The Star Formation Newsletter

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

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Cover Picture
The OMC-2 region is located in a molecular filament north of the Orion Nebula Cluster. It is active in star formation, with numerous very young embedded sources, in particular FIR-3, 4, 5, and 6, and a wealth of Herbig-Haro objects and molecular hydrogen flows. The image is about 8 arcmin in north-south extent, and is a color-composite based on J, H, K images obtained at the ESO VLT. The northern edge of the cavity around the HII region M43 can be seen at the bottom of the image.
Image courtesy Holger Drass and ESO.

Submitting your abstracts
Latex macros for submitting abstracts and dissertation abstracts (by e-mail to reipurth@ifa.hawaii.edu) are appended to each Call for Abstracts. You can also submit via the Newsletter web interface at http://www2.ifa.hawaii.edu/star-formation/index.cfm
Q: Who were the early influences on your research and what was your thesis about?

A: As an undergraduate at Berkeley, I worked with Bob Kenney, Charlie Ray, and others on experiments using the particle accelerators at what was then called the Lawrence Radiation Laboratory. They taught me a lot about scientific method, careful experiment design, and the basic physics of CP (charge-parity) violation and the tests of CPT (charge-parity-time) invariance we were doing. While I found the scientific questions fascinating, it became clear that high energy physics experiments involved big teams, in which each person had only a small role (of course, the teams are much bigger now! Someone mentioned that Charles Townes, Nobel Laureate for the laser, was starting an astrophysics group at Berkeley, so I went to see him. He was so welcoming to a random undergraduate who just showed up at his office that I decided to stay at Berkeley for graduate school in Physics and work with Townes. I worked on a variety of projects, first looking for non-Gaussian amplitude statistics in OH masers with Richard Hills, who taught me a lot about data processing. Then came formaldehyde! Ben Zuckerman and others discovered that the transition at 6 cm was absorbing the CMB, which required that the excitation temperature of that transition had to be cooled below the temperature of the CMB. That transition is between levels of a K-doublet, split by the slight asymmetry of the molecule, so the energy difference is much smaller than that of the pure rotational transitions, the lowest being around 2 mm. A pumping mechanism involving these rotational transitions had to be found. Pat Thaddeus suggested that the pump was radiative, and caused by departures of the CMB from a blackbody around 2 mm. This was long before COBE, and there was much speculation about whether the CMB was a blackbody. Working with my office-mate, Al Cheung, Townes had showed in a classical calculation that collisions of hydrogen with formaldehyde could also cool the K-doublet levels. Since the relevant quantum numbers were 1 or 2, a classical calculation could not be justified, so I undertook a quantum calculation. I actually spent more time on this that on anything else, but it wound up as an appendix in my thesis. Simple approximations (Born, Sudden) gave a result opposite to that of the classical calculation. After graduating to the then fastest computer at the Lawrence Radiation Laboratory, and adding enough virtual transitions, I finally recovered the classical result that collisions could cool and deviations in the CMB were not required. But could we rule them out? The two models made opposite predictions about the next higher K-doublet transition at 2 cm: emission for the CMB pumping; absorption for the collisional pumping. About that time, Ben Zuckerman arrived on a sabbatical from Maryland, and Townes arranged a collaboration for us to use a new 2-cm maser receiver on the Goldstone Tracking Station 64-m dish near Barstow, California. We would get a few hours here and there between tracking spacecraft, and Ben and I would fly to Los Angeles and drive a cheap rental car out into the desert. Eventually, we saw absorption against the CMB in dark clouds, clearly ruling out the CMB explanation for the cooling of the K doublets. Two papers on these observations and models of the excitation formed the bulk of my thesis.

So Charles Townes taught me molecular physics, how to treat students with kindness, and how to test theories. Ben Zuckerman taught me a lot about astronomy and suggested that these molecules could be good for something besides testing basic physics: maybe they could tell us something about star formation. In that sense, Ben triggered my interest in astronomy.

Q: In the 70’s and 80’s you were interested in infrared sources in molecular clouds and the energetics of the clouds. What were the tools available to you, and what was the state of knowledge then?

A: Early studies of dark clouds and regions near HII regions showed peaks of CO emission, indicating elevated kinetic temperatures. Peter Goldreich and John Kwan suggested that the gas was heated by collisions with dust grains that in turn were heated by radiation from forming stars. Steve Beckwith at Caltech and I tested this idea by mapping the gas temperature and density with molecular line maps and the dust temperature with far-infrared observations on the KAO. Beckwith and I used his newly built infrared photometer (a single-pixel camera in modern lingo) to search for mid-infrared sources that might be the heat sources. One of us manually scanned the Mt. Wilson 60-inch telescope while the other sat in the control room, watching a strip chart for any sign of a deflection. The night we discovered the infrared sources in Mon R2
was among the most exciting of my career. The strip chart pinned and I shouted into the intercom to stop, turn down the gain, and scan backwards. By the end of the night, we had discovered the three strongest mid-infrared sources in that cloud. After further studies, working with Paul Van den Bout and others at Texas, we confirmed the basic idea of Goldreich and Kwan. As detector arrays became available in the near-infrared, we began to map bigger regions, cataloging what came to be called YSOs. My former student Elizabeth Lada led this work in the late 80’s to early 90’s. Her work was the first to indicate that YSOs were highly concentrated to regions of dense gas.

Q: In 1999 you published a large review in ARAA on physical conditions in star forming regions. What are the major developments since then?

A: Way too many to list. We would have to include among the most important all of the following: surveys for YSOs with Spitzer; large scale mapping of continuum in the far-infrared and submillimeter with Herschel and ground-based telescopes; cataloging of the rich array of ices on dust grains; and most recently, the detailed molecular line and continuum studies with ALMA. We now have a much more detailed picture of the conditions, including dynamical and chemical complexity. Clearly, molecules freeze on dust grains, react to build more complex species, and evaporate when they are heated by protostars. There is strong circumstantial, and some direct, evidence that accretion onto the forming star is episodic, producing luminosity variations with consequences for chemistry in the envelope and the starting point of disk evolution once infall has ceased. So, in general, we know that the story is much richer and more complex than we thought. Theory has not quite kept up with observations, but a new generation of theorists is taking up the challenge.

Q: You and the Spitzer team published a large paper on star-formation rates and efficiencies, and the evolution and lifetimes of young stars. What were the key results?

A: The results from the Spitzer surveys of nearby clouds (c2d and Gould Belt) firm up age estimates, indicate a picture of episodic accretion, and strongly indicate that star formation is very concentrated to regions of high extinction. The census of YSOs in the nearby clouds is fairly complete with subsequent studies such as Mike Dunham’s paper including all c2d and Gould Belt data. If the half-life of disks around stars is 2 Myr, the half-life of infalling envelopes is about 0.5 Myr; the ratio is fixed by the census, so you can compute your own number if you prefer a larger lifetime for disks. The large number of sources with quite low luminosities compelled us to say that stars form when we are not looking. That is, much of the accretion from disk to star must happen when we are not observing the sources. Since we lack time series surveys in the deep infrared, it is easy to miss the periods of high accretion, hence luminosity. Models by Dunham and collaborators confirm that episodic accretion can explain the distribution of luminosities that we found. The relatively complete coverage of the clouds with Spitzer firm up what most people already thought: star formation is highly concentrated to regions of high extinction ($A_V > 7$ or 8 mag). Amanda Heiderman and I quantified this result, and Charlie Lada and co-workers independently found the same result. The fact that the vast majority of the gas in the clouds is not forming stars provides a possible explanation of the most enduring puzzle in star formation: why is it so slow and inefficient?

Q: When you say that star formation is slow and inefficient, what exactly do you mean?

A: This issue goes back to a paper than Ben Zuckerman and I wrote in 1974, part of how he got me interested in astronomical questions. Goldreich and Kwan’s paper had not only laid out the correct idea for how gas is heated in star forming regions, but it had also suggested that the newly discovered molecular clouds were collapsing and thus forming stars rapidly. The discovery of vast molecular clouds was seen by many as the answer to the puzzle of where new stars came from. Furthermore, the linewidths of molecular lines were very superthermal, so Goldreich and Kwan suggested that these linewidths were caused by cloud collapse. Ben was not buying it. He and Pat Palmer had used early surveys of CO to estimate the total mass of molecular gas in the Milky Way, combined this with an estimated free-fall time, and derived a star formation rate about 100 times higher than the average over the last Gyr or so. Ben convinced me to join him on a paper that used some of the 6-cm formaldehyde data toward HII regions to look for redshifted absorption, which would be predicted by the collapse model. The data showed no evidence for collapse. Ben and I suggested that the superthermal linewidths were instead caused by turbulence, and I added the suggestion that the linewidths were consistent with Alfvén speeds if the interstellar magnetic field scaled up with density, so the turbulence was likely to be magnetic. This short paper is still frequently cited, mostly for the idea that clouds are turbulent and for our repetition of the Zuckerman-Palmer argument, but not for my little suggestion about magnetic turbulence.

The Zuckerman-Palmer analysis should have finished off the idea that the free-fall time is relevant to the star formation rate, but theorists cannot let go of this seemingly natural timescale, even if they have to introduce a fudge factor of 100. That is the sense in which star formation is slow. It is also inefficient, in the sense that masses of clusters are generally much less than masses of clouds. The most massive clusters may be exceptions, where large scale collapse does happen. In most cases, however, the cloud must be dispersed after only a few percent of the mass
has formed stars. This efficiency factor of a few percent is about the same for clouds that are not forming any massive stars as well as for clouds forming massive stars that produce lots of feedback. That’s something that partisans of feedback as the explanation for inefficiency have not been able to explain.

Q: You have been interested in global star formation relations and have tested theoretical ideas against data on nearby star forming regions. What are the main results and remaining issues?

A: Inspired by a question from Sandy Faber, I have devoted some fraction of my time over the last 15 years to finding common ground for those studying star formation in our Galaxy and those studying star formation in other galaxies or in the context of galaxy evolution. When I visited Rob Kennicutt in Cambridge to work on the 2012 ARAA article on this topic, we spent many hours just understanding the context and language employed by the two groups. I see encouraging signs that the extragalactic star formation community is starting to look beneath the star formation relations, like the Kennicutt-Schmidt relation, for more fundamental understanding. Similarly, molecular cloud formation and evolution is probably best studied in other galaxies, where line-of-sight confusion is less, so we have much to learn from each other. As I mentioned in my last answer, the nearby clouds clearly indicate that the most reliable predictor of the star formation rate is not the molecular cloud mass, or the mass divided by the free-fall time, but simply the mass of dense gas (gas at AV > 7 mag for the nearby clouds). We have recently extended this result to regions forming massive stars in the Milky Way, and my former student, Jingwen Wu, connected it to extragalactic work using the luminosity of HCN. Our recent paper (Vutisalchavakul et al.) shows that the scatter in the log of the star formation rate per unit mass, ranging from nearby clouds to whole starburst galaxies, is decreased by a factor of three when the mass of dense gas is used rather than the mass of molecular gas.

I suggested in my 1999 review that most molecular gas is sterile, being dispersed before it ever forms stars. That seems to be borne out by these studies. Since low mass clouds probably do not produce enough feedback to disperse the cloud, we should re-examine the idea that molecular clouds are bound entities, which goes back to the days when they were discovered. If the clouds are just the molecular part of the unbound neutral flows, the star forming entities are the dense, bound clumps within them, containing a few percent of the mass. This idea, argued recently by Claire Dobbs and Jim Pringle, solves the efficiency problem. Even within the dense clumps, however, star formation is still slow compared to the free-fall estimates. The only place we see free-fall in the strict sense is in the inner regions of individual cores forming protostars.

Q: You have led a couple of large projects on Spitzer and Herschel. Since you left high-energy physics in part to avoid large teams, how did these large projects come about?

A: Right, that does sound a bit contradictory. I did enjoy many years of working in small groups, mostly with my wonderful students. Then in about 1999, I heard Mike Werner talk at the AAS meeting in Austin about Legacy programs on Spitzer (SIRTF at that time). It occurred to me that there should be one on star/planet formation, so I started emailing colleagues to see what they were planning. Eventually, I wound up leading the c2d project, only because I started the conversation. That was an incredible experience, working with people all over the world to fashion a coherent project with opportunities for young people to lead papers in various areas. It meant taking a step back from the front-line science and spending most of my time on coordinating, managing funding, presenting the program and results, etc. In the course of that project, my scientific collaboration with Ewine van Dishoeck deepened, and she suggested the Herschel Key project, which became DIGIT. I have enjoyed the very international flavor of these projects, and I encourage such collaborations whenever I can. One of the most beautiful things about science is the absence of national borders to our enquiries about the Universe.

Q: Most recently, you and your collaborators have used ALMA to measure infall in the B335 Bok globule, which you have studied over many years. Are models and observations converging?

A: This work picks up from work in the 90’s and 00’s on infall of molecular cores. We realized then that ALMA would be able to see red-shifted absorption against the continuum emission from the disk and inner envelope. Working with my colleagues from the old days, we obtained data on the quintessential region of simple infall, B335, that showed the predicted absorption. The data were consistent with models of simple inside-out collapse. Further studies of this sort will allow us to test the infall as a function of radius, learn how the situation changes with mass of the core, and further refine the models. All this will require more complete 3-D models with rotation and outflows, and these are now possible with the new generation of radiative transport codes.

Q: What are your plans?

A: I am retiring on Sept. 1, which means I will give up my night job of preparing classes. I plan to continue to be active in research as an Emeritus faculty member, to work with graduate students, and to serve on boards and review committees. I will use my new freedom to visit other institutes. I am spending October at the Korean Astronomy and Space Science Institute and part of November at the Kavli Institute in Beijing.
1 Jets from young stars

Jets are powerful signatures of astrophysical activity and are observed over a wide range of luminosity and spatial scale. Among a wide variety of jet sources - including relativistic sources such as active galactic nuclei, micro-quasars, and probably pulsars and gamma-ray bursts - young stellar objects (YSO) are of particular interest, as many properties of them that are important for dynamical modeling are known from observations in contrast to the relativistic sources.

In particular, observations have indicated that the outflow mass fluxes are proportional to the disk accretion rate, suggesting a direct physical link between accretion and ejection (Cabrit et al. 1990, Hartigan et al. 1995, Edwards et al. 2006). Observational data also show signatures of the magnetic field in the regions where jets are formed (Ray et al. 1997, Carrasco-González et al. 2010), as well as a considerable magnetization of the jet-launching source (see e.g. Bouvier 1990, Edwards et al. 1994).

