THE STAR FORMATION NEWSLETTER

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

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The Star Formation Newsletter

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

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Cover Picture

The Herbig Ae/Be star XY Per is seen illuminating the reflection nebula vdB 24 in the Lynds 1440 cloud in Perseus. XY Per has a spectral type of A2II and it has a companion with a separation of 1.8 arcsec. The image is 9 arcmin wide, with north up and east left.

Image courtesy Travis Rector
http://www.aftar.uaa.alaska.edu

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

Eric Becklin

in conversation with Bo Reipurth

Q: *How did you become an infrared astronomer in the 1960s? Who were the most influential people in the beginning of your career?*

A: I went to Caltech as a graduate student, but I had no interest in astronomy and I actually thought I might be a high-energy physicist or even doing theory, because I had done well as an undergraduate at the University of Minnesota. But at Caltech I actually failed out of graduate quantum mechanics the first year so I had to back off and take it later. In the meantime I started taking some astronomy courses and then met Gerry Neugebauer. I got lucky because he was right then starting his infrared program and it sounded just right for me and particularly it fit very well with my interests and talents, so that's how I became an infrared astronomer. By far the most influential person was Gerry Neugebauer, who just passed away this past year, he was my advisor and I collaborated with him throughout my career. Another very influential person was Bob Leighton, who built the CSO and developed the two-micron sky survey telescope that Gerry started working on, and I was fortunate to be part of their team. Leighton also discovered solar oscillations, and he wrote a book on high-energy physics. Yet another very important person was Guido Münch and I'll get into that story shortly, he was a professor in the astronomy department at Caltech and also on the staff at Mt. Palomar and Mt. Wilson.

Q: *You and Gerry Neugebauer discovered the famous Becklin-Neugebauer object in Orion, can you tell about the circumstances of discovery?*

A: The paper was published in 1967 but I actually made the discovery in 1965. As a graduate student I was working with Gerry Neugebauer and Bob Leighton on the two-micron sky survey, and as my first job they asked me to complete building a photometer to do follow-up observations that Dowell Martz - you may recognize his name from NML Cygnus - had started. It was meant to go on an optical telescope like the 60-inch but we eventually put it on the 200 inch. In 1965 I had time, thanks to Bob Leighton, on the 60-inch of Mt. Wilson to use this photometer and was wondering what to observe. Orion was something that Bob Leighton always talked about as a place to look for protostars, so I decided to just go and see what I could find in Orion. I looked through the telescope and there was the Trapezium with θ^1 Ori C, and θ^2 Ori to the south. I decided to scan away from θ^2 Ori and the Trapezium stars because they were optical, and if there was a protostar maybe it would be behind a lot of dust. At least that's what I remember. I started scanning, and all of a sudden there came this new source on the strip chart recorder, it was about the same brightness at 2.2 μm as θ^1 Ori C. I still have a copy of it on the wall behind me. I sat on that scan for a year, I had tried to get both Leighton and Neugebauer interested, but they were so focused on the two-micron sky survey that I couldn't get them involved, and I was also doing courses at the time and trying to recover from failing quantum mechanics. Then Guido Münch came over one day, and I said 'Guido, I have this interesting thing I found up at the Mt. Wilson 60-inch, could you take a look at it?' Guido took one look at the scan, and said 'Wow, this is one of the most interesting things I have ever seen, we've got to go down to Palomar and get more data at longer wavelengths', and so we took the photometer down to Palomar and we got additional measurements at 3.5 μm and also at 1.6 μm where we just barely detected it. Subsequently Westphal got 10 μm measurements. Guido was very interested in the beginning, but after getting the data he lost interest, he was always curious about the most interesting new things, he was just a fantastic guy. So then Gerry worked with me to write up the paper. Incidentally, Frank Low came to visit us as we were just about to submit the paper or had already submitted it, and we showed the new source to him, he got very interested, and he went out with Doug Kleinmann and made a measurement at 20 μm and discovered the Kleinmann-Low nebula basically in the same place as the BN object, they are offset by about 10-15 arcseconds.

Q: *You had a follow-up paper on the BN object in 1973.*

A: Yes. I should start by saying that in the 1967 paper we stated that the source had the properties of a protostar, but we didn't even use the infall equation, we just used the Kelvin-Helmholtz time scale, we were just physicists, we didn't really know what we were doing. Then after we made the discovery, Mike Penston, Dave Allen, and Harry Hyland wrote a paper saying that it was not a protostar inside the cloud, but it could well be that it was a background supergiant that was just reddened by the dust that was in that region. Hyland had a spectrum, which showed no features. But for the follow-up paper which we did - that was now with Neugebauer and Wynn-Williams - in 1973 we made 20 μm measurements, and we showed that it had a substantial 20 μm excess. In the original paper we said that it looked like a 600 degree blackbody and at most of the wavelengths it did. However, it had a silicate feature and combined with the 20 μm excess we concluded that it was much more likely to be something that is actually inside the cloud. And by then we also knew that there was a molecular cloud in that general region, at the time of discovery there was no cloud known nor any molecular masers known there.

Q: *You defended your thesis in 1968, and it included your discovery of the location of the Galactic Center. Was that discovery a Eureka moment, or a long, slow process?*

A: The data for my thesis were combined from the 24-inch, the 60-inch, and the 100-inch telescopes, all at Mt. Wilson, as well as from the 200-inch telescope at Mt. Palomar. The discovery actually was a relatively long, slow process. Leighton knew that the Galactic center was interesting, and from his calculations he thought it ought to have been detected with the two-micron sky survey. Neugebauer was asked by Leighton to go and get the coordinates for the Galactic Center from the astronomers and then check to see if the two-micron survey had seen it. Neugebauer got the coordinates but somehow there was some miscommunication along the way, because the precession got mixed up, and nothing was found in the two-micron survey data at those coordinates. But I looked at the center of M31 and it was quite bright, and from reading papers by Guido Münch and others I knew the reddening towards the Galactic Center region. I did a simple calculation and felt that we should be able to detect the Galactic Center region, so I went out to measure it. Gerry actually said that 'don't bother because we looked at the two-micron survey and it's not there', but I went up anyway and sure enough on the very first scan there it was. I didn't get the peak right at the beginning, because I didn't take into account refraction correctly but later of course we did and then the rest is all history. Later, after it got published, I went back to the two-micron sky survey, and there it was, it was not as obvious as it was on the 24 inch or on the 200-inch, but it could have been discovered earlier.

Q: *In 1979 you became the first director of the NASA InfraRed Telescope Facility on Mauna Kea, what are your recollections from that period?*

A: The IRTF was a very interesting story. NASA in the mid-1970s decided it needed an infrared telescope to do follow-up to all of its satellite missions to the various planets, they were just not getting enough time on the regular telescopes. They did a survey to find out where to put it, and there was a major competition between Hawaii and Arizona as to which was the better place to put the IRTF. The people in Arizona like Frank Low felt very strongly that it should be in Arizona, but there were people like Jim Westphal that did a survey to find out how the infrared background was and also the infrared transmission, and he firmly believed that Mauna Kea was one of the best sites in the world. In the end NASA decided to put it on Mauna Kea, but at that time they did not have a strong enough infrared team, so John Jefferies, the then director of the UH Institute for Astronomy, asked me to come out to be the first director of IRTF, because I knew a lot about the telescope and its site since Gerry Neugebauer had been heavily involved in the design and construction of IRTF. I left Caltech and went to Hawaii for 13 years and that was certainly a life changing experience for me. I had the support of Rich Capps, who was a very good infrared astronomer and instrumentalist, and we got IRTF going with some really good instrumentation. This was long before remote observing, so I went up to the telescope at least once a month and must have spent more than 500 nights observing from the summit. I think one of my greatest accomplishments during that time was the observational support for the Voyager flyby, which was what NASA was congressionally required to do. I couldn't have done it without the great support of the excellent IRTF staff, some of which we still know today, like Jim Harwood and Alan Tokunaga. 50% of the observing went to planetary observations and some important studies were made in that field, including the characterization of thermal properties of the volcanoes on Io that were discovered by Voyager, as well as many astrophysical discoveries.

Q: *Please tell how you and Ben Zuckerman in 1988 discovered the first L-dwarf, GD 165B, orbiting a white dwarf.*

A: I first got to really know Ben in 1980 when I invited him to spend a sabbatical in Hawaii. He ended up working with Mel Dyke, and subsequently they and Ted Simon discovered the IR companion to T Tauri. I then went to Edinburgh and learned a bit about brown dwarfs because they were doing a 1 μm sky survey looking for brown dwarfs. When I came back, Ben came to me and said 'You know, I think it would be of interest to do some more work on companions to white dwarfs.' I knew that others had tried this on the IRTF, but we felt it could be done better. So we started with white dwarfs in the Hyades cluster and the one Pleiades white dwarf, and then moved on to field white dwarfs. One of the first that was detected to have an excess was GD165, and that companion later became the first L-dwarf ever discovered; it is now almost universally accepted as a brown dwarf, so it was also one of the first brown dwarfs discovered. Its temperature is about 2000 K, and its atmosphere shows clouds and has led to many of the follow-on discoveries of brown dwarfs.

Q: *You have flown many times on the Kuiper Airborne Observatory, with which, among many other things, you and your collaborators Ian Gatley and Mike Werner discovered our Galaxy's central circumnuclear ring.*

A: Yes, I did a number of experiments on the Kuiper, but I think the circumnuclear ring was the best one that I was involved in. We also did a solar eclipse experiment, and studied M17 where we showed that molecular clouds could be heated sometimes from the outside by bright OB stars. It was fantastic to observe on the Kuiper, it was a bit noisy, but one of the greatest experiences I ever had was observing on the Kuiper and making discoveries on it.

Q: *You were named Chief Scientist for SOFIA in 1996, please tell about those years.*

A: I got involved in SOFIA because Bill Howard put me on a red team tasked with writing the funding proposal, so I went down to Waco and started working with the team on this seemingly crazy idea to put a 2.5m telescope on a 747 aircraft. I actually started really enjoying that and worked with a number of good people - Jackie Davidson, Ed Erickson, and others - and we actually won the proposal. Once we got the funding to build SOFIA, there was a lot of work and difficulties ahead. One important task was to make a call for the next generation of instruments, and we had to define all the requirements for what we were actually building, for example how we were going to interface the 2.5m telescope, that the Germans were building, into the observatory and make sure all of the weights were correct and that the whole thing would fly afterwards. The biggest challenge in putting SOFIA together was actually to get the door in place without having the plane fall completely apart, because the opening where the door is located is part of the structure of the aircraft so you can't just cut a hole in the fuselage. I thought we were doing a fairly good job, but I knew we were taking too long for the development, and NASA also felt the same, and all of a sudden we were out of the budget. As a consequence NASA made some changes to the management structure, and the Dryden Flight Research Center had to help Ames in the development. In the meantime, the Germans had done a fantastic job with the telescope, and we got it into the aircraft. Testing took a long time, getting all the bugs out, and getting that door to work correctly was also a really strenuous process. But in 2010 we made the first observations, and I could right away see - with the FORCAST imager at 37 μm - that the potential of SOFIA was there, we had the basics of a very fine flying observatory. The next instrument was the GREAT heterodyne instrument, they had been working hard in Bonn and Cologne to build this instrument and it went on the telescope and just worked right down to the expected performance. At this point Herschel was also observing, but we quickly beat Herschel on the important C+ line at 158 μm with GREAT. We also added a unique, very sensitive, OI channel at 63 μm on GREAT. Herschel of course ran out of cryogens about 2 years ago. So right now I am extremely positive on SOFIA, for one thing we really don't have anything besides SOFIA in the 30 to 300 μm region at the moment. ALMA and the telescopes in the Atacama and also down at the South Pole don't go below 300 μm, and at 30 μm the groundbased telescopes and JWST stop at 28 μm, so for imaging and spectroscopy there really is nothing else. You can do a few balloon experiments but they are so one-off and they have to be so targeted. SOFIA has great potential to really have a major impact. If you talk about far-infrared spectroscopy in that region from 30 to 300 μm, there is nothing else for the next about 20 years. SPICA appears unlikely to be operational before 2030. So we are the observatory of the future in the far-infrared/submm region. It's been a long hard road but one that I think is well worth it.

Q: *You just turned 75, but remain very active. What are your current interests?*

A: Okay, well, I have a number of projects that I find fascinating. I am working with Andrea Ghez and Mark Morris on Sgr-A*, which has a massive black hole, and we are trying to determine its mass by measuring the orbits of bright stars. This has led to a side project, because every time we look at Sgr-A* we can see variations at 3.5 μm and 2.2 μm, Sgr-A* is bubbling away which is seen also in X-rays and the radio. I am just captivated with these variations and what they mean. I am doing this both on the ground and working on a Spitzer observation with Giovanni Fazio that combines X-rays from Chandra, and Mark Morris and Andrea are also involved in this. I just find it fascinating that we can say something about the accretion disk which is at $\sim$0.1 AU from the massive black hole, and the material falling onto it - we don't know exactly where the emission is occurring, but from the timescale of variations it is probably happening very close in.

I am also working with Hans Zinnecker and Andrea and Mark again on some Orion proper motions using adaptive optics on the Keck telescope, and that goes right along with the motions that other people have been looking at with radio sources and other techniques, trying to see what is actually happening in the flow of material in Orion.

I should also mention that SOFIA is going down to New Zealand to make a measurement of an occultation of Pluto, it is happening just two weeks before the New Horizons flyby. Pluto and its atmosphere has been observed now for about 20 years, yielding different results, so the atmosphere of Pluto changes. Now we want to get a ground zero truth on it as New Horizons goes by, and I'm involved with Ted Dunham and Ian McLean and using the FliteCam and HIPO instruments on SOFIA to make these measurements from 0.4 to 2.2 μm.

My Favorite Object

The HH 211 Protostellar System

Chin-Fei Lee

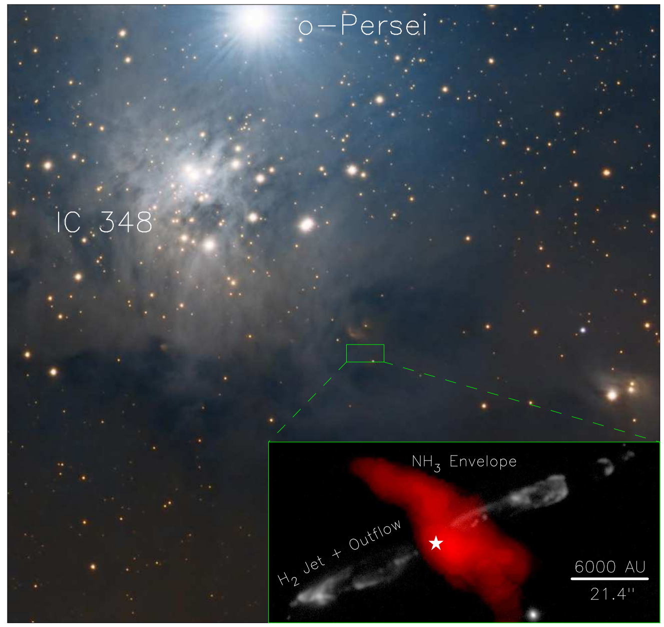

Figure 1: Optical image of the Perseus molecular cloud in the east end, taken with Moravian G2 8300 FW Camera by Patrick Hochleitner. The insert shows the H_2 jet and outflow (gray, Hirano et al. 2006), and the NH_3 envelope (red, Wiseman 2001) in the HH 211 system.

HH 211 is one of the most beautiful protostellar outflows. It is very young and nearby, allowing us to study the star-forming process at very early stages in great detail. It is located near the east end of the Perseus molecular cloud at a distance of ~ 280 pc. In this part of the cloud (Figure 1), the IC 348 cluster is located, with more than 400 young stars (mostly Class II or III YSOs), at ages of less than 5 Myr (Muench et al. 2007). The dark molecular cloud core located $10'$ southwest of IC 348 is the active star-forming region containing the HH 211 protostellar system (see the insert in Figure 1). More than 10 protostellar outflows are detected in this region (Walawender et al. 2006). As suggested in Bally et al. (2008), the star formation in this southwestern region could be triggered by action of the now mostly inactive young stars in the IC 348 cluster. Winds and outflows from IC 348 may have compressed the surrounding material and triggered core collapse.

