The Star Formation Newsletter

A community newsletter on Star and Planet Formation research

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Links to sections

Cover image caption

And just like that, star and planet formation research enters the JWST age. The now famous "Cosmic Cliffs" image was part of the first JWST image release. NGC 3324 (a lesser known corner of the large Carina complex), located roughly 2.3 kpc away, was imaged by Webb's Near-Infrared Camera (NIRCam) and Mid-Infrared Instrument (MIRI). From Carina to nearby galaxies to faraway galaxies, the new JWST images are a multicolor reminder of the fundamental role of star formation in shaping the Universe. Credit: NASA, ESA, CSA, and STScI.

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 or the SFN.

Abstracts

1. Analytic Approach to the Late Stages of Giant Planet Formation

Fred C Adams, Konstantin Batygin ★ This paper constructs an analytic description for the late stages of giant planet formation. During this phase of evolution, the planet gains the majority of its final mass through gas accretion at a rapid rate. This work determines the density and velocity fields for material falling onto the central planet and its circumplanetary disk, and finds the corresponding column density of this infalling envelope. We derive a steady-state solution for the surface density of the disk as a function of its viscosity (including the limiting case where no disk accretion occurs). Planetary magnetic fields truncate the inner edge of the disk and determine the boundary conditions for mass accretion onto the planet from both direct infall and from the disk. The properties of the forming planet and its circumplanetary disk are determined, including the luminosity contributions from infall onto the planet and disk surfaces, and from disk viscosity. The radiative signature of the planet formation process is explored using a quasi-spherical treatment of the emergent spectral energy distributions. The analytic solutions developed herein show how the protoplanet properties (envelope density distribution, velocity field, column density, disk surface density, luminosity, and radiative signatures) vary with input parameters (instantaneous mass, orbital location, accretion rate, and planetary magnetic field strength).

2. Quantifying kinematic substructure in star-forming regions with statistical tests of spatial autocorrelation

Becky Arnold, Nicholas J. Wright, Richard J. Parker ★ We investigate whether spatial-kinematic substructure in young star-forming regions can be quantified using Moran's I statistic. Its presence in young star clusters would provide an indication that the system formed from initially substructured conditions, as expected by the hierarchical model of star cluster formation, even if the cluster were spatially smooth and centrally concentrated. Its absence, on the other hand, would be evidence that star clusters form monolithically. The Moran's I statistic is applied to N-body simulations of star clusters with different primordial spatial-velocity structures, and its evolution over time is studied. It is found that this statistic can be used to reliably quantify spatial-kinematic substructure, and can be used to provide evidence as to whether the spatial-kinematic structure of regions with ages $\lesssim$ 6 Myr is best reproduced by the hierarchical or monolithic models of star formation. Moran's I statistic is also able to conclusively say whether the data are *not* consistent with initial conditions that lack kinematic substructure, such as the monolithic model, in regions with ages up to, and potentially beyond, 10 Myrs. This can therefore provide a kinematic signature of the star cluster formation process that is observable for many Myr after any initial spatial structure has been erased.

3. Parameters of the Radcliffe wave from masers, radio stars and T Tauri stars

Vadim Bobylev, Anisa Bajkova, Yury Mishurov ★ The presence of the Radcliffe wave is shown both in the positions and in the vertical velocities of masers and radio stars belonging to the Local Arm. This gives the impression that the structure of the Radcliffe wave is not a wave in the full sense of the word. It is more like a local high-amplitude burst, rapidly fading away. Moreover, this structure has the largest amplitude in the immediate vicinity of the Sun, where the main "contributors" are the Gould Belt stars. Based on the spectral analysis of masers, the following estimates of the geometric and kinematic characteristics of the wave were obtained: the largest value of the vertical coordinate $z_{max} = 87 \pm 4$ pc and the wavelength $\lambda = 2.8 \pm 0.1$ kpc, the vertical velocity perturbation amplitude reaches $W_{max} = 5.1 \pm 0.7$ km s^{-1} and the wavelength found from vertical velocities is $\lambda = 3.9 \pm 1.6$ kpc. The Radcliffe wave also manifests itself in the positions of very young stars that have not reached the main sequence stage. We extracted a sample of such stars from the Gaia DR2×AllWISE database and obtained the following estimates from them: $z_{max} = 118 \pm 3$ pc and wavelength $\lambda = 2.0 \pm 0.1$ kpc.

4. Synthetic Polarization Maps of an Outflow Zone from Magnetohydrodynamic Simulations

Gianfranco Bino, Shantanu Basu, Masahiro N Machida, Aris Tritsis, Mahmoud Sharkawi, Kundan Kadam, Indrani Das ★ The canonical theory of star formation in a magnetized environment predicts the formation of hourglass-shaped magnetic fields during the prestellar collapse phase. In protostellar cores, recent observations reveal complex and strongly distorted magnetic fields in the inner regions that are sculpted by rotation and outflows. We conduct resistive, nonideal magnetohydrodynamic (MHD) simulations of a protostellar core and employ the radiative transfer code POLARIS to produce synthetic polarization segment maps. Comparison of our mock-polarization maps based on the toroidal-dominated magnetic field in the outflow zone with the observed polarization vectors of SiO lines in Orion Source I shows a reasonable agreement when the magnetic axis is tilted at an angle $\theta = 15^\circ$ with respect to the plane-of-sky and if the SiO lines have a net polarization parallel to the local magnetic field. Although the observed polarization is from SiO lines and our synthetic maps are due to polarized dust emission, a comparison is useful and allows us to resolve the ambiguity of whether the line polarization is parallel or perpendicular to the local magnetic field direction.

