The Star Formation Newsletter

A community newsletter on Star and Planet Formation research

No. 342 — 21 June 2021
Editor: João Alves
www.starformation.news

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Cover image caption

The Lupus 3 molecular cloud. The cloud lies at about 150 pc from Earth and is part of the Sco-Cen OB association at a distance. The two bright stars (HR5999 and HR6000) mark the center of a rich group of T Tauri stars. HR5999, the southern of the two, is one of the best-studied AeBe stars. Credit: ESO/R. Colombari.

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. **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. Observability of the Vertical Shear Instability in protoplanetary disk CO kinematics

Marcelo Barraza-Alfaro, Mario Flock, Sebastian Marino, Sebastián Pérez ★
Context. Dynamical and turbulent motions of gas in a protoplanetary disk are crucial for their evolution and affect planet formation. Recent observations suggest weak turbulence in the disk's outer regions. However, the physical mechanism of turbulence in these outer regions remains uncertain. The vertical shear instability (VSI) is a promising mechanism to produce turbulence in disks. Aims. Our aim is to study the observability of the gas velocity structure produced by the VSI via CO kinematics with ALMA. Methods. We perform global 3D hydrodynamical simulations of a VSI-unstable disk. We post-process the simulation results with radiative transfer calculations, and produce synthetic predictions of CO rotational emission lines. Following, we compute the line of sight velocity map, and its deviations from a sub-Keplerian equilibrium solution. We explore the detectability of the VSI by identifying kinematic signatures using realistic simulated observations. Results. Our 3D simulations of the VSI show the steady state dynamics of the gas in great detail. From the velocity structure we infer a turbulent stress value of $\alpha_{r\phi} = 1.4 \times 10^{-4}$. On large scales, we observe velocity deviations of 50 m s^{-1} as axisymmetric rings. We find optimal conditions at $i \lesssim 20^{\circ}$ to trace for the kinematic structures of the VSI. We found that current diagnostics to constrain gas turbulence from non-thermal broadening of the line emission are not applicable to anisotropic VSI turbulence. Conclusions. The detection of kinematic signatures produced by the VSI is possible with ALMA. Observations including an extended antenna configuration combined with the highest spectral resolution available are needed for robust detection. The characterization of the large-scale velocity perturbations is required to constrain the turbulence level produced by the VSI from gas observations.

2. A major asymmetric ice trap in a planet-forming disk: II. prominent SO and SO2 pointing to C/O < 1

A. S. Booth, N. van der Marel, M. Leemker, E. F. van Dishoeck, S. Ohashi ★
Gas-phase sulphur bearing volatiles appear to be severely depleted in protoplanetary disks. The detection of CS and non-detections of SO and SO2 in many disks have shown that the gas in the warm molecular layer, where giant planets accrete their atmospheres, has a high C/O ratio. In this letter, we report the detection of SO and SO2 in the Oph-IRS 48 disk using ALMA. This is the first case of prominent SO2 emission detected from a protoplanetary disk. The molecular emissions of both molecules is spatially correlated with the asymmetric dust trap. We propose that this is due to the sublimation of ices at the edge of the dust cavity and that the bulk of the ice reservoir is coincident with the millimetre dust grains. Depending on the partition of elemental sulphur between refractory and volatile materials the observed molecules can account for 15-100% of the total sulphur budget in the disk. In strong contrast to previous results, we constrain the C/O ratio from the CS/SO ratio to be < 1 and potentially solar. This has important implications for the elemental composition of planets forming within the cavities of warm transition disks.

3. Zooming into the Collimation Zone in a Massive Protostellar Jet

Carlos Carrasco-González, Alberto Sanna, Adriana Rodríguez-Kamenetzky, Luca Moscadelli, Melvin Hoare, José M. Torrelles, Roberto Galván-Madrid, Andrés F. Izquierdo ★ Protostellar jets have a fundamental role at the earliest evolution of protostars of all masses. In the case of low-mass (<8 Msun) protostars, strong observational evidence exists that the launching and collimation is due to the X- and/or disk-wind mechanisms. In these models, it is the protostar/disk system that creates all the necessary conditions to launch and collimate the jets near the protostar via strong magnetic fields. The origin of jets from more massive protostars has been investigated much less, in part because of the difficulty of resolving the collimation zone in these more distant objects. Here we present the highest angular resolution observations of a jet powered by a massive protostar, the Cep A HW2 radio jet. We imaged the radio emission at projected distances of only 20 au from the protostar, resolving the innermost 100 au of a massive protostellar jet for the first time. The morphology of the radio jet emission in this massive object is very different than what is usually observed in jets from low-mass protostars. We found that the outflowing material in HW2 has two components: a wide-angle wind launched from the protostar/disk system, and a highly collimated jet starting at 20-30 au from the protostar. We discuss two possible scenarios: an extension of the classical disk-wind to a massive protostar, or external collimation of a wide-angle wind. These results have important consequences for our understanding of how stars of different masses are formed.

