocities of 45 and 51 km s^{-1}, are found. In the position-velocity plots, a relatively weak ^{13}CO emission is detected at intermediate velocities (i.e. 47.5–49.5 km s^{-1}) between these two clouds, illustrating a link between two parallel elongated velocity structures. These clouds are physically connected in both space and velocity. The MAGPIS data at 20 cm trace free-free continuum emission toward the IRAS 18223-1243 source. Using the *Spitzer* and UKIDSS photometric data, we have identified infrared-excess young stellar objects (YSOs), and have observed their groups toward the intersection zones of the clouds. IRAS 18223-1243 is also spatially seen at an interface of the clouds. Considering these observational findings, we propose the onset of the collision of two clouds in the IRAS site about 1 Myr ago, which triggered the birth of massive star(s) and the YSO groups. A non-uniform distribution of the GPIPS H-band starlight mean polarization angles is also observed toward the colliding interfaces, indicating the impact of the collision on the magnetic field morphology.

The Eccentric Cavity, Triple Rings, Two-Armed Spirals, and Double Clumps of the MWC 758 Disk

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Spatially resolved structures in protoplanetary disks hint at unseen planets. Previous imaging observations of the transitional disk around MWC 758 revealed an inner cavity, a ring-like outer disk, emission clumps, and spiral arms, all possibly generated by companions. We present ALMA dust continuum observations of MWC 758 at 0.87 millimeter (mm) wavelength with 43×39 mas angular resolution (6.9×6.2 AU) and 20 μJy beam^{-1} rms. The central sub-mm emission cavity is revealed to be eccentric; once deprojected, its outer edge can be well-fitted by an ellipse with an eccentricity of 0.1 and one focus on the star. The broad ring-like outer disk is resolved into three narrow rings with two gaps in between. The outer two rings tentatively show the same eccentricity and orientation as the innermost ring bounding the inner cavity. The two previously known dust emission clumps are resolved in both the radial and azimuthal directions, with radial widths equal to ~4 $\times$ the local scale height. Only one of the two spiral arms previously imaged in near-infrared (NIR) scattered light is revealed in ALMA dust emission, at a slightly larger stellocentric distance owing to projection effects. We also submit evidence of disk truncation at ~100 AU based on comparing NIR imaging observations with models. The spirals, the north clump, and the truncated disk edge are all broadly consistent with the presence of one companion exterior to the spirals at roughly 100 AU.

Is stellar multiplicity universal? Tight stellar binaries in the Orion Nebula Cluster

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We present a survey for the tightest visual binaries among 0.3–$2\,M_\odot$ members the Orion Nebula Cluster (ONC). Among 42 targets, we discovered 13 new 0.025–0.15 arcsec companions. Accounting for the Branch bias, we find a companion star fraction (CSF) in the 10–60 au range of $21^{+8}_{-5}\%$, consistent with that observed in other star-forming regions (SFRs) and twice as high as among field stars; this excess is found with a high level of confidence. Since our sample is dominated by disk-bearing targets, this indicates that disk disruption by close binaries is inefficient, or has not yet taken place, in the ONC. The resulting separation distribution in the ONC drops sharply outside 60 au. These findings are consistent with a scenario in which the initial multiplicity properties, set by the star formation process itself, are identical in the ONC and in other SFRs and subsequently altered by the cluster's dynamical evolution. This implies that the fragmentation process does not depend on the global properties of a molecular cloud, but on the local properties of prestellar cores, and that the latter are self-regulated to be nearly identical in a wide range of environments. These results, however, raise anew the question of the origin of field stars as the tight binaries we have discovered will not be destroyed as the ONC dissolves into the galactic field. It thus appears that most field stars formed in regions that differ from well-studied SFRs in the Solar neighborhood, possibly due to changes in core fragmentation on Gyr timescales.

Protoplanetary Disk Properties in the Orion Nebula Cluster: Initial Results from Deep, High-Resolution ALMA Observations

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We present ALMA 850 μm continuum observations of the Orion Nebula Cluster that provide the highest angular resolution ($\sim 0\rlap{.}''1 \approx 40$ AU) and deepest sensitivity (~ 0.1 mJy) of the region to date. We mosaicked a field containing ~ 225 optical or near-IR-identified young stars, ~ 60 of which are also optically-identified "proplyds". We detect continuum emission at 850 μm towards $\sim 80\%$ of the proplyd sample, and $\sim 50\%$ of the larger sample of previously-identified cluster members. Detected objects have fluxes of ~ 0.5–80 mJy. We remove sub-mm flux due to free-free emission in some objects, leaving a sample of sources detected in dust emission. Under standard assumptions of isothermal, optically thin disks, sub-mm fluxes correspond to dust masses of ~ 0.5 to 80 Earth masses. We measure the distribution of disk sizes, and find that disks in this region are particularly compact. Such compact disks are likely to be significantly optically thick. The distributions of sub-mm flux and inferred disk size indicate smaller, lower-flux disks than in lower-density star-forming regions of similar age. Measured disk flux is correlated weakly with stellar mass, contrary to studies in other star forming regions that found steeper correlations. We find a correlation between disk flux and distance from the massive star θ^1 Ori C, suggesting that disk properties in this region are influenced strongly by the rich cluster environment.

Parsec-scale jets driven by high-mass young stellar objects. Connecting the au- and the parsec-scale jet in IRAS 13481-6124

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Context: Protostellar jets in high-mass young stellar objects (HMYSOs) play a key role in the understanding of star formation and provide us with an excellent tool to study fundamental properties of HMYSOs. Aims: We aim at studying the physical and kinematic properties of the near-IR (NIR) jet of IRAS 13481-6124 from au to parsec scales. *Methods:* Our study includes NIR data from the Very Large Telescope instruments SINFONI, CRIRES, and ISAAC. Information about the source and its immediate environment is retrieved with SINFONI. The technique of spectro-astrometry is performed with CRIRES to study the jet on au scales. The parsec-scale jet and its kinematic and dynamic properties are investigated using ISAAC.
Results: The SINFONI spectra in the H and K band are rich in emission lines that are mainly associated with ejection and accretion processes. Spectro-astrometry is applied to the Brγ line, and for the first time, to the Brα line, revealing their jet origin with milliarcsecond-scale photocentre displacements ($11 - 15$ au). This allows us to constrain the kinematics of the au-scale jet and to derive its position angle ($\sim 216°$). ISAAC spectroscopy reveals H$_2$ emission along the parsec-scale jet, which allows us to infer kinematic and dynamic properties of the NIR parsec-scale jet. The mass-loss rate inferred for the NIR jet is $\dot{M}_{ejec} \sim 10^{-4}\,M_\odot\,\mathrm{yr}^{-1}$ and the thrust is $\dot{P} \sim 10^{-2}\,M_\odot\,\mathrm{yr}^{-1}\,\mathrm{km\,s}^{-1}$, which is roughly constant for the formation history of the young star. A tentative estimate of the ionisation fraction is derived

for the massive jet by comparing the radio and NIR mass-loss rates. An ionisation fraction $\lesssim 8\%$ is obtained, which means that the bulk of the ejecta is traced by the NIR jet and that the radio jet only delineates a small portion of it.

Are Elias 2–27's spiral arms driven by self-gravity, or by a companion? A comparative spiral morphology study

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The spiral waves detected in the protostellar disc surrounding Elias 2–27 have been suggested as evidence of the disc being gravitationally unstable. However, previous work has shown that a massive, stable disc undergoing an encounter with a massive companion are also consistent with the observations. We compare the spiral morphology of smoothed particle hydrodynamic simulations modelling both cases. The gravitationally unstable disc produces symmetric, tightly wound spiral arms with constant pitch angle, as predicted by the literature. The companion disc's arms are asymmetric, with pitch angles that increase with radius. However, these arms are not well-fitted by standard analytic expressions, due to the high disc mass and relatively low companion mass. We note that differences (or indeed similarities) in morphology between pairs of spirals is a crucial discriminant between scenarios for Elias 2–27, and hence future studies must fit spiral arms individually. If Elias 2–27 continues to show symmetric tightly wound spiral arms in future observations, then we posit that it is the first observed example of a gravitationally unstable protostellar disc.

BANYAN. XIII. A First Look at Nearby Young Associations with Gaia Data Release 2

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In this paper we examine the nearest 100 pc entries in the data release 2 of Gaia to identify previously unrecognized candidate members in young associations. We analyze 695 952 stars with the BANYAN Σ Bayesian classification software and discover 898 new high-likelihood candidate members that span a wide range in properties, from spectral types B9 to L2, including 104 co-moving systems, 111 brown dwarfs and 31 new bona fide members. Our sample is mostly composed of highly active M dwarfs and will be crucial to examine the low-mass end of the initial mass function of young associations. Our sample includes new candidate members near the Galactic plane where previous surveys suffered from a high rate of contamination. This paper represents the first step towards a full reassessment of young associations in the Solar neighborhood with the second data release of the Gaia mission.

The Gould's Belt Distances Survey (GOBELINS).
IV. Distance, Depth and Kinematics of the Taurus Star-Forming Region

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We present new trigonometric parallaxes and proper motions of young stellar objects in the Taurus molecular cloud complex from observations collected with the Very Long Baseline Array as part of the Gould's Belt Distances Survey (GOBELINS). We detected 26 young stellar objects and derived trigonometric parallaxes for 18 stars with an accuracy of 0.3% to a few percent. We modeled the orbits of six binaries and determined the dynamical masses of the individual components in four of these systems (V1023 Tau, T Tau S, V807 Tau and V1000 Tau). Our results are consistent with the first trigonometric parallaxes delivered by the Gaia satellite and reveal the existence of significant depth effects. We find that the central portion of the dark cloud Lynds 1495 is located at $d = 129.5 \pm 0.3$ pc while the B 216 clump in the filamentary structure connected to it is at $d = 158.1 \pm 1.2$ pc. The closest and remotest stars in our sample are located at $d = 126.6 \pm 1.7$ pc and $d = 162.7 \pm 0.8$ pc yielding a distance difference of about 36 pc. We also provide a new distance estimate for HL Tau that was recently imaged. Finally, we compute the spatial velocity of the stars with published radial velocity and investigate the kinematic properties of the various clouds and gas structures in this region.

