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 ∼2 Myr young cluster Westerlund 2 is among the most massive known in the Milky Way, with at least a dozen O stars and several Wolf-Rayet stars. It is located towards Carina at a distance of about 6,000 pc. The near-infrared image is about 4.3 pc wide, and was obtained with WFC3 on HST.
Hubble 25th Anniversary image. Courtesy STScI.

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
Bob O’Dell
in conversation with Bo Reipurth

Q: You got your PhD in 1962, what was it about, and who was your advisor?

A: I was lucky to have been admitted early into the Department of Astronomy at Wisconsin from a teacher’s college in Illinois (now Illinois State University). Wisconsin astronomers had pioneered photoelectric photometry and when Art Code and Don Osterbrock left CalTech for Wisconsin they started a new era. I was lucky to have been given this chance since I was in the first generation of my family to go attend high school let alone graduate from college. Wisconsin is where photoelectric photometry became modern and was first applied to quantitative analysis of stars and nebulae. Although I first worked for Art Code for 8 months in the early days of the Orbiting Astronomical Observatories, I quickly paired off with Don Osterbrock, who directed me into a career path of the study of HII regions, planetary nebulae, comets, and the occasional supernova remnant. During one of the three years I was at Wisconsin Don was on leave at the Institute for Advanced Study in Princeton. Fortunately for me, the Carnegie Institution required its faculty to retire at 65 and the recently retired Rudolph Minkowski substituted for Don, before moving on to Berkeley. The bottom line is that I had two superb advisors.

My thesis project was the application of the new technology of narrow band interference filters and spectrum scanners with photomultiplier detectors to do quantitative measurements of Planetary Nebulae and the Crab Nebula’s continuum. I then became a Carnegie Fellow at the (then) Mt. Wilson and Palomar Observatories and more accurately calibrated a method of determination of Planetary Nebula distances first developed by Joseph Shklovsky (using photographic broadband photometry) using my Planetary Nebula fluxes. This led to establishing that the Central Stars of Planetary Nebulae were initially highly luminous stars that were collapsing to become White Dwarfs on the same time-scale that the nebular shells were visible. Shklovsky had argued for this earlier, as had George Abell, but neither could establish this as fact.

Q: You were among the founders of the Hubble Space Telescope. Please tell about your involvement with the HST.

A: I had always enjoyed making and using telescopes and instrumentation, starting in grade school. At Wisconsin I helped build a spectrum scanner and two years after leaving there I joined the faculty at the University of Chicago’s Yerkes Observatory. When I became Director I was charged with the construction of a 41-inch Ritchey-Chretien telescope and designed and built the first successful astronomical echelle spectrograph. I had learned about echelles from George Herbig, who built a small instrument that never produced any publishable-by George’s high standards-results. This new instrument was used for stratospheric observations of water in the atmosphere of Venus (producing a usefully low upper-limit) from a Lear Jet operated at the Ames Research Center, and for mapping the internal velocities of several HII regions. It was the ”fastest” nebular spectrograph built up to that time.

While at Yerkes I had been drawn into advising NASA about future astronomy missions. This gave me a good idea of the potential for space astronomy, a subject viewed as “opportunists” by many traditional astronomers. In 1971 I joined Lyman Spitzer and a half dozen others on a NASA advisory group established and chaired by Nancy Roman. We were charged with giving scientific advice and guidelines for a 3-m class space observatory, that was then being given its first consideration during a low-level, one-year feasibility study. The basic idea was first formulated by Hermann Oberth in the 1920’s and refined in a report by Lyman soon after WW II when Army-Surplus V-2 rockets were brought to the USA. Lyman had led the very successful Copernicus satellite project and Princeton had several programs, including rockets and balloon-borne telescopes that could provide fundamental information necessary for taking on a big space telescope project.

Through my participation in other space telescope activities conducted by non-NASA parts of the USA government, I had derived an even more complete picture of what could be done.

Lyman and I had met in July of 1967 when we were members of a climbing trip in British Columbia organized by George Wallerstein. Two weeks in the same tent and often on the same rope, we came to know one another well. At the end of NASA’s feasibility study, he seemed the natural person to become the chief scientist for the Large Space Telescope (later named the Space Telescope to make it easier to sell to the Congress and finally the Hubble Space Telescope). However, he was well settled at Princeton,
in his mid-50’s, and unwilling to relocate to the Marshall Space Flight Center in Huntsville, Alabama to give the project his full attention. He fingered me (then 35) as the appropriate person. I was willing to gamble that support for the LST project could created and that the observatory would be the most important built in my professional lifetime. I left my professorship at Chicago to join an unapproved and unfunded project to become the first Project Scientist for the LST.

It is hard to appreciate today that the HST was not an easy sell to American astronomers. The usual response was that the projected $300M would be better spent building 20 copies of the Palomar 200-inch. Much of my early work was organizing the science advisory structure to draw in scientists from most of the major astronomy facilities and to educate the community. Multiple times over the next several years the project was dead, unfunded by the Congress. I worked with John Bahcall, Lyman Spitzer, and George Field in organizing "advocate" campaigns to educate and influence key members of House and Senate committees. Eventually this worked and we were finally approved for construction in the fiscal year 1978 budget. During the years since the end of the feasibility study a final design had been created and competitions were held for the contractors to be used. During this time we also entered into a highly successful agreement with the European Space Agency for a 15% partnership. By 1982 much of the observatory was well underway in construction and I thought that the position of Project Scientist did not require a full-time person and I relocated to Rice University. After one year a major financial and schedule crisis hit the project and I was asked to come back full-time. I declined, choosing to stay at Rice and continue working as a NASA employee. Then the greatest surprise of my life occurred when all of those who had guaranteed time chipped in a fraction of their reward to give me an equal share (it came out to be 30-orbits of time). Even though Lyman Spitzer had been the early great champion of the HST, his Princeton team had failed to win the competition for building one of the Scientific Instruments and then the proposal for management of the STScI that would have based it in Princeton failed. To me this was cosmically unfair and I immediately gave Lyman half of my reward. To their credit, Al Boggess of Goddard (then the Project Scientist) and Ed Weiler (then head of Astronomy in NASA headquarters) supported the actions of sharing the reward with me and my sharing it with Lyman. My first mosaic of images of the Orion Nebula were made with that reward time and since then I’ve enjoyed good success in landing time using the evolving complement of Scientific Instruments, although successful proposals are like love, you can never have enough.

Q: You have written extensively about the Orion Nebula, including an Annual Reviews article and several other reviews and a popular book. How did your fascination with the Orion Nebula start?

A: During my first semester at Wisconsin the storage space for equipment and new graduate students was the annular pier room under the observing floor of the original observatory’s big refractor. Someone long before had mounted a large rendering of the visual drawing by George Bond made just before Henry Draper’s first blurry photographic images. The detail was wonderful and somehow the idea was planted that it would be great to understand this object. Happily, my training with Osterbrock and Minkowski fed that interest, and one thing led to another. After my Carnegie Fellowship I was at Berkeley, where I had the good fortune to work with the Mexican graduate student Manuel Peimbert, performing emission-line photometry of not only the Huygens Region (the brightest region, imaged in the first published drawings of the Orion Nebula), but also the half degree diameter Extended Orion Nebula, establishing that the outer parts are dominated by scattered light that originates in the inner part of the nebula.

Q: You introduced the concept of proplyds based on your HST images of the ONC. What have we learned over the years about this kind of objects?

A: The bright-edged proplyds were first seen as unresolved emission-line stars by Laques and Vidal in 1979 and interpreted as ionized cloudlets. Later (1987), when Ed Churchwell and others surveyed the Huygens Region with the VLA he was able to make out bright arcs on one side of some of the Laques and Vidal stars. Among several possible interpretations posited was that they were young stellar objects, but he could not establish that as the most likely interpretation. When the first HST images became available to me (even before the December, 1993 HST servicing mission that improved the image quality so dramatically) I had an eureka moment when the pieces fit together and I could clearly recognize the proplyds for what they are.
I came up with this new term because these objects were distinct from other young stellar objects. They were not physically different, rather, their conditions for discovery and their evolution would clearly be different. For those that are directly illuminated by a hot ionizing star (θ^{1} Ori C in the case of the Huygens Region) there is photoionization on the side facing the star, making them quite visible and those objects shielded from the Lyman Continuum of the star (e.g. by the Veil of the Orion Nebula) the objects are seen in silhouette against the bright background of the nebula. Some show both characteristics. We now know that both types of proplyds are shedding mass from their inner disks through photo ablation driven by non-ionizing UV radiation that passes through the Veil or the ionization front facing the star. At this point, through HST imaging and spectroscopy we have a good idea of the basic physics of these objects and can predict that they have limited lifetimes because of being near a hot luminous star. How long they can last will depend on how much material is in their inner disks. Determination of dust masses of those inner regions has only recently begun to mature, because of confusion with far IR thermal radiation from dust in the background of the nebula. I expect that ALMA will be a key to the study of these inner regions. This is an important problem because it is generally thought that most stars form in rich clusters and this means that hot stars are modifying the protoplanetary disks around many objects that will become field stars.

Q: You have discovered more than a hundred Herbig-Haro objects in the Orion Nebula, is there one flow that you have found particularly interesting?

A: The most interesting to me is the grouping of outflows that originate from a region about 50" southwest of θ^{1} Ori C called Orion-South. The outflows power the large-scale outflows to the East (HH 529), West (HH 269) Southeast (HH 203 and HH 204) and Northwest (HH 202), in addition to multiple smaller flows. These are the subject of a large paper recently accepted for publication in the AJ. The flows are of the same total magnitude as in the Orion Fingers that arise from BN-KL, but the HST astrometry show that there are multiple sources over a region of about 10". This region houses an embedded secondary region of star formation. It may be within a bump on the irregular concave surface of the the blister of ionized gas that produces the optically visible Huygens Region, or it may be a cloud of molecular gas lying within the cavity of the blister.

Q: I understand that you had an interesting avocation.

A: I was raised near a WW II pilot training facility (Parks College of Aviation which later became part of St. Louis University) and caught the aviation "bug" quite young. I received my pilot’s license as a senior in high school. At my request, my training included doing spins and loops. When I relocated to Huntsville I had the chance to train in aerobatic flying in one of the first manufactured planes capable of safely doing all the basic maneuvers. I soon bought a second-hand homebuilt biplane (a Pitts Special) that could do all the maneuvers in the aerobatics repertoire. I taught myself the advanced maneuvers and progressed through the various levels of national competition to eventually fly in the "unlimited" (top) category, although never finishing higher than the middle of the pack. Along the way I wrote a quite successful book about aerobatics hat went into a second edition. I also upgraded the Pitts Special with new wings that I had built, installed a more powerful engine, etc. until little except the centerline of the plane was original, at which time the FAA gave me the "builder’s certificate" for the plane. Unlimited flying was becoming a "deep pockets" sport as very high performance airplanes were then available commercially and competition aerobatics in gliders (an established sport in Europe) was just starting in the USA. In 1985 I made the change to glider aerobatics and had greater success there, flying with the USA team in four World Championships. I stopped doing aerobatics as I turned 60, but continued to fly power planes until turning 76 (two years ago), when it seemed a good time to stop stretching my luck.

Q: What are you currently working on?

A: The Orion Nebula is a "tar baby" (c.f. the Uncle Remus tale of that name) from which I find myself unable to break free. Nick Abel of Cincinnati, his former thesis advisor and my frequent collaborator Gary Ferland of Kentucky, and the Kentucky radio astronomer Tom Troland are in the final stages of modeling the Veil of gas and dust that lies in front (towards the observer) of the Huygens Region. This is probably a remnant of the champagne phase of the nebula, which broke-out to the southeast, leaving a layer of almost pristine material in front. We’ve gathered new HST high velocity resolution UV absorption line spectra of H₂, CI, CI*, CI**, SIII, PIII, together with 21-cm absorption lines, and a strong HeI optical absorption line to create an accurate model of the two layers within the Veil. These are probably the best defined samples of the Interstellar Medium because we know exactly the conditions of photo-illumination, abundance, and even the magnetic field strength (through Zeeman splitting of the 21-cm line). This is not a narrowly focused study because Orion’s Veil is the source of the ONC extinction, which shares the characteristics of other young star clusters of having an unusually grey wavelength dependence. Hopefully we will soon understand why.
1 Introduction

BHR 71 is a nearby (200 pc) isolated Bok globule located in the constellation Musca, not far from the Coalsack. It has become well known for its spectacular outflow(s), with the most prominent of these lying almost in the plane of the sky and having a high degree of collimation (Bourke et al. 1997). Abundance enhancements of many molecular tracers have been measured, a phenomenon only observed in a very small number of outflows (Garay et al. 1998, 2002; Bovill et al. 2002). Its isolation, nearness to Earth, and outflow activity has led to a number of studies over the years, while its outflow structure and chemistry has resulted in comparisons to the L1157 outflow in the far northern sky, so that BHR 71 outflow is the "L1157 of the south". But L1157 is a single protostar while BHR 71 is a wide binary (components denoted as IRS 1 and IRS 2), a difference that has not yet been fully exploited.

2 Discovery

2.1 Ammonia and Near-infrared surprises

The discovery of the impressive outflows in BHR 71 is an interesting story. For my Master research I compiled a list of southern Bok globules, using the Hartley dark cloud catalogue (Hartley et al. 1986) and the Clemens & Barvainis (1988; hereafter CB88) criteria for selecting candidates. Many days were then spent poring over the Schmidt survey plates at Mt Stromlo Observatory to locate and inspect the candidates for their suitability as small isolated Bok globules. The resulting BHR catalog (Bourke, Hyland & Robinson 1995) lists 169 globules and with the 248 clouds listed in CB88 provides a uniformly selected all-sky sample of Bok globule candidates. We investigated the IRAS properties of the BHR sample, and embarked on an ammonia survey using the Parkes radio telescope (Bourke et al. 1995b), with the aim of comparing their dense gas properties with those of the Myers’ cores, also observed in ammonia with similar angular resolution (Myers & Benson 1983; Benson & Myers 1989). Each pointing with Parkes took an hour, so a single observation of each globule was planned before any mapping was to take place. But the first observation of BHR 71 was quite an impressive result once the data were reduced (in real time at the telescope), showing a line much brighter than other globules. Immediately it was decided to map it rather than survey other globules, a good decision in retrospect. At about the same time we had begun to map some of the globules with one of the new near-infrared array cameras just becoming available, with the goal of mapping the extinction through the globules and hence their density distributions (Jones, Hyland & Bailey 1984). In our case we used the 128×128 pixel camera IRIS on the AAT (Allen et al. 1993). Observations with IRIS provided the real "a-ha" moment, when we observed BHR 71 on the night of 15 February 1992 (Bourke et al. 1993), my first ever OIR observing run, on a premier facility (4-m looks rather small these days!). After a quick subtraction of a less-than-ideal sky frame, the fan-shaped nebula of BHR 71-IRS 1 appeared on the computer screen in the AAT control room. It was stunning. One must remember that IR cameras were very new, so that no large imaging surveys like 2MASS were yet available. Once the full NIR mosaic was obtained it was clear the nebulosity was due to a bipolar outflow, even without supporting molecular line observations (Bourke et al. 1993). Only one telescope existed that could undertake such observations (SEST) but we did not have access to it (see next section). During our IRIS run in early 1993 when BHR 71 was again visible we took narrow-band images and K-band spectra which clearly showed that a large fraction of the nebulosity was due to (shocked) molecular hydrogen emission (Bourke 1994).