4. Constraining Spatial Densities of Early Ice Formation in Small Dense Molecular Cores from Extinction Maps

Laurie E. U. Chu, Klaus W. Hodapp ★ Tracing dust in small dense molecular cores is a powerful tool to study the conditions required for ices to form during the pre-stellar phase. To study these environments, five molecular cores were observed: three with ongoing low-mass star formation (B59, B335, and L483) and two starless collapsing cores (L63 and L694-2). Deep images were taken in the infrared JHK bands with the United Kingdom Infrared Telescope (UKIRT) WFCAM (Wide Field Camera) instrument and IRAC channels 1 and 2 on the Spitzer Space Telescope. These five photometric bands were used to calculate extinction along the line of sight toward background stars. After smoothing the data, we produced high spatial resolution extinction maps (∼13-29") . The maps were then projected into the third dimension using the AVIATOR algorithm implementing the inverse Abel transform. The volume densities of the total hydrogen were measured along lines of sight where ices (H_2O, CO, and CH_3OH) have previously been detected. We find that lines of sight with pure CH_3OH or a mixture of CH_3OH with CO have maximum volume densities above 1.0×10^5 cm^{-3}. These densities are only reached within a small fraction of each of the cores (∼0.3-2.1%). CH_3OH presence may indicate the onset of complex organic molecule formation within dense cores and thus we can constrain the region where this onset can begin. The maximum volume densities toward star-forming cores in our sample (∼$1.2\text{-}1.7\times10^6$ cm^{-3}) are higher than those toward starless cores (∼$3.5\text{-}9.5\times10^5$ cm^{-3}).

5. TRAO Survey of the nearby filamentary molecular clouds, the universal nursery of stars (TRAO FUNS). II. Filaments and Dense cores in IC 5146

Eun Jung Chung, Chang Won Lee, Shinyoung Kim, Maheswar Gopinathan, Mario Tafalla, Paola Caselli, Philip C. Myers, Tie Liu, Hyunju Yoo, Kyoung Hee Kim, Mi-Ryang Kim, Archana Soam, Jungyeon Cho, Woojin Kwon, Changhoon Lee, Hyunwoo Kang ★ We present the results on the physical properties of filaments and dense cores in IC 5146, as a part of the TRAO FUNS project. We carried out On-The-Fly mapping observations using the Taeduk Radio Astronomy Observatory (TRAO) 14m telescope covering about 1 square degree of the area of IC 5146 using various molecular lines. We identified 14 filaments (24 in total, including sub-filaments) from the $C^{18}O$ (1-0) data cube and 22 dense cores from the N_2H^+ (1-0) data. We examined the filaments' gravitational criticality, turbulence properties, accretion rate from filaments to dense cores, and relative evolutionary stages of cores. Most filaments in IC 5146 are gravitationally supercritical within the uncertainty, and most dense cores are formed in them. We found that dense cores in the hubs show a systemic velocity shift of 0.3 km/s between the N_2H^+ and $C^{18}O$ gas. Besides, these cores are subsonic or transonic, while the surrounding filament gas is transonic or supersonic, indicating that the cores in the hubs are likely formed by the turbulence dissipation in the colliding turbulent filaments and the merging is still ongoing. We estimated the mass accretion rate of $15-35\ M_\odot$ Myr^{-1} from the filaments to the dense cores, and the required time scales to collect the current core mass are consistent with the lifetime of the dense cores. The structures of filaments and dense cores in the hub can form by a collision of turbulent converging flows, and mass flow along the filaments to the dense cores may play an important role in forming dense cores.

6. Probing jets from young embedded sources: clues from HST near-IR [Fe II] images

Jessica Erkal, Brunella Nisini, Deirdre Coffey, Francesca Bacciotti, Patrick Hartigan, Simone Antoniucci, Teresa Giannini, Jochen Eislöffel, Carlo Felice Manara ★ We present near-infrared [Fe II] images of four Class 0/I jets (HH 1/2, HH 34, HH 111, HH 46/47) observed with the Hubble Space Telescope Wide Field Camera 3. The unprecedented angular resolution allows us to measure proper motions, jet widths and trajectories, and extinction along the jets. In all cases, we detect the counter-jet which was barely visible or invisible at shorter wavelengths. We measure tangential velocities of a few hundred km/s, consistent with previous HST measurements over 10 years ago. We measure the jet width as close as a few tens of au from

the star, revealing high collimations of about 2 degrees for HH 1, HH 34, HH 111 and about 8 degrees for HH 46, all of which are preserved up to large distances. For HH 34, we find evidence of a larger initial opening angle of about 7 degrees. Measurement of knot positions reveals deviations in trajectory of both the jet and counter-jet of all sources. Analysis of asymmetries in the inner knot positions for HH 111 suggests the presence of a low mass stellar companion at separation 20-30 au. Finally, we find extinction values of 15-20 mag near the source which gradually decreases moving downstream along the jet. These observations have allowed us to study the counter-jet at unprecedented high angular resolution, and will be a valuable reference for planning future JWST mid-infrared observations which will peer even closer into the jet engine.

7. Impact of Size-dependent Grain Temperature on Gas-Grain Chemistry in Protoplanetary Disks: the case of low mass star disks