In summary, observational data have confirmed several features that are essential for the modeling and our understanding of how jets are formed. These are

- (1) the existence of an accretion disk in jet sources, and estimates of the accretion rates
- (2) the existence of a strong magnetic field in jets and jet sources,
- (3) jet knots that are believed to be shocked gas,

from which essential dynamical parameters such as jet velocity and density can be derived.


2 Jet launching

In this article, we distinguish between "jet launching", that is the actual transition from accretion to ejection, and "jet formation" that denotes the processes of acceleration and collimation of a disk wind into a narrow jet beam.

Jet formation is usually understood as due to the magneto-centrifugal mechanism discovered by Blandford & Payne (1982) and Pudritz & Norman (1983). Outflows of lower velocity are understood as so-called tower jets accelerated by the magnetic pressure gradient of the toroidal field (Lynden-Bell 1996). The latter is an important process in particular in star formation / collapse simulations.

Jet launching is more difficult to treat numerically as the jet physical times scales are shorter than the disk physical time scales. For example, accretion disks are viscous and magnetically diffusive, while jets and outflows can be treated in ideal MHD. Also, disk turbulence is thought to be generated by the magneto-rotational instability (MRI; Balbus & Hawley 1991), thus generating a relatively strong tangled field component, while fast jets rely on the existence of a large-scale field component.

Understanding jet launching - the processes involved in the transition between accretion and ejection - is motivated by two topical questions:

1 We like to understand how jets originate: jets seem to live much shorter than accretion disks - what kind of disks form jets and which ones do not?

2 We wish to quantify the star formation feedback from jets and outflows: How much mass, energy, or angular momentum is re-cycled to the interstellar medium?

3 Earlier approaches

In order to understand what kind of disks launch jets and what kind of disks do not, it is essential to include the disk evolution in the treatment. The first works on this subject followed an analytical approach (e.g. Pudritz &
Today, numerical simulations of the accretion-ejection process play an essential role for the understanding of jet launching. However, note that it was as early as 1985 when the first jet launching simulations were published (Uchida & Shibata 1985, Shibata & Uchida 1986). The accretion process in magnetized disks has been studied by numerical simulations in detail first by Stone & Norman (1994).

The first jet launching simulations from a resistive MHD disk were presented by Casse & Keppens (2002, 2004), Kuwabara et al. (2005) and Zanni et al. (2007), extending the earlier studies to considerably longer time scales and also to larger spatial scales, enabling them to derive the corresponding mass fluxes in the disk and jet.

4 Basic physical processes

Many details of the launching process are not yet fully understood. However, both theoretical predictions of analytical models (Li 1995; Ferreira 1997) and numerical simulations (Casse & Keppens 2002, 2004; Kuwabara et al. 2005, Zanni et al. 2007) agree on the main launching mechanisms involved.

The main idea is visualized in Figure 1 (from Ferreira 1997). Gas is accreted along the disk towards smaller radii, denoted by streamlines (dashed lines). A large-scale magnetic field (solid lines) penetrates the disk. The magnetic flux distribution along the disk is affected by advection and diffusion of the magnetic field through the disk material.

Accretion of disk material across the field is possible as the disk plasma is magnetically diffusive. In other words, the magnetic diffusivity allows the material to move between magnetic flux surfaces as it is not anymore "frozen" to a certain field line. Thus the mass loading along a magnetic field line may change. The magnetic diffusivity $\eta$ is believed to be of turbulent origin (thus much larger than the microphysical value), and basically generated by the magneto-rotational instability.

The very launching process, i.e. the lifting of disk plasma to higher altitudes of the disk is a purely magnetic process (Ferreira 1997, Ferreira et al. 2006). The Lorentz force $F_L \propto \mathbf{j} \times \mathbf{B}$ plays a leading role. If the vertical Lorentz force is decreasing vertically, the gas pressure gradient may lift the material to higher altitudes. The toroidal Lorentz force may accelerate the plasma in azimuthal direction, thus leading to a centrifugal acceleration in radial direction. The efficiency of these processes depend in detail on the distribution of the electric current (thus the toroidal magnetic field) in the disk. Figure 1 also shows how the streamline crosses the magnetic field lines, and also couples to different field lines in the disk and in the outflow.

Modeling the launching process means looking for certain magnetic field configurations (either analytically or by numerical simulations) that provide Lorentz forces in the "right way".

Once lifted above the surface of the disk and accelerated to supersonic speed, the further acceleration is by the magneto-centrifugal effect (Blandford & Payne 1982; Pudritz & Norman 1983) in case of strong poloidal magnetic fields, or by the vertical pressure gradient (tower jets; Lynden-Bell 1996) for lower fields.

The collimation of the disk wind into a narrow beam is accomplished by the pinching forces of the toroidal magnetic field $B_\phi$ - maybe also with support of the ambient gas pressure. Simulations of the acceleration and collimation processes of jets forming from the disk surface have been performed in great detail by a number of authors (see e.g. Ustyugova et al. 1995; Ouyed & Pudritz 1997; Romanova et al. 1997; Krasnopolsky et al. 1999; Fendt & Cemeljic 2002)

Note that while the magnetic field is the essential driver for the jet, its role is merely to convert potential energy from the in-falling material into kinetic energy of the outflow.

5 Simulations of jet launching

Here we will present example results of recent jet launching simulations, in particular a survey investigating the interrelation between typical jet parameters and the disk magnetization (Stepanovs & Fendt 2016), simulations considering a mean-field accretion disk dynamo to produce the jet launching magnetic field (Stepanovs & Fendt 2014),
and 3D simulations of jet launching investigating the dynamics of disks and jets in a non-axisymmetric gravitational potential (Sheikhnezami & Fendt 2015).

5.1 Jet launching and disk magnetization

We first come back to the question what kind of disks do launch which kind of jets. We recently applied a novel approach to the jet-launching problem with the aim of obtaining correlations between the physical properties of the jet and the underlying disk. In particular, we have numerically investigated a wide parameter range of disk magnetization \( \mu_D(r_0) = 10^{-3.5} \ldots 10^{-0.7} \) at the outflow launching point \( r_0 \). The magnetization \( \mu \) measures the relative strength of the magnetic pressure (or forces) to the gas pressure (or force). This study is complementary to the works of Tzeferacos et al. (2009) and Murphy et al. (2010) who investigated the jet launching along the disk surface with decreasing \( \mu_D(r) \).

Essentially, we disentangle the disk magnetization at the foot point of the outflow as the main parameter that governs the properties of the outflow. Strongly magnetized disks launch more energetic and faster jets and, due to a larger Alfvén lever arm, these jets extract more angular momentum from the underlying disk. These kinds of disk/jet systems have, however, a smaller mass loading parameter and a lower mass ejection/accretion ratio. Jets are launched at the disk surface where the magnetization is \( \mu(r, z) \approx 0.1 \). The magnetization rapidly increases vertically providing the energy reservoir for subsequent jet acceleration.

As an example, Figure 2 shows the tight correlations between the total jet energy \( e \) and the mass loading \( k \) with the disk magnetization \( \mu_D \), respectively. The mass loading parameter \( k \) measures the amount of the matter that is ejected per unit magnetic flux. Each differently colored line corresponds to a simulation with a different initial disk magnetization.

We also find indication of a critical disk magnetization \( \mu_D \approx 0.01 \) that separates the regimes of magneto-centrifugally driven and magnetic pressure-driven jets (indicated by the change in slope in Figure 2). The existence of these two regimes has been discussed by Ferreira (1997) considering the outflow ejection efficiency index. Low ejection efficiencies should lead to powerful centrifugally driven jets, high efficiencies to magnetic pressure-driven jets. Here, we find a similar dichotomy, now in the framework of the disk magnetization.

This agrees with the usual findings of the steady-state theory (e.g. Ferreira 1997, Casse & Ferreira 2000), however, we obtain these correlations from time-dependent simulations that include the dynamical evolution of the disk in the treatment.

![Figure 2: Jet physical properties with respect to the disk magnetization \( \mu_{\text{disk}} \). As examples the jet energy \( e \), and the mass loading parameter \( k \) is shown. Each (colored) line represents the evolution of a single simulation from 700 to 10,000 time units. Taken from Stepanovs & Fendt (2016).](image)

5.2 Launching by a disk-dynamo generated magnetic field

Most simulations of jet launching have been set up assuming a large-scale initial magnetic flux that is able to drive the jet. Exceptions are Bardou et al. (2001), von Rekowski at al. (2003), and von Rekowski & Brandenburg (2004) who were considering disk dynamos and stellar dynamos that generate the jet driving magnetic field (see also Dyda et al. 2015).

More recently, we have presented MHD simulations ex-
ploring the launching, acceleration, and collimation of jets and disk winds considering the generation of the magnetic field by an $\alpha - \Omega$ mean-field disk dynamo. The simulations may last for more than 10,000 orbital periods, and depending on the magnetic diffusivity model, may run "forever" until the disk is depleted of mass. Also, a large physical grid size could be used with $r_{\text{max}} \approx 1500$ inner disk radii, thus in the range of 150 AU. We found the dynamo-generated magnetic field of the inner disk is similar to the commonly found open field structure, favoring magneto-centrifugal launching. The outer disk field is highly inclined and predominantly radial. Here, differential rotation induces a strong toroidal component, which plays a key role in outflow launching. These outflows from the outer disk are slower, denser, and less collimated.

We have further invented a toy model triggering a time-dependent mean-field dynamo. The duty cycles of this dynamo lead to episodic ejections on similar timescales. When the dynamo is suppressed as the magnetization falls below a critical value, the generation of the outflows and also accretion is inhibited. The general result is that we can steer episodic ejection and large-scale jet knots by a disk-intrinsic dynamo that is time-dependent and regenerates the jet-launching magnetic field. The next logical step would be to develop a self-consistent dynamo quenching mechanism that could lead to time-dependent disk accretion and subsequent jet ejection.

Figure 3 shows snapshots of our simulation applying a time-dependent dynamo model. We see the density and velocity structure (in colors) overlaid with magnetic field lines. Dynamo-active times follow dynamo-inactive times with periods of about 100 disk rotations. During dynamo-active time periods new jet ejections happen close to the inner disk. In the figure two ejection periods are visible in the jet flow (more in velocity than in density), the latest one having reached $z = 200 R_{\text{in}}$, the earlier one currently at $z = 1200 R_{\text{in}}$.

5.3 3D-launching simulations

Extending the launching setup to 3D, we have recently presented the first ever 3D simulations of the MHD accretion-ejection structure (Sheikhnezami & Fendt 2015). Both, the 3D evolution of jets launched symmetrically from single stars, but also jets from warped disks in binary systems were investigated.

Simulations with a single star (thus an axisymmetric gravitational potential) served as a test problem for the new numerical setup. These simulations maintain a good axial symmetry and also a bipolar symmetry for more than 500 rotations of the inner disk, as obtained earlier by axisymmetric simulations (Fendt & Sheikhnezami 2013).

We have then implemented a 3D gravitational potential (Roche potential) due to a companion star and run a variety of simulations with different binary separations and mass ratios. These simulations show typical 3D deviations from axial symmetry, such as jet bending outside the Roche lobe or spiral arms forming in the accretion disk. In order to find indication for precession on the time scales that we can treat numerically, we have run a simulation with a particularly small binary separation of only $\approx 200$
inner disk radii. This simulation shows indeed a signature for the onset of jet precession - caused by the wobbling of the jet-launching disk.

Figure 4: 3D jet launching from jet sources in binary systems. Shown is a 3D cut through the density structure (colors) of the accretion-ejection system, superimposed by helical magnetic field lines (lines). Taken from Sheikhnezami & Fendt (2015).

6 Future developments

So far we have discussed global models of jet launching in which the "microphysics" of the disk is approximated by averaged quantities such as (mean) magnetic flux, plasma density, flow energy or angular momentum, and, in particular, mean turbulent diffusivity or a mean-field turbulent dynamo. This seems feasible and has so far provided promising results that are in nice agreement with analytical theory.

However, certain physical aspects that may play role in reality have not yet been addressed in detail in global numerical launching models. Some are, however, currently investigated in (local and global) accretion disk simulations and will impact the future development of disk-jet launching modeling. Examples are the following.

1 A variation of the jet launching disk structure due to heating and cooling. This has been discussed in analytical models of e.g. Casse & Ferreira 2000, and has been investigated in disk simulations - globally and in a local approach (e.g. Flock et al. 2013, Tzeferacos et al. 2013, Bai et al. 2016).


3 Similarly for a mean-field turbulent dynamo - the dynamo-α most probably originates from the same turbulence as the diffusivity η. Direct dynamo simulations are not yet possible on a global (large-scale) grid.

4 A consistent connection between the local, small-scale magneto-rotational instability producing a tangled magnetic field, and the global, large-scale field that we need to drive a jet (see e.g. Lesur et al. 2013).

5 The impact of further non-ideal MHD effects for the disk dynamics, such as ambipolar diffusion or Hall MHD. Disk simulations of that kind have found magneto-centrifugal driving and disk winds, although mostly in a local box approach (e.g. Königl et al. 2010, Bai & Stone 2013, Bai 2013, Fromang et al. 2013, Bai 2014, Gressel et al. 2015, Béthune et al. 2016).

6 All simulations discussed so far in this review consider jet launching from accretion disks and by a disk magnetic field. However, the magnetic field of the central star will definitely influence the disk launching close to the inner disk radius. Simulations considering the central star have been performed concerning the star disk interaction and accretion columns (e.g. Hayashi et al. 1996; Miller & Stone 1997; Romanova et al. 2002, 2004; Zanni & Ferreira 2009, 2013) or the global interaction of disk and stellar field concerning jet formation from the disk surface (Meliani et al. 2006; Fendt 2009). Global launching simulations considering the disk structure have been pioneered by Goodson et al. (1997) and Matt et al. (2002), but were somewhat limited by time and spatial resolution.

7 Similar to the stellar magnetic field, outflows from massive young stars will be affected by radiation pressure. Vaidya et al. (2011) have numerically investigated this effect in the limit of line forces. Considering the above long list of points 1)-7), we may expect a variety of new physical effects - new answers and new questions - that affect the launching of jets from young stars (but also from other jet sources).

