THE STAR FORMATION NEWSLETTER

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

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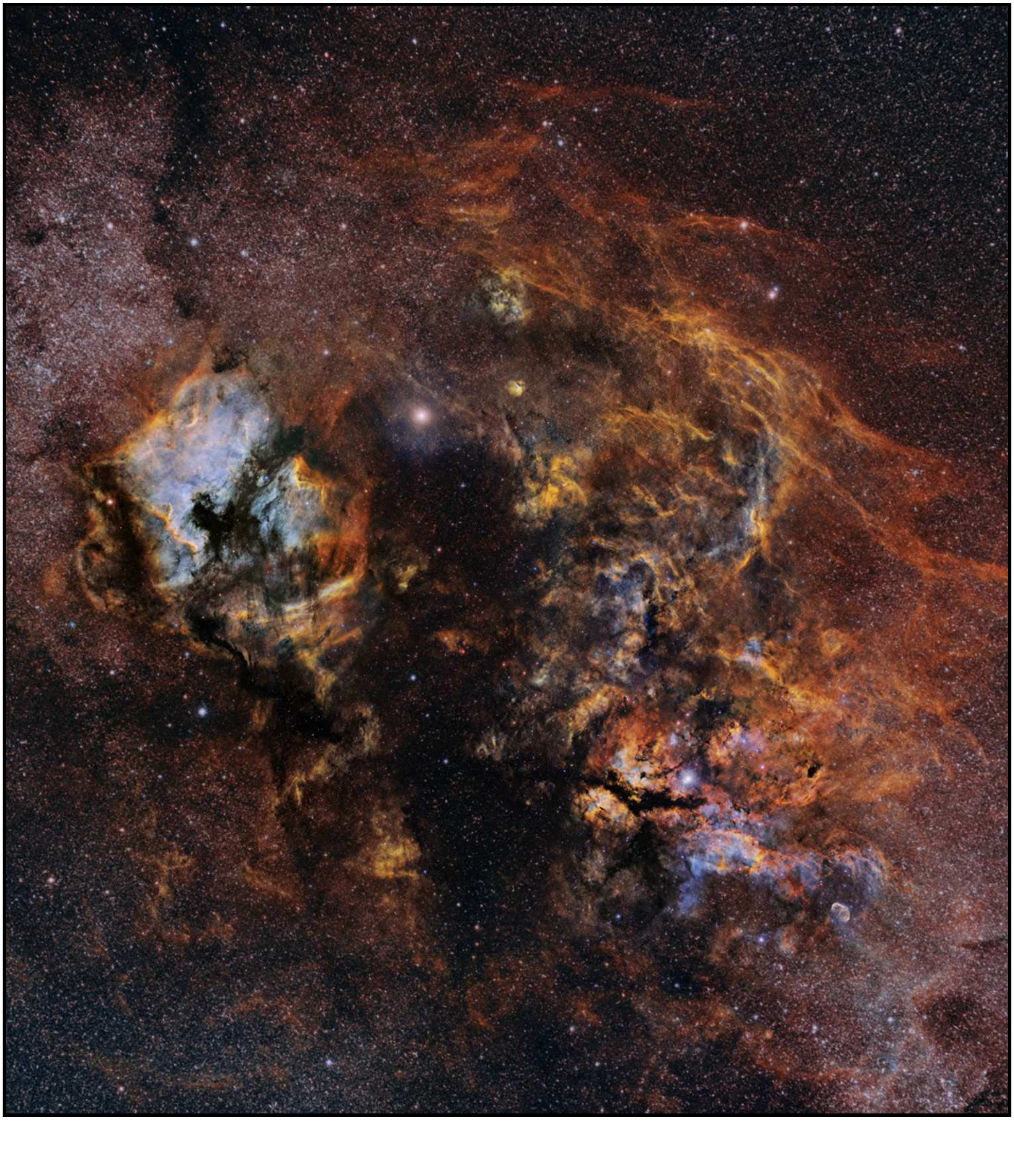

The Star Formation Newsletter

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.

Newsletter Archive

www.ifa.hawaii.edu/users/reipurth/newsletter.htm

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Cover Picture

The North America/Pelican and the Cygnus-X regions are here seen in an ultradeep wide field image. The region was imaged by Alistair Symon, who has uploaded to his website both this overview as well as a much more detailed 22-image mosaic with a total of 140 hours exposure time in Hα (52 hr, green), [SII] (52 hr, red), and [OIII] (36 hours, blue). This is likely the deepest wide-field image taken of the Cygnus Rift region. Higher resolution images are available at the website below.

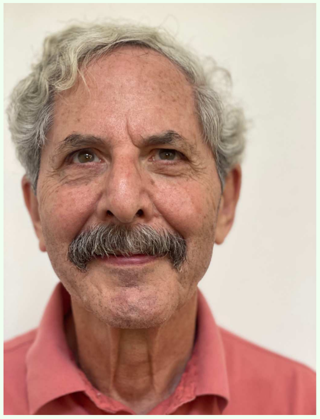
Courtesy Alistair Symon
http://woodlandsobservatory.com

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

Paul Goldsmith

in conversation with Bo Reipurth



Q: *As a graduate student in Berkeley, you were inspired by Charles Townes to do a theoretical study of collisional excitation of carbon monoxide in interstellar clouds, which appeared in 1972. What was the state of affairs on this subject back then?*

A: The situation was unbelievably primitive by current standards. There were no reliable calculations of cross sections for collisions of CO, HCN, and other widely–observed molecules with H_2, recognized as the key partner for collisional excitation. There was work going on to understand the apparent "cooling" of the 6 cm transition of formaldehyde, indicated by its being observed in absorption against the cosmic microwave background. Different approximate solutions led to quite different answers. But remember, the computer codes for such calculations were carried around in boxes of punched cards.

In any case, Charlie Townes suggested that I investigate the collisional excitation of carbon monoxide. Only the lowest J = 1-0 rotational transition at 115 GHz had been observed, but the J = 2 -1 line was coming soon, and I think, with his usual impressive physical intuition, Townes thought that the relative intensities of different transitions would provide valuable information. I came up with a program that solved the equations of statistical equilibrium in the optically thin limit, but other than for collisions with electrons (in which J changes by only ± 1), I had to "guess" the rates for different J–changing collisions. With guidance from Townes, I felt that you could likely have quite significant changes in angular momentum (so–called "hard" collisions). These had the interesting effect of overpopulating the J = 1 level and producing weak maser emission. This was a big surprise and was met with some skepticism at the time. This process has been confirmed by observations of a different linear molecule, HC_3N, but does not have a huge effect on the emergent intensity. Fortunately, pioneers such as Sheldon Green got interested in carrying out proper quantum calculations, and we started having reliable collision rates for simple molecules. This is an ongoing effort over almost 50 years since then, but methods have improved enormously and more complex molecules can be handled. Astronomers really do need the ongoing work of this sort to make progress in interpreting observations.

Q: *For your subsequent PhD you followed up with an observational study of CO using the Lick 120-inch telescope.*

A: It seemed that having more than one transition of a single molecule coud provide unique information on temperatures, densities, and other physical conditions, and I focused on building a receiver for 230 GHz, the frequency of the J = 2-1 transition of CO. That was a challenge, as it was a very high frequency at the time, and technology and tools were limited. I got enormous help from Bell Laboratories, where Gerry Wrixon and Martin Schneider were making low capacitance Schottky diodes that worked reasonably well at this frequency. With those diodes, and with a lot of help from fellow graduate student Richard Plambeck, I built a receiver that had 11,000 K double sideband noise temperature, which seemed very good then; now the state of the art is close to 1000 times better! But where to use it? No "radio" telescope had a good enough surface, so after checking that the thin, evaporated aluminum coating was thick enough to be a good reflector at 1.3 mm wavelength, I decided that an optical telescope should work. We could only get daytime on the 120" telescope at Lick Observatory since nights were too valuable to be given to this new type of observations. With Professor Raymond Chiao, we took our equipment to Mt. Hamilton, and after some embarrassing mistakes detected the CO J = 2-1 line in several sources, and even detected the ^{13}CO J = 2-1 line in Orion. The intensity of the latter relative to J = 1-0 line indicated that even the rare isotopologue is optically thick – a hint of how much molecular material was present.

Q: *In 1978 you and Bill Langer wrote a very highly cited paper on molecular cooling and thermal balance in molecular clouds. What were the key new insights?*

A: I had moved to Bell Laboratories in Holmdßel, NJ after receiving my PhD in 1975, and was working with Arno Penzias and Bob Wilson, developing instrumentation for the soon–to–arrive 7m millimeter telescope. Bill Langer had been working on modeling the chemistry of molecular clouds and had a good idea of what abundances of various species were reasonable in well–shielded regions. We combined that information with a statistical equilibrium plus radiative transfer code that could handle a wide variety of molecules and calculate the emission from all spectral lines of relevance at modest temperatures. By adding these up, we could calculate the total cooling. We combined this with estimates of some representative heating rates in different types of clouds, and could thus determine the steady–state gas temperatures. We were able to derive what may have been the first general expression for cooling as function of temperature and density. This proved very useful for numerous studies of thermal balance in interstellar clouds. The most enduring single result was that the balance between molecular cooling and cosmic ray heating predicted dark cloud temperatures in the range 8 K to 12 K. This agreed with the limited observations then available, and has held up with much more extensive surveys of such regions that have been carried out since then.

Q: *Together with a team of collaborators you have analyzed a unique ^{12}CO and ^{13}CO Nyquist-sampled map of 98 deg^2 of the Taurus clouds on a $20'$ grid. What were the key results?*

A: Just as the 7m telescope was beginning to operate, I left Bell Laboratories to take a faculty position at the University of Massachusetts, Amherst. There I worked on receivers and other systems for the 14m FCRAO telescope. An excellent team including Neal Erickson developed focal plane array receivers that enabled large–scale, high spatial dynamic range imaging of interstellar clouds. The sensitivity and large amount of time on the FCRAO 14m telescope with the SEQUOIA 32–element focal plane array made the large Taurus map possible. I think the most interesting result is that a significant fraction of the mass of the cloud is in very weak, diffuse emission coming from outside the cloud boundary as it was generally defined. This emission is tracing the interface between the essentially totally molecular well-shielded interior, and the atomic interstellar medium. But there is a lot more molecular gas in these extended, low–density regions than was recognized at that point. The ^{12}CO and ^{13}CO images, each with 3 million spectra, also revealed that the interior of the cloud is highly nonuniform, with multiple filaments and shell-like structures present. We also found that star formation (traced by embedded young stars) is restricted to regions with visual extinctions above 6 mag., an early demonstration of this threshold in dark clouds. In addition, we saw that the diffuse molecular gas was clearly striated, with structures oriented parallel to the local magnetic field, while the dense gas filaments are largely perpendicular to the field direction. These conclusions had obvious bearing on the relationship of the magnetic field and gas that is potentially going to form stars,

Q: *In 2000 you led a large team in search of O_2 with the Submillimeter Wave Astronomy Satellite. This led to a null result, indicating that O_2 is not a major coolant. How are these results understood in terms of chemical and dynamical cloud models and what is the present state of this problem?*

A: I had been interested in molecular oxygen since work on cloud cooling, as mentioned earlier. O_2 was predicted to be a significant (after CO and H_2O in importance) coolant. But was it there? You have to be above the atmosphere to look for O_2 emission from Galactic sources, and searching for this elusive species was one of the key tasks for SWAS. I started work on SWAS with Gary Melnick, the PI, when I was at UMASS, but by the time it was launched, I had moved to Cornell University, where I was also Director of NAIC, operating the Arecibo Observatory. SWAS' O_2 channel ran in parallel with the channel observing the ground state water line, which we could detect and map, but we never could unambiguously detect molecular oxygen. We knew the instrument was working as at one point the antenna beam swung through the Earth and we easily detected O_2 in our atmosphere! The resulting upper limits on the O_2 fractional abundance, on the order of 100 times below the predictions of gas–phase chemistry, clearly showed that something was amiss with those models. The missing piece was pinpointed in an effort led by SWAS team member Ted Bergin, and was the impact of interstellar grains. In this picture, oxygen atoms stick to grain surfaces and are hydrogenated to form water ice. The remaining gas–phase oxygen is almost entirely tied up in CO. This model also explained the low abundance of H_2O found by SWAS. These results encouraged development of sophisticated astrochemical models, including grain surface depletion and chemistry, that have proven essential for understanding the many results that have been obtained. This is an area with laboratory measurements, theoretical calculations, and observations coming together to explain ever more complex molecules being found with increasingly sensitive instruments.

Q: *With the launch of Herschel, major new information about cloud chemistry became available, and you and your collaborators performed a Galactic plane survey of [NII] fine structure emission. What did you learn?*

A: Having worked extensively on [CII] emission with the *Herschel* GOTC+ project with JPL collaborators, the question of the origin of the emission from C^+ had to be addressed. One of the possibilities was emission from the ionized component of the ISM, and one way to estimate this would be to quantify this component through the emission of ionized nitrogen, which is produced only in this material, unlike C^+, which can come from neutral and even partially molecular regions. There are two [NII] fine structure lines, which had been previously recognized, their ratio is an excellent tracer of the electron density in ionized regions. This led to the use of the PACS instrument on *Herschel*, which covered both lines, albeit without the velocity resolution to measure line profiles. The survey was very successful in that we detected the lines through most of the inner galaxy. The line ratio yielded the surprise that the characteristic electron density was typically 20 to 50 cm^{-3} - too low to be "normal" HII regions, but far higher than the Warm Ionized Medium (WIM), which is very extended, but typically thought to have density 0.1 to 1 cm^{-3}. Might this be a different phase of the ISM, possibly very extended low density HII regions or interface regions between ionized and neutral material? This same electron density was determined from [NII] observations of external galaxies, indicating that this is a widespread component of the ISM. The fraction of [CII] coming from ionized gas is modest, but has to be considered in understanding the origin of [CII] emission and how it traces star formation in the Milky Way and other galaxies. This is one of the goals of GUSTO, an Explorer MO balloon mission, scheduled for December 2021. Obtaining images of electron densities that are velocity–resolved and thus give insight into the line of sight structure requires observation of **both** [NII] lines (which cannot be done from aircraft altitude), but which is the key goal of the ASTHROS balloon mission scheduled for December 2023.

Q: *In a 2019 paper, you have modeled the [OI] 63 μm fine structure line in PDR regions. What has this revealed?*

A: The 63 μm fine structure transition of atomic oxygen is one of the strongest FIR lines, and in the warmest portions of photon dominated regions is the most important gas coolant. It has thus been widely observed in Galactic and extragalactic surveys, but until recently almost no velocity-resolved spectra were available. There had been a number of studies, mostly with ISO, of [OI] 63μm seen in absorption against strong continuum sources; these implied extremely large column densities of low-excitation O^0, plausibly associated with molecular clouds, but with O^0/CO well in excess of unity. Other studies using the 145 μm [OI] line together with the 63 μm line also suggested very large column densities of atomic oxygen. To try and understand this, we obtained a large set of observations of GMCs, with the high spectral resolution provided by the upGREAT instrument on SOFIA. The 2019 paper suggested that significant opacity in the 63 μm line would be revealed by self-absorption from low-excitation atoms in the outer regions of the cloud where radiative trapping was insufficient to thermalize the line. In realistic regions with density gradients, this effect could be dramatic. Initial analysis of the [OI] spectra shows that a substantial fraction of sources are characterized by very prominent self-absorption; so strong that the line seen in emission is just the line wings of what would be a far stronger line. The fact that the absorbed portion of the line is almost exactly centered on what is left of the emission profile indicates that the absorbing gas is almost certainly associated with the hot, dense photon–dominated region gas producing the emission. Thus, [OI] 63 μm is more problematic in terms of determining the "true" luminosity produced by massive young stars than are [CII] or [NII] emission, and velocity–resolved spectra are essential. Understanding how to use these fine structure lines to trace star formation, measure the effect of formation of massive stars, and determine what controls the rate of star formation, remains a very exciting challenge.