5. Revealing the dust grain polarization properties as a function of extinction and distance towards NGC 1893

N. Bijas, Chakali Eswaraiah, Jia-Wei Wang, Jessy Jose, Wen-Ping Chen, Di Li, Shih-Ping Lai, D. K. Ojha ★ Dust polarization observations at optical wavelengths help to understand the dust grain properties and trace the plane-of-the-sky component of the magnetic field. In this study, we make use of the I-band polarization data acquired from AIMPOL along with the distances (d) and extinction (A_V) data to study the variation of polarization fraction (P) as a function of A_V and d towards the star-forming region, NGC 1893. We employ a broken power-law fit and Bayesian analysis on extinction (A_V) versus polarization efficiency (P/A_V) and distance (d) versus rate of polarization (P/d). We find that P/A_V shows a break at an extinction of ∼0.9 mag, whereas P/d exhibits a break at a distance of ∼1.5 kpc. Based on these, we categorize the dust towards NGC 1893 into two populations: (i) foreground dust confined to $A_V < \sim 1$ mag and distance up to ∼2 kpc and (ii) Perseus spiral arm dust towards NGC 1893 characterized with $A_V > \sim 1$ mag and distance beyond ∼2 kpc. Foreground dust exhibits higher polarization efficiency but a lower polarization rate, whereas Perseus dust shows a lower polarization efficiency but a slightly higher polarization rate. Hence, we suggest that while polarization efficiency reveals the dust grain alignment, the rate of polarization infers about the distribution of dust grains towards NGC 1893. Further, we also shed a light on the spatial variation of intrinsic polarization and magnetic field orientation, and other parameters within the intra-cluster medium of NGC 1893.

6. ALMA-IMF IV – A comparative study of the main hot cores in W43-MM1: detection, temperature and molecular composition

N. Brouillet, D. Despois, J. Molet, T. Nony, F. Motte, A. Gusdorf, F. Louvet, S. Bontemps, F. Herpin, M. Bonfand, T. Csengeri, A. Ginsburg, N. Cunningham, R. Galvan-Madrid, L. Maud, G. Busquet, L. Bronfman, M. Fernandez-Lopez, D. L. Jeff, B. Lefloch, Y. Pouteau, P. Sanhueza, A. M. Stutz, M. Valeille-Manet ★ W43-MM1 is a young region, very rich in terms of high-mass star formation. We aim to systematically identify the massive cores which contain a hot core and compare their molecular composition. We used ALMA high-spatial resolution (2500 au) data of W43-MM1 to identify line-rich protostellar cores and make a comparative study of their temperature and molecular composition. The identification of hot cores is based on both the spatial distribution of the complex organic molecules and the contribution of molecular lines relative to the continuum intensity. We rely on the analysis of CH3CN and CH3CCH to estimate the temperatures of the selected cores. Finally, we rescale the spectra of the different hot cores based on their CH3OCHO line intensities to directly compare the detections and line intensities of the other species. W43-MM1 turns out to be a region rich in massive hot cores with at least 1 less massive and 7 massive hot cores. The excitation temperature of CH3CN is of the same order for all of them (120-160 K). There is a factor of up to 30 difference in the intensity of the complex organic molecules (COMs) lines. However the molecular emission of the hot cores appears to be the same within a factor 2-3. This points towards both a similar chemical composition and excitation of most of the COMs over these massive cores, which span about an order of magnitude in core mass. In contrast, CH3CCH emission is found to preferentially trace more the envelope, with a temperature ranging from 50 K to 90 K. Core 1, the most massive hot core of W43-MM1, shows a richer line spectrum than the other cores. In core 2, the emission of O-bearing molecules does not peak at the dust continuum core center; the blue and red shifted emission correspond to the outflow lobes, suggesting a formation via the sublimation of the ice mantles through shocks or UV irradiation on the walls of the cavity.

7. Complex organic molecules detected in twelve high-mass star-forming regions with Atacama Large Millimeter/submillimeter Array (ALMA)

Giseon Baek, Jeong-Eun Lee, Tomoya Hirota, Kee-Tae Kim, Mi Kyoung Kim ★ Recent astrochemical models and experiments have explained that complex organic molecules (COMs; molecules composed of six or more atoms) are produced on the dust grain mantles in cold and dense gas in prestellar cores. However, the detailed chemical processes and the roles of physical conditions on chemistry are still far from understood. To address these questions, we investigated twelve high-mass star-forming regions using the ALMA band 6 observations. They are associated with 44/95GHz class I and 6.7 GHz class II CH_3OH masers, indicative of undergoing active accretion. We found 28 hot cores with COMs emission among 68 continuum peaks at 1.3 mm and specified 10 hot cores associated with 6.7 GHz class II CH_3OH masers. Up to 19 COMs are identified including oxygen- and nitrogen-bearing molecules and their isotopologues in cores. The derived abundances show a good agreement with those from other low- and high-mass star-forming regions, implying that the COMs chemistry is predominantly set by the ice chemistry in the prestellar core stage. One clear trend is that the COMs detection rate steeply grows with the gas column density, which can be attributed to the efficient formation of COMs in dense cores. In addition, cores associated with a 6.7 GHz class II CH_3OH maser tend to be enriched with COMs. Finally, our results suggest that the enhanced abundances of several molecules in our hot cores could be originated by the active accretion as well as different physical conditions of cores.