First direct detection of a polarized companion outside of a resolved circumbinary disk around CS Cha

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In the present study we aim to investigate the circumstellar environment of the spectroscopic binary T Tauri star CS Cha. From unresolved mid- to far-infrared photometry it is predicted that CS Cha hosts a disk with a large cavity. In addition, SED modeling suggests significant dust settling, pointing towards an evolved disk that may show signs of ongoing or completed planet formation. We observed CS Cha with the high contrast imager VLT/SPHERE in polarimetric differential imaging mode to resolve the circumbinary disk in near infrared scattered light. These observations were followed-up by VLT/NACO L-band observations and complemented by archival VLT/NACO K-band and HST/WFPC2 I-band data. We resolve the compact circumbinary disk around CS Cha for the first time in scattered light. We find a smooth, low inclination disk with an outer radius of ∼55 au (at 165 pc). We do not detect the inner cavity but find an upper limit for the cavity size of ∼15 au. Furthermore, we find a faint co-moving companion with a projected separation of 210 au from the central binary outside of the circumbinary disk. The companion is detected in polarized light and shows an extreme degree of polarization (13.7±0.4 % in J-band). The companion's J- and H-band magnitudes are compatible with masses of a few $M_{\rm Jup}$. However, K-, L- and I-band data draw this conclusion into question. We explore with radiative transfer modeling whether an unresolved circum-companion disk can be responsible for the high polarization and complex photometry. We find that the set of observations is best explained by a heavily extincted low mass (∼20 $M_{\rm Jup}$) brown dwarf or high mass planet with an unresolved disk and dust envelope.

ALMA Observations of Polarized 872 μm Dust Emission from the Protostellar Systems VLA 1623 and L1527

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We present high-sensitivity ($\sigma_I \sim$ 0.2–0.5 mJy, $\sigma_{QU} \sim$ 0.05 mJy), high-resolution ($\sim 0\farcs12 - 0\farcs2$) observations of polarized 872 μm dust emission from the young multiple system VLA 1623 in ρ Ophiuchus and the protostar L1527 in Taurus. We detect the circumstellar material of VLA 1623A, the extended Keplerian disk surrounding VLA 1623A which we call VLA 1623CBdisk, VLA 1623B, VLA 1623W, and L1527 strongly in the polarized emission, at the ∼1–3% level. We spatially resolve VLA 1623A into two sources, VLA 1623Aa and VLA 1623Ab, separated by ∼30 au and located within a cavity of radius ∼50 au within the circumbinary Keplerian disk, as well as the edge-on disk of VLA 1623W. The polarization angle of the emission is uniform across each protostellar source and nearly coincides with each disk's minor axis. The offsets between the minor axis and the polarization angle are not uniformly distributed at the $P \lesssim 2 \times 10^{-4}$ level. The circumbinary disk surrounding VLA 1623Aab is azimuthally symmetrically polarized. Each compact source's emission is partially optically thick ($\tau \gtrsim 1$) at 872 μm, complicating interpretations of polarization

involving aligned grains. We find evidence against alignment by radiative flux in each source, particularly in the edge-on VLA 1623W and L1527. We detect astrometric offsets between the polarized emission and the total intensity in VLA 1623Aa, VLA 1623Ab, and VLA 1623B, as predicted if self-scattering in the optically thick limit operates. We conclude that self-scattering is likely responsible for disk-scale polarization at 872 μm in these systems.

A Dual Power Law Distribution for the Stellar Initial Mass Function

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We introduce a new dual power law (DPL) probability distribution function for the mass distribution of stellar and substellar objects at birth, otherwise known as the initial mass function (IMF). The model contains both deterministic and stochastic elements, and provides a unified framework within which to view the formation of brown dwarfs and stars resulting from an accretion process that starts from extremely low mass seeds. It does not depend upon a top down scenario of collapsing (Jeans) masses or an initial lognormal or otherwise IMF-like distribution of seed masses. Like the modified lognormal power law (MLP) distribution, the DPL distribution has a power law at the high mass end, as a result of exponential growth of mass coupled with equally likely stopping of accretion at any time interval. Unlike the MLP, a power law decay also appears at the low mass end of the IMF. This feature is closely connected to the accretion stopping probability rising from an initially low value up to a high value. This might be associated with physical effects of ejections sometimes (i.e., rarely) stopping accretion at early times followed by outflow driven accretion stopping at later times, with the transition happening at a critical time (therefore mass). Comparing the DPL to empirical data, the critical mass is close to the substellar mass limit, suggesting that the onset of nuclear fusion plays an important role in the subsequent accretion history of a young stellar object.

Long-term BVRI photometric light curves of 15 PMS stars in the IC 5070 star-forming region

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This paper reports the results from the multicolor photometric observations of 15 pre-main sequence stars collected in the period 2010 September - 2017 October. The stars from our study are located in the star-forming HII region IC 5070. These objects were previously detected as either emission line stars, flare stars, T Tauri variables or Herbig Ae/Be stars. Photometric observations, especially concerning the long-term behavior of the objects are missing in the literature. We present the first photometric monitoring for all stars from our study. The analysis of the obtained BVRI photometric data allows to draw a conclusion that all investigated objects are variable stars. In the case of LkHa 146 we identified previously unknown periodicity in its photometric variability.

Weak Magnetic Fields in Two Herbig Ae Systems: The SB2 AK Sco and the Presumed Binary HD 95881

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We report the detection of weak mean longitudinal magnetic fields in the Herbig Ae double-lined spectroscopic binary AK Sco and in the presumed spectroscopic Herbig Ae binary HD 95881 using observations with HARPSpol attached to ESO's 3.6 m telescope. Employing a multi-line singular value decomposition (SVD) method, we detect a mean longitudinal magnetic field $\langle B_z \rangle = -83 \pm 31$ G in the secondary component of AK Sco on one occasion. For HD 95881, we measure $\langle B_z \rangle = -93 \pm 25$ G and $\langle B_z \rangle = 105 \pm 29$ G at two different observing epochs. For all the detections the false alarm probability is smaller than 10^{-5}. For AK Sco system, we discover that accretion diagnostic Na I doublet lines and photospheric lines show intensity variations over the observing nights. The double-lined spectral appearance of HD 95881 is presented here for the first time.

Radial migration of gap-opening planets in protoplanetary disks. I. The case of a single planet

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A large planet orbiting a star in a protoplanetary disk opens a density gap along its orbit due to the strong disk-planet interaction and migrates with the gap in the disk. It is expected that in the ideal case, a gap-opening planet migrates at the viscous drift speed, which is referred to as type II migration. However, recent hydrodynamic simulations have shown that in general, the gap-opening planet is not locked to the viscous disk evolution. A new physical model is required to explain the migration speed of such a planet. For this reason, we re-examined the migration of a planet in the disk, by carrying out the two-dimensional hydrodynamic simulations in a wide parameter range. We have found that the torque exerted on the gap-opening planet depends on the surface density at the bottom of the gap. The planet migration slows down as the surface density of the bottom of the gap decreases. Using the gap model developed in our previous studies, we have constructed an empirical formula of the migration speed of the gap-opening planets, which is consistent with the results given by the hydrodynamic simulations performed by us and other researchers. Our model easily explains why the migration speed of the gap-opening planets can be faster than the viscous gas drift speed. It can also predict the planet mass at which the type I migration is no longer adequate due to the gap development in the disk, providing a gap formation criterion based on planetary migration.

The circumstellar environment of HD50138 revealed by VLTI/AMBER at high angular resolution

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HD 50138 is a Herbig B[e] star with a circumstellar disc detected at infrared and millimeter wavelength. Its brightness makes it a good candidate for near-infrared interferometry observations. We aim to resolve, spatially and spectrally, the continuum and hydrogen emission lines in the 2.12-2.47 micron region, to shed light on the immediate circumstellar environment of the star. Very Large Telescope-Interferometer/*AMBER* (VLTI/*AMBER*) K-band observations provide spectra, visibilities, differential phases, and closure phases along three long baselines for the continuum, and HI emission in Brγ and five high-n Pfund lines. By computing the pure-line visibilities, we derive the angular size of the different line-emitting regions. A simple local thermodynamic equilibrium (LTE) model was created to constrain the physical conditions of HI emitting region. The continuum region cannot be reproduced by a geometrical two-dimensional (2D) elongated Gaussian fitting model. We estimate the size of the region to be 1 au. We find the detected hydrogen lines (Brγ and Pfund lines) come from a more compact region of size 0.4 au. The Brγ line exhibits an S-shaped differential phase, indicative of rotation. The continuum and Brγ line closure phase show offsets of $\sim$-25$\pm$5^o and 20$\pm$10°, respectively. This is evidence of an asymmetry in their origin, but with opposing directions. We find that we cannot converge on constraints for the HI physical parameters without a more detailed model. Our analysis reveals that HD 50138 hosts a complex circumstellar environment. Its continuum emission cannot be reproduced by a simple disc brightness distribution. Similarly, several components must be evoked to reproduce the interferometric observables within the Brγ line. Combining the spectroscopic and interferometric data of the Brγ and Pfund lines favours an origin in a wind region with a large opening angle. Finally, although we cannot exclude the possibility that HD 50138 is a young star our results point to an evolved source.

A 100 au-Wide Bipolar Rotating Shell Emanating From the HH 212 Protostellar Disk: A Disk Wind?

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HH 212 is a Class 0 protostellar system found to host a "hamburger"-shaped dusty disk with a rotating disk atmosphere and a collimated SiO jet at a distance of $\sim$400 pc. Recently, a compact rotating outflow has been detected in SO and SO$_2$ toward the center along the jet axis at $\sim$52 au (0$''$13) resolution. Here we resolve the compact outflow into a small-scale wide-opening rotating outflow shell and a collimated jet, with the observations in the same S-bearing molecules at $\sim$16 au (0$''$04) resolution. The collimated jet is aligned with the SiO jet, tracing the shock interactions in the jet. The wide-opening outflow shell is seen extending out from the inner disk around the SiO jet and has a width of $\sim$100 au. It is not only expanding away from the center, but also rotating around the jet axis. The specific angular momentum of the outflow shell is $\sim$40 au km s^{-1}. Simple modeling of the observed kinematics suggests that the rotating outflow shell can trace either a disk wind or disk material pushed away by an unseen wind from the inner disk or protostar. We also resolve the disk atmosphere in the same S-bearing molecules, confirming the Keplerian rotation there.