Q: *In addition to observations and modeling, you've worked on instrumentation development. What do you see as the connection?*

A: I certainly enjoy development of instrumentation for astronomy. There is a whole range of reasons why I think this is good for the person who does this, as well as being of value to astronomy. For the individual, understanding how an instrument really works helps you employ it better and more effectively. I have focused on low–noise radiometers for millimeter and submillimeter wavelengths, which is where you can see that my astronomical interests lie. I feel that by getting into the "nitty gritty" of antennas, feed systems, and signal processing components, I have understood how the data that they produce can best be used. Working with a system on a laboratory bench gives you a head start in appreciating what problems it may have when mounted on a radio telescope or a spacecraft. For example, it makes you a little more suspicious of the data, since you've seen strange things happening on the bench and you don't forget them when you are faced with a strange spectral artifact or baseline ripple in your data. To me it is also exciting to come up with a new idea that enables new astronomical observations. Sometimes such ideas start with a suggestion from a colleague, or from something you read about. But if after turning the idea over in your mind, you come to the conclusion that it could make a better system, and you get to build it, and it does – that's a really great feeling! And to be honest, it's wonderful to see others using a piece of equipment or technology you've helped develop, and obtaining exciting astronomical data. It's the intersection of two worlds, that I find personally is rewarding and very stimulating. I only hope that the increasing specialization in instrumentation development does not preclude astronomers from getting involved, getting their hands dirty, and developing new technology and thus contributing to the future of our field.

Abstracts of recently accepted papers

Outflows, cores, and magnetic field orientations in W43-MM1 as seen by ALMA

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It has been proposed that the magnetic field, pervasive in the ISM, plays an important role in the process of massive star formation. To better understand its impact at the pre and protostellar stages, high-angular resolution observations of polarized dust emission toward a large sample of massive dense cores are needed. To this end, we used the Atacama Large Millimeter Array in Band 6 (1.3 mm) in full polarization mode to map the polarized emission from dust grains at a physical scale of ∼2700 au in the massive protocluster W43-MM1. We used these data to measure the orientation of the magnetic field at the core scale. Then, we examined the relative orientations of the core-scale magnetic field, of the protostellar outflows determined from CO molecular line emission, and of the major axis of the dense cores determined from 2D Gaussian fit in the continuum emission. We found that the orientation of the dense cores is not random with respect to the magnetic field. Instead, the dense cores are compatible with being oriented 20-50° with respect to the magnetic field. The outflows could be oriented 50-70° with respect to the magnetic field, or randomly oriented with respect to the magnetic field, similar to current results in low-mass star-forming regions. In conclusion, the observed alignment of the position angle of the cores with respect to the magnetic field lines shows that the magnetic field is well coupled with the dense material; however, the 20-50° preferential orientation contradicts the predictions of the magnetically-controlled core-collapse models. The potential correlation of the outflow directions with respect to the magnetic field suggests that, in some cases, the magnetic field is strong enough to control the angular momentum distribution from the core scale down to the inner part of the circumstellar disks where outflows are triggered.

Accepted by A&A

https://arxiv.org/pdf/2005.12921

The velocity structure of Cygnus OB2

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The kinematic structure of the Cygnus OB2 association is investigated. No evidence of expansion or contraction is found at any scale within the region. Stars that are within ∼0.5 parsecs of one another are found to have more similar velocities than would be expected by random chance, and so it is concluded that velocity substructure exists on these scales. At larger scales velocity substructure is not found. We suggest that bound substructures exist on scales of ∼0.5 parsecs, despite the region as a whole being unbound. We further suggest that any velocity substructure that existed on scales $>$ 0.5 parsecs has been erased. The results of this study are then compared to those of other kinematic studies of Cygnus OB2.

Accepted by MNRAS

http://arxiv.org/pdf/2005.10260

On the Origin of the Bimodal Rotational Velocity Distribution in Stellar Clusters: Rotation on the Pre-Main Sequence

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We address the origin of the observed bimodal rotational distribution of stars in massive young and intermediate age stellar clusters. This bimodality is seen as split main sequences at young ages and also has been recently directly observed in the $V\sin i$ distribution of stars within massive young and intermediate age clusters. Previous models have invoked binary interactions as the origin of this bimodality, although these models are unable to reproduce all of the observational constraints on the problem. Here we suggest that such a bimodal rotational distribution is set up early within a cluster's life, i.e., within the first few Myr. Observations show that the period distribution of low-mass ($\lesssim$2 $M_\odot$) pre-main sequence (PMS) stars is bimodal in many young open clusters and we present a series of models to show that if such a bimodality exists for stars on the PMS that it is expected to manifest as a bimodal rotational velocity (at fixed mass/luminosity) on the main sequence for stars with masses in excess of $\sim$1.5 $M_\odot$. Such a bimodal period distribution of PMS stars may be caused by whether stars have lost (rapid rotators) or been able to retain (slow rotators) their circumstellar discs throughout their PMS lifetimes. We conclude with a series of predictions for observables based on our model.

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http://arxiv.org/pdf/2005.01779

Formation of Giant Planet Satellites

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Recent analyses have shown that the concluding stages of giant planet formation are accompanied by the development of large-scale meridional flow of gas inside the planetary Hill sphere. This circulation feeds a circumplanetary disk that viscously expels gaseous material back into the parent nebula, maintaining the system in a quasi-steady state. Here we investigate the formation of natural satellites of Jupiter and Saturn within the framework of this newly outlined picture. We begin by considering the long-term evolution of solid material, and demonstrate that the circumplanetary disk can act as a global dust trap, where $s_\bullet \sim 0.1$–10 mm grains achieve a hydrodynamical equilibrium, facilitated by a balance between radial updraft and aerodynamic drag. This process leads to a gradual increase in the system's metallicity, and eventually culminates in the gravitational fragmentation of the outer regions of the solid sub-disk into $R \sim 100$ km satellitesimals. Subsequently, satellite conglomeration ensues via pairwise collisions, but is terminated when disk-driven orbital migration removes the growing objects from the satellitesimal feeding zone. The resulting satellite formation cycle can repeat multiple times, until it is brought to an end by photo-evaporation of the parent nebula. Numerical simulations of the envisioned formation scenario yield satisfactory agreement between our model and the known properties of the Jovian and Saturnian moons.

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http://arxiv.org/pdf/2005.08330

Photoionising feedback in spiral arm molecular clouds

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We present simulations of a 500 pc^2 region, containing gas of mass 4×10^6 $M_\odot$, extracted from an entire spiral galaxy simulation, scaled up in resolution, including photoionising feedback from stars of mass >18 $M_\odot$. Our region is evolved for 10 Myr and shows clustered star formation along the arm generating $\approx$ 5000 cluster sink particles $\approx$ 5% of which contain at least one of the $\approx$ 4000 stars of mass >18 $M_\odot$. Photoionisation has a noticeable effect on the gas in the region, producing ionised cavities and leading to dense features at the edge of the HII regions. Compared to the no-feedback case, photoionisation produces a larger total mass of clouds and clumps, with around twice as many such objects, which are individually smaller and more broken up. After this we see a rapid decrease in the total mass in clouds and the number of clouds. Unlike studies of isolated clouds, our simulations follow the long range effects of ionisation, with some already-dense gas becoming compressed from multiple sides by neighbouring HII regions. This causes star formation that is both accelerated and partially displaced throughout the spiral arm with up to 30% of our cluster sink particle mass forming at distances >5 pc from sites of sink formation in the absence of feedback. At later times, the star formation rate decreases to below that of the no-feedback case.

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https://arxiv.org/pdf/2005.06234

Possible evidence of ongoing planet formation in AB Aurigae. A showcase of the SPHERE/ALMA synergy

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Context. Planet formation is expected to take place in the first million years of a planetary system through various processes, which remain to be tested through observations. Aims. With the recent discovery, using ALMA, of two gaseous spiral arms inside the ∼120 au cavity and connected to dusty spirals, the famous protoplanetary disk around AB Aurigae presents a strong incentive for investigating the mechanisms that lead to giant planet formation. A candidate protoplanet located inside a spiral arm has already been claimed in an earlier study based on the same ALMA data.
Methods. We used SPHERE at the Very Large Telescope to perform near-infrared high-contrast imaging of AB Aur in polarized and unpolarized light in order to study the morphology of the disk and search for signs of planet formation.
Results. SPHERE has delivered the deepest images ever obtained for AB Aur in scattered light. Among the many structures that are yet to be understood, we identified not only the inner spiral arms, but we also resolved a feature in the form of a twist in the eastern spiral at a separation of about 30 au. The twist of the spiral is perfectly reproduced with a planet-driven density wave model when projection effects are accounted for. We measured an azimuthal displacement with respect to the counterpart of this feature in the ALMA data, which is consistent with Keplerian motion on a 4 yr baseline. Another point sxce is detected near the edge of the inner ring, which is likely the result of scattering as opposed to the direct emission from a planet photosphere. We tentatively derived mass constraints for these two features.
Conclusions. The twist and its apparent orbital motion could well be the first direct evidence of a connection between

a protoplanet candidate and its manifestation as a spiral imprinted in the gas and dust distributions.

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https://www.aanda.org/articles/aa/pdf/2020/05/aa38008-20.pdf

Protoplanetary Disks in the Orion Nebula Cluster: Gas Disk Morphologies and Kinematics as seen with ALMA

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We present Atacama Large Millimeter Array CO (3–2) and HCO^+ (4–3) observations covering the central $1' \times 1''.5$ region of the Orion Nebula Cluster (ONC). The unprecedented level of sensitivity ($\sim$0.1 mJy beam^{-1}) and angular resolution ($\sim 0''.09 \approx 35$ AU) of these line observations enable us to search for gas-disk detections towards the known positions of submillimeter-detected dust disks in this region. We detect 23 disks in gas: 17 in CO (3–2), 17 in HCO^+ (4–3), and 11 in both lines. Depending on where the sources are located in the ONC, we see the line detections in emission, in absorption against the warm background, or in both emission and absorption. We spectrally resolve the gas with 0.5 km s^{-1} channels, and find that the kinematics of most sources are consistent with Keplerian rotation. We measure the distribution of gas-disk sizes and find typical radii of $\sim$50–200 AU. As such, gas disks in the ONC are compact in comparison with the gas disks seen in low-density star-forming regions. Gas sizes are universally larger than the dust sizes. However, the gas and dust sizes are not strongly correlated. We find a positive correlation between gas size and distance from the massive star θ^1 Ori C, indicating that disks in the ONC are influenced by photoionization. Finally, we use the observed kinematics of the detected gas lines to model Keplerian rotation and infer the masses of the central pre-main-sequence stars. Our dynamically-derived stellar masses are not consistent with the spectroscopically-derived masses, and we discuss possible reasons for this discrepancy.

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http://arxiv.org/pdf/2003.12580

An Analytic Model for an Evolving Protoplanetary Disk with a Disk Wind

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We describe an analytic model for an evolving protoplanetary disk driven by viscosity and a disk wind. The disk is heated by stellar irradiation and energy generated by viscosity. The evolution is controlled by 3 parameters: (i) the inflow velocity towards the central star at a reference distance and temperature, (ii) the fraction of this inflow caused by the disk wind, and (iii) the mass loss rate via the wind relative to the inward flux in the disk. The model gives the disk midplane temperature and surface density as a function of time and distance from the star. It is intended to provide an efficient way to calculate conditions in a protoplanetary disk for use in simulations of planet formation. In the model, disks dominated by viscosity spread radially while losing mass onto the star. Radial spreading is the main factor reducing the surface density in the inner disk. The disk mass remains substantial at late times. Temperatures in the inner region are high at early times due to strong viscous heating. Disks dominated by a wind undergo much less radial spreading and weaker viscous heating. These disks have a much lower mass at late times than purely viscous disks. When mass loss via a wind is significant, the surface density gradient in the inner disk becomes shallower, and the slope can become positive in extreme cases.

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Gas Kinematics of the Massive Protocluster G286.21+0.17 revealed by ALMA

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We study the gas kinematics and dynamics of the massive protocluster G286.21+0.17 with the Atacama Large Millimeter/submillimeter Array using spectral lines of $C^{18}O$(2-1), N_2D^+(3-2), DCO^+(3-2) and DCN(3-2). On the parsec clump scale, $C^{18}O$ emission appears highly filamentary around the systemic velocity. N_2D^+ and DCO^+ are more closely associated with the dust continuum. DCN is strongly concentrated towards the protocluster center, where no or only weak detection is seen for N_2D^+ and DCO^+, possibly due to this region being at a relatively evolved evolutionary stage. Spectra of 76 continuum defined dense cores, typically a few 1000 AU in size, are analysed to measure their centroid velocities and internal velocity dispersions. There are no statistically significant velocity offsets of the cores among the different dense gas tracers. Furthermore, the majority (71%) of the dense cores have subthermal velocity offsets with respect to their surrounding, lower density $C^{18}O$ emitting gas. Within the uncertainties, the dense cores in G286 show internal kinematics that are consistent with being in virial equilibrium. On clumps scales, the core to core velocity dispersion is also similar to that required for virial equilibrium in the protocluster potential. However, the distribution in velocity of the cores is largely composed of two spatially distinct groups, which indicates that the dense molecular gas has not yet relaxed to virial equilibrium, perhaps due to there being recent/continuous infall into the system.

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Stellar Variability in a Forming Massive Star Cluster

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We present a near-infrared (NIR) variability analysis for an 6' $\times$ 6' region, which encompasses the massive protocluster G286.21+0.17. The total sample comprises more than 5000 objects, of which 562 show signs of a circumstellar disk based on their infrared colors. The data includes HST observations taken in two epochs separated by 3 years in the F110W and F160W bands. 363 objects (7% of the sample) exhibit NIR variability at a significant level (Stetson index > 1.7), and a higher variability fraction (14%) is found for the young stellar objects (YSOs) with disk excesses. We identified 4 high amplitude (> 0.6 mag) variables seen in both NIR bands. Follow up and archival observations of the most variable object in this survey (G286.2032+0.1740) reveal a rising light curve over 8 years from 2011 to 2019, with a K band brightening of 3.5 mag. Overall the temporal behavior of G286.2032+0.1740 resembles that of typical FU Ori objects, however its pre-burst luminosity indicates it has a very low mass ($< 0.12\,M_\odot$), making it an extreme case of an outburst event that is still ongoing.

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Astrometry of H_2O Masers in W48A (G35.20-01.74) HII Region with VERA: A Compact Disk-Outflow inside Core H-2a

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W48A core H-2a is one of the young massive protostellar objects in the W48 region. We conducted multi-epoch astrometric observations of the water (H_2O) masers associated with the W48A core H-2a with VLBI Exploration of Radio Astrometry (VERA). The trigonometric annual parallax of W48A core H-2a was measured to be 0.433 ± 0.026 mas corresponding to the distance of $2.31^{+0.15}_{-0.13}$ kpc. This agrees with the revised parallax of 0.412 ± 0.014 mas by Wu et al. (2019, ApJ, 874, 94). We obtained the systemic proper motion and LSR velocity to be $(\mu_\alpha \cos\delta, \mu_\delta) = (0.26 \pm 0.73, -3.87 \pm 0.33)$ mas yr^{-1} and $v_{\rm LSR} = 41.9 \pm 0.9$ km s^{-1}, respectively. The distribution of the H_2O masers covers an area of 70 mas $\times$ 80 mas corresponding to 160 AU $\times$ 180 AU at the distance of 2.31 kpc. The internal proper motions of the H_2O masers trace an east-west bipolar outflow. With the recent absolute position measurement of the 6.7 GHz methanol (CH_3OH) masers and their elliptical distribution whose major axis is perpendicular to the axis of the bipolar outflow, we suggest the presence of a disk-outflow system in core H-2a. The spectral energy distribution (SED) of the driving source of core H-2a was previously reported to yield a luminosity and envelope mass of 8000 ± 1000 L$_\odot$ and 170 ± 30 M$_\odot$, respectively. Re-fitting the SED with the new distance, we obtained the luminosity to be 3100$\pm$388 $L_\odot$ and derived ZAMS stellar mass to be 9$\pm$1 $M_\odot$. Using our distance measurement, we derived the peculiar motion of W48A to be $(U_{\rm s}, V_{\rm s}, W_{\rm s}) = (1 \pm 4, 5 \pm 6, -15 \pm 5)$ km s^{-1}.