8. The Cygnus Allscale Survey of Chemistry and Dynamical Environments: CASCADE: Overview and first results toward DR20 from the Max Planck IRAM Observatory program (MIOP)

H. Beuther, F. Wyrowski, K. M. Menten, J. M. Winters, S. Suri, W. -J. Kim, L. Bouscasse, C. Gieser, M. Sawczuck, I. B. Christensen, I. M. Skretas ★ Context: While star formation on large molecular cloud scales and on small core and disk scales has been investigated intensely over the past decades, the connection of the large-scale interstellar material with the densest small-scale cores has been a largely neglected field. Methods: Using NOEMA and the IRAM 30 m telescope, we mapped large areas (640 arcmin^2) of the archetypical star formation complex Cygnus X at 3.6 mm wavelengths in line and continuum emission. Results: The scope and outline of The Cygnus Allscale Survey of Chemistry and Dynamical Environments (CASCADE) is presented. We then focus on the first observed subregion in Cygnus X, namely the DR20 star formation site, which comprises sources in a range of evolutionary stages from cold pristine gas clumps to more evolved ultracompact HII regions. The data covering cloud to cores scales at a linear spatial resolution of < 5000 au reveal several kinematic cloud components that are likely part of several large-scale flows onto the central cores. The temperature structure of the region is investigated by means of the HCN/HNC intensity ratio and compared to dust-derived temperatures. We find that the deuterated DCO^+ emission is almost exclusively located toward regions at low temperatures below 20 K. Investigating the slopes of spatial power spectra of dense gas tracer intensity distributions (HCO^+, $H^{13}CO^+$, and N_2H^+), we find comparatively flat slopes between -2.9 and -2.6, consistent with high Mach numbers and/or active star formation in DR20.

9. Influence of grain growth on CO2 ice spectroscopic profiles : Modelling for dense cores and disks

Emmanuel Dartois, Jennifer A. Noble, Nathalie Ysard, Karine Demyk, Marin Chabot ★ Interstellar dust grain growth in dense clouds and protoplanetary disks, even moderate, affects the observed interstellar ice profiles as soon as a significant fraction of dust grains is in the size range close to the wave vector at the considered wavelength. The continuum baseline correction made prior to analysing ice profiles influences the subsequent analysis and hence the estimated ice composition, typically obtained by band fitting using thin film ice mixture spectra. We model the effect of grain growth on ice mantle spectroscopic profiles, focusing on CO2 to see how it can affect interstellar ice mantle spectral analysis and interpretation. Using the Discrete Dipole Approximation for Scattering and Absorption of Light, the mass absorption coefficients of distributions of grains composed of ellipsoidal silicate cores with water and carbon dioxide ice mantles are calculated. A few other ice mantle compositions are also calculated. We explore the size distribution evolution from dense clouds to simulate the first steps of grain growth up to three microns in size. The results are injected into RADMC-3D full scattering radiative transfer models of spherical clouds and protoplanetary disk templates to retrieve observable spectral energy distributions. We focus on calculated profile of the CO2 antisymmetric stretching mode ice band profile at 4.27 microns, a meaningful indicator of grain growth. The observed profiles toward dense cores with the Infrared space observatory and Akari satellites already showed profiles possibly indicative of moderate grain growth.The observation of protoplanetary disks at high inclination with the JWST should present distorted profiles that will put constraints on the extent of dust growth. The more evolved the dust size distribution, the more the extraction of the ice mantle composition will require both understanding and taking into account grain growth.

10. Effects of the environment and feedback physics on the initial mass function of stars in the STARFORGE simulations

Dávid Guszejnov, Michael Y. Grudić, Stella S. R. Offner, Claude-André Faucher-Giguère, Philip F. Hopkins, Anna L. Rosen ★ One of the key mysteries of star formation is the origin of the stellar initial mass function (IMF). The IMF is observed to be nearly universal in the Milky Way and its satellites, and significant variations are only inferred in extreme environments, such as the cores of massive elliptical galaxies. In this work we present simulations from the STARFORGE project that are the first cloud-scale RMHD simulations that follow individual stars and include all relevant physical processes. The simulations include detailed gas thermodynamics, as well as stellar feedback in the form of protostellar jets, stellar radiation, winds and supernovae. In this work we focus on how stellar radiation, winds and supernovae impact star-forming clouds. Radiative feedback plays a major role in quenching star formation and disrupting the cloud, however the IMF peak is predominantly set by protostellar jet physics. We find the effect of stellar winds is minor, and supernovae occur too lateto affect the IMF or quench star formation. We also investigate the effects of initial conditions on the IMF. The IMF is insensitive to the initial turbulence, cloud mass and cloud surface density, even though these parameters significantly shape the star formation history of the cloud, including the final star formation efficiency. The characteristic stellar mass depends weakly on metallicity and the interstellar radiation field. Finally, while turbulent driving and the level of magnetization strongly influences the star formation history, they only influence the high-mass slope of the IMF.