S. Gavino, A. Dutrey, V. Wakelam, S. Guilloteau, J. Kobus, S. Wolf, W. Iqbal, E. Di Folco, E. Chapillon, V. Piétu ★ Grain surface chemistry is key to the composition of protoplanetary disks around young stars. The temperature of grains depends on their size. We evaluate the impact of this temperature dependence on the disk chemistry. We model a moderately massive disk with 16 different grain sizes. We use POLARIS to calculate the dust grain temperatures and the local UV flux. We model the chemistry using the 3-phase astrochemical code NAUTILUS. Photoprocesses are handled using frequency-dependent cross-sections, and a new method to account for self and mutual shielding. The multi-grain model outputs are compared to those of single-grain size models (0.1 μm), with two different assumptions for their equivalent temperature. We find that the Langmuir-Hinshelwood (LH) mechanism at equilibrium temperature is not efficient to form H_2 at 3-4 scale heights (H), and adopt a parametric fit to a stochastic method to model H_2 formation instead. We find the molecular layer composition (1-3 H) to depend on the amount of remaining H atoms. Differences in molecular surface densities between single and multi-grain models are mostly due to what occurs above 1.5 H. At 100 au, models with colder grains produce H_2O and CH_4 ices in the midplane, and warmer ones produce more CO_2 ices, both allowing efficient depletion of C and O as soon as CO sticks on grain surfaces. Complex organic molecules (COMs) production is enhanced by the presence of warmer grains in the multi-grain models. Using a single grain model mimicking grain growth and dust settling fails to reproduce the complexity of gas-grain chemistry. Chemical models with a single grain size are sensitive to the adopted grain temperature, and cannot account for all expected effects. A spatial spread of the snowlines is expected to result from the ranges in grain temperature. The amplitude of the effects will depend on the dust disk mass.

8. K-band GRAVITY/VLTI interferometry of "extreme" Herbig Be stars. The size-luminosity relation revisited

P. Marcos-Arenal, I. Mendigutía, E. Koumpia, R. D. Oudmaijer, M. Vioque, J. Guzmán-Díaz, C. Wichittanakom, W. J. de Wit, B. Montesinos, J. D. Ilee ★ (Abridged:) It has been hypothesized that the location of Herbig Ae/Be stars (HAeBes) within the empirical relation between the inner disk radius (r_{in}), inferred from K-band interferometry, and the stellar luminosity (L_*), is related to the presence of the innermost gas, the disk-to-star accretion mechanism, the dust disk properties inferred from the spectral energy distributions (SEDs), or a combination of these effects. This work aims to test whether the previously proposed hypotheses do, in fact, serve as a general explanation for the distribution of HAeBes in the size-luminosity diagram. GRAVITY/VLTI spectro-interferometric observations at $\sim$2.2 μm have been obtained for five HBes representing two extreme cases concerning the presence of innermost gas and accretion modes. V590 Mon, PDS 281, and HD 94509 show no excess in the near-ultraviolet, Balmer region of the spectra (ΔD_B), indicative of a negligible amount of inner gas and disk-to-star accretion, whereas DG Cir and HD 141926 show such strong ΔD_B values that cannot be reproduced from magnetospheric accretion, but probably come from the alternative boundary layer mechanism. Additional data for these and all HAeBes resolved through K-band interferometry have been compiled from the literature and updated using Gaia EDR3 distances, almost doubling previous samples used to analyze the size-luminosity relation. We find no general trend linking the presence of gas inside the dust destruction radius or the accretion mechanism with the location of HAeBes in the size-luminosity diagram. Underlying trends are present and must be taken into account when interpreting the size-luminosity correlation. Still, it is argued that the size-luminosity correlation is most likely to be physically relevant in spite of the previous statistical warning concerning dependencies on distance.

9. Hot Molecular Core Candidates in the Galactic Center 50 km/s Molecular Cloud

Ryosuke Miyawaki, Masato Tsuboi, Kenta Uehara, Atsushi Miyazaki ★ We present the results based on the 2.5 arcsec-resolution observations using Atacama Large Millimeter/submillimeter Array (ALMA) of the Galactic Center Molecular Cloud G-0.02-0.07, or the 50 km/s Molecular Cloud (50MC), in the SO ($N_J = 2_2 - 1_1$) line and 86 GHz continuum emission, the combination of which is considered to trace "hot molecular core candidates" (HMCCs) appearing in the early stage of massive star formation. In the 86-GHz continuum image, we identified nine dust cores in the central part of the 50MC, in which four famous compact HII regions are located. No new ultra-compact HII regions were found. We also identified 28 HMCCs in the 50MC with the SO line. The overall SO distribution had no clear positional correlation with the identified HII regions. The HMCCs in the 50MC showed a variety of association and non-association with dust and Class-I CH3OH maser emissions. The

variety suggests that they are not in a single evolutionary stage or environment. Nevertheless, the masses of the identified HMCCs were found to be well approximated by a single power law of their radii, $M_{LTE}/(M_\odot)=5.44 \times 10^5 (r/(pc))^{2.17}$ at T_{ex} = 50-100 K. The derived HMCC masses were larger than those of the molecular cores with the same radii in the 50MC and also than those of the molecular clumps in the Galactic disk. Additional observations are needed to confirm the nature of these HMCCs in the 50MC.

10. The Core Mass Function Across Galactic Environments. III. Massive Protoclusters

Theo J. O'Neill, Giuliana Cosentino, Jonathan C. Tan, Yu Cheng, Mengyao Liu ★ The stellar initial mass function (IMF) is fundamental for many areas of astrophysics, but its origin remains poorly understood. It may be inherited from the core mass function (CMF) or arise as a result of more chaotic, competitive accretion. Dense, gravitationally bound cores are seen in molecular clouds and some observations have suggested that the CMF is similar in shape to the IMF, though translated to higher masses by a factor of ~ 3. Here we measure the CMF in 28 dense clumps within 3.5 kpc that are likely to be central regions of massive protoclusters, observed via 1.3 mm dust continuum emission by the ALMAGAL project. We identify 222 cores using the dendrogram algorithm with masses ranging from 0.04 to 252 $M_\odot$. We apply completeness corrections for flux and number recovery, estimated from core insertion and recovery experiments. At higher masses, the final derived CMF is well described by a single power law of the form $dN/d\log M \propto M^{-\alpha}$ with $\alpha \simeq 0.94 \pm 0.08$. However, we find evidence of a break in this power-law behavior between ~ 5 and 15 $M_\odot$, which is, to our knowledge, the first time such a break has been found in distant ($\gtrsim 1$ kpc) regions by ALMA. We compare this massive protocluster CMF with those derived using the same methods in the G286 protocluster and a sample of Infrared Dark Clouds. The massive protocluster CMF is significantly different, i.e., containing more massive cores, which is a potential indication of the role of environment on the CMF and IMF.