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The Relationship between Mid-Infrared and Sub-Millimetre Variability of Deeply Embedded Protostars

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We study the relationship between the mid-infrared and sub-mm variability of deeply embedded protostars using the multi-epoch data from the Wide Infrared Survey Explorer (*WISE*/NEOWISE) and the ongoing James Clerk Maxwell Telescope (JCMT) transient survey. Our search for signs of stochastic (random) and/or secular (roughly monotonic in time) variability in a sample of 59 young stellar objects (YSOs) revealed that 35 are variable in at least one of the two surveys. This variability is dominated by secular changes. Of those objects with secular variability, 14 objects (22% of the sample) show correlated secular variability over mid-IR and sub-mm wavelengths. Variable accretion is the likely mechanism responsible for this type of variability. Fluxes of YSOs that vary in both wavelengths follow a relation of $\log_{10} F_{4.6}(t) = \eta \log_{10} F_{850}(t)$ between the mid-IR and sub-mm, with $\eta = 5.53 \pm 0.29$. This relationship arises from the fact that sub-mm fluxes respond to the dust temperature in the larger envelope whereas the mid-IR emissivity is more directly proportional to the accretion luminosity. The exact scaling relation, however, depends on the structure of the envelope, the importance of viscous heating in the disc, and dust opacity laws.

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The inner disk of RY Tau: evidence of stellar occultation by the disk atmosphere at the sublimation rim from K-band continuum interferometry

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We present models of the inner region of the circumstellar disk of RY Tau which aim to explain our near-infrared (K-band: 2.1 μm) interferometric observations while remaining consistent with the optical to near-infrared portions of the spectral energy distribution. Our sub-milliarcsecond resolution CHARA Array observations are supplemented with shorter baseline, archival data from PTI, KI and VLTI/GRAVITY and modeled using an axisymmetric Monte Carlo radiative transfer code. The K-band visibilities are well-fit by models incorporating a central star illuminating a disk with an inner edge shaped by dust sublimation at 0.210±0.005 au, assuming a viewing geometry adopted from millimeter interferometry (65° inclined with a disk major axis position angle of 23°). This sublimation radius is consistent with that expected of Silicate grains with a maximum size of 0.36–0.40 μm contributing to the opacity and is an order of magnitude further from the star than the theoretical magnetospheric truncation radius. The visibilities on the longest baselines probed by CHARA indicate that we lack a clear line-of-sight to the stellar photosphere. Instead, our analysis shows that the central star is occulted by the disk surface layers close to the sublimation rim. While we do not see direct evidence of temporal variability in our multi-epoch CHARA observations, we suggest the aperiodic photometric variability of RY Tau is likely related temporal and/or azimuthal variations in the structure of the disk surface layers.

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Formation of Orion Fingers

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"Orion fingers" are a system of dozens of bowshocks, with the wings of shocks pointing to a common system of origin, which is centered on a dynamically disintegrating system of several massive stars. The shock heads propagate with velocities of up to 300–400 km s^{-1}, but the formation and physical properties of the "bullets" leading the shocks are not known. Here we summarize two possible scenarios for the formation of the "bullets" and the resulting bowshocks ("fingers"). In the first scenario, bullets are self-gravitating, Jupiter-mass objects which were formed rapidly and then ejected during the strong dynamical interactions of massive stars and their disks. This scenario naturally explains the similar timescales for the outflow of bullets and for the dynamical interaction of the massive stars, but has some difficulty explaining the observed high velocities of the bullets. In the second scenario, bullets are formed via hydrodynamic instabilities in a massive, infrared-driven wind, naturally explaining the high velocities and the morphology of outflow, but the bullets are not required to be self-gravitating. The processes that created the Orion fingers are likely not unique to this particular star-forming region and may result in free-floating, high-velocity, core-less planets.

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Uncovering distinct environments in an extended physical system around the W33 complex

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We present a multi-wavelength investigation of a large-scale physical system containing the W33 complex. The

extended system (~50 pc × 37 pc) is selected based on the distribution of molecular gas at [29.6, 60.2] km s^{-1} and of 88 ATLASGAL 870 μm dust clumps at d ~2.6 kpc. The extended system/molecular cloud traced in the maps of ^{13}CO and $C^{18}O$ emission contains several H II regions excited by OB stars (age ~0.3–1.0 Myr) and a thermally supercritical filament ("fs1", length ~17 pc). The filament, devoid of the ionized gas, shows dust temperature (T_d) of ~19 K, while the H II regions are depicted with T_d of ~21–29 K. It suggests the existence of two distinct environments in the cloud. The distribution of Class I young stellar objects (mean age ~0.44 Myr) traces the early stage of star formation (SF) toward the cloud. At least three velocity components (around 35, 45, and 53 km s^{-1}) are investigated toward the system. The analysis of ^{13}CO and $C^{18}O$ reveals the spatial and velocity connections of cloud components around 35 and 53 km s^{-1}. The observed positions of previously known sources, W33 Main, W33 A and O4-7I stars, are found toward a complementary distribution of these two cloud components. The filament "fs1" and a previously known object W33 B are seen toward the overlapping areas of the clouds, where ongoing SF activity is evident. A scenario concerning the converging/colliding flows from two different velocity components appears to explain well the observed signposts of SF activities in the system.

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Investigating the physical conditions in extended system hosting mid-infrared bubble N14

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To observationally explore physical processes, we present a multi-wavelength study of a wide-scale environment toward l = 13.7–14.9 degrees containing a mid-infrared bubble N14. The analysis of ^{12}CO, ^{13}CO, and $C^{18}O$ gas at [31.6, 46] km s^{-1} reveals an extended physical system (extension ~59 pc × 29 pc), which hosts at least five groups of the ATLASGAL 870 μm dust clumps at d ~3.1 kpc. These spatially-distinct groups/sub-regions contain unstable molecular clumps, and are associated with several Class I young stellar objects (mean age ~0.44 Myr). At least three groups of ATLASGAL clumps associated with the expanding H II regions (including the bubble N14) and embedded infrared dark clouds, devoid of the ionized gas, are found in the system. The observed spectral indices derived using the GMRT and THOR radio continuum data suggest the presence of non-thermal emission with the H II regions. High resolution GMRT radio continuum map at 1280 MHz traces several ionized clumps powered by massive B-type stars toward N14, which are considerably young (age ~10^3–10^4 years). Locally, early stage of star formation is evident toward all the groups of clumps. The position-velocity maps of ^{12}CO, ^{13}CO, and $C^{18}O$ exhibit an oscillatory-like velocity pattern toward the selected longitude range. Considering the presence of different groups/sub-regions in the system, the oscillatory pattern in velocity is indicative of the fragmentation process. All these observed findings favour the applicability of the global collapse scenario in the extended physical system, which also seems to explain the observed hierarchy.

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Feedback of molecular outflows from protostars in NGC 1333, revealed by Herschel and Spitzer spectro-imaging observations

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Context Far infrared cooling of excited gas around protostars has been predominantly studied in the context of pointed observations. Large scale spectral maps of star forming regions enable the simultaneous, comparative study of the gas excitation around an ensemble of sources at a common frame of reference, therefore providing direct insights in the multitude of physical processes involved.
Aims We employ extended spectral-line maps to decipher the excitation, the kinematical and dynamical processes in NGC 1333 as revealed by a number of different molecular and atomic lines, aiming to set a reference for the applicability and limitations of difference tracers in constraining particular physical processes.
Methods We reconstruct line maps for H_2, CO, H_2O and [CI] using data obtained with the Spitzer/IRS spectrograph and the Herschel HIFI and SPIRE instruments. We compare the morphological features revealed in the maps and derive the gas excitation conditions for regions of interest employing LTE and non-LTE methods. We also calculate the kinematical and dynamical properties for each outflow tracer in a consistent manner, for all observed outflows driven by protostars in NGC 1333. We finally measure the water abundance in outflows with respect to carbon monoxide and molecular hydrogen.
Results CO and H_2 are highly excited around B-stars and at lower levels trace protostellar outflows. H_2O emission is dominated by a moderately fast component associated with outflows. H_2O also displays a weak, narrow-line component in the vicinity of B-stars associated to their UV field. This narrow component it is also present in a handful of outflows, indicating UV radiation generated in shocks. Intermediate J CO lines appear brightest at the locations traced by the narrow H_2O component, indicating that beyond the dominating collisional processes, a secondary, radiative excitation component can also be active. The morphology, kinematics, excitation and abundance variations of water are consistent with its excitation and partial dissociation in shocks. Water abundance ranges between 5×10^{-7} and $\sim 10^{-5}$, with the lower values being more representative. Water is brightest and most abundant around IRAS 4A which is consistent with the latter hosting a hot corino source. [CI] traces dense and warm gas in the envelopes surrounding protostars. Outflow mass flux is highest for CO and decreases by one and two orders of magnitude for H_2 and H_2O, respectively.
Conclusions Large scale spectral line maps can provide unique insights into the excitation of gas in star-forming regions. Comparative analysis of line excitation and morphologies at different locations allows to decipher the dominant excitation conditions in each region but also isolate exceptional cases.

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Strong Hα emission and signs of accretion in a circumbinary planetary mass companion from MUSE

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Context. Using intrinsic Hα emission to detect substellar companions can be advantageous for improving contrasts in direct imaging, and probing planetary formation theories through the characterisation of accreting exoplanets.
Aims. In this work we aim to characterise the young circumbinary planetary mass companion 2MASS J01033563−5515561 (AB)b (Delorme 1 (AB)b) through medium resolution spectroscopy.
Methods. We have used the new Narrow-Field Mode (NFM) for the MUSE integral-field spectrograph, located on the ESO Very Large Telescope, during SV time to obtain optical spectra of Delorme 1 (AB)b.
Results. We report the discovery of very strong Hα and Hβ emission, accompanied by He I emission, consistent with

an active accretion scenario. We provide accretion rate estimates obtained from several independent methods and find a likely mass of 12–15 $M_{\rm Jup}$ for Delorme 1 (AB)b, also consistent with previous estimates.
Conclusions. Signs of active accretion in the Delorme 1 system could indicate a younger age than the ∼30–40 Myr expected from a likely Tucana-Horologium (THA) membership. Previous works have also shown the central binary to be overluminous, which gives further indication of a younger age. However, recent discoveries of active disks in relatively old (∼40 Myr), very low-mass systems suggests that ongoing accretion in Delorme 1 (AB)b might not require in and of itself that the system is younger than the age implied by its THA membership.

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A Survey for New Stars and Brown Dwarfs in the Ophiuchus Star-forming Complex

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We have performed a survey for new members of the Ophiuchus cloud complex using high-precision astrometry from the second data release of Gaia, proper motions measured with multi-epoch images from the Spitzer Space Telescope, and color-magnitude diagrams constructed with photometry from various sources. Through spectroscopy of candidates selected with those data, we have identified 155 new young stars. Based on available measurements of kinematics, we classify 102, 47, and six of those stars as members of Ophiuchus, Upper Sco, and other populations in Sco-Cen, respectively. We have also assessed the membership of all other stars in the vicinity of Ophiuchus that have spectroscopic evidence of youth from previous studies, arriving at a catalog of 373 adopted members of the cloud complex. For those adopted members, we have compiled mid-IR photometry from Spitzer and the Wide-field Infrared Survey Explorer and have used mid-IR colors to identify and classify circumstellar disks. We find that 210 of the members show evidence of disks, including 48 disks that are in advanced stages of evolution. Finally, we have estimated the relative median ages of the populations near the Ophiuchus clouds and the surrounding Upper Sco association using absolute K-band magnitudes (M_K) based on Gaia parallaxes. If we adopt an age 10 Myr for Upper Sco, then the relative values of M_K imply median ages of ∼2 Myr for L1689 and embedded stars in L1688, 3–4 Myr for low-extinction stars near L1688, and ∼6 Myr for the group containing ρ Oph.

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Seeds of Life in Space (*SOLIS*). IX. Chemical segregation of SO_2 and SO toward the low-mass protostellar shocked region of L1157

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We present observations of SO and SO_2 lines toward the shocked regions along the L1157 chemically rich outflow, taken in the context of the Seeds Of Life In Space IRAM-NOrthern Extended Millimeter Array Large Program, and supported by data from Submillimeter Array and IRAM-30 m telescope at 1.1–3.6 mm wavelengths. We simultaneously analyze, for the first time, all of the brightest shocks in the blueshifted lobe, namely, B0, B1, and B2. We found the following. (1) SO and SO_2 may trace different gas, given that the large(-scale) velocity gradient analysis indicates for SO_2 a volume density ($10^5 - - 10^6$ cm^{-3}) denser than that of the gas emitting in SO by a factor up to an order of magnitude. (2) Investigating the 0.1 pc scale field of view, we note a tentative gradient along the path of the precessing jet. More specifically, $\chi(SO/SO_2)$ decreases from the B0-B1 shocks to the older B2. (3) At a linear resolution of 500–1400 au, a tentative spatial displacement between the two emitting molecules is detected, with the SO peak closer (with respect to SO_2) to the position where the recent jet is impinging on the B1 cavity wall. Our astrochemical modeling shows that the SO and SO_2 abundances evolve on timescales less than about 1000 years. Furthermore, the modeling requires high abundances (2×10^{-6}) of both H_2S/H and S/H injected in the gas phase due to the shock occurrence, so pre-frozen OCS only is not enough to reproduce our new observations.

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The chemical structure of young high-mass star-forming clumps: (I) Deuteration

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The chemical structure of high-mass star nurseries is important for a general understanding of star formation. Deuteration is a key chemical process in the earliest stages of star formation because its efficiency is sensitive to the environment. Using the IRAM-30 m telescope at 1.3–4.3 mm wavelengths, we have imaged two parsec-scale high-mass protostellar clumps (P1 and S) that show different evolutionary stages but are located in the same giant filamentary infrared dark cloud G28.34+0.06. Deep spectral images at subparsec resolution reveal the dust and gas physical structures of both clumps. We find that (1) the low-J lines of N_2H^+, HCN, HNC, and HCO^+ isotopologues are subthermally excited; and (2) the deuteration of N_2H^+ is more efficient than that of HCO^+, HCN, and HNC by an order of magnitude. The deuterations of these species are enriched toward the chemically younger clump S compared with P1, indicating that this process favors the colder and denser environment ($T_{kin} \sim 14$K, $N(NH_3) \sim 9 \times 10^{15}$ cm^{-2}). In contrast, single deuteration of NH_3 is insensitive to the environmental difference between P1 and S; and (3) single deuteration of CH_3OH ($> 10\%$) is detected toward the location where CO shows a depletion of ~ 10. This comparative chemical study between P1 and S links the chemical variations to the environmental differences and shows chemical similarities between the early phases of high- and low-mass star-forming regions.