11. Centrifugal Barrier and Super-Keplerian Rotation in Protostellar Disk Formation

Dylan C. Jones, Ka Ho Lam, Zhi-Yun Li, Yisheng Tu ★ With the advent of ALMA, it is now possible to observationally constrain how disks form around deeply embedded protostars. In particular, the recent ALMA C3H2 line observations of the nearby protostar L1527 have been interpreted as evidence for the so-called "centrifugal barrier," where the protostellar envelope infall is gradually decelerated to a stop by the centrifugal force in a region of super-Keplerian rotation. To test the concept of centrifugal barrier, which was originally based on angular momentum conserving-collapse of a rotating test particle around a fixed point mass, we carry out simple axisymmetric hydrodynamic simulations of protostellar disk formation including a minimum set of ingredients: self-gravity, rotation, and a prescribed viscosity that enables the disk to accrete. We find that a super-Keplerian region can indeed exist when the viscosity is relatively large but, unlike the classic picture of centrifugal barrier, the infalling envelope material is not decelerated solely by the centrifugal force. The region has more specific angular momentum than its surrounding envelope material, which points to an origin in outward angular momentum transport in the disk (subject to the constraint of disk expansion by the infalling envelope), rather than the spin-up of the envelope material envisioned in the classic picture as it falls closer to the center in order to conserve angular momentum. For smaller viscosities, the super-Keplerian rotation is weaker or non-existing. We conclude that, despite the existence of super-Keplerian rotation in some parameter regime, the classic picture of centrifugal barrier is not supported by our simulations.

12. Ice features of low-luminosity protostars in near-infrared spectra of AKARI/IRC

Jaeyeong Kim, Jeong-Eun Lee, Woong-Seob Jeong, Il-Seok Kim, Yuri Aikawa, Jeniffer A. Noble, Minho Choi, Ho-Gyu Lee, Michael M. Dunham, Chul-Hwan Kim, Bon-Chul Koo ★ We present near-infrared spectra of three low-luminosity protostars and one background star in the Perseus molecular cloud, acquired using the Infrared Camera (IRC) onboard the *AKARI* space telescope. For the comparison with different star-forming environments, we also present spectra of the massive protostar AFGL 7009S, where the protostellar envelope is heated significantly, and the low-mass protostar RNO 91, which is suspected to be undergoing an episodic burst. We detected ice absorption features of H2O, CO2, and CO at all spectra around the wavelengths of 3.05, 4.27, and 4.67 μm, respectively. At least two low-luminosity protostars, we also detected the XCN ice feature at 4.62 μm. The presence of the crystalline H2O ice and XCN ice components indicates that the low-luminosity protostars experienced a hot phase via accretion bursts during the past mass accretion process. We compared the ice abundances of low-luminosity protostars with those of the embedded low-mass protostars and the dense molecular clouds and cores, suggesting that their ice abundances reflect the strength of prior bursts and the timescale after the last burst.

13. Resolving the core of R136 in the optical

Venu M. Kalari, Elliott P. Horch, Ricardo Salinas, Jorick S. Vink, Morten Andersen, Joachim M. Bestenlehner, Monica Rubio ★ The sharpest optical images of the R136 cluster in the Large Magellanic Cloud are presented, allowing for the first time to resolve members of the central core, including R136a1, the most massive star known. These data were taken using the Gemini speckle imager Zorro in medium-band filters with effective wavelengths similar to BVRI achieving angular resolutions between 30-40 mas. All stars previously known in the literature, having V <16 mag within the central $2'' \times 2''$ were recovered. Visual companions ($\geq$40 mas; 2000 au) were detected for the WN5h stars R136 a1, and a3. Photometry of the visual companion of a1 suggests it is of mid O spectral type. Based on new photometric luminosities using the resolved Zorro imaging, the masses of the individual WN5h stars are estimated to be between 150-200 $M_{\odot}$, lowering significantly the present-day masses of some of the most massive stars known. These mass estimates are critical anchor points for establishing the stellar upper-mass function.

14. Discovery of a coherent, wave-like velocity pattern for the Radcliffe Wave

Guang-Xing Li, Bing-Qiu Chen ★ Recently studies discovered that part of the Gould Belt belongs to a 2.7 kpc-long coherent, thin wave consisting of a chain of clouds, where a damped undulation pattern has been identified from the spatial arrangement of the clouds. We use the proper motions of Young Stellar Objects (YSOs) anchored inside the clouds to study the kinematic structure of the Radcliffe Wave in terms of v_z, and identify a damped, wave-like pattern from the v_z space, which we call "velocity undulation". We propose a new formalism based on the Ensemble Empirical Mode Decomposition (EEMD) to determine the amplitude, period, and phase of the undulation pattern, and find that the spatial and the velocity undulation share an almost identical spatial frequency of about 1.5 kpc, and both are damped when measured from one side to the other. Measured for the first cycle, they exhibit a phase difference of around $2\pi/3$. The structure is oscillating around the midplane of the Milky Way disk with an amplitude of $\sim$ 130 $\pm$ 20 pc. The vertical extent of the Radcliffe Wave exceeds the thickness of the molecular disk, suggesting that the undulation of the undulation signature might originate from a perturbation, e.g. the passage of a dwarf galaxy.

15. Weather Forecast of the Milky Way: Shear and Stellar feedback determine the lives of Galactic-scale filaments

Guang-Xing Li, Ji-Xuan Zhou, Bing-Qiu Chen ★ The interstellar medium (ISM) is an inseparable part of the Milky Way ecosystem whose evolutionary history remains a challenging question. We trace the evolution of the molecular ISM using a sample of Young Stellar Objects (YSO) association –molecular cloud complex (YSO-MC complex). We derive their three-dimensional (3D) velocities by combining the Gaia astrometric measurements of the YSO associations and the CO observations of the associated molecular clouds. Based on the 3D velocities, we simulate the motions of the YSO-MC complexes in the Galactic potential and forecast the ISM evolution by tracing the motions of the individual complexes, and reveal the roles of shear and stellar feedback in determining ISM evolution: Galactic shear stretches Galactic-scale molecular cloud complexes, such as the G120 Complex, into Galactic-scale filaments, and it also contributes to the destruction of the filaments; while stellar feedback creates interconnected superbubbles whose expansion injects peculiar velocities into the ISM. The Galactic-scale molecular gas clumps are often precursors of the filaments and the Galactic-scale filaments are transient structures under a constant stretch by shear. This evolutionary sequence sets a foundation to interpret other gas structures. Animations are available at https://gxli.github.io/ISM-6D/movie.html.

