

THE STAR FORMATION NEWSLETTER

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The Star Formation Newsletter

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Cover Picture

This image shows the massive young cluster IC 1805 situated within the W4 complex in Cassiopeia, a large molecular shell about $1^\circ \times 1.5^\circ$ in diameter. The cluster stars have ages between 1 and 3 Myr and include at least 9 O-stars. VLBI parallax measurements of masers indicate a distance of 1.95 ± 0.04 kpc. The cluster drives one of the most spectacular superbubbles known, a 100 pc wide chimney rising out of the Galactic plane.

Image courtesy Terry Hancock
(www.downunderobservatory.com)

Submitting your abstracts

Latex macros for submitting abstracts and dissertation abstracts (by e-mail to reipurth@ifahawaii.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>

Francesco Palla

in conversation with Bo Reipurth



Q: *You first started working on primordial star formation. Was that in connection with your doctoral thesis?*

A: Only partially. My thesis project was on the infrared emission from dust grains in galactic molecular clouds, under the supervision of Antonella Natta at the University of Rome. The interest on primordial star formation developed later after attending a series of lectures by Joe Silk during a Saas Fee school on "Star Formation". Part of his course was on the first stars and Joe discussed the critical role that H_2 molecules could play in a gas of pristine composition with no metals and dust grains. He mentioned that a small, but not negligible fraction (of order 10^{-5} - 10^{-3}) of atomic H could be converted into H_2 molecules purely by gas phase reactions thanks to the residual ionization left over after recombination. This tiny fraction of H_2 molecules could help cooling the gas, promoting fragmentation and induce the formation of massive, or very massive stars. I couldn't believe that so little H_2 could have such a large impact on first star formation. So, when I got an ESA Fellowship to continue my research on dust grains and infrared emission in Mayo Greenberg's Laboratory in The Netherlands, I decided instead to switch topic and explore the unusual (for the time) field of primordial stars. Thus, I ended up at Cornell University to work with Prof. Ed Salpeter, a master of everything including molecules and the interstellar medium. It was there that I met with Steve Stahler and that it all started. At the end of the project, we realized that the initially atomic gas could be converted into a fully molecular mixture thanks to the three body reactions that take place whenever sufficiently high density (of order 10^9 cm^{-3} and more) are achieved during gravitational collapse. As a result, continued fragmentation would allow the formation of low-mass stars even in these unique conditions.

Q: *In the early 90's, you and Steve Stahler performed pio-*

neering calculations of the structure of intermediate mass protostars. What were your main conclusions?

A: Steve and I had acquired experience in the numerical calculations of accreting massive stars for our project on primordial protostars. Thus, it was natural for me to continue the collaboration on present-day protostars and extend the models that Steve had developed for solar and sub-solar masses. The results were extremely satisfying as, among other things, we identified a new mechanism, deuterium-shell burning, that caused a large swelling of the protostellar radius and a concurrent delay in the contraction of $2\text{-}3 M_\odot$ protostars toward the main sequence. I remember with excitement and affection the days when the numerical code would give us troubles in convergence due to the fast increase of the radius in very short time steps. We thought of all possible numerical errors, but the results were in fact real and robust. In this way, we could proceed further with the calculations of more massive stars by varying the accretion flow and exploring different accretion geometries all the way up to massive objects.

Q: *This was followed by a widely cited study of the early evolution of intermediate mass stars and a comparison with the Herbig Ae/Be stars.*

A: Yes, the new results had a direct impact on the understanding of the location of the intermediate-mass stars in the HR diagram. The puzzle was that the Herbig Ae/Be stars occupy a limited portion of the diagram well above the main sequence that all the previous models of protostellar evolution had failed to explain. Our birthline computed at the fiducial rate of $10^{-5} M_\odot \text{ yr}^{-1}$ did provide a gratifying match to the upper envelope of the observed distribution of most of the known Herbig Ae/Be stars. Few of them actually laid above the birthline, suggestive of a mass accretion rate higher than the fiducial value for more massive stars, an issue that is still with us today. The other interesting prediction of our models was that stars of mass above $8\text{-}10 M_\odot$ should be found on the main sequence even during the accretion phase, due to the short Kelvin-Helmholtz contraction time compared to the accretion time, thus excluding a pre-main sequence phase for such objects. I remember meeting with George Herbig at the conference on "his" stars in 1993 in Amsterdam. He was quite pleased, in his own characteristic style, with our results.

Q: *You and Steve have compared your evolutionary tracks with observations of clusters and associations, such as the Orion Nebula Cluster and the Taurus-Auriga region, and have found evidence that star formation is accelerating. Is this a universal phenomenon?*

A: Ah, this is controversial! But we still maintain that the interpretation of the pattern of accelerating star formation, in spite of all the simplifying assumptions of our

analysis and the uncertainties with the evolutionary tracks and models, is an intrinsic property of the way molecular cloud and dense cores turn the gas into stars. So, if it works, it should be a universal feature. I had stumbled on it while thinking of a solution to the post-T Tauri stars (or lack thereof) based on the fact that star formation is not a rapid process and also that it doesn't occur at a constant rate during the cloud lifetime. Then, the paucity of old T Tauri stars in young associations and clusters would not be an observational problem, but just an intrinsic fact common to all such regions. Afterwards, I have tried to find independent evidence of the observed large spread of the stellar distributions in the HR diagram from a variety of indicators, mainly spectroscopic (i.e. variation of surface gravity, lithium abundance etc.). The discussion that was spurred after our suggestion is still lively today, although the advocates of a rapid mode of star formation appear to have a louder voice. However, recent numerical models that follow the gravitational contraction of molecular clouds under their own gravity have corroborated our empirical finding, showing that the star formation rate indeed increases with time.

Q: *Ten years ago, you and Isabelle Baraffe predicted that brown dwarfs might pulsate. What is the latest status?*

A: Isabelle and I were very excited at this result, mainly for two reasons. First, unlike traditional pulsation instabilities excited in the outer layers of the stars by opacity effects (the so-called "kappa" mechanism), those associated with brown dwarfs are due to the high sensitivity of the energy generation rate of deuterium burning in the core to small temperature and density perturbations (the "epsilon" mechanism). The latter has never been observed in any astronomical object. We thought that the ephemeral, but critical, D-burning phase of young BDs would provide a splendid opportunity to search for this process. Second, if present, the observed frequencies would have offered a unique way to probe the interior of these peculiar objects and to test evolutionary models. Unfortunately, given the linear nature of our study, we could not determine the amplitude of the predicted pulsations, but we just computed the expected periods of a few hours. Now, dedicated optical and infrared photometric searches for the periodic variations have been carried out (in particular by Anne Marie Cody and Lynne Hillenbrand in σ Ori) without a positive result down to stringent limits in amplitudes (a few mmag). However, σ Ori might not be the ideal case where to look at, while for example Cha I with its younger age is better suited for such studies.

Q: *Lately you have focused on lithium depletion in YSOs.*

A: Being a nuclear clock, lithium burning offers a very precise way of gauging stellar ages. The application of the lithium depletion boundary to unambiguously identify brown dwarfs is a beautiful demonstration of its po-

tential. I have been involved in the determination of the LDB in pre-main sequence clusters in the age range of 25-40 Myr, finding in some cases a very good agreement with the isochronal ages, but also departures. When applied to individual stars in younger clusters and star forming regions, the derived abundances in low-mass stars (in the mass range 0.2-0.4 M_{\odot}) have yielded large nuclear ages consistent with the isochronal ones, thus providing support for the co-existence of a tail of older stars in a predominantly younger population. This data will be greatly expanded by the results of the Gaia-ESO survey that will accumulate high quality spectra, including the lithium feature, on an extended sample of young clusters and associations.

Q: *Although your work is mainly theoretical, you have had a life-long passion for observations of masers.*

A: Apart from the very interesting physics that is involved with astrophysical masers, my interest in water masers was mainly driven by their property of being excellent signposts of massive star formation throughout the Galaxy. Now, in the early 1990s the Arcetri group was deeply involved with water maser studies using the Medicina 32m radiotelescope and we had noticed that all the bright IRAS sources selected using the Wood & Churchwell color criteria were inevitably associated with strong H_2O masers. Part of our group had developed a keen interest in the search for young massive stars, but it was difficult at the time to select the appropriate sources. The water masers identified by us formed the basis of a rich sample that was later exploited by Riccardo Cesaroni, Sergio Molinari and others to make big progress in the study of the initial conditions of massive star formation.

Q: *As director of Arcetri Observatory, how do you see the current situation in Italy affecting the life of the institute?*

A: Well, since 2012 I'm no longer director of the Observatory, but I've been following the status of the research in our National Institute for Astrophysics. If I'm allowed a personal reflection on my experience as director, I would say that the most gratifying result of all the effort required to run an institute is the possibility to hire young people with a passion in astronomy and give them the same (or even better) chances that I had at a similar age. This is now almost impossible, both at the local and general level. While the amount of funding might have increased in recent years, mostly for dedicated large-scale observational/instrumental projects, the number of positions has shrunk to a number absolutely insufficient for the younger generation to be able to compete for permanent jobs. At the same time, the number of short-term contracts has increased abnormally, creating a huge pressure on the institutions. I am afraid that this situation will not improve in the next years unless a radical change in the political attitude at the national and European levels will occur.

My Favorite Object
The FU Orionis Object HBC 722
Evgeni Semkov



1 Introduction, or What is a FUor

The FU Orionis (FUor, Ambartsumian 1971) phenomenon is one of the most attractive and exciting events during the pre-main sequence (PMS) evolution. The flare-up of FU Orionis itself occurred in 1936, and for several decades it was the only known object of that type. Herbig (1977) defined FUors as a class of young variables after the discovery of outbursts from two more objects - V1057 Cyg and V1515 Cyg. Several additional objects have since been assigned to this class of young variables (see Reipurth & Aspin 2010, Audard et al. 2014, and references therein).

Despite the small number of objects classified as FUors, their basic characteristics are well defined. The main characteristics of FUors are an increase in optical brightness of about 4-5 mag, a F-G supergiant spectrum, strong infrared excess, connection with reflection nebulae, and location in star-forming regions. Typical spectroscopic properties of FUors include a gradual change in the spectrum from earlier to later spectral type from the blue to the infrared, a strong Li I (λ 6707) line, P Cygni profiles of H α and Na I (λ 5890/5896) lines, and the presence of CO bands in the near infrared spectra. The light curves of FUors are varying from one object to another, but as a rule the rise goes faster than the subsequent decline in brightness. A typical outburst of FUor objects can last for several decades or even a century.

FUor stars seem to be related to the low-mass PMS objects (T Tauri stars), which have massive circumstellar disks. According to a commonly accepted view, the FUor outburst is produced by a sizable increase in accretion from a circumstellar disk onto the stellar surface (Hartmann & Kenyon 1996). The cause of this increase in accretion from $\sim 10^{-7} M_{\odot}/\text{yr}$ up to $\sim 10^{-4} M_{\odot}/\text{yr}$ appears to be thermal or gravitational instability in the circumstel-

lar disk. Another possible triggering mechanism could be the interactions of the circumstellar disk with a planet or nearby stellar companion on an eccentric orbit (Lodato & Clarke 2004, Reipurth & Aspin 2004, Pfalzner 2008). For a period of ~ 100 years, the circumstellar disk adds $\sim 10^{-2} M_{\odot}$ onto the central star and ejects $\sim 10\%$ of the accreting material in a high-velocity stellar wind. Because only a small number of FUor stars have been detected to date, photometric and spectral studies of every new object are of great interest.

2 How to identify new FUors?

One could monitor a particular region of star formation for a few years, but without any guarantee to witness a FUor eruption. Therefore, in the case of HBC 722 (also known as V2493 Cyg, PTF 10qpf and LkH α 188-G4) the discovery happened somewhat accidentally. Since about two decades, we are performing a program of optical photometric observations in the field of "the Gulf of Mexico". Our aim is to study the long-term variability of PMS stars in this region of active star formation (Reipurth & Schneider 2008). At present we analyze the first results from this study and prepare them for publication. But, when watching for a long time on the monitor the same area of the sky, your eyes begin to "remember" the field and it is easier to notice any significant change (Fig. 1). Then in mid-August 2010, we sent a telegram (Semkov & Peneva 2010) to inform as soon as possible the astronomical community of the new FUor candidate. The outburst was independently discovered by Miller et al. (2011) during the regular monitoring of NGC 7000 with the Palomar 48-in telescope.

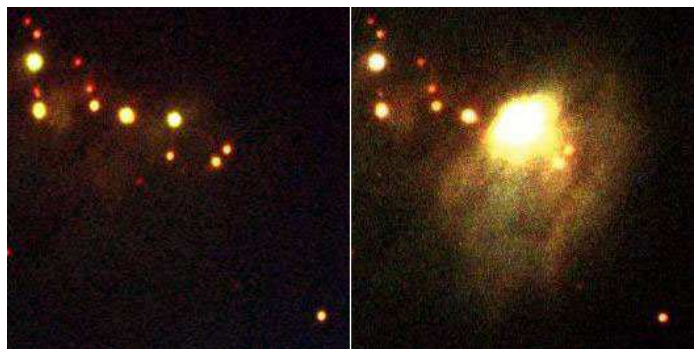


Figure 1: Color images of HBC 722 obtained with the 2-m RCC telescope in National Astronomical Observatory Rozhen, Bulgaria. *Left*: on 2007 Aug. 16, *Right*: on 2010 Oct. 31.

Due to the large-scale optical and infrared monitoring programs carried out at several observatories and the contri-

butions of amateur astronomers, some new objects have been observed to undergo large amplitude outbursts, V733 Cep (Reipurth et al. 2007, Peneva et al. 2010), V1647 Ori (Briceño et al. 2004), V2492 Cyg (Aspin 2011, Hillenbrand et al. 2013, Kóspál et al. 2013), V2494 Cyg (Aspin et al. 2009), V2495 Cyg (Movsessian et al. 2006), V900 Mon (Reipurth et al. 2012), V2775 Ori (Fischer et al. 2012), V582 Aur (Semkov et al. 2013). The contribution of amateur astronomers was essential for the discovery of the following objects - V733 Cep (Roger Persson), V1647 Ori (J. McNeil), V900 Mon, (Jim Thommes), V2492 Cyg (Itagaki and Yamagata), V582 Aur (Anton Khruslov).

3 A FUor outburst happening right before your eyes

HBC 722 is the first FUor object whose outburst was observed from its very beginning, and the second after V1057 Cyg with a known pre-outburst spectrum (Cohen & Kuhi 1979, Semkov et al. 2010). The outburst generated considerable interest and was studied across a wide spectral range. Follow-up photometric observations by Miller et al. (2011), Semkov et al. (2010), and Kóspál et al. (2011) recorded an ongoing light increase in both the optical and infrared through the end of 2010. Follow-up high and low resolution spectroscopic observations by Munari et al. (2010), Miller et al. (2011), Lee et al. (2011), Lorenzetti et al. (2012) and Semkov et al. (2010, 2012) showed significant changes in both the profiles and intensity of the spectral lines (Fig. 2).

We have tried to construct the historical light curve of HBC 722 using data from the photographic plate archives of several observatories (Semkov et al. 2012). The result is shown in Figure 3, wherein the archival observations are plotted together with the current CCD observations. The photometric observations obtained before the outburst displayed only small amplitude variations in all pass-bands typical of T Tauri stars. Other large-amplitude eruptions have not been registered in our long-term photometric study. The observational data indicate that the outburst started sometime before May 2010, and reached the first maximum value in September/October 2010. Since October 2010, a slow fading in brightness of HBC 722 was observed and up to May 2011 the star brightness decreased by 1.4 mag (V). During the period from May 2011 till October 2011 no significant changes in the brightness of the star were observed, its brightness remained at 3.3 mag (V) above the quiescence level. Since the autumn of 2011, another light increase occurred and the star became brighter by 1.8 mag (V) until April 2013. During the period from April 2013 till now, the star keeps its maximum brightness with only minor fluctua-

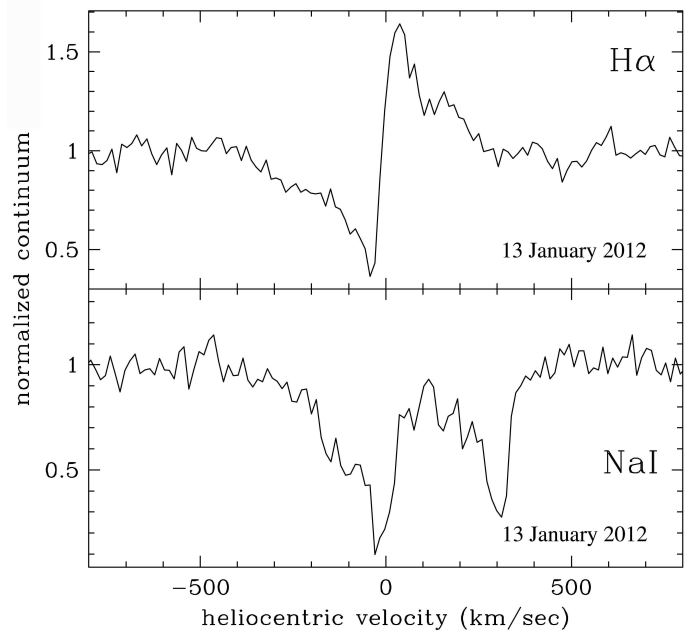


Figure 2: The profiles of H α and Na I D lines extracted from the spectrum of HBC 722 obtained with the REOSC echelle spectrograph mounted on the 1.82-m telescope in Asiago Observatory, Italy

tions around it. By comparing with brightness levels in 2009, we derive the following values for the outburst amplitude: $\Delta I=4.1$ mag, $\Delta R=4.7$ mag, $\Delta V=5.1$ mag, and $\Delta B=5.1$ mag. Similar changes in brightness over the same period have been observed in the near-infrared (Sung et al. 2013).

