The Star Formation Newsletter

A community newsletter on Star and Planet Formation research

No. 340 — 21 April 2021
Editor: João Alves www.starformation.news

Links to sections

Interviews	Reviews	Perspective	Favorite objects	Archive
Meetings	Jobs	New PhDs	Announcements	Books

Cover image caption

Simulation of diffuse Interstellar Medium flows passing through a spiral shock (face-on view in the galactic disk). Colors represent velocity, from red (at about 20 to 30 km/s) to blue (at about −20 km/s). Gas enters the spiral arm from the bottom left with positive velocities of $10 - 30$ km/s, while gas already present in the arm has negative velocities. This produces a convergent flow and a shock of the order of 20 to 30 km/s (red color). The figure covers about 500 pc in x and y. Credit: Smilgys & Bonnell 2016.

Note from the Editor

The Star Formation Newsletter is now on the web at **www.starformation.news**. This PDF file contains the monthly Abstracts and links to the different Newsletter sections. Red text in this PDF is a url link. Submitting an abstract to the SFN is as simple as entering the arXiv ID (e.g., 2006.10139) in a web form on the SFN web site. We extract the title, authors, and the abstract's text directly from the arXiv, **so please do not remove the LaTeX formatting when submitting to the arXiv**. If you do, your abstract will not look great either at the arXiv (which uses MathJax to convert LaTeX math symbols to the web) or the SFN.

Abstracts

1. ALMA-IRDC: Dense gas mass distribution from cloud to core scales

A. T. Barnes, J. D. Henshaw, F. Fontani, J. E. Pineda, G. Cosentino, J. C. Tan, P. Caselli, I. Jiménez-Serra, C. Y. Law, A. Avison, F. Bigiel, S. Feng, S. Kong, S. N. Longmore, L. Moser, R. J. Parker, Á. Sánchez-Monge, K. Wang ★ Infrared dark clouds (IRDCs) are potential hosts of the elusive early phases of high-mass star formation (HMSF). Here we conduct an in-depth analysis of the fragmentation properties of a sample of 10 IRDCs, which have been highlighted as some of the best candidates to study HMSF within the Milky Way. To do so, we have obtained a set of large mosaics covering these IRDCs with ALMA at band 3 (or 3mm). These observations have a high angular resolution (3arcsec or 0.05pc), and high continuum and spectral line sensitivity (0.15mJy/beam and 0.2K per 0.1km/s channel at the N2H+(1-0) transition). From the dust continuum emission, we identify 96 cores ranging from low- to high-mass (M = 3.4 to 50.9 Msun) that are gravitationally bound (alpha$_{vir}$ = 0.3 to 1.3) and which would require magnetic field strengths of B = 0.3 to 1.0mG to be in virial equilibrium. We combine these results with a homogenised catalogue of literature cores to recover the hierarchical structure within these clouds over four orders of magnitude in spatial scale (0.01pc to 10pc). Using supplementary observations at an even higher angular resolution, we find that the smallest fragments (<0.02pc) within this hierarchy do not currently have the mass and/or the density required to form high-mass stars. Nonetheless, the new ALMA observations presented in this paper have facilitated the identification of 19 (6 quiescent and 13 star-forming) cores that retain >16Msun without further fragmentation. These high-mass cores contain trans-sonic non-thermal motions, are kinematically sub-virial, and require moderate magnetic field strengths for support against collapse. The identification of these potential sites of high-mass star formation represents a key step in allowing us to test the predictions from high-mass star and cluster formation theories.

2. Fragmentation and kinematics in high-mass star formation: CORE-extension targeting two very young high-mass star-forming regions

H. Beuther, C. Gieser, S. Suri, H. Linz, P. Klaassen, D. Semenov, J. M. Winters, Th. Henning, J. D. Soler, J. S. Urquhart, J. Syed, S . Feng, T. Moeller, M. T. Beltran, A. Sanchez-Monge, S. N. Longmore, T. Peters, J. Ballesteros-Paredes, P. Schilke, L. Moscadelli, A. Palau, R. Cesaroni, S. Lumsden, R. Pudritz, F. Wyrowski, R. Kuiper, A. Ahmadi ★ Context: The formation of high-mass star-forming regions from their parental gas cloud and the subsequent fragmentation processes lie at the heart of star formation research. Aims: We aim to study the dynamical and fragmentation properties at very early evolutionary stages of high-mass star formation. Methods: Employing the NOrthern

Extended Millimeter Array (NOEMA) and the IRAM 30m telescope, we observed two young high-mass star-forming regions, ISOSS22478 and ISOSS23053, in the 1.3mm continuum and spectral line emission at a high angular resolution (∼0.8"). Results: We resolved 29 cores that are mostly located along filament-like structures. Depending on the temperature assumption, these cores follow a mass-size relation of approximately $M \sim r^{2.0}$, corresponding to constant mean column densities. However, with different temperature assumptions, a steeper mass-size relation up to $M \sim r^{3.0}$, which would be more likely to correspond to constant mean volume densities, cannot be ruled out. The correlation of the core masses with their nearest neighbor separations is consistent with thermal Jeans fragmentation. We found hardly any core separations at the spatial resolution limit, indicating that the data resolve the large-scale fragmentation well. Although the kinematics of the two regions appear very different at first sight - multiple velocity components along filaments in ISOSS22478 versus a steep velocity gradient of more than 50km/s/pc in ISOSS23053 - the findings can be explained within the framework of a dynamical cloud collapse scenario. Conclusions: While our data are consistent with a dynamical cloud collapse scenario and subsequent thermal Jeans fragmentation, the importance of additional environmental properties, such as the magnetization of the gas or external shocks triggering converging gas flows, is nonetheless not as well constrained and would require future investigation.

3. SEDBYS: A python-based SED Builder for Young Stars

Claire L Davies ★ Spectral energy distributions (SEDs) are useful primary and complementary tools in the analysis of observations of young stars. However, the process of collating, inspecting, and flux-converting archival photometry and spectroscopy to build spectral energy distributions for young stars can be time-consuming. Here, I present SEDBYS (Spectral Energy Distribution Builder for Young Stars), a python-based repository of command-line tools built to (i) query online photometric and spectroscopic catalogs and a distributed database of archival photometry, (ii) use a look-up table of zero points to flux-convert the acquired data, (iii) enable visual inspection of the SED and (iv) handle book-keeping to collate references in bibTeX format. The code is distributed via git and is equipped with additional tools to enable users to add existing or forthcoming catalogs to the list of sources queried, ensuring the longevity of SEDBYS as a tool for the star formation community.

4. Magnetic fields and Star Formation around HII regions: The S235 complex

R. Devaraj, D. P. Clemens, L. K. Dewangan, A. Luna, T. P. Ray, J. Mackey ★ Magnetic fields are ubiquitous and essential in star formation. In particular, their role in regulating formation of stars across diverse environments like HII regions needs to be well understood. In this study, we present magnetic field properties towards the S235 complex using near-infrared (NIR) H-band polarimetric observations, obtained with the Mimir and POLICAN instruments. We selected 375 background stars in the field through combination of Gaia distances and extinctions from NIR colors. The plane-of-sky (POS) magnetic field orientations inferred from starlight polarization angles reveal a curved morphology tracing the spherical shell of the HII region. The large-scale magnetic field traced by Planck is parallel to the Galactic plane. We identified 11 dense clumps using 1.1 mm dust emission, with masses between $33 - 525\,M_\odot$. The clump averaged POS magnetic field strengths were estimated to be between $36 - 121\,\mu$G, with a mean of $\sim 65\,\mu$G. The mass-to-flux ratios for the clumps are found to be sub-critical with turbulent Alfvén Mach numbers less than 1, indicating a strongly magnetized region. The clumps show scaling of magnetic field strength vs density with a power-law index of 0.52 ± 0.07, similar to ambipolar diffusion models. Our results indicate the S235 complex is a region where stellar feedback triggers new stars and the magnetic fields regulate the rate of new star formation.

5. Unraveling the inner substructure of new candidate hub-filament system in the HII region G25.4NW

L. K. Dewangan ★ We present multi-scale and multi-wavelength data of the Galactic HII region G25.4-0.14 (hereafter G25.4NW, distance 5.7 kpc). The SHARC-II 350 micron continuum map displays a hub-filament configuration containing five parsec scale filaments and a central compact hub. Through the 5 GHz radio continuum map, four ionized clumps (i.e., Ia-Id) are identified toward the central hub, and are powered by massive OB-stars. The Herschel temperature map depicts the warm dust emission (i.e., Td 23-39 K) toward the hub. High resolution Atacama Large Millimeter/submillimeter Array (ALMA) 1.3 mm continuum map (resolution 0".82 X 0".58) reveals three cores (c1-c3; mass 80-130 Msun) toward the ionized clumps Ia, and another one (c4; mass 70 Msun) toward the ionized clump Ib. A compact near-infrared (NIR) emission feature (extent 0.2 pc) is investigated toward the ionized clump Ia excited by an O8V-type star, and contains at least three embedded K-band stars. In the direction of the ionized clump Ia, the ALMA map also shows an elongated feature (extent 0.2 pc) hosting the cores c1-c3. All these findings together illustrate the existence of a small cluster of massive stars in the central hub. Considering the detection of the hub-filament morphology and the spatial locations of the mm cores, a global non-isotropic collapse (GNIC) scenario appears to be applicable in G25.4NW, which includes the basic ingredients of the global hierarchical collapse and clump-fed accretion models. Overall, the GNIC scenario explains the birth of massive stars in G25.4NW.

