# The Star Formation Newsletter

A community newsletter on Star and Planet Formation research

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**Cover image caption**

Near-Infrared color composite (JHKs) of the head of the Orion A molecular cloud. The image covers about $2 \times 2$ deg$^2$ or about $14 \times 14$ pc$^2$ at the distance of 400 pc. The distribution of dense star-forming gas in the region (not visible in the image) follows a narrow, seven pc long filament in the shape of an integral sign (the Integral Shape Filament) containing the well-known Orion Nebula and the closest factory of massive stars, the Trapezium Cluster, that are powering the nebula. This region is the most active star-forming region in the local kpc of the Milky Way. Credit: VISION Survey, Meingast et al. 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. **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. The stellar content of H72.97-69.39, a potential super star cluster in the making

**M. Andersen, H. Zinnecker, A. S. Hirschauer, O. Nayak, M. Meixner** ★ Young Massive Clusters (YMCs) and Super Star Clusters (SSCs) represent an extreme mode of star formation. Far-infrared imaging of the Magellanic Clouds has identified one potential embedded SSC, HSO BMHERICC J72.971176-69.391112 (HH in short), in the south-west outskirts of the Large Magellanic Cloud. We present Gemini Flamingos 2 and GSAOI near-infrared imaging of a 3'x3' region around HH in order to characterize the stellar content of the cluster. The stellar content is probed down to 1.5 Msun. We find substantial dust extinction across the cluster region, extending up to $A_K$ of 3. Deeply embedded stars are associated with ALMA-detected molecular gas suggesting that star formation is ongoing. The high spatial resolution of the GSAOI data allows identification of the central massive object associated with the 13CO ALMA observations and to detect fainter low-mass stars around the H30alpha ALMA source. The morphology of the molecular gas and the nebulosity from adjacent star formation suggest they have interacted covering a region of several pc. The total stellar content in the cluster is estimated from the intermediate- and high-mass stellar content to be at least 10000 Msun, less than R136 with up to 100 000 Msun within 4.7 pc radius, but places it in the regime of a super star cluster. Based on the extinction determination of individual stars we estimate a molecular gas mass in the vicinity of HH of 6600 Msun, suggesting more star formation can be expected.

## 2. ALMA Observations toward the S-shaped Outflow and the Envelope around NGC1333 IRAS 4A2

**Chen-Yu Chuang, Yusuke Aso, Naomi Hirano, Shingo Hirano, Masahiro N. Machida** ★ We have analyzed the ALMA archival data of the SO ($J_N = 6_5 - 5_4$ and $J_N = 7_6 - 6_5$), CO ($J = 2-1$), and CCH ($N = 3-2, J = 7/2-5/2, F = 4-3$) lines from the class 0 protobinary system, NGC1333 IRAS 4A. The images of SO ($J_N = 6_5 - 5_4$) and CO ($J = 2-1$) successfully separate two northern outflow lobes connected to each protostar, IRAS 4A1 and IRAS 4A2. The outflow from IRAS 4A2 shows an S-shaped morphology, consisting of a flattened envelope around IRAS 4A2 with two outflow lobes connected to both edges of the envelope. The flattened envelope surrounding IRAS 4A2 has an opposite velocity gradient to that of the circumbinary envelope. The observed features are reproduced by the magnetohydrodynamic simulation of the collapsing core whose magnetic field direction is misaligned to the rotational axis. Our simulation shows that the intensity of the outflow lobes is enhanced on one side, resulting in the formation of S-shaped morphology. The S-shaped outflow can also be explained by the precessing outflow launched from an unresolved binary with a separation larger than 12 au (0.04arcsec). Additionally, we discovered a previously unknown extremely high velocity component at ~45-90 km/s near IRAS 4A2 with CO. CCH ($J_{N,F} = 7/2_{3,4} - 5/2_{2,3}$)

emission shows two pairs of blobs attaching to the bottom of shell like feature, and the morphology is significantly different from those of SO and CO lines. Toward IRAS 4A2, the S-shaped outflow shown in SO is overlapped with the edges of CCH shells, while CCH shells have the velocity gradients opposite to the flattened structure around IRAS 4A2.

## 3. Variation of the Core Lifetime and Fragmentation Scale in Molecular Clouds as an Indication of Ambipolar Diffusion

**Indrani Das, Shantanu Basu, Philippe Andre** ★ Ambipolar diffusion likely plays a pivotal role in the formation and evolution of dense cores in weakly-ionized molecular clouds. Linear analyses show that the evolutionary times and fragmentation scales are significantly greater than the hydrodynamic (Jeans) values even for clouds with mildly supercritical mass-to-flux ratio. We utilize values of fragmentation scales and growth times that correspond to typical ionization fractions within a molecular cloud, and apply to the context of the observed estimated lifetime of prestellar cores as well as the observed number of such embedded cores forming in a parent clump. By varying a single parameter, the mass-to-flux ratio, over the range of observationally measured densities, we fit the range of estimated prestellar core lifetimes ($\sim 0.1$ to a few Myr) identified with Herschel as well as the number of embedded cores formed in a parent clump measured in Perseus with the Submillimeter Array (SMA). Our model suggests that the prestellar cores are formed with a transcritical mass-to-flux ratio and higher densities correspond to somewhat higher mass-to-flux ratio but the normalized mass-to-flux ratio $\mu$ remains in the range $1 \lesssim \mu \lesssim 2$. Our best-fit model exhibits $B \propto n^{0.43}$ for prestellar cores, due to partial flux-freezing as a consequence of ambipolar diffusion.