In the first spectroscopic study of HBC 722 published by Cohen & Kuhi (1979), the spectrum of the pre-outburst star was classified as K7-M0, with strong Balmer and oxygen emission lines. During the rise in brightness, the spectrum gradually changed from emission to absorption and the spectral class determined in the optical range became G3I. Simultaneously with the increase in brightness the star color changed significantly, becoming considerably bluer. But while both indices $V - I$ and $R - I$ decreased, the $B - V$ index has remained relatively constant before and during the outburst (Fig. 4). Moreover, there is a significant difference in the values of the $V - I$ and $R - I$ indices during the two peaks of brightness (Fig. 5). Such a phenomenon can be explained by a gradual expansion of the emitting region around the star.

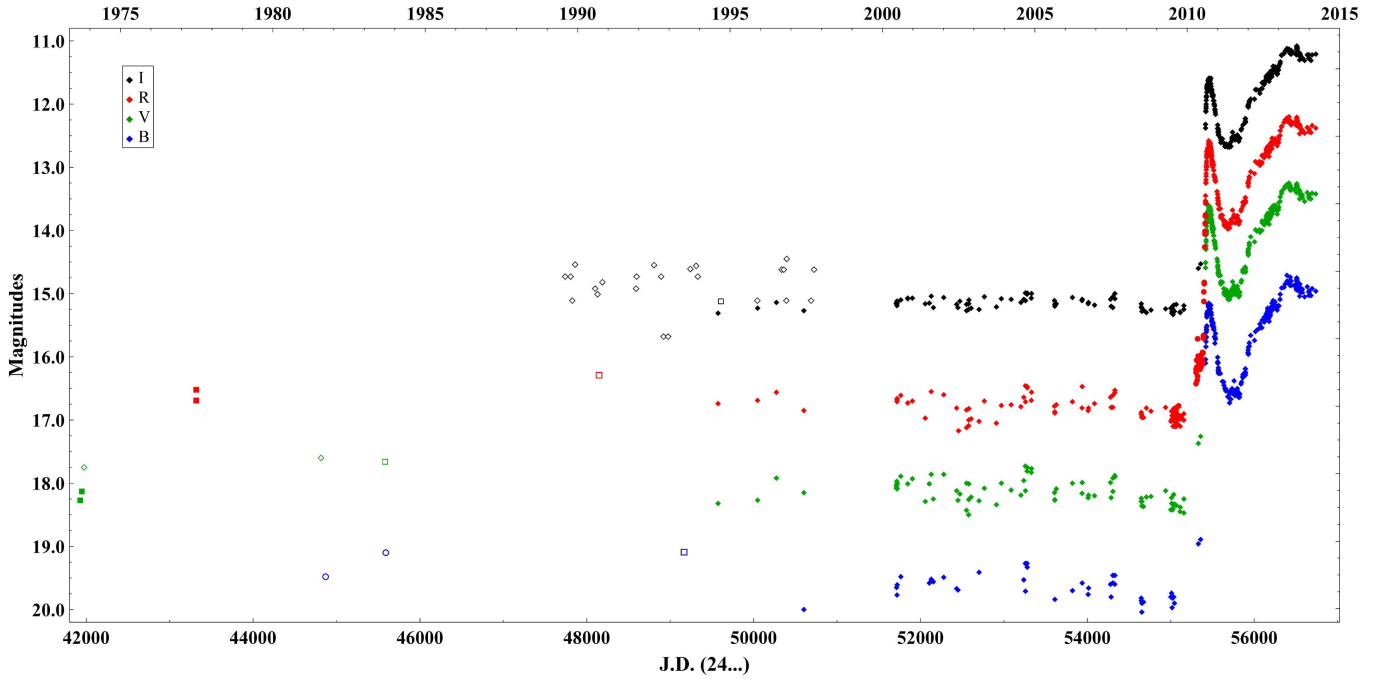


Figure 3: *BVRI* light curves of HBC 722 for the period September 1973 - March 2014

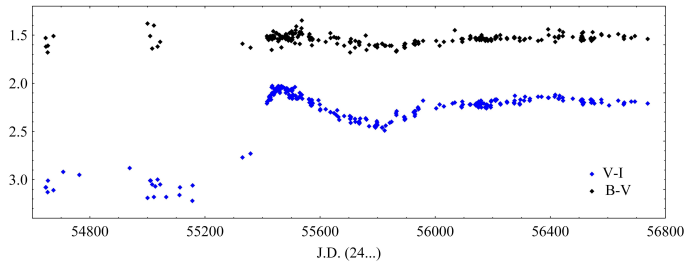


Figure 4: Color evolution of HBC 722 from June 2008 till March 2014

4 Observations of HBC 722 from the ground and space

During the years passing since the beginning of this outburst the interest in HBC 722 has continuously increased. The pre-outburst spectral energy distribution (SED) of HBC 722 is discussed in the papers of Miller et al. (2011) and Kóspál et al. (2011). The authors concluded that before the eruption HBC 722 was a Class II young stellar object - most often associated with Classical T Tauri stars. The calculated pre-outburst bolometric luminosity of the object is $0.85 L_{\odot}$ (Kóspál et al. 2011), while during the outburst it rose to $\sim 12 L_{\odot}$ (Miller et al. 2011). This value is at the bottom of the luminosity scale for FUor

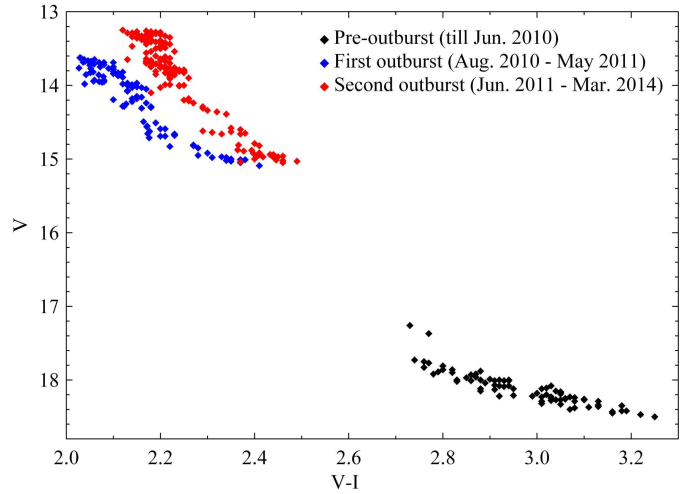


Figure 5: $V/V - I$ diagram from all available VI photometric CCD data.

outbursts, but still comparable to the luminosity of some FUor objects like L1551 IRS5 and HH381 IRS (Reipurth & Aspin 2010).

Green et al. (2011) analyze the submillimeter emission surrounding HBC 722 using images and spectroscopy from the Herschel Space Observatory and the Caltech Submillimeter Observatory. The authors detect CO emission in

the surrounding region, evidence of outflow-driven heating in the vicinity of the object. HBC 722 does not show evidence for a circumstellar envelope or shocked gas, and appears to have erupted from a disk-like state, similar to FU Orionis itself. In a subsequent paper, Green et al. (2013a) report that HBC 722 exhibits strong [O I] emission at 63 and 145 μm . The authors suggest that HBC 722 appears to be a relatively evolved source that may have passed through previous outbursts not so long ago.

Dunham et al. (2012) report data from submillimeter continuum and molecular line observations in the vicinity of HBC 722. The authors detect seven 1.3 mm continuum sources in the field of HBC 722, but none of which coincides with HBC722 itself. They define the upper limit of $0.02M_{\odot}$ for the mass of the circumstellar disk, by arguing that the disk provides sufficient mass to power a FUor outburst. A molecular outflow driven by one of the nearby submillimeter sources was detected.

Green et al. (2013b) find periodic variability of HBC 722 in the r-band light curve. They have found two main periods at 5.8-day (0.044 mag amplitude) and 1.28-day (0.016 mag amplitude). The first period is attributed to stellar rotation, and the second to Keplerian rotation at the inner radius of the accretion disk. Presuming the central stellar mass as $0.5M_{\odot}$, the authors derive an inner disk radius of $2.0R_{\star}$, and magnetic field strength of 2.2-2.7 kG, slightly larger than typical of T Tauri stars. The disk instability region was derived to range from 2.0 to $5.4R_{\star}$, consistent with models of FUor disks.

Gramajo et al. (2014) modeled the pre-outburst and the post-outburst SEDs of HBC 722 and found significant changes in the stellar temperature (increase from 5600K to 7100K) and in the disk mass accretion rate (increase from $4 \times 10^{-7} M_{\odot}/\text{yr}$ to $4 \times 10^{-6} M_{\odot}/\text{yr}$). The authors note that the envelope parameters do not change, suggesting the outbursts are triggered by an instability after a long build-up phase.

Thus, we already have strong evidence that HBC 722 is indeed proceeding through a *bona fide* FUor eruption. The outburst has continued for nearly four years, and the object still has a maximum brightness. Given the small number of known FUor objects, photometric and spectral studies of HBC 722 in the future are of great interest.

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Perspective

High-mass star formation and molecular masers

Ciriaco Goddi



High-mass star formation is an unsolved problem.

High-mass stars are prominent in the ecology of the interstellar medium and the evolution of galaxies. Though much needed, there is no general theory of high-mass star formation (HMSF). The main difficulty arises because the intense radiation pressure from the stellar luminosity and the thermal pressure from the HII region around the massive young stellar objects (MYSOs) may be sufficient to reverse the accretion flow and prevent matter from reaching the star. However, recent theoretical studies have demonstrated that the radiation pressure problem can be solved if accretion occurs through a circumstellar disk (e.g., Kuiper et al. 2011), thus explaining the formation of stars up to $140 M_{\odot}$. Despite the theoretical evidence, the balance of forces in proximity to MYSOs is difficult to infer from observations, because high extinction, clustering, and large distances of high-mass star forming regions (HMSFRs) hinder attempts to resolve the circumstellar gas at small radii (i.e. <1000 AU) where outflows are believed to be launched and collimated from accretion disks. One practical obstacle is that the typical angular-resolutions of present interferometers in the radio-mm regimes ($>0.1''$) translate into linear resolutions of a few hundreds to thousands of AU, at typical distances of HMSFRs (a few kpc). Direct imaging on scales of hundreds of AU is instead required to derive structure, dynamics, and small-scale physical properties at the disk/outflow interface. The other major limitation is that we have not yet identified a single “proto-O star” in the Galaxy, the high-mass equivalent to a “Class 0” low-mass protostar. Identifying the youngest high-mass protostars and direct imaging on scales of hundreds of AU are thus critical to enable us to test theoretical models via comparison with observations.

Molecular masers as diagnostic probes of HMSF.

From earlier single-dish surveys of molecular masers in our Galaxy, it appeared immediately clear that masers are one of the first observed signposts of HMSF (e.g., Menten 1991; Caswell et al. 1995). And for a long time, this has been their primary function in HMSF studies. Although progress has been slow towards the goal of using masers as diagnostic probes of HMSF, in the last decade or so we have witnessed a positive acceleration. This may be explained with the profusion of high-resolution observations from (sub)mm to mid-IR wavelengths, which is providing complementary information of thermal tracers at resolutions comparable to the maser sources. In fact, because of their compactness, high brightness, and ubiquity, masers can be regarded as a unique diagnostic probe. In particular, since they are ideal targets for Very Long Baseline Interferometry (VLBI), maser emission from a number of molecules (OH, H_2O , CH_3OH , SiO, NH_3) can probe physical and dynamical properties of the circumstellar gas at the smallest accessible scales around MYSOs. Interestingly, when carried out at several epochs, VLBI observations enable to accurately measure, besides positions and line-of-sight (l.o.s.) velocities, also proper motions of individual maser spots, thus providing the 3D kinematics of circumstellar gas (and in some cases also l.o.s. accelerations). Besides gas dynamics, since maser emission can be highly polarized in presence of a magnetic field, polarimetric observations can yield the strength and structure of the magnetic field at scales not accessible with other techniques. Additionally, since different maser species and/or transitions from the same species require different conditions for their excitation, they trace a continuous range of conditions of the circumstellar gas, at different radii from the exciting MYSOs, as well as different environments, and possibly different evolutionary stages of MYSOs. Finally, masers have proved to be invaluable in astrometry, providing parallaxes for accurate measurements of distances and the reconstruction of Galactic structure and rotation.

In the following, I will focus on four key aspects: I) gas dynamics, II) magnetic fields, III) population studies & evolutionary sequence, IV) distances & Galaxy structure.

I) 3D Gas Dynamics. VLBI observations of molecular masers have been proved to be a unique tool to study gas dynamics at distances of tens/hundreds of AU from MYSOs, revealing a variety of interesting (sometimes unexpected!) phenomena and probing different environments.

- CH_3OH . Among different molecular masers, methanol (in particular its transition at 6.7 GHz; Menten 1991) is especially interesting, because it is exclusively associated with HMSF and provides an excellent probe of accretion. One remarkable result of early VLBI imaging surveys of 6.7 GHz masers is that they show linear distributions with regular l.o.s. velocity gradients (e.g., Minier et al. 2000).

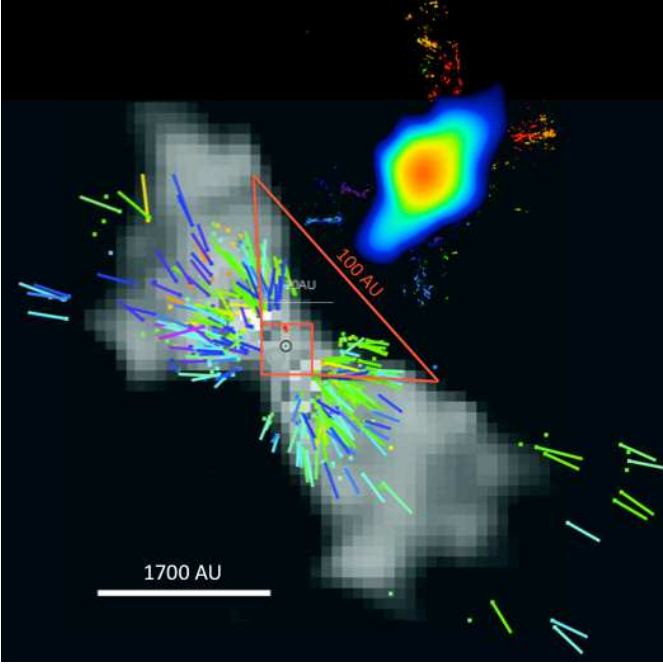


Figure 1: The disk/outflow in Orion Source I. Radii 10-100 AU: vibrationally-excited SiO masers (imaged with the VLBA, Matthews et al. 2010) probe material ablated from a compact disk (traced by the 7mm continuum imaged with the VLA; Goddi et al. 2011) in a rotating disk-wind. Radii 100-1000 AU: ground-state SiO maser proper motions (measured with the VLA) and integrated emission (imaged with CARMA by Plambeck et al. 2009; greyscale) probe outflow recollimation (Greenhill et al. 2013).

One long-standing question is if these linearly distributed methanol masers trace edge-on disks (e.g., Minier et al. 2000) or collimated outflows (e.g., De Buizer 2003). One famous case is that of NGC7538 IRS1, which is considered by many the best high-mass accretion disk candidate around an O-type young star in the northern hemisphere. Minier et al. (1998) first identified a linear distribution of 6.7 and 12.2 GHz CH_3OH masers and later Pestalozzi et al. (2004) proposed a model of an edge-on Keplerian disk surrounding a $30 M_\odot$ star. Moscadelli & Goddi (submitted) used a multi-epoch dataset of CH_3OH masers to measure, besides l.o.s. velocities, also l.o.s. accelerations, and presented new evidence that NGC7538 IRS1 actually consists of a multiple system of MYSOs surrounded by individual accretion disks (within a 1000 AU). ALMA-resolution observations are really needed to resolve the thermal emission from this multiple system of MYSOs. Besides the linear structures, recent VLBI surveys have revealed complex 6.7 GHz maser structures, including several with a ring-like morphology (Bartkiewicz et al. 2009). Kinematics of the maser spots based solely on l.o.s. velocities, revealed that outflow/infall dominates over Keplerian

rotation in a disk, as for ex. demonstrated by Torstensson et al. (2011) in the well-known case of Cepheus A, the second closest MYSO (at 700 pc), claimed to be a $20 M_\odot$ protostar surrounded by an accretion disk (Fig. 2).