16. Detection of an excess of young stars in the Galactic center Sagittarius B1 region

Francisco Nogueras-Lara, Rainer Schödel, Nadine Neumayer ★ The Milky Way's center is the closest galaxy nucleus and the most extreme environment of the Galaxy. Although its volume is less than 1% of that of the Galactic disk, up to 10% of all new-born stars in the Galaxy in the past 100 Myr formed there. Therefore, it constitutes a perfect laboratory to understand star formation under extreme conditions, similar to those in starburst or high-redshift galaxies. However, the only two known Galactic center young clusters account for <10% of the expected young stellar mass. We analyze the star formation history of Sagittarius (Sgr) B1, a Galactic center region associated with strong HII emission, and find evidence for the presence of several 10^5 solar masses of young stars, that formed $\sim$10 Myr ago. We also detect the presence of intermediate age stars (2-7 Gyr) in Sgr B1 that appear to be rare (or absent) in the inner regions of the nuclear stellar disk, and might indicate inside out formation. Our results constitute a large step toward a better understanding of star formation at the Galactic center, such as the fate of young clusters, and the possibly different initial mass function in this region.

17. Momentum and energy injection by a wind-blown bubble into an inhomogeneous interstellar medium

J. M. Pittard ★ We investigate the effect of mass-loading from embedded clouds on the evolution of wind-blown bubbles. We use 1D hydrodynamical calculations and assume that the clouds are numerous enough that they can be treated in the continuous limit, and that rapid mixing occurs so that the injected mass quickly merges with the global flow. The destruction of embedded clouds adds mass into the bubble, increasing its density. Mass-loading increases the temperature of the unshocked stellar wind due to the frictional drag, and reduces the temperature of the hot shocked gas as the available thermal energy is shared between more particles. Mass-loading may increase or decrease the volume-averaged bubble pressure. Mass-loaded bubbles are smaller, have less retained energy and lower radial momentum, but in all cases examined are still able to do significant PdV work on the swept-up gas. In this latter respect, the bubbles more closely resemble energy-conserving bubbles than the momentum-conserving-like behaviour of "quenched" bubbles.

18. Gas disk interactions, tides and relativistic effects in the rocky planet formation at the substellar mass limit

Mariana B. Sanchez, Gonzalo C. de Elia, Juan J. Downes ★ Our main goal is to study the formation of rocky planets and the first 100 Myr of their dynamical evolution around a star with mass $0.08M_{\odot}$ close to the substellar mass limit. We developed two sets of N-body simulations assuming an embryo population affected by tidal and general relativistic effects refined by the inclusion of the spin-up and contraction of the central star, and immerse in a gas disk during the first 10 Myr. Each set of simulations incorporates a different prescription from literature to calculate the interaction between the gas-disk and the embryos: one widely used prescription based on results from hydrodynamics simulations, and a recent prescription based on the analytic treatment of dynamical friction. We found that given a standard disk model, the dynamical evolution and the final architectures of the resulting rocky planets is strongly related with the prescription used to treat the interaction within the gas and the embryos, having a big impact on the resulting close-in planet population and particularly on those located inside the habitable zone. We found a good agreement within the distribution of period ratio of adjacent confirmed exoplanets observed around very low mass stars and brown dwarfs and those obtained from our simulations only when the prescription based on dynamical friction for gas-embryo interaction is used. Our results also reproduce a close-in planet population of interest located inside the habitable zone. A fraction of those planets will be exposed for a long period of time to the stellar irradiation inside the inner edge of the evolving habitable zone until the zone reaches them.

19. Star Forming Regions

Salvatore Sciortino (see `Reviews` section) ★ Since the '80s the *Einstein* observatory has shown the Young Stellar Objects (YSOs), emit X-rays with luminosities, in the 0.3–8 keV bandpass, up to 10^3–10^4 times than the Sun and that the X-ray emission is highly variable. ROSAT has confirmed the pervasiveness of X-ray emission from YSOs and ASCA has provided evidence that the emission of Class I YSOs is largely originating from optical thin-plasma at temperature of 1-50 $\times 10^6$ K. These intrinsic, unexpected, properties and the transformational capabilities of the *Chandra* and *XMM-Newton* observatories has made X-rays a powerful tool to trace the star formation process up to distance of a few kpc around the Sun. Starting from the early evidences of the '80s and the intriguing questions they raised, I will summarize the results obtained and how they have influenced our current understanding of physical processes at work and I will discuss some of the still open issues and some of the likely avenues that next generation X-ray observatory will open.

20. Environmental Effects on the Dynamical Evolution of Star Clusters in Turbulent Molecular Clouds

Paolo Suin, Steven N. Shore, Václav Pavlík ★ Context: Star clusters form within giant molecular clouds that are strongly altered by the feedback action of the massive stars, but the cluster still remains embedded in a dense, highly turbulent medium and interactions with ambient structures may modify its dynamical evolution from that expected if it were isolated. Aims: We aim to study coupling mechanisms between the dynamical evolution of the cluster, accelerated by the mass segregation process, with harassment effects caused by the gaseous environment. Methods: We simulated the cluster dynamical evolution combining N-body and hydrodynamic codes within the Astronomical Multipurpose Software Environment (AMUSE). Conclusions: Tidal harassment produces a sparser configuration more rapidly than the isolated reference simulations. The evolution of the asymptotic power-law density distribution exponent also shows substantially different behaviour in the two cases. The background is more effective on clusters in advanced stages of dynamical development.