2.2 The Spectacular Molecular Outflow

Kimmo Lehtinen in Finland was also using IRIS in service time to observe the Thumbprint Nebula, near Cham III, as part of his PhD work (Lehtinen & Mattila 1996), and had been in touch with me for some assistance with his data. This lead to a collaboration to observe BHR 71 with SEST through Onsala time in early 1994, and the CO observations revealed the outflow. We started mapping also in CS and HCO+ and the CO isotopologues, and proposed to map SiO based on these data.
Meanwhile in Chile, Leo Bronfman and collaborators (Bronfman, Nyman & May 1996) were observing IRAS-selected candidate UCHII regions in CS 2-1 with the Onsala 20-m and SEST. IRAS 11590-6452 (aka BHR 71-IRS 1) was one of the candidates and was easily detected with SEST. I hope I recall my conversations with Guido Garay correctly, but I believe he used the survey spectra to identify outflow candidates for follow-up CO observations in 1995 with SEST, in ESO time, and soon realised that the outflow from IRAS 11590, in Sa 136 (Sandquist 1977) was rather special. His team started mapping the outflow in SiO, methanol, CS and HCO$^+$, and preliminary results were published in the Messenger (Garay et al. 1996).

Kimmo and I had become aware of Guido’s program through the SEST schedule and through conversations with Diego Marcondes, then a student at Harvard in Phil Myers’ group (which I had recently joined) co-supervised by Guido. We didn’t know exactly what data he was taking. There was no co-ordination between Onsala and ESO on the allocation of telescope time, so Guido had time in September 1995 and we had time in October 1995 to undertake essentially the same observations. Guido visited the CfA in 1995-96, and we discussed the situation – Guido had a student who was to focus on the chemically active outflow angle. Thankfully we agreed to collaborate on the molecular data analysis and co-wrote the outflow discovery paper (1997) and the molecular enhancements paper (1998).

In 1994 I had attended a nice conference at the Haystack observatory on Cloud Cores (proceedings edited by Clemens & Barvainis!), and met some other students working on Bok globules, Ralf Launhardt and Joao Alves, as well as many others who became collaborators and/or friends. Ralf had been observing northern globules in mm dust continuum and was looking to expand his program to the south, so shortly after he observed BHR 71 during one of his SEST bolometer runs and collaborated with us on the discovery paper (Bourke et al. 1997). If you know Ralf you should ask him about his travel adventures getting to Haystack!
A CO 1-0 map of the main (IRS1) outflow is shown in Figure 2 (Bourke et al. 1997) and a CO 3-2 maps of both outflows in Figure 3 (Parise et al. 2006). The lobes are very well collimated after an initial semi-opening angle of about 15°, becoming increasingly collimated at higher velocities (Bourke et al. 1997; Parise et al. 2006), and are well separated, with an inclination angle of about 85° to the line-of-sight. The lobes extend to 0.3 pc from the mm peak (IRS1) with a total mass of about 1 M⊙. Correcting for the inclination, the outflow velocities in the bulk flow reach up to ~30 km/s, not including the observed higher-velocity components. The general details of the outflow are seen in both CO 1-0 and 3-2 maps, with outer blue (south) and red peaks (north) equally separated from the protostar, with an inner blue peak located at the termination of the optical nebula at the globule edge, as seen in Figure 2. A red (northern) counterpart to the inner blue (southern) peak is seen in the details of the CO 3-2 and 6-5 maps (Gusdorf et al. 2015). The higher-J CO observations (J=3...10) indicate temperatures 50-100 K in the gas traced by these lines, with the emission possibly a result of photon heating of the outflow cavity walls, due to internal shocks and/or internal jet/ambient gas interactions (van Kempen et al. 2009; Yildiz et al. 2013, 2015).

3 A Binary System with Bipolar Outflows

BHR 71 is a binary protostellar system with a wide separation of 3400 AU (IRS1 & IRS2; Myers & Mardones 1998; Bourke 2001). Observations with ISO and SEST, combined with near-infrared observations, clearly show that each protostar is driving its own collimated CO outflow, and shocks are present in each outflow (Bourke 2001; Corporon & Reipurth 1997; Parise et al. 2006). The outflow from IRS2 is shorter, with each lobe extending about 0.1 pc from the protostar, and its inclination angle is less than 65°. However, seen in Figure 5 (just before the arrowhead indicating the SE lobe of the IRS2 outflow; see also Fig. 4), there is a knot of H₂ emission which lies along the axis of the IRS2 red lobe, but quite a distance away from its end. This may represent an earlier outflow episode from IRS2. IRS1 dominates the emission at almost all wavelengths (Chen et al. 2008), and hence the bolometric luminosity of the system. Its luminosity is 13-14 L⊙ while that of IRS2 is only ~0.5 L⊙ (Chen et al. 2008). Their properties are consistent with being Class 0 protostars, although more data points at wavelengths longer than ~500µm are needed. PACS spectral-line scanning covering CO lines up to J=40 indicate temperatures around IRS1 of ~500 K (Green et al. 2013). The outflows are not aligned, which may suggest the rotational axes of the protostars are also not aligned, but this remains to be tested.
Chen et al. (2008) suggest the binary formed via prompt rotational fragmentation of the collapsing core. Although they clearly formed in the same core, as BHR 71 is isolated, there is insufficient data to confirm this scenario. In particular the kinematics of the dense gas associated with IRS2 have not yet been revealed, something we are trying to rectify with ALMA observations (Tobin et al. in prep.). The envelope traced by high-resolution $N_2H^+$ observations shows a hole at the location of IRS1, likely due to destruction of the molecule by the outflowing CO gas, while the velocities are consistent with rotational motions about IRS1. A lack of emission at IRS1 and IRS2 is also seen in high-resolution $NH_3$ and $N_2D^+$ data (Tobin et al. in prep.). In infrared extinction the envelope is flattened, but models of hydrostatic sheets or filaments do not provide a good fit to the data (Tobin et al. 2010). The outflows are not perpendicular to this envelope; in fact the IRS2 outflow is almost aligned with the long axis of the core.

4 Shocks in the Outflow

Shocks in the BHR 71 outflows were evident in the earliest observations of infrared, molecular and optical lines (Bourke 1994; Garay et al. 1996, 1998; Corporon & Reipurth 1997; Yun et al. 1997). The majority of the nebulosity seen at near and mid-infrared wavelengths is due to $H_2$ emission, outside of the IRS1 fan-nebulosity (Fig. 3 and 4), and both outflows contain Herbig-Haro objects (Fig. 5).

Abundance enhancements of a number of molecular species are observed in the outflow lobes of IRS1. In particular the abundances of SiO ($\times 350$) and CH$_3$OH ($\times 40$) are significantly greater than in the surrounding cloud, while CS is unchanged and HCO$^+$ is decreased (Garay et al. 1998), relative to the values at IRS1. When comparing to an ambient position within the cloud, the enhancement of SiO is even greater ($>600$). HCO$^+$, $H_2CO$, HCN, CS and SO are enhanced by 10-30 or more, while DCO$^+$ and $N_2H^+$ are depleted by factors of at least 5-10 (Bovill et al. 2002). These values are lower than observed in L1157, which appears to be unusual even among the small number of chemically active outflows. The abundance of water has been measured in the outflow with Odin and SWAS (Bjerkeli et al. 2009) to be $10^{-5} - 10^{-4}$, in agreement with shock models (Bergin, Melnick & Neufeld 1998).

Lines of molecular hydrogen have been used to study the BHR 71 shocks in detail (Gianni et al. 2004, 2011; Neufeld et al. 2009; Takami et al. 2010; Gusdorf et al. 2015; Velusamy et al. 2014). Interestingly, no [FeII] emission has been detected at near-infrared wavelengths, although HH objects are present. The reason for this is unclear. Modelling the near-infrared emission from HH320 in the IRS2 outflow as a J-shock with a magnetic precursor suggests pre-shock densities of $10^4$ cm$^{-3}$, shock velocities $\sim 40$ km/s, and age $< 500$ yr. Pure rotational lines observed with Spitzer in the mid-infrared are sensitive to higher densities in both flows of $>10^6$ cm$^{-3}$, with both cool ($300-500$ K) and warm ($\sim 1500$ K) components detected. The young age of the flows is evident in the ortho-to-para $H_2$ ratio, measured at 2-2.5 rather than 3 as expected in equilibrium. The addition of SiO data generally supports the conclusions from the $H_2$ observations, although they suggest slightly lower pre-shock densities and shock velocities.

Observations of CO $J_{up} = 16,11,7,6,4,3$ at select positions in the red (northern) lobe of IRS1 have been used to study the shocks (Gusdorf et al. 2015). The results are consistent with those given above for the near-infrared data, but suggest an older age of a few thousand years. The observations and modelling show that SiO must be formed due to release of Si from grains due to the shocks, consistent with earlier models of grain-sputtering by shocks (Schilke et al. 1997).
5 Future Directions

Although much is now known about the protostars and outflows in BHR 71, there are some key pieces of information missing, and some exciting ongoing studies.

5.1 Proper Motions

Maps of the BHR 71 outflows in the 2.12 \( \mu m \) line of \( H_2 \) have been made since 1993 and can be used to study the proper motions of IR knots in the flows (Caratti o Garatti et al. in preparation), and to monitor the brightness of the nebulosities. The motions of 20 groups of knots have been measured to have tangential velocities from 10 to over 100 km/s. The proper motion vectors allow the flow directions to be mapped, generally following the smoothed curved structure seen in the infrared maps. This record also shows that BHR 71-IRS 1 brightened sometime in the mid 1990s, and likely spawned a new set of shock knots close to IRS1 as part of this event (evident after continuum subtraction). Continuing these observations into future epochs will be important to determine whether the shock knots studied in detailed at the SiO peaks are stationary or moving with the flow, and to monitor the progress of the newly emerged shock knots.

5.2 Binary/Core kinematics

As BHR 71 is nearby, isolated, and contains two Class 0 protostars in a binary system, it offers a rare opportunity to understand the formation of wide binaries. The protostars reside in a common envelope, as traced in high resolution NH\(_3\) observations (Tobin et al. in prep.) and as they are both young are unlikely to have dynamically evolved. Observations on size scales from 10,000 AU down to \( \sim 1000 \) AU will enable the angular momentum on different size scales to be determined and thus allow different formation models to be tested, e.g., rotational fragmentation or turbulent fragmentation. We have recently obtained ALMA observations of \( ^{13}C_2\)O, and \( N_2D^+ \) (Tobin et al. in prep.), which combined with our NH\(_3\) data should allow us to seriously address this question.

5.3 High Velocity Gas

Observations of the outflows have focused on the main, relatively low-velocity component of the gas, as seen in Figs. 2 & 3, with line-of-sight velocities up to about 10 km/s. Deep integrations of CO and SiO at the shock positions in the red-lobe shows velocities up to \( \sim 40 \) km/s relative to the systemic velocity (Fig. 6; Garay et al. 1998; Gusdorf et al. 2011, 2015), but this component has not yet been mapped. At the position of IRS1, extremely high-velocity compact emission, with velocities up to 100 km/s, has been observed in water and [OI] \( 63 \) \( \mu m \) emission, and in CO 3-2 and CO 10-9 (Kristensen et al. 2012; Yildiz et al. 2013; Nisini et al. 2015). Although the [OI] data indicate offset blue and red-shifted emission, a high-angular resolution map is needed to better locate this emission and compare it to the recent IR outburst. The lack of an ionised jet (e.g., no [FeII] emission) suggests that the
high-velocity jet component will be primarily molecular and atomic and can be mapped with existing facilities (i.e., APEX, ALMA, SOFIA), and perhaps in HI with SKA in the future.

5.4 The IRS2 outflow

Not much attention has been given to the IRS2 outflow. In CO emission it appears to be shorter than the IRS1 outflow, but significantly warmer (Fig. 3; Parise et al. 2006). This should be tested with the high-J CO line mapping data already available. The IR knot in the SE visible in Figs. 4 & 5 may be from the IRS2 outflow, so CO observations should be made at this position (or very-high spectral resolution IR observations) to measure the gas velocity.

5.5 Structure in the IRS1 nebulosity

The fan-shaped nebula south of IRS1 shows a regular striped pattern, also seen in the northern lobe in the area of shocked H$_2$ emission associated with the SiO peak (Fig. 7). What is causing this pattern of stripes? Does it represent regular episodic ejection events from a precessing protostar, perhaps due to the influence of IRS2? These stripes are also seen in the Spitzer data and the VLT optical image (Fig. 1), so they are real. Further sensitive, high-resolution near-infrared imaging is needed together with some theoretical thinking to make progress on this question.

6 Summary

The BHR 71 system consists of two well collimated molecular outflows powered by a wide protostellar binary of Class 0 protostars. One protostar is 10$\times$ more luminous than the other and drives a large, more massive outflow in which abundance enhancements of a number of molecules is is observed. Its southern location makes it a prime target for ALMA observations and future southern facilities and I expect it will continue to provide us with many insights into protostar and outflow formation and evolution in the years to come.

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1 Introduction

Studying exoplanet atmospheres is a daunting task. The high contrast ratio of exoplanets to host stars precludes many detailed direct imaging or spectroscopic techniques which can yield a wealth of knowledge about the composition and patterns within an atmosphere. Emerging as a bridge population to giant exoplanets are young (20-130 Myr), isolated brown dwarfs that are vastly easier to study (Faherty et al. 2013ab, Allers & Liu 2013, Gagné et al. 2014abc, Gagné et al. 2015ab, Cruz et al. 2009). They are isolated, bright, and can be studied with a variety of small to large facilities from either the ground or space. Young brown dwarfs and directly-imaged exoplanets have enticingly similar photometric and spectroscopic characteristics, indicating that their cool, low gravity atmospheres should be studied in concert. Similarities between the peculiar shaped $H$ band, near- and mid-IR photometry as well as location on color magnitude diagrams provide important clues about how to extract physical properties of planets from current brown dwarf observations.

When it comes to scientific attention, exoplanets are the celebrities. For years, I would attend exoplanet conferences as a brown dwarf scientist and feel like a little kid who was invited to a classmates party but knew I was only there because my friends mom made them invite the whole class. Now in 2015, much of that has changed with brown dwarf discoveries rivaling some of the best directly imaged exoplanets. In this article I will summarize the exciting crossover between these two disciplines and highlight why young brown dwarfs are the key to solving the mysteries of directly imaged exoplanets.

2 The Overlap of Brown Dwarfs and Giant Planets

At masses $< 75 \, M_{Jup}$ – the Hydrogen burning mass limit –, the interior of a compact source changes drastically. At these lower masses, electron degeneracy pressure halts contraction preventing the core from ever reaching the required temperature for nuclear fusion. Therefore, objects with masses $< 75 \, M_{Jup}$ cool through their lives, their spectral energy distributions morphing due to changing atmospheric chemistry. As demonstrated in Figure 1, this evolution produces a temperature, age, and mass degeneracy that leads to an important – and at times completely indistinguishable – overlap in the physical properties of the lowest mass stars, brown dwarfs and planets.

To date, all directly imaged giant exoplanets have estimated temperatures squarely in the well-studied brown dwarf regime. In other words, each planet has a population of equivalent temperature, older, higher mass analogs which are isolated hence much easier to follow-up on with ground and space based instruments. Even more interesting, over the past few years, a population of brown dwarfs that share both the effective temperatures ($T_{eff}$) AND the ages of giant exoplanets has emerged making them ideal targets for detangling the effects of atmosphere, gravity, and mass in observable features of both populations (e.g. Faherty et al. 2013ab, Liu et al. 2013, Gagne et al. 2014abc, 2015ab, Gizis et al. 2012).
3 Identifying Young, Isolated Brown Dwarfs

Brown dwarfs discovered to date were primarily found in large area sky surveys such as 2MASS, SDSS, WISE, and UKIDSS by identifying isolated point sources on color-color diagrams for spectroscopic follow-up (see Kirkpatrick 2005 for a review of early brown dwarf searches). Once the population of individual brown dwarfs had emerged with significant numbers of sources at each spectral subtype, outliers became obvious (see for example Faherty et al. 2009). At the extremes there were sources that looked old/low metallicity/cloudless or young/cloudy/high metallicity. For the latter, there were distinct spectral features such as weak collision-induced H$_2$ absorption, a sharply peaked H band spectrum, weakened alkali lines, and enhanced metal-oxide absorption bands (see for example Cruz et al. 2009, Allers & Liu 2013, Gagné et al. 2015ab and an example in Figure 3). Moreover these same sources were red photometric outliers compared to spectrally “normal” counterparts in the near and mid infrared (see Figure 3).