## 4. 1I/'Oumuamua as an N2 ice fragment of an exo-pluto surface. II. Generation of N2 ice fragments and the origin of 'Oumuamua

**Steven J. Desch, Alan P. Jackson** ★ The origin of the interstellar object 1I/'Oumuamua, has defied explanation. In a companion paper (Jackson & Desch, 2021), we show that a body of N2 ice with axes 45 m x 44 m x 7.5 m at the time of observation would be consistent with its albedo, non-gravitational acceleration, and lack of observed CO or CO2 or dust. Here we demonstrate that impacts on the surfaces of Pluto-like Kuiper belt objects (KBOs) would have generated and ejected $10^14$ collisional fragments–roughly half of them H2O ice fragments and half of them N2 ice fragments–due to the dynamical instability that depleted the primordial Kuiper belt. We show consistency between these numbers and the frequency with which we would observe interstellar objects like 1I/'Oumuamua, and more comet-like objects like 2I/Borisov, if other stellar systems eject such objects with efficiency like that of the Sun; we infer that differentiated KBOs and dynamical instabilities that eject impact-generated fragments may be near-universal among extrasolar systems. Galactic cosmic rays would erode such fragments over 4.5 Gyr, so that fragments are a small fraction ( 0.1%) of long-period Oort comets, but C/2016 R2 may be an example. We estimate 'Oumuamua was ejected about 0.4-0.5 Gyr ago, from a young ( $10^8$ yr) stellar system, which we speculate was in the Perseus arm. Objects like 'Oumuamua may directly probe the surface compositions of a hitherto-unobserved type of exoplanet: "exo-plutos". 'Oumuamua may be the first sample of an exoplanet brought to us.

## 5. Estimate on dust scale height from ALMA dust continuum image of the HD 163296 protoplanetary disk

**Kiyoaki Doi, Akimasa Kataoka** ★ We aim at estimating the dust scale height of protoplanetary disks from millimeter continuum observations. First, we present a general expression of intensity of a ring in a protoplanetary disk, and show that we can constrain the dust scale height by the azimuthal intensity variation. Then, we apply the presented methodology to the two distinct rings at 68 au and at 100 au of the protoplanetary disk around HD 163296. We constrain the dust scale height by comparing the DSHARP high-resolution millimeter dust continuum image with radiative transfer simulations using RADMC-3D. We find that $h_d/h_g > 0.84$ at the inner ring and $h_d/h_g < 0.11$ at the outer ring with the 3 sigma uncertainties, where $h_d$ is the dust scale height and $h_g$ is the gas scale height. This indicates that the dust is flared at the inner ring and settled at the outer ring. We further constrain the ratio of turbulence parameter alpha to gas-to-dust-coupling parameter St from the derived dust scale height; alpha/St $> 2.4$ at the inner ring, and alpha/St $< 1.1 \times 10^{-2}$ at the outer ring. This result shows that the turbulence is stronger or the dust is smaller at the inner ring than at the outer ring.

## 6. Two-component Magnetic Field along the Line of Sight to the Perseus Molecular Cloud: Contribution of the Foreground Taurus Molecular Cloud

**Yasuo Doi, Tetsuo Hasegawa, Pierre Bastien, Mehrnoosh Tahani, Doris Arzoumanian, Simon Coudé, Masafumi Matsumura, Sarah Sadavoy, Charles L. H. Hull, Yoshito Shimajiri, Ray S. Furuya, Doug Johnstone, Rene Plume, Shu-ichiro Inutsuka, Jungmi Kwon, Motohide Tamura** ★ Optical stellar polarimetry in the Perseus molecular cloud direction is known to show a fully mixed bi-modal distribution of position angles across the cloud (Goodman et al. 1990). We study the Gaia trigonometric distances to each of these stars and reveal that the two components in position angles trace two different dust clouds along the line of sight. One component, which shows a polarization angle of -37.6 deg +/- 35.2 deg and a higher polarization fraction of 2.0 +/- 1.7%, primarily traces the Perseus molecular cloud at a distance of 300 pc. The

other component, which shows a polarization angle of +66.8 deg +/- 19.1 deg and a lower polarization fraction of 0.8 +/- 0.6%, traces a foreground cloud at a distance of 150 pc. The foreground cloud is faint, with a maximum visual extinction of $< 1$ mag. We identify that foreground cloud as the outer edge of the Taurus molecular cloud. Between the Perseus and Taurus molecular clouds, we identify a lower-density ellipsoidal dust cavity with a size of 100 – 160 pc. This dust cavity locates at l = 170 deg, b = -20 deg, and d = 240 pc, which corresponds to an HI shell generally associated with the Per OB2 association. The two-component polarization signature observed toward the Perseus molecular cloud can therefore be explained by a combination of the plane-of-sky orientations of the magnetic field both at the front and at the back of this dust cavity.

## 7. A Novel Survey for Young Substellar Objects with the W-band filter III: Searching for very low mass brown dwarfs in Serpens South and Serpens Core

**Sophie Dubber, Beth Biller, Katelyn Allers, Jessy Jose, Loïc Albert, Blake Pantoja, Clémence Fontanive, Michael Liu, Zhoujian Zhang, Wen-Ping Chen, Bhavana Lalchand, Belinda Damian, Tanvi Sharma** ★ We present CFHT photometry and IRTF spectroscopy of low-mass candidate members of Serpens South and Serpens Core (∼430 pc, ∼0.5 Myr), identified using a novel combination of photometric filters, known as the W-band method. We report SC182952+011618, SS182959-020335 and SS183032-021028 as young, low-mass Serpens candidate members, with spectral types in the range M7-M8, M5-L0 and M5-M6.5 respectively. Best-fit effective temperatures and luminosities imply masses of $< 0.12 M_{\odot}$ for all three candidate cluster members. We also present Hubble Space Telescope imaging data (F127M, F139M and F850LP) for six targets in Serpens South. We report the discovery of the binary system SS183044-020918AB. The binary components are separated by ≈45 AU, with spectral types of M7-M8 and M8-M9, and masses of 0.08-0.1 and 0.05-0.07$M_{\odot}$. We discuss the effects of high dust attenuation on the reliability of our analysis, as well as the presence of reddened background stars in our photometric sample.