While the main launching mechanism seems to be well understood from global launching simulations, a yet further, full understanding of jet launching will require a more
complete understanding of the internal disk evolution that will require a high resolution and will be computed in a localized disk area.

Besides the theoretical-numerical investigations of the jet launching mechanism (on which this review concentrated), crucial input can be expected from high resolution observations of the launching region by ALMA.

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A GMRT survey of regions towards the Taurus Molecular Cloud at 323 and 608 MHz

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We present observations of three active sites of star formation in the Taurus Molecular Cloud complex taken at 323 and 608 MHz (90 and 50 cm, respectively) with the Giant Metrewave Radio Telescope (GMRT). Three pointings were observed as part of a pathfinder project, targeted at the young stellar objects (YSOs) L1551 IRS 5, T Tau and DG Tau (the results for these target sources were presented in a previous paper). In this paper, we search for other YSOs and present a survey comprising of all three fields; a by-product of the large instantaneous field of view of the GMRT.

The resolution of the survey is of order 10 arcsec and the best rms noise at the centre of each pointing is of order 100\(\mu\)Jy beam\(^-1\) at 323 MHz and 50\(\mu\)Jy beam\(^-1\) at 608 MHz. We present a catalogue of 1815 and 687 field sources detected above 5\(\sigma_{\text{rms}}\) at 323 and 608 MHz, respectively. A total of 440 sources were detected at both frequencies, corresponding to a total unique source count of 2062 sources. We compare the results with previous surveys and showcase a sample of extended extragalactic objects. Although no further YSOs were detected in addition to the target YSOs based on our source finding criteria, these data can be useful for targeted manual searches, studies of radio galaxies or to assist in the calibration of future observations with the Low Frequency Array (LOFAR) towards these regions.

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A GMRT survey of regions towards the Taurus Molecular Cloud at 323 and 608 MHz

Spiral Structure and Differential Dust Size Distribution in the LkH\(\alpha\) 330 Disk

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Dust trapping accelerates the coagulation of dust particles, and thus it represents an initial step toward the formation of planetesimals. We report $H$-band (1.6 $\mu$m) linear polarimetric observations and 0.87 mm interferometric continuum observations toward a transitional disk around LkH$\alpha$ 330. As results, a pair of spiral arms were detected in the $H$-band emission and an asymmetric (potentially arm-like) structure was detected in the 0.87 mm continuum emission. We discuss the origin of the spiral arm and the asymmetric structure, and suggest that a massive unseen planet is the most plausible explanation. The possibility of dust trapping and grain growth causing the asymmetric structure was also investigated through the opacity index ($\beta$) by plotting the observed SED slope between 0.87 mm from our SMA observation and 1.3 mm from literature. The results imply that grains are indistinguishable from ISM-like dust in the east side ($\beta = 2.0 \pm 0.5$), but much smaller in the west side $\beta = 0.7^{+0.5}_{-0.4}$, indicating differential dust size distribution between the two sides of the disk. Combining the results of near-infrared and submillimeter observations, we conjecture that the spiral arms exist at the upper surface and an asymmetric structure resides in the disk interior. Future observations at centimeter wavelengths and differential polarization imaging in other bands (Y to K) with extreme AO imagers are required to understand how large dust grains form and to further explore the dust distribution in the disk.

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Why do some cores remain starless?
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Physical conditions that could render a core starless (in the local Universe) is the subject of investigation in this work. To this end we studied the evolution of four starless cores, B68, L694-2, L1517B, L1689, and L1521F, a VeLLO. The density profile of a typical core extracted from an earlier simulation developed to study core-formation in a molecular cloud was used for the purpose. We demonstrate - (i) cores contracted in quasistatic manner over a timescale on the order of \( \sim 10^5 \) years. Those that remained starless did briefly acquire a centrally concentrated density configuration that mimicked the density profile of a unstable Bonnor Ebert sphere before rebounding, (ii) three of our test cores viz. L694-2, L1689-SMM16 and L1521F remained starless despite becoming thermally super-critical. On the contrary B68 and L1517B remained sub-critical; L1521F collapsed to become a VeLLO only when gas-cooling was enhanced by increasing the size of dust-grains. This result is robust, for other cores viz. B68, L694-2, L1517B and L1689 that previously remained starless could also be similarly induced to collapse. Our principle conclusions are : (a) acquiring the thermally super-critical state does not ensure that a core will necessarily become protostellar, (b) potentially star-forming cores (VeLLO L1521F here), could be experiencing coagulation of dust-grains that must enhance the gas-dust coupling and in turn lower the gas temperature, thereby assisting collapse. This hypothesis appears to have some observational support, and (c) depending on its dynamic state at any given epoch, a core could appear to be pressure-confined, gravitationally/virially bound, suggesting that gravitational/virial boundedness of a core is insufficient to ensure it will form stars, though it is crucial for gas in a contracting core to cool efficiently so it can collapse further to become protostellar.

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Dipper disks not inclined towards edge-on orbits
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The so-called “dipper” stars host circumstellar disks and have optical and infrared light curves that exhibit quasi-periodic or aperiodic dimming events consistent with extinction by transiting dusty structures orbiting in the inner disk. Most of the proposed mechanisms explaining the dips—i.e., occulting disk warps, vortices, and forming planetesimals—assume nearly edge-on viewing geometries. However, our analysis of the three known dippers with publicly available resolved sub-mm data reveals disks with a range of inclinations, most notably the face-on transition disk J1604-2130 (EPIC 204638512). This suggests that nearly edge-on viewing geometries are not a defining characteristic of the dippers and that additional models should be explored. If confirmed by further observations of more dippers, this would point to inner disk processes that regularly produce dusty structures far above the outer disk midplane in regions relevant to planet formation.

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Analytic Models of Brown Dwarfs and The Substellar Mass Limit
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We present the current status of the analytic theory of brown dwarf evolution and the lower mass limit of the hydrogen burning main sequence stars. In the spirit of a simplified analytic theory we also introduce some modifications to
the existing models. We give an exact expression for the pressure of an ideal non-relativistic Fermi gas at a finite temperature, therefore allowing for non-zero values of the degeneracy parameter \( \psi = \frac{kT}{\mu_F} \), where \( \mu_F \) is the Fermi energy. We review the derivation of surface luminosity using an entropy matching condition and the first-order phase transition between the molecular hydrogen in the outer envelope and the partially-ionized hydrogen in the inner region. We also discuss the results of modern simulations of the plasma phase transition, which illustrate the uncertainties in determining its critical temperature. Based on the existing models and with some simple modification we find the maximum mass for a brown dwarf to be in the range \( 0.064M_\odot - 0.087M_\odot \). An analytic formula for the luminosity evolution allows us to estimate the time period of the non-steady state (i.e., non-main sequence) nuclear burning for substellar objects. Standard models also predict that stars that are just above the substellar mass limit can reach an extremely low luminosity main sequence after at least a few million years of evolution, and sometimes much longer. We estimate that \( \approx 11\% \) of stars take longer than \( 10^7 \) yr to reach the main-sequence, and \( \approx 5\% \) of stars take longer than \( 10^8 \) yr.

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Self-Destructing Spiral Waves: Global Simulations of a Spiral Wave Instability in Accretion Disks

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We present results from a suite of three-dimensional global hydrodynamic simulations which show that spiral density waves propagating in circumstellar disks are unstable to the growth of a parametric instability that leads to breakdown of the flow into turbulence. This spiral wave instability (SWI) arises from a resonant interaction between pairs of inertial waves, or inertial-gravity waves, and the background spiral wave. The development of the instability in the linear regime involves the growth of a broad spectrum of inertial modes, with growth rates on the order of the orbital time, and results in a nonlinear saturated state in which turbulent velocity perturbations are of a similar magnitude to those induced by the spiral wave. The turbulence induces angular momentum transport, and vertical mixing, at a rate that depends locally on the amplitude of the spiral wave (we obtain a stress parameter \( \alpha \sim 5 \times 10^{-4} \) in our reference model). The instability is found to operate in a wide-range of disk models, including those with isothermal or adiabatic equations of state, and in viscous disks where the dimensionless kinematic viscosity \( \nu \leq 10^{-5} \). This robustness suggests that the instability will have applications to a broad range of astrophysical disk-related phenomena, including those in close binary systems, planets embedded in protoplanetary disks (including Jupiter in our own Solar System) and FU Orionis outburst models. Further work is required to determine the nature of the instability, and to evaluate its observational consequences, in physically more complete disk models than we have considered in this paper.

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Binary system and jet precession and expansion in G35.20–0.74N

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Context. Atacama Large Millimeter/submillimeter Array (ALMA) observations of the high-mass star-forming region G35.20−0.74N have revealed the presence of a Keplerian disk in core B rotating about a massive object of 18 $M_\odot$, as computed from the velocity field. The luminosity of such a massive star would be comparable to (or higher than) the luminosity of the whole star-forming region. To solve this problem it has been proposed that core B could harbor a binary system. This could also explain the possible precession of the radio jet associated with this core, which has been suggested by its S-shaped morphology.

Aims. We establish the origin of the free-free emission from core B and investigate the existence of a binary system at the center of this massive core and the possible precession of the radio jet.

Methods. We carried out VLA continuum observations of G35.20−0.74N at 2 cm in the B configuration and at 1.3 cm and 7 mm in the A and B configurations. The bandwidth at 7 mm covers the CH$_3$OH maser line at 44.069 GHz. Continuum images at 6 and 3.6 cm in the A configuration were obtained from the VLA archive. We also carried out VERA observations of the H$_2$O maser line at 22.235 GHz.

Results. The observations have revealed the presence of a binary system of UC/HC H II regions at the geometrical center of the radio jet in G35.20−0.74N. This binary system, which is associated with a Keplerian rotating disk, consists of two B-type stars of 11 and 6 $M_\odot$. The S-shaped morphology of the radio jet has been successfully explained as being due to precession produced by the binary system. The analysis of the precession of the radio jet has allowed us to better interpret the IR emission in the region, which would be not tracing a wide-angle cavity open by a single outflow with a position angle of ∼55°, but two different flows: a precessing one in the NE−SW direction associated with the radio jet, and a second one in an almost E−W direction. Comparison of the radio jet images obtained at different epochs suggests that the jet is expanding at a maximum speed on the plane of the sky of 300 km s$^{-1}$. The proper motions of the H$_2$O maser spots measured in the region also indicate expansion in a direction similar to that of the radio jet.

Conclusions. We have revealed a binary system of high-mass young stellar objects embedded in the rotating disk in G35.20−0.74N. The presence of a massive binary system is in agreement with the theoretical predictions of high-mass star formation, according to which the gravitational instabilities during the collapse would produce the fragmentation of the disk and the formation of such a system. For the first time, we have detected a high-mass young star associated with an UC/HC H II region and at the same time powering a radio jet.

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Kinetics and mechanisms of the acid-base reaction between NH$_3$ and HCOOH in interstellar ice analogs

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Interstellar complex organic molecules (COMs) are commonly observed during star formation, and are proposed to form through radical chemistry in icy grain mantles. Reactions between ions and neutral molecules in ices may provide an alternative cold channel to complexity, as ion-neutral reactions are thought to have low or even no energy barriers. Here we present a study of the kinetics and mechanisms of a potential ion-generating acid-base reaction between NH$_3$ and HCOOH to form the salt NH$_3^+$HCOO$^-$. We observe salt growth at temperatures as low as 15K, indicating that this reaction is feasible in cold environments. The kinetics of salt growth are best fit by a two-step model involving a slow "pre-reaction" step followed by a fast reaction step. The reaction energy barrier is determined to be 70 ± 30K with a pre-exponential factor 1.4 ± 0.4 x 10$^{-3}$ s$^{-1}$. The pre-reaction rate varies under different experimental conditions and likely represents a combination of diffusion and orientation of reactant molecules. For a diffusion-limited case, the pre-reaction barrier is 770 ± 110K with a pre-exponential factor of ∼7.6 x 10$^{-3}$ s$^{-1}$. Acid-base chemistry of common ice constituents is thus a potential cold pathway to generating ions in interstellar ices.

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The System of Molecular Clouds in the Gould Belt
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Based on high-latitude molecular clouds with highly accurate distance estimates taken from the literature, we have redetermined the parameters of their spatial orientation. This system can be approximated by a $350 \times 235 \times 140$ pc ellipsoid inclined by the angle $i = 17 \pm 2$ degrees to the Galactic plane with the longitude of the ascending node $l_0 = 337 \pm 1$ degrees. Based on the radial velocities of the clouds, we have found their group velocity relative to the Sun to be $(u_0, v_0, w_0) = (10.6, 18.2, 6.8) \pm (0.9, 1.7, 1.5)$ km s$^{-1}$. The trajectory of the center of the molecular cloud system in the past in a time interval of $\sim 60$ Myr has been constructed. Using data on masers associated with low-mass protostars, we have calculated the space velocities of the molecular complexes in Orion, Taurus, Perseus, and Ophiuchus. Their motion in the past is shown to be not random.

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New detections of embedded clusters in the Galactic halo
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Until recently it was thought that high Galactic latitude clouds were a non-star-forming ensemble. However, in a previous study we reported the discovery of two embedded clusters (ECs) far away from the Galactic plane ($\sim 5$ kpc). In our recent star cluster catalogue we provided additional high and intermediate latitude cluster candidates. This work aims to clarify if our previous detection of star clusters far away from the disc represents just an episodic event or if the star cluster formation is currently a systematic phenomenon in the Galactic halo. We analyse the nature of four clusters found in our recent catalogue and report the discovery of three new ECs with unusually high latitude and distance from the Galactic disc midplane. All of these clusters are younger than 5 Myr. The high-latitude ECs C 932, C 934, and C 939 appear to be related to a cloud complex about 5 kpc below the Galactic disc, under the Local arm. The other clusters are above the disc, C 1074 and C 1100 with a vertical distance of $\sim 3$ kpc, C 1099 with $\sim 2$ kpc, and C 1101 with $\sim 1.8$ kpc. According to the derived parameters there occur ECs located below and above the disc, which is an evidence of widespread star cluster formation throughout the Galactic halo. Thus, this study represents a paradigm shift, in the sense that a sterile halo becomes now a host of ongoing star formation. The origin and fate of these ECs remain open. There are two possibilities for their origin, Galactic fountain or infall. The discovery of ECs far from the disc suggests that the Galactic halo is more actively forming stars than previously thought and since most ECs do not survive the infant mortality it may be raining stars from the halo into the disc, and/or the halo harbours generations of stars formed in clusters like those hereby detected.