In a series of papers, Goddi, Moscadelli, Sanna, and collaborators demonstrated the power of multi-epoch VLBI in tracing the 3D kinematics close to MYSOs towards a small sample of well-studied HMSFRs. Combining observations of 6.7 GHz methanol masers within a time-span of a few years, they detected various motions such as outflow, rotation, infall, in the close proximity of these MYSOs. Remarkably, Goddi et al. (2011b) reported a convincing signature of infall of a circumstellar molecular envelope with a radius of only 300 AU around a B-type forming star in AFGL 5142. A measurement of the 3D velocity field from CH_3OH masers provides a more direct and less biased measurement of infall, as compared with spectral signatures (e.g. inverse P-Cygni profiles).

- H_2O . Water masers generally probe shocked material at the interface between protostellar flows and the ambient medium (e.g., Goddi et al. 2005). Besides collimated jets in B-type MYSOs (e.g., Moscadelli et al. 2011, Goddi et al. 2011b), a few cases of isotropic or quasi-spherical ejections have been discovered in more massive objects: Cepheus A R5 (Torrelles et al. 2001), W75N-VLA2 (Torrelles et al. 2003), G24.78 (Moscadelli et al. 2007). While G24.78 is thought to be an O-type MYSO associated with an expanding hypercompact-HII region, at a relatively evolved stage when gas accretion has terminated (Moscadelli et al. 2007), Cepheus A R5 and W75N-VLA2 are believed to be at a much earlier stage (i.e. pre-ZAMS). This finding seems to contradict the existing paradigm, postulating that the degree of collimation decreases with age, due to the build-up of an HII region and the dynamical effects of the stellar radiation (e.g., Vaidya et al. 2011). Maser observations seem instead to indicate that uncollimated (episodic?) ejections may occur during the earliest stages of evolution of MYSOs, but the mechanism powering these ejections is still unclear. Therefore, our present understanding of the physics governing the mass-loss process in HMSF may be incomplete. Interestingly, Kim et al. (2013) followed the evolution of the water maser shell in W75N-VLA2 over 8 years, witnessing the passage from a spherical to a progressively more elliptical structure. This finding is qualitatively in agreement with recent MHD simulations, which suggest that initially outflows can be poorly collimated, and then progressively become more collimated due to the build-up of Keplerian disks (Seifried et al. 2012). Future VLBI imaging monitoring studies will help us understand these intriguing phenomena and refine MHD models.

- SiO . In addition to methanol and water, there are detailed data from SiO masers that have provided a unique

perspective on the making of a massive star, in the closest known HMSFR, Orion BN/KL, at 415 pc. Matthews et al. (2010) monitored the Orion Source I with the VLBA in vibrationally-excited SiO transitions every month for over three years, and created a movie of the 3D molecular gas flow, tracing a compact rotating disk and a wide-angle wind emanating from the disk at radii <100 AU, which can be modeled as an MHD wind (Vaidya & Goddi 2013). VLA imaging of less excited ground-state SiO transitions, probing larger scales, showed that the wide-angle wind collimates into a bipolar outflow at radii of 100-1000 AU (Greenhill et al. 2013). This study has provided direct evidence for the formation of a massive star via disk-mediated accretion and revealed for the first time the launch and collimation region of an outflow from a rotating compact disk on scales comparable with the Solar System (Fig. 1).

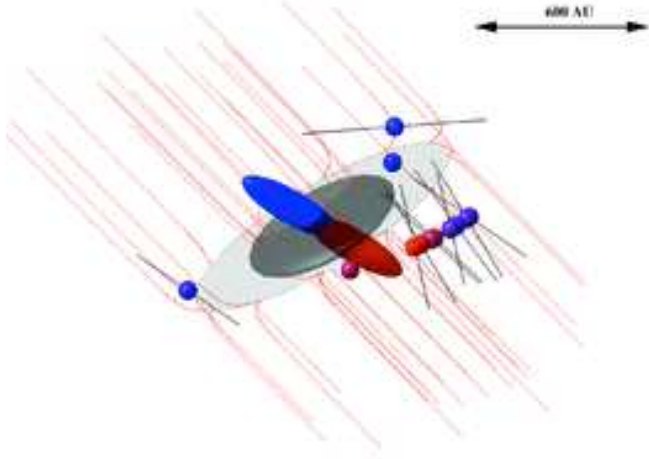


Figure 2: The 3D magnetic field structure around the MYSO Cepheus A HW2. Spheres indicate the CH_3OH masers (colours code velocity), black vectors indicate the magnetic field direction and the red lines the proposed field morphology, the grey ellipses indicate the accretion disk perpendicular to the outflow (blue- and redshifted lobes).

II) Polarization and Magnetic Fields.

Besides dynamics, another important contribution of maser studies to our understanding of HMSF is provided by magnetic field measurements. With a detailed theory of maser polarization propagation, polarimetric observations can yield the strength of the magnetic field along the l.o.s. from circular polarization (Zeeman effect) and the 2D (or even the 3D) field structure from linear polarization (see Vlemmings 2012 for a review). This is relevant, since magnetic fields could be key in the HMSF process, first by supporting the molecular cloud against gravitational collapse, and then by regulating mass-accretion and mass-

loss (e.g., Banerjee & Pudritz 2007). Interestingly, maser polarization observations conducted in the last few years (Vlemmings et al. 2010; Surcis et al. 2011, 2013), reveal that the magnetic field is oriented along protostellar outflows at scales larger than a 1000 AU (probed by both H_2O and CH_3OH), whereas closer to the protostar it seems to probe material accreting onto the protostar along the field lines from a disk/torus (probed only by CH_3OH ; Fig. 2). It is important to point out that maser measurements often show a good agreement with dust polarization measurements at lower resolution. This indicates that masers do not probe isolated parcels of magnetized gas, but are indeed good probes of the magnetic field in the circumstellar gas. Interestingly, since different maser species probe different density and temperature regimes, masers also enable to determine the relation between magnetic field and gas density. Specifically, OH maser polarization measurements ($n_{\text{H}_2} \sim 10^7 \text{ cm}^{-3}$, $R > 10000$ AU, $B \sim 1\text{-}10$ mG), indicate a relation with the Galactic magnetic field (e.g., Caswell et al. 2009, 2011; Green et al. 2012). H_2O measurements ($n_{\text{H}_2} \sim 10^9 \text{ cm}^{-3}$, $R > 100\text{-}1000$ AU, $B \sim 10\text{-}100$ mG) provide magnetic field strength along outflows (Surcis et al. 2011). Magnetic field measurements with both maser and dust emission indicate that the field strength as a function of number density follows a $B \approx n^{0.5}$ scaling law over a wide range of densities (Vlemmings 2008). This implies that the magnetic field remains partly coupled to the gas up to the highest number densities.

In summary, maser measurements indicate that magnetic fields are dynamically important in HMSF, both in shaping outflows and regulating gas accretion, in agreement with theoretical simulations (e.g., Banerjee & Pudritz 2007).

III) Population studies and Evolutionary Stages.

Where, when and how do masers arise? Any type of maser requires a specific range of physical conditions. The strongest and most common transitions should trace conditions common to all HMSFRs which persist in time. Conversely, rare transitions may require either a more narrow range of conditions (e.g., probing a small portion of the circumstellar gas), or conditions which arise less frequently (e.g., a short-lived stage). This leads to the exciting idea that the presence/absence of different maser species/transitions could be used to trace an evolutionary timeline for HMSF. This is not a new idea, it was indeed proposed in the seventies in the first maser studies. Its implementation, however, requires large, sensitive, high-resolution, unbiased surveys of different maser transitions, as well as complementary observations at a wide range of wavelengths. And this is becoming possible only now. For ex., combining data from existing unbiased OH maser surveys (Caswell 1998) with the MMB 6.7 GHz survey (Caswell et al. 2010; Green et al. 2010), the HOPS 22 GHz water maser survey (Walsh et al. 2011) and complementary data at other wavelengths (e.g., the Spitzer

GLIMPSE survey and the submm ATLASGAL survey), it is becoming feasible to make statistical studies of the properties of HMSF. For ex., by assessing the presence/absence of different maser species/lines and by comparing their locations with other HMSF tracers (e.g. mm dust clumps, radio continuum, and IR sources), one can establish the relation between specific evolutionary stages and different masers (e.g., Purcell et al. 2009, Breen et al. 2010, Urquhart et al. 2010, Pandian et al. 2010).

A maser-based evolutionary timeline involving all the common and intense maser transitions observed in HMSF (see Fig. 3) is now taking shape (e.g., Purcell et al. 2009, Breen et al. 2010, Ellingsen et al. 2013). The Class I methanol masers (e.g., 36 and 44 GHz lines), which are collisionally excited and are detected further from the central objects, at the interface between outflows and ambient molecular gas (e.g., Voronkov et al. 2014), should be the earliest masers. The OH and Class II methanol masers (e.g., 6.7 and 12.2 GHz transitions), which are radiatively excited, arise in hot molecular cores, UC-HII regions, and mid-IR sources, and should probe a more evolved stage (with the OH and 12 GHz masers being the most evolved). The water masers generally trace post-shocked gas in outflows, so they should be excited during the whole accretion/outflow phase. In general, most maser sources are likely at the hot-core, or earlier evolutionary stages, before the HII stage, as was suggested by earlier studies (e.g., Walsh et al. 1998). However, some discussion continues to refine this evolutionary relation. For ex., in a series of papers Cyganowski et al. observed in several maser species a catalogue of 300 “EGOs”, identified in GLIMPSE at $4.5\mu\text{m}$ as MYSOs driving outflows (Cyganowski et al. 2008). They found that Class I CH_3OH masers can be excited by both young (hot core) and older (UC HII) sources in the same HMSFR. More work and larger samples are therefore needed to refine the evolutionary timeline based on masers.

IV) Distances and Structure of the Galaxy.

Perhaps one of the most striking contributions of maser studies is the reconstruction of the structure of the Galaxy. Parallaxes of masers are in fact an excellent method to measure distances and 3D motions of MYSOs. Distances are crucial to obtain accurate estimates of luminosity, mass, and age of young OB stars, while the stellar 3D motions provide a reference system for studies of gas dynamics. Even more importantly, accurate knowledge of the location of HMSFRs and their 3D motions, provides the unique opportunity to map the spiral arms of our own Galaxy as well as to directly constrain its fundamental parameters, including the distance to the Galactic center and the circular orbital speed at the Sun (e.g., Reid et al. 2009).

Two major projects to map the Galactic spiral structure are providing parallaxes and proper motions using water and methanol masers associated with HMSFRs spread across the Milky Way. The Bar and Spiral Structure

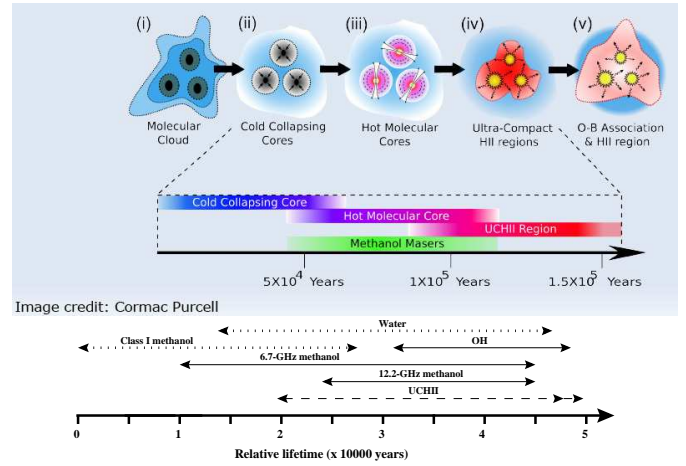


Figure 3: Proposed HMSF evolutionary sequence (top panel; credit Purcell C.R.), with the associated maser timeline (bottom panel; Breen et al. 2010).

Legacy (BeSSeL) Survey (Reid et al. 2009; Brunthaler et al. 2011) and the Japanese VLBI Exploration of Radio Astrometry (VERA) (Honma et al. 2012) have obtained over 100 parallax measurements with typical accuracies of about $\pm 20\mu\text{as}$ (some as good as $\pm 5\mu\text{as}$), using the VLBA, VERA, and the European VLBI Network (Rygl et al., 2010). Remarkably, this accuracy exceeds the goal of the Gaia mission (launched in December 2013). While Gaia aims to observe $\sim 10^9$ stars, way more than practical for VLBI surveys, Gaia will be limited by extinction in the optical and will not be able to probe the Galactic plane. Recently, Reid et al (2014) combined the parallax data from the BeSSeL and VERA surveys, finding that the HMSFRs with measured parallaxes are clearly tracing the major spiral arms of the Milky Way (see Fig. 4). Given measurements of position, parallax, proper motion and Doppler shift, one can then construct a model of the Milky Way and estimate the main Galactic parameters. Reid et al. (2014) find the distance to the Galactic center, $R_0 = 8.34 \pm 0.16$ kpc, the circular rotation speed at the Sun, $\Theta_0 = 240 \pm 8$ km s $^{-1}$, and the thin disk scale length, $R_D = 2.44 \pm 0.16$ kpc. They also find that the rotation curve is nearly flat (with a slope of -0.2 ± 0.4 km s $^{-1}$ kpc $^{-1}$) between Galactocentric radii of 5 and 16 kpc. Interestingly, the increased Θ_0 from the IAU recommended value may have a widespread impact in Astrophysics, from a decrease in the estimated luminosities (and masses) of young stars, to an increase in the estimated (dark-matter dominated) mass of the Galaxy.

Concluding remarks. Astrophysical masers are one of the most readily detected signposts of HMSF in the Galaxy. Despite the first discovery dates back to 50 years, for years their usage as diagnostic probes had been less prominent than expected, in contrast with other fields

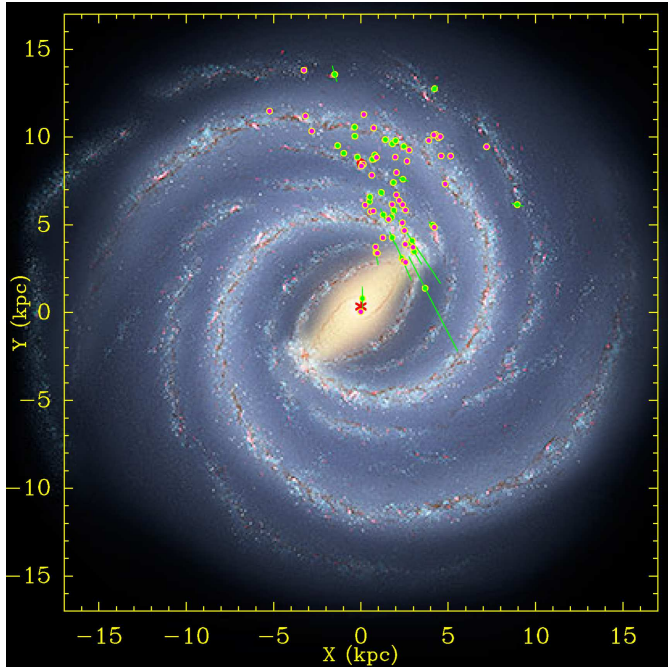


Figure 4: Locations of HMSFRs with maser parallaxes measured with VLBI overlaid on a schematic image of the Milky Way spiral structure (Brunthaler et al. 2011).

like evolved stars and active galaxies, where maser studies were key to a number of new discoveries. A possible explanation is the fact that there had been relatively little complementary high-resolution information at other wavelengths available till recently. With observations in the mid-IR through submm regimes at (sub-)arcsec resolutions starting to reveal the global environment in which masers form, the potential of masers as a powerful tool to investigate HMSF is eagerly emerging. In this piece, I have reported some highlights showing that masers represent the ultimate high-resolution probe of HMSF, with the potential to reveal information on gas dynamics, magnetic fields, and perhaps physical conditions and evolutionary stages in the associated regions, at the smallest accessible scales. While some of the questions relating to masers have been addressed using a statistical approach through single-dish surveys (e.g. occurrence of specific masers in specific stages of HMSF), their usage as high resolution probes has been possible only in a limited number of objects, owing chiefly to the complexity of VLBI data calibration, as well as long time-scales for proper motion measurements (e.g., several years for methanol). The small statistics has certainly limited the scientific return of these results. Luckily a large sample of maser sources (about 400) studied with VLBI is now available from the BeSSeL survey, which will enable us to measure the structure, 3D dynamics, and potentially magnetic fields of the circumstellar gas around MYSOs using a statistical approach.

We are confident that more exciting results will come in the next years, and that in synergy with the upgraded e-MERLIN and JVLBA, as well as with ALMA at higher frequencies and with the SKA at the lower frequencies, the role of masers to study small scale dynamics and magnetic fields will become more prominent, including the possibility to test the time sequence for masers with high-resolution observations at other wavelengths.

