IAU Symposium 412

Hub Filament Structures in Star Formation

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Talk Abstracts Booklet

1. An observational review of Hub Filaments Systems

Nicolas Peretto

Nicolas Peretto

Hub Filament Structures, or Hub Filament Systems (HFSs), are small networks of filaments that converge towards a high-density region where stars are actively forming. In the past 15 years or so, the key role played by HFSs in star formation has come to light, and this conference is testament to how important they have become. While HFSs are found in both low-mass and high-mass star-forming clouds, it has been shown that all young stellar objects with luminosity above 105 Lsun are found at the centre of HFSs, highlighting the ability of these structures to focus large amounts of mass into small volumes. If there is thus little doubt now that HFSs are conducive to high-mass star formation, the physics behind the formation and evolution of HFSs remains uncertain. I will here review our current understanding of HFSs from an observational standpoint, focussing on a few key questions: Do HFSs have a specific physical scale? Does the hub-filament transition represent a change in the physics of the gas? What drives the dynamical evolution of HFSs?

2. 67898 Shock–Cloud Interaction as a Pathway to Hub–Filament System Formation in Magnetized Molecular Clouds

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Shingo Nozaki, Shu-ichiro Inutsuka

Recent observations have identified hub-filament systems (HFSs) as the primary formation sites of massive stars and star clusters. Some HFSs are characterized by multiple filaments aligned radially toward a central high-density hub. However, the physical origin of radially aligned filaments remains unknown. Here, we propose a new formation mechanism of HFSs driven by the interaction of a fast magnetohydrodynamic shock with a molecular cloud characterized by an hourglass-shaped magnetic field and density inhomogeneity. Our three-dimensional magnetohydrodynamic simulations show that the shock propagation leads to the formation of radially aligned filamentary structures with line masses slightly above the thermally critical line mass and lengths of 1-3 pc, and widths of 0.06-0.08 pc. High-density filamentary gas (n_H2 ~ 10^4 cm^−3) selectively exhibits inward velocities of 1−4 km s^−1 that increase toward the hub center, while the ambient low-density inter-filament gas retains low velocities regardless of the radius. Mass accretion onto the hub is channeled through dense filaments. The filament formation is driven by oblique shocks generated at the bent magnetic field lines. The resulting post-shock amplification of the tangential magnetic field induces a magnetically guided inflow. The shock-interface interaction amplifies density perturbations, resembling Richtmyer-Meshkov instability modes, which promotes the fragmentation of the shocked layer into multiple filaments. The process explains both the morphology of radially aligned filaments and the selective mass accretion observed in HFSs. In our simulation, the resulting star formation efficiency is ~4%, suggesting that the shock-driven evolution limits the SFE to only a few percent. We will also discuss preliminary results suggesting that variations in the relative orientation between the shock and the magnetic field may produce the diverse filament morphologies and magnetic-field configurations observed among HFSs.

3. 67774 An ALMA study of a massive protocluster

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Shivani Gupta, Tapas Baug, Archana Soam, Tie Liu et. al.

We present an ALMA study of a massive protocluster G318.049+00.086 using ATOMS and QUARKS data. The protocluster contains 12 prestellar and 4 protostellar cores as reported in previous studies. Gas filaments identified in H13CO+ have strong spatial correlation with the filamentary structures detected in the dust continuum map. At least four identified filaments converge into a dense central region, forming a hub-filament system (HFS). We found high velocity gradients (10-20 km s−1 pc−1) along three of those filaments indicative of mass flowing onto the central hub. Estimation shows that these filaments are having significant mass inflow rates of more than 10^3 M⊙ Myr−1, and hence, the central hub is capable of forming massive star. Further investigation about the possible infall motions in the cores using the H13CO+ and CCH line data revealed most of the cores have characteristic blue asymmetric line profiles, indicating gravitational collapse. A few cores exhibit red profiles indicative of outflows or expansion. The mass infall rates of the protostellar cores located in the central hub are found to be significantly high compared to those in filaments. The mass-radius relationship of the cores suggested that the cores with red profiles are lying in the high-mass star formation regime. However, velocity gradient analysis along the filaments suggests these particular cores are losing material to the hub, supporting a competitive accretion scenario in which mass is funneled from less gravitationally dominant cores toward the potentially favorable position.

4. 67874 Formation of Hub–Filament Systems through Magnetized Filament Collisions: Insights from 3D MHD Simulations

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Filamentary molecular clouds are the primary sites of star formation (e.g., André et al. 2014). Observations suggest that massive stars and stellar clusters often form at junctions of multiple filaments, known as hub–filament systems (e.g., Myers 2009; Kumar et al. 2020). However, the formation mechanism of hub–filament systems remains unclear. Motivated by these findings, we investigate filament–filament collisions as a possible formation pathway for hub-filament systems (e.g., Kashiwagi et al., 2023&2024) and explore the specific collision conditions for hub–filament formation (Kashiwagi et al., 2026). We perform three-dimensional ideal MHD simulations including self-gravity for collisions between two identical finite-length magnetized filaments. We systematically vary the collision angle between the filament axes, the collision velocity (perpendicular to the axes), and the initial line mass to investigate how these parameters regulate the evolution of the collision-compressed cloud (hub) and the formation of hub–filament systems. The post-collision evolution of the compressed cloud (hub) can be classified into two modes: collapse and expansion. We find that this transition is explained by the energy balance of the compressed cloud immediately after the filaments fully collide. When the magnitude of the gravitational energy exceeds the sum of the kinetic, thermal, and magnetic energies, the cloud collapses; otherwise, it expands. We further focus on the condition required for maintaining a hub–filament morphology. At sufficiently high collision velocities, non-colliding filament segments detach from the compressed cloud and escape, preventing the system from forming a hub–filament structure. This implies that the non- colliding segments must remain gravitationally bound to the hub for hub–filament formation. Based on this result, we estimate an upper limit on the collision velocity for the formation of hub–filament systems. Our results show that hub–filament formation is fundamentally regulated by whether the post-collision structure remains gravitationally bound.