1.

6. The Hi-GAL compact source catalogue – II. The 360° catalogue of clump physical properties

D. Elia, M. Merello, S. Molinari, E. Schisano, A. Zavagno, D. Russeil, P. Mège, P. G. Martin, L. Olmi, M. Pestalozzi, R. Plume, S. E. Ragan, M. Benedettini, D. J. Eden, T. J. T. Moore, A. Noriega-Crespo, R. Paladini, P. Palmeirim, S. Pezzuto, G. L. Pilbratt, K. L. J. Rygl, P. Schilke, F. Strafella, J. C. Tan, A. Traficante, A. Baldeschi, J. Bally, A. M. di Giorgio, E. Fiorellino, S. J. Liu, L. Piazzo, D. Polychroni ★ We present the 360° catalogue of physical properties of Hi-GAL compact sources, detected between 70 and 500 μm. This release not only completes the analogous catalogue previously produced by the Hi-GAL collaboration for $-71^\circ \lesssim \ell \lesssim 67^\circ$, but also meaningfully improves it thanks to a new set of heliocentric distances, 120808 in total. About a third of the 150223 entries are located in the newly added portion of the Galactic plane. A first classification based on detection at 70 μm as a signature of ongoing star-forming activity distinguishes between protostellar sources (23 per cent of the total) and starless sources, with the latter further classified as gravitationally bound (pre-stellar) or unbound. The integral of the spectral energy distribution, including ancillary photometry from $\lambda = 21$ to 1100 μm, gives the source luminosity and other bolometric quantities, while a modified black body fitted to data for $\lambda \geq 160\,\mu$m yields mass and temperature. All tabulated clump properties are then derived using photometry and heliocentric distance, where possible. Statistics of these quantities are discussed with respect to both source Galactic location and evolutionary stage. No strong differences in the distributions of evolutionary indicators are found between the inner and outer Galaxy. However, masses and densities in the inner Galaxy are on average significantly larger, resulting in a higher number of clumps that are candidates to host massive star formation. Median behaviour of distance-independent parameters tracing source evolutionary status is examined as a function of the Galactocentric radius, showing no clear evidence of correlation with spiral arm positions.

7. Launching the asymmetric bipolar jet of DO Tau

J. Erkal, C. Dougados, D. Coffey, S. Cabrit, F. Bacciotti, R. Garcia-Lopez, D. Fedele, A. Chrysostomou ★ The role of bipolar jets in the formation of stars, and in particular how they are launched, is still not well understood. We probe the protostellar jet launching mechanism, via high resolution observations of the near-IR [FeII] 1.53,1.64 micron lines. We consider the bipolar jet from the Classical T Tauri star, DO Tau, investigate jet morphology and kinematics close to the star, using AO-assisted IFU observations from GEMINI/NIFS. The brighter, blue-shifted jet is collimated quickly after launch. This early collimation requires the presence of magnetic fields. We confirm velocity asymmetries between the two jet lobes, and confirm no time variability in the asymmetry over a 20 year interval. This sustained asymmetry is in accordance with recent simulations of magnetised disk-winds. We examine the data for jet rotation. We report an upper limit on differences in radial velocity of 6.3 and 8.7 km/s for the blue and red-shifted jets, respectively. Interpreting this as an upper limit on jet rotation implies that any steady, axisymmetric magneto-centrifugal model of jet launching is constrained to a launch radius in the disk-plane of 0.5 and 0.3 au for the blue and red-shifted jets, respectively. This supports an X-wind or narrow disk-wind model. This pertains only to the observed high velocity [FeII] emission, and does not rule out a wider flow launched from a wider radius. We report detection of small amplitude jet axis wiggling in both lobes. We rule out orbital motion of the jet source as the cause. Precession can better account for the observations but requires double the precession angle, and a different phase for the counter-jet. Such non-solid body precession could arise from an inclined massive Jupiter companion, or a warping instability induced by launching a magnetic disk-wind. Overall, our observations are consistent with an origin of the DO Tau jets from the inner regions of the disk.

8. Magnetic Fields in Massive Star-Forming Regions (MagMaR) I. Linear Polarized Imaging of the UCHII Region G5.89-0.39

M. Fernández-López, P. Sanhueza, L. A. Zapata, I. Stephens, C. Hull, Q. Zhang, J. M. Girart, P. M. Koch, P. Cortés, A. Silva, K. Tatematsu, F. Nakamura, A. E. Guzmán, Q. Nguyen Luong, E. Guzmán Ccolque, Y. -W. Tang, V. Chen ★ We report 1.2 mm polarized continuum emission observations carried out with the Atacama Large Millimeter/submillimeter Array (ALMA) toward the high-mass star formation region G5.89-0.39. The observations show a prominent 0.2 pc north-south filamentary structure. The UCHII in G5.89-0.39 breaks the filament in two pieces. Its millimeter emission shows a dusty belt with a mass of 55-115 $M_\odot$ and 4,500 au in radius, surrounding an inner part comprising mostly ionized gas with a dust emission only accounting about 30millimeter emission. We also found a lattice of convex arches which may be produced by dragged dust and gas from the explosive dispersal event involving the O5 Feldt's star. The north-south filament has a mass between 300-600 $M_\odot$ and harbours a cluster of about 20 millimeter envelopes with a median size and mass of 1700 au and 1.5 $M_\odot$, respectively, some of which are already forming protostars. We interpret the polarized emission in the filament as mainly coming from magnetically aligned dust grains. The polarization fraction is 4.4filaments and 2.1Filament and perpendicular to the South Filament. In the Central Shell, the magnetic fields are roughly radial in a ring surrounding the dusty belt between 4,500 and 7,500 au, similar to the pattern recently found in the surroundings of Orion BN/KL. This may be an independent observational signpost of explosive dispersal outflows and should be further investigated in other regions.

9. Streaming instability in a global patch simulation of protoplanetary disks

Mario Flock, Andrea Mignone ★ In the recent years, sub/mm observations of protoplanetary disks have discovered an incredible diversity of substructures in the dust emission. An important result was the finding that dust grains of mm size are embedded in very thin dusty disks. This implies that the dust mass fraction in the midplane becomes comparable to the gas, increasing the importance of the interaction between the two components there. We address this problem by means of numerical 2.5D simulations in order to study the gas and dust interaction in fully global stratified disks. To this purpose, we employ the recently developed dust grain module in the PLUTO code. Our model focuses on a typical T Tauri disk model, simulating a short patch of the disk at 10 au which includes grains of constant Stokes number of $St = 0.01$ and $St = 0.1$, corresponding to grains with sizes of 0.9 cm and 0.9 mm, respectively, for the given disk model. By injecting a constant pebble flux at the outer domain, the system reaches a quasi steady state of turbulence and dust concentrations driven by the streaming instability. For our given setup and using resolutions up to 2500 cells per scale height we resolve the streaming instability, leading to local dust clumping and concentrations. Our results show dust density values of around 10-100 times the gas density with a steady state pebble flux between 3.5×10^{-4} and $2.5 \times 10^{-3} M_{\rm Earth}/year$ for the models with $St = 0.01$ and $St = 0.1$. The grain size and pebble flux for model $St = 0.01$ compares well with dust evolution models of the first million years of disk evolution. For those grains the scatter opacity dominates the extinction coefficient at mm wavelengths. These types of global dust and gas simulations are a promising tool for studies of the gas and dust evolution at pressure bumps in protoplanetary disks.

10. Clustered star formation towards Berkeley 87 / ON2. I. Multi-wavelength census and the population overlap problem

Diego de la Fuente, Carlos G. Román-Zúñiga, Elena Jiménez-Bailón, João Alves, Miriam Garcia, Sean Venus ★ (ABRIDGED) Disentangling line-of-sight alignments of young stellar populations is crucial for observational studies of star-forming complexes. This task is particularly problematic in a Cygnus-X subregion where several components, located at different distances, are overlapped: the Berkeley 87 young massive cluster, the poorly-known [DB2001] Cl05 embedded cluster, and the ON2 star-forming complex, in turn composed of several HII regions. We aim at providing a methodology for building an exhaustive census of young objects that can consistently deal with large differences in both extinction and distance. OMEGA2000 near-infrared observations of the Berkeley 87 / ON2 field are merged with archival data from Gaia, Chandra, Spitzer, and Herschel, as well as cross-identifications from the literature. To address the incompleteness effects and selection biases that arise from the line-of-sight overlap, we adapt existing methods for extinction estimation and young object classification, and we define the intrinsic reddening index, $R_{\rm int}$, a new tool to separate intrinsically red sources from those whose infrared color excess is caused by extinction. We also introduce a new method to find young stellar objects based on $R_{\rm int}$. The flexibility of our approach allows to overcome photometric biases in order to obtain homogeneous catalogs of young sources. As a result, we find 571 objects whose classification is related to recent or ongoing star formation. Together with other point sources with individual estimates of distance or extinction, we compile a catalog of 3005 objects to be used for further membership work. A new distance for Berkeley 87, (1673 ± 17) pc, is estimated as a median of 13 spectroscopic members with accurate Gaia EDR3 parallaxes. Our multi-wavelength census will serve as a basis for disentangling the overlapped populations.