1. Introduction to the HH 211 System

The HH 211 bipolar outflow system was first discovered in shock excited molecular hydrogen emission by McCaughrean et al. (1994), appearing as a highly collimated jet surrounded by a collimated outflow (see Figure 1 insert). The jet was mapped later in CO by Gueth & Guilloteau (1999) and SiO by Chandler & Richer (2001). The central driving source was detected in 1.3 mm continuum by Gueth & Guilloteau (1999), in between the western and eastern components of the jet. It was not detected at near-IR wavelengths. It is a low-luminosity ($\sim 3.6\ L_\odot$ at a distance of ~ 280 pc) Class 0 protostar with a low bolometric temperature ($T_{bol} \sim 31$ K, Froebrich et al. 2003).

2.1 Large Rotating Flattened Envelope

Wiseman et al. (2001) mapped the HH 211 region in NH_3 (1,1) with the Very Large Array (VLA). They detected a large flattened envelope with a radius $> 20''$ (i.e., 5600 AU) oriented roughly perpendicular to the jet axis (Figure 1 insert). A velocity gradient was seen in the envelope along the major axis going from the northeast to the southwest across the jet axis (Figure 2a, see also Tanner & Arce 2011), indicating that the envelope is rotating around the central source. Notice that the central source (with the position defined by the 1.3 mm continuum peak in Gueth & Guilloteau 1999) lies near the eastern edge of the NH_3 envelope. This is because the envelope, when resolved at higher resolution, is clumpy, and the central source is associated with a clump in the eastern edge (Tanner & Arce 2011). The total mass of the envelope is $\sim 0.4\ M_\odot$ (Tanner & Arce 2011). No clear infall motion has been detected in this flattened envelope.

2.2 Inner Envelope and Binary Companion

Lee at al. (2009, 2014) mapped the inner part of the envelope in 0.85 mm continuum with the Submillimeter Array (SMA). The continuum emission traces the thermal dust emission arising from the inner envelope, with a peak

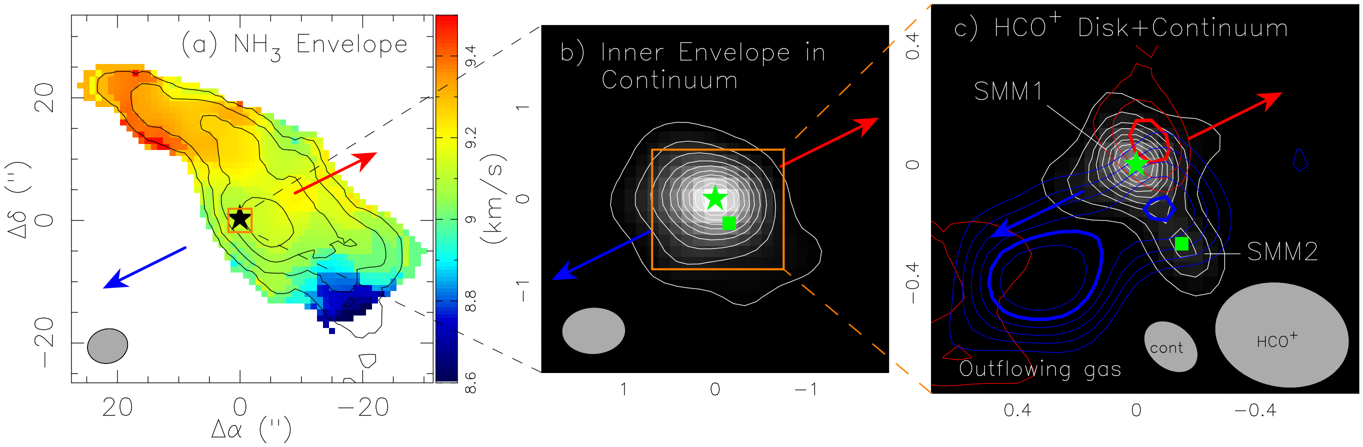

Figure 2: Envelope and Disk in HH 211 (Lee et al. 2009, 2014). (a) NH_3 envelope. Contours show the intensity. Color image shows the velocity. (b) Inner envelope in 0.85 mm continuum. (c) Innermost envelope and disk in 0.85 mm continuum (gray) and high-velocity HCO^+ emission (red and blue). A secondary peak is seen in continuum at $\sim 0\farcs3$ southwest of the central source. High-velocity redshifted and blueshifted HCO^+ emission are seen roughly on the opposite sides of the jet axis, arising from the disk around SMM1. Outflowing gas is also seen parallel to the jet axis.

at the central source position (Figure 2b). The envelope is slightly flattened perpendicular to the jet axis. It is slightly asymmetric about the central source, extending more to the SW and SE than to the NE and NW. When zooming into the innermost part of the envelope at $\sim 0\farcs2$ resolution, a secondary peak is seen at $\sim 0\farcs3$ (84 AU) southwest of the central source (Figure 2c). Thus, the central source is now called SMM1, and it is the source driving the jet. The secondary source is called the binary companion SMM2 and it seems to have a planetary mass.

2.3 Very Young Rotating Disk

The innermost envelope was also mapped in HCO^+ J=4-3 (Lee et al. 2009). A Keplerian rotation was detected in the position-velocity diagram of the HCO^+ emission cut perpendicular to the jet axis across the source SMM1 (see Figure 4a in Lee et al. 2009). The redshifted and blueshifted emission at high velocity are also seen roughly on the opposite sides of the jet axis (Figure 2c). Therefore, the innermost envelope seems to have formed a rotationally supported (Keplerian) disk around SMM1. The disk has a radius of $\sim 0\farcs3$ (84 AU) and it could be truncated by the companion SMM2. The redshifted emission is shifted slightly to the northwest, likely because of an outflow contamination on the redshifted side. The blueshifted emission is brighter than the redshifted emission, likely because part of the redshifted emission is absorbed by the inner envelope that is expected to have an infall motion. In the blueshifted emission, outflowing gas is also seen going out (from the disk) parallel to the jet axis.

From the Keplerian rotation, the mass of SMM1 was estimated to be $\sim 0.05\ M_\odot$ (or a mass of a brown dwarf), consistent with that derived from an evolution model by Froebrich et al. (2003), which was found to be $0.06\ M_\odot$. The mass of the disk was estimated to be $\sim$ 1-3 $M_{\rm Jup}$, using the continuum emission within $0\farcs3$ of SMM1. Later, other Class 0 sources were also found to be surrounded by a rotating disk, e.g., NGC 1333 IRAS 4A2 ($M_* \sim 0.08\ M_\odot$, $r_{\rm disk} \sim 130$ AU, Choi et al 2010), L 1527 ($M_* \sim 0.2\ M_\odot$, $r_{\rm disk} \sim 125$ AU, Tobin et al. 2013), VLA 1623 ($M_* \sim 0.2\ M_\odot$, $r_{\rm disk} \geq 150$ AU, Murillo et al. 2013), and HH 212 ($M_* \sim 0.2\ M_\odot$, $r_{\rm disk} \leq 100$ AU, Lee et al. 2014a). Thus, HH 211 SMM1 is currently the lowest-mass protostar found to be associated with a rotating disk. Since it has an (accretion) age of $\sim 1-2\times10^4$ yrs (Froebrich et al. 2003, Lee et al. 2009), it could also be the youngest found to be associated with a rotating disk.

2.4 Magnetic Field in the Envelope

In order to study the role of magnetic fields in star formation, Lee et al. (2014b) carried out dust polarization observation in 0.85 mm continuum with the SMA and detected dust polarization in the inner envelope. The field lines implied from the polarization have different orientations (Figure 3a), but they are not incompatible with current gravitational collapse models of a rotating magnetized cloud core, which predict different orientations depending on the region/distance (Figure 3b).

The NW field lines can trace the toroidal fields in the inner envelope generated by the rotation. The SE field

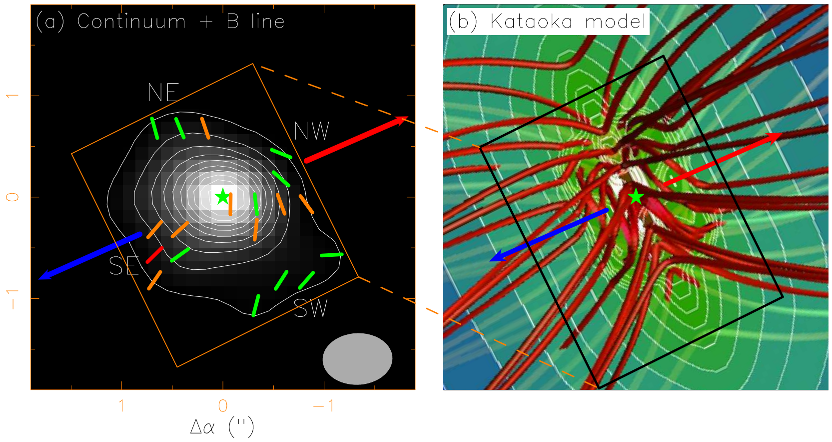

Figure 3: Continuum intensity, magnetic field orientation, and model magnetic field morphology in the inner envelope, adopted from Lee et al. 2014b. In (a), the image and contours show the continuum intensity map. The asterisk marks the position of SMM1. The blue and red arrows show the approaching and receding sides of the mean jet axis, respectively. Line segments show the magnetic field orientations (orange for 2-2.5σ, green for 2.5-3σ, and red for 3-3.5σ detection). (b) shows the model density (white contours and color image) and field (red and light green lines) morphology adopted from Kataoka et al. (2012), with the field axis (blue and red arrows) aligned with the jet axis of HH 211. The box marks the inner region that corresponds to our observation of the inner envelope.

lines are further away from the center and thus can trace the fields at the outer edge of the inner envelope, where the fields are still mainly poloidal. The SW field lines are slightly pinched and thus can trace the hourglass field lines dragged in by the gravitational collapse. The NE field lines are located closer to the source, where the hourglass field lines are expected to be dragged in more by the gravitational collapse and thus bent to be roughly perpendicular to the jet axis (see also Figure 4a in Allen et al. 2003). Note that it is also possible that the field lines there trace the toroidal fields generated by the rotation, as claimed in the case of NGC 1333 IRAS 4A (Crutcher 2012).

Hourglass field morphologies have been seen in other Class 0 systems, e.g., NGC 1333 IRAS 4A (a binary system) at $\sim$ 400 AU resolution (Girart et al. 2006) and L 1157 at 300-525 AU resolution (Stephens et al. 2013). At higher, $\sim$ 180 AU, resolution, toroidal field lines have also been detected tentatively in NGC 1333 IRAS 4A within 300 AU of the center (Crutcher 2012). In HH 211, a partial hourglass field morphology has also been seen at $\sim$ 1000 AU resolution, with a pinched field morphology in the SW (Hull et al. 2014). Here at higher, $\sim$ 170 AU, resolution, we may have detected not only the hourglass field morphology in the SW further in but also the toroidal field lines in the inner envelope within 300 AU of the center. Thus, higher resolution observations are needed to reveal the toroidal fields, likely because the rotation dominates only in the very inner region in the Class 0 phase.

In current theory, the pinched geometry of the magnetic field in the inner envelope can produce a magnetic braking, preventing a rotationally supported disk from being formed at the center (Allen et al. 2003). Fortunately, a magnetic-field-rotation misalignment on a larger size scale could reduce the magnetic braking, allowing the disk to be formed (Joos et al. 2012; Li et al. 2013). In such a larger size scale (arc-minute scale) (Matthews et al. 2009), the magnetic field lines are found to be roughly north-south oriented, neither aligned with nor perpendicular to the jet axis. However, the rotation axis on this scale is found to be roughly aligned with the jet axis (Figure 2a). Thus, there is a misalignment of $\sim 30^\circ$ between the large-scale field axis and the rotation axis, and it may help the disk formation.

3.1 Molecular Jet

In the early phases of star formation, such as the source of HH 211, jets appear to be mainly molecular. They could be originally atomic at the launching point. However, shortly after launched, they could become molecular, because of high formation rate of molecular gas due to the high mass-loss rate (Glassgold et al. 1991) in these jets. The jet in HH 211 was first discovered in H_2. The inner part of the jet, however, cannot be seen in H_2 because of dust extinction due to the envelope (Figure 4a). Fortunately, the inner jet can be seen in, e.g., CO J=3-2, SiO J=8-7, and SO $N_J = 9_8 - 8_7$ (Figure 4b), at submillimeter wavelengths.

The jet shows a clear wiggle about the source SMM1. Such a reflection-symmetric wiggle, detected for the first time

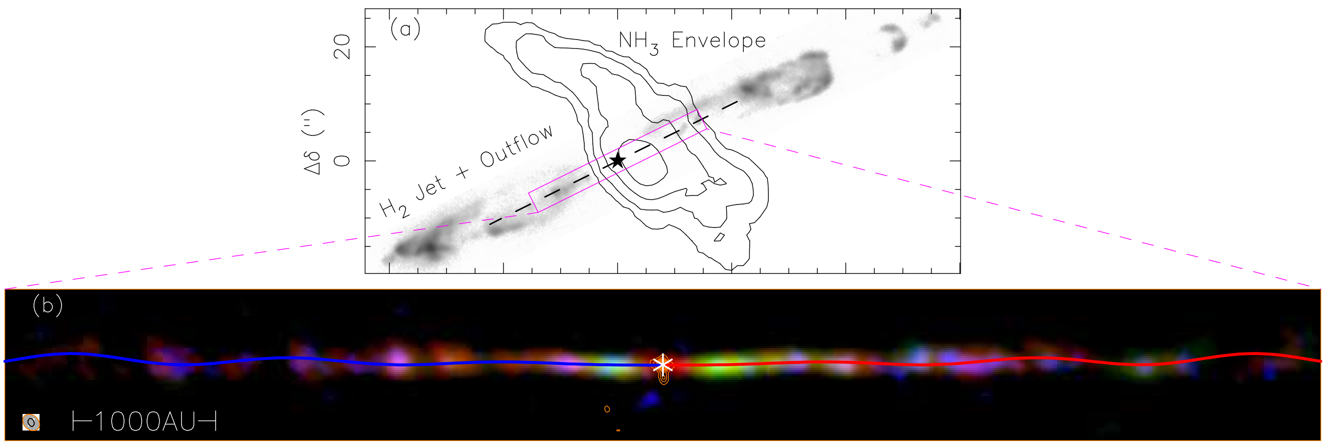

Figure 4: (a) The NH_3 envelope (Wiseman et al. 2001) plotted atop the H_2 jet and outflow (Hirano et al. 2006). (b) The inner part of the jet mapped with the SMA, with CO in red, SiO in green and SO in blue. The jet shows a reflection-symmetric wiggle about the source SMM1, which can be modeled assuming that the jet source is orbiting a close binary companion with a binary separation of $\sim$ 5 AU (blue and red curves) (Lee et al. 2010).

in a protostellar system, can be explained if SMM1 itself is a close binary system, consisting of a jet source orbiting a companion (Figure 4b). The formation of such a binary system could be due to a rotational fragmentation (Machida et al. 2008), which could be more common than we thought, and may be a way to partly resolve the long-standing excess angular momentum problem.

The jet consists of a chain of knots, with an interknot spacing of $2''-3''$. The knots are believed to be formed by a periodic variation in the jet velocity, which in turn could be due to a periodic perturbation of the accretion disk by the close binary companion (Lee et al. 2007). If so, since the interknot spacing is roughly half of the wavelength of the wiggle, there would be two perturbations per orbit, e.g., one at periastron and one at apastron.

3.2 Jet Rotation

Two competing magneto-centrifugal models, the X-wind model (Shu et al. 2000) and disk-wind model (Pudritz et al. 2007), have been used to explain the jet launching. The launching radius in these two models is different and thus can be used to differentiate between them. Since the launching radius is small ($\leq$ 1 AU), direct measurements are difficult. Fortunately, since the angular momentum can be assumed to be conserved along any field line, the launching radius can be derived from jet specific angular momentum and thus rotation (Anderson et al. 2003).