## 8. 870 Micron Dust Continuum of the Youngest Protostars in Ophiuchus

**Frankie J. Encalada, Leslie W. Looney, John J. Tobin, Sarah I. Sadavoy, Dominique Segura-Cox, Erin Cox, Zhi-Yun Li, Giles Novak** ★ We present a 0.15″ resolution (21 au) ALMA 870 $\mu$m continuum survey of 25 pointings containing 31 young stellar objects in the Ophiuchus molecular clouds. Using the dust continuum as a proxy for dust mass and circumstellar disk radius in our sample, we report a mean mass of $2.8^{+2.1}_{-1.3}$ and $2.5^{+9.2}_{-1.1}$ $M_{\oplus}$ and a mean radii of $23.5^{+1.8}_{-1.2}$ and $16.5^{+2.8}_{-0.9}$ au, for Class I and Flat spectrum protostars, respectively. In addition, we calculate the multiplicity statistics of the dust surrounding young stellar objects in Ophiuchus. The multiplicity fraction (MF) and companion star fraction (CSF) of the combined Class I and Flats based solely on this work is 0.25 ± 0.09 and 0.33 ± 0.10, respectively, which are consistent with the values for Perseus and Orion. While we see clear differences in mass and radius between the Ophiuchus and Perseus/Orion protostellar surveys, we do not see any significant differences in the multiplicities of the various regions. We posit there are some differences in the conditions for star formation in Ophiuchus that strongly affects disk size (and consequently disk mass), but does not affect system multiplicity, which could imply important variation in planet formation processes.

## 9. SIRIUS project II: a new tree-direct hybrid code for smoothed particle hydrodynamics/N-body simulations of star clusters

**M. S. Fujii, T. R. Saitoh, L. Wang, Y. Hirai** ★ Star clusters form via clustering star formation inside molecular clouds. In order to understand the dynamical evolution of star clusters in their early phase, in which star clusters are still embedded in their surrounding gas, we need an accurate integration of individual stellar orbits without gravitational softening in the systems including both gas and stars, as well as modeling individual stars with a realistic mass function. We develop a new tree-direct hybrid smoothed particle hydrodynamics/N-body code, ASURA+BRIDGE, in which stars are integrated using a direct N-body scheme or PeTar, a particle-particle particle-tree scheme code, without gravitational softening. In ASURA+BRIDGE, stars are assumed to have masses randomly drawn from a given initial mass function. With this code, we perform star-cluster formation simulations starting from molecular clouds without gravitational softening. We find that artificial dense cores in star-cluster centers due to the softening disappear when we do not use softening. We further demonstrate that star clusters are built up via mergers of smaller clumps. Star clusters formed in our simulations include some dynamically formed binaries with the minimum semi-major axes of a few au, and the binary fraction is higher for more massive stars.

## 10. X-ray Super-Flares From Pre-Main Sequence Stars: Flare Energetics And Frequency

**Konstantin V. Getman, Eric D. Feigelson** ★ Solar-type stars exhibit their highest levels of magnetic activity during their early convective pre-main sequence (PMS) phase of evolution. The most powerful PMS flares, super-flares and mega-flares, have peak X-ray luminosities of $\log(L_X) = 30.5 - 34.0$ erg s$^{-1}$ and total energies $\log(E_X) = 34 - 38$ erg. Among $> 24,000$ X-ray selected young ($t < 5$ Myr) members of 40 nearby star-forming regions from our earlier *Chandra* MYStIX and SFiNCs surveys, we identify and analyze a well-defined sample of 1,086 X-ray super-flares and mega-flares, the largest sample ever studied. Most are considerably more powerful than optical/X-ray super-flares detected on main sequence stars. This study presents energy

estimates of these X-ray flares and the properties of their host stars. These events are produced by young stars of all masses over evolutionary stages ranging from protostars to diskless stars, with the occurrence rate positively correlated with stellar mass. Flare properties are indistinguishable for disk-bearing and diskless stars indicating star-disk magnetic fields are not involved. A slope $\alpha \simeq 2$ in the flare energy distributions $dN/dE_X \propto E_X^{-\alpha}$ is consistent with those of optical/X-ray flaring from older stars and the Sun. Mega-flares ($\log(E_X) > 36.2$ erg) from solar-mass stars have occurrence rate of $1.7^{+1.0}_{-0.6}$ flares/star/year and contribute at least $10-20\%$ to the total PMS X-ray energetics. These explosive events may have important astrophysical effects on protoplanetary disk photoevaporation, ionization of disk gas, production of spallogenic radionuclides in disk solids, and hydrodynamic escape of young planetary atmospheres. Our following paper details plasma and magnetic loop modeling of the $> 50$ brightest X-ray mega-flares.

## 11. Homogeneous study of Herbig Ae/Be stars from spectral energy distributions and Gaia EDR3

**J. Guzman-Diaz, I. Mendigutia, B. Montesinos, R. D. Oudmaijer, M. Vioque, C. Rodrigo, E. Solano, G. Meeus, P. Marcos-Arenal** ★ (Abridged) Herbig Ae/Be stars (HAeBes) have so far been studied based on relatively small samples that are scattered throughout the sky. Their fundamental stellar and circumstellar parameters and statistical properties were derived with heterogeneous approaches before Gaia. Our main goal is to contribute to the study of HAeBes from the largest sample of such sources to date, for which stellar and circumstellar properties have been determined homogeneously from the analysis of the spectral energy distributions (SEDs) and Gaia EDR3 parallaxes and photometry. Multiwavelength photometry was compiled for 209 bona fide HAeBes for which Gaia EDR3 distances were estimated. Using the Virtual Observatory SED Analyser (VOSA), photospheric models were fit to the optical SEDs to derive stellar parameters, and the excesses at infrared (IR) and longer wavelengths were characterized to derive several circumstellar properties. The stellar temperature, luminosity, radius, mass, and age were derived for each star based on optical photometry. In addition, their IR SEDs were classified according to two different schemes, and their mass accretion rates, disk masses, and the sizes of the inner dust holes were also estimated uniformly. The initial mass function fits the stellar mass distribution of the sample within $2 < \mathrm{M}_{star}/\mathrm{M}_{sun} < 12$. In this aspect, the sample is therefore representative of the HAeBe regime and can be used for statistical purposes when it is taken into account that the boundaries are not well probed. A statistical analysis was carried out mainly focused on the different circumstellar properties of Herbig Ae (HAe) and Be (HBe) stars. The complete dataset is available online through a Virtual Observatory-compliant archive, representing the most recent reference for statistical studies on the HAeBe regime.