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Abstracts of recently accepted papers

Shielding by Water and OH in FUV and X-ray Irradiated Protoplanetary Disks

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We present an integrated thermal-chemical model for the atmosphere of the inner region of a protoplanetary disk that includes irradiation by both far ultraviolet (FUV) and X-ray radiation. We focus on how the photodissociation of H₂O and OH affects the abundances of these and related species and how it contributes to the heating of the atmosphere. The dust in the atmosphere plays several important roles, primarily as the site of H₂ formation and by absorbing the FUV. Large amounts of water can be synthesized within the inner 4 AU of a disk around a typical classical T Tauri star. OH is found primarily at the top of a warm region where the gas temperature is $T_g \approx 650 - 1000$ K and H₂O below it where the temperature is lower, $T_g \approx 250 - 650$ K. The amounts of H₂O and OH and the temperatures of the regions in which they formed are in agreement with recent *Spitzer* measurements and support the notion of *in situ* production of water in the inner regions of protoplanetary disks. We find that the synthesized water is effective in shielding the disk midplane from stellar FUV radiation.

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Spectro-astrometry of V1515 Cyg

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FU Orionis objects are a class of young stars with important bursts in luminosity and which show evidence of accretion and ejection activity. It is generally accepted that they are surrounded by a Keplerian circumstellar disk and an infalling envelope. The outburst would occur because of a sudden increase in the accretion rate. We aim at studying the regions closer to the central star in order to observe the signs of the accretion/ejection activity. We present optical observations of the H α line using the Integral Field Spectrograph OASIS, at the William Herschel Telescope, combined with Adaptive Optics. Since this technique gives the spectral information for both spatial directions, we carried out a two-dimensional spectro-astrometric study of the signal. We measured a clear spectro-astrometric signal in the North-South direction. The cross-correlation between the spectra showed a spatial distribution in velocity suggestive of scattering by a disk surrounding the star. This would be one of the few spatial inferences of a disk observed in a FU Orionis object. However, in order to fully understand the observed structure, higher angular and spectral resolution observations are required. V1515 Cyg appears now as an important object to be observed with a new generation of instruments to increase our knowledge about the disk and outflows structure in FU Orionis objects.

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Time evolution of a viscous protoplanetary disk with a free geometry: toward a more self-consistent picture

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Observations of protoplanetary disks show that some characteristics seem recurrent, even in star formation regions that are physically distant such as surface mass density profiles varying as r^{-1} , or aspect ratios about 0.03 to 0.23. Accretion rates are also recurrently found around 10^{-8} – $10^{-6} M_{\odot} \text{ yr}^{-1}$ for disks already evolved (Isella et al. 2009; Andrews et al. 2009, 2010). Several models have been developed in order to recover these properties. However, most of them usually simplify the disk geometry if not its mid-plane temperature. This has major consequences for modeling the disk evolution over million years and consequently planet migration. In the present paper, we develop a viscous evolution hydrodynamical numerical code that determines simultaneously the disk photosphere geometry and the mid-plane temperature. We then compare our results of long-term simulations with similar simulations of disks with a constrained geometry along the Chiang & Goldreich (1997) prescription ($d\ln H/d\ln r = 9/7$). We find that the constrained geometry models provide a good approximation of the disk surface density evolution. However, they differ significantly regarding the temperature time evolution. In addition, we find that shadowed regions naturally appear at the transition between viscously dominated and radiation dominated regions that falls in the region of planetary formation. We show that χ (photosphere height to pressure scale height ratio) cannot be considered as a constant, consistently with Watanabe et al. (2008). Comparisons with observations show that all disk naturally evolve toward a shallow surface density disk ($\Sigma \propto r^{-1}$). The mass flux across the disk stabilizes in about 1 million year typically.

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Study of Eclipsing Binary and Multiple Systems in OB Associations II. The Cygnus OB Region: V443 Cyg, V456 Cyg and V2107 Cyg

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Three presumably young eclipsing binary systems in the direction of the Cygnus OB1, OB3 and OB9 associations are studied. Component spectra are reconstructed and their orbits are determined using light curves and spectra disentangling techniques. V443 Cyg and V456 Cyg have circular orbits, while the light curve of V2107 Cyg imposes a slightly eccentric orbit ($e = 0.045 \pm 0.03$). V443 Cyg harbours F-type stars, and not young early-A stars as previously suggested in the literature based on photometry solely. It appears to be situated in the foreground (distance 0.6 ± 0.2 kpc) of the young stellar populations in Cygnus. V456 Cyg, at a distance of 0.50 ± 0.03 kpc consists of a slightly metal-weak A-type and an early-F star. The age of both systems, on or very near to the main sequence, remains uncertain by an order of magnitude. V2107 Cyg is a more massive system (8.94 ± 2 and $4.5 \pm 1.2 M_{\odot}$) at 1.5 ± 0.5 kpc and, also kinematically, a strong candidate-member of Cyg OB1. The more massive component is slightly evolved and appears to undergo non-radial Cep-type pulsations. The Doppler signal of the secondary is barely detectable. A more extensive study is important to fix masses more precisely, and an asteroseismological study would then become appropriate. Nevertheless, the position of the primary in the HR-diagram confines the age already reasonably well to 20 ± 5 Myr, indicating for Cyg OB1 a similar extent of star formation history as established for Cyg OB2.

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A perfect starburst cluster made in one go: the NGC 3603 young cluster

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Understanding how distinct, near-spherical gas-free clusters of very young, massive stars shape out of vast, complex clouds of molecular hydrogen is one of the biggest challenges in astrophysics. A popular thought dictates that a single gas cloud fragments into many new-born stars which, in turn, energize and rapidly expel the residual gas to form a gas-free cluster. This study demonstrates that the above classical paradigm remarkably reproduces the well-observed central, young cluster (HD 97950) of the Galactic NGC 3603 star-forming region, in particular, its shape, internal motion and the mass distribution of stars, naturally and consistently follow from a single model calculation. Remarkably, the same parameters (star formation efficiency, gas expulsion time scale and delay) reproduce HD 97950 as were found to reproduce the Orion Nebula Cluster, Pleiades and R136. The present results thereby provide intriguing evidences of formation of star clusters through single-starburst events followed by significant residual gas expulsion.

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Sizes of protoplanetary discs after star-disc encounters

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Most stars do not form in isolation, but as part of a star cluster or association. These young stars are initially surrounded by protoplanetary discs. In these cluster environments tidal interactions with other cluster members can alter the disc properties. Besides the disc frequency, its mass, angular momentum, and energy, in particular the disc's size is prone to being changed by a passing star. So far the change in disc size was only investigated for a small number of very specific encounters. Several studies investigated the effect of the cluster environment on the sizes of planetary systems, like our own solar system, based on a generalisation of information from this limited sample. We performed numerical simulations covering the wide parameter space typical for young star clusters, to test the validity of this approach. Here the sizes of discs after encounters are presented, based on a size definition which is comparable to that one used in observational studies. We find that, except for encounters between equal-mass stars, the usually applied estimates are insufficient. They tend to severely overestimate the remaining disc size. We show that the disc size after an encounter can be described by a relatively simple dependence on the periastron distance and the mass ratio of the encounter partners. This knowledge allows, for example, to pin down the types of encounter possibly responsible for the structure of today's solar system.

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An ALMA Continuum Survey of Circumstellar Disks in the Upper Scorpius OB Association

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We present ALMA 880 μm continuum observations of 20 K and M-type stars in the Upper Scorpius OB association that are surrounded by protoplanetary disks. These data are used to measure the dust content in disks around low mass stars ($0.1\text{--}1.6 M_{\odot}$) at a stellar age of 5–11 Myr. Thirteen sources were detected in the 880 μm dust continuum at $\geq 3\sigma$ with inferred dust masses between 0.3 and $52 M_{\oplus}$. The dust masses tend to be higher around the more massive stars, but the significance is marginal in that the probability of no correlation is $p \approx 0.03$. The evolution in the dust content in disks was assessed by comparing the Upper Sco observations with published continuum measurements of

disks around $\sim 1\text{--}2$ Myr stars in the Class II stage in the Taurus molecular cloud. While the dust masses in the Upper Sco disks are on average lower than in Taurus, any difference in the dust mass distributions is significant at less than 3σ . For stellar masses between $0.49 M_{\odot}$ and $1.6 M_{\odot}$, the mean dust mass in disks is lower in Upper Sco relative to Taurus by $\Delta \log M_{\text{dust}} = 0.44 \pm 0.26$.

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Formation of Magnetized Prestellar Cores with Ambipolar Diffusion and Turbulence

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We investigate the roles of magnetic fields and ambipolar diffusion during prestellar core formation in turbulent giant molecular clouds (GMCs), using three-dimensional numerical simulations. Our simulations focus on the shocked layer produced by a converging flow within a GMC, and survey varying ionization and angle between the upstream flow and magnetic field. We also include ideal magnetohydrodynamic (MHD) and hydrodynamic models. From our simulations, we identify hundreds of self-gravitating cores that form within 1 Myr, with masses $M \sim 0.04 - 2.5 M_{\odot}$ and sizes $L \sim 0.015 - 0.07$ pc, consistent with observations of the peak of the core mass function (CMF). Median values are $M = 0.47 M_{\odot}$ and $L = 0.03$ pc. Core masses and sizes do not depend on either the ionization or upstream magnetic field direction. In contrast, the mass-to-magnetic flux ratio does increase with lower ionization, from twice to four times the critical value. The higher mass-to-flux ratio for low ionization is the result of enhanced transient ambipolar diffusion when the shocked layer first forms. However, ambipolar diffusion is not necessary to form low-mass supercritical cores. For ideal MHD, we find similar masses to other cases. These masses are 1 – 2 orders of magnitude lower than the value that defines a magnetically supercritical sphere under post-shock ambient conditions. This discrepancy is the result of anisotropic contraction along field lines, which is clearly evident in both ideal MHD and diffusive simulations. We interpret our numerical findings using a simple scaling argument which suggests that gravitationally critical core masses will depend on the sound speed and mean turbulent pressure in a cloud, regardless of magnetic effects.

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Spitzer View of Massive Star Formation in the Tidally Stripped Magellanic Bridge

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The Magellanic Bridge is the nearest low-metallicity, tidally stripped environment, offering a unique high-resolution view of physical conditions in merging and forming galaxies. In this paper we present analysis of candidate massive

young stellar objects (YSOs), i.e., *in situ*, *current* massive star formation (MSF) in the Bridge using *Spitzer* mid-IR and complementary optical and near-IR photometry. While we definitely find YSOs in the Bridge, the most massive are $\sim 10 M_{\odot}$, $\ll 45 M_{\odot}$ found in the Large Magellanic Cloud (LMC). The intensity of MSF in the Bridge also appears decreasing, as the most massive YSOs are less massive than those formed in the past. To investigate environmental effects on MSF, we have compared properties of massive YSOs in the Bridge to those in the LMC. First, YSOs in the Bridge are apparently less embedded than in the LMC: 81% of Bridge YSOs show optical counterparts, compared to only 56% of LMC sources with the same range of mass, circumstellar dust mass, and line-of-sight extinction. Circumstellar envelopes are evidently more porous or clumpy in the Bridge's low-metallicity environment. Second, we have used whole samples of YSOs in the LMC and the Bridge to estimate the probability of finding YSOs at a given HI column density, $N(\text{HI})$. We found that the LMC has $\sim 3 \times$ higher probability than the Bridge for $N(\text{HI}) > 10 \times 10^{20} \text{ cm}^{-2}$, but the trend reverses at lower $N(\text{HI})$. Investigating whether this lower efficiency relative to HI is due to less efficient molecular cloud formation, or less efficient cloud collapse, or both, will require sensitive molecular gas observations.

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Spiral arms in the disk of HD 142527 from CO emission lines with ALMA

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In view of both the size of its gap and the previously reported asymmetries and near-infrared spiral arms, the transition disk of the Herbig Fe star HD 142527 constitutes a remarkable case study. This paper focuses on the morphology of the outer disk through ALMA observations of ^{12}CO J=2-1, ^{12}CO J=3-2 and ^{13}CO J=2-1. Both ^{12}CO J=2-1 and ^{12}CO J=3-2 show spiral features of different sizes. The innermost spiral arm (S1) is a radio counterpart of the first near-infrared spiral observed by Fukagawa et al. (2006), but it is shifted radially outward. However, the most conspicuous CO spiral arm (S2) lies at the outskirts of the disk and had not been detected before. It corresponds to a cold density structure, with both brightness and excitation temperatures of order 13 ± 2 K and conspicuous in the ^{12}CO J=2-1 peak-intensity map, but faint in ^{12}CO J=3-2. There is also a faint counterarm (S3), point-symmetrical of S2 with respect to the star. These three spirals are modeled separately with two different formulae that approximate the loci of density maxima in acoustic waves due to embedded planets. S1 could be fit relatively well with these formulae, compared to S2 and S3. Alternative scenarios such as gravitational instability or external tidal interaction are discussed. The impact of channelization on spectrally and spatially resolved peak intensity maps is also briefly addressed.

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Temperaments of young stars: Rapid mass-accretion rate changes in T Tauri and Herbig Ae stars

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Variability in emission lines is a characteristic feature in young stars and can be used as a tool to study the physics of the accretion process. Here we present a study of $H\alpha$ variability in 15 T Tauri and Herbig Ae stars (K7–B2) over

a wide range of time windows, from minutes, to hours, to days, and years. We assess the variability using linewidth measurements and the time series of line profiles. All objects show gradual, slow profile changes on time-scales of days. In addition, in three cases there is evidence for rapid variations in H α with typical time-scales of 10 min, which occurs in 10% of the total covered observing time. The mean accretion-rate changes, inferred from the line fluxes, are 0.01–0.07 dex for time-scales of < 1 hour, 0.04–0.4 dex for time-scales of days, and 0.13–0.52 dex for time-scales of years.

In Costigan et al. 2012 we derived an upper limit finding that the intermediate (days) variability dominated over longer (years) variability. Here our new results, based on much higher cadence observations, also provide a lower limit to accretion-rate variability on similar time-scales (days), thereby constraining the accretion rate variability physics in a much more definitive way. A plausible explanation for the gradual variations over days is an asymmetric accretion flow resulting in a rotational modulation of the accretion-related emission, although other interpretations are possible as well. In conjunction with our previous work, we find that the time-scales and the extent of the variability is similar for objects ranging in mass from ~ 0.1 to $\sim 5 M_{\odot}$. This confirms that a single mode of accretion is at work from T Tauri to Herbig Ae stars - across a wide range of stellar masses.

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On the probability distribution function of the mass surface density of molecular clouds I

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The probability distribution function (PDF) of the mass surface density is an essential characteristic of the structure of molecular clouds or the interstellar medium in general. Observations of the PDF of molecular clouds indicate a composition of a broad distribution around the maximum and a decreasing tail at high mass surface densities. The first component is attributed to the random distribution of gas which is modeled using a log-normal function while the second component is attributed to condensed structures modeled using a simple power-law. The aim of this paper is to provide an analytical model of the PDF of condensed structures which can be used by observers to extract information about the condensations. The condensed structures are considered to be either spheres or cylinders with a truncated radial density profile at cloud radius r_{cl} . The assumed profile is of the form $\rho(r) = \rho_c / (1 + (r/r_0)^2)^{n/2}$ for arbitrary power n where ρ_c and r_0 are the central density and the inner radius, respectively. An implicit function is obtained which either truncates (sphere) or has a pole (cylinder) at maximal mass surface density. The PDF of spherical condensations and the asymptotic PDF of cylinders in the limit of infinite overdensity $\rho_c / \rho(r_{\text{cl}})$ flattens for steeper density profiles and has a power law asymptote at low and high mass surface densities and a well defined maximum. The power index of the asymptote $\Sigma^{-\gamma}$ of the logarithmic PDF ($\Sigma \times P(\Sigma)$) in the limit of high mass surface densities is given by $\gamma = (n+1)/(n-1) - 1$ (spheres) or by $\gamma = n/(n-1) - 1$ (cylinders in the limit of infinite overdensity).

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On the nature of the deeply embedded protostar OMC-2 FIR 4

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We use mid-infrared to submillimeter data from the Spitzer, Herschel, and APEX telescopes to study the bright sub-mm source OMC-2 FIR 4. We find a point source at 8, 24, and 70 μm , and a compact, but extended source at 160, 350, and 870 μm . The peak of the emission from 8 to 70 μm , attributed to the protostar associated with FIR 4, is displaced relative to the peak of the extended emission; the latter represents the large molecular core the protostar is embedded within. We determine that the protostar has a bolometric luminosity of 37 L_{\odot} , although including more extended emission surrounding the point source raises this value to 86 L_{\odot} . Radiative transfer models of the protostellar system fit the observed SED well and yield a total luminosity of most likely less than 100 L_{\odot} . Our models suggest that the bolometric luminosity of the protostar could be just 12–14 L_{\odot} , while the luminosity of the colder (~ 20 K) extended core could be around 100 L_{\odot} , with a mass of about 27 M_{\odot} . Our derived luminosities for the protostar OMC-2 FIR 4 are in direct contradiction with previous claims of a total luminosity of 1000 L_{\odot} (Crimier et al. 2009). Furthermore, we find evidence from far-infrared molecular spectra (Kama et al. 2013, Manoj et al. 2013) and 3.6 cm emission (Reipurth et al. 1999) that FIR 4 drives an outflow. The final stellar mass the protostar will ultimately achieve is uncertain due to its association with the large reservoir of mass found in the cold core.