5. 67853 An Origin of Hub-Filament Systems

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Recent theoretical study of the shock-cloud interaction identifies the origin of radially aligned dense filamentary molecular clouds as a result of shock wave propagating roughly along the mean magnetic field lines in a molecular cloud. This line of study may not only explain the formation of a radially aligned hub- filament system (HFS) but also provides strong motivation to categorize various morphologies of HFSs. I will show our preliminary analyses and discuss future directions.

6. 67782 JCMT-SURFING: Unveiling the Velocity-Coherent Filaments and Dense Cores in the Serpens South Hub Filament System

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Satyajeet Moharana, Chang Won Lee, The JCMT-SURFING Collaboration

We present results from mapping observations of the CO (2--1) isotopologues toward the Serpens South hub-filament system obtained with the JCMT (`Ũ`ū) as part of the JCMT-SURFING program, aimed to investigate the role of filamentary structures in dense core formation. Using a ‘Friends-of-Friends’ algorithm applied to the Gaussian-decomposed C18O velocity components, we identify 37 velocity-coherent filaments in the region. In addition, 76 dense cores are identified by applying the ‘FellWalker’ algorithm on the N2H+ (1--0) integrated intensity map obtained from the Nobeyama archive.

Most of the filaments and particularly all those hosting dense cores, are gravitationally bound. Similarly, the majority of the dense cores, including all those harboring young stellar objects (YSOs) are also found to be gravitationally bound. Velocity gradients are observed along the filaments in the vicinity of dense cores, suggesting that filamentary accretion contributes to core formation. The median velocity gradient and longitudinal mass accretion rate are estimated to be ~1 km s-1 pc-1 and ~20 M⊙ Myr-1, respectively.

Furthermore, owing to the superior angular resolution of the JCMT data compared to earlier TRAO observations, a lambda/4 phase shift between sinusoidal oscillations in velocity and column density distributions is detected in several filaments, providing additional evidence of core-forming longitudinal mass flow along the long axis of the filaments. Analysis of non-thermal motions indicates that the filaments predominantly exhibit transonic to supersonic motions, whereas dense cores without YSOs generally remain in the subsonic to transonic regime. In contrast, dense cores containing YSOs, consistently exhibit supersonic motions, likely driven by feedback processes such as protostellar outflows.

The differential core mass function derived from the identified cores shows a shallower slope than the characteristic Salpeter value, which may reflect the influence of the hub-filament morphology of Serpens South. Overall, these results highlight the critical role of filamentary structures in regulating the formation and evolution of dense cores.

7. 67845 Dynamics of Dense Gas Filaments in Serpens South

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Measuring multi-scale gas flows through filamentary networks is crucial for understanding how hub-filament systems supply mass to cluster-forming regions. We present a study of the kinematic properties of dense gas filaments in the Serpens South system using GBT/VLA NH3 (1,1) and CARMA N2H+ (1-0) observations at < 0.02 pc resolution. We identified velocity-coherent filaments from multi-component fits to the line data, then calculated velocity gradients to search for evidence of mass accretion onto and along filaments. Velocity gradient orientations were then compared to filament structure and to the gravitational acceleration field derived from H2 column density to investigate the role of gravity in driving dense gas motions. We identified orientation trends within individual filaments and across the filament population, using the Histogram of Relative Orientation (HRO) and Projected Rayleigh Statistic (PRS) methods to quantify their statistical significance. Our results show that filaments in Serpens South exhibit a range of dynamical states. We do not find evidence of large- scale velocity gradients along the prominent southeast filament toward the central hub. However, we also identify regions consistent with accretion along filaments including a system of filaments northeast of the hub that could be actively accreting from their surroundings and along filaments towards a potentially cluster-forming core. These results suggest that the dynamics of filaments in Serpens South are more complex than a simple scenario of global accretion toward a single hub

8. Quantification of systematic biases in continuum-derived dust temperature and column density

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Cold, dense cores represent the earliest observable phase of star formation and are primarily characterised through dust continuum observations, from which column density and dust temperature maps are derived under simplifying assumptions. Their reliability remains uncertain in the presence of temperature gradients and line-of-sight effects. In this work, we present a self-consistent radiative transfer modelling with RADMC-3D to quantify biases in continuum-based diagnostics of cold cores. Synthetic Herschel-like observations are generated and analysed using modified blackbody fitting, enabling direct comparison between intrinsic model properties, analytical column density profiles, and observationally inferred quantities. We find that column density and dust temperature are intrinsically coupled in the inversion process, leading to systematic biases: column densities are underestimated, while dust temperatures are overestimated, in both 1D and 3D configurations. By introducing an isothermal baseline, we isolate intrinsic numerical uncertainties and identify the excess deviation as the true inversion bias. This bias is found to be the strongest in the inner regions of the core and it decreases towards the outward regions. These results demonstrate that standard continuum-based analyses systematically misestimate the physical structure of cold cores, highlighting the need for correction when interpreting column density and dust temperature from far-infrared observations. In this work we not only quantitatively determine this bias but we also provide correction relations and/or constraints to converting the inversion derived dust temperature to the true dust temperature.

9. 67902 The Origin of Hub-Filament Systems: Radiation-MHD Simulations toward Understanding Massive Star Formation

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Stars are born in filamentary molecular clouds, and observations show that nearly all high-mass stars form in so-called “hub–filament systems (HFS)” (Kumar, M.S.N., et al. 2020). A hub–filament system consists of multiple filaments converging to a common intersection (the hub). Motivated by these findings, a new paradigm for high-mass star formation is emerging. Observations indicate strong gas accretion along filaments, which may trigger gravitational fragmentation in circumstellar disks and lead to high-mass binaries. At the same time, the star formation efficiency—the fraction of gas converted into stars—is generally low, and its origin remains unclear. In HFS, filamentary inflows drive mass growth at the hub, while radiation feedback from massive stars disperses diffuse gas, suppressing star formation efficiency. Understanding both the origin of high-mass binaries and the low efficiency requires a self-consistent investigation from large scales down to disk fragmentation, yet the origin of HFS itself remains poorly understood. In this study, we investigate filament formation by shock compression using the radiation-MHD code Athena++ (Stone, J., et al., 2020, Tomida, K., & Stone, J., 2023, Kim, J.-G. et al., 2017). We find that large-scale shock-driven flows gather pre-existing filaments and assemble them into a hub, possibly aided by fluid instabilities such as the nonlinear thin-shell instability (Vishniac, E., 1994). Gas accretion analysis shows that dense gas flows into the hub while diffuse gas is expelled by radiation feedback. This is consistent with observed filamentary accretion and supports a scenario in which massive star formation proceeds with low efficiency. Finally, analysis of the hub’s angular momentum provides insights into the formation of high-mass binaries.