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APEX CO observations towards the photodissociation region of RCW120

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The edges of ionized (HII) regions are important sites for the formation of (high-mass) stars. Indeed, at least 30% of the galactic high mass star formation is observed there. The radiative and compressive impact of the HII region could induce the star formation at the border following different mechanisms such as the Collect & Collapse (C&C)

or the Radiation Driven Implosion (RDI) models and change their properties. We study the properties of two zones located in the Photo Dissociation Region (PDR) of the Galactic HII region RCW120 and discussed them as a function of the physical conditions and young star contents found in both clumps. Using the APEX telescope, we mapped two regions of size $1'.5 \times 1'.5$ toward the most massive clump of RCW120 hosting young massive sources and toward a clump showing a protrusion inside the HII region and hosting more evolved low-mass sources. The $^{12}CO(J{=}3–2)$, $^{13}CO(J{=}3–2)$ and $C^{18}O(J{=}3–2)$ lines are used to derive the properties and dynamics of these clumps. We discuss their relation with the hosted star-formation. The increase of velocity dispersion and T_{ex} are found toward the center of the maps, where star-formation is observed with Herschel. Furthermore, both regions show supersonic Mach number. No strong evidences have been found concerning the impact of far ultraviolet (FUV) radiation on $C^{18}O$ photodissociation. The fragmentation time needed for the C&C to be at work is equivalent to the dynamical age of RCW120 and the properties of region B are in agreement with bright-rimmed clouds. It strengthens the fact that, together with evidences of compression, C&C might be at work at the edges of RCW120. Additionally, the clump located at the eastern part of the PDR is a good candidate of pre-existing clump where star-formation may be induced by the RDI mechanism.

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Measuring turbulent motion in planet-forming disks with ALMA: A detection around DM Tau and non-detections around MWC 480 and V4046 Sgr

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Turbulence is a crucial factor in many models of planet formation, but it has only been directly constrained among a small number of planet forming disks. Building on the upper limits on turbulence placed in disks around HD 163296 and TW Hya, we present ALMA CO J=2-1 line observations at ~ 0.3 arcsec (20-50 au) resolution and 80 ms^{-1} channel spacing of the disks around DM Tau, MWC 480, and V4046 Sgr. Using parametric models of disk structure, we robustly detect non-thermal gas motions around DM Tau of between 0.25 c_s and 0.33 c_s, with the range dominated by systematic effects, making this one of the only systems with directly measured non-zero turbulence. Using the same methodology, we place stringent upper limits on the non-thermal gas motion around MWC 480 ($<0.08c_s$) and V4046 Sgr (<0.12 c_s). The preponderance of upper limits in this small sample, and the modest turbulence levels consistent with dust studies, suggest that weak turbulence ($\alpha \lesssim 10^{-3}$) may be a common, albeit not universal, feature of planet-forming disks. We explore the particular physical conditions around DM Tau that could lead this system to be more turbulent than the others.

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Gas and dust dynamics in starlight-heated protoplanetary disks

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Theoretical models of the ionization state in protoplanetary disks suggest the existence of large areas with low ionization and weak coupling between the gas and magnetic fields. In this regime hydrodynamical instabilities may become important. In this work we investigate the gas and dust structure and dynamics for a typical T Tauri system under the influence of the vertical shear instability (VSI). We use global 3D radiation hydrodynamics simulations covering all 360° of azimuth with embedded particles of 0.1 and 1mm size, evolved for 400 orbits. Stellar irradiation heating is included with opacities for 0.1- to 10-μm-sized dust. Saturated VSI turbulence produces a stress-to-pressure ratio of $\alpha \simeq 10^{-4}$. The value of α is lowest within 30 au of the star, where thermal relaxation is slower relative to the orbital period and approaches the rate below which VSI is cut off. The rise in α from 20 to 30 au causes a dip in the surface density near 35 au, leading to Rossby wave instability and the generation of a stationary, long-lived vortex spanning about 4 au in radius and 40 au in azimuth. Our results confirm previous findings that mm size grains are strongly vertically mixed by the VSI. The scale height aspect ratio for 1mm grains is determined to be 0.037, much higher than the value $H/r = 0.007$ obtained from millimeter-wave observations of the HL Tau system. The measured aspect ratio is better fit by non-ideal MHD models. In our VSI turbulence model, the mm grains drift radially inwards and many are trapped and concentrated inside the vortex. The turbulence induces a velocity dispersion of ~ 12 m/s for the mm grains, indicating that grain-grain collisions could lead to fragmentation.

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Enrichment of the HR 8799 planets by minor bodies and dust

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In the Solar System, minor bodies and dust deliver various materials to planetary surfaces. Several exoplanetary systems are known to host inner and outer belts, analogues of the main asteroid belt and the Kuiper belt. We study the possibility that exominor bodies and exodust deliver volatiles and refractories to the exoplanets in the system HR8799 by performing N-body simulations. The model consists of the host star, four giant planets (HR8799 e, d, c, and b), 650000 test particles representing the inner belt, and 1450000 test particles representing the outer belt. Moreover we modelled dust populations that originate from both belts. Within a million years, the two belts evolve towards the expected dynamical structure (also derived in other works), where mean-motion resonances with the planets carve the analogues of Kirkwood gaps. We find that, after this point, the planets suffer impacts by objects from the inner and outer belt at rates that are essentially constant with time, while dust populations do not contribute significantly to the delivery process. We convert the impact rates to volatile and refractory delivery rates using our best estimates of the total mass contained in the belts and their volatile and refractory content. Over their lifetime, the four giant planets receive between 10^{-4} and 10^{-3} $M_\oplus$ of material from both belts. The total amount of delivered volatiles and refractories, 5×10^{-3} $M_\oplus$, is small compared to the total mass of the planets, 11×10^3 $M_\oplus$. However, if the planets were formed to be volatile-rich, their exogenous enrichment in refractory material may well be significant and observable, for example with JWST-MIRI. If terrestrial planets exist within the snow line of the system, volatile delivery would be an important astrobiological mechanism and may be observable as atmospheric trace gases.

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Efficient Methanol Production on the Dark Side of a Prestellar Core

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We present Atacama Large Millimeter/submillimeter Array maps of the starless molecular cloud core Ophiuchus/H-MM1 in the lines of deuterated ammonia (ortho-NH_2D), methanol (CH_3OH), and sulfur monoxide (SO). The dense core is seen in NH_2D emission, whereas the CH_3OH and SO distributions form a halo surrounding the core. Because methanol is formed on grain surfaces, its emission highlights regions where desorption from grains is particularly efficient. Methanol and sulfur monoxide are most abundant in a narrow zone that follows the eastern side of the core. This side is sheltered from the stronger external radiation field coming from the west. We show that photodissociation on the illuminated side can give rise to an asymmetric methanol distribution but that the stark contrast observed in H-MM1 is hard to explain without assuming enhanced desorption on the shaded side. The region of the brightest emission has a wavy structure that rolls up at one end. This is the signature of Kelvin-Helmholtz instability occurring in sheared flows. We suggest that in this zone, methanol and sulfur are released as a result of grain–grain collisions induced by shear vorticity.

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Tracking the evolutionary stage of protostars by the abundances of astrophysical ices

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We report on a study of the high-mass star formation in the the HII region W28A2 by investigating the molecular clouds extended over ∼5–10 pc from the exciting stars using the ^{12}CO and ^{13}CO (J=1–0) and ^{12}CO (J=2–1) data taken by the NANTEN2 and Mopra observations. These molecular clouds consist of three velocity components with the CO intensity peaks at $V_{\rm LSR} \sim -4$ km s^{-1}, 9 km s^{-1} and 16 km s^{-1}. The highest CO intensity is detected at $V_{\rm LSR} \sim 9$ km s^{-1}, where the high-mass stars with the spectral types of O6.5–B0.5 are embedded. We found bridging features connecting these clouds toward the directions of the exciting sources. Comparisons of the gas distributions with the radio continuum emission and 8 μm infrared emission show spatial coincidence/anti-coincidence, suggesting physical associations between the gas and the exciting sources. The ^{12}CO J=2–1 to 1–0 intensity ratio shows a high

value (>0.8) toward the exciting sources for the -4 km s^{-1} and $+9$ km s^{-1} clouds, possibly due to heating by the high-mass stars, whereas the intensity ratio at the CO intensity peak ($V_{\rm LSR} \sim 9$ km s^{-1}) lowers down to ~0.6, suggesting self absorption by the dense gas in the near side of the $+9$ km s^{-1} cloud. We found partly complementary gas distributions between the -4 km s^{-1} and $+9$ km s^{-1} clouds, and the -4 km s^{-1} and $+16$ km s^{-1} clouds. The exciting sources are located toward the overlapping region in the -4 km s^{-1} and $+9$ km s^{-1} clouds. Similar gas properties are found in the Galactic massive star clusters, RCW 38 and NGC 6334, where an early stage of cloud collision to trigger the star formation is suggested. Based on these results, we discuss a possibility of the formation of high-mass stars in the W28A2 region triggered by the cloud-cloud collision.

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Magnetic Field Structure of Orion Source I

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We observed polarization of the SiO rotational transitions from Orion Source I (SrcI) to probe the magnetic field in bipolar outflows from this high mass protostar. Both 43 GHz J=1-0 and 86 GHz J=2-1 lines were mapped with ~20 AU resolution, using the VLA and ALMA, respectively. The ^{28}SiO transitions in the ground vibrational state are a mixture of thermal and maser emission. Comparison of the polarization position angles in the J=1-0 and J=2-1 transitions allows us to set an upper limit on possible Faraday rotation of 10^4 radians m^{-2}, which would twist the J=2-1 position angles typically by less than 10 degrees. The smooth, systematic polarization structure in the outflow lobes suggests a well ordered magnetic field on scales of a few hundred AU. The uniformity of the polarization suggests a field strength of ~30 milli-Gauss. It is strong enough to shape the bipolar outflow and possibly lead to sub-Keplerian rotation of gas at the base of the outflow. The strikingly high fractional linear polarizations of 80-90% in the ^{28}SiO v=0 masers require anisotropic pumping. We measured circular polarizations of 60% toward the strongest maser feature in the v=0 J=1-0 peak. Anisotropic resonant scattering (ARS) is likely to be responsible for this circular polarization. We also present maps of the ^{29}SiO ν=0 J=2-1 maser and several other SiO transitions at higher vibrational levels and isotopologues.

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Frankenstein: Protoplanetary disc brightness profile reconstruction at sub-beam resolution with a rapid Gaussian process

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Interferometric observations of the mm dust distribution in protoplanetary discs are now showing a ubiquity of annular gap and ring substructures. Their identification and accurate characterization is critical to probing the physical processes responsible. We present Frankenstein (frank), an open source code that recovers axisymmetric disc structures

at sub beam resolution. By fitting the visibilities directly, the model reconstructs a disc's 1D radial brightness profile nonparametrically using a fast (less than about 1 min) Gaussian process. The code avoids limitations of current methods that obtain the radial brightness profile by either extracting it from the disc image via nonlinear deconvolution at the cost of reduced fit resolution, or by assumptions placed on the functional forms of disc structures to fit the visibilities parametrically. We use mock ALMA observations to quantify the method's intrinsic capability and its performance as a function of baseline-dependent signal-to-noise. Comparing the technique to profile extraction from a CLEAN image, we motivate how our fits accurately recover disc structures at a sub-beam resolution. Demonstrating the model's utility in fitting real high and moderate resolution observations, we conclude by proposing applications to address open questions on protoplanetary disc structure and processes.

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Outbursts in Global Protoplanetary Disk Simulations

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While accreting through a circumstellar disk, young stellar objects are observed to undergo sudden and powerful accretion events known as FUor or EXor outbursts. Although such episodic accretion is considered to be an integral part of the star formation process, the triggers and mechanisms behind them remain uncertain. We conducted global numerical hydrodynamics simulations of protoplanetary disk formation and evolution in the thin-disk limit, assuming both magnetically layered and fully magnetorotational instability (MRI)-active disk structure. In this paper, we characterize the nature of the outbursts occurring in these simulations. The instability in the dead zone of a typical layered disk results in "MRI outbursts". We explore their progression and their dependence on the layered disk parameters as well as cloud core mass. The simulations of fully MRI-active disks showed an instability analogous to the classical thermal instability. This instability manifested at two temperatures–above approximately 1400 K and 3500 K–due to the steep dependence of Rosseland opacity on the temperature. The origin of these thermally unstable regions is related to the bump in opacity resulting from molecular absorption by water vapor and may be viewed as a novel mechanism behind some of the shorter duration accretion events. Although we demonstrated local thermal instability in the disk, more investigations are needed to confirm that a large-scale global instability will ensue. We conclude that the magnetic structure of a disk, its composition, as well as the stellar mass, can significantly affect the nature of episodic accretion in young stellar objects.

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Gap, shadows, spirals, streamers: SPHERE observations of binary-disk interactions in GG Tau A

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A large fraction of stars is found to be part of binary or higher-order multiple systems. The ubiquity of planets found around single stars raises the question if and how planets in binary systems may form. Protoplanetary disks are the birthplaces of planets, and their characterization is crucial in order to understand the planet formation process.

Our aim is to characterize the morphology of the GG Tau A disk, one of the largest and most massive circumbinary disks, and trace evidence for binary-disk interactions. We obtained observations in polarized scattered light of GG Tau A using the SPHERE/IRDIS instrument in the *H*-band filter. We analyze the observed disk morphology and substructures. We run 2D hydrodynamical models simulating the evolution of the circumbinary ring over the lifetime of the disk. The disk, as well as the cavity and the inner region are highly structured with several shadowed regions, spiral structures, and streamer-like filaments, some of them detected for the first time. The streamer-like filaments appear to connect the outer ring with the northern arc. Their azimuthal spacing suggests that they may be generated by periodic perturbations by the binary, tearing off material from the inner edge of the outer disk once during each orbit. By comparing observations to hydrodynamical simulations we find that the main features, in particular the gap size, as well as the spiral and streamer filaments, can be qualitatively explained by the gravitational interactions of a binary with semi-major axis of ∼35 au on an orbit coplanar with the circumbinary ring.

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Multiple outflows in the high-mass cluster forming region, G25.82−0.17

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We present results of continuum and spectral line observations with ALMA and 22 GHz water (H_2O) maser observations using KaVA and VERA toward a high-mass star-forming region, G25.82−0.17. Multiple 1.3 mm continuum sources are revealed, indicating the presence of young stellar objects (YSOs) at different evolutionary stages, namely an ultra-compact HII region, G25.82-E, a high-mass young stellar object (HM-YSO), G25.82-W1, and starless cores, G25.82-W2 and G25.82-W3. Two SiO outflows, at N-S and SE-NW orientations, are identified. The CH_3OH 8_{-1}–7_0 E line, known to be a class I CH_3OH maser at 229 GHz is also detected showing a mixture of thermal and maser emission. Moreover, the H_2O masers are distributed in a region $\sim0\farcs25$ shifted from G25.82-W1. The CH_3OH 22_4–21_5 E line shows a compact ring-like structure at the position of G25.82-W1 with a velocity gradient, indicating a rotating disk or envelope. Assuming Keplerian rotation, the dynamical mass of G25.82-W1 is estimated to be >25 $M_\odot$ and the total mass of 20 $M_\odot$–84 $M_\odot$ is derived from the 1.3 mm continuum emission. The driving source of the N-S SiO outflow is G25.82-W1 while that of the SE-NW SiO outflow is uncertain. Detection of multiple high-mass starless/protostellar cores and candidates without low-mass cores implies that HM-YSOs could form in individual high-mass cores as predicted by the turbulent core accretion model. If this is the case, the high-mass star formation process in G25.82 would be consistent with a scaled-up version of low-mass star formation.