11. An ALMA Survey of Protoplanetary Disks in Lynds 1641

Sierra L. Grant, Catherine C. Espaillat, John Wendeborn, John J. Tobin, Enrique Macías, Anneliese Rilinger, Álvaro Ribas, S. Thomas Megeath, William J. Fischer, Nuria Calvet, Kyoung Hee Kim ★ We present ALMA observations of 101 protoplanetary disks within the star-forming region Lynds 1641 in the Orion Molecular Cloud A. Our observations include 1.33 mm continuum emission and spectral windows covering the J=2-1 transition of ^{12}CO, ^{13}CO, and C^{18}O. We detect 89 protoplanetary disks in the dust continuum at the 4σ level (∼88and 31 in ^{12}CO, 13 in ^{13}CO, and 4 in C^{18}O. Our sample contains 23 transitional disks, 20 of which are detected in the continuum. We target infrared-bright Class II objects, which biases our sample towards massive disks. We determine dust masses or upper limits for all sources in our sample and compare our sample to protostars in this region. We find a decrease in dust mass with evolutionary state. We also compare this sample to other regions surveyed in the (sub-)millimeter and find that Lynds 1641 has a relatively massive dust disk population compared to regions of similar and older ages, with a median dust mass of $11.1^{+32.9}_{-4.6}$ $M_\oplus$ and 27masses equal to or greater than the minimum solar nebula dust mass value of ∼30 $M_\oplus$. We analyze the disk mass-accretion rate relationship in this sample and find that the viscous disk lifetimes are similar to the age of the region, however with a large spread. One object, [MGM2012] 512, shows large-scale (>5000 AU) structure in both the dust continuum and the three gas lines. We discuss potential origins for this emission, including an accretion streamer with large dust grains.

12. Dispersal timescale of protoplanetary disks in the low-metallicity young cluster Dolidze 25

M. G. Guarcello, K. Biazzo, J. J. Drake, G. Micela, L. Prisinzano, S. Sciortino, F. Damiani, E. Flaccomio, C. Neiner, N. J. Wright ★ The dispersal of protoplanetary disks sets the timescale available for planets to assemble, and thus it is one of the fundamental parameters in theories of planetary formation. Disk dispersal is determined by several properties of the central star, the disk itself, and the surrounding environment. In particular, the metallicity of disks may impact their evolution, even if to date controversial results exist: in low-metallicity clusters disks seem to rapidly disperse, while in the Magellanic Clouds some evidence supports the existence of accreting disks few tens of Myrs old. In this paper we study the dispersal timescale of disks in Dolidze 25, the young cluster in proximity of the Sun with lowest metallicity, with the aim of understanding whether disk evolution is impacted by the low-metallicity of the cluster. We have analyzed Chandra/ACIS-I observations of the cluster and combined the resulting source catalog with existing optical and infrared catalogs of the region. We selected the disk-bearing population and the disk-less population of Dolidze 25. We have derived stellar parameters from isochrones fitted to color-magnitude diagrams. We derived a disk fraction of about 34existing estimates of the disk fraction of clusters younger than 10 Myrs, our study suggests that the disk fraction of Dolidze 25 is lower than what is expected from its age alone. Even if our results are not conclusive given the intrinsic uncertainty on stellar ages estimated from isochrones fitting to color-magnitude diagrams, we suggest that disk evolution in Dolidze 25 may be impacted by the environment. Given the poor O star population and low stellar density of the cluster, it is more likely that disks dispersal timescale is dictated more by the low metallicity of the cluster rather than external photoevaporation or dynamical encounters.

13. Analysis of physical processes in eruptive YSOs with near infrared spectra and multi-wavelength light curves

Zhen Guo, P. W. Lucas, C. Contreras Peña, L. C. Smith, C. Morris, R. G. Kurtev, J. Borissova, J. Alonso-García, D. Minniti, A. -N. Chené, M. S. N. Kumar, A. Caratti o Garatti, D. Froebrich, W. H. Stimson ★ The decade-long Vista Variables in the Via Lactea (VVV) survey has detected numerous highly variable young stellar objects (YSOs). We present a study of 61 highly variable VVV YSOs (ΔK_s = 1-5 mag), combining near infrared spectra from Magellan and VLT with VVV and NEOWISE light curves to investigate physical mechanisms behind eruptive events. Most sources are spectroscopically confirmed as eruptive variables (typically Class I YSOs) but variable extinction is also seen. Among them, magnetically controlled accretion, identified by HI recombination emission (usually accompanied by CO emission), is observed in 46 YSOs. Boundary layer accretion, associated with FU Ori-like outbursts identified by CO overtone and H_2O absorption, is observed only in longer duration events ($\geq$5 yr total duration). However, even in long duration events, the magnetically controlled accretion mode predominates, with amplitudes similar to the boundary layer mode. Shorter (100-700 days) eruptive events usually have lower amplitudes and these events are generally either periodic accretors or multiple timescale events, wherein large photometric changes occur on timescales of weeks and years. We find that the ratio of amplitudes in K_s and $W2$ can distinguish between variable accretion and variable extinction. Several YSOs are periodic or quasi-periodic variables. We identify examples of periodic accretors and extinction-driven periodicity among them (with periods up to 5 yr) though more data are needed to classify some cases. The data suggest that dynamic interactions with a companion may control the accretion rate in a substantial proportion of eruptive systems, although star-disc interactions should also be considered.

14. An HST Survey of Protostellar Outflow Cavities: Does Feedback Clear Envelopes?

Nolan M. Habel, S. Thomas Megeath, Joseph Jon Booker, William J. Fischer, Marina Kounkel, Charles Poteet, Elise Furlan, Amelia Stutz, P. Manoj, John J. Tobin, Zsofia Nagy, Riwaj Pokhrel, Dan Watson ★ We study protostellar envelope and outflow evolution using Hubble Space Telescope NICMOS or WFC3 images of 304 protostars in the Orion Molecular clouds. These near-IR images resolve structures in the envelopes delineated by the scattered light of the central protostars with 80 AU resolution and they complement the 1.2-870 micron spectral energy distributions obtained with the Herschel Orion Protostar Survey program (HOPS). Based on their 1.60 micron morphologies, we classify the protostars into five categories: non-detections, point sources without nebulosity, bipolar cavity sources, unipolar cavity sources, and irregulars. We find point sources without associated nebulosity are the most numerous, and show through monochromatic Monte Carlo radiative transfer modeling that this morphology occurs when protostars are observed at low inclinations or have low envelope densities. We also find that the morphology is correlated with the SED-determined evolutionary class with Class 0 protostars more likely to be non-detections, Class I protostars to show cavities and flat-spectrum protostars to be point sources. Using an edge detection algorithm to trace the projected edges of the cavities, we fit power-laws to the resulting cavity shapes, thereby measuring the cavity half-opening angles and power-law exponents. We find no evidence for the growth of outflow cavities as protostars evolve through the Class I protostar phase, in contradiction with previous studies of smaller samples. We conclude that the decline of mass infall with time cannot be explained by the progressive clearing of envelopes by growing outflow cavities. Furthermore, the low star formation efficiency inferred for molecular cores cannot be explained by envelope clearing alone.

15. Discovery of an Edge-on Circumstellar Debris Disk Around BD+45°598: a Newly Identifed Member of the β Pictoris Moving Group

Sasha Hinkley, Elisabeth C. Matthews, Charlène Lefevre, Jean-Francois Lestrade, Grant Kennedy, Dimitri Mawet, Karl R. Stapelfeldt, Shrishmoy Ray, Eric Mamajek, Brendan P. Bowler, David Wilner, Jonathan Williams, Megan Ansdell, Mark Wyatt, Alexis Lau, Mark W. Phillips Jorge Fernandez Fernandez, Jonathan Gagné, Emma Bubb, Ben J. Sutlieff, Thomas J. G. Wilson, Brenda Matthews, Henry Ngo, Danielle Piskorz, Justin R. Crepp, Erica Gonzalez, Andrew W. Mann, Gregory Mace ★ We report the discovery of a circumstellar debris disk viewed nearly edge-on and associated with the young, K1 star BD+45°598 using high-contrast imaging at 2.2μm obtained at the W.M. Keck Observatory. We detect the disk in scattered light with a peak significance of $\sim 5\sigma$ over three epochs, and our best-fit model of the disk is an almost edge-on $\sim$70 AU ring, with inclination angle $\sim$87°. Using the NOEMA interferometer at the Plateau de Bure Observatory operating at 1.3mm, we find resolved continuum emission aligned with the ring structure seen in the 2.2μm images. We estimate a fractional infrared luminosity of $L_{IR}/L_{tot} \simeq 6^{+2}_{-1} \times 10^{-4}$, higher than that of the debris disk around AU Mic. Several characteristics of BD+45°598, such as its galactic space motion, placement in a color-magnitude diagram, and strong presence of Lithium, are all consistent with its membership in the β Pictoris Moving Group with an age of 23±3 Myr. However, the galactic position for BD+45°598 is slightly discrepant from previously-known members of the β Pictoris Moving Group, possibly indicating an extension of members of this moving group to distances of at least 70pc. BD+45°598 appears to be an example from a population of young circumstellar debris systems associated with newly identified members of young moving groups that can be imaged in scattered light, key objects for mapping out the early evolution of planetary systems from $\sim$10-100 Myr. This target will also be ideal for northern-hemisphere, high-contrast imaging platforms to search for self-luminous, planetary mass companions residing in this system.