Vortex survival in 3D self-gravitating accretion discs

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Large-scale, dust-trapping vortices may account for observations of asymmetric protoplanetary discs. Disc vortices are also potential sites for accelerated planetesimal formation by concentrating dust grains. However, in 3D discs vortices are subject to destructive 'elliptic instabilities', which reduces their viability as dust traps. The survival of vortices in 3D accretion discs is thus an important issue to address. In this work, we perform shearing box simulations to show that disc self-gravity enhances the survival of 3D vortices, even when self-gravity is weak in the classic sense (e.g. with a Toomre $Q \simeq 5$). We find a 3D, self-gravitating vortex can grow on secular timescales in spite of the elliptic instability. The vortex aspect-ratio decreases as it strengthens, which feeds the elliptic instability. The result is a 3D vortex with a turbulent core that persists for $\sim 10^3$ orbits. We find when gravitational and hydrodynamic stresses become comparable, the vortex may undergo episodic bursts, which we interpret as interaction between elliptic and gravitational instabilities. We estimate the distribution of dust particles in self-gravitating, turbulent vortices. Our results suggest large-scale vortices in protoplanetary discs are more easily observed at large radii.

http://arxiv.org/pdf/1805.05825

Detection of 40–48 GHz dust continuum linear polarization towards the Class 0 young stellar object IRAS 16293−2422

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We performed the new JVLA full polarization observations at 40–48 GHz (6.3–7.5 mm) towards the nearby ($d = 147 \pm 3.4$ pc) Class 0 YSO IRAS 16293−2422, and compare with the previous SMA observations reported by Rao et al. (2009; 2014). We observed the quasar J1407+2827 which is weakly polarized and can be used as a leakage term calibrator for <9 GHz observations, to gauge the potential residual polarization leakage after calibration. We did not detect Stokes Q, U, and V intensities from the observations of J1407+2827, and constrain (3σ) the residual polarization leakage after calibration to be $\lesssim 0.3\%$. We detect linear polarization from one of the two binary components of our target source, IRAS 16293−2422 B. The derived polarization position angles from our observations are in excellent agreement with those detected from the previous observations of the SMA, implying that on the spatial scale we are probing (~ 50–1000 au), the physical mechanisms for polarizing the continuum emission do not vary significantly over the wavelength range of ~ 0.88–7.5 mm. We hypothesize that the observed polarization position angles trace the magnetic field which converges from large scale to an approximately face-on rotating accretion flow. In this scenario, magnetic field is predominantly poloidal on >100 au scales, and becomes toroidal on smaller scales. However, this interpretation remains uncertain due to the high dust optical depths at the central region of IRAS 16293−2422 B and the uncertain temperature profile. We suggest that dust polarization at wavelengths comparable or longer than 7 mm may still trace interstellar magnetic field. Future sensitive observations of dust polarization in the fully optically thin regime will have paramount importance for unambiguously resolving the magnetic field configuration.

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The straight and isolated G350.54+0.69 filament: density profile and star formation content

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We investigate the global properties of the straight and isolated filamentary cloud G350.54+0.69 using Herschel continuum and APEX molecular line data. The overall straight morphology is similar to two other well studied nearby filaments (Musca and Taurus-B211/3) while the isolated nature of G350.54+0.69 appears similar to Musca. G350.54+0.69 is composed of two distinct filaments with a length ∼5.9 pc for G350.5-N (∼2.3 pc for G350.5-S), a total mass of ∼810 $M_\odot$ (∼110 $M_\odot$), and a mean temperature of ∼18.2 K (∼17.7 K). We identify 9 dense and gravitationally bound cores in the whole cloud G350.54+0.69. The separations between cores and the line mass of the whole cloud appear to follow the predictions of the "sausage" instability theory, which suggests that G350.54+0.69 could have undergone radial collapse and fragmentation. The presence of young protostars is consistent with this hypothesis. The line masses of the two filaments (∼120 $M_\odot$ pc^{-1} for G350.5-N, and ∼45 $M_\odot$ pc^{-1} for G350.5-S), mass-size distributions of the dense cores, and low-mass protostars collectively suggest that G350.54+0.69 is a site of ongoing low-mass star formation. Based on the above evidence, we place G350.54+0.69 in an intermediate evolutionary state between Musca and Taurus-B211/3. We suggest that investigations into straight (and isolated) versus those distributed inside molecular clouds may provide important clues into filament formation and evolution.

An Isothermal Outflow in High-mass Star-forming Region G240.31+0.07

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We present Atacama Pathfinder EXperiment (APEX) observations toward the massive star-forming region G240.31+0.07 in the CO J = 3–2, 6–5, and 7–6 lines. We detect a parsec-sized, bipolar, and high velocity outflow in all the lines, which allow us, in combination with the existing CO J = 2–1 data, to perform a multi-line analysis of physical conditions of the outflowing gas. The CO 7–6/6–5, 6–5/3–2, and 6–5/2–1 ratios are found to be nearly constant over a velocity range of ∼5–25 km s^{-1} for both blueshifted and redshifted lobes. We carry out rotation diagram and large velocity gradient (LVG) calculations of the four lines, and find that the outflow is approximately isothermal with a gas temperature of ∼50 K, and that the the CO column density clearly decreases with the outflow velocity. If the CO abundance and the velocity gradient do not vary much, the decreasing CO column density indicates a decline in the outflow gas density with velocity. By comparing with theoretical models of outflow driving mechanisms, our observations and calculations suggest that the massive outflow in G240.31+0.07 is being driven by a wide-angle wind and further support a disk mediated accretion at play for the formation of the central high-mass star.

A search for transiting planets in the β Pictoris system

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The bright ($V = 3.86$) star β Pictoris is a nearby young star with a debris disk and gas giant exoplanet, β Pictoris b, in a multi-decade orbit around it. Both the planet's orbit and disk are almost edge-on to our line of sight. We carry out a search for any transiting planets in the β Pictoris system with orbits of less than 30 days that are coplanar with the planet β Pictoris b. We search for a planetary transit using data from the BRITE-Constellation nanosatellite BRITE-Heweliusz, analyzing the photometry using the Box-Fitting Least Squares Algorithm (BLS). The sensitivity of the method is verified by injection of artificial planetary transit signals using the Bad-Ass Transit Model cAlculatioN (BATMAN) code. No planet was found in the BRITE-Constellation data set. We rule out planets larger than 0.6 R_J for periods of less than 5 days, larger than 0.75 R_J for periods of less than 10 days, and larger than 1.05 R_J for periods of less than 20 days.

Efficient radiative transfer techniques in hydrodynamic simulations

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Radiative transfer is an important component of hydrodynamic simulations as it determines the thermal properties of a physical system. It is especially important in cases where heating and cooling regulate significant processes, such as in the collapse of molecular clouds, the development of gravitational instabilities in protostellar discs, disc-planet interactions, and planet migration. We compare two approximate radiative transfer methods which indirectly estimate optical depths within hydrodynamic simulations using two different metrics: (i) the gravitational potential and density of the gas (Stamatellos et al.), and (ii) the pressure scale-height (Lombardi et al.). We find that both methods are accurate for spherical configurations e.g. in collapsing molecular clouds and within clumps that form in protostellar discs. However, the pressure scale-height approach is more accurate in protostellar discs (low and high-mass discs, discs with spiral features, discs with embedded planets). We also investigate the β-cooling approximation which is commonly used when simulating protostellar discs, and in which the cooling time is proportional to the orbital period of the gas. We demonstrate that the use of a constant β cannot capture the wide range of spatial and temporal variations of cooling in protostellar discs, which may affect the development of gravitational instabilities, planet migration, planet mass growth, and the orbital properties of planets.

M Dwarf Exoplanet Surface Density Distribution: A Log-Normal Fit from 0.07-400 AU

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We fit a log-normal function to the M dwarf orbital surface density distribution of gas giant planets, over the mass range 1-10 times that of Jupiter, from 0.07-400 AU. We use a Markov Chain Monte Carlo approach to explore the likelihoods of various parameter values consistent with point estimates of the data given our assumed functional form. This fit is

consistent with radial velocity, microlensing, and direct imaging observations, is well-motivated from theoretical and phenomenological viewpoints, and makes predictions of future surveys. We present probability distributions for each parameter as well as a Maximum Likelihood Estimate solution. We suggest this function makes more physical sense than other widely used functions, and explore the implications of our results on the design of future exoplanet surveys.

Tracing the cold and warm physico-chemical structure of deeply embedded protostars: IRAS 16293-2422 versus VLA 1623-2417

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Much attention has been placed on the dust distribution in protostellar envelopes, but there are still many unanswered questions regarding the structure of the gas. We aim to start identifying the factors that determine the chemical structure of protostellar regions, by studying and comparing low-mass embedded systems in key molecular tracers. The cold and warm chemical structures of two embedded Class 0 systems, IRAS16293 and VLA1623 are characterized through interferometric observations. DCO^+, N_2H^+ and N_2D^+ are used to trace the spatial distribution and physics of the cold regions of the envelope, while c-C_3H_2 and C_2H from models of the chemistry are expected to trace the warm (UV-irradiated) regions. Both sources show a number of striking similarities and differences. DCO^+ consistently traces the cold material at the disk-envelope interface, where gas and dust temperatures are lowered due to disk shadowing. N_2H^+ and N_2D^+, also tracing cold gas, show low abundances towards VLA1623, but for IRAS16293, the distribution of N_2D^+ is consistent with the same chemical models that reproduce DCO^+. c-C_3H_2 and C_2H show different spatial distributions for the two systems. For IRAS16293, c-C_3H_2 traces the outflow cavity wall, while C_2H is found in the envelope material but not the outflow cavity wall. In contrast, toward VLA1623 both molecules trace the outflow cavity wall. Finally, hot core molecules are abundantly observed toward IRAS16293 but not toward VLA1623. We identify temperature as one of the key factors in determining the chemical structure of protostars as seen in gaseous molecules. More luminous protostars, such as IRAS16293, will have chemical complexity out to larger distances than colder protostars, such as VLA1623. Additionally, disks in the embedded phase have a crucial role in controlling both the gas and dust temperature of the envelope, and consequently the chemical structure.