Assuming two objects at the same spectral subtype are close in effective temperature, the major differences between an old and a young object arise because younger sources have a lower surface gravity hence significantly different pressure ($P \sim g/\kappa_R$, where $\kappa_R$ is the Rosseland mean opacity). Hence the young population emerges with spectral properties attributable to gravity effects. In order to categorize the sources discovered in this “young” category, two classification schemes have emerged: (1) Cruz et al. 2009 examines the optical data and assigns a low-surface gravity ($\gamma$), intermediate gravity ($\beta$), or field gravity based on the strength of metal oxide absorption bands and alkali lines. On this scheme, $\gamma$ and $\beta$ objects are thought to be younger than Pleiades age stars (age $< \sim 120$ Myr). (2) Allers & Liu 2013 examine near-infrared spectral data and use spectral indices to assign a very low gravity (vl-g), intermediate gravity (int-g), or field gravity (fld-g) to a given source. As discussed in Allers & Liu 2013, the optical and near infrared systems are roughly consistent. However, in order to ground the gravity designations and their accompanying spectral peculiarities as age indicators, a sample of age-calibrated objects is required.

4 An Age Calibrated Exoplanet Analog Sample

There are now over 100 isolated, late-type M and L dwarfs with anomalous spectral, photometric and luminosity features attributed to a lower surface gravity (e.g, Cruz et al. 2009, Faherty et al. 2013ab, Gagné et al. 2014abc, Gagné...
Figure 4: The spectral type versus absolute magnitude diagram in 2MASS J as well as WISE W2 from Faherty et al. in prep. The grey distribution is the polynomial fit to “normal” objects from Dupuy & Liu 2012. Young objects are displayed as in Figure 3. While the majority of L dwarfs are normal or underbright for their spectral type in M/J, this trend reverses by M/W.

5 Clouds on Brown Dwarfs

At $T_{\text{eff}} < 3000$ K, the emergent spectra of objects are shaped by gas and condensation chemistry. The low temperatures and high-pressures ($1 \text{ bar} < P < 10 \text{ bar}$) favor the formation of molecules such as CO, CH$_4$, N$_2$, NH$_3$, and H$_2$O. The spectral classification for sources in the range ($3000 \text{ K} > T_{\text{eff}} > 500 \text{ K}$) corresponds to late-type M, L, T and Y with each class defined by the effects of changing molecular species available in the atmospheres.

At the warmest temperatures, the atmosphere is too hot for the condensation of solids (Allard & Hauschildt 1995; Lodders 1999). But as the $T_{\text{eff}}$ falls below 2500 K, both liquid (e.g. Fe) and solid (e.g. CaTiO$_3$, VO) mineral and metal condensates settle into discrete cloud layers (Ackerman & Marley 2001; Tsuji et al. 1996; Woitke & Helling 2004; Allard et al. 2001). These condensates strongly influence spectral flux distributions and can imprint silicon grain absorption features such as the one detected at mid-infrared wavelengths in the prototypical young L dwarf 2M0355 (Burgasser et al. in prep and Cushing et al. 2006).

5.1 The Interplay of Age and Clouds

Confounding our understanding of cloud formation in low-temperature atmospheres is mounting evidence for a correlation between enhanced photospheric dust and youth. From studies of young brown dwarfs, low-surface gravity sources (Figure 3) are found to have unusually red near to mid-infrared colors (NIR, MIR respectively) and they are underbright through $\sim 2.5 \mu$m when compared to their equivalent temperature counterparts (Faherty et al. 2012; 2013ab, see Figure 2 and Figure 4 left panel). In a detailed study of the prototypical isolated, young brown dwarf, Faherty et al. (2013a) found that the deviant colors and under-luminosity was best explained by enhanced dust or thick photospheric clouds shifting flux to longer wavelengths. This behavior is exemplified in Figure 2.
where two objects having very similar bolometric luminosity, with nearly identical spectral types in the optical and the near infrared are plotted. They have quite different flux calibrated spectral energy distributions (scaled with a parallax measurement for each) despite their other similarities. While the younger one appears to be under-bright in the optical through near infrared, it switches to overbright in the midinfrared indicating a redistribution of flux for young objects.

The recognition that cloud properties and age are correlated has led to some of the most important developments in atmospheric models to date.

6 The Diversity in the Sample

Several questions have emerged from the young brown dwarf sample. Do the gravity features used to identify them as peculiar correspond with age? Does the extent of photometric deviation in the NIR or MIR indicate atmospheric conditions? Do the bolometric luminosities and subsequent effective temperatures trend the way the “normal” or older sample does? Figures 3-5 answer many of those questions. As can be seen in Figure 3 for sources kinematically linked to the same group hence assumed to be co-eval, there are both very low gravity (or $\gamma$ sources) and intermediate gravity (or $\beta$ sources). This indicates that spectral features are not fully correspondent with age. Furthermore, the reddest sources are not the youngest ones in the associations. Hence while Figure 2 seems to indicate that enhanced photospheric dust or high lying clouds in the young sources redistribute the flux to longer wavelengths driving objects redder, this is not correlated with the age range seen among the listed moving groups with members. The diversity seen among the kinematic sample implies a complex relationship between clouds and spectral features.

Figure 5 shows the bolometric luminosity and the subsequent effective temperature for the parallax sample of young brown dwarfs along with directly imaged giant exoplanets (from Filippazzo et al. 2015, Faherty et al. in prep). From a physical point of view, one would expect...
that the young sources should be overluminous compared to an equivalent type object because they are still contracting to their final radius. Indeed the young late-type M dwarfs appear to follow that trend. However, there is a stark difference with the L dwarfs which appear normal or slightly underluminous. Using a model radius estimate, one can convert the bolometric luminosity to an effective temperature. On the left panel of Figure 5 one can see that the luminosity differences translate into a difference of up to 300K between the young and the field age L dwarfs. The directly imaged exoplanets show a similar trend which has been noted in the literature (e.g. Males et al. 2015, Bowler et al. 2014).

7 What lies ahead

Combining all the information gleaned from the young brown dwarf sample it is clear that there is tremendous diversity even among coeval age calibrated objects. Furthermore it is clouds and weather related phenomena that likely drive much of the diversity we see in the young objects. Hence future work on known and new exoplanet discoveries will require a better understanding of the composition and turbulent nature of the atmosphere. As it is unlikely that exoplanet techniques will surpass what we can do with isolated brown dwarfs in the near future, brown dwarfs will remain the “cool” sample to go after.

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Spectroscopy and Linear Spectropolarimetry of the early Herbig Be Stars PDS 27 and PDS 37

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The number of well-studied early-type pre-main-sequence objects is very limited, hampering the study of massive star formation from an observational point of view. Here, we present the results of VLT/FORS2 spectropolarimetric and VLT/X-shooter spectroscopic observations of two recently recognised candidate Herbig Be stars, PDS 27 and PDS 37. Through analysis of spectral lines and photometry, we find that these two objects are hot, 17500±3500 K, have large radii, 17.0±4.0 and 25.8±5.0 R⊙, and are very massive, 15.3±5.4 and 21.1±5.3 M⊙ for PDS 27 and PDS 37, respectively. This suggests that these two objects are very young in their evolution and may become O-type stars. Their youth is supported by their high accretion rates of the order of 10−3–10−4.5 M⊙ yr−1. A change in linear polarisation across the absorption component of Hα is detected in both objects. This change indicates that the circumstellar environment close to the star, at scales of several stellar radii, has a flattened structure, which we identify as an inner accretion disk. Strong variability is seen in both objects in many lines as further indication of an active circumstellar environment.

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Untangling the Recombination Line Emission from HII Regions with Multiple Velocity Components

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H II regions are the ionized spheres surrounding high-mass stars. They are ideal targets for tracing Galactic structure because they are predominantly found in spiral arms and have high luminosities at infrared and radio wavelengths. In the Green Bank Telescope H II Region Discovery Survey (GBT HRDS) we found that > 30% of first Galactic quadrant H II regions have multiple hydrogen radio recombination line (RRL) velocities, which makes determining their Galactic locations and physical properties impossible. Here we make additional GBT RRL observations to determine the discrete H II region velocity for all 117 multiple-velocity sources within 18° < l < 65°. The multiple-velocity sources are concentrated in the zone 22° < l < 32°, coinciding with the largest regions of massive star formation, which implies that the diffuse emission is caused by leaked ionizing photons. We combine our observations with analyses of the electron temperature, molecular gas, and carbon recombination lines to determine the source velocities for 103 discrete H II regions (88% of the sample). With the source velocities known, we resolve the kinematic distance ambiguity for 47 regions, and thus determine their heliocentric distances.

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A WISE Census of Young Stellar Objects in Perseus OB2 Association

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We have performed a WISE (Wide-Field Infrared Survey Explorer) based study to identify and characterize young stellar objects (YSOs) in 12° × 12° Perseus OB2 association. Spectral energy distribution (SED) slope in range of 3.4–12 µm and a 5σ selection criteria were used to select our initial sample. Further manual inspection reduced our final catalog to 156 known and 119 YSO candidate. The spatial distribution of newly found YSOs all over the field shows an older generation of star formation which most of its massive members have evolved into main sequence stars. In contrast, the majority of younger members lie within the Perseus molecular cloud and currently active star forming clusters such as NGC1333 and IC348. We also identified additional 66 point sources which passed YSO selection criteria but are likely AGB stars. However their spatial distribution suggests that they may contain a fraction of the YSOs. Comparing our results with the commonly used color-color selections, we found that while color selection method fails in picking up bright but evolved weak disks, our SED fitting method can identify such sources, including transitional disks. In addition we have less contamination with background sources such as galaxies, but in a price of loosing fainter ($J_{\text{mag}} > 12$) YSOs. Finally we employed a Bayesian Monte Carlo SED fitting method to determine the characteristics of each YSO candidate. Distribution of SED slopes and model driven age and mass confirms separated YSO populations with suggested three age groups of younger than 1 Myr old, 1–5 Myr old, and older than 5 Myrs which agrees with the age of Per OB2 association and currently star forming sites within the cloud.

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An empirical sequence of disk gap opening revealed by rovibrational CO

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The fundamental rovibrational band of CO near 4.7 µm is a sensitive tracer of the presence and location of molecular gas in the planet-forming region of protoplanetary disks at 0.01–10 AU. We present a new analysis of a high-resolution spectral survey ($R \sim 96,000$, or $\sim 3.2 \text{ km s}^{-1}$) of CO rovibrational lines from protoplanetary disks spanning a wide range of stellar masses and of evolutionary properties. We find that the CO emission originates in two distinct velocity components. Line widths of both components correlate strongly with disk inclination, as expected for gas in Keplerian rotation. By measuring the line flux ratios between vibrational transitions $F_{v=2-1}/F_{v=1-0}$, we find that the two velocity components are clearly distinct in excitation. The broad component ($\text{FWHM} = 50 – 200 \text{ km s}^{-1}$) probes the disk region near the magnetospheric accretion radius at $\approx 0.05 \text{ AU}$, where the gas is hot ($800 – 1500 \text{ K}$). The narrow component ($\text{FWHM} = 10 – 50 \text{ km s}^{-1}$) probes the disk at larger radii of 0.1–10 AU, where the gas is typically colder (200–700 K). CO excitation temperatures and orbital radii define an empirical temperature-radius relation as a power law with index $-0.3 \pm 0.1$ between 0.05–3 AU. The broad CO component, co-spatial with the observed orbital distribution of hot Jupiters, is rarely detected in transitional and Herbig Ae disks, providing evidence for an early dissipation of the innermost disk. An inversion in the temperature profile beyond 3 AU is interpreted as a tracer of a regime dominated by UV pumping in largely devoid inner disks, and may be a signature of the last stage before the disk enters the gas-poor debris phase.

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The Three-mm Ultimate Mopra Milky Way Survey I. Survey Overview, Initial Data Releases and First Results

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We describe a new mm-wave molecular-line mapping survey of the southern Galactic Plane and its first data releases. The Three-mm Ultimate Mopra Milky Way Survey (ThrUMMS) maps a 60° × 2° sector of our Galaxy’s fourth quadrant, using a combination of fast mapping techniques with the Mopra radio telescope, simultaneously in the $J = 1 \rightarrow 0$ lines of $^{12}$CO, $^{13}$CO, C$^{18}$O, and CN near 112 GHz at ~arcminute and ~0.3 km s$^{-1}$ resolution, with ~2 K channel$^{-1}$ sensitivity for $^{12}$CO and ~1 K channel$^{-1}$ for the other transitions. The calibrated data cubes from these observations are made available to the community after processing through our pipeline. Here, we describe the motivation for ThrUMMS, the development of new observing techniques for Mopra, and how these techniques were optimised to the objectives of the survey. We showcase some sample data products and describe the first science results on CO-isotopologue line ratios. These vary dramatically across the Galactic Plane, indicating a very wide range of optical depth and excitation conditions, from warm and translucent to cold and opaque. The population of cold clouds in particular have optical depths for $^{12}$CO easily exceeding 100. We derive a new, nonlinear conversion law from $^{12}$CO integrated intensity to column density, which suggests that the molecular mass traced by CO in the Galactic disk may have been substantially underestimated. This further suggests that some global relationships in disk galaxies, such as star formation laws, may need to be recalibrated. The large ThrUMMS team is proceeding with several other science investigations.

http://www.astro.ufl.edu/~peterb/research/thrumms/papers/

Filaments in the Lupus molecular clouds

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We have studied the filaments extracted from the column density maps of the nearby Lupus 1, 3, and 4 molecular clouds, derived from photometric maps observed with the Herschel satellite. Filaments in the Lupus clouds have quite low column densities, with a median value of $\sim 1.5 \times 10^{21} \text{cm}^{-2}$ and most have masses per unit length lower than the maximum critical value for radial gravitational collapse. Indeed, no evidence of filament contraction has been seen in the gas kinematics. We find that some filaments, that on average are thermally subcritical, contain dense cores that may eventually form stars. This is an indication that in the low column density regime, the critical condition for the formation of stars may be reached only locally and this condition is not a global property of the filament. Finally, in Lupus we find multiple observational evidences of the key role that the magnetic field plays in forming filaments, and determining their confinement and dynamical evolution.

Hierarchical fragmentation and collapse signatures in a high-mass starless region

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Aims: Understanding the fragmentation and collapse properties of the dense gas during the onset of high-mass star formation.

Methods: We observed the massive ($\sim 800 M_\odot$) starless gas clump IRDC 18310-4 with the Plateau de Bure Interferometer (PdBI) at sub-arcsecond resolution in the 1.07 mm continuum and N\textsuperscript{2}H\textsuperscript{+}(3–2) line emission.

Results: Zooming from a single-dish low-resolution map to previous 3 mm PdBI data, and now the new 1.07 mm continuum observations, the sub-structures hierarchically fragment on the increasingly smaller spatial scales. While the fragment separations may still be roughly consistent with pure thermal Jeans fragmentation, the derived core masses are almost two orders of magnitude larger than the typical Jeans mass at the given densities and temperatures. However, the data can be reconciled with models using non-homogeneous initial density structures, turbulence and/or magnetic fields. While most sub-cores remain (far-)infrared dark even at 70 $\mu$m, we identify weak 70 $\mu$m emission toward one core with a comparably low luminosity of $\sim 16 L_\odot$, re-enforcing the general youth of the region. The spectral line data always exhibit multiple spectral components toward each core with comparably small line widths for the individual components (in the 0.3 to 1.0 km s\textsuperscript{-1} regime). Based on single-dish C\textsuperscript{18}O(2–1) data we estimate a low virial-to-gas-mass ratio $\leq 0.25$. We discuss that the likely origin of these spectral properties may be the global collapse of the original gas clump that results in multiple spectral components along each line of sight. Even within this dynamic picture the individual collapsing gas cores appear to have very low levels of internal turbulence.