16. The Extraordinary Outburst in the Massive Protostellar System NGC6334I-MM1: Strong Increase in Mid-Infrared Continuum Emission

T. R. Hunter, C. L. Brogan, J. M. De Buizer, A. P. M. Towner, C. D. Dowell, G. C. MacLeod, B. Stecklum, C. J. Cyganowski, S. J. El-Abd, B. A. McGuire ★ In recent years, dramatic outbursts have been identified toward massive protostars via infrared and millimeter dust continuum and molecular maser emission. The longest lived outburst ($>$ 6 yr) persists in NGC6334I-MM1, a deeply-embedded object with no near-IR counterpart. Using FORCAST and HAWC+ on SOFIA, we have obtained the first mid-infrared images of this field since the outburst began. Despite being undetected in pre-outburst ground-based 18 μm images, MM1 is now the brightest region at all three wavelengths (25, 37, and 53 μm), exceeding the ultra-compact HII region MM3 (NGC6334F). Combining the SOFIA data with ALMA imaging at four wavelengths, we construct a spectral energy distribution of the combination of MM1 and the nearby hot core MM2. The best-fit Robitaille radiative transfer model yields a luminosity of $(4.9 \pm 0.8) \times 10^4 L_\odot$. Accounting for an estimated pre-outburst luminosity ratio MM1:MM2 = 2.1 ± 0.4, the luminosity of MM1 has increased by a factor of 16.3 ± 4.4. The pre-outburst luminosity implies a protostar of mass 6.7 $M_\odot$, which can produce the ionizing photon rate required to power the pre-outburst hypercompact HII region surrounding the likely outbursting protostar MM1B. The total energy and duration of the outburst exceed the S255IR-NIRS3 outburst by a factor of $\gtrsim 3$, suggesting a different scale of event involving expansion of the protostellar photosphere (to $\gtrsim 20$ $R_\odot$), thereby supporting a higher accretion rate ($\gtrsim$0.0023 $M_\odot$ yr^{-1}) and reducing the ionizing photon rate. In the grid of hydrodynamic models of Meyer et al. 2021, the combination of outburst luminosity and magnitude (3) places the NGC6334I-MM1 event in the region of moderate total accretion ($\sim$0.1-0.3 $M_\odot$) and hence long duration ($\sim$40-130 yr).

17. Long-term $V(RI)_c$ CCD photometry of pre-main-sequence stars in the association Cepheus OB3

Sunay Ibryamov, Gabriela Zidarova, Evgeni Semkov, Stoyanka Peneva ★ Results from optical CCD photometric observations of 13 pre-main-sequence stars collected during the period from February 2007 to November 2020 are presented. These stars are located in the association Cepheus OB3, in the field of the young star V733 Cephei. Photometric observations, especially concerning the long-term variability of the stars, are missing in the literature. We present the first long-term $V(RI)_c$ monitoring for them, that cover 13 years. Results from our study indicate that all of the investigated stars manifest strong photometric variability. The presented paper is a part of our program for the photometric study of PMS stars located in active star-forming regions.

18. MRI-active inner regions of protoplanetary discs. I. A detailed model of disc structure

Marija R. Jankovic, James E. Owen, Subhanjoy Mohanty, Jonathan C. Tan ★ Short-period super-Earth-sized planets are common. Explaining how they form near their present orbits requires understanding the structure of the inner regions of protoplanetary discs. Previous studies have argued that the hot inner protoplanetary disc is unstable to the magneto-rotational instability (MRI) due to thermal ionization of potassium, and that a local gas pressure maximum forms at the outer edge of this MRI-active zone. Here we present a steady-state model for inner discs accreting viscously, primarily due to the MRI. The

structure and MRI-viscosity of the inner disc are fully coupled in our model; moreover, we account for many processes omitted in previous such models, including disc heating by both accretion and stellar irradiation, vertical energy transport, realistic dust opacities, dust effects on disc ionization and non-thermal sources of ionization. For a disc around a solar-mass star with a standard gas accretion rate ($\dot{M}$~10^{-8}M$_\odot$yr^{-1}) and small dust grains, we find that the inner disc is optically thick, and the accretion heat is primarily released near the midplane. As a result, both the disc midplane temperature and the location of the pressure maximum are only marginally affected by stellar irradiation, and the inner disc is also convectively unstable. As previously suggested, the inner disc is primarily ionized through thermionic and potassium ion emission from dust grains, which, at high temperatures, counteract adsorption of free charges onto grains. Our results show that the location of the pressure maximum is determined by the threshold temperature above which thermionic and ion emission become efficient.

19. Gas infalling motions in the envelopes of Very Low Luminosity Objects

Mi-Ryang Kim, Chang Won Lee, Maheswar, G, Philip C. Myers, Gwanjeong Kim ★ We present the results of a single dish survey toward 95 VeLLOs in optically thick (HCN 1-0) and thin (N_2H^+ 1-0) lines performed for the purpose of understanding the physical processes of inward motions in the envelopes of the VeLLOs and characterizing their true nature. The normalized velocity differences (δV_{HCN}) between the peak velocities of the two lines were derived for 41 VeLLOs detected in both lines. The δV distribution of these VeLLOs is found to be significantly skewed to the blue, indicating the dominance of infalling motions in their envelopes. The infall speeds were derived for 15 infall candidates by using the HILL5 radiative transfer model. The speeds were in the range of 0.03 km s^{-1} to 0.3 km s^{-1}, with a median value of 0.16 km s^{-1}, being consistent with the gravitational free-fall speeds from pressure-free envelopes. The mass infall rates calculated from the infall speeds are mostly of the order of $10^{-6} M_\odot\ yr^{-1}$ with a median value of $3.4 \pm 1.5 \times 10^{-6}M_\odot$ yr^{-1}. These are found to be also consistent with the values predicted with the inside-out collapse model and show a fairly good correlation with the internal luminosities of the VeLLOs. This again indicates that the infall motions observed toward the VeLLOs are likely to be due to the gravitational infall motions in their envelopes. Our study suggests that most of the VeLLOs are potentially faint protostars while two of the VeLLOs could possibly be proto-brown dwarf candidates.

20. Efficiently Cooled Stellar Wind Bubbles in Turbulent Clouds I. Fractal Theory and Application to Star-Forming Clouds

Lachlan Lancaster, Eve C. Ostriker, Jeong-Gyu Kim, Chang-Goo Kim ★ Winds from massive stars have velocities of 1000 km/s or more, and produce hot, high pressure gas when they shock. We develop a theory for the evolution of bubbles driven by the collective winds from star clusters early in their lifetimes, which involves interaction with the turbulent, dense interstellar medium of the surrounding natal molecular cloud. A key feature is the fractal nature of the hot bubble's surface. The large area of this interface with surrounding denser gas strongly enhances energy losses from the hot interior, enabled by turbulent mixing and subsequent cooling at temperatures T = 10^4-10^5 K where radiation is maximally efficient. Due to the extreme cooling, the bubble radius scales differently (R $\sim$ t$^{1/2}$) from the classical Weaver (1977) solution, and has expansion velocity and momentum lower by factors of 10-10^2 at given R, with pressure lower by factors of 10^2 - 10^3. Our theory explains the weak X-ray emission and low shell expansion velocities of observed sources. We discuss further implications of our theory for observations of the hot bubbles and cooled expanding shells created by stellar winds, and for predictions of feedback-regulated star formation in a range of environments. In a companion paper, we validate our theory with a suite of hydrodynamic simulations.

21. Efficiently Cooled Stellar Wind Bubbles in Turbulent Clouds II. Validation of Theory with Hydrodynamic Simulations

Lachlan Lancaster, Eve C. Ostriker, Jeong-Gyu Kim, Chang-Goo Kim ★ In a companion paper, we develop a theory for the evolution of stellar wind driven bubbles in dense, turbulent clouds. This theory proposes that turbulent mixing at a fractal bubble-shell interface leads to highly efficient cooling, in which the vast majority of the input wind energy is radiated away. This energy loss renders the majority of the bubble evolution momentum-driven rather than energy-driven, with expansion velocities and pressures orders of magnitude lower than in the classical Weaver (1977) solution. In this paper, we validate our theory with three-dimensional, hydrodynamic simulations. We show that extreme cooling is not only possible, but is generic to star formation in turbulent clouds over more than three orders of magnitude in density. We quantify the few free parameters in our theory, and show that the momentum exceeds the wind input rate by only a factor about 1.2-4. We verify that the bubble/cloud interface is a fractal with dimension about 2.5-2.7. The measured turbulent amplitude (v$_t$ about 200-400 km/s) in the hot gas near the interface is shown to be consistent with theoretical requirements for turbulent diffusion to efficiently mix and radiate away most of the wind energy. The fraction of energy remaining after cooling is only 1-Θ $\sim$ 0.1-0.01, decreasing with time, explaining observations that indicate low hot-gas content and weak dynamical effects of stellar winds.