10. 67839 A Rotating and Expanding Molecular Ring-like Structure at the Hub of a Hub–Filament System

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A. K. Maity, L. K. Dewangan, H. Sano, and the ATOMS Collaboration

In this talk, I will present the discovery of a molecular ring-like structure with a radius of ~0.1 pc in the massive star-forming region G328.307+0.423, using Atacama Large Millimeter/submillimeter Array (ALMA) observations. Massive star-forming activity is concentrated at the rim of the ring, which resides within the hub of a hub–filament system (HFS) identified using SEDIGISM 13CO(2–1) and C18O(2–1) data. The HFS has a mass inflow rate of ~7 × 10^−3 M⊙/yr into the hub through the filaments. Analytical modeling of the ring's velocity field as a rotating and expanding structure yields systemic, rotational, and expansion velocities of −93.53, 4.27, and 0.93 km/s, respectively, with a velocity range from −93.53−3.42 to −93.53+3.42 km/s across the ring. The rotational energy of the ring exceeds the expansion energy by a factor of ~21, and may facilitate angular momentum redistribution from larger to smaller scales. Meanwhile, expansion of the ring facilitates the accumulation of material at the ring edge, potentially promoting massive star formation (MSF). An estimated dynamical timescale of ~ 10^5 yr, based on the ring radius and expansion velocity, suggests that the ring structure is dynamically linked to the ongoing MSF activity in the region. Overall, this study provides a rare observational insight into the early dynamical stages of MSF, traced by a rotating and expanding molecular ring-like structure with MSF at its rim in the hub of a HFS

11. 67826 Identifying filamentary structure in massive star forming protoclusters using ALMA data cubes

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Filamentary structures naturally arise from the interaction between different phases of the interstellar medium. In particular, the high angular resolution and spectral capabilities of ALMA have revealed complex filamentary networks in massive star-forming protoclusters with unprecedented detail. However, the physical mechanisms driving their formation, and their role in star formation, accretion, and the redistribution of dense gas, remain open questions. In this talk, I will briefly introduce the theoretical context of filamentary structures in massive star- forming protoclusters and present an observational analysis of the morphology of filamentary gas structure in a sample of 12 regions from the ALMA-IMF large program. The study focuses on the identification, morphological characterization, and statistical analysis of filamentary structures directly in molecular-line velocity cubes, using FilFinder together with methodological adaptations designed to trace complex hub-filament systems. This work provides a framework to identify and quantify filamentary structures in massive protocluster environments by retaining spatial and kinematic information that would be lost in purely integrated maps. I will discuss the resulting distributions of filament lengths, widths, curvature, and orientations, and how these properties vary across the studied sample.

12. 67770 Characterizing the hierarchical structure of filaments. I. On the origin of the length-mass (L-M) scaling relation

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Rahul Patel, Daniel Seifried, Alvaro Hacar

Filamentary structures are widely recognized as fundamental components of the star formation process. Observations consistently report a scaling relation between the length (L) and mass (M) of these structures in the form L\propto M^\alpha, with \alpha≃0.5. In this work, we characterize this relation using high-resolution, 3D magnetohydrodynamical (MHD) simulations of molecular clouds to investigate the influence of hierarchical fragmentation and spatial resolution on this scaling.

We apply a two-step filament identification method that combines the Rolling Hough Transform for structural detection with dendrogram-based segmentation for hierarchical decomposition. By analyzing the resulting structures across multiple spatial resolutions, we find that the ensemble consistently exhibits a sub-linear L−M relation with \alpha≃0.5. This suggests that the relation is an intrinsic property of hierarchically structured clouds rather than an artifact of resolution blending.

While the ensemble average remains robust and consistent with a random-walk interpretation of turbulent fragmentation, decomposing individual structures at the highest resolution reveals a wide range of L−M slopes (\alpha≃0.2 to 3.0). We present a simple geometric toy model demonstrating that this diversity arises from local variations in column density and segmentation boundaries. Our results indicate that the L\propto M^{0.5} relation is a robust signature of the hierarchical fragmentation occurring within molecular clouds, providing a bridge between simulated cloud dynamics and observed filamentary properties.

13. 67891 A Multiscale View of Hub-Filament Systems: From Cloud-Scale Filamentary Accretion to Protocluster Formation

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N. K. Bhadari

Hub-filament systems (HFSs) are emerging as a universal mode of hierarchical mass assembly, yet the observational link between large-scale filamentary inflow and small-scale protocluster formation remains poorly established. I will present a multi-scale view of HFSs spanning cloud to protostellar core scales. At cloud scales (1–10 pc), using CO molecular line data alongside dust continuum, we investigate the fundamental nature of HFSs: what constitutes reliable observational proxies for identifying genuine HFSs, and what distinguishes actively accreting filaments from passive ones. At sub-parsec scales (<0.6 pc), our recent study of two HFSs unveils their pristine filamentary architecture through JWST near-infrared imaging, while ALMA observations of dense gas tracers (N_2H^+, $H^{13}CO^+$) reveal active gas streams flowing toward the hubs. We find a dynamical transition in velocity-gravity alignment between a younger and a more evolved system, evidence for competitive accretion through preferential concentration of massive cores near the hub center, and a wavy funnel-shaped structure in position–position–velocity space highlighting the important role of sub-filaments in channeling mass toward the hub. Together, these results build toward a coherent, scale-bridging picture of how HFSs hierarchically funnel material from parsec-scale reservoirs down to individual protostellar cores, with implications for our understanding of high-mass star formation.