The HH 211 jet has a diameter of $\sim$ 40 AU ($0\farcs15$). With SMA observations at $\sim 0\farcs26$ resolution, Lee et al. (2009) have tentatively detected velocity gradients across the jet axis for the innermost pair of SiO knots, with $\sim$ 0.5-1.0 km s^{-1} at $\sim 0\farcs05$ from the jet axis (see their Figure 10). The gradients seem to arise from jet rotation, with the velocity sense the same as that seen in the rotating envelope-disk around the source, and with the redshifted and blueshifted emission slightly displaced on opposite sides of the jet axis (see their Figure 11). If real, the jet specific angular momentum would be $\sim$ 7-14 AU km s^{-1}. Then, with the jet velocity of $\sim$ 120 km s^{-1} (Jhan & Lee in prep.), the launching radius would be $0.04-0.06$ AU, and thus would be more consistent with the X-wind model.

3.3 Magnetic field in the Jet

The magnetic field morphology in protostellar jets is still poorly determined due to a lack of polarization detection. In current jet-launching models (Shu et al 2000; Pudritz et al. 2007), a poloidal field is needed to launch the jet and a toroidal field is needed to collimate the jet. Therefore, the jet is expected to be magnetized with a helical field. For high-mass systems, the jet can emit synchrotron radiation, allowing us to map the field morphology with polarization observations in synchrotron continuum (Carrasco-Gonzalez et al. 2010). For low-mass systems, the jet can emit molecular line emission, allowing us to map the field morphology with line polarization due to the Goldreich-Kylafis (GK) effect (Goldreich 1981, Goldreich1982).

Lee et al. (2014b) might have detected with the SMA for the first time polarized SiO line emission in the inner jet due to the GK effect (Figure 5). Two polarization detections, one in knot RK2 and one in between knots BK2 and BK3, are greater than 3σ, and thus should be real. Their polarization vectors have different orientations, with the

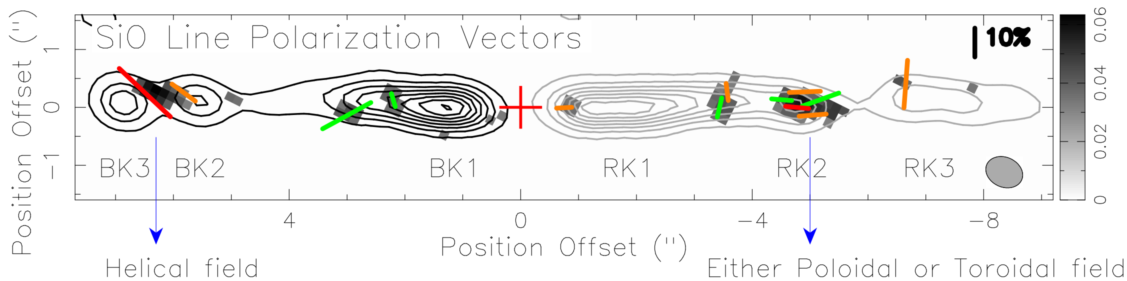

Figure 5: Polarized SiO line emission detected for the inner part of the jet with 2 to 3.5σ (orange for 2-2.5σ, green for 2.5-3σ, and red for 3-3.5σ). Polarization degree is indicated by the length of the vector. (Lee et al. 2014b)

former parallel to the jet axis and the latter highly inclined by $\sim 50°$ to the jet axis. Other detections are below 3σ and thus should be considered as tentative. No polarization is detected toward the bright innermost pair of knots probably because of the higher density and opacity there than other regions as well as the insufficient resolution.

According to the GK effect, the implied field lines in between knots BK2 and BK3 are also highly inclined to the jet axis, and thus could be helical. In knot RK2, on the other hand, the implied field lines could be either parallel or perpendicular to the polarization vectors. Therefore, the fields there could be either poloidal or toroidal. Further observations are needed to confirm these results and to determine the field morphology.

4 Summary

HH 211 is a very young and very low-mass protostellar system. At the center of the system, there are two sources, SMM1 and SMM2, with a projected separation of $\sim$ 84 AU. SMM1 is the one that powers the highly collimated jet and outflow in the system. A compact Keplerian rotating disk seems to have formed around SMM1. From the Keplerian rotation, the mass of SMM1 was estimated to be $\sim 0.05\ M_{\odot}$, which is a mass of a brown dwarf. On the other hand, SMM2 has a planetary mass. The magnetic field morphology in the inner envelope around the sources is consistent with a collapse model of a magnetized rotating core. Toroidal field is seen near the sources generated by the rotation.

The jet shows a reflection-symmetric wiggle about SMM1. This suggests that SMM1 itself could be a close binary, with a jet source orbiting a close companion. There is a tentative detection of a small jet rotation. If real, the implied launching radius would be 0.04-0.06 AU. There is also a tentative detection of polarized SiO line emission in the jet, with the implied field morphology not inconsistent with current magnetized jet models.

Overall, HH 211 shows various components that can be used to test current models of star formation. In addition, the formation of a close binary system and the presence of jet rotation may partly resolve the long-standing excess angular momentum problem. Future ALMA observations with unprecedented high sensitivity and resolution are really needed to confirm our results and better constrain the star formation models.

I would like to take this opportunity to thank all my collaborators who have been working on this beautiful protostellar system together over the years.

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Abstracts of recently accepted papers

Analytical Formulas of Molecular Ion Abundances and N_2H^+ Ring in Protoplanetary Disks

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We investigate the chemistry of ion molecules in protoplanetary disks, motivated by the detection of N_2H^+ ring around TW Hya. While the ring inner radius coincides with the CO snow line, it is not apparent why N_2H^+ is abundant outside the CO snow line in spite of the similar sublimation temperatures of CO and N_2. Using the full gas-grain network model, we reproduced the N_2H^+ ring in a disk model with millimeter grains. The chemical conversion of CO and N_2 to less volatile species (sink effect hereinafter) is found to affect the N_2H^+ distribution. Since the efficiency of the sink depends on various parameters such as activation barriers of grain surface reactions, which are not well constrained, we also constructed the no-sink model; the total (gas and ice) CO and N_2 abundances are set constant, and their gaseous abundances are given by the balance between adsorption and desorption. Abundances of molecular ions in the no-sink model are calculated by analytical formulas, which are derived by analyzing the full-network model. The N_2H^+ ring is reproduced by the no-sink model, as well. The 2D (R-Z) distribution of N_2H^+, however, is different among the full-network model and no-sink model. The column density of N_2H^+ in the no-sink model depends sensitively on the desorption rate of CO and N_2, and the flux of cosmic ray. We also found that N_2H^+ abundance can peak at the temperature slightly below the CO sublimation, even if the desorption energies of CO and N_2 are the same.

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A SCUBA-2 850-μm survey of circumstellar disks in the λ Orionis cluster

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We present results from an 850-μm survey of the $\sim$5 Myr old λ Orionis star-forming region. We used the SCUBA-2 camera on the James Clerk Maxwell Telescope to survey a $\sim$0.5-diameter circular region containing 36 (out of 59) cluster members with infrared excesses indicative of circumstellar disks. We detected only one object at $>3\sigma$ significance, the Herbig Ae star HD 245185, with a flux density of $\sim$74 mJy beam^{-1} corresponding to a dust mass of $\sim$150 $M_\oplus$. Stacking the individually undetected sources did not produce a significant mean signal but gives an upper limit on the average dust mass for λ Orionis disks of $\sim$3 $M_\oplus$. Our follow-up observations of HD 245185 with the Submillimeter Array found weak CO 2–1 line emission with an integrated flux of $\sim$170 mJy km s^{-1} but no ^{13}CO or C^{18}O isotopologue emission at 30 mJy km s^{-1} sensitivity, suggesting a gas mass of $\leq$1 $M_{\rm Jup}$. The implied gas-to-dust ratio is thus $\geq$50 times lower than the canonical interstellar medium value, setting HD 245185 apart from other Herbig Ae disks of similar age, which have been found to be gas rich; as HD 245185 also shows signs of accretion, we may be catching it in the final phases of disk clearing. Our study of the ? Orionis cluster places quantitative constraints on planet formation timescales, indicating that at $\sim$5 Myr the average disk no longer has sufficient dust and gas to form giant planets and perhaps even super Earths; the bulk material has been mostly dispersed or is locked in pebbles/planetesimals larger than a few mm in size.

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BANYAN. VI. Discovery of a companion at the brown dwarf/planet-mass limit to a Tucana-Horologium M dwarf

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We report the discovery of a substellar companion to 2MASS J02192210−3925225, a young M6 γ candidate member of the Tucana-Horologium association (30–40 Myr). This L4 γ companion has been discovered with seeing-limited direct imaging observations; at a $4''$ separation (160 AU) and a modest contrast ratio, it joins the very short list of young low-mass companions amenable to study without the aid of adaptive optics, enabling its characterization with a much wider suite of instruments than is possible for companions uncovered by high-contrast imaging surveys. With a model-dependent mass of 12–15 $M_{\rm Jup}$, it straddles the boundary between the planet and brown dwarf mass regimes. We present near-infrared spectroscopy of this companion and compare it to various similar objects uncovered in the last few years. The J0219−3925 system falls in a sparsely populated part of the host mass versus mass ratio diagram for binaries; the dearth of known similar companions may be due to observational biases in previous low-mass companion searches.

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Asymmetric features in the protoplanetary disk MWC 758

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The study of dynamical processes in protoplanetary disks is essential to understand planet formation. In this context, transition disks are prime targets because they are at an advanced stage of disk clearing and may harbor direct signatures of disk evolution. We aim to derive new constraints on the structure of the transition disk MWC 758, to detect non-axisymmetric features and understand their origin. We obtained infrared polarized intensity observations of the protoplanetary disk MWC 758 with SPHERE/VLT at 1.04 μm to resolve scattered light at a smaller inner working angle (0.093″) and a higher angular resolution (0.027″) than previously achieved. We observe polarized scattered light within 0.53″ (148 au) down to the inner working angle (26 au) and detect distinct non-axisymmetric features but no fully depleted cavity. The two small-scale spiral features that were previously detected with HiCIAO are resolved more clearly, and new features are identified, including two that are located at previously inaccessible radii close to the star. We present a model based on the spiral density wave theory with two planetary companions in circular orbits. The best model requires a high disk aspect ratio (H/r ∼0.20 at the planet locations) to account for the large pitch angles which implies a very warm disk. Our observations reveal the complex morphology of the disk MWC 758. To understand the origin of the detected features, the combination of high-resolution observations in the sub-millimeter with ALMA and detailed modeling is needed.

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THOR - The HI, OH, Recombination Line Survey of the Milky Way - The pilot study: HI observations of the giant molecular cloud W43

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To study the atomic, molecular, and ionized emission of giant molecular clouds (GMCs) in the Milky Way, we initiated a large program with the Karl G. Jansky Very Large Array (VLA): 'THOR - The HI, OH, Recombination Line survey of the Milky Way'. We map the 21cm HI line, 4 OH lines, up to 19 Hα recombination lines and the continuum from 1 to 2 GHz of a significant fraction of the Milky Way ($l = 15° - 67°$, $|b| \leq 1°$) at an angular resolution of $\sim 20''$. Starting in 2012, as a pilot study we mapped 4 square degrees of the GMC associated with the W43 star formation complex. The rest of the THOR survey area was observed during 2013 and 2014. In this paper, we focus on the HI emission from the W43 GMC complex. Classically, the HI 21cm line is treated as optically thin with properties such as the column density calculated under this assumption. This approach might yield reasonable results for regions of low-mass star formation, however, it is not sufficient to describe GMCs. We analyzed strong continuum sources to measure the optical depth along the line of sight, and thus correct the HI 21cm emission for optical depth effects and weak diffuse continuum emission. Hence, we are able to measure the HI mass of this region more accurately and our analysis reveals a lower limit for the HI mass of $M = 6.6_{-1.8} \times 10^6\,\mathrm{M}_\odot$ ($v_{\mathrm{LSR}} = 60 - 120\,\mathrm{km\,s^{-1}}$), which is a factor of 2.4 larger than the mass estimated with the assumption of optically thin emission. The HI column densities are as high as $N_{\mathrm{HI}} \sim 150\,\mathrm{M}_\odot\,\mathrm{pc}^{-2} \approx 1.9 \times 10^{22}\,\mathrm{cm}^{-2}$, which is an order of magnitude higher than for low-mass star formation regions. This result challenges theoretical models that predict a threshold for the HI column density of $\sim 10\,\mathrm{M}_\odot\,\mathrm{pc}^{-2}$, at which the formation of molecular hydrogen should set in. By assuming an elliptical layered structure for W43, we estimate the particle density profile. For the atomic gas particle density, we find a linear decrease toward the center of W43 with values decreasing from $n_{\mathrm{HI}} = 20\,\mathrm{cm}^{-3}$ near the cloud edge to almost $0\,\mathrm{cm}^{-3}$ at its center. On the other hand, the molecular hydrogen, traced via dust observations with the Herschel Space Observatory, shows an exponential increase toward the center with densities increasing to $n_{\mathrm{H_2}} > 200\,\mathrm{cm}^{-3}$, averaged over a region of $\sim$10 pc. While atomic and molecular hydrogen are well mixed at the cloud edge, the center of the cloud is strongly dominated by H_2 emission. We do not identify a sharp transition between hydrogen in atomic and molecular form. Our results, which challenge current theoretical models, are an important characterization of the atomic to molecular hydrogen transition in an extreme environment.

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Orbital Survival of m-size and Larger Bodies During Gravitationally Unstable Phases of Protoplanetary Disk Evolution

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A long-standing problem in the collisional accretion of terrestrial planets is the possible loss of m-size bodies through their inward migration onto the protostar as a result of gas drag forces. Such inward migration can be halted, and indeed even reversed, in a protoplanetary disk with local pressure maxima, such as marginally gravitationally unstable (MGU) phases of evolution, e.g., FU Orionis events. Results are presented for a suite of three-dimensional models of MGU disks extending from 1 AU to 10 AU and containing solid particles with sizes of 1 cm, 10 cm, 1 m, or 10 m, subject to disk gas drag and gravitational forces. These hydrodynamical models show that over disk evolution time scales of $\sim 6 \times 10^3$ yr or longer, during which over half the gaseous disk mass is accreted by the protostar, very few 1 m and 10 m bodies are lost through inward migration: most bodies survive and orbit stably in the outer disk. A greater fraction of 1 cm and 10 cm particles are lost to the central protostar during these time periods, as such particles are more closely tied to the disk gas accreting onto the protostar, but even in these cases, a significant fraction survive and

undergo transport from the hot inner disk to the cold outer disk, perhaps explaining the presence of small refractory particles in Comet Wild 2. Evidently MGU disk phases offer a means to overcome the m-sized migration barrier to collisional accumulation.

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https://home.dtm.ciw.edu/users/boss/ftp/orbital.pdf

An ALMA Constraint on the GSC 6214-210 B Circum-Substellar Accretion Disk Mass

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We present Atacama Large Millimeter/submillimeter Array (ALMA) observations of GSC 6214−210 A and B, a solar-mass member of the 5–10 Myr Upper Scorpius association with a 15±2 $M_{\rm jup}$ companion orbiting at ≈330 AU (2.″2). Previous photometry and spectroscopy spanning 0.3–5 μm revealed optical and thermal excess as well as strong Hα and Paβ emission originating from a circum-substellar accretion disk around GSC 6214−210 B, making it the lowest mass companion with unambiguous evidence of a subdisk. Despite ALMA's unprecedented sensitivity and angular resolution, neither component was detected in our 880 μm (341 GHz) continuum observations down to a 3σ limit of 0.22 mJy beam^{-1}. The corresponding constraints on the dust mass and total mass are <0.15 $M_\oplus$ and <0.05 $M_{\rm jup}$, respectively, or <0.003% and <0.3% of the mass of GSC 6214−210 B itself assuming a 100:1 gas-to-dust ratio and characteristic dust temperature of 10–20 K. If the host star possesses a putative circum-stellar disk then at most it is a meager 0.0015% of the primary mass, implying that giant planet formation has certainly ceased in this system. Considering these limits and its current accretion rate, GSC 6214−210 B appears to be at the end stages of assembly and is not expected to gain any appreciable mass over the next few Myr.