22. A Low-mass Cold and Quiescent Core Population in a Massive Protocluster

Shanghuo Li, Xing Lu, Qizhou Zhang, Chang-Won Lee, Patricio Sanhueza, Henrik Beuther, Izaskun, Jiménez-Serra, Keping Qiu, Aina Palau, Siyi Feng, Thushara Pillai, Kee-Tae Kim, Hong-Li Liu, Josep Miquel. Girart, Tie Liu, Junzhi Wang, Ke Wang, Hauyu Baobab Liu, Howard A. Smith, Di Li, Jeong-Eun Lee, Fei Li, Juan Li, Shinyoung Kim, Nannan Yue, Shaye Strom ★ Pre-stellar cores represent the initial conditions of star formation. Although these initial conditions have been investigated in detail toward low-mass pre-stellar cores, such initial conditions remain vastly unexplored for massive star-forming regions. We report the detection of a cluster of low-mass starless and pre-stellar core candidates in a massive protocluster forming cloud, NGC6334S. With the ALMA observations at a ∼0.02 pc spatial resolution, we identified 17 low-mass starless core candidates that do not show any evidence of protostellar activity. These candidates present small velocity dispersions, high fractional abundances of NH_2D, high NH_3 deuterium fractionations, and are completely dark in the infrared wavelengths from 3.6 up to 70 μm. Turbulence is significantly dissipated and the gas kinematics are dominated by thermal motions toward these candidates. Nine out of the 17 cores are gravitationally bound, and therefore are identified as pre-stellar core candidates. The embedded cores of NGC6334S show a wide diversity in masses and evolutionary stages.

23. A Multi-wavelength Study on the Formation of AFGL 333-Ridge

XiaoLian Liang, Jin-Long Xu, Ye Xu, Jun-Jie Wang ★ We presented a multi-wavelength study of AFGL 333-Ridge. The molecular line data reveals that the AFGL 333-Ridge has two independent velocity components at -50.5 km/s and -48.0 km/s. In the Position-Velocity diagram, the bridge feature connects with two parts that are spatially correlated but separated in velocity. These observational evidences support the scenario that the two velocity components have collided and merged into one molecular cloud. The majority of Class I YSOs are distributed within the collision region, suggesting that the cloud-cloud collision has induced the YSOs formation in the ridge. Using the radio recombination line (RRL) data obtained by the Five-hundred-meter Aperture Spherical radio Telescope (FAST), the RRL velocities of three HII regions are consistent with that of the AFGL 333-Ridge. By comparing the three HII regions' dynamical ages with the collision timescale of the two components, we conclude that the influence of the three HII regions may not drive the two clouds to merge. The formation of the AFGL 333-Ridge is probably due to the expansion of the giant HII region W4.

24. Revealing Ionization Conditions of Sz 102 with Spatially Resolved [Ne III] Microjets

Chun-Fan Liu, Hsien Shang, Gregory J. Herczeg, Frederick M. Walter ★ Forbidden neon emission lines from small-scale microjets can probe high-energy processes in low-mass young stellar systems. We obtained spatially resolved [Ne III] spectra of the microjets from the classical T Tauri Star Sz 102 using the Hubble Space Telescope Imaging Spectrograph (HST/STIS) at a spatial resolution of 0".1. The blueshifted and redshifted [Ne III] emission both peak in intensity within 0".1 of the star and gradually decay along the flow outward to 0".24. The spatial distribution and extent of the [Ne III] microjet is consistent with a jet that is ionized close to the base and subsequently recombines on a longer timescale than the flow time. Ca II H and K lines are also detected from the redshifted microjet with a line full-width at half-maximum of 170 km/s, consistent with those of other forbidden emission lines, atop a 300-km/s wide stellar component. The launching radius of the Sz 102 jet, inferred from the observed line centroids and the range of inclination angles and stellar masses from the literature, is on the order of 0.03 au. The possible proximity of the launching region to the star allows immediate ionization without distance dilution from the circumstellar ionization sources, most likely keV X-ray flares generated by magnetic reconnection events in the star-disk system, to sustain the observed [Ne III] flux.

25. Do ultra compact dwarf galaxies form monolithically or as merged star cluster complexes?

Hamidreza Mahani, Akram Hasani Zonoozi, Hosein Haghi, Tereza Jerabkova, Pavel Kroupa, Steffen Mieske ★ Some ultra-compact dwarf galaxies (UCDs) have elevated observed dynamical V-band mass-to-light ($M/L_{\rm V}$) ratios with respect to what is expected from their stellar populations assuming a canonical initial mass function (IMF). Observations have also revealed the presence of a compact dark object in the centers of several UCDs, having a mass of a few to 15% of the present-day stellar mass of the UCD. This central mass concentration has typically been interpreted as a super-massive black hole, but can in principle also be a sub-cluster of stellar remnants. We explore the following two formation scenarios of UCDs, i) monolithic collapse and ii) mergers of star clusters in cluster complexes as are observed in massively star-bursting regions. We explore the physical properties of the UCDs at different evolutionary stages assuming different initial stellar masses of the UCDs and the IMF being either universal or changing systematically with metallicity and density according to the Integrated Galactic IMF (IGIMF) theory. While the observed elevated $M/L_{\rm V}$ ratios of the UCDs cannot be reproduced if the IMF is invariant and universal, the empirically derived IMF which varies systematically with density and metallicity shows agreement with the observations. Incorporating the UCD-mass-dependent retention fraction of dark remnants improves this agreement. In addition we apply the results of N-body simulations to young UCDs and show that the same initial conditions describing the observed $M/L_{\rm V}$ ratios reproduce the observed relation between the half-mass radii and the present-day masses of the UCDs.

The findings thus suggest that the majority of UCDs that have elevated $M/L_{\rm V}$ ratios could have formed monolithically with significant remnant-mass components that are centrally concentrated, while those with small M/L_V values may be merged star-cluster complexes.

26. PENELLOPE: the ESO data legacy program to complement the Hubble UV Legacy Library of Young Stars (ULLYSES) I. Survey presentation and accretion properties of Orion OB1 and σ-Orionis

PENELLOPE team - C. F. Manara et al. ★ The evolution of young stars and disks is driven by the interplay of several processes, notably accretion and ejection of material. Critical to correctly describe the conditions of planet formation, these processes are best probed spectroscopically. About five-hundred orbits of the Hubble Space Telescope (HST) are being devoted in 2020-2022 to the ULLYSES public survey of about 70 low-mass (M<2Msun) young (age<10 Myr) stars at UV wavelengths. Here we present the PENELLOPE Large Program that is being carried out at the ESO Very Large Telescope (VLT) to acquire, contemporaneous to HST, optical ESPRESSO/UVES high-resolution spectra to investigate the kinematics of the emitting gas, and UV-to-NIR X-Shooter medium-resolution flux-calibrated spectra to provide the fundamental parameters that HST data alone cannot provide, such as extinction and stellar properties. The data obtained by PENELLOPE have no proprietary time, and the fully reduced spectra are made available to the whole community. Here, we describe the data and the first scientific analysis of the accretion properties for the sample of thirteen targets located in the Orion OB1 association and in the sigma-Orionis cluster, observed in Nov-Dec 2020. We find that the accretion rates are in line with those observed previously in similarly young star-forming regions, with a variability on a timescale of days of <3. The comparison of the fits to the continuum excess emission obtained with a slab model on the X-Shooter spectra and the HST/STIS spectra shows a shortcoming in the X-Shooter estimates of <10uncertainty. Its origin can be either a wrong UV extinction curve or due to the simplicity of this modelling, and will be investigated in the course of the PENELLOPE program. The combined ULLYSES and PENELLOPE data will be key for a better understanding of the accretion/ejection mechanisms in young stars.

27. Magnetic Properties of Star-Forming Dense Cores

Philip C. Myers, Shantanu Basu ★ Magnetic and energetic properties are presented for 17 dense cores within a few hundred pc of the Sun. Their plane-of-sky field strengths are estimated from the dispersion of polarization directions, following Davis, Chandrasekhar and Fermi (DCF). Their ratio of mass to magnetic critical mass is 0.5-3, indicating nearly critical field strengths. The field strength B_{pos} is correlated with column density N as $B_{pos} \sim N^p$, where p=1.05±0.08, and with density n as $B_{pos} \sim n^q$, where q=0.66±0.05. These magnetic properties are consistent with those derived from Zeeman studies (Crutcher et al. 2010), with less scatter. Relations between virial mass M_V, magnetic critical mass M_B, and Alfven amplitude sigma_B/B match the observed range of M/M_B for cores observed to be nearly virial, with M/M_V=0.5-2, with moderate Alfven amplitudes, and with sigma_B/B=0.1-0.4. The B-N and B-n correlations in the DCF and Zeeman samples can be explained when such bound, Alfvenic, and nearly-critical cores have central concentration and spheroidal shape. For these properties, B N because M/M_B is nearly constant compared to the range of N, and $B \sim n^{2/3}$ because $M^{1/3}$ is nearly constant compared to the range of $n^{2/3}$. The observed core fields which follow $B \sim n^{2/3}$ need not be much weaker than gravity, in contrast to core fields which follow $B \sim n^{2/3}$ due to spherical contraction at constant mass (Mestel 1966). Instead, the nearly critical values of M/M_B suggest that the observed core fields are nearly as strong as possible, among values which allow gravitational contraction.