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STARBench: The D-type expansion of an H II region

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The growth of planets by pebble accretion in evolving protoplanetary discs

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The formation of planets depends on the underlying protoplanetary disc structure, which influences both the accretion and migration rates of embedded planets. The disc itself evolves on time-scales of several Myr during which both temperature and density profiles change as matter accretes onto the central star. Here we use a detailed model of an evolving disc to determine the growth of planets by pebble accretion and their migration through the disc. Cores that reach their pebble isolation mass accrete gas to finally form giant planets with extensive gas envelopes, while planets that do not reach pebble isolation mass are stranded as ice giants and ice planets containing only minor amounts of gas in their envelopes. Unlike earlier population synthesis models, our model works without any artificial reductions in migration speed and for protoplanetary discs with gas and dust column densities similar to those inferred from observations. We find that in our nominal disc model the emergence of planetary embryos preferably occurs after approximately 2 Myr in order to not exclusively form gas giants, but also ice giants and smaller planets. The high pebble accretion rates ensure that critical core masses for gas accretion can be reached at all orbital distances. Gas giant planets nevertheless experience significant reduction in semi-major axes by migration. Considering instead
planetesimal accretion for planetary growth, we show that formation time-scales are too long to compete with the migration time-scales and the dissipation time of the protoplanetary disc. Altogether, we find that pebble accretion overcomes many of the challenges in the formation of ice and gas giants in evolving protoplanetary discs.

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Triggering Collapse of the Presolar Dense Cloud Core and Injecting Short-Lived Radioisotopes with a Shock Wave. IV. Effects of Rotational Axis Orientation

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Both astronomical observations of the interaction of Type II supernova remnants (SNR) with dense interstellar clouds as well as cosmochemical studies of the abundances of daughter products of short-lived radioisotopes (SLRIs) formed by supernova nucleosynthesis support the hypothesis that the Solar Systems SLRIs may have been derived from a supernova. This paper continues a series devoted to examining whether such a shock wave could have triggered the dynamical collapse of a dense, presolar cloud core and simultaneously injected sufficient abundances of SLRIs to explain the cosmochemical evidence. Here we examine the effects of shock waves striking clouds whose spin axes are oriented perpendicular, rather than parallel, to the direction of propagation of the shock front. The models start with 2.2 $M_\odot$ cloud cores and shock speeds of 20 or 40 km $s^{-1}$. Central protostars and protoplanetary disks form in all models, though with disk spin axes aligned somewhat randomly. The disks derive most of their angular momentum not from the initial cloud rotation, but from the Rayleigh-Taylor fingers that also inject shock wave SLRIs. Injection efficiencies, $f_i$, the fraction of the incident shock wave material injected into the collapsing cloud core, are $0.04 - 0.1$ in these models, similar to when the rotation axis is parallel to the shock propagation direction. Evidently altering the rotation axis orientation has only a minor effect on the outcome, strengthening the case for this scenario as an explanation for the Solar Systems SLRIs.

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Observing the onset of outflow collimation in a massive protostar


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The current paradigm of star formation through accretion disks, and magnetohydrodynamically driven gas ejections, predicts the development of collimated outflows, rather than expansion without any preferential direction. We present radio continuum observations of the massive protostar W75N(B)-VLA 2, showing that it is a thermal, collimated
ionized wind and that it has evolved in 18 years from a compact source into an elongated one. This is consistent with the evolution of the associated expanding water-vapor maser shell, which changed from a nearly circular morphology, tracing an almost isotropic outflow, to an elliptical one outlining collimated motions. We model this behavior in terms of an episodic, short-lived, originally isotropic, ionized wind whose morphology evolves as it moves within a toroidal density stratification.

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Star and jet multiplicity in the high-mass star forming region IRAS 05137+3919

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We present a study of the complex high-mass star forming region IRAS05137+3919 (also known as Mol8), where multiple jets and a rich stellar cluster have been described in previous works. Our goal is to determine the number of jets and shed light on their origin, and thus determine the nature of the young stars powering these jets. We also wish to analyse the stellar clusters by resolving the brightest group of stars. The star forming region was observed in various tracers and the results were complemented with ancillary archival data. The new data represent a substantial improvement over previous studies both in resolution and frequency coverage. In particular, adaptive optics provides us with an angular resolution of 80 mas in the near IR, while new mid- and far-IR data allow us to sample the peak of the spectral energy distribution and thus reliably estimate the bolometric luminosity.

Thanks to the near-IR continuum and millimetre line data we can determine the structure and velocity field of the bipolar jets and outflows in this star forming region. We also find that the stars are grouped into three clusters and the jets originate in the richest of these, whose luminosity is $\sim 2.4 \times 10^4 L_\odot$. Interestingly, our high-resolution near-IR images allow us to resolve one of the two brightest stars (A and B) of the cluster into a double source (A1+A2). We confirm that there are two jets and establish that they are powered by B-type stars belonging to cluster C1. On this basis and on morphological and kinematical arguments, we conclude that the less extended jet is almost perpendicular to the line of sight and that it originates in the brightest star of the cluster, while the more extended one appears to be associated with the more extincted, double source A1+A2. We propose that this is not a binary system, but a small bipolar reflection nebula at the root of the large-scale jet, outlining a still undetected circumstellar disk. The gas kinematics on a scale of $\sim 0.2$ pc seems to support our hypothesis, because it appears to trace rotation about the axis of the associated jet.

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Evolution of the protolunar disk: dynamics, cooling timescale and implantation of volatiles onto the Earth

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It is thought that the Moon accreted from the protolunar disk that was assembled after the last giant impact on Earth. Due to its high temperature, the protolunar disk may act as a thermochemical reactor in which the material is processed before being incorporated into the Moon. Outstanding issues like devolatilisation and isotopic evolution are tied to the disk evolution, however its lifetime, dynamics and thermodynamics are unknown. Here, we numerically explore the long term viscous evolution of the protolunar disk using a one dimensional model where the different phases (vapor and condensed) are vertically stratified. Viscous heating, radiative cooling, phase transitions and gravitational instability are accounted for whereas Moon’s accretion is not considered for the moment. The viscosity of the gas, liquid and solid phases dictates the disk evolution. We find that (1) the vapor condenses into liquid in about 10 years, (2) a large fraction of the disk mass flows inward forming a hot and compact liquid disk between 1 and 1.7 Earth’s radii, a region where the liquid is gravitationally stable and can accumulate, (3) the disk finally solidifies in 1000 to 100,000 years. Viscous heating is never balanced by radiative cooling. If the vapor phase is abnormally viscous, due to magneto-rotational instability for instance, most of the disk volatile components are transported to Earth leaving a disk enriched in refractory elements. This opens a way to form a volatile-depleted Moon and would suggest that the missing Moon’s volatiles are buried today into the Earth. The disk cooling timescale may be long enough to allow for planet-disk isotopic equilibration. However large uncertainties on the disk physics remain because of the complexity of its multi-phased structure.

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On planet formation in HL Tau

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We explain the axisymmetric gaps seen in recent long-baseline observations of the HL Tau protoplanetary disc with the Atacama Large Millimetre/Submillimetre Array (ALMA) as being due to the different response of gas and dust to embedded planets in protoplanetary discs. We perform global, three dimensional dusty smoothed particle hydrodynamics calculations of multiple planets embedded in dust/gas discs which successfully reproduce most of the structures seen in the ALMA image. We find a best match to the observations using three embedded planets with masses of 0.2, 0.27 and 0.55 $M_J$ in the three main gaps observed by ALMA, though there remain uncertainties in the exact planet masses from the disc model.

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A spectroscopic survey of Herbig Ae/Be stars with X-Shooter I: Stellar parameters and accretion rates

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Herbig Ae/Be stars span a key mass range that links low and high mass stars, and thus provide an ideal window from which to explore their formation. This paper presents VLT/X-Shooter spectra of 91 Herbig Ae/Be stars, HAeBes; the
largest spectroscopic study of HAeBe accretion to date. A homogeneous approach to determining stellar parameters is undertaken for the majority of the sample. Measurements of the ultra-violet (UV) are modelled within the context of magnetospheric accretion, allowing a direct determination of mass accretion rates. Multiple correlations are observed across the sample between accretion and stellar properties: the youngest and often most massive stars are the strongest accretors, and there is an almost 1:1 relationship between the accretion luminosity and stellar luminosity. Despite these overall trends of increased accretion rates in HAeBes when compared to classical T Tauri stars, we also find noticeable differences in correlations when considering the Herbig Ae and Herbig Be subsets. This, combined with the difficulty in applying a magnetospheric accretion model to some of the Herbig Be stars, could suggest that another form of accretion may be occurring within the Herbig Be mass range.

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Curveballs in protoplanetary disks — the effect of the Magnus force on planet formation
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Spinning planetesimals in a gaseous protoplanetary disk may experience a hydrodynamical force perpendicular to their relative velocities. We examine the effect this force has on the dynamics of these objects using analytical arguments based on a simple laminar disk model and numerical integrations of the equations of motion for individual grains. We focus in particular on meter-sized boulders traditionally expected to spiral in to the central star in as little as 100 years from 1 A.U. We find that there are plausible scenarios in which this force extends the lifetime of these solids in the disk by a factor of several. More importantly the velocities induced by the Magnus force can prevent the formation of planetesimals via gravitational instability in the inner disk if the size of the dust particles is larger than of order 10 cm. We find that the fastest growing linear modes of the streaming instability may still grow despite the diffusive effect of the Magnus force, but it remains to be seen how the Magnus force will alter the non-linear evolution of these instabilities.

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The UWISH2 extended H2 source catalogue
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We present the extended source catalogue for the UKIRT Widefield Infrared Survey for H2 (UWISH2). The survey is unbiased along the inner Galactic Plane from l≈357° to l≈65° and |b| ≤ 1.5° and covers 209 square degrees. A further 42.0 and 35.5 square degrees of high dust column density regions have been targeted in Cygnus and Auriga. We have identified 33200 individual extended H2 features. They have been classified to be associated with about 700 groups of jets and outflows, 284 individual (candidate) Planetary Nebulae, 30 Supernova Remnants and about 1300 Photo-Dissociation Regions. We find a clear decline of star formation activity (traced by H2 emission from jets and photo-dissociation regions) with increasing distance from the Galactic Centre. More than 60% of the detected candidate Planetary Nebulae have no known counterpart and 25% of all Supernova Remnants have detectable H2 emission associated with them.
Chondrule Transport in Protoplanetary Disks
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Chondrule formation remains one of the most elusive early Solar System events. Here, we take the novel approach of employing numerical simulations to investigate chondrule origin beyond purely cosmochemical methods. We model the transport of generically-produced chondrules and dust in a 1D viscous protoplanetary disk model, in order to constrain the chondrule formation events. For a single formation event we are able to match analytical predictions of the memory chondrule and dust populations retain of each other (complementarity), finding that a large mass accretion rate (≥10−7 M⊙ yr−1) allows for delays on the order of the disk’s viscous timescale between chondrule formation and chondrite accretion. Further, we find older disks to be severely diminished of chondrules, with accretion rates ≲10−9 M⊙ yr−1 for nominal parameters. We then characterize the distribution of chondrule origins in both space and time, as functions of disk parameters and chondrule formation rates, in runs with continuous chondrule formation and both static and evolving disks. Our data suggest that these can account for the observed diversity between distinct chondrite classes, if some diversity in accretion time is allowed for.

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Gravitational fragmentation caught in the act: the filamentary Musca molecular cloud
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Filamentary structures are common in molecular clouds. Explaining how they fragment to dense cores is a missing step in understanding their role in star formation. We perform a case study of whether low-mass filaments are close-to hydrostatic prior to their fragmentation, and whether their fragmentation agrees with gravitational fragmentation models. For this, we study the ∼6.5 pc long Musca molecular cloud that is an ideal candidate for a filament at an early stage of fragmentation. We employ dust extinction mapping in conjunction with near-infrared JHKs band data from the CTIO/NEWFIRM instrument, and 870 μm dust continuum emission data from the APEX/LABOCA instrument, to estimate column densities in Musca. We use the data to identify fragments from the cloud and to determine the radial density distribution of its filamentary part. We compare the cloud’s morphology with 13CO and C18O line emission observed with the APEX/SHeFI instrument. The Musca cloud is pronouncedly fragmented at its ends, but harbours a remarkably well-defined, ∼1.6 pc long filament in its Center region. The line mass of the filament is 21−31 M⊙ pc−1 and FWHM 0.07 pc. The radial profile of the filament can be fitted with a Plummer profile that has the power-index of 2.6 ± 11%, flatter than that of an infinite hydrostatic filament. The profile can also be fitted with a hydrostatic cylinder truncated by external pressure. These models imply a central density of ∼5−10×104 cm−3. The fragments in the cloud have a mean separation of ∼0.4 pc, in agreement with gravitational fragmentation. These properties, together with the subsonic and velocity-coherent nature of the cloud, suggest a scenario in which an initially hydrostatic cloud is currently gravitationally fragmenting. The fragmentation has started a few tenths of a
Myr ago from the ends of the cloud, leaving its centre yet relatively non-fragmented, possibly because of gravitational focusing in a finite geometry.

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Classical T Tauri stars with VPHAS+: I: Hα and u-band accretion rates in the Lagoon Nebula M8

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We estimate the accretion rates of 235 Classical T Tauri star (CTTS) candidates in the Lagoon Nebula using ugrHa photometry from the VPHAS+ survey. Our sample consists of stars displaying Hα-excess, the intensity of which is used to derive accretion rates. For a subset of 87 stars, the intensity of the u-band excess is also used to estimate accretion rates. We find the mean variation in accretion rates measured using Hα and u-band intensities to be ~0.17 dex, agreeing with previous estimates (0.04-0.4 dex) but for a much larger sample. The spatial distribution of CTTS align with the location of protostars and molecular gas suggesting that they retain an imprint of the natal gas fragmentation process. Strong accretors are concentrated spatially, while weak accretors are more distributed. Our results do not support the sequential star forming processes suggested in the literature.

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Millimeter-wave polarization of protoplanetary disks due to dust scattering

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We present a new method to constrain the grain size in protoplanetary disks with polarization observations at millimeter wavelengths. If dust grains are grown to the size comparable to the wavelengths, the dust grains are expected to have a large scattering opacity and thus the continuum emission is expected to be polarized due to self-scattering. We perform 3D radiative transfer calculations to estimate the polarization degree for the protoplanetary disks having radial Gaussian-like dust surface density distributions, which have been recently discovered. The maximum grain size is set to be 100 \( \mu \)m and the observing wavelength to be 870 \( \mu \)m. We find that the polarization degree is as high as 2.5% with a subarcsec spatial resolution, which is likely to be detected with near-future ALMA observations. The emission is polarized due to scattering of anisotropic continuum emission. The map of the polarization degree shows a double peaked distribution and the polarization vectors are in the radial direction in the inner ring and in the azimuthal direction in the outer ring. We also find the wavelength dependence of the polarization degree: the polarization degree is the highest if dust grains have a maximum size of \( a_{\text{max}} \sim \lambda/2\pi \), where \( \lambda \) is the observing wavelength. Hence, multi-wave and spatially resolved polarization observations toward protoplanetary disks enable us to put a constraint on the grain size. The constraint on the grain size from polarization observations is independent of or may be even stronger than that from the opacity index.