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Planets Around Low-Mass Stars (PALMS). V. Age-Dating Low-Mass Companions to Members and Interlopers of Young Moving Groups

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We present optical and near-infrared adaptive optics (AO) imaging and spectroscopy of 13 ultracool (>M6) companions to late-type stars (K7–M4.5), most of which have recently been identified as candidate members of nearby young moving groups (YMGs; 8–120 Myr) in the literature. The inferred masses of the companions ($\sim$10–100 $M_{\rm jup}$) are highly sensitive to the ages of the primary stars so we critically examine the kinematic and spectroscopic properties of each system to distinguish bona fide YMG members from old field interlopers. 2MASS J02155892−0929121 C is a new M7 substellar companion (40–60 $M_{\rm jup}$) with clear spectroscopic signs of low gravity and hence youth. The primary, possibly a member of the $\sim$40 Myr Tuc-Hor moving group, is visually resolved into three components, making it a young low-mass quadruple system in a compact (<100 AU) configuration. In addition, Li 1 λ6708 absorption in the intermediate-gravity M7.5 companion 2MASS J15594729+4403595 B provides unambiguous evidence that it is young (<200 Myr) and resides below the hydrogen burning limit. Three new close-separation (<1″) companions (2MASS J06475229−2523304 B, PYC J11519+0731 B, and GJ 4378 Ab) orbit stars previously reported as candidate YMG members, but instead are likely old (>1 Gyr) tidally-locked spectroscopic binaries without convincing kinematic associations with any known moving group. The high rate of false positives in the form of old active stars with YMG-like kinematics underscores the importance of radial velocity and parallax measurements to validate candidate young stars identified via proper motion and activity selection alone. Finally, we spectroscopically confirm the cool temperature and substellar nature of HD 23514 B, a recently discovered M8 benchmark brown dwarf orbiting the dustiest-known member of the Pleiades.

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Observational Diagnostics of Self-Gravitating MHD Turbulence in Giant Molecular Clouds

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We study the observable signatures of self-gravitating MHD turbulence by applying the probability density functions (PDFs) and the spatial density power spectrum to synthetic column density maps. We find that there exists three characterizable stages of the evolution of the collapsing cloud which we term "early," "intermediate," and "advanced." At early times, i.e. $t < 0.15t_{ff}$, the column density has a power spectral slope similar to nongravitating supersonic turbulence and a lognormal distribution. At an intermediate stage, i.e. $0.15t_{ff} < t \leq 0.35t_{ff}$, there exists signatures of the prestellar cores in the shallower PDF and power spectrum power law slopes. The column density PDF power law tails at these times have line of sight averaged slopes ranging from -2.5 to -1.5 with shallower values belonging to simulations with lower magnetic field strength. The density power spectrum slope becomes shallow and can be characterized by $P(k) = A_1 k^{\beta_2} e^{-k/k_c}$, where A_1 describes the amplitude, k^{β_2} describes the classical power law behavior and the scale k_c characterizes the turn over from turbulence dominated to self-gravity dominated. At advanced stages of collapse, i.e. $\approx t > 0.35t_{ff}$, the power spectral slope is positive valued, and a dramatic increase is observed in the PDF moments and the Tsallis incremental PDF parameters, which gives rise to deviations between PDF-sonic Mach number relations. Finally, we show that the imprint of gravity on the density power spectrum can be replicated in non-gravitating turbulence by introducing a delta-function with amplitude equivalent to the maximum valued point in a given self-gravitating map. We find that the turbulence power spectrum restored through spatial filtering of the high density material.

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Investigating 2MASS J06593158-0405277: a FUor burst in a triple system?

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FUor outbursts in young stellar objects (YSOs) are the most dramatic events among episodic accretion phenomena. The origin of these bursts is not clear: disk instabilities and/or disk perturbations by an external body being the most viable hypotheses. Here, we report our VLT/SINFONI high angular resolution AO-assisted observations of 2MASS J06593158-0405277, which is undergoing a recently discovered FUor outburst. Our observations reveal the presence of an extended disc-like structure around the FUor, a very low-mass companion (2MASS J06593158-0405277B) at ∼100 au in projection, and, possibly, a third closer companion at ∼11 au. These sources appear to be young, displaying accretion signatures. Assuming the components are physically linked, 2MASS J06593158-0405277 would then be one of the very few triple systems observed in FUors.

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Principal Component Analysis of computed emission lines from proto-stellar jets

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A very important issue concerning protostellar jets is the mechanism behind their formation. Obtaining information on the region at the base of a jet can shed light into the subject and some years ago this has been done through a search

for a rotational signature at the jet line spectrum. The existence of such signatures, however, remains controversial. In order to contribute to the clarification of this issue, in this paper we show that the Principal Component Analysis (PCA) can potentially help to distinguish between rotation and precession effects in protostellar jet images. This method reduces the dimensions of the data, facilitating the efficient extraction of information from large datasets as those arising from Integral Field Spectroscopy. The PCA transforms the system of correlated coordinates into a system of uncorrelated coordinates, the eigenvectors, ordered by principal components of decreasing variance. The projection of the data on these coordinates produces images called tomograms, while eigenvectors can be displayed as eigenspectra. The combined analysis of both can allow the identification of patterns correlated to a particular physical property that would otherwise remain hidden, and can help separating in the data the effect of physically uncorrelated phenomena. These are for example, rotation and precession in the kinematics of a stellar jet. In order to show the potential of the PCA analysis, we apply it to synthetic spectro-imaging datacubes generated as an output of numerical simulations of protostellar jets. In this way we generate a benchmark to which a PCA diagnostics of real observations can be confronted. Using the computed emission line profiles for [O I]λ6300 and [S II]λ6716, we recover and analyze the effects of rotation and precession in tomograms generated by PCA. We show that different combinations of the eigenvectors can be used to enhance and to identify the rotation features present in the data. Our results indicate that the PCA can be useful for disentangling rotation from precession in jets with an inclination of the jet with respect to the plane of the sky as high as 45°. We have been able to recover the initially imposed rotation jet profile for models at moderate inclination angle ($\phi \leq 15°$) and without precession.

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Indirect Detection of Forming Protoplanets via Chemical Asymmetries in Disks

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We examine changes in the molecular abundances resulting from increased heating due to a self-luminous planetary companion embedded within a narrow circumstellar disk gap. Using 3D models that include stellar and planetary irradiation, we find that luminous young planets locally heat up the parent circumstellar disk by many tens of Kelvin, resulting in efficient thermal desorption of molecular species that are otherwise locally frozen out. Furthermore, the heating is deposited over large regions of the disk, $\pm$5 AU radially and spanning $\lesssim$60° azimuthally. From the 3D chemical models, we compute rotational line emission models and full ALMA simulations, and find that the chemical signatures of the young planet are detectable as chemical asymmetries in $\sim$10h observations. HCN and its isotopologues are particularly clear tracers of planetary heating for the models considered here, and emission from multiple transitions of the same species is detectable, which encodes temperature information in addition to possible velocity information from the spectra itself. We find submillimeter molecular emission will be a useful tool to study gas giant planet formation in situ, especially beyond $R \gtrsim 10$ AU.

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Examining the T Tauri system with SPHERE

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Context. The prototypical low-mass young stellar object, T Tauri, is a well-studied multiple system with at least three components.

Aims. We aim to explore the T Tau system with the highest spatial resolution, study the time evolution of the known components, and re-determine the orbital parameters of the stars.
Methods. Near-infrared classical imaging and integral field spectrograph observations were obtained during the Science Verification of SPHERE, the new high-contrast imaging facility at the VLT. The obtained FWHM of the primary star varies between $0\farcs050$ and $0\farcs059$, making these the highest spatial resolution near-infrared images of the T Tauri system obtained to date.
Results. Our near-infrared images confirm the presence of extended emission south of T Tau Sa, reported in the literature. New narrow-band images show, for the first time, that this feature shows strong emission in both the Br-γ and H_2 1–0 S(1) lines. Broadband imaging at 2.27 μm shows that T Tau Sa is 0.92 mag brighter than T Tau Sb, which is in contrast to observations from Jan. 2014 (when T Tau Sa was fainter than Sb), and demonstrates that T Tau Sa has entered a new period of high variability. The newly obtained astrometric positions of T Tau Sa and Sb agree with orbital fits from previous works. The orbit of T Tau S (the center of gravity of Sa and Sb) around T Tau N is poorly constrained by the available observations and can be fit with a range of orbits ranging from a nearly circular orbit with a period of 475 years to highly eccentric orbits with periods up to 2.7×10^4 years. We also detected a feature south of T Tau N, at a distance of 144±3 mas, which shows the properties of a new companion.

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Direct Imaging and Spectroscopy of a Young Extrasolar Kuiper Belt in the Nearest OB Association

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We describe the discovery of a bright, young Kuiper belt-like debris disk around HD 115600, a ∼1.4–1.5 $M_\odot$, ∼15 Myr old member of the Sco-Cen OB Association. Our H-band coronagraphy/integral field spectroscopy from the *Gemini Planet Imager* shows the ring has a (luminosity scaled) semi major axis of (∼22 AU) ∼48 AU, similar to the current Kuiper belt. The disk appears to have neutral scattering dust, is eccentric ($e \sim$ 0.1–0.2), and could be sculpted by analogues to the outer solar system planets. Spectroscopy of the disk ansae reveal a slightly blue to gray disk color, consistent with major Kuiper belt chemical constituents, where water-ice is a very plausible dominant constituent. Besides being the first object discovered with the next generation of extreme adaptive optics systems (i.e. SCExAO, GPI, SPHERE), HD 115600's debris ring and planetary system provides a key reference point for the early evolution of the solar system, the structure and composition of the Kuiper belt, and the interaction between debris disks and planets.

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A Disk-based Dynamical Mass Estimate for the Young Binary AK Sco

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We present spatially and spectrally resolved Atacama Large Millimeter/submillimeter Array (ALMA) observations of gas and dust in the disk orbiting the pre-main sequence binary AK Sco. By forward-modeling the disk velocity field traced by CO J=2−1 line emission, we infer the mass of the central binary, $M_* = 2.49 \pm 0.10\,M_\odot$, a new dynamical measurement that is independent of stellar evolutionary models. Assuming the disk and binary are co-planar within ∼2 degrees, this disk-based binary mass measurement is in excellent agreement with constraints from radial velocity monitoring of the combined stellar spectra. These ALMA results are also compared with the standard approach of estimating masses from the location of the binary in the Hertzsprung-Russell diagram, using several common pre-main sequence model grids. These models predict stellar masses that are marginally consistent with our dynamical measurement (at $\sim 2\,\sigma$), but are systematically high (by ∼10%). These same models consistently predict an age of 18 ± 1 Myr for AK Sco, in line with its membership in the Upper Centaurus-Lupus association but surprisingly old for it to still host a gas-rich disk. As ALMA accumulates comparable data for large samples of pre-main sequence stars, the methodology employed here to extract a dynamical mass from the disk rotation curve should prove extraordinarily useful for efforts to characterize the fundamental parameters of early stellar evolution.

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Near-IR High-Resolution Imaging Polarimetry of the SU Aur Disk: Clues for Tidal Tails?

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We present new high-resolution (∼0".09) H-band imaging observations of the circumstellar disk around the T Tauri star SU Aur. Our observations with Subaru-HiCIAO have revealed the presence of scattered light as close as 0".15 (∼20 AU) to the star. Within our image, we identify bright emission associated with a disk with a minimum radius of ∼90 AU, an inclination of ∼35° from the plane of the sky, and an approximate P.A. of 15° for the major axis. We find a brightness asymmetry between the northern and southern sides of the disk due to a non-axisymmetric disk structure. We also identify a pair of asymmetric tail structures extending east and west from the disk. The western tail extends at least 2".5 (350 AU) from the star, and is probably associated with a reflection nebula previously observed at optical and near-IR wavelengths. The eastern tail extends at least 1" (140 AU) at the present signal-to-noise. These tails are likely due to an encounter with an unseen brown dwarf, but our results do not exclude the explanation that these tails are outflow cavities or jets.

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The complex chemistry of outflow cavity walls exposed: the case of low-mass protostars

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Complex organic molecules are ubiquitous companions of young low-mass protostars. Recent observations suggest that their emission stems, not only from the traditional hot corino, but also from offset positions. In this work, 2D physicochemical modelling of an envelope-cavity system is carried out. Wavelength-dependent radiative transfer calculations are performed and a comprehensive gas-grain chemical network is used to simulate the physical and chemical structure. The morphology of the system delineates three distinct regions: the cavity wall layer with time-dependent and species-variant enhancements; a torus rich in complex organic ices, but not reflected in gas-phase abundances; and the remaining outer envelope abundant in simpler solid and gaseous molecules. Strongly irradiated regions, such as the cavity wall layer, are subject to frequent photodissociation in the solid phase. Subsequent recombination of the photoproducts leads to frequent reactive desorption, causing gas-phase enhancements of several orders of magnitude. This mechanism remains to be quantified with laboratory experiments. Direct photodesorption is found to be relatively inefficient. If radicals are not produced directly in the icy mantle, the formation of complex organics is impeded. For efficiency, a sufficient number of FUV photons needs to penetrate the envelope; and elevated cool dust temperatures need to enable grain-surface radical mobility. As a result, a high stellar luminosity and a sufficiently wide cavity favor chemical complexity. Furthermore within this paradigm, complex organics are demonstrated to have unique lifetimes and be grouped into early (formaldehyde, ketene, methanol, formic acid, methyl formate, acetic acid, glycolaldehyde) and late (acetaldehyde, dimethyl ether, ethanol) species.

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Search for associations containing young stars (SACY). VI. Is multiplicity universal? Stellar multiplicity in the range 3-1000 au from adaptive-optics observations

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Context. Young loose nearby associations are unique samples of close (<150 pc), young (≈5-100 Myr) pre-main sequence (PMS) stars. A significant number of members of these associations have been identified in the SACY collaboration. We can use the proximity and youth of these members to investigate key ingredients in star formation processes, such as multiplicity.
Aims. With the final goal to better understand multiplicity properties at different evolutionary stages of PMS stars, we present the statistics of identified multiple systems from 113 confirmed SACY members. We derive multiplicity frequencies, mass-ratio, and physical separation distributions in a consistent parameter space, and compare our results to other PMS populations and the field.
Methods. We have obtained adaptive-optics assisted near-infrared observations with NACO (ESO/VLT) and IRCAL (Lick Observatory) for at least one epoch of all 113 SACY members. We have identified multiple systems using co-moving proper-motion analysis for targets with multi-epoch data, and using contamination estimates in terms of mass-ratio and physical separation for targets with single-epoch data. We have explored ranges in projected separation and mass-ratio of a [3–1000 au], and q [0.1–1], respectively.
Results. We have identified 31 multiple systems (28 binaries and 3 triples). We derive a multiplicity frequency (MF) of $\mathrm{MF}_{3-1000\,\mathrm{au}}=28.4^{+4.7}_{-3.9}\%$ and a triple frequency (TF) of $\mathrm{TF}_{3-1000\,\mathrm{au}}=2.8^{+2.5}_{-0.8}\%$ in the separation range of 3-1000 au. We do not find any evidence for an increase in the MF with primary mass. The estimated mass-ratio of our statistical sample (with power-law index $\gamma=-0.04\pm0.14$) is consistent with a flat distribution ($\gamma=0$).
Conclusions. Analysis from previous work using tight binaries indicated that the underlying multiple system distribution of the SACY dataset and the young star-forming region (SFR) Taurus are statistically similar, supporting the idea that these two populations formed in a similar way. In this work, we show further similarities (but also hints of discrepancies) between the two populations: flat mass-ratio distributions and statistically similar MF and TF values. We also compared the SACY sample to the field (in the separation range of 19-100 au), finding that the two distributions are indistinguishable, suggesting a similar formation mechanism.