14. 67814 Towards a predictive theory for the star formation outcome of Giant Molecular Clouds

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Shivan Khullar

Giant Molecular Clouds are messy systems to model because of the multi-scale multi-physics nature of star formation. While we have made tremendous progress over the last few decades in building our theoretical understanding of star forming regions, we do not currently have a predictive theory of star formation that can take the properties of a GMC as input and predict the time-dependent star formation outcome of the system. Existing theories typically assume a steady-state lognormal density PDF and do not include (a) the time-dependent evolution, (b) the environment a GMC is embedded in, or (c) feedback from young stars. I will present a semi-analytical model based on the excursion set formalism used in cosmology. This semi-analytical model follows the gravo-turbulent fragmentation of dense gas down to cores and protostars. It can also predict the time-dependent evolution of the density PDF, star formation rate and initial mass function for a given GMC. I will discuss my recent work on improving the model to also care about the environment, magnetic fields, and fragmentation in filamentary structures. I will also discuss our results from testing predictions from earlier turbulence- regulated models and this semi-analytical model against the STARFORGE RMHD simulations.

15. A short history of filamentary star-forming clouds

Phil Myers

Center for Astrophysics | Harvard and Smithsonian

Philip C. Myers

We review milestones in our understanding of star-forming clouds. Our views have changed from the earliest optical observations to present-day studies at millimeter, submillimeter, and infrared wavelengths, aided by improving instruments, new ideas, and more powerful simulations. Within living memory we have learned that stars are born in groups and clusters in molecular clouds, in condensations structured by gravity, turbulent and magnetic pressure, and by stellar feedback. Our ideas about star-forming gas have become more detailed, from clouds to clumps to cores to filamentary networks, including hub-filament systems (HFSs). We describe well-studied examples of HFS and models of their origins.

16. The role of filaments and hub-filament systems in the origin of the prestellar core mass function and the IMF

Philippe André

Philippe Andre

I will give an overview of recent observational studies on the fragmentation of dense

molecular gas into clumps, filaments, and cores, with an emphasis on the associated mass functions and the link to the origin of the stellar IMF. Special attention will be paid to the distinction between the mass functions of self-gravitating prestellar cores, unbound starless cores, and protostellar cores. In nearby regions of low-mass star formation, the prestellar CMF derived from Herschel data generally exhibits a peak

below ~1 Msun and a tail consistent with a Salpeter-like slope at higher core masses. The filament line mass function (FLMF) is also observed to follow a Salpeter-like power law in the regime of thermally supercritical filaments. In contrast, “top-heavy” CMFs - shallower than the Salpeter IMF at the high-mass end - have been found with ALMA in more distant, denser Galactic clumps associated with massive hub-filament systems, and I will discuss possible explanations for this difference. Overall, submillimeter observations point to the key role of the quasi-universal filamentary structure pervading molecular clouds, through filament fragmentation in the low-mass regime and filamentary accretion within hub-filament systems in the high-mass regime. More specifically, the dense cores making up the peak of the prestellar CMF - and indirectly the peak of the IMF – may result from gravitational fragmentation of molecular filaments near the critical mass per unit length. The Salpeter power-law tail of the CMF/IMF may originate from a combination of filamentary accretion and a Salpeter-like FLMF.

17. 67851 Star and Dense Core Formation in Hub-Filamentary Clouds Using the Taeduk Radio Astronomy Observatory Survey of Filaments, the Universal Nursery of Stars (TRAO-FUNS)

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Satyajeet Mohanara, Shinyoung Kim, Eun Jung Chung, and TRAO-FUNS team

TRAO-FUNS is a dedicated survey project designed to investigate the velocity structure, kinematic behavior, and chemical properties of low-density filaments and dense cores in nine molecular clouds within the Gould Belt region using mainly C18O and N2H+ 1-0 lines. To date, studies of four cloud regions have been published. In this meeting, we will focus on how hub-filament structures influence the formation of stars and dense cores using data from the TRAO-FUNS survey. We will discuss the observed kinematic and chemical characteristics of these regions and examine the role of filamentary accretion and hub dynamics in the early stages of star formation.

18. 67988 Quantifying Filament Fragmentation and Core-to-filament mass fractions

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Akshat Asthana, Doris Arzoumanian, Satoko Takahashi, Kshitiz Mallick

The fragmentation of interstellar filaments plays a pivotal role in regulating the star formation process, directly setting the initial conditions for the formation of dense cores. Observational studies suggest that the physical properties of these filamentary structures govern core characteristics such as masses, densities, and their spatial distribution. Furthermore, the filament mass function exhibits compelling similarities to the core mass function and, by extension, the stellar initial mass function, hinting at a fundamental relationship governing mass transfer throughout the fragmentation, core collapse, and accretion phases. To statistically quantify this evolutionary link, we present a study of the core-to-filament mass fractions across a diverse, large sample of star-forming filaments, spanning distances from ~0.8 to 3 kpc. We apply the getsf core and filament identification algorithm to high-resolution (~8'') column density maps constructed using Herschel (PACS/SPIRE) and ArTeMIS (APEX) data to extract the physical and spatial properties of filaments and cores. Building upon the mass fraction analysis, we examine the spatial distribution of the filaments to determine how observed core spacing relates to the underlying fragmentation distribution. We compare these structural metrics against theoretical Jeans lengths, masses, and classical models of cylindrical fragmentation to assess how specific fragmentation modes dictate the resulting core mass hierarchy. By statistically linking these properties across contrasting regions — ranging from isolated structures to complex hub-filament systems, our results aim to constrain the environmental dependence of core formation and the overarching physical processes driving mass transfer from parsec-scale filaments down to pre-stellar cores.

19. Origin of the IMF revisited thanks to constraints on core subfragmentation and mass growth

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Motte, Veyry, Brouillet, Nony and the ALMA-IMF consortium

The physical process by which stars inherit their mass from the properties of their parental cloud is the fundamental issue that guides all star formation studies, and it has profound implications for many areas of astrophysics. The distribution of masses of dense, gravitationally bound cores, known as the Core Mass Function (CMF), was long assumed to directly determine the distribution of stellar masses at birth, the so-called Initial Mass Function (IMF). However, the "CMF-to-IMF" paradigm, which posits that cores are the gas mass reservoir devoted to star formation, is now being debated because these reservoirs remain poorly defined despite efforts to establish them more physically. Accurately predicting the IMF that will emerge from the fragmentation of a given cloud requires moving beyond a static, single-scale description of star formation reservoirs. Instead, we must focus on the physical processes that shape and evolve the mass function of fragments throughout the multiscale hierarchy of clouds.