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The Coolest Isolated Brown Dwarf Candidate Member of TWA

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We present two new late-type brown dwarf candidate members of the TW Hydrae association (TWA) : 2MASS J12074836–3900043 and 2MASS J12474428–3816464, which were found as part of the BANYAN all-sky survey (BASS) for brown dwarf members to nearby young associations. We obtained near-infrared (NIR) spectroscopy for both objects (NIR spectral types are respectively L1 and M9), as well as optical spectroscopy for J1207–3900 (optical spectral type is L0 γ), and show that both display clear signs of low-gravity, and thus youth. We use the BANYAN II Bayesian inference tool to show that both objects are candidate members to TWA with a very low probability of being field contaminants, although the kinematics of J1247–3816 seem slightly at odds with that of other TWA members. J1207–3900 is currently the latest-type and the only isolated L-type candidate member of TWA. Measuring the distance and radial velocity of both objects is still required to claim them as bona fide members. Such late-type objects are predicted to have masses down to 11–15 M_{Jup} at the age of TWA, which makes them compelling targets to study atmospheric properties in a regime similar to that of currently known imaged extrasolar planets.

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Core-Halo Age Gradients and Star Formation in the Orion Nebula and NGC 2024 Young Stellar Clusters

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We analyze age distributions of two nearby rich stellar clusters, the NGC 2024 (Flame Nebula) and Orion Nebula Cluster (ONC) in the Orion molecular cloud complex. Our analysis is based on samples from the MYStIX survey and a new estimator of pre-main sequence (PMS) stellar ages, AgeJX, derived from X-ray and near-infrared photometric data. To overcome the problem of uncertain individual ages and large spreads of age distributions for entire clusters, we compute median ages and their confidence intervals of stellar samples within annular subregions of the clusters. We find core-halo age gradients in both the NGC 2024 cluster and ONC: PMS stars in cluster cores appear younger and thus were formed later than PMS stars in cluster peripheries. These findings are further supported by the spatial gradients in the disk fraction and K-band excess frequency. Our age analysis is based on AgeJX estimates for PMS stars, and is independent of any consideration of OB stars. The result has important implications for the formation of young stellar clusters. One basic implication is that clusters form slowly and the apparent age spreads in young stellar clusters, which are often controversial, are (at least in part) real. The result further implies that simple models where clusters form inside-out are incorrect, and more complex models are needed. We provide several star formation scenarios that alone or in combination may lead to the observed core-halo age gradients.

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Age Gradients in the Stellar Populations of Massive Star Forming Regions Based on a New Stellar Chronometer

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A major impediment to understanding star formation in massive star forming regions (MSFRs) is the absence of a reliable stellar chronometer to unravel their complex star formation histories. We present a new estimation of stellar ages using a new method that employs near-infrared (NIR) and X-ray photometry, AgeJX. Stellar masses are derived from X-ray luminosities using the L_x - Mass relation from the Taurus cloud. J-band luminosities are compared to mass-dependent pre-main-sequence evolutionary models to estimate ages. AgeJX is sensitive to a wide range of evolutionary stages, from disk-bearing stars embedded in a cloud to widely dispersed older pre-main sequence stars. The MYStIX (Massive Young Star-Forming Complex Study in Infrared and X-ray) project characterizes 20 OB-dominated MSFRs using X-ray, mid-infrared, and NIR catalogs. The AgeJX method has been applied to 5525 out of 31,784 MYStIX Probable Complex Members. We provide a homogeneous set of median ages for over a hundred subclusters in 15 MSFRs; median subcluster ages range between 0.5 Myr and 5 Myr. The important science result is the discovery of age gradients across MYStIX regions. The wide MSFR age distribution appears as spatially segregated structures with different ages. The AgeJX ages are youngest in obscured locations in molecular clouds, intermediate in revealed stellar clusters, and oldest in distributed populations. The NIR color index J-H, a surrogate measure of extinction, can serve as an approximate age predictor for young embedded clusters.

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Dense molecular globulettes and the dust arc towards the runaway O star AE Aur (HD 34078)

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Some runaway stars are known to display IR arc-like structures around them, resulting from their interaction with surrounding interstellar material. The properties of these features as well as the processes involved in their formation are still poorly understood. We aim at understanding the physical mechanisms that shapes the dust arc observed near the runaway O star AE Aur (HD34078). We obtained and analyzed a high spatial resolution map of the CO(1-0) emission that is centered on HD34078, and that combines data from both the IRAM interferometer and 30m single-dish antenna. The line of sight towards HD34078 intersects the outer part of one of the detected globulettes, which accounts for both the properties of diffuse UV light observed in the field and the numerous molecular absorption lines detected in HD34078's spectra, including those from highly excited H_2 . Their modeled distance from the star is compatible with the fact that they lie on the 3D paraboloid which fits the arc detected in the 24 μm Spitzer image. Four other compact CO globulettes are detected in the mapped area. These globulettes have a high density and linewidth, and are strongly pressure-confined or transient. The good spatial correlation between the CO globulettes and the IR arc suggests that they result from the interaction of the radiation and wind emitted by HD 34078 with the ambient gas. However, the details of this interaction remain unclear. A wind mass loss rate significantly larger than the value inferred from UV lines is favored by the large IR arc size, but does not easily explain the low velocity of the CO globulettes. The effect of radiation pressure on dust grains also meets several issues in explaining the observations. Further observational and theoretical work is needed to fully elucidate the processes shaping the gas and dust in bow shocks around runaway O stars.

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The tiny globulettes in the Carina Nebula

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Small molecular cloudlets are abundant in many H II regions surrounding newborn stellar clusters. In optical images these so-called globulettes appear as dark silhouettes against the bright nebular background. We have located close to 300 globulettes in the Carina Nebula. The objects appear as well-confined dense clumps and, as a rule, lack thinner envelopes, bright rims, and tails. Some globulettes are slightly elongated with their major axes oriented in the direction of young clusters in the complex. Many objects are quite isolated and reside at projected distances > 1.5 pc from other molecular structures in the region. No globulette coincides in position with recognized pre-main-sequence objects in the area.

The objects are systematically much smaller, less massive, and much denser than those surveyed in other H II regions. Practically all globulettes are of planetary mass, and most have masses less than one Jupiter mass. The average number densities exceed 10^5 cm^{-3} in several objects. We have found a statistical relation between density and radius (mass) in the sense that the smallest objects are also the densest.

The population of small globulettes in Carina appears to represent a more advanced evolutionary state than those investigated in other H II regions. The objects are subject to erosion in the intense radiation field, which would lead

to a removal of any thinner envelope and an unveiling of the core, which becomes more compact with time. We discuss the possibility that the core may become gravitationally unstable, in which case free-floating planetary mass objects can form.

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The dynamical properties of dense filaments in the infrared dark cloud G035.39-00.33

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Infrared Dark Clouds (IRDCs) are unique laboratories to study the initial conditions of high-mass star and star cluster formation. We present high-sensitivity and high-angular resolution IRAM PdBI observations of N_2H^+ ($1-0$) towards IRDC G035.39-00.33. It is found that G035.39-00.33 is a highly complex environment, consisting of several *mildly* supersonic filaments ($\sigma_{\text{NT}}/c_s \sim 1.5$), separated in velocity by $< 1 \text{ km s}^{-1}$. Where multiple spectral components are evident, moment analysis overestimates the non-thermal contribution to the line-width by a factor ~ 2 . Large-scale velocity gradients evident in previous single-dish maps may be explained by the presence of substructure now evident in the interferometric maps. Whilst *global* velocity gradients are small ($< 0.7 \text{ km s}^{-1} \text{ pc}^{-1}$), there is evidence for dynamic processes on *local* scales ($\sim 1.5\text{--}2.5 \text{ km s}^{-1} \text{ pc}^{-1}$). Systematic trends in velocity gradient are observed towards several continuum peaks. This suggests that the kinematics are influenced by dense (and in some cases, *starless*) cores. These trends are interpreted as either infalling material, with accretion rates $\sim (7 \pm 4) \times 10^{-5} \text{ M}_{\odot} \text{ yr}^{-1}$, or expanding shells with momentum $\sim 24 \pm 12 \text{ M}_{\odot} \text{ km s}^{-1}$. These observations highlight the importance of high-sensitivity and high-spectral resolution data in disentangling the complex kinematic and physical structure of massive star forming regions.

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An Optical Spectroscopic Study of T Tauri Stars. I. Photospheric Properties

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Measurements of masses and ages of young stars from their location in the HR diagram are limited by not only the typical observational uncertainties that apply to field stars, but also by large systematic uncertainties related to circumstellar phenomena. In this paper, we analyze flux calibrated optical spectra to measure accurate spectral types and extinctions of 283 nearby T Tauri stars. The primary advances in this paper are (1) the incorporation of a simplistic accretion continuum in optical spectral type and extinction measurements calculated over the full optical wavelength range and (2) the uniform analysis of a large sample of stars. Comparisons between the non-accreting TTS photospheric templates and stellar photosphere models are used to derive conversions from spectral type to temperature. Differences between spectral types can be subtle and difficult to discern, especially when accounting for accretion and extinction. The spectral types measured here are mostly consistent with spectral types measured over the past decade. However, our new spectral types are 1–2 subclasses later than literature spectral types for the original members of the TWA and are discrepant with literature values for some well known Taurus CTTSs. Our

extinction measurements are consistent with other optical extinction measurements but are typically 1 mag lower than nIR measurements, likely the result of methodological differences and the presence of nIR excesses in most CTTs. As an illustration of the impact of accretion, SpT, and extinction uncertainties on the HR diagrams of young clusters, we find that the resulting luminosity spread of stars in the TWA is 15–30%. The luminosity spread in the TWA and previously measured for binary stars in Taurus suggests that for a majority of stars, protostellar accretion rates are not large enough to significantly alter the subsequent evolution.

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ALMA view of G0.253+0.016: Can cloud-cloud collision form the cloud?

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We present the results of sulfur monoxide, SO line emission observations of G0.253+0.016 with the Atacama Large Millimeter/submillimeter Array (ALMA) at an angular resolution of 1arcsec.7. The dense and massive molecular cloud of G0.253+0.016 is highly sub-structured, yet shows no obvious signs of cluster formation. We found three outstanding features of the cloud from the SO emission, namely, shell structure of radius 1.3 pc, large velocity gradients of 20 km s⁻¹ pc⁻¹ with the cloud, and cores with large velocity dispersions (30–40 km s⁻¹) around the shell structure. We suggest that these large-velocity dispersion cores will form high-mass stars in the future. In attempt to explore the formation scenario of the dense cloud, we compared our results with numerical simulations, thus, we propose that G0.253+0.016 may have formed due to a cloud-cloud collision process.

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Self-Sustained Turbulence without Dynamical Forcing: A Two-Dimensional Study of a Bistable Interstellar Medium

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In this paper, the nonlinear evolution of a bistable interstellar medium is investigated using two-dimensional simulations with a realistic cooling rate, thermal conduction, and physical viscosity. The calculations are performed using periodic boundary conditions without any external dynamical forcing. As the initial condition, a spatially uniform unstable gas under thermal equilibrium is considered. At the initial stage, the unstable gas quickly segregates into two phases: cold neutral medium (CNM) and warm neutral medium (WNM). Then, self-sustained turbulence with velocity dispersion of 0.1-0.2 km s⁻¹ is observed in which the CNM moves around in the WNM. We find that the interfacial medium (IFM) between the CNM and WNM plays an important role in sustaining the turbulence. The self-sustaining mechanism can be divided into two steps. First, thermal conduction drives fast flows streaming into concave CNM surfaces toward the WNM. The kinetic energy of the fast flows in the IFM is incorporated into that of the CNM through the phase transition. Second, turbulence inside the CNM deforms interfaces and forms other concave CNM surfaces, leading to fast flows in the IFM. This drives the first step again and a cycle is established by which turbulent motions are self-sustained.

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Fomalhaut b as a Cloud of Dust: Testing Aspects of Planet Formation Theory

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We consider the ability of three models – impacts, captures, and collisional cascades – to account for a bright cloud of dust in Fomalhaut b. Our analysis is based on a novel approach to the power-law size distribution of solid particles central to each model. When impacts produce debris with (i) little material in the largest remnant and (ii) a steep size distribution, the debris has enough cross-sectional area to match observations of Fomalhaut b. However, published numerical experiments of impacts between 100 km objects suggest this outcome is unlikely. If collisional processes maintain a steep size distribution over a broad range of particle sizes (300 microns to 10 km), Earth-mass planets can capture enough material over 1–100 Myr to produce a detectable cloud of dust. Otherwise, capture fails. When young planets are surrounded by massive clouds or disks of satellites, a collisional cascade is the simplest mechanism for dust production in Fomalhaut b. Several tests using HST or JWST data – including measuring the expansion/elongation of Fomalhaut b, looking for trails of small particles along Fomalhaut b’s orbit, and obtaining low resolution spectroscopy – can discriminate among these models.

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Cloud Disruption via Ionized Feedback: Tracing Pillar Dynamics in Vulpecula

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The major physical processes responsible for shaping and sculpting pillars in the clouds surrounding massive stars (i.e. the ‘Pillars of Creation’) are now being robustly incorporated into models quantifying the ionizing radiation from massive stars. The detailed gas dynamics within these pillars can now be compared with observations. Our goal is to quantify the gas dynamics in a pillar being sculpted by a nearby massive star. To do this, we use the CO, ¹³CO, and C¹⁸O J=1-0 emission towards a pillar in the Vulpecula Rift. These data are a combination of CARMA and FCRAO observations providing high resolution ($\sim 5''$) imaging of large scale pillar structures ($> 100''$). We find that this cold (~ 18 K), low density material ($8 \times 10^3 \text{ cm}^{-3}$) material is fragmenting on Jeans scales, has very low velocity dispersions ($\sim 0.5 \text{ km s}^{-1}$), and appears to be moving away from the ionizing source. We are able to draw direct comparisons with three models from the literature, and find that those with lower velocity dispersions best fit our data, although the dynamics of any one model do not completely agree with our observations. We do however, find that our observed pillar exhibits many of the characteristics expected from simulations.

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SPARCO : a semi-parametric approach for image reconstruction of chromatic objects

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The emergence of optical interferometers with three and more telescopes allows image reconstruction of astronomical objects at the milliarcsecond scale. However, some objects contain components with very different spectral energy distributions (SED; i.e. different temperatures), which produces strong chromatic effects on the interferograms that have to be managed with care by image reconstruction algorithms. For example, the gray approximation for the image reconstruction process results in a degraded image if the total (u, v) -coverage given by the spectral supersynthesis is used. The relative flux contribution of the central object and an extended structure changes with wavelength for different temperatures. For young stellar objects, the known characteristics of the central object (i.e., stellar SED), or even the fit of the spectral index and the relative flux ratio, can be used to model the central star while reconstructing the image of the extended structure separately. We present a new method, called **SPARCO** (semi-parametric algorithm for the image reconstruction of chromatic objects), which describes the spectral characteristics of both the central object and the extended structure to consider them properly when reconstructing the image of the surrounding environment. We adapted two image-reconstruction codes (**Macim**, **Squeeze**, and **MiRA**) to implement this new prescription. **SPARCO** is applied using **Macim**, **Squeeze** and **MiRA** on a young stellar object model and also on literature data on HR 5999 in the near-infrared with the VLTI. We obtain smoother images of the modeled circumstellar emission and improve the χ^2 by a factor 9. This method paves the way to improved aperture-synthesis imaging of several young stellar objects with existing datasets. More generally, the approach can be used on astrophysical sources with similar features such as active galactic nuclei, planetary nebulae, and asymptotic giant branch stars.