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The Transitional Disk around IRAS 04125+2902

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Resolved submillimeter imaging of transitional disks is increasingly revealing the complexity of disk structure. Here we present the first high-resolution submillimeter image of a recently identified transitional disk around IRAS 04125+2902 in the Taurus star-forming region. We measure an inner disk hole of ∼20 AU around IRAS 04125+2902 by simultaneously modeling new 880 μm Submillimeter Array (SMA) data along with an existing spectral energy distribution supplemented by new Discovery Channel Telescope (DCT) photometry. We also constrain the outer radius of the dust disk in IRAS 04125+2902 to ∼50–60 AU. Such a small dust disk could be attributed to initial formation conditions, outward truncation by an unseen companion, or dust evolution in the disk. Notably, the dust distribution of IRAS 04125+2902 resembles a narrow ring (ΔR∼35 AU) composed of large dust grains at the location of the disk wall. Such narrow dust rings are also seen in other transitional disks and may be evidence of dust trapping in pressure bumps, possibly produced by planetary companions. More sensitive submillimeter observations of the gas are necessary to further probe the physical mechanisms at work in shaping the spatial distribution of large dust in this disk. Interestingly, the IRAS 04125+2902 disk is significantly fainter than other transitional disks that have been resolved at submillimeter wavelengths, hinting that more objects with large disk holes may exist at the faint end of the submillimeter luminosity distribution that await detection with more sensitive imaging telescopes.

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Smoke in the Pipe Nebula: dust emission and grain growth in the starless core FeSt 1-457

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Methods. We derive maps of submillimeter dust optical depth and effective dust temperature from Herschel data that were calibrated against Planck. After calibration, we then fit a modified blackbody to the long-wavelength Herschel data, using the Planck-derived dust opacity spectral index beta, derived on scales of 30′ (or ∼1 pc). We use this model to make predictions of the submillimeter flux density at 850 micron, and we compare these in turn with APEX-Laboca observations.
Results. A comparison of the submillimeter dust optical depth and near-infrared extinction data reveals evidence for an increased submillimeter dust opacity at high column densities, interpreted as an indication of grain growth in the inner parts of the core. Additionally, a comparison of the Herschel dust model and the Laboca data reveals that the frequency dependence of the submillimeter opacity, described by the spectral index beta, does not change. A single beta that is only slightly different from the Planck-derived value is sufficient to describe the data, $\beta = 1.53 \pm 0.07$. We apply a similar analysis to Barnard 68, a core with significantly lower column densities than FeSt 1-457, and we do not find evidence for grain growth but also a single β.
Conclusions. While we find evidence for grain growth from the dust opacity in FeSt 1-457, we find no evidence for significant variations in the dust opacity spectral index beta on scales $0.02 < x < 1$ pc (or $36'' < x < 30'$). The correction to the Planck-derived dust beta that we find in both cases is on the order of the measurement error, not including any systematic errors, and it would thus be reasonable to directly apply the dust beta from the Planck all-sky dust model. As a corollary, reliable effective temperature maps can be derived which would be otherwise affected by beta variations.

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Mid-infrared spectroscopy of SVS13: Silicates, quartz and SiC in a protoplanetary disc

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We present N-band (8−13 μm) spectroscopic observations of the low-mass, embedded pre-main-sequence close binary system SVS13. Absorption features are clearly detected which are attributable to amorphous silicates, crystalline forsterite, crystalline enstatite and annealed SiO_2. Most intriguingly, a major component of the dust in the envelope or disc around SVS13 appears to be SiC, required to model adequately both the total intensity and polarisation spectra. Silicon carbide is a species previously detected only in the spectra of C-rich evolved star atmospheres, wherein it is a dust condensate. It has not been unambiguously identified in the interstellar medium, and never before in a molecular cloud, let alone in close proximity to a forming star. Yet pre-Solar grains of SiC have been identified in meteorites, possibly suggesting an interesting parallel between SVS13 and our own Solar-System evolution. The uniqueness of the spectrum suggests that we are either catching SVS13 in a short-lived evolutionary phase and/or that there is something special about SVS13 itself that makes it rare amongst young stars. We speculate on the physical origin of the respective dust species and why they are all simultaneously present toward SVS13. Two scenarios are presented: a disc-instability-induced fragmentation, with subsequent localised heating and orbital evolution firstly annealing initially amorphous silicates and then dispersing their crystalline products throughout a circumstellar disc; and a newly discovered shock-heating mechanism at the interface between the circumstellar and circumbinary discs providing the crystallisation process. One or both of these mechanisms acting on carbon-rich grain material can also feasibly produce the SiC signature.

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New constraints on the multiplicity of massive young stars in Upper Scorpius

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Observations and simulations have clearly established that most stars form in multiple systems. Characterizing their properties is thus important for our understanding of the star formation process. To provide statistics about the number of companions per star over the full range of angular distances, infrared long-baseline interferometric studies can be employed to fill the gap between spectroscopic and adaptive optics searches. The Upper Scorpius OB association is a good target for such observations, because its stellar content is very well known from both spectroscopic and adaptive optics searches. We used the ESO Very Large Telescope Interferometer to perform long-baseline interferometric observations of a sample of seven B stars. Furthermore, we used ROSAT X-ray data to search for indications of low-mass companions. With the interferometric observations, we find previously known companions around σ Sco and HR 6027.For the other targets we determine the parameter space in which the presence of companions can be excluded from our data. For two of the B stars in our sample, π Sco and HR 6026, the detection of X-ray emission provides indirect evidence of previously unknown low-mass companions. In total we find two previously unknown companions. We can exclude the presence of other unknown companions within the separation range of ~ 2 to ~ 100 mas and for a brightness ratio ≥ 0.1.

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Empirical Isochrones for Low Mass Stars in Nearby Young Associations

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Absolute ages of young stars are important for many issues in pre-main sequence stellar and circumstellar evolution but are long recognized as difficult to derive and calibrate. In this paper, we use literature spectral types and photometry to construct empirical isochrones in HR diagrams for low-mass stars and brown dwarfs in the η Cha, ϵ Cha, and TW Hya Associations and the β Pic and Tuc-Hor Moving Groups. A successful theory of pre-main sequence evolution should match the shapes of the stellar loci for these groups of young stars. However, when comparing the combined empirical isochrones to isochrones predicted from evolutionary models, discrepancies lead to a spectral type (mass) dependence in stellar age estimates. Improved prescriptions for convection and boundary conditions in the latest models of pre-main sequence models lead to a significantly improved correspondence between empirical and model isochrones, with small offsets at low temperatures that may be explained by observational uncertainties or by model limitations. Independent of model predictions, linear fits to combined stellar loci of these regions provide a simple empirical method to order clusters by luminosity with a reduced dependence on spectral type. Age estimates calculated from various sets of modern models that reproduce Li depletion boundary ages of the β Pic Moving Group also imply a $\sim$4 Myr age for the low mass members of the Upper Sco OB Association, which is younger than the 11 Myr age that has been recently estimated for intermediate mass members.

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A Simple Calculation in Service of Constraining the Rate of FU Orionis Outburst Events from Photometric Monitoring Surveys

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An enigmatic and rare type of young stellar object is the FU Orionis class. The members are interpreted as "outbursting," that is, currently in a state of enhanced accretion by several orders of magnitude relative to the more modest disk-to-star accretion rates measured in typical T Tauri stars. They are key to our understanding of the history of stellar mass assembly and pre-main sequence evolution, as well as critical to consider in the chemical and physical evolution of the circumstellar environment – where planets form. A common supposition is that *all* T Tauri stars undergo repeated such outbursts, more frequently in their earlier evolutionary stages when the disks are more massive, so as to build up the requisite amount of stellar mass on the required time scale. However, the actual data supporting this traditional picture of episodically enhanced disk accretion are limited, and the observational properties of the known sample of FU Ori objects quite diverse. To improve our understanding of these rare objects, we outline the logic for meaningfully constraining the rate of FU Ori outbursts and present numbers to guide parameter choices in the analysis of time domain surveys.

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Discovery of Seven Companions to Intermediate Mass Stars with Extreme Mass Ratios in the Scorpius-Centaurus Association

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We report the detection of seven low mass companions to intermediate-mass stars (SpT B/A/F; $M{\sim}1.5$-$4.5\,M_{\odot}$) in the Scorpius-Centaurus Association using nonredundant aperture masking interferometry. Our newly detected objects have contrasts $\Delta L'{\approx}4$–6, corresponding to masses as low as $\sim 20\,M_{Jup}$ and mass ratios of $q{\sim}0.01$-0.08, depending on the assumed age of the target stars. With projected separations $\rho{\approx}10$-30 AU, our aperture masking detections sample an orbital region previously unprobed by conventional adaptive optics imaging of intermediate mass Scorpius-Centaurus stars covering much larger orbital radii (∼30-3000 AU). At such orbital separations, these objects resemble higher mass versions of the directly imaged planetary mass companions to the 10-30 Myr, intermediate-mass stars HR 8799, β Pictoris, and HD 95086. These newly discovered companions span the brown dwarf desert, and their masses and orbital radii provide a new constraint on models of the formation of low-mass stellar and substellar companions to intermediate-mass stars.

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The Formation and Destruction of Molecular Clouds and Galactic Star Formation

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We describe an overall picture of galactic-scale star formation. Recent high-resolution magneto-hydrodynamical simulations of two-fluid dynamics with cooling/heating and thermal conduction have shown that the formation of molecular clouds requires multiple episodes of supersonic compression. This finding enables us to create a scenario in which molecular clouds form in interacting shells or bubbles on a galactic scale. First we estimate the ensemble-averaged growth rate of molecular clouds over a timescale larger than a million years. Next we perform radiation hydrodynamics simulations to evaluate the destruction rate of magnetized molecular clouds by the stellar FUV radiation. We also investigate the resultant star formation efficiency within a cloud which amounts to a low value (a few percent) if we adopt the power-law exponent -2.5 for the mass distribution of stars in the cloud. We finally describe the time evolution of the mass function of molecular clouds over a long timescale (>1 Myr) and discuss the steady state exponent of the power-law slope in various environments.

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The HCN/HNC abundance ratio toward different evolutionary phases of massive star formation

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Using the $H^{13}CN$ and $HN^{13}C$ $J = 1$–0 line observations, the abundance ratio of HCN/HNC has been estimated for different evolutionary stages of massive star formation: Infrared dark clouds (IRDCs), High-mass protostellar object (HMPOs), and Ultra-compact HII regions (UCHIIs). IRDCs were divided into 'quiescent IRDC cores' and 'active IRDC cores', depending on star formation activity. The HCN/HNC ratio is known to be higher at active and high

temperature regions related to ongoing star formation, compared to cold and quiescent regions. Our observations toward 8 quiescent IRDC cores, 16 active IRDC cores, 23 HMPOs, and 31 UCHIIs show consistent results; the ratio is 0.97 ($\pm$0.10), 2.65 ($\pm$0.88), 4.17 ($\pm$1.03) and 8.96 ($\pm$3.32) in these respective evolutionary stages, increasing from quiescent IRDC cores to UCHIIs. The change of the HCN/HNC abundance ratio, therefore, seems directly associated with the evolutionary stages of star formation, which have different temperatures. One suggested explanation for this trend is the conversion of HNC to HCN, which occurs effectively at higher temperatures. To test the explanation, we performed a simple chemical model calculation. In order to fit the observed results, the energy barrier of the conversion must be much lower than the value provided by theoretical calculations.

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Spiral arms in scattered light images of protoplanetary discs: Are they the signposts of planets?

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One of the striking discoveries of protoplanetary disc research in recent years are the spiral arms seen in several transitional discs in polarised scattered light. An interesting interpretation of the observed spiral features is that they are density waves launched by one or more embedded (proto-)planets in the disc. In this paper we investigate whether planets can be held responsible for the excitation mechanism of the observed spirals. We use locally isothermal hydrodynamic simulations as well as analytic formulae to model the spiral waves launched by planets. Then *H*-band scattered light images are calculated using a 3D continuum radiative transfer code to study the effect of surface density and pressure scale height perturbation on the detectability of the spirals. We find that a relative change of $\sim$3.5 in the surface density ($\delta\Sigma/\Sigma$) is required for the spirals to be detected with current telescopes in the near-infrared for sources at the distance of typical star-forming regions (140 pc). This value is a factor of eight higher than what is seen in hydrodynamic simulations. We also find that a relative change of only 0.2 in pressure scale height is sufficient to create detectable signatures under the same conditions. Therefore, we suggest that the spiral arms observed to date in protoplanetary discs are the results of changes in the vertical structure of the disc (e.g. pressure scale height perturbation) instead of surface density perturbations.

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Mass Estimates of a Giant Planet in a Protoplanetary Disk from the Gap Structures

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A giant planet embedded in a protoplanetary disk forms a gap. An analytic relationship among the gap depth, planet mass M_p, disk aspect ratio h_p, and viscosity α has been found recently, and the gap depth can be written in terms of a single parameter $K = (M_p/M_*)^2 h_p^{-5} \alpha^{-1}$. We discuss how observed gap features can be used to constrain the disk and/or planet parameters based on the analytic formula for the gap depth. The constraint on the disk aspect ratio is critical in determining the planet mass so the combination of the observations of the temperature and the image can provide a constraint on the planet mass. We apply the formula for the gap depth to observations of HL Tau and HD 169142. In the case of HL Tau, we propose that a planet with $\gtrsim$0.3 is responsible for the observed gap at 30 AU from the central star based on the estimate that the gap depth is $\lesssim$1/3. In the case of HD 169142, the planet mass that causes the gap structure recently found by VLA is $\gtrsim$0.4 $M_{\rm J}$. We also argue that the spiral structure, if observed, can be used to estimate the lower limit of the disk aspect ratio and the planet mass.

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Orbital evolution of planetesimals in gaseous disks

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Planets are formed from collisional growth of small bodies in a protoplanetary disk. Bodies much larger than approximately 1 m are mainly controlled by the gravity of the host star and experience weak gas drag; their orbits are mainly expressed by orbital elements: semimajor axes a, eccentricities e, and inclinations i, which are modulated by gas drag. In a previous study, $\dot{a}$, $\dot{e}$, and $\dot{i}$ were analytically derived for $e \ll 1$ and $i \ll H/a$, where H is the scale height of the disk. Their formulae are valid in the early stage of planet formation. However, once massive planets are formed, e and i increase greatly. Indeed, some small bodies in the solar system have very large e and i. Therefore, in this paper, I analytically derive formulae for $\dot{a}$, $\dot{e}$, and $\dot{i}$ for $1-e^2 \ll 1$ and $i \ll H/a$ and for $i \gg H/a$. The formulae combined from these limited equations will represent the results of orbital integration unless $e \geq 1$ or $i > \pi - H/a$. Since the derived formulae are applicable for bodies not only in a protoplanetary disk but also in a circumplanetary disk, I discuss the possibility of the capture of satellites in a circumplanetary disk using the formulae.

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The Mass-Radius Relation of Young Stars, I: UScoCTIO 5, An M4.5 Eclipsing Binary in Upper Scorpius Observed By K2

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Evolutionary models of pre-main sequence stars remain largely uncalibrated, especially for masses below that of the Sun, making each new dynamical mass and radius measurement a valuable test of theoretical models. Stellar mass dependent features of star formation (such as disk evolution, planet formation, and even the IMF) are fundamentally tied to these models, which implies a systematic uncertainty that can only be improved with precise measurements of calibrator stars. We present the discovery that UScoCTIO 5, a known spectroscopic binary in the Upper Scorpius star-forming region ($P = 34$ days, $M_{tot} \sin(i) = 0.64 M_\odot$), is an eclipsing system with both primary and secondary eclipses apparent in K2 light curves obtained during Campaign 2. We have simultaneously fit the eclipse profiles from the K2 light curves and the existing RV data to demonstrate that UScoCTIO 5 consists of a pair of nearly identical M4.5 stars with $M_A = 0.329 \pm 0.002 M_\odot$, $R_A = 0.834 \pm 0.006 R_\odot$, $M_B = 0.317 \pm 0.002 M_\odot$, and $R_B = 0.810 \pm 0.006 R_\odot$. The radii are broadly consistent with pre-main sequence ages predicted by stellar evolutionary models, but none agree to within the uncertainties. All models predict systematically incorrect masses at the 25–50% level for the HR diagram position of these mid-M dwarfs, suggesting significant modifications to mass-dependent outcomes of star and planet formation. The form of the discrepancy for most model sets is not that they predict luminosities that are too low, but rather that they predict temperatures that are too high, suggesting that the models do not fully encompass the physics of energy transport (via convection and/or missing opacities) and/or a miscalibration of the SpT-$T_{\rm eff}$ scale. The simplest modification to the models (changing $T_{\rm eff}$ to match observations) would yield an older age for this system, in line with the recently proposed older age of Upper Scorpius ($\tau \sim 11$ Myr).