K2 Ultracool Dwarfs Survey. IV. Monster flares observed on the young brown dwarf CFHT-BD-Tau 4

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We present photometric measurements of two superflares observed on a very young brown dwarf CFHT-BD-Tau 4, observed during Campaign 13 of the *Kepler K2* mission. The stronger of the two superflares brightened by a factor of

∼48 relative to the quiescent photospheric level, with an increase in *Kepler* magnitude $\Delta\tilde{K}_p = -4.20$. It has an equivalent duration of ∼107 hour, a flare duration of 1.7 day, and an estimated total bolometric (ultraviolet/optical/infrared) energy up to 2.1×10^{38} erg. The weaker of the two superflares is a complex (multipeaked) flare with an estimated total bolometric (UV/optical/IR) energy up to 4.7×10^{36} erg. They are the strongest flares observed on any brown dwarf so far. The flare energies are strongly dependent on the value of visual extinction parameter A_V used for extinction correction. If we apply a solar flare-model to interpret the two superflares, we find that the magnetic fields are required to be stronger by as much as an order of magnitude than previous reports of field measurements in CFHT-BD-Tau 4 by Reiners et al. (2009b). On the other hand, if we interpret our data in terms of accretion, we find that the requisite rate of accretion for the stronger superflare exceeds the rates which have been reported for other young brown dwarfs.

On the evolution of vortices in massive protoplanetary discs

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It is expected that a pressure bump can be formed at the inner edge of a dead-zone, and where vortices can develop through the Rossby Wave Instability (RWI). It has been suggested that self-gravity can significantly affect the evolution of such vortices. We present the results of 2D hydrodynamical simulations of the evolution of vortices forming at a pressure bump in self-gravitating discs with Toomre parameter in the range 4–30. We consider isothermal plus non-isothermal disc models that employ either the classical β prescription or a more realistic treatment for cooling. The main aim is to investigate whether the condensating effect of self-gravity can stabilize vortices in sufficiently massive discs. We confirm that in isothermal disc models with $Q \gtrsim 15$, vortex decay occurs due to the vortex self-gravitational torque. For discs with $3 \lesssim Q \lesssim 7$, the vortex develops gravitational instabilities within its core and undergoes gravitational collapse, whereas more massive discs give rise to the formation of global eccentric modes. In non-isothermal discs with β cooling, the vortex maintains a turbulent core prior to undergoing gravitational collapse for $\beta \lesssim 0.1$, whereas it decays if $\beta \geq 1$. In models that incorpore both self-gravity and a better treatment for cooling, however, a stable vortex is formed with aspect ratio $\chi \sim 3$–4. Our results indicate that self-gravity significantly impacts the evolution of vortices forming in protoplanetary discs, although the thermodynamical structure of the vortex is equally important for determining its long-term dynamics.

Resolved millimeter-dust continuum cavity around the very low mass young star CIDA 1

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Context: Transition disks (TDs) are circumstellar disks with inner regions highly depleted in dust. TDs are observed in a small fraction of disk-bearing objects at ages of 1-10 Myr. They are important laboratories to study evolutionary effects in disks, from photoevaporation to planet-disk interactions.
Aims: We report the discovery of a large inner dust-empty region in the disk around the very low mass star CIDA 1

$(M_\star \sim 0.1 - 0.2\,M_\odot)$.

Methods: We used ALMA continuum observations at $887\,\mu$m, which provide a spatial resolution of 0.21×0.12 arcsec ($\sim 15 \times 8$ au in radius at 140 pc).

Results: The data show a dusty ring with a clear cavity of radius ~ 20 au, the typical characteristic of a TD. The emission in the ring is well described by a narrow Gaussian profile. The dust mass in the disk is $\sim 17\,M_\oplus$. CIDA 1 is one of the lowest mass stars with a clearly detected millimeter cavity. When compared to objects of similar stellar mass, it has a relatively massive dusty disk (less than $\sim 5\%$ of Taurus Class II disks in Taurus have a ratio of $M_{\rm disk}/M_\star$ larger than CIDA 1) and a very high mass accretion rate (CIDA 1 is a disk with one of the lowest values of $M_{\rm disk}/\dot{M}$ ever observed). In light of these unusual parameters, we discuss a number of possible mechanisms that can be responsible for the formation of the dust cavity (e.g., photoevaporation, dead zones, embedded planets, close binary). We find that an embedded planet of a Saturn mass or a close binary are the most likely possibilities.

Homogeneous Analysis of the Dust Morphology of Transition Disks Observed with ALMA: Investigating dust trapping and the origin of the cavities

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We analyze the dust morphology of 29 transition disks (TDs) observed with Atacama Large (sub-)Millimeter Array (ALMA) at (sub-) millimeter emission. We perform the analysis in the visibility plane to characterize the total flux, cavity size, and shape of the ring-like structure. First, we found that the $M_{\rm dust} - M_\star$ relation is much flatter for TDs than the observed trends from samples of class II sources in different star forming regions. This relation demonstrates that cavities open in high (dust) mass disks, independent of the stellar mass. The flatness of this relation contradicts the idea that TDs are a more evolved set of disks. Two potential reasons (not mutually exclusive) may explain this flat relation: the emission is optically thick or/and millimeter-sized particles are trapped in a pressure bump. Second, we discuss our results of the cavity size and ring width in the context of different physical processes for cavity formation. Photoevaporation is an unlikely leading mechanism for the origin of the cavity of any of the targets in the sample. Embedded giant planets or dead zones remain as potential explanations. Although both models predict correlations between the cavity size and the ring shape for different stellar and disk properties, we demonstrate that with the current resolution of the observations, it is difficult to obtain these correlations. Future observations with higher angular resolution observations of TDs with ALMA will help to discern between different potential origins of cavities in TDs.

Kinematic evidence for an embedded protoplanet in a circumstellar disc

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Discs of gas and dust surrounding young stars are the birthplace of planets. However, the direct detection of proto-planets forming within discs has proved elusive to date. We present the detection of a large, localized deviation from Keplerian velocity in the protoplanetary disc surrounding the young star HD 163296. The observed velocity pattern is consistent with the dynamical effect of a two-Jupiter-mass planet orbiting at a radius ∼260 au from the star.

Space-Based Coronagraphic Imaging Polarimetry of the TW Hydrae Disk: Shedding New Light on Self-Shadowing Effects

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We present *Hubble Space Telescope* Near-Infrared Camera and Multi-Object Spectrometer coronagraphic imaging polarimetry of the TW Hydrae protoplanetary disk. These observations simultaneously measure the total and polarized intensity, allowing direct measurement of the polarization fraction across the disk. In accord with the self-shadowing hypothesis recently proposed by Debes et al., we find that the total and polarized intensity of the disk exhibits strong azimuthal asymmetries at projected distances consistent with the previously reported bright and dark ring-shaped structures (∼45–99 au). The sinusoidal-like variations possess a maximum brightness at position angles near ∼268–300° and are up to ∼28% stronger in total intensity. Furthermore, significant radial and azimuthal variations are also detected in the polarization fraction of the disk. In particular, we find that regions of lower polarization fraction are associated with annuli of increased surface brightness, suggesting that the relative proportion of multiple-to-single scattering is greater along the ring and gap structures. Moreover, we find strong (∼20%) azimuthal variation in the polarization fraction along the shadowed region of the disk. Further investigation reveals that the azimuthal variation is not the result of disk flaring effects, but instead from a decrease in the relative contribution of multiple-to-single scattering within the shadowed region. Employing a two-layer scattering surface, we hypothesize that the diminished contribution in multiple scattering may result from shadowing by an inclined inner disk, which prevents direct stellar light from reaching the optically thick underlying surface component.

A comparison of the radio and optical time-evolution of HH 1 and 2

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We present a comparison between the time-evolution over the past $\sim$ 20 years of the radio continuum and Hα emission of HH 1 and 2. We find that the radio continuum and the Hα emission of both objects show very similar trends, with HH 1 becoming fainter and HH 2 brightening quite considerably (about a factor of 2). We also find that the $F_{\mathrm{H}\alpha}/F_{ff}$ (Hα to free-free continuum) ratio of HH 1 and 2 has higher values than the ones typically found in planetary nebulae (PNe), which we interpret as an indication that the Hα and free-free emission of HH 1/2 is produced in emitting regions with lower temperatures ($\sim$ 2000 K) than the emission of PNe (with $\sim 10^4$ K).

ALMA Survey of Circumstellar Disks in the Young Stellar Cluster IC 348

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We present a 1.3 mm continuum survey of the young (2-3 Myr) stellar cluster IC 348, which lies at a distance of 310 pc, and is dominated by low-mass stars ($M_\star \sim$ 0.1-0.6 $M_\odot$). We observed 136 Class II sources (disks that are optically thick in the infrared) at 0.8″ (200 au) resolution with a 3σ sensitivity of $\sim$ 0.45 mJy ($M_{\mathrm{dust}} \sim$ 1.3 $M_\oplus$).
We detect 40 of the targets and construct a mm-continuum luminosity function. We compare the disk mass distribution in IC 348 to those of younger and older regions, taking into account the dependence on stellar mass. We find a clear evolution in disk masses from 1 to 5-10 Myr. The disk masses in IC 348 are significantly lower than those in Taurus (1-3 Myr) and Lupus (1-3 Myr), similar to those of Chamaleon I, (2-3 Myr) and σ Ori (3-5 Myr) and significantly higher than in Upper Scorpius (5−10 Myr).
About 20 disks in our sample ($\sim$5% of the cluster members) have estimated masses (dust + gas) >1 M_{Jup} and hence might be the precursors of giant planets in the cluster.
Some of the most massive disks include transition objects with inner opacity holes based on their infrared SEDs.
From a stacking analysis of the 96 non-detections, we find that these disks have a typical dust mass of just < 0.4 $M_\oplus$, even though the vast majority of their infrared SEDs remain optically thick and show little signs of evolution. Such low-mass disks may be the precursors of the small rocky planets found by *Kepler* around M-type stars.

Long-term simulation of MHD jet launching from an orbiting star-disk system

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We present fully three-dimensional magnetohydrodynamic jet launching simulations of a jet source orbiting in a binary system.

We consider a time-dependent binary gravitational potential, thus all tidal forces that are experienced in the non-inertial frame of the jet-launching primary. We investigate systems with different binary separation, different mass ratio, and different inclination between the disk plane and the orbital plane. The simulations run over a substantial fraction of the binary orbital period.

All simulations show similar local and global non-axisymmetric effects such as local instabilities in the disk and the jet, or global features such as disk spiral arms and warps, or a global re-alignment of the inflow-outflow structure.

The disk accretion rate is higher than for axisymmetric simulations, most probably due to the enhanced angular momentum transport by spiral waves.