## 12. The Disc Miner I: A statistical framework to detect and quantify kinematical perturbations driven by young planets in discs

**Andres F. Izquierdo, Leonardo Testi, Stefano Facchini, Giovanni P. Rosotti, Ewine F. van Dishoeck** ★ [Abridged] The study of disc kinematics has recently opened up as a promising method to detect unseen planets. However, a systematic, statistically meaningful analysis of such an approach remains missing. The aim of this work is to devise an automated, statistically robust technique to identify kinematical perturbations induced by the presence of planets in a gas disc, and to accurately infer their location. For this purpose, we produce hydro simulations of planet-disc interactions with different planet masses, 0.3, 1.0 and 3.0 $M_{Jup}$, at a radius of $R = 100$ au in the disc, and perform radiative transfer calculations of CO to simulate observables for 13 planet azimuths. Using the DISCMINER package, we fit the synthetic data cubes with a Keplerian model of the channel-by-channel emission to study line profile differences, including deviations from Keplerian rotation. The detection technique, based on line centroid differences, captures localised planet-driven perturbations, and can distinguish them from axisymmetric velocity perturbations. The method can detect all three simulated planets, at all azimuths, with an average accuracy of $\pm 3^\circ$ in azimuth and $\pm 8$ au in radius. Owing to disc structure and line-of-sight projection effects, planets at azimuths close to $\pm 45^\circ$ yield the highest velocity fluctuations, whereas those at limiting cases, $0^\circ$ and $\pm 90^\circ$, drive the lowest. The observed peak velocities range within $40-70$, $70-170$ and $130-450$ m s$^{-1}$ for 0.3, 1.0 and 3.0 $M_{Jup}$ planets. Our analysis indicates that the variance of peak velocities is boosted near planets due to organised gas motions prompted by their localised gravitational well. We propose an approach that exploits this velocity coherence to provide, for the first time, statistically significant detections of localised planet-driven perturbations in the gas disc kinematics.

## 13. 1I/'Oumuamua as an N2 ice fragment of an exo-Pluto surface: I. size and compositional constraints

**Alan P. Jackson, Steven J. Desch** ★ The origin of the interstellar object 1I/'Oumuamua has defied explanation. We perform calculations of the non-gravitational acceleration that would be experienced by bodies composed of a range of different ices and demonstrate that a body composed of N2 ice would satisfy the available constraints on the non-gravitational acceleration, size and albedo, and lack of detectable emission of CO or CO2 or dust. We find that 'Oumuamua was small, with dimensions 45 m x 44 m x 7.5 m at the time of observation at 1.42 au from the Sun, with a high albedo of 0.64. This albedo is consistent with the N2 surfaces of bodies like Pluto and Triton. We estimate 'Oumuamua was ejected about 0.4-0.5 Gyr ago from a

young stellar system, possibly in the Perseus arm. Objects like 'Oumuamua may directly probe the surface compositions of a hitherto-unobserved type of exoplanet: "exo-plutos". In a companion paper (Desch & Jackson, 2021) we demonstrate that dynamical instabilities like the one experienced by the Kuiper belt, in other stellar systems, plausibly could generate and eject large numbers of N2 ice fragments. 'Oumuamua may be the first sample of an exoplanet brought to us.

## 14. Modeling chemistry during star formation: Water deuteration in dynamic star-forming regions

**S. S. Jensen, J. K. Jørgensen, K. Furuya, T. Haugbølle, Y. Aikawa** ★ Recent observations of the HDO/$H_2O$ ratio toward protostars in isolated and clustered environments show an apparent dichotomy, where isolated sources show higher D/H ratios than clustered counterparts. Establishing which physical and chemical processes create this differentiation can provide insights into the chemical evolution of water during star formation and the chemical diversity during the star formation process and in young planetary systems. Methods: The evolution of water is modeled using 3D physicochemical models of a dynamic star-forming environment. The physical evolution during the protostellar collapse is described by tracer particles from a 3D MHD simulation of a molecular cloud region. Each particle trajectory is post-processed using RADMC-3D to calculate the temperature and radiation field. The chemical evolution is simulated using a three-phase grain-surface chemistry model and the results are compared with interferometric observations of $H_2O$, HDO, and $D_2O$ in hot corinos toward low-mass protostars. Results: The physicochemical model reproduces the observed HDO/$H_2O$ and $D_2O$/HDO ratios in hot corinos, but shows no correlation with cloud environment for similar identical conditions. The observed dichotomy in water D/H ratios requires variation in the initial conditions (e.g., the duration and temperature of the prestellar phase). Reproducing the observed D/H ratios in hot corinos requires a prestellar phase duration $t$ ∼1-3 Myr and temperatures in the range $T \sim$ 10-20 K prior to collapse. This work demonstrates that the observed differentiation between clustered and isolated protostars stems from differences in the molecular cloud or prestellar core conditions and does not arise during the protostellar collapse itself.