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A Stellar Census of the Tucana-Horologium Moving Group

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We report the selection and spectroscopic confirmation of 129 new late-type (K3–M6) members of the Tuc-Hor moving group, a nearby (~ 40 pc), young (~ 40 Myr) population of comoving stars. We also report observations for 13/17 known Tuc-Hor members in this spectral type range, and that 62 additional candidates are likely to be unassociated field stars; the confirmation frequency for new candidates is therefore $129/191 = 67\%$. We have used RVs, H α emission, and Li₆₇₀₈ absorption to distinguish contaminants and bona fide members. Our expanded census of Tuc-Hor increases the known population by a factor of ~ 3 in total and by a factor of ~ 8 for members with SpT > K3, but even so, the K–M dwarf population of Tuc-Hor is still markedly incomplete. The spatial distribution of members appears to trace a 2D sheet, with a broad distribution in X and Y , but a very narrow distribution (± 5 pc) in Z . The corresponding velocity distribution is very small, with a scatter of ± 1.1 km s^{−1} about the mean UVW velocity. We also show that the isochronal age (20–30 Myr) and the lithium depletion age (40 Myr) disagree, following a trend seen in other PMS populations. The H α emission follows a trend of increasing EW with later SpT, as seen for young clusters. We find that members have been depleted of lithium for spectral types of K7.0–M4.5. Finally, our purely kinematic and color-magnitude selection procedure allows us to test the efficiency and completeness for activity-based selection of young stars. We find that 60% of K–M dwarfs in Tuc-Hor do not have ROSAT counterparts and would be omitted in X-ray selected samples. GALEX UV-selected samples using a previously suggested criterion for youth achieve completeness of 77% and purity of 78%. We suggest new selection criteria that yield >95% completeness for ~ 40 Myr populations.

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The Spatial Structure of Young Stellar Clusters. I. Subclusters

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The clusters of young stars in massive star-forming regions show a wide range of sizes, morphologies, and numbers of stars. Their highly subclustered structures are revealed by the MYStIX project's sample of 31,754 young stars in nearby sites of star formation (regions at distances <3.6 kpc that contain at least one O-type star.) In 17 of the regions surveyed by MYStIX, we identify subclusters of young stars using finite mixture models – collections of isothermal ellipsoids that model individual subclusters. Maximum likelihood estimation is used to estimate the model parameters, and the Akaike Information Criterion is used to determine the number of subclusters. This procedure often successfully finds famous subclusters, such as the BN/KL complex behind the Orion Nebula Cluster and the KW-object complex in M 17. A catalog of 142 subclusters is presented, with 1 to 20 subclusters per region. The subcluster core radius distribution for this sample is peaked at 0.17 pc with a standard deviation of 0.43 dex, and subcluster core radius is negatively correlated with gas/dust absorption of the stars – a possible age effect. Based on the morphological arrangements of subclusters, we identify four classes of spatial structure: long chains of subclusters, clumpy structures, isolated clusters with a core-halo structure, and isolated clusters well fit by a single isothermal ellipsoid.

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<http://astro.psu.edu/mystix>

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ALMA Results of the Pseudodisk, Rotating disk, and Jet in Continuum and HCO⁺ in the Protostellar System HH 212

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HH 212 is a nearby (400 pc) Class 0 protostellar system showing several components that can be compared with theoretical models of core collapse. We have mapped it in 350 GHz continuum and HCO⁺ J=4-3 emission with ALMA at up to $\sim 0''.4$ resolution. A flattened envelope and a compact disk are seen in continuum around the central source, as seen before. The HCO⁺ kinematics shows that the flattened envelope is infalling with small rotation (i.e., spiraling) into the central source, and thus can be identified as a pseudodisk in the models of magnetized core collapse. Also, the HCO⁺ kinematics shows that the disk is rotating and can be rotationally supported. In addition, to account for the missing HCO⁺ emission at low-redshifted velocity, an extended infalling envelope is required, with its material flowing roughly parallel to the jet axis toward the pseudodisk. This is expected if it is magnetized with an hourglass B-field morphology. We have modeled the continuum and HCO⁺ emission of the flattened envelope and disk simultaneously. We find that a jump in density is required across the interface between the pseudodisk and the disk. A jet is seen in HCO⁺ extending out to ~ 500 AU away from the central source, with the peaks upstream of those seen before in SiO. The broad velocity range and high HCO⁺ abundance indicate that the HCO⁺ emission traces internal shocks in the jet.

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Velocity-resolved [Ne III] from X-ray Irradiated Sz 102 Microjets

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Neon emission lines are good indicators of high-excitation regions close to a young stellar system because of their high ionization potentials and large critical densities. We have discovered [Ne III] $\lambda 3869$ emission from the microjets of Sz 102, a low-mass young star in Lupus III. Spectroastrometric analyses of two-dimensional [Ne III] spectra obtained from archival high-dispersion ($R \approx 33,000$) Very Large Telescope/UVES data suggest that the emission consists of two velocity components spatially separated by $\sim 0''.3$, or a projected distance of ~ 60 AU. The stronger redshifted component is centered at $\sim +21$ km s⁻¹ with a line width of ~ 140 km s⁻¹, and the weaker blueshifted component at ~ -90 km s⁻¹ with a line width of ~ 190 km s⁻¹. The two components trace velocity centroids of the known microjets and show large line widths that extend across the systemic velocity, suggesting their potential origins in wide-angle winds that may eventually collimate into jets. Optical line ratios indicate that the microjets are hot ($T \leq 1.6 \times 10^4$ K) and ionized ($n_e \geq 5.7 \times 10^4$ cm⁻³). The blueshifted component has $\sim 13\%$ higher temperature and $\sim 46\%$ higher electron density than the redshifted counterpart, forming a system of asymmetric pair of jets. The detection of the [Ne III] $\lambda 3869$ line with the distinct velocity profile suggests that the emission originates in flows that may have been strongly ionized by deeply embedded hard X-ray sources, most likely generated by magnetic processes. The discovery of [Ne III] $\lambda 3869$ emission along with other optical forbidden lines from Sz 102 support the picture of wide-angle winds surrounding magnetic loops in the close vicinity of the young star. Future high sensitivity X-ray imaging and high angular-resolution optical spectroscopy may help confirm the picture proposed.

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Molecular line mapping of the giant molecular cloud associated with RCW 106 - IV. Ammonia towards dust emission

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Here we report observations of the two lowest inversion transitions of ammonia (NH₃) with the 70-m Tidbinbilla radio telescope. The aim of the observations is to determine the kinetic temperatures in the dense clumps of the G333 giant molecular cloud associated with RCW 106 (hereafter known as the G333 GMC) and to examine the effect that accurate measures of temperature have on the calculation of derived quantities such as mass. This project is part of a larger investigation to understand the timescales and evolutionary sequence associated with high-mass star formation,

particularly its earliest stages. Assuming that the initial chemical composition of a giant molecular cloud is uniform, any abundance variations within will be due to evolutionary state.

We have identified 63 clumps using SIMBA 1.2-mm dust continuum maps and have calculated gas temperatures for most (78 per cent) of these dense clumps. After using *Spitzer* GLIMPSE 8.0 μm emission to separate the sample into IR-bright and IR-faint clumps, we use statistical tests to examine whether our classification shows different populations in terms of mass and temperature. We find that in terms of log clump mass ($2.44 - 4.12 M_{\odot}$) and log column density ($15.3 - 16.6 \text{ cm}^{-2}$), that there is no significant population difference between IR-bright and IR-faint clumps, and that kinetic temperature is the best parameter to distinguish between the gravitationally bound state of each clump. The kinetic temperature was the only parameter found to have a significantly low probability of being drawn from the same population. This suggests that clump radii does not have a large effect on the temperature of a clump, so clumps of similar radii may have different internal heating mechanisms. We also find that while the IR-bright clumps have a higher median log virial mass than the IR-faint clumps (IR-bright: $2.88 M_{\odot}$; IR-faint: $2.73 M_{\odot}$), both samples have a similar range for both virial mass and FWHM (IR-bright: log virial mass = $2.03 - 3.68 M_{\odot}$, FWHM = $1.17 - 4.50 \text{ km s}^{-1}$; IR-faint: log virial mass = $2.09 - 3.35 M_{\odot}$, FWHM = $1.05 - 4.41 \text{ km s}^{-1}$). There are 87 per cent (40 of 46) of the clumps with masses larger than the virial mass, suggesting that they will form stars or are already undergoing star formation.

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ALMA Observations of the Orion Proplyds

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We present ALMA observations of protoplanetary disks (“proplyds”) in the Orion Nebula Cluster. We imaged 5 individual fields at 856 μm containing 22 HST-identified proplyds and detected 21 of them. Eight of those disks were detected for the first time at submillimeter wavelengths, including the most prominent, well-known proplyd in the entire Orion Nebula, 114-426. Thermal dust emission in excess of any free-free component was measured in all but one of the detected disks, and ranged between 1–163 mJy, with resulting disk masses of $0.3\text{--}79 M_{\text{jup}}$. An additional 26 stars with no prior evidence of associated disks in HST observations were also imaged within the 5 fields, but only 2 were detected. The disk mass upper limits for the undetected targets, which include OB stars, θ^1 Ori C and θ^1 Ori F, range from $0.1\text{--}0.6 M_{\text{jup}}$. Combining these ALMA data with previous SMA observations, we find a lack of massive ($>3 M_{\text{jup}}$) disks in the extreme-UV dominated region of Orion, within 0.03 pc of O-star θ^1 Ori C. At larger separations from θ^1 Ori C, in the far-UV dominated region, there is a wide range of disk masses, similar to what is found in low-mass star forming regions. Taken together, these results suggest that a rapid dissipation of disk masses likely inhibits potential planet formation in the extreme-UV dominated regions of OB associations, but leaves disks in the far-UV dominated regions relatively unaffected.

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Detection of a dense clump in a filament interacting with W51e2

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In the framework of the Herschel/PRISMAS Guaranteed Time Key Program, the line of sight to the distant ultracompact H II region W51e2 has been observed using several selected molecular species. Most of the detected absorption features are not associated with the background high-mass star-forming region and probe the diffuse matter along the line of sight. We present here the detection of an additional narrow absorption feature at $\sim 70 \text{ km s}^{-1}$ in the observed spectra of HDO, NH_3 and C_3 . The 70 km s^{-1} feature is not uniquely identifiable with the dynamic components (the main cloud and the large-scale foreground filament) so-far identified toward this region. The narrow absorption feature is similar to the one found toward low-mass protostars, which is characteristic of the presence of a cold external envelope. The far-infrared spectroscopic data were combined with existing ground-based observations of ^{12}CO , ^{13}CO , CCH, CN, and C_3H_2 to characterize the 70 km s^{-1} component. Using a non-LTE analysis of multiple transitions of NH_3 and CN, we estimated the density ($n(\text{H}_2) \sim (1-5) 10^5 \text{ cm}^{-3}$) and temperature (10–30 K) for this narrow feature. We used a gas-grain warm-up based chemical model with physical parameters derived from the NH_3 data to explain the observed abundances of the different chemical species. We propose that the 70 km s^{-1} narrow feature arises in a dense and cold clump that probably is undergoing collapse to form a low-mass protostar, formed on the trailing side of the high-velocity filament, which is thought to be interacting with the W51 main cloud. While the fortuitous coincidence of the dense clump along the line of sight with the continuum-bright W51e2 compact HII region has contributed to its non-detection in the continuum images, this same attribute makes it an appropriate source for absorption studies and in particular for ice studies of star-forming regions.

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The Correlation of Dust and Gas Emission in Star-Forming Environments

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We present ammonia maps of portions of the W3 and Perseus molecular clouds in order to compare gas emission with submillimetre continuum thermal emission which are commonly used to trace the same mass component in star-forming regions, often under the assumption of LTE.

The Perseus and W3 star-forming regions are found to have significantly different physical characteristics consistent with the difference in size scales traced by our observations. Accounting for the distance of the W3 region does not fully reconcile these differences, suggesting that there may be an underlying difference in the structure of the two regions.

Peak positions of submillimetre and ammonia emission do not correlate strongly. Also, the extent of diffuse emission is only moderately matched between ammonia and thermal emission. Source sizes measured from our observations are consistent between regions, although there is a noticeable difference between the submillimetre source sizes with sources in Perseus being significantly smaller than those in W3.

Fractional abundances of ammonia are determined for our sources which indicate a dip in the measured ammonia abundance at the positions of peak submillimetre column density.

Virial ratios are determined which show that our sources are generally bound in both regions, although there is considerable scatter in both samples. We conclude that sources in Perseus are bound on smaller scales than in W3 in

a way that may reflect their previous identification as low- and high-mass, respectively. Our results indicate that assumptions of local thermal equilibrium and/or the coupling of the dust and gas phases in star-forming regions may not be as robust as commonly assumed.

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Multifluid simulations of the Magnetorotational Instability in protostellar disks

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Turbulent motion driven by the magnetorotational instability (MRI) is believed to provide an anomalous viscosity strong enough to account for observed accretion rates in protostellar accretion disks. In the first of two papers, we perform large-scale, three fluid simulations of a weakly ionised accretion disk and examine the linear and non-linear development of the MRI in the net-flux and zero net-flux cases. This numerical study is carried out using the multifluid MHD code HYDRA. We examine the role of non-ideal effects, including ambipolar diffusion, the Hall effect, and parallel resistivity, on the non-linear evolution of the MRI in weakly ionised protostellar disks in the region where the Hall effect is believed to dominate.

We find that angular momentum transport, parametrised by the alpha parameter, is enhanced by inclusion of non-ideal effects in the parameter space of the disk model. The case where the angular momentum and magnetic field are anti-parallel is explored and the Hall effect is shown to have a stabilizing influence on the disk in this case.

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Rotational Instability in the Outer Region of Protoplanetary Disks

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We analytically calculate the marginally stable surface density profile for rotational instability of protoplanetary disks. The derived profile can be utilized for considering the region in a rotating disk where radial pressure gradient force is comparable to the gravitational force, such as an inner edge, steep gaps or bumps and an outer region of the disk. In this paper we especially focus on the rotational instability in the outer region of disks. We find an protoplanetary disk with a surface density profile of similarity solution becomes rotationally unstable at a certain radius, depending on its temperature profile and a mass of the central star. If the temperature is relatively low and the mass of the central star is high, disks have rotationally stable similarity profiles. Otherwise, deviation from the similarity profiles of surface density could be observable, using facilities with high sensitivity, such as ALMA.

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Spatial differences between stars and brown dwarfs: a dynamical origin?

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We use N -body simulations to compare the evolution of spatial distributions of stars and brown dwarfs in young star-forming regions. We use three different diagnostics; the ratio of stars to brown dwarfs as a function of distance from the region's centre, R_{SSR} , the local surface density of stars compared to brown dwarfs, Σ_{LDR} , and we compare the global spatial distributions using the Λ_{MSR} method. From a suite of twenty initially statistically identical simulations, 6/20 attain $R_{\text{SSR}} \ll 1$ and $\Sigma_{\text{LDR}} \ll 1$ and $\Lambda_{\text{MSR}} \ll 1$, indicating that dynamical interactions could be responsible for observed differences in the spatial distributions of stars and brown dwarfs in star-forming regions. However, many simulations also display apparently contradictory results - for example, in some cases the brown dwarfs have much lower local densities than stars ($\Sigma_{\text{LDR}} \ll 1$), but their global spatial distributions are indistinguishable ($\Lambda_{\text{MSR}} = 1$) and the relative proportion of stars and brown dwarfs remains constant across the region ($R_{\text{SSR}} = 1$). Our results suggest that extreme caution should be exercised when interpreting any observed difference in the spatial distribution of stars and brown dwarfs, and that a much larger observational sample of regions/clusters (with complete mass functions) is necessary to investigate whether or not brown dwarfs form through similar mechanisms to stars.

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SMA observations of the proto brown dwarf candidate SSTB213 J041757

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Context. The previously identified source SSTB213 J041757 is a proto brown dwarf candidate in Taurus, which has two possible components A and B. It was found that component B is probably a class 0/I proto brown dwarf associated with an extended envelope.

Aims. Studying molecular outflows from young brown dwarfs provides important insight into brown dwarf formation mechanisms, particularly brown dwarfs at the earliest stages such as class 0, I. We therefore conducted a search for molecular outflows from SSTB213 J041757.

Methods. We observed SSTB213 J041757 with the Submillimeter Array to search for CO molecular outflow emission from the source.

Results. Our CO maps do not show any outflow emission from the proto brown dwarf candidate.

Conclusions. The non-detection implies that the molecular outflows from the source are weak; deeper observations are therefore needed to probe the outflows from the source.

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Diversity in the outcome of dust radial drift in protoplanetary discs

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The growth of dust particles into planet embryos needs to circumvent the radial-drift barrier, i.e. the accretion of dust particles onto the central star by radial migration. The outcome of the dust radial migration is governed by simple criteria between the dust-to-gas ratio and the exponents p and q of the surface density and temperature power laws. The transfer of radiation provides an additional constraint between these quantities because the disc thermal structure is fixed by the dust spatial distribution. To assess which discs are primarily affected by the radial-drift barrier, we used the radiative transfer code MCFOST to compute the temperature structure of a wide range of disc models, stressing the particular effects of grain size distributions and vertical settling. We find that the outcome of the dust migration process is very sensitive to the physical conditions within the disc. For high dust-to-gas ratios (>0.01) or flattened disc structures ($H/R < 0.05$), growing dust grains can efficiently decouple from the gas, leading to a high concentration of grains at a critical radius of a few AU. Decoupling of grains can occur at a large fraction (>0.1) of the initial radius, for a dust-to-gas ratio greater than ~ 0.05 . The exact value of the required dust-to-gas ratio for dust to stop its migration is strongly dependent on the disc temperature structure. Non growing dust grains are accreted for discs with flat surface density profiles ($p < 0.7$) while they always remain in the disc if the surface density is steep enough ($p > 1.2$). Both the presence of large grains and vertical settling tend to favour the accretion of non growing dust grains onto the central object, but it slows down the migration of growing dust grains. All the disc configurations are found to have favourable temperature profiles over most of the disc to retain their planetesimals.