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A census of dense cores in the Aquila cloud complex: SPIRE/PACS observations from the Herschel Gould Belt survey

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We present and discuss the results of the Herschel Gould Belt survey (HGBS) observations in an \( \sim 11 \) deg\(^2\) area of the Aquila molecular cloud complex at \( d \sim 260 \) pc, imaged with the SPIRE and PACS photometric cameras in parallel mode from 70 \( \mu \)m to 500 \( \mu \)m. Using the multi-scale, multi-wavelength source extraction algorithm getsources, we identify a complete sample of starless dense cores and embedded (Class 0-I) protostars in this region, and analyze their global properties and spatial distributions. We find a total of 651 starless cores, \( \sim 60\% \pm 10\% \) of which are gravitationally bound prestellar cores, and they will likely form stars in the future. We also detect 58 protostellar cores. The core mass function (CMF) derived for the large population of prestellar cores is very similar in shape to the stellar initial mass function (IMF), confirming earlier findings on a much stronger statistical basis and supporting the view that there is a close physical link between the stellar IMF and the prestellar CMF. The global shift in mass scale observed between the CMF and the IMF is consistent with a typical star formation efficiency of \( \sim 40\% \) at the level of an individual core. By comparing the numbers of starless cores in various density bins to the number of young stellar objects (YSOs), we estimate that the lifetime of prestellar cores is \( \sim 1 \) Myr, which is typically \( \sim 4 \) times longer than the core free-fall time, and that it decreases with average core density. We find a strong correlation between the spatial distribution of prestellar cores and the densest filaments observed in the Aquila complex. About 90\% of the Herschel-identified prestellar cores are located above a background column density corresponding to \( A_V \sim 7 \), and \( \sim 75\% \) of them lie within filamentary structures with supercritical masses per unit length \( \gtrsim 16 \) \( M_\odot/\)pc. These findings support a picture wherein the cores making up the peak of the CMF (and probably responsible for the base of the IMF) result primarily from the gravitational fragmentation of marginally supercritical filaments. Given that filaments appear to dominate the mass budget of dense gas at \( A_V > 7 \), our findings also suggest that the physics of prestellar core formation within filaments is responsible for a characteristic “efficiency” \( \text{SFR}/M_{\text{dense}} \sim 5^{+2}_{-2} \times 10^{-8} \text{ yr}^{-1} \).
for the star formation process in dense gas.

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Associated products (maps and core catalogs) are available from http://gouldbelt-herschel.cea.fr/archives (Aquila row).

The Spatial Structure of Young Stellar Clusters. III. Physical Properties and Evolutionary States

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We analyze the physical properties of stellar clusters that are detected in massive star-forming regions in the MYStIX project—a comparative, multiwavelength study of young stellar clusters within 3.6 kpc that contain at least one O-type star. Tabulated properties of subclusters in these regions include physical sizes and shapes, intrinsic numbers of stars, absorptions by the molecular clouds, and median subcluster ages. Physical signs of dynamical evolution are present in the relations of these properties, including statistically significant correlations between subcluster size, central density, and age, which are likely the result of cluster expansion after gas removal. We argue that many of the subclusters identified in Paper I are gravitationally bound because their radii are significantly less than what would be expected from freely expanding clumps of stars with a typical initial stellar velocity dispersion of \(\sim 3\,\text{km s}^{-1}\) for star-forming regions. We explore a model for cluster formation in which structurally simpler clusters are built up hierarchically through the mergers of subclusters—subcluster mergers are indicated by an inverse relation between the numbers of stars in a subcluster and their central densities (also seen as a density vs. radius relation that is less steep than would be expected from pure expansion). We discuss implications of these effects for the dynamical relaxation of young stellar clusters.

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Period change of massive binaries from combined photometric and spectroscopic data in Cygnus OB2

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Context. Mass loss is an important property in evolution models of massive stars. As up to 90\% of the massive stars have a visual or spectroscopic companion and many of them exhibit mass exchange, mass-loss rates can be acquired through the period study of massive binaries.

Aims. Using our own photometric observations as well as archival data, we look for variations in orbital periods of seven massive eclipsing binary systems in the Cygnus OB2 association and estimate their mass-loss rates and stellar parameters.

Methods. We use a Bayesian parameter estimation method to simultaneously fit the period and period change to all available data and a stellar modelling tool to model the binary parameters from photometric and radial-velocity data.

Results. Four out of the seven selected binaries show non-zero period change values at two-sigma confidence level. We
The structure of the Cepheus E protostellar outflow: The jet, the bowshock, and the cavity

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Protostellar outflows are a crucial ingredient of the star-formation process. However, the physical conditions in the warm outflowing gas are still poorly known.

We present a multi-transition, high spectral resolution CO study of the outflow of the intermediate-mass Class 0 protostar Cep E-mm. The goal is to determine the structure of the outflow and to constrain the physical conditions of the various components in order to understand the origin of the mass-loss phenomenon.

We have observed the J = 12-11, J = 13-12, and J = 16-15 CO lines at high spectral resolution with SOFIA/GREAT and the J = 5-4, J = 9-8, and J = 14-13 CO lines with HIFI/Herschel towards the position of the terminal bowshock HH377 in the southern outflow lobe. These observations were complemented with maps of CO transitions obtained with the IRAM 30m telescope (J = 1-0, 2-1), the Plateau de Bure interferometer (J = 2-1), and the James Clerk Maxwell Telescope (J = 3-2, 4-3).

We identify three main components in the protostellar outflow: the jet, the cavity, and the bow shock, with a typical size of 1.7 arcsec × 21 arcsec, 4.5 arcsec, and 22 arcsec × 10 arcsec, respectively. In the jet, the emission from the low-J CO lines is dominated by a gas layer at T_{kin} = 80–100 K, column density N(CO) = 9 × 10^{16} cm^{-2}, and density n(H_2) = (0.5–1) × 10^5 cm^{-3}; the emission of the high-J CO lines arises from a warmer (T_{kin} = 400–750 K), denser (n(H_2) = (0.5–1) × 10^6 cm^{-3}), lower column density (N(CO) = 1.5 × 10^{16} cm^{-2}) gas component. Similarly, in the outflow cavity, two components are detected: the emission of the low-J lines is dominated by a gas layer of column density N(CO) = 7 × 10^{17} cm^{-2} at T_{kin} = 55–85 K and density in the range (1-8) × 10^{5} cm^{-3}; the emission of the high-J lines is dominated by a hot, denser gas layer with T_{kin} = 500–1500 K, n(H_2) = (1-5) × 10^6 cm^{-3}, and N(CO) = 6 × 10^{16} cm^{-2}. A temperature gradient as a function of the velocity is found in the high-excitation gas component. In the terminal bowshock HH377, we detect gas of moderate excitation, with a temperature in the range T_{kin} ≈ 400–500 K, density n(H_2) ≃ (1-2) × 10^6 cm^{-3} and column density N(CO) = 10^{17} cm^{-2}. The amounts of momentum carried away in the jet and in the entrained ambient medium are similar. Comparison with time-dependent shock models shows that the hot gas emission in the jet is well accounted for by a magnetized shock with an age of 220–740 yr propagating at 20–30 km s^{-1} in a medium of density n(H_2) = (0.5–1) × 10^5 cm^{-3}, consistent with that of the bulk material. The Cep E protostellar outflow appears to be a convincing case of jet bow shock driven outflow. Our observations trace the recent impact of the protostellar jet into the ambient cloud, producing a non-stationary magnetized shock, which drives the formation of an outflow cavity.

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A homogeneous analysis of disks around brown dwarfs

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We re-analyzed the Herschel/PACS data of a sample of 55 brown dwarfs (BDs) and very low mass stars with spectral types ranging from M5.5 to L0. We investigated the dependence of disk structure on the mass of the central object in the substellar regime based on a homogeneous analysis of Herschel data from flux density measurements to spectral energy distribution (SED) modeling. A systematic comparison between the derived disk properties and those of sun-like stars shows that the disk flaring of BDs and very low mass stars is generally smaller than that of their higher mass counterparts, the disk mass is orders of magnitude lower than the typical value found in T Tauri stars, and the disk scale heights are comparable in both sun-like stars and BDs. We further divided our sample into an early-type brown dwarf (ETBD) group and a late-type brown dwarf (LTBD) group by using spectral type (=M8) as the border criterion. We systematically compared the modeling results from Bayesian analysis between these two groups, and found the trends of flaring index as a function of spectral type also present in the substellar regime. The spectral type independence of the scale height is also seen between high-mass and very low-mass BDs. However, both the ETBD and LTBD groups feature a similar median disk mass of $10^{-5} M_\odot$ and no clear trend is visible in the distribution, probably due to the uncertainty in translating the far-IR photometry into disk mass, the detection bias and the age difference among the sample. Unlike previous studies, our analysis is completely homogeneous in Herschel/PACS data reduction and modeling with a statistically significant sample. Therefore, we present evidence of stellar-mass-dependent disk structure down to the substellar mass regime, which is important for planet formation models.

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Toroidal vortices and the conglomeration of dust into rings in protoplanetary discs

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We identify a new hydrodynamical instability in protoplanetary discs that may arise due to variations in the dust-to-gas ratio and may lead to concentration of dust grains within a disc. The instability can arise due to dust settling, which produces a vertical compositional entropy gradient. The entropy gradient drives a baroclinic instability that is capable of creating toroidal gas vortices that gather dust into rings. Such dust rings are potentially observable via continuum emission of the dust or scattered light. Indeed, this instability may offer an explanation for the rings recently observed in the discs around the young stars HL Tau and TW Hya that does not rely on clearing by protoplanets. The instability may also have wider ramifications, potentially aiding dust agglomeration, altering the radial migration of larger planetesimals, and modifying angular momentum transport within a disc.

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Animations available at: http://www.astro.ex.ac.uk/people/mbate/Animations/dust1.html

Tentative detection of ethylene glycol toward W51/e2 and G34.3+0.2

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With only a few low- and high-mass star-formation regions studied in detail so far, it is unclear what role the environment plays in complex molecule formation. In this light, a comparison of relative abundances of related species between sources might be useful for explaining any observed differences. We seek to measure the relative abundance between three important complex organic molecules, ethylene glycol ((CH$_2$OH)$_2$), glycolaldehyde (CH$_2$OHCHO) and methyl formate (HCOOCH$_3$), toward high-mass protostars and thereby provide additional constraints on their formation pathways. We use IRAM 30-m single-dish observations of the three species toward two high-mass star-forming regions – W51/e2 and G34.3+0.2 – and report a tentative detection of (CH$_2$OH)$_2$ toward both sources. Assuming that (CH$_2$OH)$_2$, CH$_2$OHCHO, and HCOOCH$_3$ spatially coexist, relative abundance ratios, HCOOCH$_3$/(CH$_2$OH)$_2$, of 31 and 35 are derived for G34.3+0.2 and W51/e2, respectively. CH$_2$OHCHO is not detected, but the data provide lower limits to the HCOOCH$_3$/CH$_2$OHCHO abundance ratios of ≥193 for G34.3+0.2 and ≥550 for W51/e2. A comparison of these results to measurements from various sources in the literature indicates that the source luminosities may be correlated with the HCOOCH$_3$/(CH$_2$OH)$_2$ and HCOOCH$_3$/CH$_2$OHCHO ratios. This apparent correlation may be a consequence of the relative time scales each source spend at different temperature ranges in their evolution. Furthermore, we obtain lower limits to the ratio of (CH$_2$OH)$_2$/CH$_2$OHCHO for G34.3+0.2 ($\geq 6$) and W51/e2 ($\geq 16$). This result confirms that a high (CH$_2$OH)$_2$/CH$_2$OHCHO abundance ratio is not a specific property of comets, as previously speculated.

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A hot Jupiter for breakfast? — Early stellar ingestion of planets may be common

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Models of planet formation and evolution predict that giant planets form efficiently in protoplanetary disks, that most of these migrate rapidly to the disk’s inner edge, and that, if the arriving planet’s mass is $<\sim$ Jupiter’s mass, it could remain stranded near that radius. We argue that such planets would be ingested by tidal interaction with the host star on a timescale $\llsim 1$Gyr, and that, in the case of a solar-type host, this would cause the stellar spin to approach the direction of the ingested planet’s orbital axis even if the two were initially highly misaligned. Primordially misaligned stars whose effective temperatures are $>\sim 6250$K cannot be realigned in this way because, in contrast with solar-type hosts, their angular momenta are typically higher than the orbital angular momentum of the ingested planet as a result of inefficient magnetic braking and of a comparatively large moment of inertia. Hot Jupiters located farther out from the star can contribute to this process, but their effect is weaker because the tidal interaction strength decreases rapidly with increasing semimajor axis. We demonstrate that, if ~50% of planetary systems harbored a stranded hot Jupiter, this scenario can in principle account for (1) the good alignment exhibited by planets around cool stars irrespective of the planet’s mass or orbital period, (2) the prevalence of misaligned planets around hot stars, (3) the apparent upper bound on the mass of hot Jupiters on retrograde orbits, and (4) the inverse correlation between stellar spin periods and hot-Jupiter masses.

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A distance-limited sample of massive star-forming cores from the RMS survey

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We analyse \(^{18}\)O (J = 3-2) data from a sample of 99 infrared (IR)-bright massive young stellar objects (MYSOs) and compact HII regions that were identified as potential molecular outflow sources in the Red MSX Source survey. We extract a distance limited (D < 6 kpc) sample shown to be representative of star formation covering the transition between the source types. At the spatial resolution probed, Larson-like relationships are found for these cores, though the alternative explanation, that Larsons relations arise where surface-density limited samples are considered, is also consistent with our data. There are no significant differences found between source properties for the MYSOs and HII regions, suggesting that the core properties are established prior to the formation of massive stars, which subsequently have little impact at the later evolutionary stages investigated. There is a strong correlation between dust-continuum and \(^{18}\)O gas masses, supporting the interpretation that both trace the same material in these IR-bright sources. A clear linear relationship is seen between the independently established core masses and luminosities. The position of MYSOs and compact HII regions in the mass-luminosity plane is consistent with the luminosity expected from the most massive protostar in the cluster when using an ~40 per cent star formation efficiency and indicates that they are at a similar evolutionary stage, near the end of the accretion phase.

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On the origin of the correlations between the accretion luminosity and emission line luminosities in pre-main sequence stars

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Correlations between the accretion luminosity and emission line luminosities (L_{\text{acc}} and L_{\text{line}}) of pre-main sequence (PMS) stars have been published for many different spectral lines, which are used to estimate accretion rates. Despite the origin of those correlations is unknown, this could be attributed to direct or indirect physical relations between the emission line formation and the accretion mechanism. This work shows that all (near-UV/optical/near-IR) L_{\text{acc}}-L_{\text{line}} correlations are the result of the fact that the accretion luminosity and the stellar luminosity (L_*) are correlated, and are not necessarily related with the physical origin of the line. Synthetic and observational data are used to illustrate how the L_{\text{acc}}-L_{\text{line}} correlations depend on the L_{\text{acc}}-L_* relationship. We conclude that because PMS stars show the L_{\text{acc}}-L_* correlation immediately implies that L_{\text{acc}} also correlates with the luminosity of all emission lines, for which the L_{\text{acc}}-L_{\text{line}} correlations alone do not prove any physical connection with accretion but can only be used with practical purposes to roughly estimate accretion rates. When looking for correlations with possible physical meaning, we suggest that L_{\text{acc}}/L_* and L_{\text{line}}/L_* should be used instead of L_{\text{acc}} and L_{\text{line}}. Finally, the finding that L_{\text{acc}} has a steeper dependence on L_* for T-Tauri stars than for intermediate-mass Herbig Ae/Be stars is also discussed. That is explained from the magnetospheric accretion scenario and the different photospheric properties in the near-UV.