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High Resolution Optical and NIR Spectra of HBC 722

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We present the results of high resolution ($R \geq 30{,}000$) optical and near-IR spectroscopic monitoring observations of HBC 722, a recent FU Orionis object that underwent an accretion burst in 2010. We observed HBC 722 in optical/near-IR with the BOES, HET-HRS, and IGRINS spectrographs, at various points in the outburst. We found atomic lines with strongly blueshifted absorption features or P Cygni profiles, both evidence of a wind driven by the accretion. Some lines show a broad double-peaked absorption feature, evidence of disk rotation. However, the wind-driven and disk-driven spectroscopic features are anti-correlated in time; the disk features became strong as the wind features disappeared. This anti-correlation might indicate that the rebuilding of the inner disk was interrupted by the wind pressure during the first two years. The Half-Width at Half-Depth (HWHD) of the double-peaked profiles decreases with wavelength, indicative of the Keplerian rotation; the optical spectra with the disk feature are fitted by a G5 template stellar spectrum convolved with a rotation velocity of 70 km s^{-1} while the near-IR disk features are fitted by a K5 template stellar spectrum convolved with a rotation velocity of 50 km s^{-1}. Therefore, the optical and near-IR spectra seem to trace the disk at 39 and 76 $R_\odot$, respectively. We fit a power-law temperature distribution in the disk, finding an index of 0.8, comparable to optically thick accretion disk models.

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Modeling gravitational instabilities in self-gravitating protoplanetary disks with adaptive mesh refinement techniques

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The astonishing diversity in the observed planetary population requires theoretical efforts and advances in planet formation theories. Numerical approaches provide a method to tackle the weaknesses of current planet formation models and are an important tool to close gaps in poorly constrained areas. We present a global disk setup to model the first stages of giant planet formation via gravitational instabilities (GI) in 3D with the block-structured adaptive mesh refinement (AMR) hydrodynamics code ENZO. With this setup, we explore the impact of AMR techniques on the fragmentation and clumping due to large-scale instabilities using different AMR configurations. Additionally, we seek to derive general resolution criteria for global simulations of self-gravitating disks of variable extent. We run a grid of simulations with varying AMR settings, including runs with a static grid for comparison, and study the effects of varying the disk radius. Adopting a marginally stable disk profile ($Q_{\rm init} = 1$), we validate the numerical robustness of our model for different spatial extensions, from compact to larger, extended disks ($R_{\rm disk} = 10$, 100 and 300 AU, $M_{\rm disk} \sim 0.05\ M_\odot$, $M_{\rm star} = 0.646\ M_\odot$). By combining our findings from the resolution and parameter studies we find a lower limit of the resolution to be able to resolve GI induced fragmentation features and distinct, turbulence inducing clumps. Irrespective of the physical extension of the disk, topologically disconnected clump features are only resolved if the fragmentation-active zone of the disk is resolved with at least 100 cells, which holds as a minimum requirement for all global disk setups. Our simulations illustrate the capabilities of AMR-based modeling techniques for planet formation simulations and underline the importance of balanced refinement settings to reproduce fragmenting structures.

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Constraints to the magnetospheric properties of T Tauri stars - II. The Mg II ultraviolet feature

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The atmospheric structure of T Tauri Stars (TTSs) and its connection with the large scale outflow is poorly known. Neither the effect of the magnetically mediated interaction between the star and the disc in the stellar atmosphere is well understood. The Mg II multiplet is a fundamental tracer of TTSs atmospheres and outflows, and is the strongest feature in the near-ultraviolet spectrum of TTSs. The International Ultraviolet Explorer and Hubble Space Telescope data archives provide a unique set to study the main physical compounds contributing to the line profile and to derive the properties of the line formation region. The Mg II profiles of 44 TTSs with resolution 13,000 to 30,000 are available in these archives. In this work, we use this data set to measure the main observables: flux, broadening, asymmetry, terminal velocity of the outflow, and the velocity of the Discrete Absorption Components. For some few sources repeated observations are available and variability has been studied. There is a warm wind that at sub-AU scales absorbs the blue wing of the Mg II profiles. The main result found in this work is the correlation between the line broadening, Mg II flux, terminal velocity of the flow and accretion rate. Both outflow and magnetospheric plasma contribute to the Mg II flux. The flux-flux correlation between Mg II and C IV or He II is confirmed; however, no correlation is found between the Mg II flux and the ultraviolet continuum or the H_2 emission.

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X-Shooter study of accretion in ρ-Ophiuchus: very low-mass stars and brown dwarfs

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We present new VLT/X-Shooter optical and near-infrared spectra of a sample of 17 candidate young low-mass stars and brown dwarfs located in the ρ-Ophiucus cluster. We derived the spectral type and extinction for all the targets, and then we determined their physical parameters. All the objects but one have $M_\star<0.6\ M_\odot$, and eight have mass below or close to the hydrogen-burning limit. Using the intensity of various permitted emission lines present in their spectra, we determined the accretion luminosity and mass accretion rates ($\dot{M}_{\rm acc}$) for all the objects. When compared with previous works targeting the same sample, we find that, in general, these objects are not as strongly accreting as previously reported, and we suggest that the reason is our more accurate estimate of the photospheric parameters. We also compare our findings with recent works in other slightly older star-forming regions, such as Lupus, to investigate possible differences in the accretion properties, but we find that the accretion properties for our targets have the same dependence on the stellar and substellar parameters as in the other regions. This leads us to conclude that we do not find evidence for a different dependence of $\dot{M}_{\rm acc}$ with $M_\star$ when comparing low-mass stars and brown dwarfs. Moreover, we find a similar small ($\lesssim$1 dex) scatter in the $\dot{M}_{\rm acc}$-$M_\star$ relation as in some of our recent works in other star-forming regions, and no significant differences in $\dot{M}_{\rm acc}$ due to different ages or properties of the regions. The latter result suffers, however, from low statistics and sample selection biases in the current studies. The small scatter in the $\dot{M}_{\rm acc}$-$M_\star$ correlation confirms that mass accretion rate measurements in the literature based on uncertain photospheric parameters and single accretion indicators, such as the Hα width, can lead to a scatter that is unphysically large. Our studies show that only broadband spectroscopic surveys coupled with a detailed analysis of the photospheric and accretion properties allows us to properly study the evolution of disk accretion rates in star-forming regions.

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Massive Stars in the W33 Giant Molecular Complex

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Rich in HII regions, giant molecular clouds are natural laboratories to study massive stars and sequential star formation. The Galactic star forming complex W33 is located at $l \sim 12\overset{\circ}{.}8$ and at a distance of 2.4 kpc, has a size of $\sim$10 pc and a total mass of $\sim(0.8\text{–}8.0) \times 10^5\ M_\odot$. The integrated radio and IR luminosity of W33 - when combined with the direct detection of methanol masers, the protostellar object W33A, and protocluster embedded within the radio source W33 main - mark the region out as a site of vigorous ongoing star formation. In order to assess the long term star formation history, we performed an infrared spectroscopic search for massive stars, detecting for the first time fourteen early-type stars, including one WN6 star and four O4–7 stars. The distribution of spectral types suggests that this population

formed during the last ∼2–4 Myr, while the absence of red supergiants precludes extensive star formation at ages 6–30 Myr. This activity appears distributed throughout the region and does not appear to have yielded the dense stellar clusters that characterize other star forming complexes such as Carina and G305. Instead, we anticipate that W33 will eventually evolve into a loose stellar aggregate, with Cyg OB2 serving as a useful, albeit richer and more massive, comparator. Given recent distance estimates, and despite a remarkably similar stellar population, the rich cluster Cl 1813−178 located on the north-west edge of W33 does not appear to be physically associated with W33.

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Detailed structure of the outer disk around HD 169142 with polarized light in *H*-band

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Coronagraphic imagery of the circumstellar disk around HD 169142 in H-band polarized intensity (PI) with Subaru/HiCIAO is presented. The emission scattered by dust particles at the disk surface in $0.2'' \leq r \leq 1.2''$, or $29 \leq r \leq 174$ AU, is successfully detected. The azimuthally-averaged radial profile of the PI shows a double power-law distribution, in which the PIs in $r = 29 - 52$ AU and $r = 81.2 - 145$ AU respectively show r^{-3}-dependence. These two power-law regions are connected smoothly with a transition zone (TZ), exhibiting an apparent gap in $r = 40 - 70$ AU. The PI in the inner power-law region shows a deep minimum whose location seems to coincide with the point source at $\lambda = 7$ mm. This can be regarded as another sign of a protoplanet in TZ. The observed radial profile of the PI is reproduced by a minimally flaring disk with an irregular surface density distribution or with an irregular temperature distribution or with the combination of both. The depletion factor of surface density in the inner power-law region ($r < 50$ AU) is derived to be ≥ 0.16 from a simple model calculation. The obtained PI image also shows small scale asymmetries in the outer power-law region. Possible origins for these asymmetries include corrugation of the scattering surface in the outer region, and shadowing effect by a puffed up structure in the inner power-law region.

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Protoplanetary disks including radiative feedback from accreting planets

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While recent observational progress is converging on the detection of compact regions of thermal emission due to embedded protoplanets, further theoretical predictions are needed to understand the response of a protoplanetary disk to the planet formation radiative feedback. This is particularly important to make predictions for the observability of circumplanetary regions. In this work we use 2D hydrodynamical simulations to examine the evolution of a viscous protoplanetary disk in which a luminous Jupiter-mass planet is embedded. We use an energy equation which includes the radiative heating of the planet as an additional mechanism for planet formation feedback. Several models are computed for planet luminosities ranging from 10^{-5} to 10^{-3} Solar luminosities. We find that the planet radiative feedback enhances the disk's accretion rate at the planet's orbital radius, producing a hotter and more luminous environement around the planet, independently of the prescription used to model the disk's turbulent viscosity. We also estimate the thermal signature of the planet feedback for our range of planet luminosities, finding that the emitted spectrum of a purely active disk, without passive heating, is appreciably modified in the infrared. We simulate the protoplanetary disk around HD 100546 where a planet companion is located at about 68 AU from the star. Assuming the planet mass is 5 Jupiter masses and its luminosity is $\sim 2.5 \times 10^{-4}$ $L_\odot$, we find that the radiative feedback of the planet increases the luminosity of its ~ 5 AU circumplanetary disk from 10^{-5} $L_\odot$ (without feedback) to 10^{-3} $L_\odot$, corresponding to an emission of ~ 1 mJy in L' band after radiative transfer calculations, a value that is in good agreement with HD 100546b observations.

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First detection of thermal radio jets in a sample of proto-brown dwarf candidates

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We observed with the JVLA at 3.6 and 1.3 cm a sample of 11 proto-brown dwarf candidates in Taurus in a search for thermal radio jets driven by the most embedded brown dwarfs. We detected for the first time four thermal radio jets in proto-brown dwarf candidates. We compiled data from UKIDSS, 2MASS, Spitzer, WISE and Herschel to build the Spectral Energy Distribution (SED) of the objects in our sample, which are similar to typical Class I SEDs of Young Stellar Objects (YSOs). The four proto-brown dwarf candidates driving thermal radio jets also roughly follow the well-known trend of centimeter luminosity against bolometric luminosity determined for YSOs, assuming they belong to Taurus, although they present some excess of radio emission compared to the known relation for YSOs. Nonetheless, we are able to reproduce the flux densities of the radio jets modeling the centimeter emission of the thermal radio jets using the same type of models applied to YSOs, but with corresponding smaller stellar wind velocities and mass-loss rates, and exploring different possible geometries of the wind or outflow from the star. Moreover, we also find that the modeled mass outflow rates for the bolometric luminosities of our objects agree reasonably well with the trends found between the mass outflow rates and bolometric luminosities of YSOs, which indicates that, despite the "excess" centimeter emission, the intrinsic properties of proto-brown dwarfs are consistent with a continuation of those of very low mass stars to a lower mass range. Overall, our study favors the formation of brown dwarfs as a scaled-down version of low-mass stars.

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The snow line in viscous disks around low-mass stars: implications for water delivery to terrestrial planets in the habitable zone

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The water ice or snow line is one of the key properties of protoplanetary disks that determines the water content of terrestrial planets in the habitable zone. Its location is determined by the properties of the star, the mass accretion rate through the disk, and the size distribution of dust suspended in the disk. We calculate the snow line location from recent observations of mass accretion rates and as a function of stellar mass. By taking the observed dispersion in mass accretion rates as a measure of the dispersion in initial disk mass, we find that stars of a given mass will exhibit a range of snow line locations. At a given age and stellar mass, the observed dispersion in mass accretion rates of 0.4 dex naturally leads to a dispersion in snow line locations of ∼0.2 dex. For ISM-like dust sizes, the one-sigma snow line location among solar mass stars of the same age ranges from ∼2 to ∼5 au. For more realistic dust opacities that include larger grains, the snow line is located up to two times closer to the star. We use these locations and the outcome of N-body simulations to predict the amount of water delivered to terrestrial planets that formed in situ in

the habitable zone. We find that the dispersion in snow line locations leads to a large range in water content. For ISM-like dust sizes, a significant fraction of habitable-zone terrestrial planets around sun-like stars remain dry, and no water is delivered to the habitable zones of low-mass M stars ($< 0.5 M_\odot$) as in previous works. The closer-in snow line in disks with larger grains enables water delivery to the habitable zone for a significant fraction of M stars and all FGK stars. Considering their larger numbers and higher planet occurrence, M stars may host most of the water-rich terrestrial planets in the galaxy if these planets are able to hold on to their water in their subsequent evolution.

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A low-mass protostar's disk-envelope interface: disk-shadowing evidence from ALMA DCO+ observations of VLA1623

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Due to instrumental limitations and a lack of disk detections, the structure between the envelope and the rotationally supported disk has been poorly studied. This is now possible with ALMA through observations of CO isotopologs and tracers of freezeout. Class 0 sources are ideal for such studies given their almost intact envelope and young disk. The structure of the disk-envelope interface of the prototypical Class 0 source, VLA1623A which has a confirmed Keplerian disk, is constrained from ALMA observations of DCO^+ 3–2 and $C^{18}O$ 2–1. The physical structure of VLA1623 is obtained from the large-scale SED and continuum radiative transfer. An analytic model using a simple network coupled with radial density and temperature profiles is used as input for a 2D line radiative transfer calculation for comparison with the ALMA Cycle 0 12m array and Cycle 2 ACA observations of VLA1623. DCO^+ emission shows a clumpy structure bordering VLA1623A's Keplerian disk, suggesting a cold ring-like structure at the disk-envelope interface. The radial position of the observed DCO^+ peak is reproduced in our model only if the region's temperature is between 11–16K, lower than expected from models constrained by continuum and SED. Altering the density has little effect on the DCO^+ position, but increased density is needed to reproduce the disk traced in $C^{18}O$. The DCO^+ emission around VLA1623A is the product of shadowing of the envelope by the disk. Disk-shadowing causes a drop in the gas temperature outside of the disk on >200 AU scales, encouraging deuterated molecule production. This indicates that the physical structure of the disk-envelope interface differs from the rest of the envelope, highlighting the drastic impact that the disk has on the envelope and temperature structure. The results presented here show that DCO^+ is an excellent cold temperature tracer.

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Characteristic structure of star-forming clouds

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This paper gives a new way to diagnose the star-forming potential of a molecular cloud region from the probability density function of its column density (N-pdf). It gives expressions for the column density and mass profiles of a

symmetric filament having the same *N*-pdf as a filamentary region. The central concentration of this characteristic filament can distinguish regions and can quantify their fertility for star formation. Profiles are calculated for *N*-pdfs which are pure lognormal, pure power law, or a combination. In relation to models of singular polytropic cylinders, characteristic filaments can be unbound, bound, or collapsing depending on their central concentration. Such filamentary models of the dynamical state of *N*-pdf gas are more relevant to star-forming regions than are models of spherical collapse. The star formation fertility of a bound or collapsing filament is quantified by its mean mass accretion rate when in radial free fall. For a given mass per length, the fertility increases with the filament mean column density and with its initial concentration. In selected regions the fertility of their characteristic filaments increases with the level of star formation.