11. Interstellar objects follow the collapse of molecular clouds

Susanne Pfalzner, Dylan Paterson, Michele T. Bannister, Simon Portegies Zwart ★ Interstellar objects (ISOs), the parent population of 1I/Oumuamua and 2I/Borisov, are abundant in the interstellar medium of the Milky Way. This means that the interstellar medium, including molecular cloud regions, has three components: gas, dust, and ISOs. From the observational constraints for the field density of ISOs drifting in the solar neighbourhood, we infer a typical molecular cloud of 10 pc diameter contains some 10^{18} ISOs. At typical sizes ranging from hundreds of metres to tens of km, ISOs are entirely decoupled from the gas dynamics in these molecular clouds. Here we address the question of whether ISOs can follow the collapse of molecular clouds. We perform low-resolution simulations of the collapse of molecular clouds containing initially static ISO populations toward the point where stars form. In this proof-of-principle study, we find that the interstellar objects definitely follow the collapse of the gas – and many become bound to the new-forming numerical approximations to future stars (sinks). At minimum, 40% of all sinks have one or more ISO test particles gravitationally bound to them for the initial ISO distributions tested here. This value corresponds to at least 10^{10} actual interstellar objects being bound after three initial free-fall times. Thus, ISOs are a relevant component of star formation. We find that more massive sinks bind disproportionately large fractions of the initial ISO population, implying competitive capture of ISOs. Sinks can also be solitary, as their ISOs can become unbound again – particularly if sinks are ejected from the system. Emerging planetary systems will thus develop in remarkably varied environments, ranging from solitary to richly populated with bound ISOs.

12. Understanding the angular momentum evolution of T Tauri and Herbig Ae/Be stars

Giovanni Pinzón, Jesús Hernández, Javier Serna, Alexandra García, Ezequiel Manzo-Martínez, Alexandre Roman-Lopes, Carlos G. Román-Zúñiga, Maria Gracia Batista, Julio Ramírez-Vélez, Yeisson Osorio, Ronald Avendaño ★ We investigate a sample of 6 Herbig Ae/Be stars belonging to the Orion OB1 association, as well as 73 low mass objects, members of the σ Orionis cluster, in order to explore the angular momentum evolution at early stages of evolution, and its possible connection with main-sequence Ap/Bp magnetic stars. Using FIES and HECTOCHELLE spectra, we obtain projected rotational velocities through two independent methods. Individual masses, radii, and ages were computed using evolutionary models, distance, and cluster extinction. Under the assumption that similar physical processes operate in both, T Tauri and Herbig Ae/Be stars, we construct snapshots of the protostar's rotation against mass during the first 10 Myr with the aid of a rotational model that includes a variable disc lifetime, changes in the stellar moment of inertia, a dipolar magnetic field with variable strength, and angular momentum loss through stellar winds powered by accretion. We use these snapshots, as well as the rotational data, to infer a plausible scenario for the angular momentum evolution. We find that magnetic field strengths of a few kG at 3 Myr are required to match the rotational velocities of both groups of stars. Models with masses between 2-3 $M_\odot$ display larger angular momentum by a factor of ~ 3, in comparison to stars of similar spectral types on the main-sequence. Even though some quantitative estimates on this dramatic decrease with age, for Ap/Bp magnetic main-sequence stars are presented, the results obtained for the angular momentum evolution do not explain their low rotation.

13. Census of High- and Medium-mass Protostars V. CO Abundance and the Galactic $X_{\rm CO}$ Factor

Rebecca L. Pitts, Peter J. Barnes ★ We present the second dust continuum data release in the Census of High- and Medium-mass Protostars (CHaMP), expanding the methodology trialed in Pitts et al. 2019 to the entire CHaMP survey area ($280^\circ < l < 300^\circ$, $-4^\circ < b < +2^\circ$). This release includes maps of dust temperature (T_d), H_2 column density (N_{H_2}), gas-phase CO abundance, and temperature-density plots for every prestellar clump with Herschel coverage, showing no evidence of internal heating for most clumps in our sample. We show that CO abundance is a strong function of T_d, and can be fit with a second-order polynomial in log-space, with a typical dispersion of a factor of 2–3. The CO abundance peaks at $20.0^{+0.4}_{-1.0}$ K with a value of $7.4^{+0.2}_{-0.3} \times 10^{-5}$ per H_2; the low T_d at which this maximal abundance occurs relative to laboratory results is likely due to interstellar UV bombardment in the largest survey fields. Finally, we show that, as predicted by theoretical literature and hinted at in previous studies of individual clouds, the conversion factor from integrated ^{12}CO line intensity ($I_{^{12}CO}$) to N_{H_2}, the X_{CO}-factor, varies as a broken power-law in $I_{^{12}CO}$ with a transition zone between 70 and 90 K km^{-1}. The X_{CO}-function we propose has $N_{H_2} \propto I_{^{12}CO}^{0.51}$ for $I_{^{12}CO} \lesssim 70$ K km^{-1} and $N_{H_2} \propto I_{^{12}CO}^{2.3}$ for $I_{^{12}CO} \gtrsim 90$ K km^{-1}. The high-$I_{^{12}CO}$ side should be generalizable with known adjustments for metallicity, but the influence of interstellar UV fields on the low-$I_{^{12}CO}$ side may be sample specific. We discuss how these results expand upon previous works in the CHaMP series, and help tie together observational, theoretical, and laboratory studies on CO over the past decade.