We started studying two key processes that influence the CMF, which differs in low and high-mass protoclusters: core subfragmentation, the splitting of a single core into multiple fragments due to turbulence and/or gravitational instabilities, and core mass growth, the accretion of additional gas onto existing cores from their hub-filament surroundings. Using the graph-theory-based analysis tool FAMILY (Thomasson+ 2024), we characterized the fragmentation cascade of the W43-MM1 protocluster over two decades, from 300 au to 15 kau. We measured a low fragmentation level, high efficiency of gas mass transfer at smaller scales, and unbalanced mass partition between fragment siblings (Motte, Le Nestour, Veyry+ subm). Based on these observationally-derived parameters, we predict that the resulting IMF will be top-heavy, like those observed in young mass clusters (e.g., Hosek et al. 2019). Meanwhile, we also started studying the gas inflow through the protocluster and accretion rates toward cores, using N2H+(1–0) and DCN(3–2) lines (Veyry+ in prep). By combining constraints of core subfragmentation and mass growth, we aim to move toward a predictive, time-dependent framework linking cloud properties to the mass function of gas reservoirs and ultimately the IMF.

20. 67894 Fragmenting Filaments and Emerging Stars - An ALMA 1.3mm dust and molecular line study of OMC-1N

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Bridging the gap in our understanding of the physics that connects large scale filaments to star forming cores is essential to understanding star formation in hub-filament systems. In this context, we present the results of high spatial resolution (1arcsec~414AU) ALMA observations of the OMC-1N (Orion Molecular Cloud-1 North) region (~0.23pcX0.4pc) in the Integral-Shaped Filament of the Orion A molecular cloud. A detailed examination of the filamentary network of OMC-1N using 1.3mm dust continuum map (sensitivity~0.16mJy/beam) reveals multiple nearly parallel filaments (progressively merging into a hub-like structure), with discrete emission peaks suggesting their fragmenting nature. The nearest-neighbour distance analysis for the fragments (identified using dendrogram) shows a preferred value around 35-40", consistent with local Jeans length for the peak filament density discussed in the earlier SMA study by Teixeira et al. 2016. An analysis of compact sources detected (using getsf algorithm) in the dust continuum emission yielded 56 compact millimter sources, 12 of which are new detections - primarily embedded prestellar cores (based on their Bonnor-Ebert mass ratio<1) along the filaments. A significant number of compact sources (~50%) were found to have prior detections in near-infrared, mid-infrared, and xray catalogs, suggesting that our high-sensitivity observations likely sample the lifespan from earliest prestellar core stage to protostellar (Class0/I) and T Tauri (ClassII/III) stages of young stellar objects. CO(2-1) and SiO(5-4) spectral cubes were used to identify at least 12 bipolar outflows, 75% of which appear to be new detections, with the most extended and prominent ones embedded along the filaments. Based on the results of our analysis, we discuss a unified star formation scenario tracing the fragmentation of the cloud over two orders of spatial scales from filaments to envelopes.

21. 67986 Core-Core Interactions as a Pathway to Very-Low-Mass Star Formation in Hub-Filament Systems

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Hub-filament systems (HFSs) are key environments for the formation of massive stars and stellar clusters (Kumar et al. 2020). Observations have revealed numerous dense cores formed along filaments and near hubs, together with velocity gradients indicative of gas accretion toward the hubs (e.g., Williams et al. 2018; Trevino-Morales et al. 2019; Liu et al. 2023). It is therefore a natural consequence that, in HFSs, cores formed within filaments may flow into the hub and undergo close encounters or collisions. Core collisions in molecular clouds have recently attracted attention as a mechanism capable of producing shock-compressed layers, streamers, and binary systems (e.g., Kinoshita & Nakamura 2022; Yano et al. 2024). However, previous studies have mainly focused on envelope structures and binary formation after protostar formation, while the effect of core encounters at the first hydrostatic core (FHSC) stage on the mass growth of the central object remains unexplored. In addition, although global numerical simulations of HFS formation and mass accretion onto hubs have made significant progress (e.g., Nozaki & Inutsuka 2026), no study has yet resolved core encounters in HFSs down to the FHSC scale and investigated how such interactions affect FHSC evolution. In this study, we perform hydrodynamical simulations of encounters between gravitationally collapsing cores that form in filaments and flow toward a hub. We find that most of the gas is dissipated and becomes gravitationally unbound, leading to a strong suppression of subsequent mass accretion onto the FHSC. Core encounters in HFSs may therefore provide a new formation pathway for brown dwarfs and very-low-mass stars. In other words, HFSs, which have primarily been discussed as sites of massive star formation, may also contribute to the low-mass end of the initial mass function. Furthermore, an FHSC stripped of its outer envelope, which we refer to as a naked first core (NFC), may serve as an observational tracer of the FHSC phase. Although FHSCs are crucial objects that characterize low-mass star formation through the second collapse process (e.g., Tomisaka & Tomida 2011; Tomida et al. 2012), they are difficult to identify observationally because of their short lifetimes and because they are deeply embedded within dense envelopes (e.g., Fujishiro et al. 2020; Tokuda et al. 2025). In contrast, NFCs may be observable as rare objects because they have longer lifetimes and their radiation is not absorbed by an outer envelope. In this talk, we present the results of numerical simulations of core encounters in HFSs and discuss their implications for very-low-mass star formation via NFC formation, the thermal evolution of NFCs, and the observability of NFCs based on synthetic spectral energy distributions.