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Cloud structures in M17 SWex : Possible cloud-cloud collision

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Using wide-field ^{13}CO (J=1–0) data taken with the Nobeyama 45-m telescope, we investigate cloud structures of the infrared dark cloud complex in M17 with SCIMES. In total, we identified 118 clouds that contain 11 large clouds with radii larger than 1 pc. The clouds are mainly distributed in the two representative velocity ranges of 10–20 $\mathrm{km\,s^{-1}}$ and 30–40 $\mathrm{km\,s^{-1}}$. By comparing with the ATLASGAL catalog, we found that the majority of the ^{13}CO clouds with 10–20 $\mathrm{km\,s^{-1}}$ and 30–40 $\mathrm{km\,s^{-1}}$ are likely located at distances of 2 kpc (Sagittarius arm) and 3 kpc (Scutum arm), respectively. Analyzing the spatial configuration of the identified clouds and their velocity structures, we attempt to reveal the origin of the cloud structure in this region. Here we discuss three possibilities: (1) overlapping with different velocities, (2) cloud oscillation, and (3) cloud-cloud collision. From the position-velocity diagrams, we found spatially-extended faint emission between $\sim$20 $\mathrm{km\,s^{-1}}$ and $\sim$35 $\mathrm{km\,s^{-1}}$, which is mainly distributed in the spatially-overlapped areas of the clouds. We also found that in some areas where clouds with different velocities overlapped, the magnetic field orientation changes abruptly. The distribution of the diffuse emission in the position-position-velocity space and the bending magnetic fields appear to favor the cloud-cloud collision scenario compared to other scenarios. In the cloud-cloud collision scenario, we propose that two $\sim$35 $\mathrm{km\,s^{-1}}$ foreground clouds are colliding with clouds at $\sim$20 $\mathrm{km\,s^{-1}}$ with a relative velocity of 15 $\mathrm{km\,s^{-1}}$. These clouds may be substructures of two larger clouds having velocities of $\sim$35 $\mathrm{km\,s^{-1}}$ ($\gtrsim$10^3 $M_\odot$) and $\sim$20 $\mathrm{km\,s^{-1}}$ ($\gtrsim$10^4 $M_\odot$), respectively.

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Grain growth in newly discovered young eruptive stars

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FU Orionis-type stars are young stellar objects showing large outbursts due to highly enhanced accretion from the circumstellar disk onto the protostar. FUor-type outbursts happen in a wide variety of sources from the very embedded ones to those with almost no sign of extended emission beyond the disk. The subsequent eruptions might gradually clear up the obscuring envelope material and drive the protostar on its way to become a disk-only T Tauri star. We used VLT/VISIR to obtain the first spectra that cover the $8-13\,\mu$m mid-infrared wavelength range in low-resolution of five recently discovered FUors. Four objects from our sample show the $10\,\mu$m silicate feature in emission. We study the shape and strength of the silicate feature in these objects and find that they mostly contain large amorphous grains, suggesting that large grains are typically not settled to the midplane in FUor disks. This is a general characteristic of FUors, as opposed to regular T Tauri-type stars whose disks display anything from pristine small grains to significant grain growth. We classify our targets by determining whether the silicate feature is in emission or in absorption, and confront them with the evolutionary scenarios on the dispersal of the envelopes around young stars. In our sample, all Class II objects exhibit silicate emission, while for Class I objects, the appearance of the feature in emission or absorption depends on the viewing angle with respect to the outflow cavity. This highlights the importance of geometric effects when interpreting the silicate feature.

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Star Cluster Formation in Orion A

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We introduce new analysis methods for studying the star cluster formation processes in Orion A, especially examining the scenario of a cloud-cloud collision. We utilize the CARMA-NRO Orion survey ^{13}CO (1-0) data to compare molecular gas to the properties of YSOs from the SDSS III IN-SYNC survey. We show that the increase of $v_{13\mathrm{CO}} - v_{\mathrm{YSO}}$ and Σ scatter of older YSOs can be signals of cloud-cloud collision. SOFIA-upGREAT 158μm [CII] archival data toward the northern part of Orion A are also compared to the ^{13}CO data to test whether the position and velocity offsets between the emission from these two transitions resemble those predicted by a cloud-cloud collision model. We find that the northern part of Orion A, including regions ONC-OMC-1, OMC-2, OMC-3 and OMC-4, shows qualitative agreements with the cloud-cloud collision scenario, while in one of the southern regions, NGC1999, there is no indication of such a process in causing the birth of new stars. On the other hand, another southern cluster, L1641N, shows slight tendencies of cloud-cloud collision. Overall, our results support the cloud-cloud collision process as being an important mechanism for star cluster formation in Orion A.

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The Age-Dependence of Mid-Infrared Emission Around Young Star Clusters

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Using the star cluster catalogs from the Hubble Space Telescope program Legacy ExtraGalactic UV survey (LEGUS) and 8 μm images from the IRAC camera on the Spitzer Space Telescope for 5 galaxies within 5 Mpc, we investigate how the 8 μm dust luminosity correlates with the stellar age on the 30–50 pc scale of star forming regions. We construct a sample of 97 regions centered at local peaks of 8 μm emission, each containing one or more young star cluster candidates from the LEGUS catalogs. We find a tight anti-correlation with a Pearson correlation coefficient of $r = -0.84 \pm 0.05$ between the mass-normalized dust-only 8 μm luminosity and the age of stellar clusters younger than 1 Gyr; the 8 μm luminosity decreases with increasing age of the stellar population. Simple assumptions on a combination of stellar and dust emission models reproduce the observed trend. We also explore how the scatter of the observed trend depends on assumptions of stellar metallicity, PAH abundance, fraction of stellar light absorbed by dust, and instantaneous versus continuous star formation models. We find that variations in stellar metallicity have little effect on the scatter, while PAH abundance and the fraction of dust-absorbed light bracket the full range of the data. We also find that the trend is better explained by continuous star formation, rather than instantaneous burst models. We ascribe this result to the presence of multiple star clusters with different ages in many of the regions. Upper limits of the dust-only 8 μm emission as a function of age are provided.

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Validating Scattering-Induced (Sub)millimeter Disk Polarization through the Spectral Index, Wavelength-Dependent PolarizationPattern, and Polarization Spectrum: The Case of HD 163296

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A number of young circumstellar disks show strikingly ordered (sub)millimeter polarization orientations along the minor axis, which is strong evidence for polarization due to scattering by $\sim$ 0.1 mm-sized grains. To test this mechanism further, we model the ALMA dust continuum and polarization data of HD 163296 using RADMC-3D. We find that scattering by grains with a maximum size of 90 μm simultaneously reproduces the polarization observed at Band 7 and the unusually low spectral index ($\alpha \sim 1.5$) between Band 7 and Band 6 in the optically thick inner disk as a result of more efficient scattering at the shorter wavelength. The low spectral index of $\sim$ 2.5 inferred for the optically thin gaps is reproduced by the same grains, as a result of telescope beam averaging of the gaps (with an intrinsic $\alpha \sim 4$) and their adjacent optically thick rings (where $\alpha << 2$). The tension between the grain sizes inferred from polarization and spectral index disappears because the low α values do not require large mm-sized grains. In addition, the polarization fraction has a unique azimuthal variation: higher along the major axis than the minor axis in the gaps, but vice versa in the rings. We find a rapidly declining polarization spectrum (with $p \propto \lambda^{-3}$ approximately) in the gaps, which becomes flattened or even inverted towards short wavelengths in the optically thick rings. These contrasting behaviors in the rings and gaps provide further tests for scattering-induced polarization via resolved multi-wavelength observations.

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Magnetic fields in the early stages of massive star formation as revealed by ALMA

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We present 1.3 mm ALMA dust polarization observations at a resolution of $\sim$0.02 pc of three massive molecular clumps, MM1, MM4, and MM9, in the infrared dark cloud G28.34+0.06. With the sensitive and high-resolution continuum data, MM1 is resolved into a cluster of condensations. The magnetic field structure in each clump is revealed by the polarized emission. We found a trend of decreasing polarized emission fraction with increasing Stokes I intensities in MM1 and MM4. Using the angular dispersion function method (a modified Davis-Chandrasekhar-Fermi method), the plane-of-sky magnetic field strength in two massive dense cores, MM1-Core1 and MM4-Core4, are estimated to be $\sim$1.6 mG and $\sim$0.32 mG, respectively. The virial parameters in MM1-Core1 and MM4-Core4 are calculated to be $\sim$0.76 and $\sim$0.37, respectively, suggesting that massive star formation does not start in equilibrium. Using the polarization-intensity gradient-local gravity method, we found that the local gravity is closely aligned with intensity gradient in the three clumps, and the magnetic field tends to be aligned with the local gravity in MM1 and MM4 except for regions near the emission peak, which suggests that the gravity plays a dominant role in regulating the gas collapse. Half of the outflows in MM4 and MM9 are found to be aligned within 10° of the condensation-scale (<0.05

pc) magnetic field, indicating that the magnetic field could play an important role from condensation to disk scale in the early stage of massive star formation. We found that the fragmentation in MM1-Core1 cannot be solely explained by thermal Jeans fragmentation or turbulent Jeans fragmentation.

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VLT/SPHERE survey for exoplanets around young, early-type stars including systems with multi-belt architectures

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Dusty debris disks around pre- and main-sequence stars are potential signposts for the existence of planetesimals and exoplanets. Giant planet formation is therefore expected to play a key role in the evolution of the disk. This is indirectly confirmed by extant sub-millimeter near-infrared images of young protoplanetary and cool dusty debris disks around main sequence stars usually showing substantial spatial structures. A majority of recent discoveries of imaged giant planets have been obtained around young, early-type stars hosting a circumstellar disk. In this context, we have carried out a direct imaging program designed to maximize our chances of giant planet discovery and targeting twenty-two young, early-type stars. About half of them show indication of multi-belt architectures. Using the IRDIS dual-band imager and the IFS integral field spectrograph of SPHERE to acquire high-constrast coronagraphic differential near-infrared images, we have conducted a systematic search in the close environment of these young, dusty and early-type stars. We confirmed that companions detected around HIP 34276, HIP 101800 and HIP 117452 are stationary background sources and binary companions. The companion candidates around HIP 8832, HIP 16095 and HIP 95619 are determined as background contamination. For stars for which we infer the presence of debris belts, a theoretical minimum mass for planets required to clear the debris gaps can be calculated . The dynamical mass limit is at least 0.1 $M_{\rm J}$ and can exceed 1 $M_{\rm J}$. Direct imaging data is typically sensitive to planets down to $\sim$3.6 $M_{\rm J}$ at 1$''$, and 1.7 $M_{\rm J}$ in the best case. These two limits tightly constrain the possible planetary systems present around each target. These systems will be probably detectable with the next generation of planet imagers.

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X-Shooter survey of disk accretion in Upper Scorpius I. Very high accretion rates at age>5 Myr

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Determining the mechanisms that drive the evolution of protoplanetary disks is a necessary step to understand how planets form. Here we measure the mass accretion rate for young stellar objects with disks at age >5 Myr, a critical test for the current models of disk evolution. We present the analysis of the spectra of 36 targets in the ∼5-10 Myr old Upper Scorpius star-forming regions for which disk masses were measured with ALMA. We find that the mass accretion rates in this sample of old but still survived disks are similarly high as those of the younger (∼1 ? 3 Myr old) star-forming regions of Lupus and Chamaeleon I, when considering the dependence on stellar and disk mass. In particular, several disks show high mass accretion rates $> 10^{-9} M_{\odot}$/yr while having low disk masses. Furthermore, the median values of the measured mass accretion rates in the disk mass ranges where our sample is complete at a level ∼60 - 80% are compatible in these three regions. At the same time, the spread of mass accretion rates at any given disk mass is still >0.9 dex even at age>5 Myr. These results are in contrast with simple models of viscous evolution, which would predict that the values of the mass accretion rate diminish with time, and a tighter correlation with disk mass at age>5 Myr. Similarly, simple models of internal photoevaporation cannot reproduce the observed mass accretion rates, while external photoevaporation might explain the low disk masses and high accretion rates. A partial possible solution to the discrepancy with the viscous models is that the gas-to-dust ratio of the disks at ∼5-10 Myr is significantly different and higher than the canonical 100, as suggested by some dust and gas disk evolution models. The results shown here require the presence of several inter-playing processes, such as detailed dust evolution, external photoevaporation and possibly MHD winds, to explain the secular evolution of protoplanetary disks.

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Orbital and mass constraints of the young binary system IRAS 16293-2422 A

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We present 3 mm ALMA continuum and line observations at resolutions of 6.5 au and 13 au respectively, toward the Class 0 system IRAS 16293-2422 A. The continuum observations reveal two compact sources towards IRAS 16293-2422 A, coinciding with compact ionized gas emission previously observed at radio wavelengths (A1 and A2), confirming the long-known radio sources as protostellar. The emission towards A2 is resolved and traces a dust disk with a FWHM size of ∼12 au, while the emission towards A1 sets a limit to the FWHM size of the dust disk of ∼4 au. We also detect spatially resolved molecular kinematic tracers near the protostellar disks. Several lines of the $J = 5-4$ rotational transition of HNCO, NH_2CHO and t-HCOOH are detected, with which we derived individual line-of-sight velocities. Using these together with the CS ($J = 2-1$), we fit Keplerian profiles towards the individual compact sources and derive masses of the central protostars. The kinematic analysis indicates that A1 and A2 are a bound binary system. Using this new context for the previous 30 years of VLA observations, we fit orbital parameters to the relative motion between A1 and A2 and find the combined protostellar mass derived from the orbit is consistent with the masses derived from the gas kinematics. Both estimations indicate masses consistently higher ($0.5 < M_1 < M_2 < 2$ $M_{\odot}$) than previous estimations using lower resolution observations of the gas kinematics. The ALMA high-resolution data provides a unique insight into the gas kinematics and masses of a young deeply embedded bound binary system.

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What did the seahorse swallow? APEX 170 GHz observations of the chemical conditions in the Seahorse infrared dark cloud

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Context. Infrared dark clouds (IRDCs) are useful target sources for the studies of molecular cloud substructure evolution and early stages of star formation. Determining the chemical composition of IRDCs helps to constrain the initial conditions and timescales (via chemical clocks) of star formation in these often filamentary, dense interstellar clouds.
Aims. We aim to determine the fractional abundances of multiple different molecular species in the filamentary IRDC G304.74+01.32, nicknamed the Seahorse IRDC, and to search for relationships between the abundances and potential evolutionary trends.
Methods. We used the Atacama Pathfinder EXperiment (APEX) telescope to observe spectral lines occurring at about 170 GHz frequency towards 14 positions along the full extent of the Seahorse filament. The sample is composed of five clumps that appear dark in the mid-IR, eight clumps that are associated with mid-IR sources, and one clump that is already hosting an HII region and is, hence, likely to be in the most advanced stage of evolution of all the target sources. We also employed our previous 870 μm dust continuum imaging data of the Seahorse.
Results. Six spectral line transitions were detected ($\geq 3\sigma$) altogether, namely, SO($N_J = 4_4 - 3_3$), $H^{13}CN$($J = 2-1$), $H^{13}CO^+$($J = 2-1$), SiO($J = 4-3$), $HN^{13}C$($J = 2-1$), and C_2H($N = 2-1$). While SO, $H^{13}CO^+$, and $HN^{13}C$ were detected in every source, the detection rates for C_2H and $H^{13}CN$ were 92.9% and 85.7%, respectively. Only one source (SMM 3) showed detectable SiO emission (7.1% detection rate). Three clumps (SMM 5, 6, and 7) showed the SO, $H^{13}CN$, $H^{13}CO^+$, $HN^{13}C$, and C_2H lines in absorption. Of the detected species, C_2H was found to be the most abundant one with respect to H_2 (a few times 10^{-9} on average), while $HN^{13}C$ was found to be the least abundant species (a few times 10^{-11}). We found three positive correlations among the derived molecular abundances, of which those between C_2H and $HN^{13}C$ and $HN^{13}C$ and $H^{13}CO^+$ are the most significant (correlation coefficient $r \simeq 0.9$). The statistically most significant evolutionary trends we uncovered are the drops in the C_2H abundance and in the $[HN^{13}C]/[H^{13}CN]$ ratio as the clump evolves from an IR dark stage to an IR bright stage and then to an HII region.
Conclusions. The absorption lines detected towards SMM 6 and SMM 7 could arise from continuum radiation from an embedded young stellar object and an extragalactic object seen along the line of sight. However, the cause of absorption lines in the IR dark clump SMM 5 remains unclear. The correlations we found between the different molecular abundances can be understood as arising from the gas-phase electron (ionisation degree) and atomic carbon abundances. With the exception of $H^{13}CN$ and $H^{13}CO^+$, the fractional abundances of the detected molecules in the Seahorse are relatively low compared to those in other IRDC sources. The $[C_2H]$ evolutionary indicator we found is in agreement with previous studies, and can be explained by the conversion of C_2H to other species (e.g. CO) when the clump temperature rises, especially after the ignition of a hot molecular core in the clump. The decrease of $[HN^{13}C]/[H^{13}CN]$ as the clump evolves is also likely to reflect the increase in the clump temperature, which leads to an enhanced formation of HCN and its ^{13}C isotopologue. Both single-dish and high-resolution interferometric imaging of molecular line emission (or absorption) of the Seahorse filament are required to understand the large-scale spatial distribution of the gas and to search for possible hot, high-mass star-forming cores in the cloud.