## 15. The complex organic molecular content in the L1498 starless core

**Izaskun Jimenez-Serra, Anton I. Vasyunin, Silvia Spezzano, Paola Caselli, Giuliana Cosentino, Serena Viti** ★ Observations carried out toward starless and pre-stellar cores have revealed that complex organic molecules are prevalent in these objects, but it is unclear what chemical processes are involved in their formation. Recently, it has been shown that complex organics are preferentially produced at an intermediate-density shell within the L1544 pre-stellar core at radial distances of 4000 au with respect to the core center. However, the spatial distribution of complex organics has only been inferred toward this core and it remains unknown whether these species present a similar behaviour in other cores. We report high-sensitivity observations carried out toward two positions in the L1498 pre-stellar core, the dust peak and a position located at a distance of 11000 au from the center of the core where the emission of $CH_3OH$ peaks. Similarly to L1544, our observations reveal that small O-bearing molecules and N-bearing species are enhanced by factors 4-14 toward the outer shell of L1498. However, unlike L1544, large O-bearing organics such as CH3CHO, CH3OCH3 or CH3OCHO are not detected within our sensitivity limits. For N-bearing organics, these species are more abundant toward the outer shell of the L1498 pre-stellar core than toward the one in L1544. We propose that the differences observed between O-bearing and N-bearing species in L1498 and L1544 are due to the different physical structure of these cores, which in turn is a consequence of their evolutionary stage, with L1498 being younger than L1544.

## 16. Stars with Photometrically Young Gaia Luminosities Around the Solar System (SPYGLASS) I: Mapping Young Stellar Structures and their Star Formation Histories

**Ronan Kerr, Aaron C. Rizzuto, Adam L. Kraus, Stella S. R. Offner** ★ Young stellar associations hold a star formation record that can persist for millions of years, revealing the progression of star formation long after the dispersal of the natal cloud. To identify nearby young stellar populations that trace this progression, we have designed a comprehensive framework for the identification of young stars, and use it to identify $\sim 3\times10^4$ candidate young stars within a distance of 333 pc using Gaia DR2. Applying the HDBSCAN clustering algorithm to this sample, we identify 27 top-level groups, nearly half of which have little to no presence in previous literature. Ten of these groups have visible substructure, including notable young associations such as Orion, Perseus, Taurus, and Sco-Cen. We provide a complete subclustering analysis on all groups with substructure, using age estimates to reveal each region's star formation history. The patterns we reveal include an apparent star formation origin for Sco-Cen along a semicircular arc, as well as clear evidence for sequential star formation moving away from that arc with a propagation speed of $\sim$4 km s$^{-1}$ ($\sim$4 pc Myr$^{-1}$). We also identify earlier bursts of star formation in Perseus and Taurus that predate current, kinematically identical active star-forming events, suggesting that the mechanisms that collect gas can spark multiple generations of star formation, punctuated by gas dispersal and cloud regrowth. The large spatial scales and long temporal scales on which we observe star formation offer a bridge between the processes within individual molecular clouds and the broad forces guiding star formation at galactic scales.

## 17. ATOMS:ALMA Three-millimeter Observations of Massive Star-forming regions – III: Catalogues of candidate hot molecular cores and Hyper/Ultra compact HII regions

**ATOMS survey - Hong-Li Liu et al.** ★ We have identified 453 compact dense cores in 3 mm continuum emission maps in the ATOMS (ALMA Three-millimeter Observations of Massive Star-forming regions) survey, and compiled three catalogues of high-mass star forming cores. One catalogue, referred to as H/UC-HII catalogue, includes 89 cores that enshroud hyper/ultra compact (H/UC) HII regions as characterized by associated compact H40alpha emission. A second catalogue, referred to as pure s-cHMC, includes 32 candidate Hot Molecular Cores (HMCs) showing rich spectra (N>20lines) of complex organic molecules (COMs) but not associated with H/UC-HII regions. The third catalogue, referred to as pure w-cHMC, includes 58 candidate HMCs with relatively low levels of COM richness and not associated with H/UC-HII regions. These three catalogues of dense cores provide an important foundation for future studies of the early stages of high-mass star formation across the Milky Way. We also find that nearly half of H/UC-HII cores are candidate HMCs. From the number counts of COM-containing and H/UC-HII cores, we suggest that the duration of high-mass protostellar cores showing chemically rich features is at least comparable to the lifetime of H/UC-HII regions. For cores in the H/UC-HII catalogue, the width of the H40alpha line increases as the core size decreases, suggesting that the non-thermal dynamical and/or pressure line-broadening mechanisms dominate on the smaller scales of the H/UC-HII cores.

## 18. Membership of Stars in Open Clusters using Random Forest with Gaia Data

**Md Mahmudunnobe, Priya Hasan, Mudasir Raja, S N Hasan** ★ Membership of stars in open clusters is one of the most crucial parameters in studies of star clusters. Gaia opened a new window in the estimation of membership because of its unprecedented 6-D data. In the present study, we used published membership data of nine open star clusters as a training set to find new members from Gaia DR2 data using a supervised random forest model with a precision of around 90%. The number of new members found is often double the published number. Membership probability of a larger sample of stars in clusters is a major benefit in determination of cluster parameters like distance, extinction and mass functions. We also found members in the outer regions of the cluster and found sub-structures in the clusters studied. The color magnitude diagrams are more populated and enriched by the addition of new members making their study more promising.

## 19. Compact Disks: an explanation to faint CO emission in Lupus disks

**Anna Miotello, Giovanni Rosotti, Megan Ansdell, Stefano Facchini, Carlo F. Manara, Jonathan P. Williams, Simon Bruderer** ★ A large fraction of observed protoplanetary disks in nearby Star-Forming Regions (SFRs) are fainter than expected in CO isotopologue emission. Disks not detected in 13CO line emission are also faint and often unresolved in the continuum emission at an angular resolution of around 0.2 arcseconds. Focusing on the Lupus SFR, the aim of this work is to investigate whether the population of CO-faint disks comprises radially extended and low mass disks - as commonly assumed so far - or if it is of intrinsically radially compact disks, an interpretation that we propose in this paper. The latter scenario was already proposed for individual sources or small samples of disks, while this work targets a large population of disks in a single SFR for which statistical arguments can be made. A new grid of physical-chemical models of compact disks has been run with DALI in order to cover a region of the parameter space that had not been explored before with this code. Such models have been compared with 12CO and 13CO ALMA observations of faint disks in Lupus. Disks that are not detected in 13CO emission and with faint or undetected 12CO emission are consistent with compact disk models. For radially compact disk, the emission of CO isotopologues is mostly optically thick and it scales with the surface area: i.e., it is fainter for smaller objects. The fraction of compact disks is potentially between roughly 50% and 60% of the entire Lupus sample. Deeper observations of 12CO and 13CO at a moderate angular resolution will allow us to distinguish whether faint disks are intrinsically compact, or if they are extended but faint, without the need of resolving them. If the fainter end of the disk population observed by ALMA disk surveys is consistent with such objects being very compact, this will either create a tension with viscous spreading or require MHD winds or external processes to truncate the disks.