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Tracing planet-induced structures in circumstellar disks using molecular lines

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Circumstellar disks are considered to be the birthplace of planets. Specific structures like spiral arms, gaps, and cavities are characteristic indicators of planet-disk interaction. Investigating these structures can provide insights into the growth of protoplanets and the physical properties of the disk.
We investigate the feasibility of using molecular lines to trace planet-induced structures in circumstellar disks.
Based on 3D hydrodynamic simulations of planet-disk interactions obtained with the PLUTO code, we perform self-consistent temperature calculations and produce N-LTE molecular line velocity-channel maps and spectra of these disks using our new N-LTE line radiative transfer code *Mol3D*. Subsequently, we simulate ALMA observations using the CASA simulator. We consider two nearly face-on inclinations, five disk masses, seven disk radii, and two different typical pre-main-sequence host stars (T Tauri, Herbig Ae) at a distance of 140 pc. We calculate up to 141 individual velocity-channel maps for five molecules/isotopoloques ($^{12}C^{16}O$, $^{12}C^{18}O$, HCO^+, HCN, and CS) in a total of 32 rotational transitions to investigate the frequency dependence of the structures indicated above.
We find that the majority of protoplanetary disks in our parameter space could be detected in the molecular lines considered. However, unlike the continuum case, gap detection is not straightforward in lines. For example, gaps are not seen in symmetric rings but are masked by the pattern caused by the global (Keplerian) velocity field. By comparison with simulated observations of undisturbed disks we identify specific regions in the velocity-channel maps that are characteristic of planet-induced structures.
Simulations of high angular resolution molecular line observations demonstrate the potential of ALMA to provide complementary information about the planet-disk interaction as compared to continuum observations. In particular, the detection of planet-induced gaps is possible under certain conditions.

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The cometary composition of a protoplanetary disk as revealed by complex cyanides

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Observations of comets and asteroids show that the Solar Nebula that spawned our planetary system was rich in water and organic molecules. Bombardment brought these organics to the young Earth's surface, seeding its early chemistry.

Unlike asteroids, comets preserve a nearly pristine record of the Solar Nebula composition. The presence of cyanides in comets, including 0.01% of methyl cyanide (CH_3CN) with respect to water, is of special interest because of the importance of C-N bonds for abiotic amino acid synthesis. Comet-like compositions of simple and complex volatiles are found in protostars, and can be readily explained by a combination of gas-phase chemistry to form e.g. HCN and an active ice-phase chemistry on grain surfaces that advances complexity. Simple volatiles, including water and HCN, have been detected previously in Solar Nebula analogues - protoplanetary disks around young stars - indicating that they survive disk formation or are reformed in situ. It has been hitherto unclear whether the same holds for more complex organic molecules outside of the Solar Nebula, since recent observations show a dramatic change in the chemistry at the boundary between nascent envelopes and young disks due to accretion shocks. Here we report the detection of CH_3CN (and HCN and HC_3N) in the protoplanetary disk around the young star MWC 480. We find abundance ratios of these N-bearing organics in the gas-phase similar to comets, which suggests an even higher relative abundance of complex cyanides in the disk ice. This implies that complex organics accompany simpler volatiles in protoplanetary disks, and that the rich organic chemistry of the Solar Nebula was not unique.

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Formation of terrestrial planets in disks evolving via disk winds and implications for the origin of the solar system's terrestrial planets

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Recent three-dimensional magnetohydrodynamical simulations have identified a disk wind by which gas materials are lost from the surface of a protoplanetary disk, which can significantly alter the evolution of the inner disk and the formation of terrestrial planets. A simultaneous description of the realistic evolution of the gaseous and solid components in a disk may provide a clue for solving the problem of the mass concentration of the terrestrial planets in the solar system. We simulate the formation of terrestrial planets from planetary embryos in a disk that evolves via magnetorotational instability and a disk wind. The aim is to examine the effects of a disk wind on the orbital evolution and final configuration of planetary systems. We perform N-body simulations of sixty 0.1 Earth-mass embryos in an evolving disk. The evolution of the gas surface density of the disk is tracked by solving a one-dimensional diffusion equation with a sink term that accounts for the disk wind. We find that even in the case of a weak disk wind, the radial slope of the gas surface density of the inner disk becomes shallower, which slows or halts the type I migration of embryos. If the effect of the disk wind is strong, the disk profile is significantly altered (e.g., positive surface density gradient, inside-out evacuation), leading to outward migration of embryos inside $\sim$1 AU. Disk winds play an essential role in terrestrial planet formation inside a few AU by changing the disk profile. In addition, embryos can undergo convergent migration to $\sim$1 AU in certainly probable conditions. In such a case, the characteristic features of the solar system's terrestrial planets (e.g., mass concentration around 1 AU, late giant impact) may be reproduced.

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The jet and the disk of the HH 212 low-mass protostar imaged by ALMA: SO and SO_2 emission

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To investigate the disk formation and jet launch in protostars is crucial to comprehend the earliest stages of star and planet formation. We aim to constrain the properties of the molecular jet and the disk of the HH 212 protostellar system at unprecedented angular scales through ALMA observations of sulfur-bearing molecules, SO 9_8–8_7, SO 10_{11}–10_{10}, SO_2 $8_{2,6}$–$7_{1,7}$. 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-/red-shifted velocities the emission traces the wide-angle outflow and the fast (∼100–200 km/s) and collimated (∼90 AU) molecular jet revealing the inner knots with timescales <50 years. The jet transports a mass loss rate >0.2–2 × 10^{-6} $M_\odot$ yr^{-1}, implying high ejection efficiency (>0.03–0.3). The SO and SO_2 abundances in the jet are ∼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 >0.002–0.013 $M_\odot$, and the SO abundance in the disk is ∼10^{-8}–10^{-7}. 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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V409 Tau As Another AA Tau: Photometric Observations of Stellar Occultations by the Circumstellar Disk

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AA Tau is a well studied young stellar object that presents many of the photometric characteristics of a Classical T Tauri star (CTTS), including short-timescale stochastic variability attributed to spots and/or accretion as well as long duration dimming events attributed to occultations by vertical features (e.g., warps) in its circumstellar disk. We present new photometric observations of AA Tau from the Kilodegree Extremely Little Telescope North (KELT-North) which reveal a deep, extended dimming event in 2011, which we show supports the interpretation by Bouvier et al. (2013) of an occultation by a high-density feature in the circumstellar disk located >8 AU from the star. We also present KELT-North observations of V409 Tau, a relatively unstudied young stellar object also in Taurus-Auriga, showing short timescale erratic variability, along with two separate long and deep dimming events, one from January 2009 through late October 2010, and the other from March 2012 until at least September 2013. We interpret both dimming events to have lasted more than 600 days, each with a depth of ∼1.4 mag. From a spectral energy distribution analysis, we propose that V409 Tau is most likely surrounded by a circumstellar disk viewed nearly edge-on, and using

Keplerian timescale arguments we interpret the deep dimmings of V409 Tau as occultations from one or more features within this disk >10 AU from the star. In both AA Tau and V409 Tau, the usual CTTS short-timescale variations associated with accretion processes close to the stars continue during the occultations, further supporting the distant occulting material interpretation. Like AA Tau, V409 Tau serves as a laboratory for studying the detailed structure of the protoplanetary environments of T Tauri disks, specifically disk structures that may be signposts of planet formation at many AU out in the disk.

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A universal, turbulence-regulated star formation law: from Milky Way clouds to high-redshift disk and starburst galaxies

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Whilst the star formation rate (SFR) of molecular clouds and galaxies is key in understanding galaxy evolution, the physical processes which determine the SFR remain unclear. This uncertainty about the underlying physics has resulted in various different star formation laws, all having substantial intrinsic scatter. Extending upon previous works that define the column density of star formation ($\Sigma_{\rm SFR}$) by the gas column density ($\Sigma_{\rm gas}$), we develop a new universal star formation (SF) law based on the multi-freefall prescription of gas. This new SF law relies predominantly on the probability density function (PDF) and on the sonic Mach number of the turbulence in the star-forming clouds. By doing so we derive a relation where the star formation rate (SFR) correlates with the molecular gas mass per multi-freefall time, whereas previous models had used the average, single-freefall time. We define a new quantity called *maximum (multi-freefall) gas consumption rate* (MGCR) and show that the actual SFR is only about 0.4% of this maximum possible SFR, confirming the observed low efficiency of star formation. We show that placing observations in this new framework ($\Sigma_{\rm SFR}$ vs. MGCR) yields a significantly improved correlation with 3–4 times reduced scatter compared to previous SF laws and a goodness-of-fit parameter $R^2 = 0.97$. By inverting our new relationship, we provide sonic Mach number predictions for kpc-scale observations of Local Group galaxies as well as unresolved observations of local and high-redshift disk and starburst galaxies that do not have independent, reliable estimates for the turbulent cloud Mach number.

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Hot dust revealed during the dimming of the T Tauri star RW Aur A

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RW Aur A is a classical T Tauri star with emission line spectrum and clear signatures of accretion and wind. It is irregularly variable within V=10^m to V=12^m on a time scale of a few days. In 2010, the first long-lasting dimming event was recorded: RW Aur A faded by about 2^m and remained in low state with some fluctuations during several months. A hypothesis of occultation of the star by a distant cloud has been discussed in the literature. In 2014 the dimming event has repeated: RW Aur A has faded by $\approx 3^m$, and remained in the low state until the end of accessibility of the star in April 2015. We present new results of infrared (JHKLM) photometry of RW Aur in 2010-2015, which shed light on the cause of the dimming events. The light curves of RW Aur show that fading of brightness in visual and JH bands were accompanied by increase of brightness in KLM bands. The additional flux in KLM bands (2-5 μm) can be attributed to radiation of hot dust at the temperature of about 1000 K. The observed increase of the IR flux during the deep dimming event of 2014-2015 is not compatible with the hypothesis of a distant cloud. We argue that a hot dust in atmosphere of the inner disk is the most probable agent which obscures the star and radiates at 2-5 μm. Similarity of this phenomenon with that observed in UXors is briefly discussed. We suggest that the hot dust

was carried into the wind of RW Aur A, streaming from the inner disk towards observer.

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Dense Clumps and Candidates for Molecular Outflows in W40

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We report results of the CO(J=3-2) and HCO+(J=4-3) observations of the W40 HII region with the ASTE 10 m telescope (HPBW 22 arcsec) to search for molecular outflows and dense clumps. We found that the velocity field in the region is highly complex, consisting of at least four distinct velocity components at Vlsr 3, 5, 7, and 10 km/s. The 7 km/s component represents the systemic velocity of cold gas surroundingthe entire region, and causes heavy absorption in the CO spectra over the velocity range 6 ¡Vlsr¡ 9 km/s. The 5 and 10 km/s components exhibit high CO temperature (¿40 K) and are found mostly around the HII region, suggesting that these components are likely to be tracing dense gas interacting with the expanding shell around the HII region. Based on the CO data, we identified 13 regions of high velocity gas which we interpret as candidate outflow lobes. Using the HCO+ data, we also identified six clumps and estimated their physical parameters. On the basis of the ASTE data and near-infrared images from 2MASS, we present an updated three-dimensional model of this region. In order to investigate molecular outflows in W40, the SiO (J=1-0, v=0) emission line and some other emission lines at 40 GHz were also observed with the 45 m telescope at the Nobeyama Radio Observatory, but they were not detected at the present sensitivity.

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The accretion dynamics of EX Lupi in quiescence: The star, the spot, and the accretion column

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Context: EX Lupi is a young, accreting M0 star, prototype of EXor variable stars. Its spectrum is very rich in emission lines, including many metallic lines with narrow and broad components. It has been also proposed to have a close companion.
Aims: We use the metallic emission lines to study the accretion structures and to test the companion hypothesis.
Method: We analyse 54 spectra obtained during 5 years of quiescence time. We study the line profile variability and the radial velocity of the metallic emission lines. We use the velocity signatures of different species with various

excitation conditions and their time dependency to track the dynamics associated to accretion.
Results: We observe periodic velocity variations in the broad and the narrow line components, consistent with rotational modulation. The modulation is stronger for lines with higher excitation potentials, which are likely produced in a confined area, very close to the accretion shock.
Conclusions: We propose that the narrow line components are produced in the post-shock region, while the broad components originate in the more extended, pre-shock material. All the emission lines suffer velocity modulation due to the rotation of the star. The broad components are responsible for the line-dependent veiling observed in EX Lupi. We demonstrate that a rotationally-modulated line-dependent veiling can explain the radial velocity signature of the photospheric absorption lines, making the close-in companion hypothesis unnecessary. The accretion structure is locked to the star and very stable during the 5 years of observations. Not all stars with similar spectral types and accretion rates show the same metallic emission lines, which could be related to differences in temperature and density in their accretion structure(s). The contamination of photospheric signatures by accretion-related processes can be turned into a very useful tool to determine the innermost details of the accretion channels in the proximities of the star. The presence of emission lines from very stable accretion columns will nevertheless be a very strong limitation for the detection of companions by radial velocity in young stars, given the similarity of the accretion-related signatures with those produced by a companion.

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The VISTA Orion mini-survey: star formation in the Lynds 1630 North cloud

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The Orion cloud complex presents a variety of star formation mechanisms and properties and it is still one of the most intriguing targets for star formation studies. We present VISTA/VIRCAM near-infrared observations of the L1630N star forming region, including the stellar clusters NGC 2068 and NGC 2071, in the Orion molecular cloud B and discuss them in combination with Spitzer data. We select 186 young stellar object (YSO) candidates in the region on the basis of multi-colour criteria, confirm the YSO nature of the majority of them using published spectroscopy from the literature, and use this sample to investigate the overall star formation properties in L1630N. The K-band luminosity function of L1630N is remarkably similar to that of the Trapezium cluster, i.e., it presents a broad peak in the range 0.3-0.7 $M_\odot$ and a fraction of sub-stellar objects of $\sim$20%. The fraction of YSOs still surrounded by disk/envelopes is very high ($\sim$85%) compared to other star forming regions of similar age (1-2 Myr), but includes some uncertain corrections for diskless YSOs. Yet, a possibly high disk fraction together with the fact that 1/3 of the cloud mass has a gas surface density above the threshold for star formation ($\sim$129 $M_\odot$ pc^{-2}), points towards a still on-going star formation activity in L1630N. The star formation efficiency (SFE), star formation rate (SFR) and density of star formation of L1630N are within the ranges estimated for galactic star forming regions by the Spitzer "core to disk" and "Gould's Belt" surveys. However, the SFE and SFR are lower than the average value measured in the Orion A cloud and, in particular, lower than that in the southern regions of L1630. This might suggest different star formation mechanisms within the L1630 cloud complex.

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Tracing the general structure of Galactic molecular clouds using Planck data: I. The Perseus region as a test case

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We present an analysis of probability distribution functions (pdfs) of column density in different zones of the star-forming region Perseus and its diffuse environment based on the map of dust opacity at 353 GHz available from the Planck archive. The pdf shape can be fitted by a combination of a lognormal function and an extended power-law tail at high densities, in zones centred at the molecular cloud Perseus. A linear combination of several lognormals fits very well the pdf in rings surrounding the cloud or in zones of its diffuse neighbourhood. The slope of the mean density scaling law $\langle\rho\rangle_L \propto L^\alpha$ is steep ($\alpha = -1.93$) in the former case and rather shallow ($\alpha = -0.77 \pm 0.11$) in the rings delineated around the cloud. We interpret these findings as signatures of two distinct physical regimes: i) a gravoturbulent one which is characterized by nearly linear scaling of mass and practical lack of velocity scaling; and ii) a predominantly turbulent one which is best described by steep velocity scaling and by invariant for compressible turbulence $\langle\rho\rangle_L u_L^3/L$, describing a scale-independent flux of the kinetic energy per unit volume through turbulent cascade. The gravoturbulent spatial domain can be identified with the molecular cloud Perseus while a relatively sharp transition to predominantly turbulent regime occurs in its vicinity.