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Discovery of a Low-Mass Companion to the F7V star HD 984

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Discovery of a Low-Mass Companion to the F7V star HD 984

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We report the discovery of a low-mass companion to the nearby \((d = 47\) pc) F7V star HD 984. The companion is detected 0.19 arcsec away from its host star in the \(L'\) band with the Apodizing Phase Plate on NaCo/VLT and was recovered by \(L'\)-band non-coronagraphic imaging data taken a few days later. We confirm the companion is co-moving with the star with SINFONI integral field spectrograph \(H + K\) data. We present the first published data obtained with SINFONI in pupil-tracking mode. HD 984 has been argued to be a kinematic member of the 30 Myr-old Columba group, and its HR diagram position is not altogether inconsistent with being a ZAMS star of this age. By consolidating different age indicators, including isochronal age, coronal X-ray emission, and stellar rotation, we independently estimate a main sequence age of \(115 \pm 85\) Myr (95% CL) which does not rely on this kinematic association. The mass of directly imaged companions are usually inferred from theoretical evolutionary tracks, which are highly dependent on the age of the star. Based on the age extrema, we demonstrate that with our photometric data alone, the companion’s mass is highly uncertain: between 33 and 96 M\(_{\text{Jup}}\) (0.03-0.09 M\(_{\odot}\)) using the COND evolutionary models. We compare the companion’s SINFONI spectrum with field dwarf spectra to break this degeneracy. Based on the slope and shape of the spectrum in the \(H\)-band, we conclude that the companion is an M6.0 \(\pm\) 0.5 dwarf. The age of the system is not further constrained by the companion, as M dwarfs are poorly fit on low-mass evolutionary tracks. This discovery emphasizes the importance of obtaining a spectrum to spectral type companions around F-stars.

New members of the TW Hydreae Association and two accreting M-dwarfs in Scorpius-Centaurus

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We report the serendipitous discovery of several young mid-M stars found during a search for new members of the 30–40 Myr-old Octans Association. Only one of the stars may be considered a possible Octans(-Near) member. However, two stars have proper motions, kinematic distances, radial velocities, photometry and Li \(6708\) Å measurements consistent with membership in the 8–10 Myr-old TW Hydrae Association. Another may be an outlying member of TW Hydrae but has a velocity similar to that predicted by membership in Octans. We also identify two new lithium-rich members of the neighbouring Scorpius-Centaurus OB Association (Sco-Cen). Both exhibit large 12 and 22 \(\mu\)m excesses and strong, variable H\(\alpha\) emission which we attribute to accretion from circumstellar discs. Such stars are thought to be incredibly rare at the \(\sim 16\) Myr median age of Sco-Cen and they join only one other confirmed M-type and three higher-mass accretors outside of Upper Scorpius. The serendipitous discovery of two accreting stars hosting large quantities of circumstellar material may be indicative of a sizeable age spread in Sco-Cen, or further evidence that disc dispersal and planet formation time-scales are longer around lower-mass stars. To aid future studies of Sco-Cen we also provide a newly-compiled catalogue of 305 early-type Hipparcos members with spectroscopic radial velocities sourced from the literature.

Substellar Objects in Nearby Young Clusters (SONYC) IX: The planetary-mass domain of Chamaeleon-I and updated mass function in Lupus 3
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Substellar Objects in Nearby Young Clusters – SONYC – is a survey program to investigate the frequency and properties of substellar objects in nearby star-forming regions. We present new spectroscopic follow-up of candidate members in Chamaeleon-I (∼2 Myr, 160 pc) and Lupus 3 (∼1 Myr, 200 pc), identified in our earlier works. We obtained 34 new spectra (1.5 – 2.4 µm, R~600), and identified two probable members in each of the two regions. These include a new probable brown dwarf in Lupus 3 (NIR spectral type M7.5 and $T_{\text{eff}} = 2800$ K), and an L3 ($T_{\text{eff}} = 2200$ K) brown dwarf in Cha-I, with the mass below the deuterium-burning limit. Spectroscopic follow-up of our photometric and proper motion candidates in Lupus 3 is almost complete (> 90%), and we conclude that there are very few new substellar objects left to be found in this region, down to 0.01 – 0.02$M_\odot$ and $A_V \leq 5$. The low-mass portion of the mass function in the two clusters can be expressed in the power-law form $dN/dM \propto M^{-\alpha}$, with $\alpha \sim 0.7$, in agreement with surveys in other regions. In Lupus 3 we observe a possible flattening of the power-law IMF in the substellar regime: this region seems to produce fewer brown dwarfs relative to other clusters. The IMF in Cha-I shows a monotonic behavior across the deuterium-burning limit, consistent with the same power law extending down to 4 – 9 Jupiter masses. We estimate that objects below the deuterium-burning limit contribute of the order 5 – 15% to the total number of Cha-I members.

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The Nature and Frequency of Outflows from Stars in the Central Orion Nebula Cluster

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Recent Hubble Space Telescope images have allowed the determination with unprecedented accuracy of motions and changes of shocks within the inner Orion Nebula. These originate from collimated outflows from very young stars, some within the ionized portion of the nebula and others within the host molecular cloud. We have doubled the number of Herbig-Haro objects known within the inner Orion Nebula. We find that the best-known Herbig-Haro shocks originate from a relatively few stars, with the optically visible X-ray source COUP 666 driving many of them.

While some isolated shocks are driven by single collimated outflows, many groups of shocks are the result of a single stellar source having jets oriented in multiple directions at similar times. This explains the feature that shocks aligned in opposite directions in the plane of the sky are usually blue shifted because the redshifted outflows pass into the optically thick Photon Dominated Region behind the nebula. There are two regions from which optical outflows originate for which there are no candidate sources in the SIMBAD data base.

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Copies of this large (90.4 MB) paper may be obtained at the anonymous ftp site orion.phy.vanderbilt.edu within the outgoing directory, where it is named ORION_MOTIONS.pdf.
The jet and the disk of the HH 212 low-mass protostar imaged by ALMA: SO and SO$_2$ emission
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Context. The investigation of the disk formation and jet launching mechanism in protostars is crucial to understanding the earliest stages of star and planet formation.

Aims. We aim to constrain the physical and dynamical properties of the molecular jet and disk of the HH 212 protostellar system at unprecedented angular scales, exploiting the capabilities of the Atacama Large Millimeter Array (ALMA).

Methods. The ALMA observations of HH 212 in emission lines from sulfur-bearing molecules, SO $^9_8$--$^8_7$, SO $^{10}_{11}$--$^{10}_{10}$, SO$_2$ $^8_{2,6}$--$^7_{1,7}$, are compared with simultaneous CO $^3_2$--$^2_1$, SiO $^8_7$--$^7_6$ data. The molecules column density and abundance are estimated using simple radiative transfer models.

Results. SO $^9_8$--$^8_7$ and SO$_2$ $^8_{2,6}$--$^7_{1,7}$ show broad velocity profiles. At systemic velocity, they probe the circumstellar gas and the cavity walls. Going from low to high blue- and red-shifted velocities the emission traces the wide-angle outflow and the fast ($\approx 100$--200 km s$^{-1}$) and collimated ($\approx 90$ AU) molecular jet revealing the inner knots with timescales $\lesssim 50$ years. The jet transports a mass-loss rate $\geq 0.2-2 \times 10^{-6}$ M$_\odot$ yr$^{-1}$, implying high ejection efficiency ($\geq 0.03-0.3$). The SO and SO$_2$ abundances in the jet are $\sim 10^{-7}$--$10^{-6}$. SO $^{10}_{11}$--$^{10}_{10}$ emission is compact and shows small-scale velocity gradients, indicating that it originates partly from the rotating disk previously seen in HCO$^+$ and C$^{17}$O, and partly from the base of the jet. The disk mass is $\geq 0.002-0.013$ M$_\odot$ and the SO abundance in the disk is $\sim 10^{-8}$--$10^{-7}$.

Conclusions. SO and SO$_2$ are effective tracers of the molecular jet in the inner few hundreds AU from the protostar. Their abundances indicate that $1\%$--$40\%$ of sulfur is in SO and SO$_2$ due to shocks in the jet/outflow and/or to ambipolar diffusion at the wind base. The SO abundance in the disk is $3-4$ orders of magnitude larger than in evolved protoplanetary disks. This may be due to an SO enhancement in the accretion shock at the envelope-disk interface or in spiral shocks if the disk is partly gravitationally unstable.

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YSOVAR: mid-infrared variability of young stellar objects and their disks in the cluster IRAS 20050+2720
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We present a time-variability study of young stellar objects in the cluster IRAS 20050+2720, performed at 3.6 and 4.5 μm with the Spitzer Space Telescope; this study is part of the Young Stellar Object VARIability project (YSOVAR).

We have collected light curves for 181 cluster members over 40 days. We find a high variability fraction among embedded cluster members of ca. 70%, whereas young stars without a detectable disk display variability less often (in ca. 50% of the cases) and with lower amplitudes. We detect periodic variability for 33 sources with periods primarily in the range of 2–6 days. Practically all embedded periodic sources display additional variability on top of their periodicity. Furthermore, we analyze the slopes of the tracks that our sources span in the color-magnitude diagram (CMD). We find that sources with long variability time scales tend to display CMD slopes that are at least partially influenced by accretion processes, while sources with short variability time scales tend to display extinction-dominated slopes. We find a tentative trend of X-ray detected cluster members to vary on longer time scales than the X-ray undetected members.

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Recombination and collisionally excited Balmer lines

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We present a model for the statistical equilibrium of the levels of H, considering recombinations to excited levels, collisional excitations up from the ground state and spontaneous radiative transitions. This problem has a simple “cascade matrix” solution, describing a cascade of downwards spontaneous transitions fed by both recombinations and collisional excitations. The resulting predicted Balmer line ratios show a transition between a low temperature and a high temperature regime (dominated by recombinations and by collisional excitations, respectively), both with only a weak line ratio vs. temperature dependence. This clear characteristic allows a direct observational identification of regions in which the Balmer lines are either recombination or collisionally excited transitions. We find that for a gas in coronal ionization equilibrium the Hα and Hβ lines are collisionally excited for all temperatures. In order to have recombination Hα and Hβ it is necessary to have higher ionization fractions of H than the ones obtained from coronal equilibrium (e.g., such as the ones found in a photoionized gas).

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A Combined Spitzer and Herschel Infrared Study of Gas and Dust in the Circumbinary Disk Orbiting V4046 Sgr

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We present results from a spectroscopic Spitzer and Herschel mid-to-far-infrared study of the circumbinary disk orbiting the evolved (age $\sim 12–23$ Myr) close binary T Tauri system V4046 Sgr. Spitzer IRS spectra show emission lines of [Ne II], H$_2$ S(1), CO$_2$ and HCN, while Herschel PACS and SPIRE spectra reveal emission from [O I], OH, and tentative detections of H$_2$O and high-J transitions of CO. We measure [Ne III]/[Ne II] < 0.13, which is comparable to other X-ray/EUV luminous T Tauri stars that lack jets. We use the H$_2$ S(1) line luminosity to estimate the gas mass in the relatively warm surface layers of the inner disk. The presence of [O I] emission suggests that CO, H$_2$O, and/or OH is being photodissociated, and the lack of [C I] emission suggests any excess C may be locked up in HCN, CN and other organic molecules. Modeling of silicate dust grain emission features in the mid-infrared indicates that the inner disk is composed mainly of large ($r \sim 5$ $\mu$m) amorphous pyroxene and olivine grains ($\sim 86\%$ by mass) with a relatively large proportion of crystalline silicates. These results are consistent with other lines of evidence indicating that planet building is ongoing in regions of the disk within $\sim 30$ AU of the central, close binary.

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Infrared study of transitional disks in Ophiuchus with Herschel
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Context. Observations of nearby star-forming regions with the Herschel Space Observatory complement our view of the protoplanetary disks in Ophiuchus with information about the outer disks. Aims. The main goal of this project is to provide new far-infrared fluxes for the known disks in the core region of Ophiuchus and to identify potential transitional disks using data from Herschel.

Methods. We obtained PACS and SPIRE photometry of previously spectroscopically confirmed young stellar objects (YSO) in the region and analysed their spectral energy distributions.

Results. From an initial sample of 261 objects with spectral types in Ophiuchus, we detect 49 disks in at least one Herschel band. We provide new far-infrared fluxes for these objects. One of them is clearly a new transitional disk candidate.

Conclusions. The data from Herschel Space Observatory provides fluxes that complement previous infrared data and that we use to identify a new transitional disk candidate.

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Internal and relative motions of the Taurus and Ophiuchus star-forming regions
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We investigate the internal and relative motions of the Taurus and Ophiuchus star-forming regions using a sample of young stars with accurately measured radial velocities and proper motions. We find no evidence for expansion or contraction of the Taurus complex, but a clear indication for a global rotation, resulting in velocity gradients of order 0.1 km s$^{-1}$ pc$^{-1}$ across the region. In the case of Ophiuchus more data are needed to reliably establish its internal kinematics. Both Taurus and Ophiuchus have a bulk motion relative to the LSR (i.e. a non-zero mean peculiar velocity) of order 5 km s$^{-1}$. Interestingly, these velocities are roughly equal in magnitude, but nearly exactly opposite in direction. Moving back in time, we find that Taurus and Ophiuchus must have been very near each other 20 to 25 Myr ago. This suggests a common origin, possibly related to that of Gould’s Belt.

Herschel Observations of the W3 GMC (II): Clues to the Formation of Clusters of High-Mass Stars

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The W3 GMC is a prime target for investigating the formation of high-mass stars and clusters. This second study of W3 within the HOBYS Key Program provides a comparative analysis of subfields within W3 to further constrain the processes leading to the observed structures and stellar population. Probability density functions (PDFs) and cumulative mass distributions (CMDs) were created from dust column density maps, quantified as extinction $A_V$. The shape of the PDF, typically represented with a lognormal function at low $A_V$ “breaking” to a power-law tail at high $A_V$, is influenced by various processes including turbulence and self-gravity. The breaks can also be identified, often
more readily, in the CMDs. The PDF break from lognormal \((A_V^{SF}) \approx 6-10 \text{ mag}\) appears to shift to higher \(A_V\) by stellar feedback, so that high-mass star-forming regions tend to have higher PDF breaks. A second break at \(A_V > 50 \text{ mag}\) traces structures formed or influenced by a dynamic process. Because such a process has been suggested to drive high-mass star formation in W3, this second break might then identify regions with potential for hosting high-mass stars/clusters. Stellar feedback appears to be a major mechanism driving the local evolution and state of regions within W3. A high initial star formation efficiency in a dense medium could result in a self-enhancing process, leading to more compression and favourable star-formation conditions (e.g., colliding flows), a richer stellar content, and massive stars. This scenario would be compatible with the “convergent constructive feedback” model introduced in our previous Herschel study.

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Star Formation Across the W3 Complex
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We present a multi-wavelength analysis of the history of star formation in the W3 complex. Using deep, near-infrared ground-based images, combined with images obtained with Spitzer and Chandra observatories, we identified and classified young embedded sources. We identified the principal clusters in the complex, and determined their structure and extension. We constructed extinction-limited samples for five principal clusters, and constructed K-band luminosity functions (KLF) that we compare with those of artificial clusters with varying ages. This analysis provided mean ages and possible age spreads for the clusters. We found that IC 1795, the centermost cluster of the complex, still hosts a large fraction of young sources with circumstellar disks. This indicates that star formation was active in IC 1795 as recently as 2 Myr ago, simultaneous to the star forming activity in the flanking embedded clusters, W3-Main and W3(OH). A comparison with carbon monoxide emission maps indicates strong velocity gradients in the gas clumps hosting W3-Main and W3(OH) and show small receding clumps of gas at IC 1795, suggestive of rapid gas removal (faster than the T Tauri timescale) in the cluster forming regions. We discuss one possible scenario for the progression of cluster formation in the W3 complex. We propose that early processes of gas collapse in the main structure of the complex could have defined the progression of cluster formation across the complex with relatively small age differences from one group to another. However, triggering effects could act as catalysts for enhanced efficiency of formation at a local level, in agreement with previous studies.