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The big sibling of AU Mic: a cold dust-rich debris disk around CP-72 2713 in the β Pic moving group

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Analyzing Spitzer and Herschel archival measurements we identified a hitherto unknown debris disk around the young K7/M0 star CP-72 2713. The system belongs to the 24 Myr old β Pic moving group. Our new 1.33 mm continuum observation, obtained with the ALMA 7-m array, revealed an extended dust disk with a peak radius of 140 au, probably tracing the location of the planetesimal belt in the system. The disk is outstandingly large compared to known spatially resolved debris disks and also to protoplanetary disks around stars of comparable masses. The dynamical excitation of the belt at this radius is found to be reconcilable with planetary stirring, while self-stirring by large planetesimals embedded in the belt can work only if these bodies form very rapidly, e.g. via pebble concentration. By analyzing the spectral energy distribution we derived a characteristic dust temperature of 43 K and a fractional luminosity of 1.1×10^{-3}. The latter value is prominently high, we know only four other similarly dust-rich Kuiper-belt analogs within 40 pc of the Sun.

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Protostellar Outflows at the EarliesT Stages (POETS). IV. Statistical properties of the 22 GHz H_2O masers

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Context. 22 GHz water masers are the most intense and widespread masers in star-forming regions. They are commonly associated with protostellar winds and jets emerging from low- and high-mass young stellar objects (YSO).
Aims. We wish to perform for the first time a statistical study of the location and motion of individual water maser cloudlets, characterized by typical sizes that are within a few au, with respect to the weak radio thermal emission from YSOs.
Methods. For this purpose, we have been carrying out the Protostellar Outflows at the EarliesT Stages (POETS) survey of a sample (38) of high-mass YSOs. The 22 GHz water maser positions and three-dimensional (3D) velocities were determined through multi-epoch Very Long Baseline Array (VLBA) observations with accuracies of a few milliarcsec (mas) and a few km s^{-1}, respectively. The position of the ionized core of the protostellar wind, marking the YSO, was determined through sensitive radio continuum, multi-frequency Jansky Very Large Array (JVLA) observations with a typical error of $\approx$ 20 mas.
Results. The statistic of the separation of the water masers from the radio continuum shows that 84% of the masers are found within 1000 au from the YSO and 45% of them are within 200 au. Therefore, we can conclude that the 22 GHz water masers are a reliable proxy for locating the position of the YSO. The distribution of maser luminosity is strongly peaked towards low values, indicating that about half of the maser population is still undetected with the current Very Long Baseline Interferometry (VLBI) detection thresholds of 50–100 mJy beam^{-1}. Next-generation, sensitive (at the nJy level) radio interferometers will have the capability to exploit these weak masers for an improved sampling of the velocity and magnetic fields around the YSOs. The average direction of the water maser proper motions provides a statistically-significant estimate for the orientation of the jet emitted by the YSO: 55% of the maser proper motions are directed on the sky within an angle of 30° from the jet axis. Finally, we show that our measurements of 3D maser velocities statistically support models in which water maser emission arises from planar shocks with propagation direction close to the plane of the sky.

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The High-Mass Protostellar Population of a Massive Infrared Dark Cloud

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We conduct a census of the high-mass protostellar population of the $\sim 70,000\,M_\odot$ Infrared Dark Cloud (IRDC) G028.37+00.07, identifying 35 sources based on their 70 μm emission, as reported in the *Herschel* Hi-GAL catalog of Molinari et al. (2016). We perform aperture photometry to construct spectral energy distributions (SEDs), which are then fit with the massive protostar models of Zhang & Tan (2018). We find that the sources span a range of isotropic luminosities from ∼20 to 4,500 $L_\odot$. The most luminous sources are predicted to have current protostellar masses of $m_* \sim 10\,M_\odot$ forming from cores of mass $M_c \sim 40$ to $400\,M_\odot$. The least luminous sources in our sample are predicted to be protostars with masses as low as $\sim 0.5\,M_\odot$ forming from cores with $M_c \sim 10\,M_\odot$, which are the minimum values explored in the protostellar model grid. The detected protostellar population has a total estimated protostellar mass of $M_* \sim 100\,M_\odot$. Allowing for completeness corrections, which are constrained by comparison with an *ALMA* study in part of the cloud, we estimate a star formation efficiency per free-fall time of ∼ 3% in the IRDC. Finally, analyzing the spatial distribution of the sources, we find relatively low degrees of central concentration of the protostars. The protostars, including the most massive ones, do not appear to be especially centrally concentrated in the protocluster as defined by the IRDC boundary.

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Magnetic Field Structure in Spheroidal Star-Forming Clouds. II. Estimating Field Structure from Observed Maps

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This paper presents models to estimate the structure of density and magnetic field strength in spheroidal condensations, from maps of their column density and their polarization of magnetically aligned dust grains. The density model is obtained by fitting a column density map with an embedded $p = 2$ Plummer spheroid of any aspect ratio and inclination. The magnetic properties are based on the density model, on the Davis-Chandrasekhar-Fermi (DCF) model of Alfvénic fluctuations, and on the Spheroid Flux Freezing (SFF) model of mass and flux conservation in Paper I. The field strength model has the resolution of the column density map, which is finer than the resolution of the DCF estimate of field strength. The models are applied to ALMA observations of the envelope of the protostar BHR71 IRS1. Column density fits give the density model, from $(2.0 \pm 0.4) \times 10^5 \mathrm{cm}^{-3}$ to $(7 \pm 1) \times 10^7 \mathrm{cm}^{-3}$. The density model predicts the field directions map, which fits the polarization map best within 1100 au, with standard deviation of angle differences 17°. In this region the DCF mean field strength is 0.7±0.2 mG and the envelope mass is supercritical, with ratio of mass to magnetic critical mass 1.5±0.4. The SFF field strength profile scales with the DCF field strength, from 60±10 μG to 4±1 mG. The spatial resolution of the SFF field strength estimate is finer than the DCF resolution by a factor ∼ 7, and the peak SFF field strength exceeds the DCF field strength by a factor ∼ 4.

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Cradle(s) of the Sun

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The Sun likely formed as part of a group of stars. A close stellar flyby by one of the solar siblings is probably responsible for the sharp outer edge in the solar system's mass distribution. The frequency of such close flybys can be used to determine the likely type of birth environment of the solar system. Young stellar groups develop very quickly, expanding significantly within just a few Myr. Here we model this strong dynamical development of young stellar groups and determine the resulting close flyby history. We find that solar system equivalents are predominantly produced in areas with stellar densities in the range $5 \times 10^4 \mathrm{pc}^{-3} < n_{local} < 2 \times 10^5 \mathrm{pc}^{-3}$. Remarkably we find that only two very distinct types of stellar groups can be considered as serious contestants as the cradle of the Sun — high-mass, extended associations ($M_c > 20\,000\ M_\odot$) and intermediate-mass mass, compact clusters ($M_c < 3000\ M_\odot$). Current day counterparts would be the association NGC 2244 and the M44 cluster, respectively. In these two types of stellar groups, close flybys take place at a sufficiently high rate, while not being too destructive either. A final decision between these two remaining options will require incorporation of constraints from cosmo-chemical studies.

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X-ray irradiation and evaporation of the four young planets around V1298 Tau

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Planets around young stars are thought to undergo atmospheric evaporation due to the high magnetic activity of the host stars. Here we report on X-ray observations of V1298 Tau, a young star with four transiting exoplanets. We use X-ray observations of the host star with Chandra and ROSAT to measure the current high-energy irradiation level of the planets, and employ a model for the stellar activity evolution together with exoplanetary mass loss to estimate the possible evolution of the planets. We find that V1298 Tau is X-ray bright with $\log L_X [\mathrm{erg\ s}^{-1}] = 30.1$ and has a mean coronal temperature of ≈9 MK. This places the star amongst the more X-ray luminous ones at this stellar age. We estimate the radiation-driven mass loss of the exoplanets, and find that it depends sensitively on the possible evolutionary spin-down tracks of the star as well as on the current planetary densities. Assuming the planets are of low density due to their youth, we find that the innermost two planets can lose significant parts of their gaseous envelopes, and could be evaporated down to their rocky cores depending on the stellar spin evolution. However, if the planets are heavier and follow the mass-radius relation of older planets, then even in the highest XUV irradiation scenario none of the planets is expected to cross the radius gap into the rocky regime until the system reaches an age of 5 Gyr.

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Illuminating a tadpole's metamorphosis II: observing the on-going transformation with ALMA

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We present new Atacama Large Millimeter/submillimeter Array (ALMA) observations of the tadpole, a small globule in the Carina Nebula that hosts the HH 900 jet+outflow system. Our data include ^{12}CO, ^{13}CO, C^{18}O J=2-1, ^{13}CO, C^{18}O J=3-2, and serendipitous detections of DCN J=3-2 and CS J=7-6. With angular resolution comparable to the *Hubble Space Telescope (HST)*, our data reveal for the first time the bipolar molecular outflow in CO, seen only inside the globule, that is launched from the previously unseen jet-driving protostar (the HH 900 YSO). The biconical morphology joins smoothly with the externally irradiated outflow seen in ionized gas tracers outside the globule, tracing the overall morphology of a jet-driven molecular outflow. Continuum emission at the location of the HH 900 YSO appears to be slightly flattened perpendicular to outflow axis. Model fits to the continuum have a best-fit spectral index of ~ 2, suggesting cold dust and the onset of grain growth. In position-velocity space, ^{13}CO and C^{18}O gas kinematics trace a C-shaped morphology, similar to infall profiles seen in other sources, although the global dynamical behaviour of the gas remains unclear. Line profiles of the CO isotopologues display features consistent with externally heated gas. We estimate a globule mass of ~ 1.9 M$_\odot$, indicating a remaining lifetime of ~ 4 Myr, assuming a constant photoevaporation rate. This long globule lifetime will shield the disk from external irradiation perhaps prolonging its life and enabling planet formation in regions where disks are typically rapidly destroyed.

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DC$_3$N observations towards high-mass star-forming regions

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We present the study of deuteration of cyanoacetylene (HC_3N) towards a sample of 28 high-mass star-forming cores divided into different evolutionary stages, from starless to evolved protostellar cores. We report for the first time the detection of DC_3N towards 15 high-mass cores. The abundance ratios of DC_3N with respect HC_3N range in the interval 0.003−0.022, lower than those found in low-mas protostars and dark clouds. No significant trend with the evolutionary stage, or with the kinetic temperature of the region, has been found. We compare the level of deuteration of HC_3N with those of other molecules towards the same sample, finding weak correlation with species formed only or predominantly in gas-phase (N_2H^+ and HNC, respectively), and no correlation with species formed only or predominantly on dust grains (CH_3OH and NH_3, respectively). We also present a single-dish map of DC_3N towards the protocluster IRAS 05358+3543, which shows that DC_3N traces an extended envelope ($\sim$0.37 pc) and peaks towards two cold condensations separated from the positions of the protostars and the dust continuum. The observations presented in this work suggest that deuteration of HC_3N is produced in the gas of the cold outer parts of massive star-forming clumps, giving us an estimate of the deuteration factor prior to the formation of denser gas.

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A 3D view of the Taurus star-forming region by Gaia and Herschel: multiple populations related to the filamentary molecular cloud

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Context. Taurus represents an ideal region to study the three-dimensional distribution of the young stellar population and relate it to the associated molecular cloud.
Aims. The second Gaia data release (DR2) enables us to investigate the Taurus complex in three dimensions, starting from a previously defined robust membership. The molecular cloud structured in filaments can be traced in emission using the public far-infrared maps from Herschel.
Methods. From a compiled catalog of spectroscopically confirmed members, we analyze the 283 sources with reliable parallax and proper motions in the Gaia DR2 archive. We fit the distribution of parallaxes and proper motions with multiple populations described by multivariate Gaussians. We compute the cartesian Galactic coordinates (X,Y,Z) and, for the populations associated with the main cloud, also the galactic space velocity (U,V,W). We discuss the spatial distribution of the populations in relation to the structure of the filamentary molecular cloud traced by Herschel.
Results. We discover the presence of six populations which are all well defined in parallax and proper motions, with the only exception being Taurus D. The derived distances range between 130 and 160 pc. We do not find a unique relation between stellar population and the associated molecular cloud: while the stellar population seems to be on the cloud surface, both lying at similar distances, this is not the case when the molecular cloud is structured in filaments. Taurus B is probably moving in the direction of Taurus A, while Taurus E appears to be moving towards them.
Conclusions. The Taurus region is the result of a complex star formation history which most probably occurred in clumpy and filamentary structures that are evolving independently.

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Tracking the evolutionary stage of protostars by the abundances of astrophysical ices

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The physical evolution of Young Stellar Objects (YSOs) is accompanied by an enrichment of the molecular complexity, mainly triggered by the heating and energetic processing of the astrophysical ices. In this paper, a study of how the ice column density varies across the protostellar evolution has been performed. Tabulated data of H_2O, CO_2, CH_3OH, HCOOH observed by ground- and space-based telescopes toward 27 early-stage YSOs were taken from the literature. The observational data shows that ice column density and spectral index (α), used to classify the evolutionary stage, are well correlated. A 2D continuum radiative transfer simulation containing bare and grains covered by ices at different levels of cosmic-ray processing were used to calculate the Spectral Energy Distributions (SEDs) in different angle inclinations between face-on and edge-on configuration. The H_2O:CO_2 ice mixture was used to address the H_2O and CO_2 column density variation whereas the CH_3OH and HCOOH are a byproduct of the virgin ice after the energetic processing. The simulated spectra were used to calculate the ice column densities of YSOs in an evolutionary sequence. As a result, the models show that the ice column density variation of HCOOH with α can be justified by the envelope dissipation and ice energetic processing. On the other hand, the ice column densities are mostly overestimated in the cases of H_2O, CO_2 and CH_3OH, even though the physical and cosmic-ray processing effects are taken into account.