## 20. The ionized heart of a molecular disk. ALMA observations of the hyper-compact HII region G24.78+0.08 A1

**Luca Moscadelli, Riccardo Cesaroni, Maria T. Beltrán, Victor M. Rivilla** ★ The study of hyper-compact (HC) or ultra-compact (UC) HII regions is fundamental to understanding the process of massive ($> 8$ $M_\odot$) star formation. We employed Atacama Large Millimeter/submillimeter Array (ALMA) 1.4 mm Cycle 6 observations to investigate at high angular resolution ( 0.050", corresponding to 330 au) the HC HII region inside molecular core A1 of the high-mass star-forming cluster G24.78+0.08. We used the H30alpha emission and different molecular lines of CH3CN and 13CH3CN to study the kinematics of the ionized and molecular gas, respectively. At the center of the HC HII region, at radii $< 500$ au, we observe two mutually perpendicular velocity gradients, which are directed along the axes at PA = 39 deg and PA = 133 deg, respectively. The velocity gradient directed along the axis at PA = 39 deg has an amplitude of 22 km/s $mpc^{-1}$, which is much larger than the other's, 3 km/s $mpc^{-1}$. We interpret these velocity gradients as rotation around, and expansion along, the axis at PA = 39 deg. We propose a scenario where the H30alpha line traces the ionized heart of a disk-jet system that drives the formation of the massive

star ( 20 $M_\odot$) responsible for the HC HII region. Such a scenario is also supported by the position-velocity plots of the CH3CN and 13CH3CN lines along the axis at PA = 133 deg, which are consistent with Keplerian rotation around a 20 $M_\odot$ star. Toward the HC HII region in G24.78+0.08, the coexistence of mass infall (at radii of 5000 au), an outer molecular disk (from $<$ 4000 au to $>$ 500 au), and an inner ionized disk ($<$ 500 au) indicates that the massive ionizing star is still actively accreting from its parental molecular core. To our knowledge, this is the first example of a molecular disk around a high-mass forming star that, while becoming internally ionized after the onset of the HII region, continues to accrete mass onto the ionizing star.

## 21. Linking ice and gas in the Lambda Orionis Barnard 35A cloud

**G. Perotti, J. K. Jørgensen, H. J. Fraser, A. N. Suutarinen, L. E. Kristensen, W. R. M. Rocha, P. Bjerkeli, K. M. Pontoppidan** ★ Dust grains play an important role in the synthesis of molecules in the interstellar medium, from the simplest species to complex organic molecules. How some of these solid-state molecules are converted into gas-phase species is still a matter of debate. Our aim is to directly compare ice and gas abundances of methanol ($CH_3OH$) and CO, and to investigate the relationship between ice and gas in low-mass protostellar envelopes. We present Submillimeter Array and Atacama Pathfinder EXperiment observations of gas-phase $CH_3OH$ and CO towards the multiple protostellar system IRAS05417+0907 located in the B35A cloud. We use archival AKARI ice data toward the same target to calculate $CH_3OH$ and CO gas-to-ice ratios. The CO isotopologues emissions are extended, whereas the $CH_3OH$ emission is compact and traces the giant outflow emanating from IRAS05417+0907. A discrepancy between submillimeter dust emission and $H_2O$ ice column density is found for B35A−4 and B35A−5, similar to what has previously been reported. B35A−2 and B35A−3 are located where the submillimeter dust emission peaks and show $H_2O$ column densities lower than for B35A−4. The difference between the submillimeter continuum emission and the infrared $H_2O$ ice observations suggests that the distributions of dust and $H_2O$ ice differ around the young stellar objects in this dense cloud. The reason for this may be that the sources are located in different environments resolved by the interferometric observations: B35A−2, B35A−3 and in particular B35A−5 are situated in a shocked region plausibly affected by sputtering and heating impacting the submillimeter dust emission pattern, while B35A−4 is situated in a more quiescent part of the cloud. Gas and ice maps are essential to connect small-scale variations in the ice composition with large-scale astrophysical phenomena probed by gas observations.

## 22. The Single-Cloud Star Formation Relation

**Riwaj Pokhrel, Robert A. Gutermuth, Mark R. Krumholz, Christoph Federrath, Mark Heyer, Shivan Khullar, S. Thomas Megeath, Philip C. Myers, Stella S. R. Offner, Judith L. Pipher, William J. Fischer, Thomas Henning, Joseph L. Hora** ★ One of the most important and well-established empirical results in astronomy is the Kennicutt-Schmidt (KS) relation between the density of interstellar gas and the rate at which that gas forms stars. A tight correlation between these quantities has long been measured at galactic scales. More recently, using surveys of YSOs, a KS relationship has been found within molecular clouds relating the surface density of star formation to the surface density of gas; however, the scaling of these laws varies significantly from cloud to cloud. In this Letter, we use a recently developed, high-accuracy catalog of young stellar objects from *Spitzer* combined with high-dynamic-range gas column density maps of twelve nearby (<1.5 kpc) molecular clouds from *Herschel* to re-examine the KS relation within individual molecular clouds. We find a tight, linear correlation between clouds' star formation rate per unit area and their gas surface density normalized by the gas free-fall time. The measured intracloud KS relation, which relates star formation rate to the volume density, extends over more than two orders of magnitude within each cloud and is nearly identical in each of the twelve clouds, implying a constant star formation efficiency per free-fall time $\epsilon_{\rm ff} \approx 0.026$. The finding of a universal correlation within individual molecular clouds, including clouds that contain no massive stars or massive stellar feedback, favors models in which star formation is regulated by local processes such as turbulence or stellar feedback such as protostellar outflows, and disfavors models in which star formation is regulated only by galaxy properties or supernova feedback on galactic scales.