The disk outflow leaves the Roche lobe of the primary and becomes disturbed by tidal effects. While a disk-orbit inclination of $10°$ still allows for a persistent outflow, an inclination of $30°$ does not, suggesting a critical angle in between. For moderate inclination we find indication for jet precession such that the jet axis starts to follow a circular pattern with an opening cone of $\simeq 8°$.

Simulations with different mass ratio indicate a change of time scales for the tidal forces to affect the disk-jet system. A large mass ratio (a massive secondary) leads to stronger spiral arms, a higher (average) accretion and a more pronounced jet-counter jet asymmetry.

Spitzer Infrared Spectrograph Observations of the Galactic Center: Quantifying the Extreme Ultraviolet/soft X-ray fluxes

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It has long been shown that the extreme ultraviolet spectrum of the ionizing stars of H II regions can be estimated by comparing the observed line emission to detailed models. Because previous observations of the Galactic Center (GC) had shown that the ionizing spectral energy distribution (SED) of the local photon field is strange, producing both very low excitation ionized gas (indicative of ionization by late O stars) but also widespread diffuse emission from atoms too highly ionized to be found in normal H II regions, all the GC spectra taken by Spitzer's Infrared Spectrograph were downloaded from the Spitzer Heritage Archive and reduced and analyzed. This paper describes H II region densities and abundances and tabulates serendipitously discovered candidate planetary nebulae, compact shocks, and candidate young stellar objects. Models were computed with Cloudy, using SEDs from Starburst99 plus additional X-rays, and compared to the observed mid-infrared forbidden and hydrogen recombination lines. Recent theories posit a sequence of star formation in the GC along streams of gas with density enhancements caused by close encounters with the black hole, Sgr A*. The ages inferred from the model fits do not agree with this proposed star formation sequence, with Sgr B1, Sgr C, and the Arches Cluster being all about the same age, around 4.5 Myr old, with similar X-ray requirements. The fits for the Quintuplet Cluster appear to give a younger age, but that could be caused by higher energy photons from shocks from stellar winds or from a supernova.

Photometric variability of TW Hya from seconds to years as seen from space and the ground in 2013–2017

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This is the final photometric study of TW Hya based on new MOST satellite observations. During 2014 and 2017 the light curves showed stable 3.75 and 3.69 d quasi-periodic oscillations, respectively. Both values appear to be closely related with the stellar rotation period, as they might be created by changing visibility of a hot-spot formed near the magnetic pole directed towards the observer. These major light variations were superimposed on a chaotic, flaring-type activity caused by hot-spots resulting from unstable accretion - a situation reminiscent of that in 2011, when TW Hya showed signs of a moderately stable accretion state. In 2015 only drifting quasi-periods were observed, similar to those present in 2008–2009 data and typical for magnetised stars accreting in a strongly unstable regime. A rich set of multi-colour data was obtained during 2013–2017 with the primary aim to characterize the basic spectral properties of the mysterious occultations in TW Hya. Although several possible occultation-like events were identified, they are not as well defined as in the 2011 MOST data. The new ground-based and MOST data show a dozen previously unnoticed flares, as well as small-amplitude, 11 min–3 hr brightness variations, associated with 'accretion bursts'. It is not excluded that the shortest 11–15 min variations could also be caused by thermal instability oscillations in an accretion shock.

The Impact of Feedback in Massive Star Formation. II. Lower Star Formation Efficiency at Lower Metallicity

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We conduct a theoretical study of the formation of massive stars over a wide range of metallicities from 10^{-5} to $1 Z_\odot$ and evaluate the star formation efficiencies (SFEs) from prestellar cloud cores taking into account multiple feedback processes. Unlike for simple spherical accretion, in the case of disk accretion feedback processes do not set upper limits on stellar masses. At solar metallicity, launching of magneto-centrifugally-driven outflows is the dominant feedback process to set SFEs, while radiation pressure, which has been regarded to be pivotal, has only minor contribution even in the formation of over-100 $M_\odot$ stars. Photoevaporation becomes significant in over-20 $M_\odot$ star formation at low metallicities of $\lesssim 10^{-2} Z_\odot$, where dust absorption of ionizing photons is inefficient. We conclude that if initial prestellar core properties are similar, then massive stars are rarer in extremely metal-poor environments of 10^{-5}–$10^{-3} Z_\odot$. Our results give new insight into the high-mass end of the initial mass function and its potential variation with galactic and cosmological environments.

A Kinematical Detection of Two Embedded Jupiter Mass Planets in HD 163296

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We present the first kinematical detection of embedded protoplanets within a protoplanetary disk. Using archival ALMA observations of HD 163296, we demonstrate a new technique to measure the rotation curves of CO isotopologue emission to sub-percent precision relative to the Keplerian rotation. These rotation curves betray substantial deviations caused by local perturbations in the radial pressure gradient, likely driven by gaps carved in the gas surface density by Jupiter-mass planets. Comparison with hydrodynamic simulations shows excellent agreement with the gas rotation profile when the disk surface density is perturbed by two Jupiter mass planets at 83 au and 137 au. As the rotation of the gas is dependent on the pressure of the total gas component, this method provides a unique probe of the gas surface density profile without incurring significant uncertainties due to gas-to-dust ratios or local chemical abundances which plague other methods. Future analyses combining both methods promise to provide the most accurate and robust measures of embedded planetary mass. Furthermore, this method provides a unique opportunity to explore wide-separation planets beyond the mm continuum edge and to trace the gas pressure profile essential in modelling grain evolution in disks.

The Evolution of Protoplanetary Disks: Probing the Inner Disk of Very Low Accretors

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We report FUV, optical, and NIR observations of three T Tauri stars in the Orion OB1b subassociation with Hα equivalent widths consistent with low or absent accretion and various degrees of excess flux in the mid-infrared. We aim to search for evidence of gas in the inner disk in HST ACS/SBC spectra, and to probe the accretion flows onto the star using Hα and He I λ10830 in spectra obtained at the Magellan and SOAR telescopes. At the critical age of 5 Myr, the targets are at different stages of disk evolution. One of our targets is clearly accreting, as shown by redshifted absorption at free-fall velocities in the He I line and wide wings in Hα; however, a marginal detection of FUV H$_2$ suggests that little gas is present in the inner disk, although the spectral energy distribution indicates that small dust still remains close to the star. Another target is surrounded by a transitional disk, with an inner cavity in which little sub-micron dust remains. Still, the inner disk shows substantial amounts of gas, accreting onto the star at a probably low, but uncertain rate. The third target lacks both a He I line or FUV emission, consistent with no accretion or inner gas disk; its very weak IR excess is consistent with a debris disk. Different processes occurring in targets with ages close to the disk dispersal time suggest that the end of accretion phase is reached in diverse ways.

Warm CO gas generated by possible turbulent shocks in a low-mass star-forming dense core in Taurus

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We report ALMA Cycle 3 observations in CO isotopes toward a dense core, MC27/L1521F in Taurus, which is considered to be at an early stage of multiple star formation in a turbulent environment. Although most of the high-density parts of this core are considered to be as cold as $\sim$10 K, high-angular resolution ($\sim$20 au) observations in ^{12}CO ($J = 3$–2) revealed complex warm (>15–60 K) filamentary/clumpy structures with the sizes from a few tens of au to $\sim$1,000 au. The interferometric observations of ^{13}CO and C^{18}O show that the densest part with arc-like morphologies associated with previously identified protostar and condensations are slightly redshifted from the systemic velocity of the core. We suggest that the warm CO clouds may be consequences of shock heating induced by interactions among the different density/velocity components originated from the turbulent motions in the core. However, such a small-scale and fast turbulent motion does not correspond to a simple extension of line-width-size relation (i.e., Larson's law), and thus the actual origin remains to be studied. The high-angular resolution CO observations are expected to be essential in detecting small-scale turbulent motions in dense cores and to investigate protostar formation therein.

The Millimeter Continuum Size-Frequency Relationship in the UZ Tau E Disk

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We present high spatial resolution observations of the continuum emission from the young multiple star system UZ Tau at frequencies from 6 to 340 GHz. To quantify the spatial variation of dust emission in the UZ Tau E circumbinary disk, the observed interferometric visibilities are modeled with a simple parametric prescription for the radial surface

brightnesses at each frequency. We find evidence that the spectrum steepens with radius in the disk, manifested as a positive correlation between the observing frequency and the radius that encircles a fixed fraction of the emission ($R_{\rm eff} \propto \nu^{0.34\pm0.08}$). The origins of this size-frequency relation are explored in the context of a theoretical framework for the growth and migration of disk solids. While that framework can reproduce a similar size-frequency relation, it predicts a steeper spectrum than is observed. Moreover, it comes closest to matching the data only on timescales much shorter (≤ 1 Myr) than the putative UZ Tau age ($\sim$2–3 Myr). These discrepancies are the direct consequences of the rapid radial drift rates predicted by models of dust evolution in a smooth gas disk. One way to mitigate that efficiency problem is to invoke small-scale gas pressure modulations that locally concentrate drifting solids. If such particle traps reach high continuum optical depths at 30–340 GHz with a $\sim$30–60% filling fraction in the inner disk ($r \lesssim 20$ au), they can also explain the observed spatial gradient in the UZ Tau E disk spectrum.

Magnetic Seismology of Interstellar Gas Clouds: Unveiling a Hidden Dimension

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Stars and planets are formed inside dense interstellar molecular clouds, by processes imprinted on the 3-dimensional (3D) morphology of the clouds. Determining the 3D structure of interstellar clouds remains challenging, due to projection effects and difficulties measuring their extent along the line of sight. We report the detection of normal vibrational modes in the isolated interstellar cloud Musca, allowing determination of the 3D physical dimensions of the cloud. Musca is found to be vibrating globally, with the characteristic modes of a sheet viewed edge-on, not a filament as previously supposed. We reconstruct the physical properties of Musca through 3D magnetohydrodynamic simulations, reproducing the observed normal modes and confirming a sheet-like morphology.