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Chandra X-ray observation of the HII region Gum 31 in the Carina Nebula complex

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We used the Chandra observatory to perform a deep (70 ksec) X-ray observation of the Gum 31 region and detected 679 X-ray point sources. This extends and complements the X-ray survey of the central Carina nebula regions performed in the Chandra Carina Complex Project. Using deep near-infrared images from our recent VISTA survey of the Carina nebula complex, our Spitzer point-source catalog, and optical archive data, we identify counterparts for 75% of these X-ray sources. Their spatial distribution shows two major concentrations, the central cluster NGC 3324 and a partly embedded cluster in the southern rim of the HII region, but majority of X-ray sources constitute a rather homogeneously distributed population of young stars. Our color-magnitude diagram analysis suggests ages of ~ 1 – 2 Myr for the two clusters, whereas the distributed population shows a wider age range up to ~ 10 Myr. We also identify previously unknown companions to two of the three O-type members of NGC 3324 and detect diffuse X-ray emission in the region. Our results suggests that the observed region contains about 4000 young stars in total. The distributed population is probably part of the widely distributed population of ~ 1 – 10 Myr old stars, that was identified in the CCCP area. This implies that the global stellar configuration of the Carina nebula complex is a very extended stellar association, in which the (optically prominent) clusters contain only a minority of the stellar population.

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[Fe II] Emissions associated with the Young Interacting Binary UY Aurigae

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We present high resolution $1.06 - 1.28 \mu\text{m}$ spectra toward the interacting binary UY Aur obtained with GEMINI/NIFS and the AO system Altair. We have detected [Fe II] $\lambda 1.257 \mu\text{m}$ and [He I] $\lambda 1.083 \mu\text{m}$ lines from both UY Aur A (the primary source) and UY Aur B (the secondary). In [Fe II] UY Aur A drives fast and widely opening outflows with an opening angle of $\sim 90^\circ$ along a position angle of $\sim 40^\circ$, while UY Aur B is associated with a redshifted knot. The blueshifted and redshifted emissions show complicated structure between the primary and secondary. The radial velocities of the [Fe II] emission features are similar for UY Aur A and B: $\sim -100 \text{ km s}^{-1}$ for the blueshifted emission and $\sim +130 \text{ km s}^{-1}$ for the red-shifted component. The [He I] line profile observed toward UY Aur A comprises a central emission feature with deep absorptions at both blueshifted and redshifted velocities. These absorption features may be explained by stellar wind models. The [He I] line profile of UY Aur B shows only an emission feature.

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The Effect of Planets Beyond the Ice Line on the Accretion of Volatiles by Habitable-Zone Rocky Planets

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Models of planet formation have shown that giant planets have a large impact on the number, masses and orbits of terrestrial planets that form. In addition, they play an important role in delivering volatiles from material that formed exterior to the snow-line (the region in the disk beyond which water ice can condense) to the inner region of the disk where terrestrial planets can maintain liquid water on their surfaces. We present simulations of the late stages of terrestrial planet formation from a disk of protoplanets around a solar-type star, and we include a massive planet (from $1 M_\oplus$ to $1 M_J$) in Jupiter's orbit at $\sim 5.2 \text{ AU}$ in all but one set of simulations. Two initial disk models are examined with the same mass distribution and total initial water content, but with different distributions of water content. We compare the accretion rates and final water mass fraction of the planets that form. Remarkably, all of the planets that formed in our simulations without giant planets were water-rich, showing that giant planet companions are not required to deliver volatiles to terrestrial planets in the habitable zone. In contrast, an outer planet at least several times the mass of Earth may be needed to clear distant regions from debris truncating the epoch of frequent large impacts. Observations of exoplanets from radial velocity surveys suggest that outer Jupiter-like planets may be scarce, therefore the results presented here suggest the number of habitable planets that reside in our galaxy may be more than previously thought.

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Massive open star clusters using the VVV survey III: A young massive cluster at the far edge of the Galactic bar

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Context: Young massive clusters are key to map the Milky Way’s structure, and near-IR large area sky surveys have contributed strongly to the discovery of new obscured massive stellar clusters.

Aims: We present the third article in a series of papers focused on young and massive clusters discovered in the VVV survey. This article is dedicated to the physical characterization of VVV CL086, using part of its OB-stellar population.

Methods: We physically characterized the cluster using JHK_S near-infrared photometry from ESO public survey VVV images, using the VVV-SkZ pipeline, and near-infrared K-band spectroscopy, following the methodology presented in the first article of the series.

Results: Individual distances for two observed stars indicate that the cluster is located at the far edge of the Galactic bar. These stars, which are probable cluster members from the statistically field-star decontaminated CMD, have spectral types between O9 and B0V. According to our analysis, this young cluster ($1.0 \text{ Myr} < \text{age} < 5.0 \text{ Myr}$) is located at a distance of 11^{+5}_{-6} kpc, and we estimate a lower limit for the cluster total mass of $(2.8^{+1.6}_{-1.4}) \cdot 10^3 M_{\odot}$. It is likely that the cluster contains even earlier and more massive stars.

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Vega’s hot dust from icy planetesimals scattered inward by an outward-migrating planetary system

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Vega has been shown to host multiple dust populations, including both hot exo-zodiacal dust at sub-AU radii and a cold debris disk extending beyond 100 AU. We use dynamical simulations to show how Vega’s hot dust can be created by long-range gravitational scattering of planetesimals from its cold outer regions. Planetesimals are scattered progressively inward by a system of 5–7 planets from 30–60 AU to very close-in. In successful simulations the outermost planets are typically Neptune-mass. The back-reaction of planetesimal scattering causes these planets to migrate outward and continually interact with fresh planetesimals, replenishing the source of scattered bodies. The most favorable cases for producing Vega’s exo-zodi have negative radial mass gradients, with sub-Saturn- to Jupiter-mass inner planets at 5–10 AU and outer planets of 2.5 to 20 M_{\oplus} . The mechanism fails if a Jupiter-sized planet exists beyond ~ 15 AU because the planet preferentially ejects planetesimals before they can reach the inner system. Direct-imaging planet searches can therefore directly test this mechanism.

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A Herschel and BIMA study of the sequential star formation near the W48A HII region

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We present the results of Herschel HOBYS photometric mapping combined with BIMA observations and additional archival data, and perform an in-depth study of the evolutionary phases of the star-forming clumps in W 48A and their surroundings. Age estimates for the compact sources were derived from bolometric luminosities and envelope masses, which were obtained from the dust continuum emission, and agree within an order of magnitude with age estimates from molecular line and radio data. The clumps in W 48A are linearly aligned by age (east-old to west-young): we find a ultra compact (UC) HII region, a young stellar object (YSO) with class II methanol maser emission, a YSO with a massive outflow, and finally the NH₂D prestellar cores from Pillai et al. This remarkable positioning reflects the (star) formation history of the region. We find that it is unlikely that the star formation in the W 48A molecular cloud was triggered by the UCHII region and discuss the Aquila supershell expansion as a mayor influence on the evolution of W 48A. We conclude that the combination of Herschel continuum data with interferometric molecular line and radio continuum data is important to derive trustworthy age estimates and interpret the origin of large scale structures through kinematic information.

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The molecular complex associated with the Galactic HII region Sh2-90: a possible site of triggered star formation

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We investigate the star formation activity in the molecular complex associated with the Galactic HII region Sh2-90, using radio-continuum maps obtained at 1280 MHz and 610 MHz, Herschel Hi-GAL observations at 70 – 500 μ m, and deep near-infrared observation at *JHK* bands, along with Spitzer observations. Sh2-90 presents a bubble morphology in the mid-IR (size ~ 0.9 pc \times 1.6 pc). Radio observations suggest it is an evolved HII region with an electron density ~ 144 cm⁻³, emission measure $\sim 6.7 \times 10^4$ cm⁻⁶ pc and a ionized mass $\sim 55 M_{\odot}$. From Hi-GAL observations it is found that the HII region is part of an elongated extended molecular cloud (size ~ 5.6 pc \times 9.7 pc, H₂ column density $\geq 3 \times 10^{21}$ cm⁻² and dust temperature 18 – 27 K) of total mass $\geq 1 \times 10^4 M_{\odot}$. We identify the ionizing cluster of Sh2-90, the main exciting star being an O8–O9 V star. Five cold dust clumps (mass $\sim 8 - 95 M_{\odot}$), four mid-IR blobs around B stars, and a compact HII region are found at the edge of the bubble. The velocity information derived from CO (*J*=3–2) data cubes suggests that most of them are associated with the Sh2-90 region. 129 YSOs are identified (Class I, Class II, and near-IR excess sources). The majority of the YSOs are low mass (≤ 3 Msun) sources and they are distributed mostly in the regions of high column density. Four candidate Class 0/I MYSOs have been found; they will possibly evolve to stars of mass ≥ 15 Msun. We suggest multi-generation star formation is present in the complex. From the evidences of interaction, the time scales involved and the evolutionary status of stellar/protostellar sources, we argue that the star formation at the immediate border/edges of Sh2-90 might have been triggered by the expanding HII region. However, several young sources in this complex are probably formed by some other processes.

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High abundance ratio of ¹³CO to C¹⁸O toward photon-dominated regions in the Orion-A giant molecular cloud

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We have carried out wide-field (0.4 deg²) observations with an angular resolution of 25.8 arcsec (~ 0.05 pc) in ¹³CO (*J*=1–0) and C¹⁸O (*J*=1–0) toward the Orion-A giant molecular cloud using the Nobeyama 45 m telescope in the on-the-fly mode. Overall distributions and velocity structures of the ¹³CO and C¹⁸O emissions are similar to those of the ¹²CO (*J*=1–0) emission. The optical depths of the ¹³CO and C¹⁸O emission lines are estimated to be $0.05 < \tau_{13\text{CO}} < 1.54$ and $0.01 < \tau_{\text{C}^{18}\text{O}} < 0.18$, respectively. The column densities of the ¹³CO and C¹⁸O emission lines are estimated to be $0.2 \times 10^{16} < N_{13\text{CO}} < 3.7 \times 10^{17}$ cm⁻² and $0.4 \times 10^{15} < N_{\text{C}^{18}\text{O}} < 3.5 \times 10^{16}$ cm⁻², respectively. The abundance ratios between ¹³CO and C¹⁸O, $X_{13\text{CO}}/X_{\text{C}^{18}\text{O}}$, are found to be 5.7 – 33.0. The mean value of $X_{13\text{CO}}/X_{\text{C}^{18}\text{O}}$ in the nearly edge-on photon-dominated regions is found to be 16.47 ± 0.10 , which is a third larger than that the solar system value of 5.5. The mean value of $X_{13\text{CO}}/X_{\text{C}^{18}\text{O}}$ in the other regions is found to be 12.29 ± 0.02 . The difference

of the abundance ratio is most likely due to the selective FUV photodissociation of C^{18}O .

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Coreshine in L1506C - Evidence for a primitive big-grain component or indication for a turbulent core history?

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With the initial steps of the star formation process in the densest part of the ISM still under debate, much attention is paid to the formation and evolution of pre-stellar cores. The recently discovered coreshine effect can aid in exploring the core properties and in probing the large grain population of the ISM. We discuss the implications of the coreshine detected from the molecular cloud core L1506C in the Taurus filament for the history of the core and the existence of a primitive ISM component of large grains becoming visible in cores. The coreshine surface brightness of L1506C is determined from IRAC Spitzer images at $3.6\ \mu\text{m}$. We perform grain growth calculations to estimate the grain size distribution in model cores similar in gas density, radius, and turbulent velocity to L1506C. Scattered light intensities at $3.6\ \mu\text{m}$ are calculated for a variety of MRN and grain growth distributions using the DIRBE $3.5\ \mu\text{m}$ all-sky map as external interstellar radiation field, and are compared to the observed coreshine surface brightness. For a core with the overall physical properties of L1506C, no detectable coreshine is predicted with a size distribution following the shape and size limits of an MRN distribution. Extending the distribution to grain radii of about $0.65\ \mu\text{m}$ allows to reproduce the observed surface brightness level in scattered light. Assuming the properties of L1506C to be preserved, models for the growth of grains in cores do not yield sufficient scattered light to account for the coreshine within the lifetime of the Taurus complex. Only increasing the core density and the turbulence amplifies the scattered light intensity to a level consistent with the observed coreshine brightness. The coreshine observed from L1506C requires the presence of grains with sizes exceeding the common MRN distribution. The grains could be part of primitive omni-present large grain population becoming visible in the densest part of the ISM, could grow under the turbulent dense conditions of former cores, or in L1506C itself. In the later case, L1506C must have passed through a period of larger density and stronger turbulence. This would be consistent with the surprisingly strong depletion usually attributed to high column densities, and with the large-scale outward motion of the core envelope observed today.

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Does the mass distribution in discs influence encounter-induced losses in young star clusters?

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One mechanism for the external destruction of protoplanetary discs in young dense clusters is tidal disruption during the flyby of another cluster member. The degree of mass loss in such an encounter depends, among other parameters, on the distribution of the material within the disc. Previous work showed that this is especially so in encounters that truncate large parts of the outer disc. The expectation is that the number of completely destroyed discs in a cluster depends also on the mass distribution within the discs. Here we test this hypothesis by determining the influence of encounters on the disc fraction and average disc mass in clusters of various stellar densities for different mass distributions in the discs. This is done by performing NBODY6 simulation of a variety of cluster environments, where we track the encounter dynamics and determine the mass loss due to these encounters for different disc-mass distributions. We find that although the disc mass distribution has a significant impact on the disc losses for specific star-disc encounters, the overall disc frequency generally remains rather unaffected. The reason is that in

single encounters the dependence on the mass distribution is strongest if both stars have very different masses. Such encounters are rather infrequent in sparse clusters. In dense clusters such encounters are more common, however, here the disc frequency is largely determined by encounters between low-mass stars such that the overall disc frequency does not change significantly. For tidal disruption the disc destruction in clusters is fairly independent of the actual distribution of the material in the disc. The all determining factor remains the cluster density.

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Structure and Mass of Filamentary Isothermal Cloud Threaded by Lateral Magnetic Field

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Herschel observation has recently revealed that interstellar molecular clouds consist of many filaments. Polarization observations in optical and infrared wavelengths indicate that the magnetic field often runs perpendicular to the filament. In this paper, the magnetohydrostatic configuration of isothermal gas is studied, in which the thermal pressure and the Lorentz force are balanced against the self-gravity and the magnetic field is globally perpendicular to the axis of the filament. The model is controlled by three parameters: center-to-surface density ratio (ρ_c/ρ_s), plasma β of surrounding interstellar gas (β_0) and the radius of the hypothetical parent cloud normalized by the scale-height (R'_0), although there remains a freedom how the mass is distributed against the magnetic flux (mass loading). In the case that R'_0 is small enough, the magnetic field plays a role in confining the gas. However, the magnetic field generally has an effect in supporting the cloud. There is a maximum line-mass (mass per unit length) above which the cloud is not supported against the gravity. Compared with the maximum line-mass of non-magnetized cloud ($2c_s^2/G$, where c_s and G represent respectively the isothermal sound speed and the gravitational constant), that of the magnetized filament is larger than the non-magnetized one. The maximum line-mass is numerically obtained as

$$\lambda_{\max} \simeq 0.24\Phi_{\text{cl}}/G^{1/2} + 1.66c_s^2/G,$$

where Φ_{cl} represents one half of the magnetic flux threading the filament per unit length. The maximum mass of the filamentary cloud is shown to be significantly affected by the magnetic field when the magnetic flux per unit length exceeds $\Phi_{\text{cl}} \gtrsim 3 \text{ pc } \mu\text{G} (c_s/190 \text{ m s}^{-1})^2$.

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The Massive Star-forming Regions Omnibus X-ray Catalog

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We present the Massive Star-forming Regions (MSFRs) Omnibus X-ray Catalog (MOXC), a compendium of X-ray point sources from *Chandra*/ACIS observations of a selection of MSFRs across the Galaxy, plus 30 Doradus in the Large Magellanic Cloud. MOXC consists of 20,623 X-ray point sources from 12 MSFRs with distances ranging from 1.7 kpc to 50 kpc. Additionally, we show the morphology of the unresolved X-ray emission that remains after the catalogued X-ray point sources are excised from the ACIS data, in the context of Spitzer and *WISE* observations that trace the bubbles, ionization fronts, and photon-dominated regions that characterize MSFRs. In previous work, we have found that this unresolved X-ray emission is dominated by hot plasma from massive star wind shocks. This

diffuse X-ray emission is found in every MOXC MSFR, clearly demonstrating that massive star feedback (and the several-million-degree plasmas that it generates) is an integral component of MSFR physics.