28. Testing the Turbulent Origin of the Stellar Initial Mass Function

D. G. Nam, C. Federrath, M. R. Krumholz ★ Supersonic turbulence in the interstellar medium (ISM) is closely linked to the formation of stars, and hence many theories connect the stellar initial mass function (IMF) with the turbulent properties of molecular clouds. Here we test three turbulence-based IMF models (by Padoan & Nordlund 2002, Hennebelle & Chabrier 2008, and Hopkins 2012), which predict the relation between the high-mass slope (Γ) of the IMF, $\mathrm{d}N/\mathrm{d}\log M \propto M^{\Gamma}$ and the exponent n of the velocity power spectrum of turbulence, $E_v(k) \propto k^{-n}$, where $n \approx 2$ corresponds to typical ISM turbulence. Using hydrodynamic simulations, we drive turbulence with an unusual index of $n \approx 1$, measure Γ, and compare the results with $n \approx 2$. We find that reducing n from 2 to 1 primarily changes the high-mass region of the IMF (beyond the median mass), where we measure high-mass slopes within the 95 per cent confidence interval of $-1.5 < \Gamma < -1$ for $n \approx 1$ and $-3.7 < \Gamma < -2.4$ for $n \approx 2$, respectively. Thus, we find that $n = 1$ results in a significantly flatter high-mass slope of the IMF, with more massive stars formed than for $n \approx 2$. We compare these simulations with the predictions of the three IMF theories. We find that while the Padoan & Nordlund theory matches our simulations with fair accuracy, the other theories either fail to reproduce the main qualitative outcome of the simulations or require some modifications. We conclude that turbulence plays a key role in shaping the IMF, with a shallower turbulence power spectrum producing a shallower high-mass IMF, and hence more massive stars.

29. X-ray induced chemistry of water and related molecules in low-mass protostellar envelopes

Shota Notsu, Ewine F. van Dishoeck, Catherine Walsh, Arthur D. Bosman, Hideko Nomura ★ Recent water line observations toward several low-mass protostars suggest low water gas fractional abundances in the inner warm envelopes. Water destruction by X-rays has been proposed to influence the water abundances in these regions, but the detailed chemistry, including the nature of alternative oxygen carriers, is not yet understood. In this study, we aim to understand the impact of X-rays on the composition of low-mass protostellar envelopes, focusing specifically on water and related oxygen bearing species. We compute the chemical composition of two low-mass protostellar envelopes using a 1D gas-grain chemical reaction network, under various X-ray field strengths. According to our calculations, outside the water snowline, the water gas abundance increases with $L_{\rm X}$. Inside the water snowline, water maintains a high abundance of $\sim 10^{-4}$ for small $L_{\rm X}$, with water and CO being the dominant oxygen carriers. For large $L_{\rm X}$, the water gas abundances significantly decrease just inside the water snowline (down to $\sim 10^{-8} - 10^{-7}$) and in the innermost regions ($\sim 10^{-6}$). For these cases, the O_2 and O gas abundances reach $\sim 10^{-4}$ within the water snowline, and they become the dominant oxygen carriers. The HCO^+ and CH_3OH abundances, which have been used as tracers of the water snowline, significantly increase/decrease within the water snowline, respectively, as the X-ray fluxes become larger. The abundances of some other dominant molecules, such as CO_2, OH, CH_4, HCN, and NH_3, are also affected by strong X-ray fields, especially within their own snowlines. These X-ray effects are larger in lower density envelope models. Future observations of water and related molecules (using e.g., ALMA and ngVLA) will access the regions around protostars where such X-ray induced chemistry is effective.

30. The double signature of local cosmic-ray acceleration in star-forming regions

Marco Padovani, Alexandre Marcowith, Daniele Galli, Leslie K. Hunt, Francesco Fontani ★ Recently, there has been an increased interest in the study of the generation of low-energy cosmic rays (CRs; < 1 TeV) in shocks situated on the surface of a protostar or along protostellar jets. These locally accelerated CRs offer an attractive explanation for the high levels of non-thermal emission and ionisation rate, ζ, observed close to these sources. The high ζ observed in some protostellar sources is generally attributed to shock-generated UV photons. The aim of this article is to show that when synchrotron emission and a high ζ are measured in the same spatial region, a locally shock-accelerated CR flux is sufficient to explain both phenomena. We assume that relativistic particles are accelerated according to the first-order Fermi acceleration mechanism and compute ζ and the non-thermal emission at cm wavelengths. We then apply our model to the star-forming region OMC-2 FIR 3/FIR 4. Using a Bayesian analysis, we constrain the parameters of the model and estimate the spectral indices of the non-thermal radio emission. We demonstrate that the local CR acceleration model makes it possible to simultaneously explain the synchrotron emission along the HOPS 370 jet within the FIR 3 region and ζ observed near the FIR 4 protocluster. Our model constrains the magnetic field strength (250-450 μG), its turbulent component (20-40 μG), and the jet velocity in the shock reference frame for the three non-thermal sources of the HOPS 370 jet (350-1000 km s^{-1}). Beyond the modelling of the OMC-2 FIR 3/FIR 4 system, we show how the combination of continuum observations at cm wavelengths and molecular transitions is a powerful new tool for the analysis of star-forming regions: these two types of observations can be simultaneously interpreted by invoking only the presence of locally accelerated CRs, without having to resort to shock-generated UV photons.

31. Modulated accretion in T Tauri star RY Tau – stable MHD propeller or a planet at 0.2 AU?

P. P. Petrov, M. M. Romanova, K. N. Grankin, S. A. Artemenko, E. V. Babina, S. Yu. Gorda ★ Planets are thought to form at the early stage of stellar evolution when the mass accretion is still ongoing. RY Tau is a T Tauri type star at the age of a few Myr, with accretion disc seen at high inclination, so that line of sight crosses both the wind and the accretion gas flows. In a long series of spectroscopic monitoring of the star in 2013-2020, we detected variations in H-alpha and NaI D absorptions at radial velocities of infall (accretion) and outflow (wind) with a period of about 22 days. The absorptions in the infalling and the outflowing gas streams vary in anti-phase: an increase of infall is accompanied by a decrease of outflow, and vice versa. These flip-flop oscillations retain phase over several years of observations. We suggest that this may result from the MHD processes at the disk-magnetosphere boundary in the propeller mode. Another possibility is that a massive planet modulates some processes in the disc and provides the observed effects. The period, if Keplerian, corresponds to a distance of 0.2 AU, which is close to the dust sublimation radius in this star. The presence of the putative planet may be confirmed by radial velocity measurements: expected amplitude is > 90 m/s if a planet mass is > 2 Mj.

32. Significant interstellar object production by close stellar flybys

Susanne Pfalzner, Luis Aizpuru Vargas, Asmita Bhandare, Dimitri Veras ★ Within just two years, two interstellar objects (ISOs) - Oumuamuas and Borisov - have been discovered. Large quantities of planetesimals form as a by-product of planet formation. Therefore, it seems likely that ISOs are former planetesimals that became unbound from their parent star. The discoveries raise the question of the dominant ISO formation process. Here, we concentrate on planetesimals released during another star's close flybys. We quantify the amount of planetesimals released during close stellar flybys, their ejection velocity

and likely composition. We study the dependence of the effect of parabolic flybys on the mass ratio between the perturber and parent star, the periastron distance, inclination, and angle of periastron. Whenever ISOs are produced, they leave their parent system typically with velocities of 0.5-2 km/s. This ejection velocity is distinctly different to that of ISOs produced by planet scattering (4-8 km/s) and those shed during the stellar post-main-sequence phase 0.1-0.2 km/s). Using the typical disc truncation radius in various cluster environments, we find that clusters like the Orion nebula cluster are likely to produce the equivalent of 0.85 Earth-masses of ISOs per star. In contrast, clusters like NGC 3603 could produce up to 50 Earth-masses of ISOs per star. Our solar system probably produced the equivalent of 2-3 Earth masses of ISOs, which left our solar system at a mean ejection velocity of 0.7 km/s. Most ISOs produced by flybys should be comet-like, similar to Borisov. ISOs originating from compact long-lived clusters would often show a deficiency in CO. As soon as a statistically significant sample of ISOs is discovered, the combined information of their observed velocities and composition might help in constraining the dominant production process (abridged).

33. Thiols in the ISM: first detection of HC(O)SH and confirmation of C_2H_5SH

Lucas F. Rodríguez-Almeida, Izaskun Jiménez-Serra, Víctor M. Rivilla, Jesús Martín-Pintado, Shaoshan Zeng, Belén Tercero, Pablo de Vicente, Laura Colzi, Fernando Rico-Villas, Sergio Martín, Miguel A. Requena-Torres ★ The chemical compounds carrying the thiol group (-SH) have been considered essential in recent prebiotic studies regarding the polymerization of amino acids. We have searched for this kind of compounds toward the Galactic Centre quiescent cloud G+0.693-0.027. We report the first detection in the interstellar space of the trans-isomer of monothioformic acid (t-HC(O)SH) with an abundance of $\sim 1 \times 10^{-10}$. Additionally, we provide a solid confirmation of the gauche isomer of ethyl mercaptan (g-C_2H_5SH) with an abundance of $\sim 3 \times 10^{-10}$, and we also detect methyl mercaptan (CH_3SH) with an abundance of $\sim 5 \times 10^{-9}$. Abundance ratios were calculated for the three SH-bearing species and their OH-analogues, revealing similar trends between alcohols and thiols with increasing complexity. Possible chemical routes for the interstellar synthesis of t-HC(O)SH, CH_3SH and C_2H_5SH are discussed, as well as the relevance of these compounds in the synthesis of prebiotic proteins in the primitive Earth.