Disruption of circumstellar discs by large-scale stellar magnetic fields

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Spectropolarimetric surveys reveal that 8-10% of OBA stars harbor large-scale magnetic fields, but thus far no such fields have been detected in any classical Be stars. Motivated by this, we present here MHD simulations for how a pre-existing Keplerian disc – like that inferred to form from decretion of material from rapidly rotating Be stars – can be disrupted by a rotation-aligned stellar dipole field. For characteristic stellar and disc parameters of a near-critically rotating B2e star, we find that a polar surface field strength of just 10 G can significantly disrupt the disc, while a field of 100 G, near the observational upper limit inferred for most Be stars, completely destroys the disc over just a few days. Our parameter study shows that the efficacy of this magnetic disruption of a disc scales with the characteristic plasma beta (defined as the ratio between thermal and magnetic pressure) in the disc, but is surprisingly insensitive to other variations, e.g. in stellar rotation speed, or the mass loss rate of the star's radiatively driven wind. The disc disruption seen here for even a modest field strength suggests that the presumed formation of such Be discs by decretion of material from the star would likely be strongly inhibited by such fields; this provides an attractive explanation for why no large-scale fields are detected from such Be stars.

V1094 Sco: a rare giant multi-ringed disk around a T Tauri star

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A wide variety of ring-like dust structures has been detected in protoplanetary disks, but their origin and frequency are still unclear. We characterize the structure of an extended, multi-ringed disk discovered serendipitously in the ALMA Lupus disk survey and put it in the context of the Lupus disk population. ALMA observations in Band 6 at 234 GHz and Band 7 at 328 GHz at $0''3$ resolution toward the K6 star V1094 Sco in Lupus III are presented, and its disk structure is analyzed. The spectral index α_{mm} is determined in the inner 150 AU of the disk. The ALMA continuum data show a very extended disk with two gap/ring pairs. The gaps are located at 100 AU and 170 AU, the bright rings at 130 AU and 220 AU. Continuum emission is detected out to a 300 AU distance, similar to IM Lup but a factor of 5 larger than typically found for Lupus disks at this sensitivity and resolution. The bright central region of the disk (within 35 AU) is possibly optically thick at 1 mm wavelengths, and has a brightness temperature of only 13 K. The spectral index increases between the inner disk and the first ring, at the location of the first gap. Due to the low temperature of the disk midplane, snow lines can be excluded as the drivers behind the ring and gap formation in this disk. Disks the size of V1094 Sco are rare, and only 2.1±1.5% of disks in Lupus show continuum emission beyond 200 AU. Possible connections between the large primordial disk population, transition disks, and exoplanets are discussed.

VLTI/MIDI atlas of disks around low- and intermediate-mass young stellar objects

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Protoplanetary disks show large diversity regarding their morphology and dust composition. With mid-infrared interferometry the thermal emission of disks can be spatially resolved, and the distribution and properties of the

dust within can be studied. Our aim is to perform a statistical analysis on a large sample of 82 disks around low- and intermediate-mass young stars, based on mid-infrared interferometric observations. We intend to study the distribution of disk sizes, variability, and the silicate dust mineralogy. Archival mid-infrared interferometric data from the MIDI instrument on the Very Large Telescope Interferometer are homogeneously reduced and calibrated. Geometric disk models are used to fit the observations to get spatial information about the disks. An automatic spectral decomposition pipeline is applied to analyze the shape of the silicate feature. We present the resulting data products in the form of an atlas, containing N band correlated and total spectra, visibilities, and differential phases. All these data are accessible at the project website at `http://www.konkoly.hu/MIDI_atlas`. The majority of our data can be well fitted with a continuous disk model, except for a few objects, where a gapped model gives a better match. From the mid-infrared size–luminosity relation we find that disks around T Tauri stars are generally colder and more extended with respect to the stellar luminosity than disks around Herbig Ae stars. We find that in the innermost part of the disks ($r < 1$ au) the silicate feature is generally weaker than in the outer parts, suggesting that in the inner parts the dust is substantially more processed. We analyze stellar multiplicity and find that in two systems (AB Aur and HD 72106) data suggest a new companion or asymmetric inner disk structure. We make predictions for the observability of our objects with the upcoming Multi-AperTure mid-Infrared SpectroScopic Experiment (MATISSE) instrument, supporting the practical preparations of future MATISSE observations of T Tauri stars.

Giant planets around FGK stars form probably through core accretion

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We present a statistical study of the planet-metallicity (P-M) correlation, by comparing the 744 stars with candidate planets (SWPs) in the Kepler field which have been observed with LAMOST, and a sample of distance-independent, fake "twin" stars in the Kepler field with no planet reported (CKSNPs) yet. With the well-defined and carefully-selected large samples, we find for the first time a turn-off P-M correlation of $\Delta[Fe/H]_{SWPs-SNPs}$, which in average increases from $\sim 0.00 \pm 0.03$ dex to 0.06 ± 0.03 dex, and to 0.12 ± 0.03 for stars with Earth, Neptune, Jupiter-sized planets successively, and then declines to $\sim -0.01 \pm 0.03$ dex for more massive planets or brown dwarfs. Moreover, the percentage of those systems with positive $\Delta[Fe/H]$ has the same turn-off pattern. We also find FG-type stars follow this general trend, but K-type stars are different. Moderate metal enhancement (~ 0.1–0.2 dex) for K-type stars with planets of radii between 2 to 4 $R_\oplus$ as compared to CKSNPs is observed, which indicates much higher metallicities are required for Super-Earths, Neptune-sized planets to form around K-type stars. We point out that the P-M correlation is actually metallicity-dependent, i.e., the correlation is positive at solar and super-solar metallicities, and negative at subsolar metallicities. No steady increase of $\Delta[Fe/H]$ against planet sizes is observed for rocky planets, excluding the pollution scenario as a major mechanism for the P-M correlation. All these clues suggest that giant planets probably form differently from rocky planets or more massive planets/brown dwarfs, and the core-accretion scenario is highly favoured, and high metallicity is a prerequisite for massive planets to form.

Chandra Detection of An Evolved Population of Young Stars in Serpens South

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We present a Chandra study of the deeply embedded Serpens South star-forming region, examining cluster structure and disk properties at the earliest stages. In total, 152 X-ray sources are detected. Combined with Spitzer and 2MASS photometry, 66 X-ray sources are reliably matched to an IR counterpart. We identify 21 class I, 6 flat spectrum, 16 class II, and 18 class III young stars; 5 were unclassified. Eighteen sources were variable in X-rays, 8 exhibiting flare-like emission, and one periodic source. The cluster X-ray luminosity distance was estimated, the best match was to the nearer distance of 260 pc for the front of the Aquila Rift complex. The N_H vs. A_K ratio is found to be $\sim 0.68 \times 10^{22}$, similar to that measured in other young low mass regions, but lower than that measured in the ISM and high mass clusters ($\sim(1.6–2) \times 10^{22}$). We find the spatial distribution closely follows that of the dense filament from which the stars have formed, with the class II population still strongly associated with the filament. There are four sub-clusters in the field, with three forming knots in the filament, and a fourth to the west, which may not be associated but may be contributing to the distributed class III population. A high percentage of diskless class IIIs (upper limit 30% of classified X-ray sources) in such a young cluster could indicate that processing of disks is influenced by the cluster environment and is not solely time-scale dependent.

Extended ammonia observations towards the 'Integral-Shaped Filament'

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Recent observations suggest a scenario in which filamentary structures in the ISM represent the first step towards clumps/cores and eventually star formation. The densest filaments would then fragment into prestellar cores owing to gravitational instability. We seek to understand the roles filamentary structures play in high-mass star formation. We mapped the integral-shaped filament (ISF) in NH_3 (1,1) and (2,2). The whole filamentary structure is uniformly and fully sampled. We find that the morphology revealed by the map of velocity-integrated intensity of the NH_3 (1,1) line is closely associated with the dust ridge. We identify 6 "clumps" related to the well known OMC-1 to 5 and 11 "sub-clumps" within the map and they are separated not randomly but in roughly equal intervals along the ISF. The average spacing of clumps is $11'.30 \pm 1'.31$ (1.36 ± 0.16 pc) and the average spacing of sub-clumps is $7'.18 \pm 1'.19$ (0.86 ± 0.14 pc). These spacings agree well with the predicted values of the thermal (0.86 pc) and turbulent sausage instability (1.43 pc) by adopting a cylindric geometry of the ISF with an inclination of $60°$ with respect to the line of sight. We also find a velocity gradient of about 0.6 km s^{-1} pc^{-1} that runs along the ISF which likely arises from an overall rotation of the Orion A molecular cloud. The inferred ratio between rotational and gravitational energy is well below unity. Furthermore, fluctuations are seen in the centroid velocity diagram along the ISF. The OMC-1 to 5 clouds are located close to the local extrema of the fluctuations, which suggests that there exist gas flows associated with these clumps in the ISF. The derived NH_3 (1,1) and (2,2) rotation temperatures in the OMC-1 are about 30–40 K. In OMC-2, OMC-3, and the northern part of OMC-4, we find higher and lower temperatures at the boundaries and in the interior, respectively.

CO in Protostars (COPS): *Herschel*-SPIRE Spectroscopy of Embedded Protostars

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We present full spectral scans from 200–670 μm of 26 Class 0+I protostellar sources, obtained with *Herschel*-SPIRE, as part of the "COPS-SPIRE" Open Time program, complementary to the DIGIT and WISH Key programs. Based on our nearly continuous, line-free spectra from 200–670 μm, the calculated bolometric luminosities (L_{bol}) increase by 50% on average, and the bolometric temperatures (T_{bol}) decrease by 10% on average, in comparison with the measurements without *Herschel*. Fifteen protostars have the same Class using T_{bol} and $L_{\mathrm{bol}}/L_{\mathrm{smm}}$. We identify rotational transitions of CO lines from $J = 4 \to 3$ to $J = 13 \to 12$, along with emission lines of ^{13}CO, HCO$^+$, H$_2$O, and [C I]. The ratios of ^{12}CO to ^{13}CO indicate that ^{12}CO emission remains optically thick for $J_{\mathrm{up}} < 13$. We fit up to four components of temperature from the rotational diagram with flexible break points to separate the components. The distribution of rotational temperatures shows a primary population around 100 K with a secondary population at ∼350 K. We quantify the correlations of each line pair found in our dataset, and find the strength of correlation of CO lines decreases as the difference between J-level between two CO lines increases. The multiple origins of CO emission previously revealed by velocity-resolved profiles are consistent with this smooth distribution if each physical component contributes to a wide range of CO lines with significant overlap in the CO ladder. We investigate the spatial extent of CO emission and find that the morphology is more centrally peaked and less bipolar at high-J lines. We find the CO emission observed with SPIRE related to outflows, which consists two components, the entrained gas and shocked gas, as revealed by our rotational diagram analysis as well as the studies with velocity-resolved CO emission.