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Star formation activity in the southern Galactic HII region G351.63-1.25

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The southern Galactic high mass star-forming region, G351.63-1.25, is a HII region-molecular cloud complex with a luminosity of $\sim 2.0 \times 10^5 L_\odot$, located at a distance of 2.4 kpc from the Sun. In this paper, we focus on the investigation of the associated HII region, the embedded cluster and the interstellar medium in the vicinity of G351.63-1.25. We address the identification of exciting source(s) as well as the census of the stellar populations, in an attempt to unfold star formation activity in this region. The ionised gas distribution has been mapped using the Giant Metrewave Radio Telescope (GMRT), India at three frequencies: 1280, 610 and 325 MHz. The HII region shows an elongated morphology and the 1280 MHz map comprises six resolved high density regions encompassed by diffuse emission spanning $1.4 \times 1.0 \text{ pc}^2$. Based on measurements of flux densities at multiple radio frequencies, the brightest ultracompact core has electron temperature $T_e \sim 7647 \pm 153 \text{ K}$ and emission measure, $EM \sim 2.0 \pm 0.8 \times 10^7 \text{ cm}^{-6} \text{ pc}$. The zero age main-sequence (ZAMS) spectral type of the brightest radio core is O7.5. We have carried out near-infrared observations in the JHK_s bands using the SIRIUS instrument on the 1.4 m Infrared Survey Facility (IRSF) telescope. The near-infrared images reveal the presence of a cluster embedded in nebulous fan-shaped emission. The log-normal slope of the K-band luminosity function of the embedded cluster is found to be $\sim 0.27 \pm 0.03$ and the fraction of the near-infrared excess stars is estimated to be 43%. These indicate that the age of the cluster is consistent with $\sim 1 \text{ Myr}$. Other available data of this region show that the warm (mid-infrared) and cold (millimetre) dust emission peak at different locations indicating progressive stages of star formation process. The champagne flow model from a flat, thin molecular cloud is used to explain the morphology of radio emission with respect to the millimetre cloud and infrared brightness.

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The effect of luminosity bursts on the properties of protostellar disks

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We present a 2+1 dimensional numerical model for the formation and evolution of young stellar objects with (sub-)stellar mass, wherein a two-dimensional numerical hydrodynamics code for the evolution of a protostellar disk is complemented by a one-dimensional stellar evolution code and an algorithm for the reconstruction of the disk vertical structure. Using this code, we investigated the effect of luminosity bursts, similar in magnitude to FU Orionis-type objects (FUors), on the properties and thermal balance of protostellar disks. For the prototype model of FUors, we have chosen the model of disk gravitational instability and fragmentation followed by inward migration of fragments onto the protostar. It is shown that typical FUors ($L \sim 100 L_\odot$) can make a significant impact on the thermal balance of disks and parental envelopes, causing more than a factor of 2 increase in the gas and dust temperature in the disk. On the other hand, massive fragments residing in the disk are weakly affected by the bursts, partly thanks to shielding

of stellar irradiation by the disk and partly due to high temperatures in the fragment interiors caused by adiabatic compression. It is found that typical thermal timescales are much smaller than dynamical ones everywhere except massive fragments, which allows us to use a steady-state radiation transport equation when reconstructing the disk vertical structure.

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The inner circumstellar disk of the UX Ori star V1026 Sco

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The UX Ori type variables (named after the prototype of their class) are intermediate-mass pre-main sequence objects. One of the most likely causes of their variability is the obscuration of the central star by orbiting dust clouds. We investigate the structure of the circumstellar environment of the UX Ori star V1026 Sco (HD 142666) and test whether the disk inclination is large enough to explain the UX Ori variability. We observed the object in the low-resolution mode of the near-infrared interferometric VLTI/AMBER instrument and derived H - and K -band visibilities and closure phases. We modeled our AMBER observations, published Keck Interferometer observations, archival MIDI/VLTI visibilities, and the spectral energy distribution using geometric and temperature-gradient models. Employing a geometric inclined-ring disk model, we find a ring radius of 0.15 ± 0.06 AU in the H band and 0.18 ± 0.06 AU in the K band. The best-fit temperature-gradient model consists of a star and two concentric, ring-shaped disks. The inner disk has a temperature of 1257_{-53}^{+133} K at the inner rim and extends from 0.19 ± 0.01 AU to 0.23 ± 0.02 AU. The outer disk begins at $1.35_{-0.20}^{+0.19}$ AU and has an inner temperature of 334_{-17}^{+35} K. The derived inclination of $48.6_{-3.6}^{+2.9}^\circ$ approximately agrees with the inclination derived with the geometric model ($49 \pm 5^\circ$ in the K band and $50 \pm 11^\circ$ in the H band). The position angle of the fitted geometric and temperature-gradient models are $163 \pm 9^\circ$ (K band; $179 \pm 17^\circ$ in the H band) and $169.3_{-6.7}^{+4.2}^\circ$, respectively. The narrow width of the inner ring-shaped model disk and the disk gap might be an indication for a puffed-up inner rim shadowing outer parts of the disk. The intermediate inclination of $\sim 50^\circ$ is consistent with models of UX Ori objects where dust clouds in the inclined disk obscure the central star.

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Complex organic molecules in protoplanetary disks

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Protoplanetary disks are vital objects in star and planet formation, possessing all the material which may form a planetary system orbiting the new star. We investigate the synthesis of complex organic molecules (COMs) in disks to constrain the achievable chemical complexity and predict species and transitions which may be observable with ALMA. We have coupled a 2D model of a protoplanetary disk around a T Tauri star with a gas-grain chemical network including COMs. We compare synthesised line intensities and calculated column densities with observations and determine those COMs which may be observable in future. COMs are efficiently formed in the disk midplane via grain-surface chemical reactions, reaching peak grain-surface fractional abundances $\sim 10^{-6}$ – 10^{-4} that of the H nuclei number density. COMs formed on grain surfaces are returned to the gas phase via non-thermal desorption; however, gas-phase species reach lower fractional abundances than their grain-surface equivalents, $\sim 10^{-12}$ – 10^{-7} . Including the irradiation of grain mantle material helps build further complexity in the ice through the replenishment of grain-surface radicals which take part in further grain-surface reactions. There is reasonable agreement with several line transitions of H_2CO observed towards several T Tauri star-disk systems. The synthesised line intensities for CH_3OH are consistent with upper limits determined towards all sources. Our models suggest CH_3OH should be readily observable in nearby protoplanetary disks with ALMA; however, detection of more complex species may prove challenging. Our grain-surface abundances are consistent with those derived from cometary comae observations providing additional evidence for the hypothesis that comets (and other planetesimals) formed via the coagulation of icy grains in the Sun's natal disk.

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ESO-H α 574 and Par-Lup3-4 Jets: Exploring the spectral, kinematical and physical properties

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In this paper a comprehensive analysis of VLT / X-Shooter observations of two jet systems, namely ESO-H α 574 a K8 classical T Tauri star and Par-Lup 3-4 a very low mass ($0.13 M_{\odot}$) M5 star, is presented. Both stars are known to have near-edge on accretion disks. A summary of these first X-shooter observations of jets was given in a 2011 letter. The new results outlined here include flux tables of identified emission lines, information on the morphology, kinematics and physical conditions of both jets and, updated estimates of $\dot{M}_{\text{out}} / \dot{M}_{\text{acc}}$. Asymmetries in the ESO-H α 574 flow are investigated while the Par-Lup 3-4 jet is much more symmetric. The density, temperature, and therefore origin of the gas traced by the Balmer lines are investigated from the Balmer decrements and results suggest an origin in a jet for ESO-H α 574 while for Par-Lup 3-4 the temperature and density are consistent with an accretion flow. \dot{M}_{acc} is estimated from the luminosity of various accretion tracers. For both targets, new luminosity relationships and a re-evaluation of the effect of reddening and grey extinction (due to the edge-on disks) allows for substantial improvements on previous estimates of \dot{M}_{acc} . It is found that $\log(\dot{M}_{\text{acc}}) = -9.15 \pm 0.45 M_{\odot} \text{ yr}^{-1}$ and $-9.30 \pm 0.27 M_{\odot} \text{ yr}^{-1}$ for ESO-H α 574 and Par-Lup 3-4 respectively. Additionally, the physical conditions in the jets (electron density, electron temperature, and ionisation) are probed using various line ratios and compared with previous determinations from

iron lines. The results are combined with the luminosity of the [SII] λ 6731 line to derive \dot{M}_{out} through a calculation of the gas emissivity based on a 5-level atom model.

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Abstracts of recently accepted major reviews

Deuterium Fractionation: the Ariadne's Thread from the Pre-collapse Phase to Meteorites and Comets today

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The Solar System formed about 4.6 billion years ago from a condensation of matter inside a molecular cloud. Trying to reconstruct what happened is the goal of this chapter. For that, we put together our understanding of Galactic objects that will eventually form new suns and planetary systems, with our knowledge on comets, meteorites and small bodies of the Solar System today. Our specific tool is the molecular deuteration, namely the amount of deuterium with respect to hydrogen in molecules. This is the Ariadne's thread that helps us to find the way out from a labyrinth of possible histories of our Solar System. The chapter reviews the observations and theories of the deuterium fractionation in pre-stellar cores, protostars, protoplanetary disks, comets, interplanetary dust particles and meteorites and links them together trying to build up a coherent picture of the history of the Solar System formation. We emphasise the interdisciplinary nature of the chapter, which gathers together researchers from different communities with the common goal of understanding the Solar System history.

Accepted by Protostars and Planets VI

<http://www.mpia-hd.mpg.de/homes/ppvi/chapter/ceccarelli.pdf>

The Formation of Very Massive Stars

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In this chapter I review theoretical models for the formation of very massive stars. After a brief overview of some

relevant observations, I spend the bulk of the chapter describing two possible routes to the formation of very massive stars: formation via gas accretion, and formation via collisions between smaller stars. For direct accretion, I discuss the problems of how interstellar gas may be prevented from fragmenting so that it is available for incorporation into a single very massive star, and I discuss the problems presented for massive star formation by feedback in the form of radiation pressure, photoionization, and stellar winds. For collision, I discuss several mechanisms by which stars might be induced to collide, and I discuss what sorts of environments are required to enable each of these mechanisms to function. I then compare the direct accretion and collision scenarios, and discuss possible observational signatures that could be used to distinguish between them. Finally, I come to the question of whether the process of star formation sets any upper limits on the masses of stars that can form.

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Cosmic Star Formation History

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Over the last decade and a half, an avalanche of new data from multiwavelength imaging and spectroscopic surveys has revolutionized our view of galaxy formation and evolution. Making sense of it all and fitting it together into a coherent picture remains one of astronomy’s great challenges. Here we review the range of complementary techniques and theoretical tools that are allowing astronomers to map the cosmic history of star formation, heavy element production, and reionization of the universe from the cosmic “dark ages” to the present epoch. A consistent picture is emerging from modern galaxy surveys, whereby the star formation rate density peaked about 3.5 Gyr after the Big Bang, at redshift 1.9, and declined exponentially at later times, with an e-folding timescale of 3.9 Gyr. Half of the stellar mass observed today was formed before redshift 1.3. Less than 1% of today’s stars formed during the epoch of reionization, at redshift greater than 6. Under the simple assumption of a universal initial mass function, the global stellar mass density inferred at any epoch matches reasonably well the time integral of all the preceding star formation activity, although a mild disagreement may still point to unresolved issues with the measurements, or to deviations in the stellar initial mass function from conventional assumptions. The assembly histories of the stellar component of galaxies and their central black holes were quite similar, offering evidence for the co-evolution of black holes and their host galaxies. The rise of the mean metallicity of the universe to about 0.001 solar by redshift six, one Gyr after the Big Bang, appears to have been accompanied by the production of fewer than ten hydrogen Lyman-continuum photons per baryon, a rather tight budget for cosmological deionization.

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<http://arxiv.org/pdf/1403.0007>

New Jobs

PhD position in the study of magnetic fields in star formation and evolution (Laboratoire d'Astrophysique de Bordeaux)

A PhD position is available in the Star Formation group at the Laboratoire d'Astrophysique de Bordeaux (LAB, OASU, Bordeaux). This fellowship is funded by the Université de Bordeaux. The starting date of the position is October 1st 2014.

The first part of this thesis is to study the influence of the magnetic field during the stellar evolution using existing observations and new observations which will be proposed to IRAM and ALMA observatories. The PhD student will analyze and interpret the observations in the context of the formation and stellar evolution using existing tools. In addition, he will investigate what are the best molecular tracers to study the magnetic field in these objects with current and future telescopes (e.g., ALMA, IRAM, SKA). What are the possible molecular species and possibly more suited than CN, previously used, to study the magnetic field by Zeeman effect?

In addition, the student, and this is the second part of the thesis, will invest himself in the definition of an innovative instrument for performing at best these spectroscopic and polarimetric studies in the future. Based on this work, our laboratory will develop a usable spectrometer prototype for ground-based observatories but also for space, capable of correlating the four Stokes parameters, with a performance gain of more than one order of magnitude.

The gross (net) yearly salary will be 21080 (17150) euros, all benefits included. Applicants should have a Master degree and a reasonable background in astrophysics as well as interest for instrument development.

Applications, to include a CV, letter of motivation, one letter or reference, along with the course titles and grades for the past two years are to be emailed to Dr. Fabrice Herpin (herpin@obs.u-bordeaux1.fr). Informal inquiries might be directed to Fabrice Herpin (+33 5 57 77 61 57, email: herpin@obs.u-bordeaux1.fr).

The deadline for submission of applications is May 15th 2014. See also the detailed project: <http://www.obs.u-bordeaux1.fr/radi>

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.

Summary of Upcoming Meetings

The Interaction of Stars with the Interstellar Medium of Galaxies

20 - 25 April 2014 Les Houches, France

<http://ism2014.strw.leidenuniv.nl>

Habitable Worlds Across Time and Space

28 April - 1 May 2014 Baltimore, USA

<http://www.stsci.edu/institute/conference/habitable-worlds>

The Formation of the Solar System

13 - 15 May 2014 MPIfR, Bonn, Germany

<https://indico.mpifr-bonn.mpg.de/theFormationOfTheSolarSystem>

The Olympian Symposium on Star Formation

26 - 30 May 2014 Paralia Katerini's, Mount Olympus, Greece

<http://zuserver2.star.ucl.ac.uk/~ossf14/>

EPoS2014 The Early Phase of Star Formation

1 - 6 June 2014 Ringberg Castle, Tegernsee, Germany

<http://www.mpia-hd.mpg.de/homes/stein/EPoS/epos.php>

The Dance of Stars: Dense Stellar Systems from Infant to Old

2 - 6 June 2014 Bad Honnef, Germany

[http://www.astro.uni-bonn.de/\\$sim\\$sambaran/DS2014/index.html](http://www.astro.uni-bonn.de/simsambaran/DS2014/index.html)

The Submillimeter Array: First Decade of Discovery

9 - 10 June, 2014, Cambridge, MA, USA

<http://www.cfa.harvard.edu/sma/events/smaConf/>

The 18th Cambridge Workshop on Cool Stars, Stellar Systems and the Sun

9 - 13 June 2014 Flagstaff, Arizona, USA

<http://www2.lowell.edu/workshops/coolstars18/>

Summer School on Protoplanetary Disks: Theory and Modeling meet Observations

16 - 20 June 2014 Groningen, The Netherlands

<http://www.diana-project.com/summer-school>

Workshop on Dense Cores: Origin, Evolution, and Collapse

27 - 30 July 2014 Monterey, CA, USA

<http://www.aas.org/meetings/aastcs4>

Characterizing Planetary Systems Across the HR Diagram

28 July - 1 August 2014 Inst. for Astronomy, Cambridge, USA

<http://www.ast.cam.ac.uk/meetings/2013/AcrossHR>

Planet Formation and Evolution 2014

8 - 10 September 2014 Kiel, Germany

<http://www.astrophysik.uni-kiel.de/kiel2014>

Living Together: Planets, Stellar Binaries and Stars with Planets

8 - 12 September 2014 Litomysl Castle, Litomysl, Czech Republic

<http://astro.physics.muni.cz/kopal2014/>

Galactic and Extragalactic Star Formation

8 - 12 September 2014 Marseille, France

<http://gesf2014.lam.fr>

Thirty Years of Beta Pic and Debris Disk Studies

8 - 12 September 2013 Paris, France

<http://betapic30.sciencesconf.org>

Towards Other Earths II. The Star-Planet Connection

15 - 19 September 2014 Portugal

<http://www.astro.up.pt/toe2014>

Star Formation Across Space and Time

11-14 November 2014 Noordwijk, The Netherlands

<http://congrexprojects.com/14a09/>

45th “Saas-Fee Advanced Course”:

From Protoplanetary Disks to Planet Formation

15-20 March 2015, Switzerland

no website yet

Other meetings: <http://www1.cadc-ccda.hia-ihp.nrc-cnrc.gc.ca/meetings/>