34. The effect of the streaming instability on protoplanetary disc emission at millimetre wavelengths

Chiara E. Scardoni, Richard A. Booth, Cathie J. Clarke ★ In this paper, we investigate whether overdensity formation via streaming instability is consistent with recent multi-wavelength ALMA observations in the Lupus star forming region. We simulate the local action of streaming instability in 2D using the code ATHENA, and examine the radiative properties at mm wavelengths of the resulting clumpy dust distribution by focusing on two observable quantities: the optically thick fraction ff (in ALMA band 6) and the spectral index α (in bands 3-7). By comparing the simulated distribution in the $ff - \alpha$ plane before and after the action of streaming instability, we observe that clump formation causes ff to drop, because of the suppression of emission from grains that end up in optically thick clumps. α, instead, can either increase or decline after the action of streaming instability; we use a simple toy model to demonstrate that this behaviour depends on the sizes of the grains whose emission is suppressed by being incorporated in optically thick clumps. In particular, the sign of evolution of α depends on whether grains near the opacity maximum at a few tenths of a mm end up in clumps. By comparing the simulation distributions before/after clump formation to the data distribution, we note that the action of streaming instability drives simulations towards the area of the plane where the data are located. We furthermore demonstrate that this behaviour is replicated in integrated disc models provided that the instability is operative over a region of the disc that contributes significantly to the total mm flux.

35. Gaia-EDR3 Parallax Distances to the Great Carina Nebula and its Star Clusters (Trumpler 14, 15, 16)

Michael Shull, Jeremy Darling, Charles Danforth ★ Using offset-corrected Gaia-EDR3 parallax measurements and spectrophotometric methods, we have determined distances for 69 massive stars in the Carina OB1 association and associated clusters: Trumpler 16 (21 stars), Trumpler 14 (20 stars), Trumpler 15 (3 stars), Bochum 11 (5 stars), and South Pillars region (20 stars). Past distance estimates to the Carina Nebula range from 2.2 to 3.6 kpc, with uncertainties arising from photometry and anomalous dust extinction. The EDR3 parallax solutions show considerable improvement over DR2, with typical errors $\sigma_\varpi/\varpi \approx$ 3-5Great Carina Nebula lie at essentially the same distance (2.35 ± 0.08 kpc), quoting mean and rms variance. The clusters have distances of 2.32±0.12 kpc (Tr 16), 2.37±0.15 kpc (Tr 14), 2.36±0.09 kpc (Tr 15), and 2.33±0.12 kpc (Bochum 11) in good agreement with the η Car distance of around 2.3 kpc. O-star proper motions suggest internal (2D) velocity dispersions $\sim$ 4 km/s for Tr 14 and Tr 16. Reliable distances allow estimates of cluster sizes, stellar dynamics, luminosities, and fluxes of photoionizing radiation incident on photodissociation regions in the region. We estimate that Tr 14 and Tr 16 have half-mass radii $r_h = 1.5 - 1.8$ pc, stellar crossing times $t_{\rm cr} = r_h/v_m \approx 0.7 - 0.8$ Myr, and two-body relaxation times $t_{rh} \approx 40 - 80$ Myr. The underlying velocity dispersion for Tr 14, if a bound cluster, would be $v_m \approx 2.1^{+0.7}_{-0.4}$ km/s for $N = 7600^{+5800}_{-2600}$ stars. With the higher dispersions of the O-stars, mass segregation might occur slowly, on times scales of 3-6 Myr.

36. Star-disk interaction in the T Tauri star V2129 Oph: An evolving accretion-ejection structure

A. P. Sousa, J. Bouvier, S. H. P. Alencar, J. -F. Donati, E. Alecian, J. Roquette, K. Perraut, C. Dougados, A. Carmona, S. Covino, D. Fugazza, E. Molinari, C. Moutou, A. Santerne, K. Grankin, É. Artigau, X. Delfosse, G. Hebrard, the SPIRou consortium ★ Classical T Tauri stars are young low-mass systems still accreting material from their disks. These systems are dynamic on timescales of hours to years. The observed variability can help us infer the physical processes that occur in the circumstellar environment. We aim at understanding the dynamics of the magnetic interaction between the star and the inner accretion disk in young stellar objects. We present the case of the young stellar system V2129 Oph, which is a well-known T Tauri star. We performed a time series analysis of this star using high-resolution spectroscopic data at optical and infrared wavelengths from CFHT/ESPaDOnS, ESO/HARPS and CFHT/SPIRou. The new data sets allowed us to characterize the accretion-ejection structure in this system and to investigate its evolution over a timescale of a decade via comparisons to previous observational data. We measure radial velocity variations and recover a stellar rotation period of 6.53d. However, we do not recover the stellar rotation period in the variability of various circumstellar lines, such as Hα and Hβ in the optical or HeI 1083nm and Paβ in the infrared. Instead, we show that the optical and infrared line profile variations are consistent with a magnetospheric accretion scenario that shows variability with a period of about 6.0d, shorter than the stellar rotation period. Additionally, we find a period of 8.5d in Hα and Hβ lines, probably due to a structure located beyond the corotation radius, at a distance of 0.09au. We investigate whether this could be accounted for by a wind component, twisted or multiple accretion funnel flows, or an external disturbance in the inner disk. We conclude that the dynamics of the accretion-ejection process can vary significantly on a timescale of just a few years, presumably reflecting the evolving magnetic field topology at the stellar surface.

37. Undetected Binary Stars Cause an Observed Mass Dependent Age Gradient in Upper Scorpius

Kendall Sullivan, Adam Kraus ★ Young stellar associations represent a key site for the study of star formation, but to accurately compare observations to models of stellar evolution, the age of an association must be determined. The Upper Scorpius region is the youngest section of the Scorpius-Centaurus OB association, which is the largest collection of nearby, young, low-mass stars. The true age of Upper Scorpius is not clear, and an observed mass-dependent age gradient in Upper Scorpius, as well as in other star-forming regions, complicates age measurements. The age gradient may indicate a genuine astrophysical feature or may be an artifact of unrecognized systematic effects in stellar age measurements. We have conducted a synthetic red-optical low-resolution spectroscopic survey of a simulated analog to the Upper Scorpius star-forming region to investigate the effects of unresolved binary stars (which have mass-dependent demographics) on age measurements of a stellar population. We find that the observed mass-dependent age gradient in Upper Scorpius can be explained by a population of undetected binary stars. For a simulated population with an age of 10 (RMS = 2) Myr, we measure an age of 10.5 (RMS = 3.5) Myr for F stars, and 7.5 (RMS = 5.8) Myr for M stars. This discrepancy is caused by the mass-dependent mass ratio distribution and the variable steepness of the mass-luminosity relation. Our results support the previously suggested 10 Myr age for Upper Scorpius, with a small intrinsic age spread.

38. The $C^{18}O$ core mass function toward Orion A: Single-dish observations

Hideaki Takemura, Fumitaka Nakamura, Shun Ishii, Yoshito Shimajiri, Patricio Sanhueza, Takashi Tsukagoshi, Ryohei Kawabe, Tomoya Hirota, Akimasa Kataoka ★ We have performed an unbiased dense core survey toward the Orion A Giant Molecular Cloud in the $C^{18}O$ (J=1–0) emission line taken with the Nobeyama Radio Observatory (NRO) 45-m telescope. The effective angular resolution of the map is 26", which corresponds to $\sim$ 0.05 pc at a distance of 414 pc. By using the Herschel-Planck H_2 column density map, we calculate the $C^{18}O$ fractional abundance and find that it is roughly constant over the column density range of $\lesssim 5 \times 10^{22}$ cm^{-3}, although a trend of $C^{18}O$ depletion is determined toward higher column density. Therefore, $C^{18}O$ intensity can follow the cloud structure reasonably well. The mean $C^{18}O$ abundance in Orion A is estimated to be 5.7×10^{-7}, which is about 3 times larger than the fiducial value. We identified 746 $C^{18}O$ cores with astrodendro and classified 709 cores as starless cores. We compute the core masses by decomposing the Herschel-Planck dust column density using the relative proportions of the $C^{18}O$ integrated intensities of line-of-sight components. Applying this procedure, we attempt to remove the contribution of the background emission, i.e., the ambient gas outside the cores. Then, we derived mass function for starless cores and found that it resembles the stellar initial mass function (IMF). The CMF for starless cores, dN/dM, is fitted with a power-law relation of M^{α} with a power index of $\alpha = -2.25\pm 0.16$ at the high-mass slope ($\gtrsim 0.44\ M_{\odot}$). We also found that the ratio of each core mass to the total mass integrated along the line of sight is significantly large. Therefore, in the previous studies, the core masses derived from the dust image are likely to be overestimated at least by a factor of a few. Accordingly, such previous studies may underestimate the star formation efficiency of individual cores.