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Change of Magnetic Field–Gas Alignment at Gravity-Driven Alfvénic Transition in Molecular Clouds: Implications for Dust Polarization Observations
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Diffuse striations in molecular clouds are preferentially aligned with local magnetic fields whereas dense filaments tend to be perpendicular to them. When and why this transition occurs remain uncertain. To explore the physics behind this transition, we compute the histogram of relative orientation (HRO) between the density gradient and the
magnetic field in 3D MHD simulations of prestellar core formation in shock-compressed regions within GMCs. We find that, in the magnetically-dominated (sub-Alfvénic) post-shock region, the gas structure is preferentially aligned with the local magnetic field. For overdense sub-regions with super-Alfvénic gas, their elongation becomes preferentially perpendicular to the local magnetic field instead. The transition occurs when self-gravitating gas gains enough kinetic energy from the gravitational acceleration to overcome the magnetic support against the cross-field contraction, which results in a power-law increase of the field strength with density. Similar results can be drawn from HROs in projected 2D maps with integrated column densities and synthetic polarized dust emission. We quantitatively analyze our simulated polarization properties, and interpret the reduced polarization fraction at high column densities as the result of increased distortion of magnetic field directions in trans- or super-Alfvénic gas. Furthermore, we introduce measures of the inclination and tangledness of the magnetic field along the line of sight as the controlling factors of the polarization fraction. Observations of the polarization fraction and angle dispersion can therefore be utilized in studying local magnetic field morphology in star-forming regions.

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Imaging the water-snow line during a protostellar outburst

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A snow-line is the region of a protoplanetary disk at which a major volatile, such as water or carbon monoxide, reaches its condensation temperature. Snow-lines play a crucial role in disk evolution by promoting the rapid growth of ice-covered grains. Signatures of the carbon monoxide snow-line (at temperatures of around 20 kelvin) have recently been imaged in the disks surrounding the pre-main-sequence stars TW Hydra and HD163296, at distances of about 30 astronomical units (au) from the star. But the water snow-line of a protoplanetary disk (at temperatures of more than 100 kelvin) has not hitherto been seen, as it generally lies very close to the star (less than 5 au away for solar-type stars). Water-ice is important because it regulates the efficiency of dust and planetesimal coagulation, and the formation of comets, ice giants and the cores of gas giants. Here we report ALMA images at 0′′.03 resolution (12 au) of the protoplanetary disk around V883 Ori, a protostar of 1.3 solar masses that is undergoing an outburst in luminosity arising from a temporary increase in the accretion rate. We find an intensity break corresponding to an abrupt change in the optical depth at about 42 au, where the elevated disk temperature approaches the condensation point of water, from which we conclude that the outburst has moved the water snow-line. The spectral behaviour across the snow-line confirms recent model predictions: dust fragmentation and the inhibition of grain growth at higher temperatures results in soaring grain number densities and optical depths. As most planetary systems are expected to experience outbursts caused by accretion during their formation our results imply that highly dynamical water snow-lines must be considered when developing models of disk evolution and planet formation.

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On the nature of the enigmatic object IRAS 19312+1950: A rare phase of massive star formation?


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IRAS 19312+1950 is a peculiar object that has eluded firm characterization since its discovery, with combined maser properties similar to an evolved star and a young stellar object (YSO). To help determine its true nature, we obtained infrared spectra of IRAS 19312+1950 in the range 5–550 µm using the Herschel and Spitzer space observatories. The Herschel PACS maps exhibit a compact, slightly asymmetric continuum source at 170 µm, indicative of a large, dusty circumstellar envelope. The far-IR CO emission line spectrum reveals two gas temperature components: ≈0.22 $M_\odot$ at 280±18 K, and ≈1.6 $M_\odot$ at 157±3 K. The OI 63 µm line is detected on-source but no significant emission from atomic ions was found. The HIFI observations display shocked, high-velocity gas with outflow speeds up to 90 km s$^{-1}$ along the line of sight. From Spitzer spectroscopy, we identify ice absorption bands due to H$_2$O at 5.8 µm and CO$_2$ at 15 µm. The spectral energy distribution is consistent with a massive, luminous ($\sim 2 \times 10^4 L_\odot$) central source surrounded by a dense, warm circumstellar disk and envelope of total mass $\sim 500–700 M_\odot$, with large bipolar outflow cavities. The combination of distinctive far-IR spectral features suggest that IRAS 19312+1950 should be classified as an accreting high-mass YSO rather than an evolved star. In light of this reclassification, IRAS 19312+1950 becomes only the 5th high-mass protostar known to exhibit SiO maser activity, and demonstrates that 18 cm OH maser line ratios may not be reliable observational discriminators between evolved stars and YSOs.

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Brown dwarf disks with Herschel: Linking far-infrared and (sub)-mm fluxes

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Brown dwarf disks are excellent laboratories to test our understanding of disk physics in an extreme parameter regime. In this paper we investigate a sample of 29 well-characterized brown dwarfs and very low mass stars, for which Herschel far-infrared fluxes as well as (sub)-mm fluxes are available. We have measured new Herschel PACS fluxes for 11 objects and complement these with (sub)-mm data and Herschel fluxes from the literature. We analyze their spectral energy distributions in comparison with results from radiative transfer modeling. Fluxes in the far-infrared are strongly affected by the shape and temperature of the disk (and hence stellar luminosity), whereas the (sub)-mm fluxes mostly depend on disk mass. Nevertheless, there is a clear correlation between far-infrared and (sub)-mm fluxes. We argue that the link results from the combination of the stellar mass-luminosity relation and a scaling between disk mass and stellar mass. We find strong evidence of dust settling to the disk midplane. The spectral slopes between near- and far-infrared are mostly between $-0.5$ and $-1.2$ in our sample, comparable to more massive T Tauri stars, which may imply that the disk shapes are similar as well, though highly-flared disks are rare among brown dwarfs. We find that dust temperatures in the range of $7$–$15\,K$, calculated with $T \approx 25\,(L/L_\odot)^{0.25}\,K$, are appropriate for deriving disk masses from (sub)-mm fluxes for these low luminosity objects. About half of our sample hosts disks with at least one Jupiter mass, confirming that many brown dwarfs harbour sufficient material for the formation of Earth-mass planets in their midst.

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A Chandra X-ray study of the young star cluster NGC 6231: low-mass population and initial mass function

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NGC6231 is a massive young star cluster, near the center of the Sco OB1 association. While its OB members are well studied, its low-mass population has received little attention. We present high-spatial resolution Chandra ACIS-I X-ray data, where we detect 1613 point X-ray sources. Our main aim is to clarify global properties of NGC6231 down to low masses through a detailed membership assessment, and to study the cluster stars’ spatial distribution, the origin of their X-ray emission, the cluster age and formation history, and initial mass function. We use X-ray data, complemented by optical/IR data, to establish cluster membership. The spatial distribution of different stellar subgroups also provides highly significant constraints on cluster membership, as does the distribution of X-ray hardness. We perform spectral modeling of group-stacked X-ray source spectra. We find a large cluster population down to $\sim 0.3\,M_\odot$ (complete to $\sim 1\,M_\odot$), with minimal non-member contamination, with a definite age spread (1–8 Myrs) for the low-mass PMS stars. We argue that low-mass cluster stars also constitute the majority of the few hundreds unidentified X-ray sources. We find mass segregation for the most massive stars. The fraction of circumstellar-disk bearing members is found to be $\sim 5\%$. Photoevaporation of disks under the action of massive stars is suggested by the spatial distribution of the IR-excess stars. We also find strong H$\alpha$ emission in 9% of cluster PMS stars. The dependence of X-ray properties on mass, stellar structure, and age agrees with extrapolations based on other young clusters. The cluster initial mass function, computed over $\sim 2$ dex in mass, has a slope $\Gamma \sim -1.14$. The total mass of cluster members above $1\,M_\odot$ is $2280\,M_\odot$, and the inferred total mass is $4380\,M_\odot$. We also study the peculiar, hard X-ray spectrum of the Wolf-Rayet star WR79.

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Extinction law in the range 0.4 - 4.8 $\mu$m and the 8620 Å DIB towards the stellar cluster Westerlund 1

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The young stellar cluster Westerlund 1 (Wd 1: $l = 339.6^\circ$, $b = -0.4^\circ$) is one of the most massive in the local Universe, but accurate parameters are pending on better determination of its extinction and distance. Based on our photometry and data collected from other sources, we have derived a reddening law for the cluster line–of–sight representative of the Galactic Plane (-5$^\circ$ < $b$ < +5$^\circ$) in the window 0.4-4.8 $\mu$m: The power law exponent $\alpha = 2.13 \pm 0.08$ is much steeper than those published a decade ago (1.6–1.8) and our index $R_V = 2.50 \pm 0.04$ also differs from them, but in very good agreement with recent works based on deep surveys in the inner Galaxy. As a consequence, the total extinction $A_{Ks} = 0.74 \pm 0.08$ ($A_V = 11.40 \pm 2.40$) is substantially smaller than previous results(0.91–1.13), part of which ($A_{Ks} = 0.63$ or $A_V = 9.66$) is from the ISM. The extinction in front of the cluster spans a range of $\Delta A_V \sim 8.7$ with a gradient increasing from SW to NE across the cluster face, following the same general trend of warm dust distribution. The map of the $J$ – $Ks$ colour index also shows a trend of reddening in this direction. We measured the equivalent width of the diffuse interstellar band at 8620 Å (the “GAIA DIB”) for Wd 1 cluster members and derived the relation $A_{Ks} = 0.612 EW - 0.191 EW^2$. This extends the Munari et al. 2008 relation, valid for $E_{B-V} < 1$, to the non–linear regime ($A_V > 4$).

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Close-in planetesimal formation by pile-up of drifting pebbles

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The coherence of planet formation models suffers from the disconnection between the regime of small and large bodies. This is primarily caused by so-called growth barriers: the direct growth of larger bodies is halted at centimetre sized objects and particular conditions are required for the formation of larger, gravitationally bound planetesimals. We aim to connect models of dust evolution and planetesimal formation in order to identify regions of protoplanetary discs that are favourable for the formation of kilometre sized bodies and the first planetary embryos. We combine semi-analytical models of viscous protoplanetary disc evolution, dust growth and drift including backreaction of the dust particles on the gas, and planetesimal formation via the streaming instability into one numerical code. We investigate how planetesimal formation is affected by the mass of the protoplanetary disc, its initial dust content, and the stickiness of dust aggregates. We find that the dust growth and drift leads to a global redistribution of solids. The pile-up of pebbles in the inner disc provides local conditions where the streaming instability is effective. Planetesimals form in an annulus with its inner edge lying between 0.3 AU and 1 AU and its width ranging from 0.3 AU to 3 AU. The resulting surface density of planetesimals follows a radial profile that is much steeper than the initial disc profile. These results support formation of terrestrial planets in the Solar System from a narrow annulus of planetesimals, what reproduces their peculiar mass ratios.

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Cometary ices in forming protoplanetary disc midplanes

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Low-mass protostars are the extrasolar analogues of the natal Solar System. Sophisticated physicochemical models are used to simulate the formation of two protoplanetary discs from the initial prestellar phase, one dominated by viscous spreading and the other by pure infall. The results show that the volatile prestellar fingerprint is modified by the chemistry en route into the disc. This holds relatively independent of initial abundances and chemical parameters: physical conditions are more important. The amount of CO2 increases via the grain-surface reaction of OH with CO, which is enhanced by photodissociation of H2O ice. Complex organic molecules are produced during transport through the envelope at the expense of CH3OH ice. Their abundances can be comparable to that of methanol ice (few % of water ice) at large disc radii (R > 30 AU). Current Class II disc models may be underestimating the complex organic content. Planet population synthesis models may underestimate the amount of CO2 and overestimate CH3OH ices in planetesimals by disregarding chemical processing between the cloud and disc phases. The overall C/O and C/N ratios differ between the gas and solid phases. The two ice ratios show little variation beyond the inner 10 AU and both are nearly solar in the case of pure infall, but both are sub-solar when viscous spreading dominates. Chemistry in the protostellar envelope en route to the protoplanetary disc sets the initial volatile and prebiotically-significant content of icy planetesimals and cometary bodies. Comets are thus potentially reflecting the provenances of the midplane ices in the Solar Nebula.

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External photoevaporation of protoplanetary discs in sparse stellar groups: the impact of dust growth

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We estimate the mass loss rates of photoevaporative winds launched from the outer edge of protoplanetary discs impinged by an ambient radiation field. We focus on mild/moderate environments (the number of stars in the group/cluster is $N \sim 50$), and explore disc sizes ranging between 20 and 250 AU. We evaluate the steady-state structures of the photoevaporative winds by coupling temperature estimates obtained with a PDR code with 1D radial hydrodynamical equations. We also consider the impact of dust dragging and grain growth on the final mass loss rates. We find that these winds are much more significant than have been appreciated hitherto when grain growth is included in the modelling: in particular, mass loss rates $> 10^{-8} M_\odot/yr$ are predicted even for modest background field strengths ($\sim 30 G_0$) in the case of discs that extend to $R > 150$ AU. Grain growth significantly affects the final mass loss rates by reducing the average cross section at FUV wavelengths, and thus allowing a much more vigorous flow. The radial profiles of observable quantities (in particular surface density, temperature and velocity patterns) indicate that these winds have characteristic features that are now potentially observable with ALMA. In particular, such discs should have extended gaseous emission that is dust depleted in the outer regions, characterised by a non-Keplerian rotation curve, and with a radially increasing temperature gradient.

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Probing the 2D temperature structure of protoplanetary disks with Herschel observations of high-J CO lines

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The gas temperature structure of protoplanetary disks is a key ingredient for interpreting various disk observations and for quantifying the subsequent evolution of these systems. The comparison of low- and mid-J CO rotational lines is a powerful tool for assessing the temperature gradient in the warm molecular layer of disks. Spectrally resolved high-J (J_u > 14) CO lines probe intermediate distances and heights from the star that are not sampled by (sub-)millimeter CO spectroscopy. This paper presents new Herschel/HIFI and archival PACS observations of ^12CO, ^13CO, and [CII] emission in four Herbig AeBe disks (HD 100546, HD 97048, IRS 48, HD 163296) and three T Tauri disks (AS 205, S CrA, TW Hya). In the case of the T Tauri systems AS 205 and S CrA, the CO emission has a single-peaked profile, likely due to a slow wind. For all the other systems, the Herschel CO spectra are consistent with pure disk emission and the spectrally resolved lines (HIFI) and the CO rotational ladder (PACS) are analyzed simultaneously assuming power-law temperature and column density profiles, using the velocity profile to locate the emission in the disk. The temperature profile varies substantially from disk to disk. In particular, T_gas in the disk surface layers can differ by up to an order of magnitude among the four Herbig AeBe systems; HD 100546 is the hottest and HD 163296 the coldest disk in the sample. Clear evidence of a warm disk layer where T_gas > T_dust is found in all the Herbig Ae disks. The observed CO fluxes and line profiles are compared to predictions of physical-chemical models. The primary parameters affecting the disk temperature structure are the flaring angle, the gas-to-dust mass ratio, the scale height, and the dust settling.