14. Disk Masses and Dust Evolution of Protoplanetary Disks Around Brown Dwarfs

Anneliese M. Rilinger, Catherine C. Espaillat ★ We present the largest sample of brown dwarf (BD) protoplanetary disk spectral energy distributions modeled to date. We compile 46 objects with ALMA observations from four star-forming regions: ρ Ophiuchus, Taurus, Lupus, and Upper Scorpius. Studying multiple regions with various ages enables us to probe disk evolution over time. Specifically, from our models we obtain values for dust grain sizes, dust settling, and disk mass; we compare how each of these parameters vary between the regions. We find that disk mass generally decreases with age, though the youngest region, Ophiuchus, has the lowest disk masses. We find evidence of disk evolution (i.e., grain growth and significant dust settling) in all four regions, indicating that planet formation and disk evolution may begin to occur at earlier stages. We generally find these disks contain too little mass to form planetary companions, though we cannot rule out that planet formation may have already occurred. Finally, we examine the disk mass – host mass relationship and find that BD disks are largely consistent with previously-determined relationships for disks around T Tauri stars.

15. Discovery in space of ethanolamine, the simplest phospholipid head group

Víctor M. Rivilla, Izaskun Jiménez-Serra, Jesús Martín-Pintado, Carlos Briones, Lucas F. Rodríguez-Almeida, Fernando Rico-Villas, Belén Tercero, Shaoshan Zeng, Laura Colzi, Pablo de Vicente, Sergio Martín, Miguel A. Requena-Torres ★ Cell membranes are a key element of life because they keep the genetic material and metabolic machinery together. All present cell membranes are made of phospholipids, yet the nature of the first membranes and the origin of phospholipids are still under debate. We report here the first detection in space of ethanolamine, $NH_2CH_2CH_2OH$, which forms the hydrophilic head of the simplest and second most abundant phospholipid in membranes. The molecular column density of ethanolamine in interstellar space is N=(1.51±0.07)×10^{13} cm^{-2}, implying a molecular abundance with respect to H_2 of (0.9-1.4)×10^{-10}. Previous studies reported its presence in meteoritic material but they suggested that it is synthesized in the meteorite itself by decomposition of amino acids. However, we find that the proportion of the molecule with respect to water in the interstellar medium is similar to the one found in the meteorite (10^{-6}). These results indicate that ethanolamine forms efficiently in space and, if delivered onto early Earth, it could have contributed to the assembling and early evolution of primitive membranes.

16. Detection of the cyanomidyl radical (HNCN): a new interstellar species with the NCN backbone

V. M. Rivilla, I. Jiménez-Serra, J. García de la Concepción, J. Martín-Pintado, L. Colzi, L. F. Rodríguez-Almeida, B. Tercero, F. Rico-Villas, S. Zeng, S. Martín, M. A. Requena-Torres, P. de Vicente ★ We report here the first detection in the interstellar medium of the cyanomidyl radical (HNCN). Using the Yebes 40m and the IRAM 30m telescopes, we have targeted the doublets of the N=2−1, 4−3, 5−4, 6−5, and 7−6 transitions of HNCN toward the molecular cloud G+0.693-0.027. We have detected three unblended lines of HNCN, these are the N=6−5 doublet and one line of the N=4−3 transition. Additionally we present one line of the N=5−4 transition partially blended with emission from other species. The Local Thermodynamic Equilibrium best fit to the data gives a molecular abundance of (0.91±0.05)×10^{-10} with respect to H_2. The relatively low abundance of this species in G+0.693-0.027, and its high reactivity, suggest that HNCN is possibly produced by gas-phase chemistry. Our work shows that this highly reactive molecule is present in interstellar space, and thus it represents a plausible precursor of larger prebiotic molecules with the NCN backbone such as cyanamide (NH_2CN), carbodiimide (HNCNH) and formamidine (NH_2CHNH).

17. The dipper population of Taurus seen with K2

Noemi Roggero, Jérôme Bouvier, Luisa M. Rebull, Ann Marie Cody ★ Dippers are typically low-mass, pre-main-sequence stars that display dips in their light curves. These dips have been attributed to dusty warps that form in the inner part of the disk. Our goal is to derive the properties of dipper stars in Taurus to assess the physical mechanisms that induce dipper light curves. We used the light curves of K2 C4 and C13 to select a dipper sample among 179 members and possible members of the Taurus star-forming region based on the light-curve morphology. We studied the periodicities by combining periodograms with wavelet analysis and derived the stellar parameters from the photometry. We also studied the morphology of the photometric dips. We find a dipper occurrence of 30% in disk-bearing stars observed with K2 that were identified visually by us. This represents a lower limit to their true occurrence. About half of the dippers are aperiodic, and most of these are dominated by another type of variability. The chosen sample is of late spectral type (K/M), low mass and moderate mass accretion rates and has periods of a few days. We observed a transient dipper over a few rotation cycles and a dipper with a changing period. The structure of the dips can be complex and varies strongly over timescales of down to one stellar rotation. The corotation radii are located at a few stellar radii, and the temperatures at corotation allow dust survival. Many of the systems are seen at moderate to high inclination. We find that the angular extension of the dusty structure producing the dips is correlated with the stellar period. Magnetospheric accretion, which causes an accretion column and its base to occult the star, can explain most of the observed light curves. Although compatible with the model, many of the stellar inclination angles are moderate and do not exclude mechanisms other than the occultation by an inner disk warp to account for dipper light curves.