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$C^{18}O$, ^{13}CO, and ^{12}CO abundances and excitation temperatures in the Orion B molecular cloud: An analysis of the precision achievable when modeling spectral line within the Local Thermodynamic Equilibrium approximation

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CO isotopologue transitions are routinely observed in molecular clouds to probe the column density of the gas, the elemental ratios of carbon and oxygen, and to trace the kinematics of the environment. We aim at estimating the abundances, excitation temperatures, velocity field and velocity dispersions of the three main CO isotopologues towards a subset of the Orion B molecular cloud. We use the Cramer Rao Bound (CRB) technique to analyze and estimate the precision of the physical parameters in the framework of local-thermodynamic-equilibrium excitation and radiative transfer with an additive white Gaussian noise. We propose a maximum likelihood estimator to infer the physical conditions from the 1–0 and 2–1 transitions of CO isotopologues. Simulations show that this estimator is unbiased and efficient for a common range of excitation temperatures and column densities ($T_{\rm ex} > 6$ K, $N > 1\times10^{14}$–1×10^{15} cm^{-2}). Contrary to the general assumptions, the different CO isotopologues have distinct excitation temperatures, and the line intensity ratios between different isotopologues do not accurately reflect the column density ratios. We find mean fractional abundances that are consistent with previous determinations towards other molecular clouds. However, significant local deviations are inferred, not only in regions exposed to UV radiation field but also in shielded regions. These deviations result from the competition between selective photodissociation, chemical fractionation, and depletion on grain surfaces. We observe that the velocity dispersion of the $C^{18}O$ emission is 10% smaller than that of ^{13}CO. The substantial gain resulting from the simultaneous analysis of two different rotational transitions of the same species is rigorously quantified. The CRB technique is a promising avenue for analyzing the estimation of physical parameters from the fit of spectral lines.

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Erosion of planetesimals by gas flow

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The first stages of planet formation take place in protoplanetary disks that are largely made up of gas. Understanding how the gas affects planetesimals in the protoplanetary disk is therefore essential. In this paper, we discuss whether or not gas flow can erode planetesimals. We estimate how much shear stress is exerted onto the planetesimal surface by the gas as a function of disk and planetesimal properties. To determine whether erosion can take place, we compare this with previous measurements of the critical stress that a pebble-pile planetesimal can withstand before erosion begins. If erosion takes place, we estimate the erosion time of the affected planetesimals. We also illustrate our estimates with two-dimensional numerical simulations of flows around planetesimals using the lattice Boltzmann method. We find that the wall shear stress can overcome the critical stress of planetesimals in an eccentric orbit within the innermost regions of the disk. The high eccentricities needed to reach erosive stresses could be the result of shepherding by migrating planets. We also find that if a planetesimal erodes, it does so on short timescales. For planetesimals residing outside of 1 au, we find that they are mainly safe from erosion, even in the case of highly eccentric orbits.

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Gaia 18dvy: a new FUor in the Cygnus OB3 association

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We present optical-infrared photometric and spectroscopic observations of Gaia 18dvy, located in the Cygnus OB3 association at a distance of 1.88 kpc. The object was noted by the Gaia alerts system when its lightcurve exhibited a $\gtrsim$4 mag rise in 2018-2019. The brightening was also observable at mid-infared wavelengths. The infrared colors of Gaia 18dvy became bluer as the outburst progressed. Its optical and near-infrared spectroscopic characteristics in the outburst phase are consistent with those of bona fide FU Orionis-type young eruptive stars. The progenitor of the outburst is probably a low-mass K-type star with an optical extinction of $\sim$3 mag. A radiative transfer modeling of the circumstellar structure, based on the quiescent spectral energy distribution, indicates a disk with a mass of $4\times10^{-3}\,M_\odot$. Our simple accretion disk modeling implies that the accretion rate had been exponentially increasing for more than 3 years until mid-2019, when it reached a peak value of $6.9 \times 10^{-6}\,M_\odot\mathrm{yr}^{-1}$. In many respects, Gaia 18dvy is similar to the FU Ori-type object HBC 722.

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Chemical composition in the IRAS 16562–3959 high-mass star-forming region

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We have analyzed the Atacama Large Millimeter/submillimeter Array (ALMA) cycle 2 data of band 6 toward the G345.4938+01.4677 massive young protostellar object (G345.5+1.47 MYSO) in the IRAS 16562–3959 high-mass star-forming region with an angular resolution of ~ 0.3 arcsec, corresponding to ~ 760 au. We spatially resolve the central region which consists of three prominent molecular emission cores. A hypercompact (HC) HII region (Core A) and two molecule-rich cores (Core B and Core C) are identified using the moment zero images of the H30α line and a CH_3OH line, respectively. Various oxygen-bearing complex organic molecules (COMs), such as $(CH_3)_2CO$ and CH_3OCHO, have been detected toward the positions of Core B and Core C, while nitrogen-bearing species, CH_3CN, HC_3N and its ^{13}C isotopologues, have been detected toward all of the cores. We discuss the formation mechanisms of H_2CO by comparing the spatial distribution of $C^{18}O$ with that of H_2CO. The ^{33}SO emission, on the other hand, shows a ring-like structure surrounding Core A, and it peaks on the outer edge of the H30α emission region. These results imply that SO is enhanced in a shock produced by the expanding motion of the ionized region.

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Observed sizes of planet-forming disks trace viscous evolution

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The evolution of protoplanetary disks is dominated by the conservation of angular momentum, where the accretion of material onto the central star is driven by viscous expansion of the outer disk or by disk winds extracting angular momentum without changing the disk size. Studying the time evolution of disk sizes allows us therefore to distinguish between viscous stresses or disk winds as the main mechanism of disk evolution. Observationally, estimates of the disk gaseous outer radius are based on the extent of the CO rotational emission, which, during the evolution, is also affected by the changing physical and chemical conditions in the disk. We use physical-chemical DALI models to study how the extent of the CO emission changes with time in a viscously expanding disk and investigate to what degree this observable gas outer radius is a suitable tracer of viscous spreading and whether current observations are consistent with viscous evolution. We find that the gas outer radius ($R_{\mathrm{CO,\ 90\%}}$) measured from our models matches the expectations of a viscously spreading disk: $R_{\mathrm{CO,\ 90\%}}$ increases with time and for a given time $R_{\mathrm{CO,\ 90\%}}$ is larger for a disk with a higher viscosity α_{visc}. However, in the extreme case where the disk mass is low (less than 10^{-4} $\mathrm{M}_{\odot}$) and α_{visc} is high (larger than 10^{-2}), $R_{\mathrm{CO,\ 90\%}}$ will instead decrease with time as a result of CO photodissociation in the outer disk. For most disk ages $R_{\mathrm{CO,\ 90\%}}$ is up to $12\times$ larger than the characteristic size R_{c} of the disk, and $R_{\mathrm{CO,\ 90\%}}/R_{\mathrm{c}}$ is largest for the most massive disk. As a result of this difference, a simple conversion of $R_{\mathrm{CO,\ 90\%}}$ to α_{visc} will overestimate the true α_{visc} of the disk by up to an order of magnitude. We find that most observed gas outer radii in Lupus can be explained using a viscously evolving disk that starts out small ($R_{\mathrm{c}} = 10$ AU) and has a low viscosity ($\alpha_{\mathrm{visc}} = 10^{-4} - 10^{-3}$).

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Complex organic molecules in low-mass protostars on solar system scales – I. Oxygen-bearing species

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Context. Complex organic molecules (COMs) are thought to form on icy dust grains in the earliest phase of star formation. The evolution of these COMs from the youngest Class 0/I protostellar phases toward the more evolved Class II phase is still not fully understood. Since planet formation seems to start early, and mature disks are too cold for characteristic COM emission lines, studying the inventory of COMs on solar system scales in the Class 0/I stage is relevant.
Aims. The aim is to determine the abundance ratios of oxygen-bearing COMs in Class 0 protostellar systems on scales of ∼100 AU radius. These abundances will be inter-compared, and contrasted to other low-mass protostars such as IRAS16293-2422B and HH 212. Additionally, using both cold and hot COM lines, the gas-phase abundances can be tracked from a cold to a hot component, and ultimately be compared with those in ices to be measured with the *James Webb Space Telescope* (JWST). The abundance of deuterated methanol allows us to probe the ambient temperature during the formation of this species.
Methods. ALMA Band 3 (3 mm) and Band 6 (1 mm) observations are obtained of seven Class 0 protostars in the Perseus and Serpens star-forming regions. By modeling the inner protostellar region using 'LTE' models, the excitation temperature and column densities are determined for several O-bearing COMs including methanol (CH_3OH), acetaldehyde (CH_3CHO), methyl formate (CH_3OCHO), and dimethyl ether (CH_3OCH_3). Abundance ratios are taken with respect to CH_3OH.
Results. B1-c and B1-bS (both Perseus) and Serpens S68N (Serpens) show COM emission, i.e., three out of the seven of the observed sources. No clear correlation seems to exist between the occurrence of COMs and source luminosity. The abundances of several COMs such as CH_3OCHO, CH_3OCH_3, acetone (CH_3COCH_3), and ethylene glycol ($(CH_2OH)_2$) are remarkably similar for the three COM-rich sources, and to IRAS 16293-2422B and HH 212, even though these sources originate from four different star-forming regions (i.e., Perseus, Serpens, Ophiuchus, Orion). For other COMs like CH_3CHO, ethanol (CH_3CH_2OH), and glycolaldehyde (CH_2OHCHO), the abundances differ by up to an order of magnitude, indicating that local source conditions are case determining. B1-c hosts a cold ($T_{\rm ex} \approx 60$ K), more extended component of COM emission with a column density of typically a few % of the warm/hot ($T_{\rm ex} \sim 200$ K), central component. A D/H ratio of 1–3 % is derived for B1-c, S68N, and B1-bS based on the CH_2DOH/CH_3OH ratio (taking into account statistical weighting) suggesting a temperature of ∼15 K during the formation of methanol. This ratio is consistent with other low-mass protostars, but lower than for high-mass star-forming regions.
Conclusions. The abundance ratios of most O-bearing COMs are roughly fixed between different star-forming regions, and are presumably set at an earlier cold prestellar phase. For several COMs, local source properties become important. Future mid-infrared facilities such as JWST/MIRI will be essential to directly observe COM ices. Combining this with a larger sample of COM-rich sources with ALMA will allow for directly linking ice and gas-phase abundances in order to constrain the routes that produce and maintain chemical complexity during the star formation process.

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Is the gap in the DS Tau disc hiding a planet?

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Recent mm-wavelength surveys performed with the Atacama Large Millimeter Array (ALMA) have revealed pro-

toplanetary discs characterized by rings and gaps. A possible explanation for the origin of such rings is the tidal interaction with an unseen planetary companion. The protoplanetary disc around DS Tau shows a wide gap in the ALMA observation at 1.3 mm. We construct a hydrodynamical model for the dust continuum observed by ALMA assuming the observed gap is carved by a planet between one and five Jupiter masses. We fit the shape of the radial intensity profile along the disc major axis varying the planet mass, the dust disc mass, and the evolution time of the system. The best fitting model is obtained for a planet with $M_{\rm p} = 3.5\ M_{\rm Jup}$ and a disc with $M_{\rm dust} = 9.6 \times 10^{-5}\ M_{\odot}$. Starting from this result, we also compute the expected signature of the planet in the gas kinematics, as traced by CO emission. We find that such a signature (in the form of a "kink" in the channel maps) could be observed by ALMA with a velocity resolution between 0.2–0.5 km s^{-1} and a beam size between 30 and 50 mas.

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Catalogue of new Herbig Ae/Be and classical Be stars. A machine learning approach to Gaia DR2

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The intermediate-mass pre-main sequence Herbig Ae/Be stars are key to understanding the differences in formation mechanisms between low- and high-mass stars. The study of the general properties of these objects is hampered by the fact that few and mostly serendipitously discovered sources are known. Our goal is to identify new Herbig Ae/Be candidates to create a homogeneous and well defined catalogue of these objects. We have applied machine learning techniques to 4,150,983 sources with data from Gaia DR2, 2MASS, WISE, and IPHAS or VPHAS+. Several observables were chosen to identify new Herbig Ae/Be candidates based on our current knowledge of this class, which is characterised by infrared excesses, photometric variabilities, and Hα emission lines. Classical techniques are not efficient for identifying new Herbig Ae/Be stars mainly because of their similarity with classical Be stars, with which they share many characteristics. By focusing on disentangling these two types of objects, our algorithm has also identified new classical Be stars. We have obtained a large catalogue of 8470 new pre-main sequence candidates and another catalogue of 693 new classical Be candidates with a completeness of 78.8±1.4% and 85.5±1.2%, respectively. Of the catalogue of pre-main sequence candidates, at least 1361 sources are potentially new Herbig Ae/Be candidates according to their position in the Hertzsprung-Russell diagram. In this study we present the methodology used, evaluate the quality of the catalogues, and perform an analysis of their flaws and biases. For this assessment, we make use of observables that have not been accounted for by the algorithm and hence are selection-independent, such as coordinates and parallax based distances. The catalogue of new Herbig Ae/Be stars that we present here increases the number of known objects of the class by an order of magnitude.

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Thermal evolution of protoplanetary disks: from β-cooling to decoupled gas and dust temperatures

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We explore the long-term evolution of young protoplanetary disks with different approaches to computing the thermal structure determined by various cooling and heating processes in the disk and its surroundings. Numerical hydro-

dynamics simulations in the thin-disk limit were complemented with three thermal evolution schemes: a simplified β-cooling approach with and without irradiation, where the rate of disk cooling is proportional to the local dynamical time; a fiducial model with equal dust and gas temperatures calculated taking viscous heating, irradiation, and radiative cooling into account; and a more sophisticated approach allowing decoupled dust and gas temperatures. We found that the gas temperature may significantly exceed that of dust in the outer regions of young disks thanks to additional compressional heating caused by the infalling envelope material in the early stages of disk evolution and slow collisional exchange of energy between gas and dust in low-density disk regions. However, the outer envelope shows an inverse trend, with the gas temperatures dropping below that of dust. The global disk evolution is only weakly sensitive to temperature decoupling. Nevertheless, separate dust and gas temperatures may affect the chemical composition, dust evolution, and disk mass estimates. Constant-β models without stellar and background irradiation fail to reproduce the disk evolution with more sophisticated thermal schemes because of the intrinsically variable nature of the β-parameter. Constant-β models with irradiation more closely match the dynamical and thermal evolution, but the agreement is still incomplete. Models allowing separate dust and gas temperatures are needed when emphasis is placed on the chemical or dust evolution in protoplanetary disks, particularly in subsolar metallicity environments.

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A Study of Millimeter Variability in FUor Objects

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FU Orionis objects (FUors) are rapidly-accreting, pre-main sequence objects that are known to exhibit large outbursts at optical and near-infrared wavelengths, with post-eruption, small-scale photometric variability superimposed on longer-term trends. In contrast, little is known about the variability of FUors at longer wavelengths. To explore this further, we observed six FUor objects using the NOrthern Extended Millimeter Array (NOEMA) and for a subset of three objects we obtained coordinated observations with NOEMA and the Lowell Discovery Telescope (LDT). In combination with previously published NOEMA observations from 2014, our 2017 observations of V1735 Cyg provide the first detection of variability in an FUor object at 2.7 mm. In the absence of significant optical variability, we discount the possibility that the mm flux density changed as a result of irradiation from the central disk. In addition, a change in the dust mass due to infall is highly unlikely. A plausible explanation for the change in 2.7 mm flux density is variability in free-free emission due to changes in the object's jet/wind. Thus, it may be that free-free emission in some FUor objects is significant at $\sim$3 mm and must be considered when deriving disk masses in order to help constrain the mechanism responsible for triggering FUor outbursts.

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Non-ideal magnetohydrodynamics vs turbulence I: Which is the dominant process in protostellar disc formation?