39. The Core Mass Function in the Orion Nebula Cluster Region: What Determines the Final Stellar Masses?

Hideaki Takemura, Fumitaka Nakamura, Shuo Kong, Héctor G. Arce, John M. Carpenter, Volker Ossenkopf-Okada, Ralf Klessen, Patricio Sanhueza, Yoshito Shimajiri, Takashi Tsukagoshi, Ryohei Kawabe, Shun Ishii, Kazuhito Dobashi, Tomomi Shimoikura, Paul F. Goldsmith, Álvaro Sánchez-Monge, Jens Kauffmann, Thushara Pillai, Paolo Padoan, Adam Ginsberg, Rowan J. Smith, John Bally, Steve Mairs, Jaime E. Pineda, Dariusz C. Lis, Blakesley Burkhart, Peter Schilke, Hope How-Huan Chen, Andrea Isella, Rachel K. Friesen, Alyssa A. Goodman, Doyal A. Harper ★ Applying dendrogram analysis to the CARMA-NRO $C^{18}O$ (J=1–0) data having an angular resolution of $\sim$ 8", we identified 692 dense cores in the Orion Nebula Cluster (ONC) region. Using this core sample, we compare the core and initial stellar mass functions in the same area to quantify the step from cores to stars. About 22 % of the identified cores are gravitationally bound. The derived core mass function (CMF) for starless cores has a slope similar to Salpeter's stellar initial mass function (IMF) for the mass range above 1 $M_{\odot}$, consistent with previous studies. Our CMF has a peak at a subsolar mass of $\sim$ 0.1 $M_{\odot}$, which is comparable to the peak mass of the IMF derived in the same area. We also find that the current star formation rate is consistent with the picture in which stars are born only from self-gravitating starless cores. However, the cores must gain additional gas from the surroundings to reproduce the current IMF (e.g., its slope and peak mass), because the core mass cannot be accreted onto the star with a 100% efficiency. Thus, the mass accretion from the surroundings may play a crucial role in determining the final stellar masses of stars.

40. Monoceros OB4: a new association in Gaia DR2

P. S. Teixeira, J. Alves, A. Sicilia-Aguilar, A. Hacar, A. Scholz ★ We use Gaia DR2 data to survey the classic Monoceros OB1 region and look for the existence of a dispersed young population, co-moving with the cloud complex. An analysis of the distribution of proper motions reveals a 20-30 Myr association of young stars, about 300-400 pc away from the far side of the Mon OB1 complex, along the same general line-of-sight. We characterize the new association, Monoceros OB4, and estimate it contains between 1400 and 2500 stars, assuming a standard IMF, putting it on par in size with NGC 2264. We find from the internal proper motions that Mon OB4 is unbound and expanding. Our results seem to unveil a larger and more complex Monoceros star formation region, suggesting an elongated arrangement that seems to be at least 300 $\times$ 60 pc.

41. SOFIA FEEDBACK survey: exploring the dynamics of the stellar wind driven shell of RCW 49

M. Tiwari, R. Karim, M. W. Pound, M. Wolfire, A. Jacob, C. Buchbender, R. Güsten, C. Guevara, R. D. Higgins, S. Kabanovic, C. Pabst, O. Ricken, N. Schneider, R. Simon, J. Stutzki, A. G. G. M. Tielens ★ We unveil the stellar wind driven shell of the luminous massive star-forming region of RCW 49 using SOFIA FEEDBACK observations of the [CII] 158 μm line. The complementary dataset of the ^{12}CO and ^{13}CO J = 3 - 2 transitions is observed by the APEX telescope and probes the dense gas toward RCW 49. Using the spatial and spectral resolution provided by the SOFIA and APEX telescopes, we disentangle the shell from a complex set of individual components of gas centered around RCW 49. We find that the shell of radius 6 pc is expanding at a velocity of 13 km s^{-1} toward the observer. Comparing our observed data with the ancillary data at X-Ray, infrared, sub-millimeter and radio wavelengths, we investigate the morphology of the region. The shell has a well defined eastern arc, while the western side is blown open and is venting plasma further into the west. Though the stellar cluster, which is $\sim$ 2 Myr old gave rise to the shell, it only gained momentum relatively recently as we calculate the shell's expansion lifetime $\sim$ 0.27 Myr, making the Wolf-Rayet star WR20a a likely candidate responsible for the shell's re-acceleration.

42. The Southern HII Region Discovery Survey. II. The Full Catalog

Trey V. Wenger, J. R. Dawson, John M. Dickey, C. H. Jordan, N. M. McClure-Griffiths, L. D. Anderson, W. P. Armentrout, Dana S. Balser, T. M. Bania ★ The Southern HII Region Discovery Survey (SHRDS) is a 900 hour Australia Telescope Compact Array 4-10 GHz radio continuum and radio recombination line (RRL) survey of Galactic HII regions and infrared-identified HII region candidates in the southern sky. For this data release, we reprocess all previously published SHRDS data and include an additional 450 hours of observations. The search for new HII regions is now complete over the range 259 deg $<$ Galactic longitude $<$ 346 deg, |Galactic latitude| $<$ 4 deg for HII region candidates with predicted 6 GHz continuum peak brightnesses $>$30 mJy/beam. We detect radio continuum emission toward 730 targets altogether including previously known nebulae and HII region candidates. By averaging 18 RRL transitions, we detect RRL emission toward 206 previously known HII regions and 436 HII region candidates. Including the northern sky surveys, over the last decade the HII Region Discovery Surveys have more than doubled the number of known Galactic HII regions. The census of HII regions in the WISE Catalog of Galactic HII Regions is now complete for nebulae with 9 GHz continuum flux densities $>$ 250 mJy. We compare the RRL properties of the newly discovered SHRDS nebulae with those of all previously known HII regions. The median RRL full-width at half-maximum line width of the entire WISE Catalog HII region population is 23.9 km/s and is consistent between Galactic quadrants. The observed Galactic longitude-velocity asymmetry in the population of HII regions probably reflects underlying

spiral structure in the Milky Way.

43. The TMRT K Band Observations towards 26 Infrared Dark Clouds: NH_3, CCS, and HC_3N

Jinjin Xie, Gary A. Fuller, Di Li, Longfei Chen, Zhiyuan Ren, Jingwen Wu, Yan Duan, Junzhi Wang, Juan Li, Nicolas Peretto, Tie Liu, Zhiqiang Shen ★ We present one of the first Shanghai Tian Ma Radio Telescope (TMRT) K Band observations towards a sample of 26 infrared dark clouds (IRDCs). We observed the (1,1), (2,2), (3,3), and (4,4) transitions of NH_3 together with CCS (2_1-1_0) and HC_3N J =2-1, simultaneously. The survey dramatically increases the existing CCS-detected IRDC sample from 8 to 23, enabling a better statistical study of the ratios of carbon-chain molecules (CCM) to N-bearing molecules in IRDCs. With the newly developed hyperfine group ratio (HFGR) method of fitting NH_3 inversion lines, we found the gas temperature to be between 10 and 18 K. The column density ratios of CCS to NH_3 for most of the IRDCs are less than 10^{-2}, distinguishing IRDCs from low-mass star-forming regions. We carried out chemical evolution simulations based on a three-phase chemical model NAUTILUS. Our measurements of the column density ratios between CCM and NH_3 are consistent with chemical evolutionary ages of $\lesssim 10^5$ yr in the models. Comparisons of the data and chemical models suggest that CCS, HC_3N, and NH_3 are sensitive to the chemical evolutionary stages of the sources.

44. Planck Cold Clumps in the lambda Orionis Complex. III. A chemical probe of stellar feedback on cores in the lambda Orionis cloud

Hee-Weon Yi, Jeong-Eun Lee, Kee-Tae Kim, Tie Liu, Beomdu Lim, Ken'ichi Tatematsu ★ Massive stars have a strong impact on their local environments. However, how stellar feedback regulates star formation is still under debate. In this context, we studied the chemical properties of 80 dense cores in the Orion molecular cloud complex composed of the Orion A (39 cores), B (26 cores), and lambda Orionis (15 cores) clouds using multiple molecular line data taken with the Korean Very Long Baseline Interferometry Network (KVN) 21-m telescopes. The lambda Orionis cloud has an H ii bubble surrounding the O-type star lambda Ori, and hence it is exposed to the ultraviolet (UV) radiation field of the massive star. The abundances of C2H and HCN, which are sensitive to UV radiation, appear to be higher in the cores in the lambda Orionis cloud than those in the Orion A and B clouds, while the HDCO to H2CO abundance ratios show an opposite trend, indicating a warmer condition in the lambda Orionis cloud. The detection rates of dense gas tracers such as the N2H+, HCO+, and H13CO+ lines are also lower in the lambda Orionis cloud. These chemical properties imply that the cores in the lambda Orionis cloud are heated by UV photons from lambda Ori. Furthermore, the cores in the lambda Orionis cloud do not show any statistically significant excess in the infall signature of HCO+ (1 - 0), unlike the Orion A and B clouds. Our results support the idea that feedback from massive stars impacts star formation in a negative way by heating and evaporating dense materials, as in the lambda Orionis cloud.