18. Impact of the external radiation field on the structure and evolution of supernova remnants

Mario Romero, Yago Ascasibar, Jan Palouš, Richard Wünsch, Mercedes Mollá ★ We carry out 1D hydrodynamical simulations of the evolution of a spherically symmetric supernova remnant (SNR) subject to an external radiation field (ERF) that influences the cooling and heating rates of the gas. We consider homogeneous media with ambient hydrogen number densities $n_{\rm H,0}$ of 0.1 and 1 cm^{-3} permeated by an average radiation field including the cosmic microwave, extragalactic, and Galactic backgrounds, attenuated by an effective column density $N_{\rm H,eff}$ from 10^{18} to 10^{21} cm^{-2}. Our results may be classified into two broad categories: at low $N_{\rm H,eff}$, the ERF presents little absorption in the ultraviolet (ionising) regime, and all the 'unshielded' cases feature an equilibrium temperature $T_{eq} \sim 7000$ K below which the ambient gas cannot cool further. In this scenario, the SNR develops a nearly isothermal shock profile whose shell becomes thicker over time. At higher $N_{\rm H,eff}$, the ERF is heavily absorbed in the UV range, yielding a roughly constant heating function for temperatures $\lesssim 10^4$ K. These 'shielded' cases develop a thin, cold and dense shell throughout their evolution. Energy and momentum injection to the medium do not change significantly between both scenarios, albeit luminosity is higher and more uniformly distributed over the shell for unshielded SNR.

19. A multi-line study of the filamentary infrared dark cloud G351.78-0.54

O. L. Ryabukhina, I. I. Zinchenko ★ We present results of a multi-line study of the filamentary infrared dark cloud G351.78-0.54 in the 1.3 and 0.8 mm wavelength bands. The lines of the three isotopologues of carbon monoxide CO, N_2H^+, CH_3CCH and HNCO were observed. The aim was to study the general structure of the filamentary cloud, its fragmentation and physical parameters with the emphasis on properties of dense clumps in this cloud. Several dense clumps are identified from the N_2H^+ (3-2) data, their masses and virial parameters are determined using the $C^{18}O$ (2-1) line. Temperatures of some clumps are estimated from the CH_3CCH and HNCO data. Almost all clumps appear to be gravitationally unstable. The density estimates obtained from the $C^{18}O$ (3-2)/(2-1) and N_2H^+ (3-2)/(1-0) intensity ratios are in the range $n \sim (0.3-3) \times 10^5$ cm^{-2}. The HNCO emission is detected exclusively toward the first clump which contains the luminous IR source IRAS 17233-3606, and indicates an even higher density. It is observed in the outflow, too. The velocity shift of the higher excitation HNCO lines may indicate a movement of the hot core relative the surrounding medium. In some clumps there is a velocity shift ~ 1 km s^{-1} between N_2H^+ (3-2) and CO isotopologues. The large widths of the N_2H^+ (3-2) line in the clumps indicate an increase of the velocity dispersion in their dense interiors, which may be related to the star formation process. The N_2H^+ abundance drops toward the luminous IR source.

20. Evolution of the atomic component in protostellar outflows

T. Sperling, J. Eislöffel, B. Nisini, T. Giannini, C. Fischer, A. Krabbe ★ We present SOFIA/FIFI-LS observations of three Class 0 and one Class I outflows (Cep E, HH 1, HH 212, and L1551 IRS5) in the far-infrared [O I]63mum and [O I]145mum transitions. Spectroscopic [O I]63mum maps enabled us to infer the spatial extent of warm, low-excitation atomic gas within these protostellar outflows. If proper shock conditions prevail, the instantaneous mass-ejection rate is directly connected to the [O I]63mum luminosity. In order to unravel evolutionary trends, we analysed a set of 14 Class 0/I outflow sources that were spatially resolved in the [O I]63mum emission. We compared these data with a sample of 72 Class 0/I/II outflow sources that have been observed with Herschel (WISH, DIGIT, WILL, GASPS surveys) without spatially resolving the [O I]63mum line.

21. A study of the photometric and spectroscopic variations of the prototypical FU Orionis-type star V1057 Cyg

Zs. M. Szabó, Á. Kóspál, P. Ábrahám, S. Park, M. Siwak, J. D. Green, A. Moór, A. Pál, J. A. Acosta-Pulido, J. -E. Lee, B. Cseh, G. Csörnyei, O. Hanyecz, R. Könyves-Tóth, M. Krezinger, L. Kriskovics, A. Ordasi, K. Sárneczky, B. Seli, R. Szakáts, A. Szing, K. Vida ★ Among the low-mass pre-main sequence stars, a small group called FU Orionis-type objects (FUors) are notable for undergoing powerful accretion outbursts. V1057 Cyg, a classical example of an FUor, went into outburst around 1969-1970, after which it faded rapidly, making it the fastest fading FUor known. Around 1995, a more rapid increase in fading occurred. Since that time, strong photometric modulations have been present. We present nearly 10 years of source monitoring at Piszkéstető Observatory, complemented with optical/near-infrared photometry and spectroscopy from the Nordic Optical Telescope, Bohyunsan Optical Astronomy Observatory, Transiting Exoplanet Survey Satellite, and the Stratospheric Observatory for Infrared Astronomy. Our light curves show continuation of significant quasi-periodic variability in brightness over the past decade. Our spectroscopic observations show strong wind features, shell features, and forbidden emission lines. All of these spectral lines vary with time. We also report the first detection of [S II], [N II], and [O III] lines in the star.