21. An ALMA 1.3 millimeter Search for Debris Disks around Solar-type Stars in the Pleiades

Devin Sullivan, David Wilner, Luca Matra, Mark C. Wyatt, Sean M. Andrews, Meredith A. MacGregor, Brenda Matthews ★ Millimeter emission from debris disks around stars of different ages provides constraints on the collisional evolution of planetesimals. We present ALMA 1.3 millimeter observations of a sample of 76 Solar-type stars in the 115 Myr old Pleiades star cluster. These ALMA observations complement previous infrared observations of this sample by providing sensitivity to emission from circumstellar dust at lower temperatures, corresponding to debris at radii comparable to the Kuiper Belt and beyond. The observations obtain a beam size of 1.5 arcsec (200 au) and a median rms noise of 54 mircoJy/beam, which corresponds to a fractional luminosity $L_{dust}/L_{star} \sim 10^{-4}$ for 40 K dust for a typical star in the sample. The ALMA images show no significant detections of the targeted stars. We interpret these limits in the context of a steady-state collisional cascade model for debris disk evolution that provides a good description of observations of the field population near the Sun but is not well-calibrated on younger populations.The ALMA non-detections of the Pleiades systems are compatible with the disk flux predictions of this model. We find no high fractional luminosity outliers from these ALMA data that could be associated with enhanced collisions resulting from activity not accounted for by steady-state evolution. However, we note that two systems (HII 1132 and HD 22680) show 24 micron excess much higher than the predictions of this model, perhaps due to unusually high dust production from dynamical events involving planets.

22. The early evolution of young massive clusters: The kinematic history of NGC6611 / M16

Mitchel Stoop, Lex Kaper, Alex de Koter, Difeng Guo, Henny J. G. L. M. Lamers, Steven Rieder ★ In the first few Myr the massive stars dynamically interact, produce runaways and affect the initial binary population. Observing and interpreting the dynamics of young massive clusters is key to our understanding of the star formation process and predicting the outcome of stellar evolution. We have studied NGC6611 in the Eagle Nebula (M16), a young massive cluster hosting 19 O stars. We used Gaia EDR3 data to determine the membership, age, cluster dynamics and the kinematics of the massive stars including runaways. The membership analysis yields 137 members located at a mean distance of 1706 $\pm$ 7 pc. The colour - absolute magnitude diagram reveals a blue and a red population of pre-main-sequence stars, consistent with two distinct populations of stars. In line with earlier studies, the youngest population has a mean extinction $A_V = 3.6 \pm 0.1$ mag and an age = 1.3 ± 0.2 Myr, while the older population of stars has a mean extinction $A_V = 2.0 \pm 0.1$ mag and an age = 7.5 ± 0.4 Myr. The latter population is more spatially extended than the younger generation of stars. We argue that most of the OB stars belong to the younger population. We identify 8 runaways originating from the center of NGC6611, consistent with the dynamical ejection scenario. We show that 50of the O stars have velocities comparable to or greater than the escape velocity. These O stars can be traced back to the center of NGC6611 with kinematic ages ranging from 0 to 2 Myr. This suggests that dynamical interactions played an important role in the early evolution of NGC6611, which is surprising considering the low current stellar density. Comparing this to simulations of young massive clusters, the required initial radius of 0.1-0.5 pc is not consistent with that of NGC6611. The O stars could have initially formed in wide binaries and possibly harden through dynamical interactions.

23. Deep Near-Infrared Survey Toward the W40 and Serpens South Region in Aquila Rift: A Comprehensive Catalog of Young Stellar Objects

Jia Sun, Robert A. Gutermuth, Hongchi Wang, Miaomiao Zhang, Shuinai Zhang, Yuehui Ma, Xinyu Du, Min Long ★ Active star forming regions are excellent laboratories for studying the origins and evolution of young stellar object (YSO) clustering. The W40 - Serpens South region is such a region, and we compile a super near-and-mid-infrared catalog of point sources in it, based on deep NIR observations of CFHT in combination with 2MASS, UKIDSS, and Spitzer catalogs. From this catalog, we identify 832 YSOs, and classify 15, 135, 647, and 35 of them to be the deeply embedded sources, Class I, Class II YSOs, and transition disk sources, respectively. In general, these YSOs are well correlated with the filamentary structures of molecular clouds, especially the deeply embedded sources and the Class I YSOs. The W40 central region is dominated by Class II YSOs, but in the Serpens South region, a half of the YSOs are Class I. We further generate a minimum spanning tree (MST) for all the YSOs. Around the W40 cluster, there are eight prominent MST branches that may trace vestigial molecular gas filaments that once fed gas to the central natal gas clump. Of the eight, only two now include detectable filamentary gas in Herschel data and corresponding Class I YSOs, while the other six are exclusively populated with Class II. Four MST branches overlap with the Serpens South main filament, and where they intersect, molecular gas "hubs" and more Class I YSOs are found. Our results imply a mixture of YSO distributions composed of both primordial and somewhat evolved YSOs in this star forming region.