22. 67938 A complete survey of filaments in Cygnus-X

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Filamentary gas structures are widely observed in molecular clouds and are suggested to play a key role in the star formation processes. However, existing observations of molecular filaments are still biased toward case studies and small samples, and a large sample study from a single giant molecular cloud is lacking. We aim to carry out a complete census of filaments in Cygnus X and obtain their physical properties, relations with dense cores, magnetic field (B field), and HII regions. We extracted 2633 filaments and 6551 cores from the column-density map of Cygnus X, using the most updated getsf algorithm. We then investigated the mass functions for the cores on and separate from the filaments, compared the orientations of the filaments with that of the B field obtained with the Planck data, derived the radial column-density profiles of the filaments close to HII regions, and calculated the distances between the identified young stellar objects and filament spines. We also re-extracted filaments at the resolution of the Planck 353 GHz dust-emission map to study their relationship with the B field. The core mass function constructed from the cores on the filaments (onCMF) shows a power law in the high-mass-end (> 10 M⊙) with a slope of −2.30, whereas the high-mass end of the core mass function (CMF) derived from the cores outside the filaments (outCMF) has a much steeper power-law distribution with a slope of −2.83. The core mass corresponding to the peak of onCMF is much less than the Bonner-Ebert mass, but that corresponding to the peak of outCMF is well comparable to the Bonner- Ebert mass. Filaments re-extracted from the column-density map smoothed to an angular resolution identical to the Planck 353 GHz map are mostly perpendicular to the B field, except that those of the lowest column densities are parallel to the B field. The transition from parallel to perpendicular occurs at a column-density equivalent to AV = 10 mag. Most prominent filamentary gas structures and high-mass cores appear to be preferentially located along the boundaries of HII regions or at the intersections of multiple HII regions. The filaments close to the HII region boundaries show a steeper column-density profile on the side toward the HII region compared to that on the opposite side. The formation of more massive cores has a stronger dependence on filaments, and the latter may provide a mass reservoir for the former to grow in mass via accretion. The B field plays a crucial role in filament formation, and the type-O mode where filaments form at the tip of converging flows along an oblique MHD shock front may be prevalent in Cygnus X. In this context, expanding HII regions in the complex induces shocks that compress the surrounding gas, creating inhomogeneity and dense clumps, and forming filaments. The global picture of filaments, cores, and star formation in Cygnus X is apparently consistent with the bubble-filament paradigm proposed in the literature.

23. 67847 Probing Star Formation Scaling Laws in Parsec-Scale Cluster-Forming Clumps

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Most stars form in cold, dense regions of molecular clouds, known as clumps, that are located within the spiral arms of galaxies. These parsec-scale clumps, undergoing strong gravitational collapse, act as star- forming factories. However, the rate and efficiency with which gas is converted into stars across different scales of star-forming systems, from clumps to entire galaxies, remain subjects of debate. Key questions focus on how the star formation rate (SFR) and star formation efficiency (SFE) depend on factors such as gas mass, gas surface density, and characteristic timescales, relationships collectively known as star formation scaling laws. In a recent study, we analyzed nearby star-forming clumps in our Galaxy to determine the SFE in dense environments and to investigate these scaling laws, particularly the relationship between star formation surface density and gas surface density. Our results revealed a median instantaneous SFE of approximately 20% and an SFE per free-fall time of about 13%. These values are significantly higher than those typically inferred for larger-scale structures such as molecular clouds and galaxies, suggesting that star formation proceeds more efficiently in dense, cluster-forming environments. In this presentation, I will discuss these results and implications of these findings on star cluster formation and for the long-term survival of stellar clusters as gravitationally bound systems.

24. Fragmentation in high-mass star-forming regions

Suinan Zhang

Suinan Zhang

Fragmentation is a key process linking molecular clouds to newly born stars, yet its behavior in Galactic high-mass star-forming regions is not fully understood. Massive stars are believed to preferentially form in massive, dense, parsec-scale clumps located at the intersections of multiple filaments. These clumps, usually referred to as hubs, are characterized by physical conditions and geometries distinct from those elsewhere. To understand massive star formation, it is fundamental to understand how fragmentation proceeds in such dense hubs and which physical mechanisms regulate it. In this talk, I will summarize recent progress from both theoretical and observational perspectives on fragmentation in high-mass star-forming clumps. I will discuss the hierarchical nature of fragmentation across spatial scales and compare fragmentation in dense hubs with that in filaments. I will also highlight the challenges in distinguishing the roles of different physical mechanisms in controlling fragmentation, and discuss how these can be addressed by future observations and theoretical work.

25. How do massive stars keep growing? From hub feeding to core growth during feedback in W33 Main

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L. M. Böhm, K. Immer, Ashley T. Barnes

Hub-filament systems efficiently channel material toward cluster-forming hubs. However, how gas is transferred through the hierarchy of filaments, hubs, and massive cores, and whether this transport remains connected to massive-star growth once ionizing feedback becomes dynamically important, remains poorly constrained. Addressing this problem requires tracing a single system continuously from cloud scales to the immediate vicinity of forming massive stars, where accretion, fragmentation, and feedback interact.

We present a multi-scale view of the massive star-forming region W33 Main, combining archival ALMA-IMF and VLT/KMOS observations with VLA ammonia and radio recombination line data and our new ALMA observations reaching scales of approximately 100 au. Together, these observations provide a continuous view of a feedback-active hub-filament system across nearly five orders of magnitude in spatial scale, from parsec-scale filamentary accretion flows to the environments of individual massive cores.

Dense-gas kinematics reveal a network of converging filaments feeding a central hub, with coherent velocity gradients directed toward the cluster-forming center. At the same time, radio recombination lines and near-infrared feedback tracers show that the embedded HII regions do not expand isotropically, but instead drive an anisotropic blister/champagne flow in which ionized gas escapes preferentially through low-density channels. Rather than disrupting the dense-gas reservoir uniformly, feedback appears to be redirected by the hub-filament geometry, allowing organized inflow and feedback escape to coexist within the same system.

The new ALMA observations extend this picture to the scales where fragmentation, hot-core evolution, and massive-star growth occur. High-resolution continuum and CH3CN observations reveal a rich population of embedded hot cores within the central hub, while radio recombination lines provide an improved census of the UC/HCHII-region population. Extended CH3CN structures surrounding the cores offer a unique opportunity to trace the kinematics of the dense gas immediately connected to the massive protostellar systems. By linking the large-scale filament network to the embedded core population, we investigate how material is transferred through the hub-filament hierarchy and assess how efficiently hub-scale inflow is converted into the growth of individual massive cores.