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Long-Term Photometry of IC 348 with the YETI Network

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We present long-term photometric observations of the young open cluster IC 348 with a baseline time-scale of 2.4 yr. Our study was conducted with several telescopes from the Young Exoplanet Transit Initiative (YETI) network in the Bessel $R$ band to find periodic variability of young stars. We identified 87 stars in IC 348 to be periodically variable; 33 of them were unreported before. Additionally, we detected 61 periodic non-members of which 41 are new discoveries. Our wide field of view was the key to those numerous newly found variable stars. The distribution of rotation periods in IC 348 has always been of special interest. We investigate it further with our newly detected periods but we cannot find a statistically significant bimodality. We also report the detection of a close eclipsing binary in IC 348 composed of a low-mass stellar component ($M \approx 0.09 \, M_\odot$) and a K0 pre-main sequence star ($M \approx 2.7 \, M_\odot$). Furthermore, we discovered three detached binaries among the background stars in our field of view and confirmed the period of a fourth one.

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YSO jets in the Galactic Plane from UWISH2: III - Jets and Outflows in Cassiopeia and Auriga

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We present the analysis of 35.5 square degrees of images in the 1–0 S(1) line of $H_2$ from the UK Widefield Infrared Survey for $H_2$ (UWISH2) towards Cassiopeia and Auriga. We have identified 98 Molecular Hydrogen emission-line Objects (MHOs) driven by Young Stellar Objects, 60% of which are bipolar outflows and all are new discoveries. We estimate that the UWISH2 extended emission object catalogue contains fewer than 2% false positives and is complete at the 95% level for jets and outflows brighter than the UWISH2 detection limit. We identified reliable driving source candidates for three quarters of the detected outflows, 40% of which are associated with groups and clusters of stars. The driving source candidates are 20% protostars, the remainder are CTTSs. We also identified 15 new star cluster candidates near MHOs in the survey area.

We find that the typical outflow identified in the sample has the following characteristics: the position angles are randomly orientated; bipolar outflows are straight within a few degrees; the two lobes are slightly asymmetrical in length and brightness; the length and brightness of the lobes are not correlated; typical time gaps between major ejections of material are 1–3 kyr, hence FU-Ori or EX-Ori eruptions are most likely not the cause of these, but we suggest MNors as a possible source. Furthermore, we find that outflow lobe length distributions are statistically different from the widely used total length distributions. There are a larger than expected number of bright outflows indicating that the flux distribution does not follow a power law.

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Toward gas exhaustion in the W51 high-mass protoclusters


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We present new JVLA observations of the high-mass cluster-forming region W51A from 2 to 16 GHz with resolution $\theta_{\text{fwhm}} \approx 0.3 - 0.5$ arcsec. The data reveal a wealth of observational results: (1) Currently forming, very massive (proto-O) stars are traced by $^{12}$CO $2_{1,1}-2_{1,0}$ emission, suggesting that this line can be used efficiently as a massive protostar tracer; (2) there is a spatially distributed population of $\lesssim$mJy continuum sources, including hypercompact HII regions and candidate colliding wind binaries, in and around the W51 proto-clusters; and (3) there are two clearly detected protoclusters, W51e and W51 IRS2, that are gas-rich but may have most of their mass in stars within their inner $\lesssim 0.05$ pc. The majority of the bolometric luminosity in W51 most likely comes from a third population of OB stars between these clusters. The presence of a substantial population of exposed O-stars coincident with a population of still-forming massive stars, together with a direct measurement of the low mass loss rate via ionized gas outflow from W51 IRS2, implies that feedback is ineffective at halting star formation in massive protoclusters. Instead, feedback may shut off the large-scale accretion of diffuse gas onto the W51 protoclusters, implying that they are evolving toward a state of gas exhaustion rather than gas expulsion. Recent theoretical models predict gas exhaustion to be a necessary step in the formation of gravitationally bound stellar clusters, and our results provide an observational validation of this process.

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SMA observations towards the compact, short-lived bipolar water maser outflow in the LkH$\alpha$ 234 region

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We present Submillimeter Array (SMA) 1.35 mm subarcsecond angular resolution observations toward the LkH$\alpha$ 234 intermediate-mass star-forming region. The dust emission arises from a filamentary structure of $\sim 5''$ ($\sim 4500$ au) enclosing VLA 1–3 and MM 1, perpendicular to the different outflows detected in the region. The most evolved objects are located at the southeastern edge of the dust filamentary structure and the youngest ones at the northeastern edge. The circumstellar structures around VLA 1, VLA 3, and MM 1 have radii between $\sim 200$ and $\sim 375$ au and masses in the $\sim 0.08$–$0.3 M_\odot$ range. The 1.35 mm emission of VLA 2 arises from an unresolved ($r < 135$ au) circumstellar
disk with a mass of \( \sim 0.02 \, M_\odot \). This source is powering a compact (\( \sim 4000 \) au), low radial velocity (\( \sim 7 \, \text{km s}^{-1} \)) SiO bipolar outflow, close to the plane of the sky. We conclude that this outflow is the “large-scale” counterpart of the short-lived, episodic, bipolar outflow observed through H$_2$O masers at much smaller scales (\( \sim 180 \) au), and that has been created by the accumulation of the ejection of several episodic collimated events of material. The circumstellar gas around VLA 2 and VLA 3 is hot (\( \sim 130 \) K) and exhibits velocity gradients that could trace rotation. There is a bridge of warm and dense molecular gas connecting VLA 2 and VLA 3. We discuss the possibility that this bridge could trace a stream of gas between VLA 3 and VLA 2, increasing the accretion rate onto VLA 2 to explain why this source has an important outflow activity.

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Unveiling the early-stage anatomy of a protocluster hub with ALMA

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High-mass stars shape the interstellar medium in galaxies, and yet, largely because the initial conditions are poorly constrained, we do not know how they form. One possibility is that high-mass stars and star clusters form at the junction of filamentary networks, referred to as “hubs”. In this letter we present the complex anatomy of a protocluster hub within an Infrared Dark Cloud (IRDC), G035.39-00.33, believed to be in an early phase of its evolution. We use high-angular resolution (\{\( \theta_{\text{maj}}, \theta_{\text{min}} \} = \{1.4, 0.8\} \sim \{0.02 \, \text{pc}, 0.01 \, \text{pc}\} ) and high-sensitivity (0.2 mJy beam$^{-1}$; \( \sim 0.2 \, M_\odot \)) 1.07 mm dust continuum observations from the Atacama Large Millimeter Array (ALMA) to identify a network of narrow, \( \pm 0.005 \, \text{pc} \) wide, filamentary structures. These are a factor of \( \gtrsim 3 \) narrower than the proposed “quasi-universal” \( \sim 0.1 \, \text{pc} \) width of interstellar filaments. Additionally, 28 compact objects are reported, spanning a mass range 0.3 \( M_\odot \) \( < M_c \) \( < 10.4 \, M_\odot \). This indicates that at least some low-mass objects are forming coevally with more massive counterparts. Comparing to the popular “bead-on-a-string” analogy, the protocluster hub is poorly represented by a monolithic clump embedded within a single filament. Instead, it comprises multiple intra-hub filaments, each of which retains its integrity as an independent structure and possesses its own embedded core population.

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Investigating the structure and fragmentation of a highly filamentary IRDC

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We present 3.7 arcsec (~ 0.05 pc) resolution 3.2 mm dust continuum observations from the IRAM Plateau de Bure Interferometer, with the aim of studying the structure and fragmentation of the filamentary Infrared Dark Cloud G035.39-00.33. The continuum emission is segmented into a series of 13 quasi-regularly spaced (λ_{obs} ~ 0.18 pc) cores, following the major axis of the IRDC. We compare the spatial distribution of the cores with that predicted by theoretical work describing the fragmentation of hydrodynamic fluid cylinders, finding a significant (factor of >8) discrepancy between the two. Our observations are consistent with the picture emerging from kinematic studies of molecular clouds suggesting that the cores are harboured within a complex network of independent sub-filaments. This result emphasises the importance of considering the underlying physical structure, and potentially, dynamically important magnetic fields, in any fragmentation analysis. The identified cores exhibit a range in (peak) beam-averaged column density (3.6 × 10^{23} cm^{-2} < N_{H,c} < 8.0 × 10^{23} cm^{-2} ), mass (8.1 M_{⊙} < M_{c} < 26.1 M_{⊙}), and number density (6.1 × 10^{5} cm^{-3} < n_{H,c,eq} < 14.7 × 10^{5} cm^{-3}). Two of these cores, dark in the mid-infrared, centrally-concentrated, monolithic (with no traceable substructure at our PdBI resolution), and with estimated masses of the order ~ 20 – 25 M_{⊙}, are good candidates for the progenitors of intermediate-to-high-mass stars. Virial parameters span a range 0.2 < α_{vir} < 1.3. Without additional support, possibly from dynamically important magnetic fields with strengths of the order 230 μG < B < 670 μG, the cores are susceptible to gravitational collapse. These results may imply a multi-layered fragmentation process, which incorporates the formation of sub-filaments, embedded cores, and the possibility of further fragmentation.

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The Eruption of the Candidate Young Star ASASSN-15qi

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Outbursts on young stars are usually interpreted as accretion bursts caused by instabilities in the disk or the star-disk connection. However, some protostellar outbursts may not fit into this framework. In this paper, we analyze optical and near-infrared spectra and photometry to characterize the 2015 outburst of the probable young star ASASSN-15qi. The \( \sim 3.5 \) mag brightening in the \( V \) band was sudden, with an unresolved rise time of less than one day. The outburst decayed exponentially by 1 mag for 6 days and then gradually back to the pre-outburst level after 200 days. The outburst is dominated by emission from \( \sim 10,000 \) K gas. An explosive release of energy accelerated matter from the star in all directions, seen in a spectacular cool, spherical wind with a maximum velocity of 1000 km/s. The wind and hot gas both disappeared as the outburst faded and the source returned to its quiescent F-star spectrum. Nebulosity near the star brightened with a delay of 10–20 days. Fluorescent excitation of \( \text{H}_2 \) is detected in emission from vibrational levels as high as \( v = 11 \), also with a possible time delay in flux increase. The mid-infrared spectral energy distribution does not indicate the presence of warm dust emission, although the optical photospheric absorption and CO overtone emission could be related to a gaseous disk. Archival photometry reveals a prior outburst in 1976. Although we speculate about possible causes for this outburst, none of the explanations are compelling.

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Panchromatic Imaging of a Transitional Disk: The Disk of GM Aur in Optical and FUV Scattered Light

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We have imaged GM Aur with HST, detected its disk in scattered light at 1400 Å and 1650 Å, and compared these with observations at 3300 Å, 5550 Å, 1.1 \( \mu \)m, and 1.6 \( \mu \)m. The scattered light increases at shorter wavelengths. The
radial surface brightness profile at 3300 Å shows no evidence of the 24 AU radius cavity that has been previously observed in sub-mm observations. Comparison with dust grain opacity models indicates the surface of the entire disk is populated with sub-micron grains. We have compiled an SED from 0.1 µm to 1 mm, and used it to constrain a model of the star+disk system that includes the sub-mm cavity using the Monte Carlo Radiative Transfer code by Barbara Whitney. The best-fit model image indicates that the cavity should be detectable in the F330W bandpass if the cavity has been cleared of both large and small dust grains, but we do not detect it. The lack of an observed cavity can be explained by the presence of sub-microns grains interior to the sub-mm cavity wall. We suggest one explanation for this which could be due to a planet of mass <9 Jupiter masses interior to 24 AU. A unique cylindrical structure is detected in the FUV data from the Advanced Camera for Surveys/Solar Blind Channel. It is aligned along the system semi-minor axis, but does not resemble an accretion-driven jet. The structure is limb-brightened and extends 190±35 AU above the disk midplane. The inner radius of the limb-brightening is 40±10 AU, just beyond the sub-millimeter cavity wall.

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Formation of Massive Primordial Stars: Intermittent UV Feedback with Episodic Mass Accretion

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We present coupled stellar evolution (SE) and 3D radiation-hydrodynamic (RHD) simulations of the evolution of primordial protostars, their immediate environment, and the dynamic accretion history under the influence of stellar ionizing and dissociating UV feedback. Our coupled SE-RHD calculations result in a wide diversity of final stellar masses covering 10 $M_\odot$ < $M_*$ < $10^3$ $M_\odot$. The formation of very massive (> 250 $M_\odot$) stars is possible under weak UV feedback, whereas ordinary massive (a few ×10 $M_\odot$) stars form when UV feedback can efficiently halt the accretion. This may explain the peculiar abundance pattern of a Galactic metal-poor star recently reported by Aoki et al. (2014), possibly the observational signature of very massive precursor primordial stars. Weak UV feedback occurs in cases of variable accretion, in particular when repeated short accretion bursts temporarily exceed 0.01 $M_\odot$ yr$^{-1}$, causing the protostar to inflate. In the bloated state, the protostar has low surface temperature and UV feedback is suppressed until the star eventually contracts, on a thermal adjustment timescale, to create an HII region. If the delay time between successive accretion bursts is sufficiently short, the protostar remains bloated for extended periods, initiating at most only short periods of UV feedback. Disk fragmentation does not necessarily reduce the final stellar mass. Quite the contrary, we find that disk fragmentation enhances episodic accretion as many fragments migrate inward and are accreted onto the star, thus allowing continued stellar mass growth under conditions of intermittent UV feedback. This trend becomes more prominent as we improve the resolution of our simulations. We argue that simulations with significantly higher resolution than reported previously are needed to derive accurate gas mass accretion rates onto primordial protostars.