24. Hierarchical Structure of YSO Clusters in the W40 and Serpens South Region: Group Extraction and Comparison with Fractal Clusters

Jia Sun, Robert A. Gutermuth, Hongchi Wang, Shuinai Zhang, Min Long ★ Young stellar clusters are believed to inherit the spatial distribution like hierarchical structures of their natal molecular cloud during their formation. However, the change of the structures between the cloud and the young clusters is not well constrained observationally. We select the W40 - Serpens South region (7×9 pc^2) of the Aquila Rift as a testbed and investigate hierarchical properties of spatial distribution of young stellar objects (YSOs) in this region. We develop a minimum spanning tree (MST)-based method to group stars into several levels by successively cutting down edges longer than an algorithmically determined critical value. A total of 832 YSOs are divided into 5 levels with 23 groups. For describing the hierarchical properties in a controlled way, we construct a set of synthetic source distributions at various fractal dimensions, and apply the same method to explore their group characters. By comparing the Q parameter and the surface density profiles of the observed and the synthetic data, we find that the YSO observation matches spatial patterns from multi-fractal dimensions. In the periphery region where the molecular clouds are more diffuse, the YSO structure is close to a fractal dimension of 2.0, while in the core regions the fractal dimensions are close to 1.6 and 1.4 for the W40 and the Serpens South regions, respectively. Therefore, the YSOs may inherit the fractal pattern of the dense part of the molecular clouds, but such pattern dissipates slowly in several Myr.

25. Understanding star formation in molecular clouds IV. Column density PDFs from quiescent to massive molecular clouds

N. Schneider, V. Ossenkopf-Okada, S. Clarke, R. S. Klessen, S. Kabanovic, T. Veltchev, S. Bontemps, S. Dib, T. Csengeri, C. Federrath, J. Di Francesco, F. Motte, Ph. Andre, D. Arzoumanian, J. R. Beattie, L. Bonne, P. Didelon, D. Elia, V. Koenyves, A. Kritsuk, B. Ladjelate, Ph. Myers, S. Pezzuto, J. F. Robitaille, A. Roy, D. Seifried, R. Simon, J. Soler, D. Ward-Thompson ★ We present N-PDFs of 29 Galactic regions obtained from Herschel imaging at high angular resolution, covering diffuse and quiescent clouds, and those showing low-, intermediate-, and high-mass star formation (SF), and characterize the cloud structure using the Delta-variance tool. The N-PDFs are double-log-normal at low column densities, and display one or two power law tails (PLTs) at higher column densities. For diffuse, quiescent, and low-mass SF clouds, we propose that the two log-normals arise from the atomic and molecular phase, respectively. For massive clouds, we suggest that the first log-normal is built up by turbulently mixed H2 and the second one by compressed (via stellar feedback) molecular gas. Nearly all clouds have two PLTs with slopes consistent with self-gravity, where the second one can be flatter or steeper than the first one. A flatter PLT could be caused by stellar feedback or other physical processes that slow down collapse and reduce the flow of mass toward higher densities. The steeper slope could arise if the magnetic field is oriented perpendicular to the LOS column density distribution. The first deviation point (DP), where the N-PDF turns from log-normal into a PLT, shows a clustering around values of a visual extinction of AV (DP1) around 2-5. The second DP, which defines the break between the two PLTs, varies strongly. Using the Delta-variance, we observe that the AV value, where the slope changes between the first and second PLT, increases with the characteristic size scale in the variance spectrum. We conclude that at low column densities, atomic and molecular gas is turbulently mixed, while at high column densities, the gas is fully molecular and dominated by self-gravity. The best fitting model N-PDFs of molecular clouds is thus one with log-normal low column density distributions, followed by one or two PLTs.

26. The First Detection of a Protostellar CO Outflow in the Small Magellanic Cloud with ALMA

Kazuki Tokuda, Sarolta Zahorecz, Yuri Kunitoshi, Kosuke Higashino, Kei E. I. Tanaka, Ayu Konishi, Taisei Suzuki, Naoya Kitano, Naoto Harada, Takashi Shimonishi, Naslim Neelamkodan, Yasuo Fukui, Akiko Kawa-

mura, Toshikazu Onishi, Masahiro N. Machida ★ Protostellar outflows are one of the most outstanding features of star formation. The observational studies over several decades successfully demonstrated that outflows are ubiquitously associated with low- and high-mass protostars in the solar-metallicity Galactic condition. However, the environmental dependence of protostellar outflow properties is still poorly understood, particularly in the low-metallicity regime. Here we report the first detection of a molecular outflow in the Small Magellanic Cloud with 0.2 $Z_{\odot}$, using ALMA observations at a spatial resolution of 0.1 pc toward the massive protostar Y 191. The bipolar outflow is nicely illustrated by high-velocity wings of CO(3-2) emission with $\gtrsim$15 km s^{-1}. The evaluated properties of the outflow (momentum, mechanical force, etc.) are consistent with those of the Galactic counterparts. Our results suggest that the molecular outflows, i.e., the guidepost of the disk accretion at the small scale, might be universally associated with protostars across the metallicity range of$\sim$0.2-1 $Z_{\odot}$.