W33 Main therefore provides a rare opportunity to connect four regimes that are usually studied separately: filamentary transport, hub assembly, core growth, and ionized feedback. By following gas from parsec-scale filaments into a feedback-active cluster-forming hub and onward to the immediate surroundings of forming massive stars, this work places new observational constraints on how hub-filament systems regulate cluster assembly and enable the continued growth of massive stars after feedback has already broken out.

26. 67836 Hub-filament feeding a bloated massive protostar: multiscale accretion in IRAS 19520+2759

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Bloated stars are high-mass young stellar objects in a crucial evolutionary phase of active accretion, characterized by an expanding stellar surface, low effective temperature, and highly deficient radio emission. However, direct observational tests of this phase remain scarce. IRAS 19520+2759 (I19520) is currently the most compelling bloated star candidate, based on its high luminosity ($L > 10^5$ $L_\odot$), low effective temperature, and weak centimeter radio emission, further supported by our recent variability study detecting periodic variability consistent with the theoretically predicted pulsational instability. Motivated by these findings, we present new high- resolution EVLA (0.41") and ALMA (0.15") observations of I19520. The radio continuum exhibits a spectral index of 0.5, consistent with a thermal jet. A single compact millimeter continuum source is spatially coincident with the optical counterpart, making I19520 a unique massive young stellar object with a bright optical counterpart. The ^{13}CO emission reveals a prominent molecular outflow in the east–west direction, along with a possible secondary outflow, which may indicate the presence of a companion potentially accounting for the high bolometric luminosity of I19520. SO_2 transitions reveal a hot molecular core and a Keplerian disk, with a central dynamical mass of 10–15 $M_\odot$. A spiral structure visible in both continuum and multiple line tracers is consistent with a streamer feeding the circumstellar disk, as reproduced by the infalling rotating envelope model. Large-scale ALMA observations reveal six filamentary structures in $C^{18}O$ and H_2CO, distributed radially and converging on the central massive protostar, with velocity gradients consistent with inward feeding. Together, these structures reveal a coherent multiscale accretion picture from large-scale filaments down to the circumstellar disk, potentially sustaining the high accretion rates required for the bloated phase

27. 67939 Probing Hot Disk Chemistry at the End Point of Mass Supply in Massive Star Formation

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Massive stars form through the transfer of material from hub-filament systems to dense cores, envelopes, and ultimately circumstellar disks. In this mass-supply chain, disks are expected to provide the final pathway of accretion onto the forming massive star while mitigating strong radiative feedback. Recent high-resolution observations have increasingly suggested the presence of compact rotating disks around massive protostars. However, their physical and chemical properties remain poorly constrained, partly because commonly used molecular tracers often probe larger-scale envelope gas rather than the disk itself.

Refractory species such as NaCl offer a promising way to probe the hot inner regions of massive protostellar disks. Recent ALMA observations of the massive protostellar disk IRAS 16547-4247a (hereafter, the I16547a disk) have detected multiple NaCl transitions with substantially different excitation energies, providing a new opportunity to investigate hot disk chemistry and astromineralogy. As a first step toward using these lines as quantitative disk diagnostics, we developed a radiative transfer model for NaCl line emission from a plane-parallel disk structure including dust emission and scattering. We applied this model to ALMA Band 6 observations of the I16547a disk and simultaneously fitted three NaCl lines with Eu/kB = 107 K, 626 K, and 1128 K together with the dust continuum.

Our modeling shows that efficient dust scattering can suppress the continuum intensity and allow NaCl line emission to emerge even in optically thick disks where molecular lines would otherwise be masked. The fitting constrains physical properties of the disk, including temperature, column density, optical depth, and dust emissivity, as well as the chemical constraints on NaCl abundance, suggesting that about 1% of the total sodium is present as gas-phase NaCl in the I16547a disk. This abundance is orders of magnitude higher than predicted by equilibrium condensation models, suggesting chemical non-equilibrium in the hot disk. By extracting physical and chemical information from refractory molecular lines, this work provides a new observational route to characterize the disk-scale accretion environment at the end point of mass supply in massive star formation, while also opening a path toward astromineralogy in high-temperature disks. As NaCl lines have also been detected toward other massive protostellar disks, future work will expand the sample size to further constrain these environments.

28. 67811 Future massive-star growth in hub-filament systems: insights from a 3D simulation and synthetic observations

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Dana Makarova et al.

Massive stars form within dense, structured, and often clustered gas. Hub-filamentary systems (HFSs) are one commonly discussed morphology in which filaments converge toward dense central hubs. Such systems are proposed to channel mass inflow toward the formation sites of massive stars. However, it is still unclear how strongly hub-filamentary morphology is connected to the early growth of future massive stars. Confirming this connection in observations is challenging due to projection effects and line-of-sight confusion in position-position-velocity (PPV) data. To explore this connection and investigate projection effects, we use a three-dimensional MHD simulation of star formation and line radiative transfer modeling. This allows us to reconstruct time-dependent accretion histories and examine whether future massive stars are located closer to three-dimensional hub proxies during enhanced-accretion episodes. We find that the future massive star growth is highly episodic: typically, about 40\% of the accreted mass is gained during enhanced- accretion intervals that occupy only about 10\% of the growth time. During these enhanced-accretion episodes, future massive stars are located slightly closer to morphological hub proxies, suggesting a link between enhanced accretion and HFS morphology. To assess whether this relation could be recovered observationally, we analyze synthetic observations. Our analysis shows that the relation between projected hub candidates and intrinsic three-dimensional hub proxies is strongly projection-dependent. In favorable cases, projected hub candidates coincide with hub proxies and show intensity and velocity signatures similar to those expected for hubs. However, line-of- sight overlap can enhance apparent intensity peaks and make the interpretation ambiguous. Overall, our results suggest that episodic future massive-star growth is linked to the evolving HFS morphology of the gas reservoir, but this link can be difficult to recover from observational PPV data alone. This highlights the need for new analytical approaches that combine moment maps, PI/PV profiles, and 2D--3D comparisons