Stellar masses and disk properties of Lupus young stellar objects traced by velocity-aligned stacked ALMA ^{13}CO and C^{18}O spectra

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Aims. Large samples of protoplanetary disks have been observed in recent ALMA surveys. The gas distributions and velocity structures of most of the disks can still not be imaged at high S/N ratios because of the short integration time per source in these surveys. In this work, we apply the velocity-aligned stacking method to extract more information from molecular-line data of these ALMA surveys and to study the kinematics and disk properties traced by molecular lines.

Methods. We re-analyzed the ALMA ^{13}CO (3–2) and C^{18}O (3–2) data of 88 young stellar objects (YSOs) in Lupus with the velocity-aligned stacking method. This method aligns spectra at different positions in a disk based on the projected Keplerian velocities at their positions and then stacks them. This method enhances the S/N ratios of molecular-line data and allows us to obtain better detections and to constrain dynamical stellar masses and disk orientations.

Results. We obtain ^{13}CO detections in 41 disks and C^{18}O detections in 18 disks with 11 new detections in ^{13}CO and 9 new detections in C^{18}O after applying the method. We estimate the disk orientations and the dynamical masses of the central YSOs from the ^{13}CO data. Our estimated dynamical stellar masses correlate with the spectroscopic stellar masses, and in a subsample of 16 sources, where the inclination angles are better constrained, the two masses are in a good agreement within the uncertainties and with a mean difference of 0.15 $M_\odot$. With more detections of fainter disks, our results show that high gas masses derived from the ^{13}CO and C^{18}O lines tend to be associated with high dust masses estimated from the continuum emission. Nevertheless, the scatter is large and is estimated to be 0.9 dex, implying large uncertainties in deriving the disk gas mass from the line fluxes. We find that with such large uncertainties it is expected that there is no correlation between the disk gas mass and the mass accretion rate with the current data. Deeper observations to detect disks with gas masses $<10^{-5}$ $M_\odot$ in molecular lines are needed to investigate the correlation between the disk gas mass and the mass accretion rate.

https://arxiv.org/pdf/1804.06272.pdf

Complex organic molecules in the Galactic Centre: the N-bearing family

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We present an unbiased spectral line survey toward the Galactic Centre (GC) quiescent giant molecular cloud (QGMC), G+0.693 using the GBT and IRAM 30 telescopes. Our study highlights an extremely rich organic inventory of abundant amounts of nitrogen (N)-bearing species in a source without signatures of star formation. We report the detection of 17 N-bearing species in this source, of which 8 are complex organic molecules (COMs). A comparison of the derived abundances relative to H$_2$ is made across various galactic and extragalactic environments. We conclude that the unique chemistry in this source is likely to be dominated by low-velocity shocks with X-rays/cosmic rays also playing an important role in the chemistry. Like previous findings obtained for O-bearing molecules, our results for N-bearing species suggest a more efficient hydrogenation of these species on dust grains in G+0.693 than in hot cores in the Galactic disk, as a consequence of the low dust temperatures coupled with energetic processing by X-ray/cosmic ray radiation in the GC.

https://arxiv.org/pdf/1804.11321

Planet Formation in Highly Inclined Binary Systems. II. Orbital Alignment or Anti-alignment and Planet Growth Boost in Intermediate Separation Binaries

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Stars are commonly formed in binary systems, which provide a natural laboratory for studying planet formation in extreme conditions. In our first paper (Paper I) of a series (Xie et al. 2011), we have shown that the intermediate stage — from planetesimals to planetary embryos/cores — of planet formation can proceed even in highly inclined binaries. Following Paper I, here we numerically study the late stage of terrestrial planet formation, i.e., from embryos to full planets, in binary systems of various orbital configurations. We identify an orbital alignment or anti-alignment effect; namely, although an inclined binary generally misaligns the planetary orbits with respect to the spin axis of the primary host star (i.e., causing large obliquity), it could align or anti-align the planetary orbits with respect to the binary orbit. Such an orbital (anti-)alignment effect is caused by the combination of orbital differential precession and self-damping, and it is mostly significant in cases of intermediate binary separations, i.e., $a_B \sim 40$–200 AU for terrestrial planet formation around 1 AU from the primary stars. In such intermediate separation binaries, somewhat contrary to intuition, the binary companion can aid planet growth by having increased the rate of collisions, forming significantly more massive but fewer planets. In the other two ends, the companion is ether too close thus plays a violently disruptive role or too wide to have significant effect on planet formation. Future observations, which can discover more planet-bearing binary star systems and constrain their masses and 3-D orbital motions will test our numerical findings.

Abstracts of recently accepted major reviews

Planet Populations as a Function of Stellar Properties

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Exoplanets around different types of stars provide a window into the diverse environments in which planets form. This chapter describes the observed relations between exoplanet populations and stellar properties and how they connect to planet formation in protoplanetary disks. Giant planets occur more frequently around more metal-rich and more massive stars. These findings support the core accretion theory of planet formation, in which the cores of giant planets form more rapidly in more metal-rich and more massive protoplanetary disks. Smaller planets, those with sizes roughly between Earth and Neptune, exhibit different scaling relations with stellar properties. These planets are found around stars with a wide range of metallicities and occur more frequently around lower mass stars. This indicates that planet formation takes place in a wide range of environments, yet it is not clear why planets form more efficiently around low mass stars. Going forward, exoplanet surveys targeting M dwarfs will characterize the exoplanet population around the lowest mass stars. In combination with ongoing stellar characterization, this will help us understand the formation of planets in a large range of environments.

Studying Young Stellar Objects with Near-IR Non-redundant Aperture Masking and Millimeter Interferometry

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Ph.D dissertation directed by: Lucas A. Cieza

Ph.D degree awarded: March, 2018

Circumstellar disks and outflows play a central role in the growth of low-mass ($M < 2$ $M_\odot$) stars and the formation of planetary systems. These disks are ubiquitous at young ages (< 1 Myr), as they are naturally formed during the gravitational collapse of protostellar cores due to the conservation of angular momentum. Circumstellar disks feed the forming stars and provide an environment for small grains to eventually grow into rocky planets and the cores of giant planets at a wide range of stellocentric distances ($\sim$ 0.1-100 au). In parallel to the growth solids in the disk, bipolar outflows and winds are generated on similar physical scales. Outflows carry angular momentum away and help the accretion of circumstellar material onto the central object. They also play an important role in the dissipation of the envelope that marks the transition from the Class I (a deeply embedded protostar) to Class II stage (an optically visible T Tauri star). Eventually, the primordial disk disperse, leaving a star surrounded by a remnant debris (Class III) object and likely a system of planetesimals and planets.

This thesis incorporates high-sensitivity millimeter-wavelength interferometry and near-infrared Non-Redundant Mask (NRM) Interferometry to assess molecular outflow and disks properties in Class I-II objects. It explores the physical mechanisms dispersing the disk and envelope system (e.g., outflows and dynamical interactions in binary systems) and the properties of protoplanetary disks as a function of stellar mass at an age of 2-3 Myr.

We investigate the properties of the Class I molecular outflows present in HBC 494 and V883 Ori, two young stellar objects experiencing episodic events of extreme accretion known as FU Ori outbursts. These outflows help to disperse the surrounding envelope at very early stages while removing angular momentum from the disk. We estimate the kinematic properties and describe physical structures of the outflows using the ^{12}CO and ^{13}CO emissions lines. Similarly, the C^{18}O emission line is used to describe envelope material of both sources. An outstanding result is the wide-opening angle of the outflow cavities of $\sim 150^\circ$ for both sources. Outflows masses in both FUors are on the same order of magnitude, while V883 Ori shows an outflow component that is much slower (characteristic velocity of only 0.65 km s^{-1}) than seen in other FUors such as HBC 494. To date, interferometric studies of FUors are scarce and more observations needed in order to compare with other objects at a similar sensitivity and resolution.

In addition, using NRM, we searched for binary companions to objects previously classified as Transitional Disks (TD, disks with inner opacity holes) in nearby (d < 300 pc) star-forming regions (Ophiuchus, Taurus-Auriga, and IC348) and investigate the interaction with (sub)stellar companions as a possible mechanism for the depletion of their inner disks. We implement a new method of completeness correction using a combination of randomly sampled binary orbits and Bayesian inference. We find that $\sim 0.38 \pm 0.09$ of the TDs are actually circumbinary disks, while the remaining objects are transitional disks where the inner holes are the result of other internal processes such as photoevaporation, and/or planet-disk interactions.

Finally, we present an ALMA 1.3 mm survey of Class II sources in the benchmark 2-3 Myr stellar cluster IC 348 to investigate the properties of disks at the time 50% of the disks have already been completely dispersed. We find that the detection rate in 1.3 mm continuum is a strong function of stellar mass. Most targets with masses 0.3< $M_\odot$ remain undetected down to a 3-σ sensitivity of 0.45 mJy, corresponding to a disk dust mass of ~ 1.3 $M_\oplus$. A stacking analysis of the non-detections suggests that the typical dust mass around most 2-3 Myr old M-type stars is < 0.4 $M_\oplus$. A Bayesian analysis is used to statistically compare IC 348 to other star-forming regions. As a general result, this analysis shows that IC 348 disks are a factor of 4 fainter on average than in Taurus, Cha I, and Lupus. While, IC 348 and σ Ori have similar distributions. On the other hand, Upper Sco disks are definitely fainter on average than IC 348. The resulting cumulative distribution functions confirm a clear evolution (depletion of mm-sized grains) of the circumstellar disks in these regions over a period of 1-10 Myr.

Abstract submission deadline

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

The Wonders of Star Formation, a tribute to Hans Zinnecker

September 3-7, 2018
John McIntyre Conference Centre, Edinburgh, UK

Rationale: This meeting will celebrate the many and varied contributions that Hans Zinnecker has made to the study of star formation during his long and active career, and the inspiration that working with Hans has given countless astronomers, both young and old, over the years. Understanding when, where and how stars form continues to be one of the most compelling problems in astrophysics, and a new generation of instruments is set to maintain the excitement of this field into the foreseeable future. We will explore the key observations and theories, their contradictions and limitations, and the steps being taken to overcome them. The meeting will be held in the beautiful city of Edinburgh, where Hans was a postdoc 35 years ago. The aim will be to chart the progress that has been made since then, to identify the problems that still need to be addressed, and how best to go about solving them. The meetings is open to all, and we hope you will be able to join us and help to make this a memorable event.