22. The *Gaia* view of the Cepheus flare

Máté Szilágyi, Mária Kun, Péter Ábrahám ★ We present a new census of candidate pre-main-sequence stars in the Cepheus flare star-forming region, based on *Gaia* EDR3 parallaxes, proper motions, and colour−magnitude diagrams. We identified new candidate members of the previously known young stellar groups associated with NGC 7023, L1177, L1217/L1219, L1228, L1235, and L1251. We studied the 3D structure of the star-forming complex and the distribution of tangential velocities of the young stars. The young stellar groups are located between 330 and 368 pc from the Sun, divide into three kinematic subgroups, and have ages between 1−5 million years. The results confirm the scenario of propagating star formation, suggested by previous studies. In addition to the bulk pre-main-sequence star population between 330 and 370 pc, there is a scattered and more evolved pre-main-sequence population around 150−180 pc. We found new candidate members of the nearby Cepheus Association, and identified a new moving group of 46, 15−20 million years old pre-main-sequence stars located at a distance of 178 pc, around the A0-type star HD 190833. A few pre-main-sequence stars are located at 800−900 pc, indicative of star-forming regions associated with the Galactic local arm above the Galactic latitude of $+10^\circ$.

23. Molecular Cloud Cores with High Deuterium Fractions: Nobeyama Mapping Survey

Ken'ichi Tatematsu, Gwanjeong Kim, Tie Liu, Neal J. Evans II, Hee-Weon Yi, Jeong-Eun Lee, Yuefang Wu, Naomi Hirano, Sheng-Yuan Liu, Somnath Dutta, Dipen Sahu, Patricio Sanhueza, Kee-Tae Kim, Mika Juvela, L. Viktor T'oth, Orsolya Feh'er, Jinhua He, J. X. Ge, Siyi Feng, Minho Choi, Miju Kang, Mark A. Thompson, Gary A. Fuller, Di Li, Isabelle Ristorcelli, Ke Wang, James Di Francesco, David Eden, Satoshi Ohashi, Ryo Kandori, Charlotte Vastel, Tomoya Hirota, Takeshi Sakai, Xing Lu, Quang Nguyen Lu'o'ng, Hiroko Shinnaga, Jungha Kim, JCMT Large Program "SCOPE" collaboration ★ We present the results of on-the-fly mapping observations of 44 fields containing 107 SCUBA-2 cores in the emission lines of molecules, N_2H^+, HC_3N, and CCS at 82−94 GHz using the Nobeyama 45-m telescope. This study aimed at investigating the physical properties of cores that show high deuterium fractions and might be close to the onset of star formation. We found that the distributions of the N_2H^+ and HC_3N line emissions are approximately similar to that of 850-μm dust continuum emission, whereas the CCS line emission is often undetected or is distributed in a clumpy structure surrounding the peak position of the 850-μm dust continuum emission. Occasionally (12%), we observe the CCS emission which is an early-type gas tracer toward the young stellar object, probably due to local high excitation. Evolution toward star formation does not immediately affect nonthermal velocity dispersion.

24. Thermal Wave Instability as an Origin of Gap and Ring Structures in Protoplanetary Disks

Takahiro Ueda, Mario Flock, Tilman Birnstiel ★ Recent millimeter and infrared observations have shown that gap and ring-like structures are common in both dust thermal emission and scattered-light of protoplanetary disks. We investigate the impact of the so-called Thermal Wave Instability (TWI) on the millimeter and infrared scattered-light images of disks. We perform 1+1D simulations of the TWI and confirm that the TWI operates when the disk is optically thick enough for stellar light, i.e., small-grain-to-gas mass ratio of $\gtrsim 0.0001$. The mid-plane temperature varies as the waves propagate and hence gap and ring structures can be seen in both millimeter and infrared emission. The millimeter substructures can be observed even if the disk is fully optically thick since it is induced by the temperature variation, while density-induced substructures would disappear in the optically thick regime. The fractional separation between TWI-induced ring and gap is $\Delta r/r \sim 0.2$-0.4 at $\sim$ 10-50 au, which is comparable to those found by ALMA. Due to the temperature variation, snow lines of volatile species move radially and multiple snow lines are observed even for a single species. The wave propagation velocity is as fast as ~ 0.6 au yr^{-1}, which can be potentially detected with a multi-epoch observation with a time separation of a few years.