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The ALMA Protostellar Interferometric Line Survey (PILS).
First results from an unbiased submillimeter wavelength line survey of the Class 0 protostellar binary IRAS 16293-2422 with ALMA

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Context: The inner regions of the envelopes surrounding young protostars are characterised by a complex chemistry, with prebiotic molecules present on the scales where protoplanetary disks eventually may form. The Atacama Large Millimeter/submillimeter Array (ALMA) provides an unprecedented view of these regions zooming in on Solar System scales of nearby protostars and mapping the emission from rare species.

Aims: The goal is to introduce a systematic survey, “Protostellar Interferometric Line Survey (PILS)”, of the chemical complexity of one of the nearby astrochemical templates, the Class 0 protostellar binary IRAS 16293–2422, using ALMA, to understand the origin of the complex molecules formed in its vicinity. In addition to presenting the overall survey, the analysis in this paper focuses on new results for the prebiotic molecule glycolaldehyde, its isomers and rarer isotopologues and other related molecules.

Methods: An unbiased spectral survey of IRAS 16293–2422 covering the full frequency range from 329 to 363 GHz (0.8 mm) has been obtained with ALMA, in addition to a few targeted observations at 3.0 and 1.3 mm. The data consist of full maps of the protostellar binary system with an angular resolution of 0.5′′ (60 AU diameter), a spectral resolution of 0.2 km s$^{-1}$ and a sensitivity of 4–5 mJy beam$^{-1}$ km s$^{-1}$ – approximately two orders of magnitude better than any previous studies.

Results: More than 10,000 features are detected toward one component in the protostellar binary, corresponding to an average line density of approximately one line per 3 km s$^{-1}$. Glycolaldehyde, its isomers, methyl formate and acetic acid, and its reduced alcohol, ethylene glycol, are clearly detected and their emission well-modeled with an excitation temperature of 300 K. For ethylene glycol both lowest state conformers, $aGg′$ and $gGg′$, are detected, the latter for the first time in the ISM. The abundance of glycolaldehyde is comparable to or slightly larger than that of ethylene glycol. In comparison to the Galactic Center these two species are over-abundant relative to methanol, possibly an indication of formation of the species at low temperatures in CO-rich ices during the infall of the material toward the central protostar. Both $^{13}$C and deuterated isotopologues of glycolaldehyde are detected, also for the first time ever in the ISM. For the deuterated species, a D/H ratio of $\approx5\%$ is found with no differences between the deuteration in the different functional groups of glycolaldehyde, in contrast to previous estimates for methanol and recent suggestions of significant equilibration between water and -OH functional groups at high temperatures. Measurements of the $^{13}$C-species lead to a $^{12}$C:$^{13}$C ratio of $\approx30$, lower than the typical ISM value. This low ratio may reflect an enhancement of $^{13}$CO in the ice due to either ion-molecule reactions in the gas before freeze-out or differences in the temperatures where $^{12}$CO and $^{13}$CO ices sublimate.

Conclusions: The results reinforce the importance of low-temperature grain surface chemistry for the formation of prebiotic molecules seen here in the gas after sublimation of the entire ice mantle. Systematic surveys of the molecules thought to be chemically related, as well as the accurate measurements of their isotopic composition, hold strong promises for understanding the origin of prebiotic molecules in the earliest stages of young stars.
The circumstellar disk of FS Tau B - A self-consistent model based on observations in the mid-infrared with NACO

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Protoplanetary disks are a byproduct of the star formation process. In the dense mid-plane of these disks, planetesimals and planets are expected to form. The first step in planet formation is the growth of dust particles from submicrometer-sized grains to macroscopic mm-sized aggregates. The grain growth is accompanied by radial drift and vertical segregation of the particles within the disk. To understand this essential evolutionary step, spatially resolved multi-wavelength observations as well as photometric data are necessary which reflect the properties of both disk and dust.

We present the first spatially resolved image obtained with NACO at the VLT in the L_p band of the near edge-on protoplanetary disk FS Tau B. Based on this new image, a previously published Hubble image in H band and the spectral energy distribution from optical to millimeter wavelengths, we derive constraints on the spatial dust distribution and the progress of grain growth. For this purpose we perform a disk modeling using the radiative transfer code MC3D. Radial drift and vertical sedimentation of the dust are not considered.

We find a best-fit model which features a disk extending from 2 AU to several hundreds AU with a moderately decreasing surface density and $M_{disk} = 2.8 \times 10^{-2} M_\odot$. The inclination amounts to $i = 80^\circ$. Our findings indicate that substantial dust grain growth has taken place and that grains of a size equal to or larger than 1 mm are present in the disk. In conclusion, the parameters describing the vertical density distribution are better constrained than those describing the radial disk structure.

Multi-wavelength study of the low-luminosity outbursting young star HBC 722

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Context. HBC 722 (V2493 Cyg) is a young eruptive star in outburst since 2010. Spectroscopic evidences suggest that the source is an FU Orionis-type object, with an atypically low outburst luminosity.
Aims. Because it was well characterized in the pre-outburst phase, HBC 722 is one of the few FUors where we can learn about the physical changes and processes associated with the eruption, including the role of the circumstellar environment.

Methods. We monitored the source in the $BVRIJHK_S$ bands from the ground, and at 3.6 and 4.5 $\mu$m from space with the Spitzer Space Telescope. We analyzed the light curves and studied how the spectral energy distribution evolved by fitting a series of steady accretion disk models at many epochs covering the outburst. We also analyzed the spectral properties of the source based on our new optical and infrared spectra, comparing our line inventory with those published in the literature for other epochs. We also mapped HBC 722 and its surroundings at millimeter wavelengths.

Results. From the light curve analysis we concluded that the first peak of the outburst in 2010 September was mainly due to an abrupt increase of the accretion rate in the innermost part of the system. This was followed after a few months by a long term process, when the brightening of the source was mainly due to a gradual increase of the accretion rate and the emitting area. Our new observations show that the source is currently in a constant “plateau” phase. We found that the optical spectrum was similar both in the first peak and the following periods, but around the peak the continuum was bluer and the $H\alpha$ profile changed significantly between 2012 and 2013. The source was not detected in the millimeter continuum, but we discovered a flattened molecular gas structure with a diameter of 1700 au and mass of 0.3 $M_\odot$ centered on HBC 722.

Conclusions. While the first brightness peak could be interpreted as a rapid fall of piled-up material from the inner disk onto the star, the later monotonic flux rise suggests the outward expansion of a hot component according to the theory of Bell & Lin (1994). Our study of HBC 722 demonstrated that accretion-related outbursts can occur in young stellar objects even with very low mass disks, in the late Class II phase.

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Disk Detective: Discovery of New Circumstellar Disk Candidates through Citizen Science

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The Disk Detective citizen science project aims to find new stars with 22 micron excess emission from circumstellar dust using data from NASA’s WISE mission. Initial cuts on the AllWISE catalog provide an input catalog of 277,686 sources. Volunteers then view images of each source online in 10 different bands to identify false-positives (galaxies, background stars, interstellar matter, image artifacts, etc.). Sources that survive this online vetting are followed up with spectroscopy on the FLWO Tillinghast telescope. This approach should allow us to unleash the full potential
of WISE for finding new debris disks and protoplanetary disks. We announce a first list of 37 new disk candidates discovered by the project, and we describe our vetting and follow-up process. One of these systems appears to contain the first debris disk discovered around a star with a white dwarf companion: HD 74389. We also report four newly discovered classical Be stars (HD 6612, HD 7406, HD 164137, and HD 218546) and a new detection of 22 micron excess around a previously known debris disk host star, HD 22128.

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Isotopic enrichment of forming planetary systems from supernova pollution

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Heating by short-lived radioisotopes (SLRs) such as 26Al and 60Fe fundamentally shaped the thermal history and interior structure of Solar System planetesimals during the early stages of planetary formation. The subsequent thermo-mechanical evolution, such as internal differentiation or rapid volatile degassing, yields important implications for the final structure, composition and evolution of terrestrial planets. SLR-driven heating in the Solar System is sensitive to the absolute abundance and homogeneity of SLRs within the protoplanetary disk present during the condensation of the first solids. In order to explain the diverse compositions found for extrasolar planets, it is important to understand the distribution of SLRs in active planet formation regions (star clusters) during their first few Myr of evolution. By constraining the range of possible effects, we show how the imprint of SLRs can be extrapolated to exoplanetary systems and derive statistical predictions for the distribution of 26Al and 60Fe based on N-body simulations of typical to large clusters (103-104 stars) with a range of initial conditions. We quantify the pollution of protoplanetary disks by supernova ejecta and show that the likelihood of enrichment levels similar to or higher than the Solar System can vary considerably, depending on the cluster morphology. Furthermore, many enriched systems show an excess in radiogenic heating compared to Solar System levels, which implies that the formation and evolution of planetesimals could vary significantly depending on the birth environment of their host stars.

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Constraining the Movement of the Spiral Features and the Locations of Planetary Bodies within the AB Aur System

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We present new analysis of multi-epoch, H-band, scattered light images of the AB Aur system. We used a Monte Carlo, radiative transfer code to simultaneously model the system’s SED and H-band polarized intensity imagery. We find that a disk-dominated model, as opposed to one that is envelope dominated, can plausibly reproduce AB Aur’s SED and near-IR imagery. This is consistent with previous modeling attempts presented in the literature and supports the idea that at least a subset of AB Aur’s spirals originate within the disk. In light of this, we also analyzed the movement of spiral structures in multi-epoch H-band total light and polarized intensity imagery of the disk. We detect no significant rotation or change in spatial location of the spiral structures in these data, which span a 5.8 year baseline. If such structures are caused by disk-planet interactions, the lack of observed rotation constrains the location of the orbit of planetary perturbers to be >47 AU.

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ALMA observations of the Th 28 protostellar disk - A new example of counter-rotation between disk and optical jet

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Differences in Doppler shifts across the base of four close classical T-Tauri star jets have been detected with the HST in optical and NUV emission lines, and interpreted as rotation signatures under the assumption of steady state flow. To support this interpretation, it is necessary that the underlying disks rotate in the same sense. Agreement between disk rotation and jet rotation determined from optical lines has been verified in two cases and rejected in one. We propose here to perform this test on the fourth system, Th 28.

We present ALMA high angular resolution Band 7 continuum, \(^{12}\)CO (2–1) and \(^{13}\)CO (2–1) observations of the circumstellar disk around the T-Tauri star Th 28. The sub-arcsecond angular resolution (0\textquoteleft46 × 0\textquoteleft37) and high-sensitivity reached enable us to detect in CO and continuum clear signatures of a disk in Keplerian rotation around Th28. The \(^{12}\)CO emission allows us to derive estimates of disk position angle and inclination. The large velocity separation of the peaks in \(^{12}\)CO combined with the resolved extent of the emission indicate a central stellar mass in the range 1–2 \(M_\odot\). The rotation sense of the disk is well detected, in both \(^{13}\)CO and \(^{12}\)CO emission lines, and goes in the opposite sense to that implied by the transverse Doppler shifts measured in the optical lines of the jet. The Th 28 system is now the second system, among the four investigated so far, where counter-rotation between the disk and the optical jet is detected. These findings imply either that optical transverse velocity gradients detected with HST do not trace jet rotation or that modeling the flow with the steady assumption is not valid. In both cases jet rotation studies which rely solely on optical lines are not suitable to derive the launching radius of the jet.

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Tracing extended low-velocity shocks through SiO emission - Case study of the W43-MM1 ridge

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Previous literature suggests that the densest structures in the interstellar medium form through colliding flows but patent evidence of this process is still missing. Recent literature proposes using SiO line emission to trace low-velocity shocks associated with cloud formation through collision. In this paper we investigate the bright and extended SiO (2–1) emission observed along the ∼5 pc-long W43-MM1 ridge to determine its origin.

We use high-angular resolution images of the SiO (2–1) and HCN (1–0) emission lines obtained with the IRAM Plateau de Bure interferometer and combined with data from the IRAM/30m radio telescope. These data are complemented by an Herschel column density map of the region. We perform spectral analysis of SiO and HCN emission line profiles to identify protostellar outflows and spatially disentangle two velocity components associated with low- and high-velocity shocks. Then, we compare the low-velocity shock component to a dedicated grid of 1D radiative shock models.

We find that the SiO emission originates from a mixture of high-velocity shocks caused by bipolar outflows and low-velocity shocks. Using SiO and HCN emission lines, we extract seven bipolar outflows associated with massive dense cores previously identified within the W43-MM1 mini-starburst cluster. Comparing observations with dedicated Paris-Durham shock models constrains the velocity of the low-velocity shock component from 7 to 12 km s$^{-1}$.

The SiO arising from low-velocity shocks spreads along the complete length of the ridge. Its contribution represents at least 45% and up to 100% of the total SiO emission depending on the area considered. The low-velocity component of SiO is most likely associated with the ridge formation through colliding flows or cloud-cloud collision.
We present new Herschel PACS observations of 32 T Tauri stars in the young (~3 Myr) σ Ori cluster. Most of our objects are K & M stars with large excesses at 24 μm. We used irradiated accretion disk models of D’Alessio et al. (2006) to compare their spectral energy distributions with our observational data. We arrive at the following six conclusions. (i) The observed disks are consistent with irradiated accretion disks systems. (ii) Most of our objects (60%) can be explained by significant dust depletion from the upper disk layers. (iii) Similarly, 61% of our objects can be modeled with large disk sizes (Rd ≥ 100 AU). (iv) The masses of our disks range between 0.03 to 39 M_Jup, where 35% of our objects have disk masses lower than 1 Jupiter. Although these are lower limits, high mass (>0.05 M⊙) disks, which are present e.g. in Taurus, are missing. (v) By assuming a uniform distribution of objects around the brightest stars at the center of the cluster, we found that 80% of our disks are exposed to external FUV radiation of 300 ≤ G0 ≤ 1000, which can be strong enough to photoevaporate the outer edges of the closer disks. (vi) Within 0.6 pc from σ Ori we found forbidden emission lines of [NII] in the spectrum of one of our large disk (SO662), but no emission in any of our small ones. This suggests that this object may be an example of a photoevaporating disk.