## 23. HH 175: A Giant HH Flow Emanating From A Multiple Protostar

**Bo Reipurth, Per Friberg** ★ HH 175 is an isolated Herbig-Haro object seen towards the B35 cloud in the lambda Ori region. We use deep Subaru 8m interference filter images and Spitzer images to show that HH 175 is a terminal shock in a large collimated outflow from the nearby embedded source IRAS 05417+0907. The body of the eastern outflow lobe is hidden by a dense ridge of gas. The western outflow breaks out of the front of the cometary-shaped B35 cloud, carrying cloud fragments along, which are optically visible due to photoionization by the massive lambda Ori stars. The total extent of the bipolar outflow is 13.7 arcmin, which at the adopted distance of 415 pc corresponds to a projected dimension of 1.65 pc. The embedded source IRAS 05417+0907 is located on the flow axis approximately midway between the two lobes, and near-infrared images show it to be a multiple system of 6 sources, with a total luminosity of 31 Lsun. Millimeter maps in CO, 13CO, and C18O show that the B35 cloud is highly structured with multiple cores, of which the one that spawned IRAS 05417+0907 is located at the apex of B35. It is likely that the embedded source is the result of compression by an ionization-shock front driven by the lambda Ori OB stars.

## 24. Gas phase Elemental abundances in Molecular cloudS (GEMS). IV. Observational results and statistical trends

**M. Rodríguez-Baras, A. Fuente, P. Riviére-Marichalar, D. Navarro-Almaida, P. Caselli, M. Gerin, C. Kramer, E. Roueff, V. Wakelam, G. Esplugues, S. García-Burillo, R. Le Gal, S. Spezzano, T. Alonso-Albi, R. Bachiller, S. Cazaux, B. Commercon, J. R. Goicoechea, J. C. Loison, S. P. Treviño-Morales, O. Roncero, I. Jiménez-Serra, J. Laas, A. Hacar, J. Kirk, V. Lattanzi, R. Martín-Doménech, G. Muñoz-Caro, J. E. Pineda, B. Tercero, D. Ward-Thompson, M. Tafalla, N. Marcelino, J. Malinen, R. Friesen, B. M. Giuliano** ★ Gas phase Elemental abundances in Molecular CloudS (GEMS) is an IRAM 30m Large Program designed to estimate the S, C, N, and O depletions and gas ionization degree, X(e-), in a set of star-forming filaments of Taurus, Perseus and Orion. Our immediate goal is to build up a complete database of molecular abundances that can serve as an observational basis for estimating X(e-) and the C, O, N, and S depletions through chemical modeling. We observed and derived the abundances of 14 species (13CO, C18O, HCO+, H13CO+, HC18O+, HCN, H13CN, HNC, HCS+, CS, SO, 34SO, H2S, and OCS) in 244 positions, covering the AV 3 to 100 mag, n(H2) a few $10^3$ to $10^6$ $cm^{-3}$, and Tk 10 to 30 K ranges in these clouds, avoiding protostars, HII regions, and outflows. A statistical analysis is carried out to identify general trends between different species and with physical parameters. Relations between molecules reveal strong linear correlations which define three different families: (1) 13CO and C18O; (2) H13CO+, HC18O+, H13CN, and HNC; and (3) the S-bearing molecules. The abundances of the CO isotopologs increase with the gas kinetic temperature until TK 15 K. For higher temperatures, the abundance remains constant with a scatter of a factor of 3. The abundances of H13CO+, HC18O+, H13CN, and HNC are well correlated with each other, and all of them decrease with molecular hydrogen density, following the law $n(H2)^{-0.8\pm0.2}$. The abundances of S-bearing species also decrease with n(H2) at a rate of (S-bearing/H)gas $n(H2)^{-0.6\pm0.1}$. The abundances of molecules belonging to groups 2 and 3 do not present any clear trend with gas temperature. At scales of molecular clouds, the C18O abundance is the quantity that better correlates with the cloud mass. We discuss the utility of the 13CO/C18O, HCO+/H13CO+, and H13CO+/H13CN abundance ratios as chemical diagnostics of star formation in external galaxies.

## 25. Probing the structure of a massive filament: ArTeMiS 350 and 450 micron mapping of the integral-shaped filament in Orion A

**F. Schuller, Ph. André, Y. Shimajiri, A. Zavagno, N. Peretto, D. Arzoumanian, T. Csengeri, V. Könyves, P. Palmeirim, S. Pezzuto, A. Rigby, H. Roussel, H. Ajeddig, L. Dumaye, P. Gallais, J. Le Pennec, J. Martignac, M. Mattern, V. Revéret, L. Rodriguez, M. Talvard** ★ (abridged) Within the Orion A molecular cloud, the integral-shaped filament (ISF) is a prominent, degree-long structure of dense gas and dust, with clear signs of recent and on-going high-mass star formation. We used the ArTeMiS bolometer camera at APEX to map a 0.6x0.2 $deg^2$ region covering OMC-1, OMC-2, OMC-3 at 350 and 450 micron. We combined these data with Herschel-SPIRE maps to recover extended emission. The combined Herschel-ArTeMiS maps provide details on the distribution of dense, cold material, with a high spatial dynamic range, from our 8" resolution (0.016 pc) up to the size of the map 10-15 deg. By combining Herschel and ArTeMiS data at 160, 250, 350 and 450 micron, we constructed high-resolution temperature and H2 column density maps. We extracted radial profiles from the column density map in several, representative portions of the ISF, that we fitted with Gaussian and Plummer models to derive their intrinsic widths. We also compared the distribution of material traced by ArTeMiS with that seen in the higher density tracer N2H+(1-0) recently observed with the ALMA interferometer. All the radial profiles that we extracted show clear deviation from a Gaussian, with evidence for an inner plateau, previously not seen using Herschel-only data. We measure intrinsic half-power widths in the range 0.06 to 0.11 pc. This is significantly larger than the Gaussian widths measured for fibers seen in N2H+, which probably traces only the dense innermost regions of the large-scale filament. These half-power widths are within a factor of two of the value of 0.1 pc found for a large sample of nearby filaments in various low-mass star-forming regions, which tends to indicate that the physical conditions governing the fragmentation of prestellar cores within transcritical or supercritical filaments are the same over a large range of masses per unit length.