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HD 80606: Searching the chemical signature of planet formation
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Context: Binary systems with similar components are ideal laboratories which allow several physical processes to be tested, such as the possible chemical pattern imprinted by the planet formation process.

Aims: We explore the probable chemical signature of planet formation in the remarkable binary system HD 80606 - HD 80607. The star HD 80606 hosts a giant planet with 4 MJup detected by both transit and radial velocity techniques,
being one of the most eccentric planets detected to date. We study condensation temperature \( T_c \) trends of volatile and refractory element abundances to determine whether there is a depletion of refractories that could be related to the terrestrial planet formation.

**Methods:** We carried out a high-precision abundance determination in both components of the binary system, using a line-by-line strictly differential approach, using the Sun as a reference and then using HD 80606 as reference. The stellar parameters \( \text{Teff} \), \( \log g \), \([\text{Fe/H}]\) and \( v_{\text{turb}} \) were determined by imposing differential ionization and excitation equilibrium of Fe I and Fe II lines, using an updated version of the program FUNDPAR, together with 1D LTE ATLAS9 model atmospheres and the MOOG code. Then, we derived detailed abundances of 24 different species using equivalent widths and spectral synthesis with the program MOOG. The chemical patterns were compared with the solar-twins \( T_c \) trends of Melendez et al. (2009) and with a sample of solar-analog stars with \([\text{Fe/H}]\rangle+0.2 \text{ dex} \) from Neves et al. (2009). The \( T_c \) trends were also compared mutually between both stars of the binary system.

**Results:** From the study of \( T_c \) trends, we concluded that the stars HD 80606 and HD 80607 do not seem to be depleted in refractory elements, which is different for the case of the Sun. Then, following the interpretation of Melendez et al. (2009), the terrestrial planet formation would have been less efficient in the components of this binary system than in the Sun. The lack of a trend for refractory elements with \( T_c \) between both stars implies that the presence of a giant planet do not necessarily imprint a chemical signature in their host stars, similar to the recent result of Liu et al. (2014). This is also in agreement with Melendez et al. (2009), who suggest that the presence of close-in giant planets might prevent the formation of terrestrial planets. Finally, we speculate about a possible (ejected or non-detected) planet around the star HD 80607.

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**Signatures of MRI-Driven Turbulence in Protoplanetary Disks: Predictions for ALMA Observations**

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Spatially resolved observations of molecular line emission have the potential to yield unique constraints on the nature of turbulence within protoplanetary disks. Using a combination of local non-ideal magnetohydrodynamic simulations and radiative transfer calculations, tailored to properties of the disk around HD 163296, we assess the ability of ALMA to detect turbulence driven by the magnetorotational instability (MRI). Our local simulations show that the MRI produces small-scale turbulent velocity fluctuations that increase in strength with height above the mid-plane. For a set of simulations at different disk radii, we fit a Maxwell-Boltzmann distribution to the turbulent velocity and construct a turbulent broadening parameter as a function of radius and height. We input this broadening into radiative transfer calculations to quantify observational signatures of MRI-driven disk turbulence. We find that the ratio of the peak line flux to the flux at line center is a robust diagnostic of turbulence that is only mildly degenerate with systematic uncertainties in disk temperature. For the CO(3-2) line, which we expect to probe the most magnetically active slice of the disk column, variations in the predicted peak-to-trough ratio between our most and least turbulent models span a range of approximately 15%. Additional independent constraints can be derived from the morphology of spatially resolved line profiles, and we estimate the resolution required to detect turbulence on different spatial scales. We discuss the role of lower optical depth molecular tracers, which trace regions closer to the disk mid-plane where velocities in MRI-driven models are systematically lower.

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Numerical Simulations of Turbulent Molecular Clouds Regulated by Reprocessed Radiation Feedback from Nascent Super Star Clusters

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Radiation feedback from young star clusters embedded in giant molecular clouds (GMCs) is believed to be important to the control of star formation. For the most massive and dense clouds, including those in which super star clusters (SSCs) are born, pressure from reprocessed radiation exerted on dust grains may disperse a significant portion of the cloud mass back into the interstellar medium (ISM). Using our radiation hydrodynamics (RHD) code, Hyperion, we conduct a series of numerical simulations to test this idea. Our models follow the evolution of self-gravitating, strongly turbulent clouds in which collapsing regions are replaced by radiating sink particles representing stellar clusters. We evaluate the dependence of the star formation efficiency (SFE) on the size and mass of the cloud and \( \kappa \), the opacity of the gas to infrared (IR) radiation. We find that the single most important parameter determining the evolutionary outcome is \( \kappa \), with \( \kappa \gtrsim 15 \text{ cm}^2 \text{ g}^{-1} \) needed to disrupt clouds. For \( \kappa = 20–40 \text{ cm}^2 \text{ g}^{-1} \), the resulting SFE=50–70\% is similar to empirical estimates for some SSC-forming clouds. The opacities required for GMC disruption likely apply only in dust-enriched environments. We find that the subgrid model approach of boosting the direct radiation force \( L/c \) by a “trapping factor” equal to a cloud’s mean IR optical depth can overestimate the true radiation force by factors of \( \sim 4–5 \). We conclude that feedback from reprocessed IR radiation alone is unlikely to significantly reduce star formation within GMCs unless their dust abundances or cluster light-to-mass ratios are enhanced.

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Optical imaging polarimetry of the LkCa 15 protoplanetary disk with SPHERE ZIMPOL

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We present the first optical (590–890 nm) imaging polarimetry observations of the pre-transitional protoplanetary disk around the young solar analog LkCa 15, addressing a number of open questions raised by previous studies. We detect the previously unseen far side of the disk gap, confirm the highly eccentric scattered-light gap shape that was postulated from near-infrared imaging, at odds with the symmetric gap inferred from millimeter interferometry. Furthermore, we resolve the inner disk for the first time and trace it out to 30 AU. This new source of scattered light
may contribute to the near-infrared interferometric signal attributed to the protoplanet candidate LkCa 15 b, which lies embedded in the outer regions of the inner disk. Finally, we present a new model for the system architecture of LkCa 15 that ties these new findings together. These observations were taken during science verification of SPHERE ZIMPOL and demonstrate this facility’s performance for faint guide stars under adverse observing conditions.

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Elemental ratios in stars vs planets

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The chemical composition of planets is an important constraint for planet formation and subsequent differentiation. While theoretical studies try to derive the compositions of planets from planet formation models in order to link the composition and formation process of planets, other studies assume that the elemental ratios in the formed planet and in the host star are the same. Aims. Using a chemical model combined with a planet formation model, we aim to link the composition of stars with solar mass and luminosity with the composition of the hosted planets. For this purpose, we study the three most important elemental ratios that control the internal structure of a planet: Fe/Si, Mg/Si, and C/O. A set of 18 different observed stellar compositions was used to cover a wide range of these elemental ratios. The Gibbs energy minimization assumption was used to derive the composition of planets, taking stellar abundances as proxies for nebular abundances, and to generate planets in a self-consistent planet formation model. We computed the elemental ratios Fe/Si, Mg/Si and C/O in three types of planets (rocky, icy, and giant planets) formed in different protoplanetary discs, and compared them to stellar abundances. We show that the elemental ratios Mg/Si and Fe/Si in planets are essentially identical to those in the star. Some deviations are shown for planets that formed in specific regions of the disc, but the relationship remains valid within the ranges encompassed in our study. The C/O ratio shows only a very weak dependence on the stellar value.

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The molecular composition of the planet-forming regions of protoplanetary disks across the luminosity regime

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Near- to mid-IR observations of protoplanetary disks show that the inner regions (<10AU) are rich in small organic volatiles (e.g., C\textsubscript{2}H\textsubscript{2} and HCN). Trends in the data suggest that disks around cooler stars (~3000K) are potentially more carbon- and molecule-rich than their hotter counterparts. Our aims are to explore the composition of the planet-forming region of disks around stars from M dwarf to Herbig Ae and compare with the observed trends. Models of the disk physical structure are coupled with a gas-grain chemical network to map the abundances in the planet-forming zone. N\textsubscript{2} self shielding, X-ray-induced chemistry, and initial abundances, are investigated. The composition in the ‘observable’ atmosphere is compared with that in the midplane where the planet-building reservoir resides. M dwarf disk atmospheres are relatively more molecule rich than those for T Tauri or Herbig Ae disks. The weak far-UV flux helps retain this complexity which is enhanced by X-ray-induced ion-molecule chemistry. N\textsubscript{2} self shielding has only a small effect and does not explain the higher C\textsubscript{2}H\textsubscript{2}/HCN ratios observed towards cooler stars. The models
underproduce the OH/H$_2$O column density ratios constrained in Herbig Ae disks, despite reproducing the absolute value for OH: H$_2$O self shielding only increases this discrepancy. The disk midplane content is sensitive to the initial main elemental reservoirs. The gas in the inner disk is generally more carbon rich than the midplane ices and is most significant for disks around cooler stars. The atmospheric C/O ratio appears larger than it actually is when calculated using observable tracers only because gas-phase O$_2$ is predicted to be a significant oxygen reservoir. The models suggest that the gas in the inner regions of disks around cooler stars is more carbon rich; however, calculations of the molecular emission are necessary to confirm the observed trends.

Accepted by A&A

http://arxiv.org/pdf/1507.08544

Large-scale filaments associated with Milky Way spiral arms

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The ubiquity of filamentary structure at various scales throughout the Galaxy has triggered a renewed interest in their formation, evolution, and role in star formation. The largest filaments can reach up to Galactic scale as part of the spiral arm structure. However, such large scale filaments are hard to identify systematically due to limitations in identifying methodology (i.e., as extinction features). We present a new approach to directly search for the largest, coldest, and densest filaments in the Galaxy, making use of sensitive Herschel Hi-GAL data complemented by spectral line cubes. We present a sample of the 9 most prominent Herschel filaments, including 6 identified from a pilot search field plus 3 from outside the field. These filaments measure 37-99 pc long and 0.6-3.0 pc wide with masses $(0.5-8.3) \times 10^4 M_\odot$, and beam-averaged $(28''$, or $0.4-0.7$ pc) peak H$_2$ column densities of $(1.7-9.3) \times 10^{22}$ cm$^{-2}$. The bulk of the filaments are relatively cold (17-21 K), while some local clumps have a dust temperature up to 25-47 K. All the filaments are located within about 60 pc from the Galactic mid-plane. Comparing the filaments to a recent spiral arm model incorporating the latest parallax measurements, we find that 7/9 of them reside within arms, but most are close to arm edges. These filaments are comparable in length to the Galactic scale height and therefore are not simply part of a grander turbulent cascade.

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http://arxiv.org/pdf/1504.00647
http://www.eso.org/~kwang/GCF.pdf

Spectral Line Survey toward Young Massive Protostar NGC 2264 CMM3 in the 4 mm, 3 mm, and 0.8 mm Bands

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Spectral line survey observations are conducted toward the high-mass protostar candidate NGC 2264 CMM3 in the 4 mm, 3 mm, and 0.8 mm bands with the Nobeyama 45 m telescope and the Atacama Submillimeter Telescope Experiment (ASTE) 10 m telescope. In total, 265 emission lines are detected in the 4 mm and 3 mm bands, and 74
emission lines in the 0.8 mm band. As a result, 36 molecular species and 30 isotopologues are identified. In addition to the fundamental molecular species, many emission lines of carbon-chain molecules such as HC$_5$N, C$_4$H, CCS, and C$_3$S are detected in the 4 mm and 3 mm bands. Deuterated molecular species are also detected with relatively strong intensities. On the other hand, emission lines of complex organic molecules such as HCOOCH$_3$, and CH$_3$OCH$_3$ are found to be weak. For the molecules for which multiple transitions are detected, rotation temperatures are derived to be 7–33 K except for CH$_3$OH. Emission lines with high upper-state energies ($E_u > 150$ K) are detected for CH$_3$OH, indicating existence of a hot core. In comparison with the chemical composition of the Orion KL, carbon-chain molecules and deuterated molecules are found to be abundant in NGC 2264 CMM3, while sulfur-bearing species and complex organic molecules are deficient. These characteristics indicate chemical youth of NGC 2264 CMM3 in spite of its location at the center of the cluster forming core, NGC 2264 C.

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http://arxiv.org/pdf/1507.04958

A MUSE map of the central Orion Nebula (M 42)

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We present a new integral-field spectroscopic dataset of the central part of the Orion Nebula (M 42), observed with the MUSE instrument at the ESO VLT. We reduced the data with the public MUSE pipeline. The output products are two FITS cubes with a spatial size of $\sim 5.9' \times 4.9'$ (corresponding to $\sim 0.76$ pc $\times 0.63$ pc) and a contiguous wavelength coverage of 4595...9366 Å, spatially sampled at 0''.2. We provide two versions with a sampling of 1.25 Å and 0.85 Å in dispersion direction. Together with variance cubes these files have a size of 75 and 110 GiB on disk. They represent one of the largest integral field mosaics to date in terms of information content. We make them available for use in the community. To validate this dataset, we compare world coordinates, reconstructed magnitudes, velocities, and absolute and relative emission line fluxes to the literature and find excellent agreement. We derive a two-dimensional map of extinction and present de-reddened flux maps of several individual emission lines and of diagnostic line ratios. We estimate physical properties of the Orion Nebula, using the emission line ratios [N II] and [S III] (for the electron temperature $T_e$) and [S II] and [Cl III] (for the electron density $N_e$), and show two-dimensional images of the velocity measured from several bright emission lines.

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http://arxiv.org/pdf/1507.00006

YSOVAR: Mid-infrared Variability Among YSOs in the Star Formation Region GGD 12-15

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We present an IR-monitoring survey with the Spitzer Space Telescope of the star forming region GGD 12-15. Over 1000 objects were monitored including about 350 objects within the central 5′ which is found to be especially dense in cluster members. The monitoring took place over 38 days and is part of the Young Stellar Object VARiability (YSOVAR) project. The region was also the subject of a contemporaneous 67ks Chandra observation. The field includes 119 previously identified pre-main sequence star candidates. X-rays are detected from 164 objects, 90 of which are identified with cluster members. Overall, we find that about half the objects in the central 5′ are young stellar objects based on a combination of their spectral energy distribution, IR variability and X-ray emission. Most of the stars with IR excess relative to a photosphere show large amplitude (>0.1 mag) mid-IR variability. There are 39 periodic sources, all but one of these is found to be a cluster member. Almost half of the periodic sources do not show IR excesses. Overall, more than 85% of the Class I, flat spectrum, and Class II sources are found to vary. The amplitude of the variability is larger in more embedded young stellar objects. Most of the Class I/II objects exhibit redder colors in a fainter state, compatible with time-variable extinction. A few become bluer when fainter, which can be explained with significant changes in the structure of the inner disk. A search for changes in the IR due to X-ray events is carried out, but the low number of flares prevented an analysis of the direct impact of X-ray flares on the IR lightcurves. However, we find that X-ray detected Class II sources have longer timescales for change in the mid-IR than a similar set of non-X-ray detected Class IIs.