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Variable Stars in the Quintuplet stellar cluster with the VVV Survey
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The Quintuplet cluster is one of the most massive star clusters in the Milky Way, situated very close to the Galactic center. We present a new search for variable stars in the vicinity of the cluster, using the five-year database of the Vista Variables in the Via Lactea (VVV) ESO Public Survey in the near-infrared. A total of 7586 objects were identified in the zone around 2′ from the cluster center, using 55 Ks-band epochs. Thirty-three stars show Ks-band variability, 24 of them being previously undiscovered. Most of the variable stars found are slow/semiregular variables, long-period variables of the Mira type, and OH/IR stars. In addition, a good number of our candidates show variations in a rather short timescale. We also propose four Young Stellar Object (YSO) candidates, which could be cluster members.

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The magnetic field and dust filaments in the Polaris Flare
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In diffuse molecular clouds, possible precursors of star-forming clouds, the effect of the magnetic field is unclear. In this work we compare the orientations of filamentary structures in the Polaris Flare, as seen through dust emission by Herschel, to the plane-of-the-sky magnetic field orientation ($B_{\text{pos}}$) as revealed by stellar optical polarimetry with RoboPol. Dust structures in this translucent cloud show a strong preference for alignment with $B_{\text{pos}}$. 70 filaments (within $30^\circ$). We explore the spatial variation of the relative orientations and find it to be uncorrelated with the dust emission intensity and correlated to the dispersion of polarization angles. Concentrating in the area around the highest column density filament, and in the region with the most uniform field, we infer the $B_{\text{pos}}$ strength to be $24 - 120 \, \mu \text{G}$. Assuming that the magnetic field can be decomposed into a turbulent and an ordered component, we find a turbulent-to-ordered ratio of $0.2 - 0.8$, implying that the magnetic field is dynamically important, at least in these two areas. We discuss implications on the 3D field properties, as well as on the distance estimate of the cloud.

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Investigating dust trapping in transition disks with millimeter-wave polarization
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Spatially resolved polarized (sub-)mm emission has been observed for example in the protoplanetary disk around HL Tau. Magnetically aligned grains are commonly interpreted as the source of polarization. However, self-scattering by large dust grains with a high enough albedo is another polarization mechanism, becoming a compelling method independent of the spectral index to constrain the dust grain size in protoplanetary disks. We study the dust polarization at mm wavelength in the dust trapping scenario proposed for transition disks, when a giant planet opens a gap in the disk. We investigate the characteristic polarization patterns and their dependence on disk inclination, dust size evolution, planet position, and observing wavelength. We combine two-dimensional hydrodynamical simulations of planet-disk interactions with self-consistent dust growth models. These size-dependent dust density distributions are used for follow-up three-dimensional radiative transfer calculations to predict the polarization degree at ALMA bands due to scattered thermal emission. We find that the polarization pattern of a disk with a planetary gap after 1 Myr of dust evolution shows a distinctive three ring structure. Two narrow inner rings are located at the planet gap edges. For increasing observing wavelengths all three rings slightly change their position, where the innermost and outermost rings move inward. This distance is detectable comparing the results at ALMA bands 3, 6 and 7. Within the highest polarized intensity regions the polarization vectors are oriented in the azimuthal direction. For an inclined disk there is an interplay between polarization originating from a flux gradient and inclination-induced quadrupole polarization. For intermediate inclined transition disks the polarization degree is as high as $\sim 2\%$ at band 3, which is well above the detection limit of future ALMA observations.

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The CO-H$_2$ van der Waals complex and complex organic molecules in cold molecular clouds: a TMC-1C survey
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Almost 200 different species have been detected in the interstellar medium (ISM) during the last decades, revealing not only simple species but complex molecules with more than 6 atoms. Other exotic compounds, like the weakly-bound dimer (H$_2$)$_2$, have also been detected in astronomical sources like Jupiter. We aim at detecting for the first time the CO-H$_2$ van der Waals complex in the ISM, which if detected can be a sensitive indicator for low temperatures. We use the IRAM30m telescope, located in Pico Veleta (Spain), to search for the CO-H$_2$ complex in a cold, dense core in TMC-1C (with a temperature of 10 K). All the brightest CO-H$_2$ transitions in the 3 mm (80–110 GHz) band have been observed with a spectral resolution of 0.5–0.7 km s$^{-1}$, reaching a rms noise level of 2 mK. The simultaneous observation of a broad frequency band, 16 GHz, has allowed us to conduct a serendipitous spectral line survey. No lines belonging to the CO-H$_2$ complex have been detected. We have set up a new, more stringent upper limit for its abundance to be [CO-H$_2$]/[CO] = 5 × 10$^{-6}$, while we expect the abundance of the complex to be in the range 10$^{-8}$–10$^{-3}$. The spectral line survey has allowed us to detect 75 lines associated with 41 different species (including isotopologues). We detect a number of complex organic species, e.g. methyl cyanide (CH$_3$CN), methanol (CH$_3$OH), propyne (CH$_3$CCH) and ketene (CH$_2$CO), associated with cold gas (excitation temperatures about 7 K), confirming the presence of these complex species not only in warm objects but also in cold regimes.

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An analytic, entraining jet model for a stellar outflow in a stratified environment
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We present a model of a steady, entraining, isothermal jet embedded in a stratified environment. This model is appropriate for describing Herbig-Haro (HH) jets in the outer boundaries of molecular clouds. The model has a straightforward analytic solution which permits an evaluation of the slowing down of the outflow due to the entrainment of environmental material. The solution indicates that the outflow lobe travelling into regions of lower pressure might or not be slowed down (depending on the parameters of the flow) before leaving the molecular cloud. On the other hand, the outflow lobe travelling into regions of increasing environmental pressure is likely to be slowed down quite drastically regardless of the flow parameters. The analytic model presented in this paper gives simple recipes for calculating the slowing down of the two outflow lobes.

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http://bigbang.nucleares.unam.mx/astroplasmas/

Variability of the emission line fluxes and ratios of HH 1/2
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We compare spectrophotometric data of HH 1 and 2 obtained in 1978 (by Brugel et al. 1981a) with the emission line fluxes from calibrated Hubble Space Telescope (HST) images obtained in 1994 and 2014. This comparison shows that the emission line ratios of these objects have remained surprisingly invariant during the past 36 years. On the other hand, the line intensities have indeed changed, with HH 2 brightening by a factor of $\sim 4$ and HH 1 becoming $\sim 30\%$ fainter. These results would be consistent with HH 1 and 2 being leading working surfaces of heavy jets travelling into an environment of decreasing (for HH 1) or increasing (HH 2) densities.

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The prevalence of star formation as a function of Galactocentric radius

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We present large-scale trends in the distribution of star-forming objects revealed by the Hi-GAL survey. As a simple metric probing the prevalence of star formation in Hi-GAL sources, we define the fraction of the total number of Hi-GAL sources with a 70 µm counterpart as the “star-forming fraction” or SFF. The mean SFF in the inner galactic disc (3.1 kpc < R₇₀ < 8.6 kpc) is 25%. Despite an apparent pile-up of source numbers at radii associated with spiral arms, the SFF shows no significant deviations at these radii, indicating that the arms do not affect the star-forming productivity of dense clumps either via physical triggering processes or through the statistical effects of larger source samples associated with the arms. Within this range of Galactocentric radii, we find that the SFF declines with R₇₀ at a rate of −0.026±0.002 per kiloparsec, despite the dense gas mass fraction having been observed to be constant in the inner Galaxy. This suggests that the SFF may be weakly dependent on one or more large-scale physical properties of the Galaxy, such as metallicity, radiation field, pressure or shear, such that the dense sub-structures of molecular clouds acquire some internal properties inherited from their environment.

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DM Ori: A Young Star Occulted by a Disturbance in its Protoplanetary Disk

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In some planet formation theories, protoplanets grow gravitationally within a young star’s protoplanetary disk, a signature of which may be a localized disturbance in the disk’s radial and/or vertical structure. Using time-series photometric observations by the Kilodegree Extremely Little Telescope South (KELT-South) project and the All-Sky Automated Survey for SuperNovae (ASAS-SN), combined with archival observations, we present the discovery of two
extended dimming events of the young star, DM Ori. This young system faded by ~1.5 mag from 2000 March to 2002 August and then again in 2013 January until 2014 September (depth ~1.7 mag). We constrain the duration of the 2000–2002 dimming to be <860 days, and the event in 2013–2014 to be <585 days, separated by ~12.5 years. A model of the spectral energy distribution (SED) indicates a large infrared excess consistent with an extensive circumstellar disk. Using basic kinematic arguments, we propose that DM Ori is likely being periodically occulted by a feature (possibly a warp or perturbation) in its circumstellar disk. In this scenario, the occulting feature is located >6 AU from the host star, moving at ~14.6 km s⁻¹, and is ~4.9 AU in width. This localized structure may indicate a disturbance such as may be caused by a protoplanet early in its formation.

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The slow spin of the young sub-stellar companion GQ Lupi b and its orbital configuration

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The spin of a planet or brown dwarf is related to the accretion process, and therefore studying spin can help promote our understanding of the formation of such objects. We present the projected rotational velocity of the young sub-stellar companion GQ Lupi b, along with its barycentric radial velocity. The directly imaged exoplanet or brown dwarf companion joins a small but growing ensemble of wide-orbit sub-stellar companions with a spin measurement. The GQ Lupi system was observed at high spectral resolution (R ~ 100000), and in the analysis we made use of both spectral and spatial filtering to separate the signal of the companion from that of the host star. We detect both CO (S/N=11.6) and H₂O (S/N=7.7) in the atmosphere of GQ Lupi b by cross-correlating with model spectra, and we find it to be a slow rotator with a projected rotational velocity of 5.3⁺⁰.⁹⁻₁.⁰ km s⁻¹. The slow rotation is most likely due to its young age of <5 Myr, as it is still in the process of accreting material and angular momentum. We measure the barycentric radial velocity of GQ Lupi b to be 2.0±0.4 km s⁻¹, and discuss the allowed orbital configurations and their implications for formation scenarios for GQ Lupi b.

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Chemical differentiation in a prestellar core traces non-uniform illumination

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Dense cloud cores present chemical differentiation due to the different distribution of C-bearing and N-bearing molecules, the latter being less affected by freeze-out onto dust grains. In this letter we show that two C-bearing molecules, CH₃OH and c-C₃H₂, present a strikingly different (complementary) morphology while showing the same kinematics toward the prestellar core L1544. After comparing their distribution with large scale H₂ column density N(H₂) map from the Herschel satellite, we find that these two molecules trace different environmental conditions in the surrounding of L1544: the c-C₃H₂ distribution peaks close to the southern part of the core, where the surrounding molecular cloud has a N(H₂) sharp edge, while CH₃OH mainly traces the northern part of the core, where N(H₂) presents a shallower tail. We conclude that this is evidence of chemical differentiation driven by different amount of illumination from the interstellar radiation field: in the South, photochemistry maintains more C atoms in the gas phase allowing carbon chain (such as c-C₃H₂) production; in the North, C is mainly locked in CO and methanol traces

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the zone where CO starts to freeze out significantly. During the process of cloud contraction, different gas and ice compositions are thus expected to mix toward the central regions of the core, where a potential Solar-type system will form. An alternative view on carbon-chain chemistry in star-forming regions is also provided.

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Prestellar core modeling in the presence of a filament - The dense heart of L1689B

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Lacking a paradigm for the onset of star formation, it is important to derive basic physical properties of prestellar cores and filaments like density and temperature structures. We aim to disentangle the spatial variation in density and temperature across the prestellar core L1689B, which is embedded in a filament. We want to determine the range of possible central densities and temperatures that are consistent with the continuum radiation data.

We apply a new synergetic radiative transfer method: the derived 1D density profiles are both consistent with a cut through the Herschel PACS/SPIRE and JCMT SCUBA-2 continuum maps of L1689B and with a derived local interstellar radiation field. Choosing an appropriate cut along the filament major axis, we minimize the impact of the filament emission on the modeling.

For the bulk of the core (5000-20000 au) an isothermal sphere model with a temperature of around 10 K provides the best fits. We show that the power law index of the density profile, as well as the constant temperature can be derived directly from the radial surface brightness profiles. For the inner region (<5000 au), we find a range of densities and temperatures that are consistent with the surface brightness profiles and the local interstellar radiation field. Based on our core models, we find that pixel-by-pixel single temperature spectral energy distribution fits are incapable of determining dense core properties.

We conclude that, to derive physical core properties, it is important to avoid azimuthally-averaging core and filament. Correspondingly, derived core masses are too high since they include some mass of the filament, and might introduce errors when determining core mass functions. The forward radiative transfer methods also avoids the loss of information owing to smearing of all maps to the coarsest spatial resolution. We find the central core region to be colder and denser than estimated in recent inverse radiative transfer modeling, possibly indicating the start of star formation in L1689B.

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Revealing a detailed mass distribution of a high-density core MC27/L1521F in Taurus with ALMA

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We present the results of ALMA observations of dust continuum emission and molecular rotational lines toward a dense core MC27 (aka L1521F) in Taurus, which is considered to be at a very early stage of star formation. The detailed column density distribution on size scales from a few tens AU to ~10,000 AU scale are revealed by combining the ALMA (12 m array + 7 m array) data with the published/unpublished single-dish data. The high angular resolution observations at 0.87 mm with a synthesized beam size of ~0.′′74 × 0.′′32 reveal that a protostellar source, MMS-1, is not spatially resolved and lacks associated gas emission, while a starless high-density core, MMS-2, has substructures both in dust and molecular emission. The averaged radial column density distribution of the inner part of MC27/L1521F (r < 3000 AU) is \( N_\text{H}_2 \sim r^{-0.4} \), clearly flatter than that of the outer part, \( \sim r^{-1.0} \). The complex velocity/spatial structure obtained with previous ALMA observations is located inside the inner flatter region, which may reflect the dynamical status of the dense core.

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Striations in molecular clouds: Streamers or MHD waves?

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Dust continuum and molecular observations of the low column density parts of molecular clouds have revealed the presence of elongated structures which appear to be well aligned with the magnetic field. These so-called striations are usually assumed to be streams that flow towards or away from denser regions. We perform ideal magnetohydrodynamic (MHD) simulations adopting four models that could account for the formation of such structures. In the first two models striations are created by velocity gradients between ambient, parallel streamlines along magnetic field lines. In the third model striations are formed as a result of a Kelvin-Helmholtz instability perpendicular to field lines. Finally, in the fourth model striations are formed from the nonlinear coupling of MHD waves due to density inhomogeneities. We assess the validity of each scenario by comparing the results from our simulations with previous observational studies and results obtained from the analysis of CO (J = 1 - 0) observations from the Taurus molecular cloud. We find that the first three models cannot reproduce the density contrast and the properties of the spatial power spectrum of a perpendicular cut to the long axes of striations. We conclude that the nonlinear coupling of MHD waves is the most probable formation mechanism of striations.