Principle Themes: Molecular Clouds and Filaments; Low-Mass Star Formation; Jets and Outflows; Massive Star Formation; Feedback from Massive Stars; Multiple Systems; Clusters; The Initial Mass Function; Starbursts and the Galactic Context.

Invited speakers:

Matthew Bate	Bernhard Brandl	Sylvie Cabrit	Bruce Elmegreen
Yasuo Fukui	Alvaro Hacar	Patrick Hennebelle	Shu-ichiro Inutsuka
Kaitlin Kratter	Diederik Kruijssen	Rolf Kuiper	Charlie Lada
Richard Parker	Bo Reipurth	Jürgen Stutzki	Sarah Ragan
Jonathan Tan	John Tobin	Steffi Walch	Derek Ward-Thompson
Richard Wünsch	Hal Yorke	Annie Zavagno	Hans Zinnecker

Important Deadlines

Abstract submission,	2018 July 02	⟵ **revised**
Talk/poster allocation,	2018 July 31	⟵ **revised**
Late registration,	2018 July 31.	

Registration:
https://events.ph.ed.ac.uk/star-formation

SOC: Ant Whitworth (chair), Ken Rice (deputy chair), John Bally, Ian Bonnell, Cathie Clarke, Mark McCaughrean, Bo Reipurth, Dimitri Stamatellos, Steffi Walch, Hal Yorke.

School on Protoplanetary Disks in Young Stellar Objects

This school, addressed to Master and PhD students in Astronomy and Astrophysics with a strong interest in Star Formation, will be held at the Institute of Cosmos Sciences of the University of Barcelona (ICCUB) from October 22nd to 26th 2018.

One of the hot topics of modern astrophysics is the formation and evolution of protoplanetary disks in young stellar objects. The aim of the school is to provide the tools to understand the physics involved in the star and protoplanetary disk formation process and to give an overview to the current observational results and models. Special attention will be given to a hands-on approach to observational techniques, observational ALMA proposal, and data reduction tools.

The course is 100% financed by the ICCUB, through its Mara de Maeztu award. Registration is free of charge. The number of participants will be limited to 30.

LECTURES:

1. Star formation process: low- and high-mass stars
2. Jets in YSOs
3. Observation of disks in low- and high-mass star forming regions
4. Disks models in low- and high-mass stars
5. Polarization and magnetic fields in YSOs
6. Cosmic rays and disk formation
7. Masers as a tool to observe high-mass star formation

PRACTICAL WORKS:

1. Observational techniques: Radio interferometry
2. Observational techniques: Visible and near-IR
3. CASA tutorial
4. ALMA Observing Tool tutorial

INVITED LECTURERS:

Felipe O. Alves (CAS-MPIfEP), Guillem Anglada (IAA), Maite Beltrán (Arcetri), Josep Miquel Girart (ICE), Mayra Osorio (IAA), Marco Padovani (Arcetri), Álvaro Sánchez-Monge (Universität zu Köln), José Maria Torrelles (ICE)

IMPORTANT DATES:

Registration will be open from 1st June to 31st July 2018

Webpage: http://icc.ub.edu/congress/ICCUBschool/

e-mail: iccubschool2018@icc.ub.edu

Organizing Committee: Robert Estalella (ICCUB), Rosario López (ICCUB), Josep Miquel Girart (ICE, CSIC-IEEC), Gemma Busquet (ICE, CSIC-IEEC)

Chandra Science Workshop on Accretion in Stellar Systems
August 8-10, 2018 – Cambridge, MA, USA

The workshop aims to bring together people working on accretion, outflows and related processes in diverse astrophysical objects, from protostars to cataclysmic variables to super-Eddington accretion in stellar mass black hole and neutron star binaries. The focus will be to understand how accretion and ejection work, how they affect stellar evolution, what important issues remain unanswered, and what are likely to be the most promising future research directions. The workshop will cover theory, simulations and observations, spanning the time domain, the entire electromagnetic spectrum, gravitational waves and energetic particles. A special session dedicated to the late Jeff McClintock's legacy to the field will also be held.

For more information, please visit: http://cxc.cfa.harvard.edu/cdo/accr2018/
or contact: accr2018@cfa.harvard.edu

Second announcement - final conference of our COST Action CM1401
Our Astro-Chemical History: Past, Present and Future

Sept 10th -14th 2018, Assen, Netherlands

Key dates:

• registration closes June 15th 2018

• accommodation booking required by July 1st 2018

The main aim of this final conference of the EU COST action CM1401 is to discuss the scientific results from our action, focusing on the areas covered by our working groups (a) the chemistry in cold diluted gases, (b) icy grain surface chemistry, (c) UV and X-ray photochemistry and (d) isotopic fractionation. We plan to have a strong focus on new collaborations and projects originating from our funded short term scientific missions. Additional invited talks will highlight the most recent discoveries and upcoming missions/facilities related to astrochemistry. The conference is also meant to look into the future and define the key areas where progress needs to be made to move the field ahead. An overview of the preliminary program and the scheduled sessions can be found at our website

http://cost.obs.ujf-grenoble.fr/conference2018/program

The conference will take place in Assen (Netherlands) at the Hof van Saksen from 10-14 September 2018. The deadline for registration is June 15

http://www.open.ac.uk/science/physical-science-conferences/cm1401-conference-our-astro-%C2%ADchemical-history-past-present-and-future

After completing registration, you will receive the contact details to book your accomodation package (5 days, 4 nights including board and lodging) with the Hof van Saksen in Assen.

The last management meeting of the action will take place on Wednesday afternoon.

We are looking forward to seeing as many of you as possible there!

The SOC Inga Kamp, Jean-Hugues Fillion, Helen Fraser, Octavio Roncero, Dmitry Semenov, Yury Suleymanov, Charlotte Vastel, Laurent Wiesenfeld

Cosmic Rays and the Inter Stellar Medium
25 - 29 June 2018, Grenoble, France
https://crism2008.sciencesconf.org/

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

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

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

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

Summer School on Origins of the Solar System
16 - 20 July, 2018, Taipei, Taiwan
http://events.asiaa.sinica.edu.tw/school/20180716/

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

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

Chandra Science Workshop on Accretion in Stellar Systems
8 - 10 August 2018, Cambridge, MA, USA
http://cxc.cfa.harvard.edu/cdo/accre2018/

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

Star Cluster Formation: Mapping the first few Myrs
29 - 31 August 2018, Grenoble, France
https://sfm.leeds.ac.uk/registerinterest/

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

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

Triple Evolution and Dynamics
10 - 14 September 2018, Leiden, The Netherlands
http://www.lorentzcenter.nl/lc/web/2018/1016/info.php3?wsid=1016&venue=Oort

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

Planet Formation and Evolution 2019
27 February - 1 March, Rostock, Germany
http://pfe2019.stat.physik.uni-rostock.de

Zooming in on Star Formation - A tribute to Åke Nordlund
9 - 14 June 2019, Nafplio, Greece
http://www.nbia.dk/nbia-zoomstarform-2019

Moving ... ??

If you move or your e-mail address changes, please send the editor your new address. If the Newsletter bounces back from an address for three consecutive months, the address is deleted from the mailing list.

The MOJO videos on planet formation

Alessandro Morbidelli and I, with our respective groups, have just finished a project on 'Modeling the Origin of Jovian planets' (MOJO). We made a series of short (5-10 minute) videos that, while highlighting the main results of our work, describe some main aspects of planet formation. The level is that of advanced public outreach, but the videos may be useful also as an introduction of various topics to undergrad students.

The 12 videos are freely available on youtube:

- Introduction – https://youtube.com/cVe-V_UjB28

- Stages of planet formation: current paradigms – https://youtu.be/4Cs6qUHz3yA

- How common are Solar Systems? – https://youtu.be/dtwyb6eQJ9Q

- Why is Jupiter so much bigger than Earth? – https://youtu.be/QYTMZFgGdPg

- Why is Mars smaller than Earth? – https://youtu.be/cSUrfEErhSE

- Why is Earth so dry? – https://youtu.be/TOoUDQKCFFw

- Where did Earth's water come from? – https://youtu.be/2vHo93Kq4Ew

- How do super-Earths form? – https://youtu.be/mG374opbH_8

- Why super-Earths cannot have formed 'in-situ' – https://youtu.be/ANj1pK74j-Q

- Why aren't there any close-in Super-Earths in the Solar System? – https://youtu.be/LKLP5IBgVWI

- Unsolved mysteries in planet formation – https://youtu.be/mO8QYRtezcQ

- The origin of the interstellar object Oumuamua – https://youtu.be/RNIYwyhaVWY

This blog post contains a link to each video: https://planetplanet.net/2018/05/30/the-mojo-videos/

SOFIA Cycle 7 Call for Proposals Released

The SOFIA project has released two calls for proposals (CfP) for observing time in the Cycle 7 period.

The regular call solicits proposals of any size and combination of instruments. A total of 400 hours of observing time and approximately US$4 Million of funding is available to support these programs. There is a separate call for those affiliated with German institutions administered by the German SOFIA Institute (Deutsches SOFIA Institut; DSI) on behalf of the German Aerospace Center (Deutsches Zentrum für Luft und Raumfahrt; DLR) that will offer an additional approximately 70 hours of observing time.

A complementary call for proposals for "SOFIA Legacy Programs" (SLP) has also been released, soliciting large coherent programs aimed at high-impact science that also have a significant promise of valuable archival data sets. Programs up to 100 hours of observing time are solicited in this category. In addition to observing time, these programs are invited to deliver higher level data products (including supporting data, software and theory). Nominally, two SLP programs are expected to be selected per cycle, with observations carried out over two cycles, and a third year included for completion of the higher-level data processing and analysis. Up to US$1 million per cycle is available for support of the SLPs.

The main parts of the Cycle 7 calendar are:

CfP release: June 1, 2018
CfP update: July 16, 2018
Proposal Deadline: September 7, 2018 (9 p.m. PDT)
Selections announced: November 2018
Cycle 7: April 27, 2019 - April 27, 2020

For more information see https://www.sofia.usra.edu/science/proposing-and-observing/proposal-calls
Any questions about the Cycle 7 Calls for Proposals can be directed to mailto:sofia_help@sofia.usra.edu
Please feel free to direct questions and comments to the SOFIA Science Center help desk: mailto:sofia_help@sofia.usra.edu.