25. Multicolor Variability of Young Stars in the Lagoon Nebula: Driving Causes and Intrinsic Timescales

Laura Venuti, Ann Marie Cody, Luisa M. Rebull, Giacomo Beccari, Mike Irwin, Sowmya Thanvantri, Steve B. Howell, Geert Barentsen ★ Space observatories have provided unprecedented depictions of the many variability behaviors typical of low-mass, young stars. However, those studies have so far largely omitted more massive objects ($\sim$2 $M_{\odot}$ to 4-5 $M_{\odot}$), and were limited by the absence of simultaneous, multi-wavelength information. We present a new study of young star variability in the $\sim$1-2 Myr-old, massive Lagoon Nebula region. Our sample encompasses 278 young, late-B to K-type stars, monitored with Kepler/K2. Auxiliary $u, g, r, i, H\alpha$ time series photometry, simultaneous with K2, was acquired at the Paranal Observatory. We employed this comprehensive dataset and archival infrared photometry to determine individual stellar parameters, assess the presence of circumstellar disks, and tie the variability behaviors to inner disk dynamics. We found significant mass-dependent trends in variability properties, with B/A stars displaying substantially reduced levels of variability compared to G/K stars for any light curve morphology. These properties suggest different magnetic field structures at the surface of early-type and later-type stars. We also detected a dearth of some disk-driven variability behaviors, particularly dippers, among stars earlier than G. This indicates that their higher surface temperatures and more chaotic magnetic fields prevent the formation and survival of inner disk dust structures co-rotating with the star. Finally, we examined the characteristic variability timescales within each light curve, and determined that the day-to-week timescales are predominant over the K2 time series. These reflect distinct processes and locations in the inner disk environment, from intense accretion triggered by instabilities in the innermost disk regions, to variable accretion efficiency in the outer magnetosphere.

26. Tree-based solvers for adaptive mesh refinement code FLASH – II: radiation transport module TreeRay

Richard Wünsch, Stefanie Walch, František Dinnbier, Daniel Seifried, Sebastian Haid, Andre Klepitko, Anthony P. Whitworth, Jan Palouš ★ The treatment of radiative transfer with multiple radiation sources is a critical challenge in simulations of star formation and the interstellar medium. In this paper we present the novel TreeRay method for solving general radiative transfer problems, based on reverse ray tracing combined with tree-based accelerated integration. We implement TreeRay in the adaptive mesh refinement code FLASH, as a module of the tree solver developed by Wünsch et al. However, the method itself is independent of the host code and can be implemented in any grid based or particle based hydrodynamics code. A key advantage of TreeRay is that its computational cost is independent of the number of sources, making it suitable for simulations with many point sources (e.g. massive star clusters) as well as simulations where diffuse emission is important. A very efficient communication and tree-walk strategy enables TreeRay to achieve almost ideal parallel scalings. TreeRay can easily be extended with sub-modules to treat radiative transfer at different wavelengths and to implement related physical processes. Here, we focus on ionising (EUV) radiation and use the On-the-Spot approximation to test the method and its parameters. The ability to set the tree solver time step independently enables the speedy calculation of radiative transfer in a multi-phase interstellar medium, where the hydrodynamic time step is typically limited by the sound speed of the hot gas produced in stellar wind bubbles or supernova remnants. We show that complicated simulations of star clusters with feedback from multiple massive stars become feasible with TreeRay.

27. No impact of core-scale magnetic field, turbulence, or velocity gradient on sizes of protostellar disks in Orion A

Hsi-Wei Yen, Bo Zhao, Patrick M. Koch, Aashish Gupta ★ We compared the sizes and fluxes of a sample of protostellar disks in Orion A measured with the ALMA 0.87 mm continuum data from the VANDAM survey with the physical properties of their ambient environments on the core scale of 0.6 pc estimated with the GBT GAS NH3 and JCMT SCUPOL polarimetric data. We did not find any significant dependence of the disk radii and continuum fluxes on a single parameter on the core scale, such as the non-thermal line width, magnetic field orientation and strength, or magnitude and orientation of the velocity gradient. Among these parameters, we only found a positive correlation between the magnitude of the velocity gradient and the non-thermal line width. Thus, the observed velocity gradients are more likely related to turbulent motion but not large-scale rotation. Our results of no clear dependence of the disk radii on these parameters are more consistent with the expectation from non-ideal MHD simulations of disk formation in collapsing cores, where the disk size is self-regulated by magnetic braking and diffusion, compared to other simulations which only include turbulence and/or a magnetic field misaligned with the rotational axis. Therefore, our results could hint that the non-ideal MHD effects play a more important role in the disk formation. Nevertheless, we cannot exclude the influences on the observed disk size distribution by dynamical interaction in a stellar cluster or amounts of angular momentum on the core scale, which cannot be probed with the current data.

28. TIMES I: a Systematic Observation in Multiple Molecular Lines Toward the Orion A and Ophiuchus Clouds

Hyeong-Sik Yun, Jeong-Eun Lee, Yunhee Choi, Neal J. Evans II, Stella S. R. Offner, Mark H. Heyer, Brandt A. L. Gaches, Yong-Hee Lee, Giseon Baek, Minho Choi, Hyunwoo Kang, Seokho Lee, Ken'ichi Tatematsu, Yao-Lun Yang, How-Huan Chen, Youngung Lee, Jae Hoon Jung, Changhoon Lee, Jungyeon Cho ★ We have used the Taeduk Radio Astronomy Observatory to observe the Orion A and Ophiuchus clouds in the J =1−0 lines of ^{13}CO, C^{18}O, HCN, HCO$^+$, and N_2H^+ and the J =2−1 line of CS. The fully sampled maps with uniform noise levels are used to create moment maps. The variations of the line intensity and velocity dispersion with total column density, derived from dust emission maps, are presented and compared to previous work. The CS line traces dust column density over more than one order of magnitude, and the N_2H^+ line best traces the highest column density regime ($\log(N_{H_2}) > 22.8$). Line luminosities, integrated over the cloud, are compared to those seen in other galaxies. The HCO$^+$-to-HCN luminosity ratio in the Orion A cloud is similar to that of starburst galaxies, while that in the Ophiuchus cloud is in between those of active galactic nuclei and starburst galaxies.