27. Grain Growth During Protostellar Disk Formation

Yisheng Tu, Zhi-Yun Li, Ka Ho Lam ★ Recent observations indicate that mm/cm-sized grains may exist in the embedded protostellar disks. How such large grains grow from the micron size (or less) in the earliest phase of star formation remains relatively unexplored. In this study we take a first step to model the grain growth in the protostellar environment, using two-dimensional (2D axisymmetric) radiation hydrodynamic and grain growth simulations. We show that the grain growth calculations can be greatly simplified by the "terminal velocity approximation", where the dust drift velocity relative to the gas is proportional to its stopping time, which is proportional to the grain size. We find that the grain-grain collision from size-dependent terminal velocity alone is too slow to convert a significant fraction of the initially micron-sized grains into mm/cm sizes during the deeply embedded Class 0 phase. Substantial grain growth is achieved when the grain-grain collision speed is enhanced by a factor of 4. The dust growth above and below the disk midplane enables the grains to settle faster towards the midplane, which increases the local dust-to-gas ratio, which, in turn, speeds up further growth there. How this needed enhancement can be achieved is unclear, although turbulence is a strong possibility that deserves further exploration.

28. Distributed YSOs in the Perseus Molecular Cloud from the Gaia and LAMOST Surveys

Xiao-Long Wang, Min Fang, Yu Gao, Hong-Xin Zhang, Gregory J. Herczeg, Hong-Jun Ma, En Chen, Xing-Yu Zhou ★ Identifying the young optically visible population in a star-forming region is essential for fully understanding the star formation event. In this paper, We identify 211 candidate members of the Perseus molecular cloud based on Gaia astronomy. We use LAMOST spectra to confirm that 51 of these candidates are new members, bringing the total census of known members to 856. The newly confirmed members are less extincted than previously known members. Two new stellar aggregates are identified in our updated census. With the updated member list, we obtain a statistically significant distance gradient of 4.84 pc deg^{-1} from west to east. Distances and extinction corrected color-magnitude diagrams indicate that NGC 1333 is significantly younger than IC 348 and the remaining cloud regions. The disk fraction in NGC 1333 is higher than elsewhere, consistent with its youngest age. The star formation scenario in the Perseus molecular cloud is investigated and the bulk motion of the distributed population is consistent with the cloud being swept away by the Per-Tau Shell.

29. Probing Magnetic Fields in Protoplanetary Disk Atmospheres through Polarized Optical/IR Light Scattered by Aligned Grains

Haifeng Yang, Zhi-Yun Li ★ Magnetic fields play essential roles in protoplanetary disks. Magnetic fields in the disk atmosphere are of particular interest, as they are connected to the wind-launching mechanism. In this work, we study the polarization of the light scattered off of magnetically aligned grains in the disk atmosphere, focusing on the deviation of the polarization orientation from the canonical azimuthal direction, which may be detectable in near-IR polarimetry with instruments such as VLT/SPHERE. We show with a simple disk model that the polarization can even be oriented along the radial (rather than azimuthal) direction, especially in highly inclined disks with toroidally dominated magnetic fields. This polarization reversal is caused by the anisotropy in the polarizibility of aligned grains and is thus a telltale sign of such grains. We show that the near-IR light is scattered mostly by μm-sized grains or smaller at the $\tau = 1$ surface and such grains can be magnetically aligned if they contain superparamagnetic inclusions. For comparison with observations, we generate synthetic maps of the ratios of U_ϕ/I and Q_ϕ/I, which can be used to infer the existence of (magnetically) aligned grains through a negative Q_ϕ (polarization reversal) and/or a significant level of U_ϕ/I. We show that two features observed in the existing data, an asymmetric distribution of U_ϕ with respect to the disk minor axis and a spatial distribution of U_ϕ that is predominantly positive or negative, are incompatible with scattering by spherical grains in an axisymmetric disk. They provide indirect evidences for scattering by aligned non-spherical grains.

30. Characterising the orbit and circumstellar environment of the high-mass binary MWC 166 A

Sebastian A. Zarrilli, Stefan Kraus, Alexander Kreplin, John D. Monnier, Tyler Gardner, Antoine Mérand, Sam Morrell, Claire L. Davies, Aaron Labdon, Jacob Ennis, Benjamin Setterholm, Jean-Baptiste Le Bouquin, Narsireddy Anugu, Cyprien Lanthermann, Gail Schaefer, Theo ten Brummelaar ★ Context: Stellar evolution models are highly dependent on accurate mass estimates, especially for high-mass stars in the early stages of evolution. The most direct method for obtaining model-independent masses is derivation from the orbit of close binaries. Aims: To derive the first astrometric+RV orbit solution for the single-lined spectroscopic binary MWC 166 A, based on CHARA and VLTI near-infrared interferometry over multiple epochs and 100 archival radial velocity measurements, and to derive fundamental stellar parameters from this orbit. We also sought to model circumstellar activity in the system from K-band spectral lines. Methods: We geometrically modelled the dust continuum to derive astrometry at 13 epochs and constrain individual stellar parameters. We used the continuum models as a base to examine differential phases, visibilities and closure phases over the Br-γ and He-I emission lines. Results: Our orbit solution suggests a period of 367.7 ± 0.1 d, twice as long as found with previous RV orbit fits, subsequently constraining the component masses to $M_1 = 12.2 \pm 2.2 M_\odot$ and $M_2 = 4.9 \pm 0.5 M_\odot$. The line-emitting gas was found to be localised around the primary and is spatially resolved on scales of 11 stellar radii, with the spatial displacement between the line wings consistent with a rotating disc. Conclusions: The large radius and stable orientation of the line emission are inconsistent with magnetospheric or boundary-layer accretion, but indicate an ionised inner gas disk around MWC 166 Aa. We observe line variability that could be explained either with generic line variability in a Herbig star disc or V/R variations in a decretion disc. We also constrained the age of the system to $(7 \pm 2) \times 10^5$ yr, consistent with the system being comprised of a main-sequence primary and a secondary still contracting towards the main sequence.