## 26. First detection of a disk free of volatile elements around a young A-type star: A sign of collisions between rocky planets?

**M. E. van den Ancker, N. P. Gentile Fusillo, T. J. Haworth, C. F. Manara, P. A. Miles-Páez, R. D. Oudmaijer, O. Panic, D. J. M. Petit dit de la Roche, M. G. Petr-Gotzens, M. Vioque** ★ Aims. We present the first detailed analysis of the astrophysical parameters of the poorly studied Sco-Cen member HD 152384 and its circumstellar environment. Methods. We analyze newly obtained optical-near-IR XSHOOTER spectra, as well as archival TESS data, of HD 152384. In addition, we use literature photometric data to construct a detailed spectral energy distribution (SED) of the star. Results. The photospheric absorption lines in the spectrum of HD 152384 are characteristic of a A0 V star, for which we derive a stellar mass of 2.1 ± 0.1 $M_\odot$ and a stellar age > 4.5 Myr. Superimposed on the photospheric absorption, the optical spectrum also displays double-peaked emission lines of Ca II, Fe I, Mg I and Si I, typical of circumstellar disks. Notably, all Hydrogen and Helium lines appear strictly in absorption. A toy model shows that the observed emission line profiles can be reproduced by emission from a compact (radius < 0.3 au) disk seen at an inclination of 24 degrees. Further evidence for the presence of

circumstellar material comes from the detection of a moderate infrared excess in the SED, similar to those found in extreme debris disk systems. Conclusions. We conclude that HD 152384 is surrounded by a tenuous circumstellar disk which, although rich in refractory elements, is highly depleted of volatile elements. To the best of our knowledge such a disk is unique within the group of young stars. However, it is reminiscent of the disks seen in some white dwarfs, which have been attributed to the disruption of rocky planets. We suggest that the disk around HD 152384 may have a similar origin and may be due to collisions in a newly formed planetary system.

## 27. Spitzer Mid-infrared Study of Sh 2-208: Evolution of Protoplanetary Disks in Low-metallicity Environments

**Chikako Yasui** ★ This study presents sensitive MIR photometry obtained with the Spitzer/IRAC for a young cluster in Sh 2-208 (S208) located in one of the lowest-metallicity HII regions in the Galaxy, [O/H] = −0.8 dex. Previous studies suggested that the cluster is ∼0.5-Myr old and has a distance of $D = 4$ kpc, which is consistent with the astrometric distance from Gaia EDR3. In ∼3.5 × 4-arcmin field, 96 sources were detected in at least one MIR band at $\geq 10\sigma$, covering intermediate-mass stars with ∼1.0-$M_{\odot}$ mass detection limit. Total 41 probable cluster members were identified based on the spatial distributions of spectral-energy-distribution slopes derived from the NIR $K_S$ and IRAC bands and extinctions of the sources. The cumulative distribution of the SED slopes for the S208 cluster was not significantly different from those of other clusters in solar-metallicity environments with approximately the same age for intermediate-mass stars, if one also considers non-detected MIR sources identified as S208 cluster members from NIR observations. This suggests that the degree of dust growth/settling does not significantly change with metallicities as different as ∼1 dex. The fraction of stars with MIR disk emissions for the cluster members with ≥1-$M_{\odot}$ mass was 64%-93%, which is comparable to the results in solar-metallicity environments. Although this may suggest that dominant disk-dispersal mechanisms for intermediate-mass stars have either no, or very weak, dependence on metallicity, it can be argued alternatively that this may suggest that the disk dispersal process does not work effectively at this young stage.

## 28. On the interaction of a Bonnor-Ebert sphere with a stellar wind

**Oliver Zier, Andreas Burkert, Christian Alig** ★ The structure of protostellar cores can often be approximated by isothermal Bonnor-Ebert spheres (BES) which are stabilized by an external pressure. For the typical pressure of $10^4 k_B\,\mathrm{K\,cm^{-3}}$ to $10^5 k_B\,\mathrm{K\,cm^{-3}}$ found in molecular clouds, cores with masses below $1.5\,\mathrm{M_\odot}$ are stable against gravitational collapse. In this paper, we analyze the efficiency of triggering a gravitational collapse by a nearby stellar wind, which represents an interesting scenario for triggered low-mass star formation. We derive analytically a new stability criterion for a BES compressed by a stellar wind, which depends on its initial nondimensional radius $\xi_{max}$. If the stability limit is violated the wind triggers a core collapse. Otherwise, the core is destroyed by the wind. We estimate its validity range to $2.5 < \xi_{max} < 4.2$ and confirm this in simulations with the SPH Code GADGET-3. The efficiency to trigger a gravitational collapse strongly decreases for $\xi_{max} < 2.5$ since in this case destruction and acceleration of the whole sphere begin to dominate. We were unable to trigger a collapse for $\xi_{max} < 2$, which leads to the conclusion that a stellar wind can move the smallest unstable stellar mass to $0.5\,\mathrm{M_\odot}$ and destabilizing even smaller cores would require an external pressure larger than $10^5 k_B\,\mathrm{K\,cm^{-3}}$. For $\xi_{max} > 4.2$ the expected wind strength according to our criterion is small enough so that the compression is slower than the sound speed of the BES and sound waves can be triggered. In this case our criterion underestimates somewhat the onset of collapse and detailed numerical analyses are required.