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Vortices and spirals in the HD135344B transition disk

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In recent years spiral structures have been seen in scattered light observations and signs of vortices in millimeter images of protoplanetary disks, both probably linked with the presence of planets. We present ALMA Band 7 (335 GHz or 0.89 mm) continuum observations of the transition disk HD135344B at unprecedented spatial resolution of 0.16′′, using superuniform weighting. The data show that the asymmetric millimeter dust ring seen in previous work actually consists of an inner ring and an outer asymmetric structure. The outer feature is cospatial with the end of one of the spiral arms seen in scattered light, but the feature itself is not consistent with a spiral arm.
due to its coradiance. We propose a new possible scenario to explain the observed structures at both wavelengths. Hydrodynamical simulations show that a massive planet can generate a primary vortex (which dissipates at longer timescales, becoming an axisymmetric ring) and trigger the formation of a second generation vortex further out. Within this scenario the two spiral arms observed at scattered light originate from a planet at $\sim 30$ AU and from the secondary vortex at $\sim 75$ AU rather than a planet further out as previously reported.

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Star Formation Relations in the Milky Way
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The relations between star formation and properties of molecular clouds are studied based on a sample of star forming regions in the Galactic Plane. Sources were selected by having radio recombination lines to provide identification of associated molecular clouds and dense clumps. Radio continuum and mid-infrared emission were used to determine star formation rates, while $^{13}$CO and submillimeter dust continuum emission were used to obtain masses of molecular and dense gas, respectively. We test whether total molecular gas or dense gas provides the best predictor of star formation rate. We also test two specific theoretical models, one relying on the molecular mass divided by the free-fall time, the other using the free-fall time divided by the crossing time. Neither is supported by the data. The data are also compared to those from nearby star forming regions and extragalactic data. The star formation “efficiency,” defined as star formation rate divided by mass, spreads over a large range when the mass refers to molecular gas; the standard deviation of the log of the efficiency decreases by a factor of three when the mass of relatively dense molecular gas is used rather than the mass of all the molecular gas.

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Face-on accretion onto a protoplanetary disc
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Globular clusters (GCs) are known to harbor multiple stellar populations. To explain these observations Bastian et al. suggested a scenario in which a second population is formed by the accretion of enriched material onto the low-mass stars in the initial GC population. The idea is that the low-mass, pre-main sequence stars sweep up gas expelled by the massive stars of the same generation into their protoplanetary disc as they move through the GC core. We perform simulations with 2 different smoothed particle hydrodynamics codes to investigate if a low-mass star surrounded by a protoplanetary disc can accrete the amount of enriched material required in this scenario. We focus on the gas loading rate onto the disc and star as well as on the lifetime of the disc. We find that the gas loading rate is a factor of 2 smaller than the geometric rate, because the effective cross section of the disc is smaller than its surface area. The loading rate is consistent for both codes, irrespective of resolution. The disc gains mass in the high resolution runs, but loses angular momentum on a time scale of $10^4$ yrs. Two effects determine the loss of (specific) angular momentum in our simulations: 1) continuous ram pressure stripping and 2) accretion of material with no azimuthal angular momentum. Our study and previous work suggest that the former, dominant process is mainly caused by numerical rather than physical effects, while the latter is not. The latter process causes the disc to become more compact, increasing the surface density profile at smaller radii. The disc size is determined in the first place by the ram pressure when the
flow first hits the disc. Further evolution is governed by the decrease in the specific angular momentum of the disc. We conclude that the size and lifetime of the disc are probably not sufficient to accrete the amount of mass required in Bastian et al.’s scenario.

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Measuring protoplanetary disk gas surface density profiles with ALMA
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The gas and dust are spatially segregated in protoplanetary disks due to the vertical settling and radial drift of large grains. A fuller accounting of the mass content and distribution in disks therefore requires spectral line observations. We extend the modeling approach presented in Williams & Best (2014) to show that gas surface density profiles can be measured from high fidelity $^{13}$CO integrated intensity images. We demonstrate the methodology by fitting ALMA observations of the HD 163296 disk to determine a gas mass, $M_{\text{gas}} = 0.048 M_{\odot}$, and accretion disk characteristic size $R_c = 213$ au and gradient $\gamma = 0.39$. The same parameters match the C$^{18}$O 2–1 image and indicates an abundance ratio $[^{13}\text{CO}]/[\text{C}^{18}\text{O}]$ of 700 independent of radius. To test how well this methodology can be applied to future line surveys of smaller, lower mass T Tauri disks, we create a large $^{13}$CO 2–1 image library and fit simulated data. For disks with gas masses $3 - 10 M_{\text{Jup}}$ at 150 pc, ALMA observations with a resolution of $0.2 - 0.3$ and integration times of $\sim 20$ minutes allow reliable estimates of $R_c$ to within about 10 au and $\gamma$ to within about 0.2. Economic gas imaging surveys are therefore feasible and offer the opportunity to open up a new dimension for studying disk structure and its evolution toward planet formation.

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ALMA Cycle 1 Observations of the HH 46/47 Molecular Outflow: Structure, Entrainment and Core Impact


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We present Atacama Large Millimeter/sub-millimeter Array Cycle 1 observations of the HH 46/47 molecular outflow using combined 12m array and Atacama Compact Array observations. The improved angular resolution and sensitivity of our multi-line maps reveal structures that help us study the entrainment process in much more detail and allow us to obtain more precise estimates of outflow properties than previous observations. We use $^{13}$CO (1-0) and C$^{18}$O (1-0) emission to correct for the 12CO (1-0) optical depth to accurately estimate the outflow mass, momentum and kinetic energy. This correction increases the estimates of the mass, momentum and kinetic energy by factors of about 9, 5 and 2, respectively, with respect to estimates assuming optically thin emission. The new $^{13}$CO and C$^{18}$O data also allow us to trace denser and slower outflow material than that traced by the $^{12}$CO maps, and they reveal an outflow cavity wall at very low velocities (as low as 0.2 km s$^{-1}$ with respect to the cores central velocity). Adding with the slower
material traced only by $^{13}$CO and C$^{18}$O, there is another factor of 3 increase in the mass estimate and 50% increase in the momentum estimate. The estimated outflow properties indicate that the outflow is capable of dispersing the parent core within the typical lifetime of the embedded phase of a low-mass protostar, and that it is responsible for a core-to-star efficiency of 1/4 to 1/3. We find that the outflow cavity wall is composed of multiple shells associated with a series of jet bow-shock events. Within about 3000 AU of the protostar the 13CO and C18O emission trace a circumstellar envelope with both rotation and infall motions, which we compare with a simple analytic model. The CS (2-1) emission reveals tentative evidence of a slowly-moving rotating outflow, which we suggest is entrained not only poloidally but also toroidally by a disk wind that is launched from relatively large radii from the source.

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We performed a multi-wavelength study of the environment surrounding the infrared bubble N10 by using the telescopes PMO 13.7-m, IRAM 30-m, APEX and the VLA array. Infrared bubbles are ideal regions to investigate the impact of UV radiation on the molecular material. Our target is the N10 bubble, which hosts an HII region. IR studies on the young stellar content in N10 suggest a scenario of ongoing star formation, possibly triggered, at the edge of the HII region. We carried out observations of the transition \( J = 1 - 0 \) of the species \(^{12}\text{CO}\) and \(^{13}\text{CO}\) towards N10 using the PMO 13.7-m telescope. We also conduct observations with the IRAM 30-m telescope to investigate molecules that trace star formation. We analyzed the emissions at 24 \( \mu \)m, 8.0 \( \mu \)m, 20 cm and 870 \( \mu \)m from the literature. Two condensations were identified at \(^{13}\text{CO}\) emission, for which we derived properties such as size, temperature, density, and mass. We calculated the flux of ionizing photons and the electronic density inside the bubble, and we derived the fragmentation time to N10. We estimated the physical properties for the densest cold dust clump in the bubble. We identified the YSOs and derived the parameters for the Class I objects. Emission of the transitions \(^{12}\text{CO}^+\) (1 – 0), HCN (1 – 0), SiO (2 – 1), \(N_2\text{H}^+\) (1 – 0) and CS (3 – 2) were mapped. We also performed a deep integration towards the densest clump in N10 to investigate their chemical complexity. The dynamic age of N10 is lower than the estimated fragmentation time, therefore triggered star formation should occur by “Radiation-Driven Implosion” mechanism. The spatial distribution of the molecular species revealed characteristics of star formation in N10. The survey of spectral lines towards the densest clump shows a high chemical complexity, and confirms the presence of outflows and star formation activity in N10.
The Brightest from the Darkest: Deuterium Astrochemistry and the Onset of Massive Star and Star Cluster Formation in Infrared Dark Clouds

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Our understanding of massive star formation remains very limited. Whether or not high-mass stars form in a similar way as low-mass stars can be tested by finding and investigating massive starless cores, which are invoked as the initial condition in the Core Accretion model. In the Competitive Accretion model no such massive starless cores are present. We first searched for massive starless core candidates in the densest regions of Infrared Dark Clouds (IRDCs) with the deuterated species $N_2D^+$. Next we developed an astrochemical model to understand how high levels of deuteration can arise in these cores, especially tracking the deuteration fraction $D_{\text{frac}}^{N_2H^+} = [N_2D^+]/[N_2H^+]$. Our model, which includes the full spin-state reaction network that is needed because of the controlling influence of the ortho-to-para ratio (OPR) of $H_2$, shows that a high level of $D_{\text{frac}}^{N_2H^+} \gtrsim 0.1$ generally requires several local free-fall times to be established under typical core conditions. For further theoretical modeling, the astrochemical network has been implemented into (magneto-)hydrodynamic ((M)HD) simulations with the adaptive mesh refinement (AMR) code Enzo. On the observational side, we have carried out a detailed observational study to measure $[N_2D^+]$, $[N_2H^+]$ and thus $D_{\text{frac}}^{N_2H^+}$ in two massive starless/early-stage cores C1-N and C1-S. High levels of $D_{\text{frac}}^{N_2H^+} (\simeq 0.2 - 0.7)$ are found. Comparison with the theoretical chemodynamical models indicates that both cores have been contracting at rates $\sim 10$ times slower than free-fall, suggesting that the cores are in quasi virial equilibrium, which likely requires the presence of strong, $\sim 1$ mG, magnetic fields. Using ALMA, we have also extended our search for more massive starless core candidates in IRDCs in either single pointings of high mass surface density regions or mosaics of filamentary clouds, using $N_2D^+(3-2)$ emission as our primary tracer. With the knowledge of age that is provided by astrochemistry modeling, we will be able to infer the true pre-stellar core mass function (PSCMF) from the present-day PSCMF. The former is likely to be a key ingredient for the origin of the stellar initial mass function (IMF).
Giant Molecular Cloud Collisions as Triggers of Star Cluster Formation

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Stars primarily form in clusters from within giant molecular clouds (GMCs), but the dominant mechanisms triggering fragmentation and collapse are poorly understood. We investigate collisions between GMCs and their ability to induce gravitational instability and star cluster formation. This process may be a major driver of star formation activity in disk galaxies.

Using magnetohydrodynamics (MHD) simulations with adaptive mesh refinement (AMR), we focus both on understanding the prevailing physical processes as well as predicting key observational signatures. We first develop and implement new photodissociation region (PDR) based heating and cooling functions that span the atomic to molecular transition, mirroring a chemically diverse, multiphase ISM and allowing modeling of non-equilibrium temperature structures. Then we develop an idealized 2D model of magnetized GMCs, systematically exploring the parameter space and investigating magnetic criticality in the context of cloud collisions. Expanding to 3D and adding supersonic turbulence, we model physically realistic GMCs, comparing and contrasting colliding vs. non-colliding cases. We characterize the morphologies of dense gas and magnetic field structure, signatures of cloud kinematics, and cloud dynamics, comparing results to Galactic clouds. Finally, we implement stochastic star formation sub-grid models exploring various levels of density and magnetic regulation. We explore the star formation rate over time, the spatial clustering of the formed stars, and the kinematics of the star particles in comparison to their natal gas cloud.

We find key observational diagnostics of cloud collisions, especially: relative orientations between magnetic fields and density structures, like filaments; $^{13}$CO($J=2-1$), $^{12}$CO($J=3-2$), and $^{13}$CO($J=8-7$) integrated intensity maps, line ratios, and spectra; cloud virial parameters; and properties of the resulting star clusters formed through GMC collision simulations. In comparison to observations of dense GMCs, a number of indicators suggest similarities toward the colliding scenario though it is difficult to draw definitive conclusions from current data. However, we have outlined a variety of potentially new observational signatures that can be the basis for future tests.
Summary of Upcoming Meetings

Cosmic Dust
15 - 19 August 2016, Sendai, Japan
https://www.cps-jp.org/~dust/

Star Formation 2016
21-26 August 2016 Exeter, UK
http://www.astro.ex.ac.uk/sf2016

Heating and Cooling Processes in the ISM
7 -9 September 2016 Cologne, Germany
https://www.astro.uni-koeln.de/hac2016

Linking Exoplanet and Disk Compositions
12 - 14 September, 2016 Baltimore, USA

Interstellar shocks: models, observations & experiments
14-16 September 2016, Torun, Poland
http://shocks2016.faj.org.pl

Half a Decade of ALMA: Cosmic Dawns Transformed
20 - 23 September 2016 Indian Wells, USA
http://www.cvent.com/events/half-a-decade-of-alma-cosmic-dawns-transformed/event-summary-12c52aba23024057862

VIALACTEA2016: The Milky Way as a Star Formation Engine
26 - 30 September 2016, Rome, Italy
http://vialactea2016.iaps.inaf.it

The ISM-SPP Olympian School of Astrophysics 2016
3 - 7 October 2016, Mt. Olympus, Greece
http://school2016.olympiancfa.org/

The Local Truth: Galactic Star-formation and Feed-back in the SOFIA Era - Celebrating 50 years of airborne astronomy
16 - 20 October 2016, Pacific Grove, USA

Search for life: from early Earth to exoplanets
12 - 16 December 2016, Quy Nhon, Vietnam
http://rencontresduvietnam.org/conferences/2016/search-for-life

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