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Non-ideal magnetohydrodynamics (MHD) is the dominant process. We investigate the effect of magnetic fields (ideal and non-ideal) and turbulence (sub- and transsonic) on the formation of circumstellar discs that form nearly simultaneously with the formation of the protostar. This is done by modelling the gravitational collapse of a 1 $M_\odot$ gas cloud that is threaded with a magnetic field and imposed with both rotational and turbulent velocities. We investigate magnetic fields that are parallel/anti-parallel and perpendicular to the rotation axis, two rotation rates and four Mach numbers. Disc formation occurs preferentially in the models that include non-ideal MHD where the magnetic field is anti-parallel or perpendicular to the rotation axis. This is independent of the initial rotation rate and level of turbulence, suggesting that subsonic turbulence plays a minimal role in influencing the formation of discs. Aside from first core outflows which are influenced by the initial level of turbulence, non-ideal MHD processes are more important than turbulent processes during the formation of discs around low-mass stars.

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Non-ideal magnetohydrodynamics vs turbulence II: Which is the dominant process in stellar core formation?

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Non-ideal magnetohydrodynamics (MHD) is the dominant process. We investigate the effect of magnetic fields (ideal and non-ideal) and turbulence (sub- and transsonic) on the formation of protostars by following the gravitational collapse of 1 $M_\odot$ gas clouds through the first hydrostatic core to stellar densities. The clouds are imposed with both rotational and turbulent velocities, and are threaded with a magnetic field that is parallel/anti-parallel or perpendicular to the rotation axis; we investigate two rotation rates and four Mach numbers. The initial radius and mass of the stellar core are only weakly dependent on the initial parameters. In the models that include ideal MHD, the magnetic field strength implanted in the protostar at birth is much higher than observed, independent of the initial level of turbulence; only non-ideal MHD can reduce this strength to near or below the observed levels. This suggests that not only is ideal MHD an incomplete picture of star formation, but that the magnetic fields in low mass stars are implanted later in life by a dynamo process. Non-ideal MHD suppresses magnetically launched stellar core outflows, but turbulence permits thermally launched outflows to form a few years after stellar core formation.

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The role of Galactic H II regions in the formation of filaments
High-resolution submilimeter imaging of RCW 120 with ArTéMiS

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Massive stars and their associated ionized (H II) regions could play a key role in the formation and evolution of filaments that host star formation. However, the properties of filaments that interact with H II regions are still poorly known.
To investigate the impact of H II regions on the formation of filaments, we imaged the Galactic H II region RCW 120 and its surroundings where active star formation takes place and where the role of ionization feedback on the star formation process has already been studied.
We used the large-format bolometer camera ArTéMiS on the APEX telescope and combined the high-resolution ArTéMiS data at 350 μm and 450 μm with *Herschel*-SPIRE/HOBYS data at 350 and 500 μm to ensure good sensitivity to a broad range of spatial scales. This allowed us to study the dense gas distribution around RCW 120 with a resolution of 8 *arcsec* or 0.05 pc at a distance of 1.34 kpc.
Our study allows us to trace the median radial intensity profile of the dense shell of RCW 120. This profile is asymmetric, indicating a clear compression from the H II region on the inner part of the shell. The profile is observed to be similarly asymmetric on both lateral sides of the shell, indicating a homogeneous compression over the surface. On the contrary, the profile analysis of a radial filament associated with the shell, but located outside of it, reveals a symmetric profile, suggesting that the compression from the ionized region is limited to the dense shell. The mean intensity profile of the internal part of the shell is well fitted by a Plummer-like profile with a deconvolved Gaussian full width at half maximum (FWHM) of 0.09 pc, as observed for filaments in low-mass star-forming regions.
Using ArTéMiS data combined with *Herschel*-SPIRE data, we found evidence for compression from the inner part of the RCW 120 ionized region on the surrounding dense shell. This compression is accompanied with a significant (factor 5) increase of the local column density. This study suggests that compression exerted by H II regions may play a key role in the formation of filaments and may further act on their hosted star formation. ArTéMiS data also suggest that RCW 120 might be a 3D ring, rather than a spherical structure.

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http://arxiv.org/pdf/2004.05604

Abstracts of recently accepted major reviews

Star clusters near and far; tracing star formation across cosmic time

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Star clusters are fundamental units of stellar feedback and unique tracers of their host galactic properties. In this review, we will first focus on their constituents, i.e. detailed insight into their stellar populations and their surrounding ionised, warm, neutral, and molecular gas. We, then, move beyond the Local Group to review star cluster populations at various evolutionary stages, and in diverse galactic environmental conditions accessible in the local Universe. At high redshift, where conditions for cluster formation and evolution are more extreme, we are only able to observe the integrated light of a handful of objects that we believe will become globular clusters. We therefore discuss how numerical and analytical methods, informed by the observed properties of cluster populations in the local Universe, are used to develop sophisticated simulations potentially capable of disentangling the genetic map of galaxy formation and assembly that is carried by globular cluster populations.

Accepted by Space Science Reviews

http://arxiv.org/pdf/2005.06188

Physical Processes in Star Formation

Philipp Girichidis[1], Stella S.R. Offner[2], Alexei G. Kritsuk[3], Ralf S. Klessen[4], Patrick Hennebelle[5,6] et al.

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Star formation is a complex multi-scale phenomenon that is of significant importance for astrophysics in general. Stars and star formation are key pillars in observational astronomy from local star forming regions in the Milky Way up to high-redshift galaxies. From a theoretical perspective, star formation and feedback processes (radiation, winds, and supernovae) play a pivotal role in advancing our understanding of the physical processes at work, both individually and of their interactions. In this review we will give an overview of the main processes that are important for the understanding of star formation. We start with an observationally motivated view on star formation from a global perspective and outline the general paradigm of the life-cycle of molecular clouds, in which star formation is the key process to close the cycle. After that we focus on the thermal and chemical aspects in star forming regions, discuss turbulence and magnetic fields as well as gravitational forces. Finally, we review the most important stellar feedback mechanisms.

Accepted by Space Science Reviews

http://arxiv.org/pdf/2005.06472

The Physics of Star Cluster Formation and Evolution

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Star clusters form in dense, hierarchically collapsing gas clouds. Bulk kinetic energy is transformed to turbulence with stars forming from cores fed by filaments. In the most compact regions, stellar feedback is least effective in removing the gas and stars may form very efficiently. These are also the regions where, in high-mass clusters, ejecta from some kind of high-mass stars are effectively captured during the formation phase of some of the low mass stars and effectively channeled into the latter to form multiple populations. Star formation epochs in star clusters are generally set by gas flows that determine the abundance of gas in the cluster. We argue that there is likely only one star formation epoch after which clusters remain essentially clear of gas by cluster winds. Collisional dynamics is important in this phase leading to core collapse, expansion and eventual dispersion of every cluster. We review recent developments in the field with a focus on theoretical work.

Accepted by Space Science Reviews Topical collection "Star formation"

http://arxiv.org/pdf/2005.00801

On the Mass Accretion Rates of Herbig Ae/Be Stars. Magnetospheric Accretion or Boundary Layer?

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Understanding how young stars gain their masses through disk-to-star accretion is of paramount importance in astrophysics. It affects our knowledge about the early stellar evolution, the disk lifetime and dissipation processes, the way the planets form on the smallest scales, or the connection to macroscopic parameters characterizing star-forming regions on the largest ones, among others. In turn, mass accretion rate estimates depend on the accretion paradigm assumed. For low-mass T Tauri stars with strong magnetic fields there is consensus that magnetospheric accretion (MA) is the driving mechanism, but the transfer of mass in massive young stellar objects with weak or negligible magnetic fields probably occurs directly from the disk to the star through a hot boundary layer (BL). The intermediate-mass Herbig Ae/Be (HAeBe) stars bridge the gap between both previous regimes and are still optically visible during the pre-main sequence phase, thus constituting a unique opportunity to test a possible change of accretion mode from MA to BL. This review deals with our estimates of accretion rates in HAeBes, critically discussing the different accretion paradigms. It shows that although mounting evidence supports that MA may extend to late-type HAes but not to early-type HBes, there is not yet a consensus on the validity of this scenario versus the BL one. Based on MA and BL shock modeling, it is argued that the ultraviolet regime could significantly contribute in the future to discriminating between these competing accretion scenarios.

Accepted by Galaxies (2020, 8, 39) in Special Issue "Star Formation in the Ultraviolet" (Ed. Jorick Vink)

http://arxiv.org/pdf/2005.01745

The UV Perspective of Low-Mass Star Formation

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The formation of low-mass stars in molecular clouds involves accretion disks and jets, which are of broad astrophysical interest. Accreting stars represent the closest examples of these phenomena. Star and planet formation are also intimately connected, setting the starting point for planetary systems like our own. The ultraviolet (UV) spectral range is particularly suited to study star formation, because virtually all relevant processes radiate at temperatures associated with UV emission processes or have strong observational signatures in the UV. In this review, we describe how UV observations provide unique diagnostics for the accretion process, the physical properties of the protoplanetary disk, and jets and outflows.

Accepted by Galaxies special issue: “Star Formation in the UV”

http://arxiv.org/pdf/2005.10031

Star Formation in the Ultraviolet

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With the launch of JWST and the upcoming installation of extremely large telescopes, the first galaxies in our Universe will finally be revealed. Their light will be dominated by massive stars, which peak in in the ultra-violet (UV) part of the electromagnetic spectrum. Star formation is the key driver of the evolution of our Universe. At young ages, within 10 Million years, both high and low mass stars generate complex UV emission processes which are poorly understood yet are vital for interpreting high red-shift line emission. For these reasons, the Hubble Space Telescope (HST) will devote 1000 orbits to obtaining a UV Legacy Library of Young Stars as Essential Standards (ULLYSES). The purpose of this Overview is to outline the basic physical principles driving UV emission processes from local (within 100 parsecs of) star formation, ranging from huge star-forming complexes containing hundreds of massive and very-massive stars (VMS), such as 30 Doradus (the Tarantula Nebula) in the neighbouring Magellanic Clouds (only 50 kpc away), to galaxies near and far, out to the epoch of Cosmic Reionization.

Accepted by Galaxies

http://arxiv.org/pdf/2005.01753

Meetings

Star Formation: From Clouds to Discs
A Tribute to the Career of Lee Hartmann

Due to the continuing restrictions in place with regard to COVID-19 (Coronavirus) and following the advice of the Irish Health Service Executive and the Dublin Institute for Advanced Studies, as organisers, we have decided to postpone the conference “Star Formation: From Clouds to Discs - A Tribute to the Career of Lee Hartmann”. With many countries and their academic institutes indefinitely restricting travel, we feel it is not possible to proceed in 2020. The conference will now take place on **16th - 19th August 2021**, in Malahide, County Dublin, Ireland.

Abstract submission and registration will be re-opened on 1st February 2021. Everyone who is interested in attending can submit a new registration form following the revised calendar. We look forward to welcoming everyone to Dublin in 2021.

For more details, please see: https://www.dias.ie/cloudstodiscs/

EPSC2020 conference – EXO3 session "From Protoplanetary Disks to Small Bodies, Planets, and their Atmospheres"

Dear colleagues,

we would like to bring to your attention the following session that will take place during the Europlanet Science Congress 2020 (www.epsc2020.eu), as part of the Exoplanets and Origins of Planetary Systems group:

EXO3
From Protoplanetary Disks to Small Bodies, Planets, and their Atmospheres

Since the discovery of the first exoplanet in 1995 more than 4000 exoplanets have been detected to date. This indicates that planet formation is a robust mechanism and nearly every star in our Galaxy should host a system of planets. However, many crucial questions about the origin of planets are still unanswered: How and when planets formed in the Solar System and in extra-solar systems? Are protoplanetary disks massive enough to form the planets cores? And what chemical composition do planets and primitive Solar System bodies inherit from their natal environment? Is the chemical composition passed unaltered from the earliest stages of the formation of a star to its disk and then to the bodies which assemble in the disk? Or does it reflects chemical processes occurring in the disk and/or during the planet formation process?

A viable way to answer these questions is to study the planets formation site, i.e. protoplanetary disks. In the recent years, the advent of ALMA and near-infrared/optical imagers aided by extreme adaptive optics revolutionised our comprehension of planet formation by providing unprecedented insights on the protoplanetary disks structure, both in its gaseous and solid components. The aim of this session is to review the latest results on protoplanetary disks; to foster a comparison with the recent outcomes of small bodies space missions (e.g. Rosetta, Dawn, Hayabusa 2, OSIRIS-REX) and ground-based observations; and to discuss how these will affect the current models of planet formation and can guide us to investigate the origin of planets and small bodies and of their chemical composition.

Deadlines & Milestones

- EPSC2020 will be held as a virtual meeting on 21 September - 9 October 2020.

- Abstract submission is due *** 24 June 2020, 13:00 CEST ***.

- Talks and posters will be announced on July 10.
- Talks and posters upload by September 7.

We would like to encourage all people interested in this topic to submit an abstract, in particular early career scientists.

For questions, you are welcome to contact Linda Podio (lpodio@arcetri.astro.it) or other members of the SOC.

Linda Podio, Mauro Ciarniello, Cecile Favre, Carlo Felice Manara, and Francesco Marzari

https://meetingorganizer.copernicus.org/EPSC2020/session/38481

Abstract submission deadline

The deadline for submitting abstracts and other submissions is the first day of the month. Abstracts submitted after the deadline will appear in the following month's issue.

Summary of Upcoming Meetings

Check the websites of these meetings for the latest information on how they are affected by Covid-19

Astrochemical Frontiers – Quarantine Edition
15 - 19 June 2020 via Zoom
https://sites.google.com/cfa.harvard.edu/astrochemicalfrontiers

Planet Formation: From Dust Coagulation to Final Orbital Assembly
1 - 26 June 2020, Munich, Germany
http://www.munich-iapp.de/planetformation

Illuminating the Dusty Universe: A Tribute to the Work of Bruce Draine
6 - 10 July 2020, Florence, Italy
https://web.astro.princeton.edu/IlluminatingTheDustyUniverse

The Early Phase of Star Formation
12 - 17 July 2020, Ringberg, Germany
http://www.mpia.de/homes/stein/EPoS/2020/2020.php

Star Formation in Different Environments 2020
24 - 28 August 2020, Quy Nhon, Vietnam
http://icisequynhon.com/conferences/sfde/

Planetary Science: The Young Solar System
6 - 12 September 2020, Quy Nhon, Vietnam
http://www.icisequynhon.com/conferences/planetary_science/

Wheel of Star Formation: A conference dedicated to Prof. Jan Palouš
14 - 18 September 2020, Prague, Czech Republic
https://janfest2020.asu.cas.cz

Conditions and Impact of Star Formation - Across Times and Scales
28 September - 2 October 2020, Chile
https://astro.uni-koeln.de/symposium-star-formation-2020.html

From Clouds to Planets II: The Astrochemical Link
28 September - 2 October 2020, Berlin, Germany
https://events.mpe.mpg.de/event/12/

The Aftermath of a Revolution: Planet Formation Five Years after HL Tau
7 - 11 December 2020, Chile
https://www.eso.org/sci/meetings/2020/hltau2020.html

Protostars & Planets VII
1 - 7 April 2021, Kyoto, Japan
http://www.ppvii.org

Cool Stars, Stellar Systems, and the Sun 21
postponed to summer 2021, Toulouse, France
https://coolstars21.github.io/

Star Formation: From Clouds to Discs - A Tribute to the Career of Lee Hartmann
16 - 19 August 2021, Malahide, Ireland
https://www.dias.ie/cloudstodiscs/

Chemical Processes in Solar-type Star Forming Regions
13 - 17 September 2021, Torino, Italy

https://sites.google.com/inaf.it/aco-conference

The Physics of Star Formation: From Stellar Cores to Galactic Scales
~June - July 2022, Lyon, France
http:/staratlyon.univ-lyon1.fr/en

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.