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Polarization Structure of Filamentary Clouds

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Filaments are considered to be basic structures and molecular clouds consist of filaments. Filaments are often observed as extending in the direction perpendicular to the interstellar magnetic field. The structure of filaments has been studied based on a magnetohydrostatic equilibrium model (Tomisaka 2014). Here, we simulate the expected polarization pattern for isothermal magnetohydrostatic filaments. The filament exhibits a polarization pattern in which the magnetic field is apparently perpendicular to the filament when observed from the direction perpendicular to the magnetic field. When the line-of-sight is parallel to the global magnetic field, the observed polarization pattern is dependent on the center-to-surface density ratio for the filament and the concentration of the gas mass toward the central magnetic flux tube. Filaments with low center-to-surface density ratios have an insignificant degree of polarization when observed from the direction parallel to the global magnetic field. However, models with a large center-to-surface density ratio have polarization patterns that indicate the filament is perpendicularly threaded by the magnetic field. When mass is heavily concentrated at the central magnetic flux tube, which can be realized by the ambipolar diffusion process, the polarization pattern is similar to that expected for a low center-to-surface density contrast.

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Magnetic Field - Gas Density Relation and Observational Implications Revisited

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We revisit the relation between magnetic-field strength (B) and gas density (ρ) for contracting interstellar clouds and fragments (or, cores), which is central in observationally determining the dynamical importance of magnetic fields in cloud evolution and star formation. Recently, it has been claimed that a relation $B \propto \rho^{2/3}$ is statistically preferred over $B \propto \rho^{1/2}$ in molecular clouds, when magnetic field detections and nondetections from Zeeman observations are combined. This finding has unique observational implications on cloud and core geometry: The relation $B \propto \rho^{2/3}$ can only be realized under spherical contraction. However, no indication of spherical geometry can be found for the objects used in the original statistical analysis of the $B - \rho$ relation. We trace the origin of the inconsistency to simplifying assumptions in the statistical model used to arrive at the $B \propto \rho^{2/3}$ conclusion and to an underestimate of observational uncertainties in the determination of cloud and core densities. We show that, when these restrictive assumptions are relaxed, $B \propto \rho^{1/2}$ is the preferred relation for the (self-gravitating) molecular-cloud data, as theoretically predicted four decades ago.

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Abundance Anomaly of the ^{13}C Isotopic Species of c-C_3H_2 in the Low-Mass Star Formation Region L1527

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The rotational spectral lines of c-C_3H_2 and two kinds of the ^{13}C isotopic species, c-$^{13}CCCH_2$ (C_{2v} symmetry) and c-$CC^{13}CH_2$ (C_s symmetry) have been observed in the 1–3 mm band toward the low-mass star-forming region L1527. We have detected 7, 3, and 6 lines of c-C_3H_2, c-$^{13}CCCH_2$, and c-$CC^{13}CH_2$, respectively, with the Nobeyama 45 m telescope, and 34, 6, and 13 lines, respectively, with the IRAM 30 m telescope, where 7, 2, and 2 transitions, respectively, are observed with the both telescopes. With these data, we have evaluated the column densities of the normal and ^{13}C isotopic species. The [c-C_3H_2]/[c-$^{13}CCCH_2$] ratio is determined to be 310 ± 80, while the [c-C_3H_2]/[c-$CC^{13}CH_2$] ratio is determined to be 61 ± 11. The [c-C_3H_2]/[c-$^{13}CCCH_2$] and [c-C_3H_2]/[c-$CC^{13}CH_2$] ratios expected from the elemental $^{12}C/^{13}C$ ratio are 60–70 and 30–35, respectively, where the latter takes into account the statistical factor of 2 for the two equivalent carbon atoms in c-C_3H_2. Hence, this observation further confirms the dilution of the ^{13}C species in carbon-chain molecules and their related molecules, which are thought to originate from the dilution of $^{13}C^+$ in the gas-phase C^+ due to the isotope exchange reaction: $^{13}C^+ + CO \rightarrow {}^{13}CO + C^+$. Moreover, the abundances of the two ^{13}C isotopic species are different from each other. The ratio of c-$^{13}CCCH_2$ species relative to c-$CC^{13}CH_2$ is determined to be 0.20 ± 0.05. If ^{13}C were randomly substituted for the three carbon atoms, the [c-$^{13}CCCH_2$]/[c-$CC^{13}CH_2$] ratio would be 0.5. Hence, the observed ratio indicates that c-$CC^{13}CH_2$ exists more favorably. Possible

origins of the different abundances are discussed.

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The Spitzer c2d Survey of Large, Nearby, Interstellar Clouds. XII. The Perseus YSO Population as Observed with IRAC and MIPS

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The *Spitzer Space Telescope* mapped the Perseus molecular cloud complex with IRAC and MIPS as part of the c2d *Spitzer* Legacy project. This paper combines the observations from both instruments giving an overview of low-mass star formation across Perseus from 3.6 to 70 micron. We provide an updated list of young stellar objects with new classifications and source fluxes from previous works, identifying 369 YSOs in Perseus with the *Spitzer* dataset. By synthesizing the IRAC and MIPS maps of Perseus and building on the work of previous papers in this series (Jørgensen et al. 2006, Rebull et al. 2007), we present a current census of star formation across the cloud and within smaller regions. 67% of the YSOs are associated with the young clusters NGC 1333 and IC 348. The majority of the star formation activity in Perseus occurs in the regions around the clusters, to the eastern and western ends of the cloud complex. The middle of the cloud is nearly empty of YSOs despite containing regions of high visual extinction. The western half of Perseus contains three-quarters of the total number of embedded YSOs (Class 0+I and Flat SED sources) in the cloud and nearly as many embedded YSOs as Class II and III sources. Class II and III greatly outnumber Class 0+I objects in eastern Perseus and IC 348. These results are consistent with previous age estimates for the clusters. Across the cloud, 56% of YSOs and 91% of the Class 0+I and Flat sources are in areas where $A_V \geq$ 5 mag, indicating a possible extinction threshold for star formation.

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Signatures of Young Star Formation Activity Within Two Parsecs of Sgr A*

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We present radio and infrared observations indicating on-going star formation activity inside the $\sim 2-5$ pc circumnuclear ring at the Galactic center. Collectively these measurements suggest a continued disk-based mode of on-going star formation has taken place near Sgr A* over the last few million years. First, VLA observations with spatial resolution $2.17'' \times 0.81''$ reveal 13 water masers, several of which have multiple velocity components. The presence of interstellar water masers suggests gas densities that are sufficient for self-gravity to overcome the tidal shear of the $4{\times}10^6$ $M_\odot$ black hole. Second, SED modeling of stellar sources indicate massive YSO candidates interior to the molecular ring, supporting in-situ star formation near Sgr A* and appear to show a distribution similar to that of

the counter-rotating disks of ∼100 OB stars orbiting Sgr A*. Some YSO candidates (e.g., IRS 5) have bow shock structures suggesting that they have have gaseous disks that are phototoevaporated and photoionized by the strong radiation field. Third, we detect clumps of SiO (2-1) and (5-4) line emission in the ring based on CARMA and SMA observations. The FWHM and luminosity of the SiO emission is consistent with shocked protostellar outflows. Fourth, two linear ionized features with an extent of $\sim$ 0.8 pc show blue and redshifted velocities between +50 and −40 km s^{-1}, suggesting protostellar jet driven outflows with mass loss rates of $\sim 5 \times 10^{-5}$ $M_\odot$ yr^{-1}. Finally, we present the imprint of radio dark clouds at 44 GHz, representing a reservoir of molecular gas that feeds star formation activity close to Sgr A*.

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Evidence of fast pebble growth near condensation fronts in the HL Tau protoplanetary disk

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Water and simple organic molecular ices dominate the mass of solid materials available for planetesimal and planet formation beyond the water snow line. Here we analyze ALMA long baseline 2.9, 1.3 and 0.87 mm continuum images of the young star HL Tau, and suggest that the emission dips observed are due to rapid pebble growth around the condensation fronts of abundant volatile species. Specifically, we show that the prominent innermost dip at 13 AU is spatially resolved in the 0.87 mm image, and its center radius is coincident with the expected mid-plane condensation front of water ice. In addition, two other prominent dips, at distances of 32 and 63 AU, cover the mid-plane condensation fronts of pure ammonia or ammonia hydrates and clathrate hydrates (especially with CO and N_2) formed from amorphous water ice. The spectral index map of HL Tau between 1.3 and 0.87 mm shows that the flux ratios inside the dips are statistically larger than those of nearby regions in the disk. This variation can be explained by a model with two dust populations, where most of solid mass resides in a component that has grown into decimeter size scales inside the dips. Such growth is in accord with recent numerical simulations of volatile condensation, dust coagulation and settling.

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http://arxiv.org/pdf/1505.00882

Abstracts of recently accepted major reviews

New paradigms for asteroid formation

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Asteroids and meteorites provide key evidence on the formation of planetesimals in the Solar System. Asteroids are traditionally thought to form in a bottom-up process by coagulation within a population of initially km-scale planetesimals. However, new models challenge this idea by demonstrating that asteroids of sizes from 100 to 1000 km can form directly from the gravitational collapse of small particles which have organised themselves in dense filaments and clusters in the turbulent gas. Particles concentrate passively between eddies down to the smallest scales of the turbulent gas flow and inside large-scale pressure bumps and vortices. The streaming instability causes particles to take an active role in the concentration, by piling up in dense filaments whose friction on the gas reduces the radial drift compared to that of isolated particles. In this chapter we review new paradigms for asteroid formation and compare critically against the observed properties of asteroids as well as constraints from meteorites. Chondrules of typical sizes from 0.1 to 1 mm are ubiquitous in primitive meteorites and likely represent the primary building blocks of asteroids. Chondrule-sized particles are nevertheless tightly coupled to the gas via friction and are therefore hard to concentrate in large amounts in the turbulent gas. We review recent progress on understanding the incorporation of chondrules into the asteroids, including layered accretion models where chondrules are accreted onto asteroids over millions of years. We highlight in the end ten unsolved questions in asteroid formation where we expect that progress will be made over the next decade.

Accepted by ASTEROIDS IV, (University of Arizona Press) Space Science Series, edited by P. Michel, F. DeMeo and W. Bottke

http://arxiv.org/pdf/1505.02941

New Jobs

4-year Postdoctoral Position on High-Angular Resolution Studies of Protoplanetary Discs

The Astrophysics Group at the University of Exeter (UK) wishes to recruit an ambitious, highly qualified Associate Research Fellow to work with Prof. Stefan Kraus on observational studies related to protoplanetary disc structure and planet formation. This post is available as early as August 2015, but we will also consider candidates that aim to start at a later date (up to June 2016). The appointment will be for a fixed term period of 4 years, with a 12-month probationary period.

The successful candidate will work in the context of a European Research Council project that will conduct instrumentation & methodological work in infrared interferometry in order to enable breakthrough results in imaging time-variable, planet-induced structures in the inner-most AU of protoplanetary discs. The work will centre on conducting the observations, combining them with complementary data, and interpreting them with the latest physical models. We are particularly interested in applicants with expertise in radiative transfer modelling of complex multi-wavelength data sets or in high-angular imaging techniques (e.g. ALMA, VLTI, adaptive optics). Prior experience with the technique of interferometry is not required, but would be an asset. The post offers opportunities to work with our collaborators at the University of Michigan and at Georgia State University, and includes funding for computing equipment and travel as well as guaranteed access to the Exeter supercomputing facilities.

Applicants must possess a PhD in astrophysics or a related discipline, or expect to have earned one before taking up the position. The successful applicant will possess specialist knowledge in the field of radiative transfer modelling, in high angular resolution imaging, or in the theory of protoplanetary discs or planet formation. The post-holder will be expected to contribute to the supervision of PhD students.

Contact for further enquiries: Prof. Stefan Kraus, email: skraus@astro.ex.ac.uk

Deadline: June 30, 2015

Application website: https://goo.gl/FCYDwm (alternatively, visit https://jobs.exeter.ac.uk and search for the job reference number P48614 in the keywords field)

PhD grant in astrochemistry

A fully-funded PhD grant is proposed at the Laboratory Astrophysics of Bordeaux (France) to work on astrochemistry. The goal is to revisit the chemistry of protostellar envelops and/or protoplanetary disks using the gas-grain code developed in the 3DICE team (http://www.obs.u-bordeaux1.fr/amor/VWakelam/3DICE). The modeling results will be compared to existing observations obtained with various ground based and space instruments. The position is for 3 years and should start in October 2015. A primary degree in physics, astronomy or a related field is required. Programming skills are beneficial. Interested students are encouraged to send a curriculum vitae and to arrange for a letter of recommendation to be sent directly to Dr Wakelam (wakelam@obs.u-bordeaux1.fr) from whom further information can be obtained. The deadline for applications, including receipt of letters of recommendation, is June 30th 2015.

Lecturer in Astrophysics at the University of Exeter

The University of Exeter invites applications for a Lecturer position in Astrophysics. This post is available from October 1st 2015 for a period of 5 years in the first instance.

The post will contribute to extending the research profile in theoretical or observational Astrophysics at Exeter in the field of exoplanets or related areas. Preference will be given to candidates that will strengthen existing links with the Exeter-based Met Office, particularly in the area of radiative transfer and atmosphere modelling, and to candidates that will contribute to the development and scientific exploitation of the Terra Hunting Experiment. The University of Exeter is investing £1M in the Terra Hunting Experiment, which is a Doppler velocity search for Earth-twins, based on the development of the HARPS-III spectrograph.

The successful applicant will hold a PhD in Physics, Astrophysics or a related area and have an independent, internationally-recognised research programme in an active field related or complementary to existing Exeter activities in the field of exoplanets. He/she will be able to demonstrate the following qualities and characteristics: a good record in attracting research funding, or demonstrable potential to attract such funding, teamwork skills to work in collaboration with existing group members, an active and supportive approach to inter-disciplinary and multi-disciplinary research that will help to foster interactions and links both within the University and externally, the attitude and ability to engage in continuous professional development, the aptitude to develop familiarity with a variety of strategies to promote and assess learning and enthusiasm for delivering undergraduate programmes.

Appointments will be made within the Education and Research job family, salary range £33,242 - £37,394 per annum.

Informal enquiries can be made to Prof Isabelle Baraffe (tel +44 (0)1392 725123 or I.Baraffe@exeter.ac.uk).

Please apply using the University's online application system (https://jobs.exeter.ac.uk/) with the job reference P49203.

The closing date for completed applications is 31st July 2015

Moving ... ??

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

Summary of Upcoming Meetings

The Formation and Destruction of Molecular Clouds
22 - 23 June 2015 Tenerife, Spain
http://eas.unige.ch/EWASS2015/session.jsp?id=S6

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

Gordon Research Conference on Origins of Solar Systems
28 June - 3 July 2015
http://www.grc.org/programs.aspx?id=12345

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

The Stellar IMF at Low Masses: A Critical Look at Variations and Environmental Dependencies
29 June - 1 July 2015 Baltimore, Maryland, USA
http://www.stsci.edu/institute/conference/stellar-imf/

From super-Earths to brown dwarfs: Who's who
29 June - 3 July 2015 Paris, France
http://www.iap.fr/col2015

Orion (un)plugged
1-3 + 6-8 July 2015 Vienna, Austria
https://www.univie.ac.at/alveslab/orion_unplugged/

From Interstellar Clouds to Star-forming Galaxies: Universal Processes?
3 - 7 August 2015 http://astronomy2015.org/symposium_315

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

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

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

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

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

Short Announcements

A new home for the catalogue of Molecular Hydrogen emission-line Objects (MHOs) in outflows from young stars

The catalogue of Molecular Hydrogen emission-line Objects, or MHOs, was set up in 2010 to encourage those discovering H_2 features in jets and outflows from young stars to adopt a common acronym when identifying their objects (at that time a wide range of acronyms were being used, leading to potential confusion in the field). With guidance from the IAU Working Group on Designations, a scheme that simply lists objects sequentially was adopted, much like the Herbig-Haro Objects catalogue, although objects are grouped by region (Taurus, Perseus, Auriga, etc.).

Our goal has always been to maintain and update the catalogue as new MHOs are discovered. Since its inception, the number of MHOs in the catalogue has increased by 50% to over 1500. This increase has largely been driven by rapid advances in near-infrared survey capabilities. Authors of over two dozen papers published since 2010 have actively contributed to the catalogue and have used the MHO acronym in their article.

The catalogue has recently moved to a new location. Hosted by the University of Kent, Centre for Astrophysics and Planetary Science, the MHO catalogue can now be found here: http://astro.kent.ac.uk/~df/MHCat/.

Those wishing to contribute to the catalogue are encouraged to contact Dirk Froebrich (df@star.kent.ac.uk).