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GMC Collisions as Triggers of Star Formation. I. Parameter Space Exploration with 2D Simulations

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We utilize magnetohydrodynamic (MHD) simulations to develop a numerical model for GMC-GMC collisions between nearly magnetically critical clouds. The goal is to determine if, and under what circumstances, cloud collisions can cause pre-existing magnetically subcritical clumps to become supercritical and undergo gravitational collapse. We first develop and implement new photodissociation region (PDR) based heating and cooling functions that span the atomic to molecular transition, creating a multiphase ISM and allowing modeling of non-equilibrium temperature structures. Then in 2D and with ideal MHD, we explore a wide parameter space of magnetic field strength, magnetic field geometry, collision velocity, and impact parameter, and compare isolated versus colliding clouds. We find factors of 2-3 increase in mean clump density from typical collisions, with strong dependence on collision velocity and magnetic field strength, but ultimately limited by flux-freezing in 2D geometries. For geometries enabling flow along magnetic field lines, greater degrees of collapse are seen. We discuss observational diagnostics of cloud collisions, focussing on 13CO(J=2-1), 13CO(J=3-2), and 12CO(J=8-7) integrated intensity maps and spectra, which we synthesize from our
simulation outputs. We find the ratio of J=8-7 to lower-J emission is a powerful diagnostic probe of GMC collisions.

Not a galaxy: IRAS 04186+5143, a new young stellar cluster in the outer Galaxy

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We report the discovery of a new young stellar cluster in the outer Galaxy located at the position of an IRAS PSC source that has been previously mis-identified as an external galaxy. The cluster is seen in our near-infrared imaging towards IRAS 04186+5143 and in archive Spitzer images confirming the young stellar nature of the sources detected. There is also evidence of sub-clustering seen in the spatial distributions of young stars and of gas and dust. Near- and mid-infrared photometry indicates that the stars exhibit colours compatible with reddening by interstellar and circumstellar dust and are likely to be low- and intermediate-mass YSOs with a large proportion of Class I YSOs. Ammonia and CO lines were detected, with the CO emission well centred near the position of the richest part of the cluster. The velocity of the CO and NH\textsubscript{3} lines indicates that the gas is Galactic and located at a distance of about 5.5 kpc, in the outer Galaxy.

Herschel data of this region characterise the dust environment of this molecular cloud core where the young cluster is embedded. We derive masses, luminosities and temperatures of the molecular clumps where the young stars reside and discuss their evolutionary stages.

The disk-outflow system in the S255IR area of high mass star formation

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We report the results of our observations of the S255IR area with the SMA at 1.3 mm in the very extended configuration and at 0.8 mm in the compact configuration as well as with the IRAM-30m at 0.8 mm. The best achieved angular resolution is about 0.4 arcsec. The dust continuum emission and several tens of molecular spectral lines are observed. The majority of the lines is detected only towards the S255IR-SMA1 clump, which represents a rotating structure.
(probably disk) around the young massive star. The achieved angular resolution is still insufficient for conclusions about Keplerian or non-Keplerian character of the rotation. The temperature of the molecular gas reaches 130–180 K. The size of the clump is about 500 AU. The clump is strongly fragmented as follows from the low beam filling factor. The mass of the hot gas is significantly lower than the mass of the central star. A strong DCN emission near the center of the hot core most probably indicates a presence of a relatively cold ($\leq 80$ K) and rather massive clump there. High velocity emission is observed in the CO line as well as in lines of high density tracers HCN, HCO$^+$, CS and other molecules. The outflow morphology obtained from combination of the SMA and IRAM-30m data is significantly different from that derived from the SMA data alone. The CO emission detected with the SMA traces only one boundary of the outflow. The outflow is most probably driven by jet bow shocks created by episodic ejections from the center. We detected a dense high velocity clump associated apparently with one of the bow shocks. The outflow strongly affects the chemical composition of the surrounding medium.

Accepted by The Astrophysical Journal

http://arxiv.org/pdf/1507.05642

Abstracts of recently accepted major reviews

Observations of Solids in Protoplanetary Disks
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This review addresses the state of research that employs astronomical (remote sensing) observations of solids (“dust”) in young circumstellar disks to learn about planet formation. The intention is for it to serve as an accessible, introductory, pedagogical resource for junior scientists interested in the subject. After some historical background and a basic observational primer, the focus is shifted to the three fundamental topics that broadly define the field: (1) demographics – the relationships between disk properties and the characteristics of their environments and hosts; (2) structure – the spatial distribution of disk material and its associated physical conditions and composition; and (3) evolution – the signposts of key changes in disk properties, including the growth and migration of solids and the impact of dynamical interactions with young planetary systems. Based on the state of the art results in these areas, suggestions are made for potentially fruitful lines of work in the near future.

Accepted by PASP

http://adsabs.harvard.edu/pdf/2015arXiv150704758A

Observations of the Icy Universe
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Freeze-out of the gas-phase elements onto cold grains in dense interstellar and circumstellar media builds up ice mantles consisting of molecules that are mostly formed in situ ($\text{H}_2\text{O}$, $\text{NH}_3$, $\text{CO}_2$, CO, CH$_3$OH, and more). This
review summarizes the detected infrared spectroscopic ice features and compares the abundances across Galactic, extragalactic, and Solar System environments. A tremendous amount of information is contained in the ice band profiles. Laboratory experiments play a critical role in the analysis of the observations. Strong evidence is found for distinct ice formation stages, separated by CO freeze-out at high densities. The ice bands have proven to be excellent probes of the thermal history of their environment. The evidence for the long-held idea that processing of ices by energetic photons and cosmic rays produces complex molecules is weak. Recent state-of-the-art observations show promise for much progress in this area with planned infrared facilities.

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http://arxiv.org/pdf/1501.05317v2

The composition of the protosolar disk and the formation conditions for comets

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Conditions in the protosolar nebula have left their mark in the composition of cometary volatiles, thought to be some of the most pristine material in the solar system. Cometary compositions represent the end point of processing that began in the parent molecular cloud core and continued through the collapse of that core to form the protosun and the solar nebula, and finally during the evolution of the solar nebula itself as the cometary bodies were accreting. Disentangling the effects of the various epochs on the final composition of a comet is complicated. But comets are not the only source of information about the solar nebula. Protostellar disks around young stars similar to the protosun provide a way of investigating the evolution of disks similar to the solar nebula while they are in the process of evolving to form their own solar systems. In this way we can learn about the physical and chemical conditions under which comets formed, and about the types of dynamical processing that shaped the solar system we see today.

This paper summarizes some recent contributions to our understanding of both cometary volatiles and the composition, structure and evolution of protostellar disks.

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http://arxiv.org/pdf/1507.02328

Moving ... ??

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

The Astrophysical Institute and University Observatory (AIU) of the Friedrich Schiller University, Jena, Germany, is seeking candidates for two graduate student positions.

The positions are to work in the Research Unit FOR 2285 “Debris Disks in Planetary Systems”, newly established by the German Research Foundation (DFG). The successful candidates will join the theory group at the AIU and will work for one of the following two projects.

In the first project (P1, “Collisional modeling of resolved debris disks”), we plan to extend our knowledge of planetary systems harboring debris disks with the help of state-of-the-art collisional models. Such modeling is a powerful tool to decipher information encrypted in the observed dust and to connect the dust to its parent bodies, directly unobservable planetesimals. Constraints can be placed on locations and masses of planetesimal belts, their size and radial distribution, degree of dynamical excitation, material properties, etc. The graduate student is expected to refine our collisional code, incorporate recent advances from theory and laboratory work, and use the code to study a suite of resolved debris disks.

The second project (P2, “Sculpturing of debris disks by planets and companions”) aims at modelling of observed asymmetries in debris disks. Common disk features include, for instance, sharp radial boundaries, eccentric offsets, and azimuthal asymmetry. All these are signposts of underlying perturbations that shape the disks. A variety of possible mechanisms have been put forward to explain these phenomena. Many involve the gravitational influence of suggested but yet unseen planets and companions. To study this fascinating connection, the graduate student will combine the dynamical treatment (that describes these perturbations) with the collisional treatment (that describe the dust production) to construct a single numerical model.

Both students will work in close collaboration with other projects of the Research Unit that will provide key ingredients for the collisional models and calculation of observables. They will greatly benefit from the expertise available in the Unit, in general, and our group, in particular.

The positions are for three years and can start at any time, but no later than in the early 2016. The salary is standard for graduate student positions in Germany (1/2 TV-L E-13 of the German federal public service scale) and includes a number of social and family-related benefits.

The applicants should have a strong educational record and hold a Masters’ degree or equivalent in physics or astronomy. Previous experience with numerics and astronomical research, preferably with debris disk and/or exoplanet studies, would be an advantage.

Applications as a single PDF document should include a CV, a brief statement of research interests, and two names of reference. All applications received by September 30, 2015 will be given full consideration.

The Friedrich Schiller University is an equal opportunity employer and explicitly encourages women to apply. Disabled persons with equal aptitude, competence and qualification will be given preference.

Contact: P1: Prof. Alexander V. Krivov, krivov@astro.uni-jena.de
         P2: Dr. Torsten Löhne, tloehne@astro.uni-jena.de
Web: http://www.astro.uni-jena.de/index.php/jobs.html
Postdoctoral position on debris disks

The Astrophysical Institute and University Observatory (AIU) of the Friedrich Schiller University, Jena, Germany, is seeking candidates for a postdoctoral position.

The position is to work in the Research Unit FOR 2285 “Debris Disks in Planetary Systems”, newly established by the German Research Foundation (DFG). The successful candidate will join the theory group at the AIU and will work for the Research Unit’s project P3 “Origin of the warm and hot dust and planetary system architecture”. The project goals are to obtain improved statistics for the occurrence rate and parameters of warm and hot dust disks, to work out plausible scenarios for the origin of the observed warm and hot dust, to derive constraints on planetesimals and planets and the overall architecture of the systems, and to make suggestions for future observational tests. The postdoc will benefit from close collaboration with other projects of the Research Unit running in Jena, Braunschweig, Hamburg, and Kiel.

The position is for three years and can start at any time, but no later than in early 2016. The salary is standard for postdoc positions in Germany (TV-L E-13 of the German federal public service scale) and includes a number of social and family-related benefits.

The applicants should have a strong educational record and hold a doctoral degree or equivalent in physics or astronomy. Previous experience with astronomical research, preferably with debris disk and/or exoplanet studies, would be a strong advantage.

Applications as a single PDF document should include a CV, a brief statement of research interests, and three names of reference. All applications received by September 30, 2015 will be given full consideration.

The Friedrich Schiller University is an equal opportunity employer and explicitly encourages women to apply. Disabled persons with equal aptitude, competence and qualification will be given preference.

Contact: Prof. Alexander V. Krivov, krivov@astro.uni-jena.de
Web: http://www.astro.uni-jena.de/index.php/jobs.html

Two positions in submillimeter astronomy and star formation

One post doc and one Ph.D. position is available in the group of Jes Jørgensen at Centre for Star and Planet Formation and the Niels Bohr Institute at University of Copenhagen, Denmark. The group focuses on understanding the physics and chemistry of the earliest stages of star and planet formation with particular emphasis on observations of such systems using the Atacama Large Millimeter/submillimeter Array (ALMA) and other telescopes operating at far-infrared and (sub)millimeter wavelengths as well as link to theory through detailed dust and line radiative transfer modeling.

The successful candidates will be involved in the analysis of incoming data from ongoing ALMA programs but will also have ample time to carry out her/his own projects. Previous experience in long wavelength observations and a keen interest in topics related to star formation and/or astrochemistry will be a strong plus in the evaluation.

For the post doc position, the candidate should have finished his/her doctoral thesis before taking up the position. The position is initially for two years with an extension possible dependent on performance. The Ph.D. position is available for a 3-year period for applicants holding a relevant masters degree.

The deadline for applications is September 1st, 2015. The positions are open from 01 October 2015 but the exact starting dates flexible. Inquiries about the positions can be made to Jes Jørgensen (jeskj@nbi.ku.dk). For the full announcements including instructions on how to apply, information about salary and benefits - please see:
http://jobportal.ku.dk/phd/?show=752209 (Ph.D. position)
http://jobportal.ku.dk/videnskabelige-stillinger/?show=751918 (Post doc position)
Dear colleagues,

we are pleased to announce a five day conference on "The Astrophysics of Planetary Habitability", to be held at the University of Vienna, Austria, from February 8-12, 2016.

With a continuously increasing number of discovered exoplanets, research is shifting from pure detection to characterization of planets. The rapidly improving quality of observing tools and the success of space-based observations of exoplanets are driving detection and characterization toward ever smaller planets; several rocky planets have already been detected in or near the habitable zones around their host stars.

Exoplanetary studies are increasingly confronted with questions on habitable conditions. These conditions are determined by various astrophysical factors such as stellar high-energy radiation, particle winds, magnetic fields, accreting small bodies, planetary collisions, and planetary system dynamics.

This conference addresses astrophysical factors and processes that are pivotal for the formation, sustainability, and evolution of habitable conditions on planets from the era of planet formation in disks to the end of the main sequence life of the host stars.

Key topics include, among others,

- Formation of terrestrial planets in protoplanetary disks, their interactions with disk material, and the formation of protoatmospheres
- The role of stellar radiative and particle output for the evolution of planetary atmospheres
- The importance of stellar and planetary magnetic fields for habitability
- The physics of erosion processes of planetary atmospheres
- The effects due to dynamical interactions in planetary systems around single and binary stars, including collisions, migration, and transport mechanisms.

For more information on the conference, please check our website:

http://habitability.univie.ac.at

A second announcement containing information about online registration, abstract submission, online hotel room reservation, and invited speakers will be issued in early fall 2015.

We are looking forward to seeing you in Vienna in February 2016!

Manuel Guedel and Rudolf Dvorak On behalf of the Scientific and Local Organizing Committees

SOC: Eric Chassefiere (F), Manuel Güdel (A, chair), Nader Haghighipour (USA), Wilhelm Kley (D), Helmut Lammer (A, co-chair), Douglas Lin (USA), Rosemary Mardling (AU), Elke Pilat-Lohinger (A, co-chair), Heike Rauer (D), Ansgar Reiners (D), Klaus Strassmeier (D) LOC: David Bancelin, Rudolf Dvorak (chair), Bibiana Fichtinger, Colin Johnstone, Theresa Lftinger (co-chair), Thomas Maindl, Daniel Steiner
Summary of Upcoming Meetings

6th Zermatt ISM Symposium: Conditions and Impact of Star Formation - From Lab to Space
7 - 11 September 2015 Zermatt, Switzerland
http://www.astro.uni-koeln.de/zermatt2015

Cloudy Workshop
21 - 26 September 2015 Pune, India
http://cloud9.pa.uky.edu/?gary/cloudy/CloudySummerSchool/

From Clouds to Protoplanetary Disks: the Astrochemical Link
5 - 8 October 2015 Berlin, Germany
https://cas-events.mpe.mpg.de/astrolink

Exchanging Mass, Momentum and Ideas: Connecting Accretion and Outflows in Young Stellar Objects
27 - 29 October 2015 Noordwijk, The Netherlands
http://www.cosmos.esa.int/web/accretion-outflow-workshop

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

Protoplanetary Discussions
7 - 11 March 2016, Edinburgh, UK
http://www-star.st-and.ac.uk/ppdiscs

From Stars to Massive Stars
6 - 9 April 2016, Gainesville, Florida, USA
http://conference.astro.ufl.edu/STARSTOMASSIVE/

Resolving planet formation in the era of ALMA and extreme AO
16 - 20 May 2016, Santiago, Chile
http://www.eso.org/sci/meetings/2016/Planet-Formation2016.html

Diffuse Matter in the Galaxy, Magnetic Fields, and Star Formation - A Conference Honoring the Contributions of Richard Crutcher & Carl Heiles
23 - 26 May 2015, Madison, USA
no URL yet

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

EPoS 2016 The Early Phase of Star Formation - Progress after 10 years of EPoS
26 June - 1 July 2016, Ringberg Castle, Germany

Star Formation in Different Environments
25 - 29 July 2016 Quy Nhon, Viet Nam
website to be announced

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

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