29. 67795 Evidence for the gravity-driven and magnetically regularized gas flows feeding the massive protostellar cluster in Cepheus A

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The hierarchical interplay among gravity, magnetic fields, and turbulence in forming massive protostellar clusters remains elusive. We present high-resolution (~14 arc seconds ≃ 0.05 parsecs), 850-micrometer dust polarization and C18O line observations of Cepheus A using JCMT SCUBA-2/POL-2 and HARP. Our analysis reveals aligned gravitational (G), magnetic (B), and velocity fields (K), with an energy hierarchy of EG > EB > EK. Gravity, as the primary driver, induces gas flows and drags in B-field lines. Magnetic tension, as a secondary force, regulates turbulence, enabling ordered flows with an accretion rate of ~2.1 ± 0.4 × 10−4 M⊙ per year. This challenges the conventional view of B-fields resisting collapse in the clump/hub scale, instead showing cooperation with gravity. The ~0.6-parsec clump-scale B-field (with a mean position angle of ~45°) aligns coherently with fields at cloud (~5 parsecs), core (~0.05 parsecs), and disk (~2000 astronomical units) scales, offering key insights into the role of magnetic fields in multiscale star formation dynamics.

30. 67981 The dominance of turbulence over magnetism in the formation of massive star cluster seeds

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Junhao Liu

High-mass stars form in protoclusters, where gravo-magnetic processes shape collapsing clouds and clumps to be elongated preferentially perpendicular to magnetic (B) fields. Yet it remains unclear whether gravo-magnetic processes still govern the formation of smaller-scale condensations in massive-star-forming protoclusters, which are crucial for understanding the stellar initial mass function and multiplicity. Here we report the first statistical evidence that the condensation elongations are preferentially aligned with local B fields, based on high-resolution data from the largest dust polarization survey toward 30 massive star-forming regions with the Atacama Large Millimeter/submillimeter Array (ALMA). Our clustered massive star formation simulations reveal that this more parallel alignment is exclusively observed in models where initial turbulence dominates B fields. In contrast, models with initial B fields dominating turbulence distinctly exhibit a more perpendicular alignment. The comparison between observations and simulations suggests that turbulence could play a more important role than B fields in the formation of condensations in the context of clustered massive star formation, contradicting the prediction of classical magnetically regulated models. Moreover, we find a possibly turbulence-induced preferential misalignment between the B field and rotation axis of condensations, which may potentially reduce the magnetic braking efficiency and facilitate the formation of large protostellar disks. Our findings indicate that turbulence could be critical in determining the initial stellar properties.

31. Massive Star Formation from Large Scale Magnetized flows

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Shantanu Basu

The increasing variety of observed large-scale streamer and hub-filament systems raises the question -- can large scale flows change the mass assembly process of star formation? Parsec scale flows carry significant angular momentum and need to lose this angular momentum to reach a forming star. I present a new mechanism of magnetized direct collapse. The large magnetic lever arm and ram pressure of the infalling material come together to ensure that matter is channeled directly to the stellar surface. This is a new mode of star formation distinct from the usual channel for low mass stars. Numerical simulations of magnetized direct collapse show that this mode of star formation leads to rapid mass accumulation accompanied by weak outflows and a very small or nonexistent disk in the early phases.

32. The Kinematic and Astrochemical State of Hub-Filament Systems as seen through LEGO

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Jens Kauffmann & LEGO Team

The IRAM 30 m Telescope Large Program LEGO imaged molecular-line emission toward 25 Galactic star-forming regions across broad, contiguous spectral ranges covering 85–115 GHz and beyond. The sample includes nearby regions of low-mass star formation, such as Rosette and IC 5146; luminous high-mass star-forming complexes, such as W49A; and targets sampling both the central and outer Milky Way (Kauffmann & Barnes. 2022EPJWC.26500019K). In several regions, more than 30 emission lines are detected, providing a rich multi-species view of the gas physics and chemistry. These data make it possible to characterize the kinematic state of sub-filaments apparently feeding central hubs, while also constraining the evolutionary history of these regions through their astrochemical properties. Together, this kinematic and chemical information opens a new path toward revealing the physical nature of hub-filament systems.

The diagnostic power of kinematic data is illustrated by our recent SOFIA-based study of the magnetic field in the DR21 star-forming region within the Cygnus-X complex (Pillai et al. [2026arXiv260512604P]). In that work, molecular-line kinematics proved essential for interpreting the observed magnetic-field structure. Published data show line-of-sight velocities well below free-fall speeds for sub-filaments that appear to stream into the central DR21 hub. We argue that these observations are consistent with a picture of magnetically guided accretion into star-forming hubs. In this talk, I will present additional physical modeling that supports this interpretation, including a novel theoretical description of free-fall motions into hubs that is of general relevance to the study of hub-filament systems (Imming et al., in prep.).

The underutilized diagnostic power of astrochemical data is demonstrated through molecular line-ratio studies across several LEGO targets. We show that, for some molecules such as HCN, the emission efficiency per unit gas mass varies by at least an order of magnitude between regions (Kauffmann et al. [2017A&A...605L...5K]; Barnes et al. [2020MNRAS.497.1972B]). We propose that these variations reflect the astrochemical evolution of the targets over time, including the effects of feedback after the onset of star formation. If correct, this implies that astrochemical observations provide information that is largely orthogonal to the dynamical and structural diagnostics currently used to interpret hub-filament systems. LEGO therefore demonstrates how broadband molecular-line surveys can connect filament kinematics, hub accretion, magnetic regulation, and chemical evolution into a more complete picture of clustered star formation.

33. 67837 Mapping the evolution of magnetized hub-filament systems leading to the formation of star-clusters with low- to high-mass stars

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Doris Arzoumanian, Jihye Hwang, Paolo Suin, Nanda Kumar, Shu-ichiro Inutsuka

Observations reveal the organization of the interstellar medium into filament networks. In molecular clouds, the densest filaments are identified as the precise birthplaces of solar-mass stars, while high-mass stars form preferentially in the hubs where the filaments merge. To understand the formation process of star- clusters, it is thus essential to describe the formation and evolution of hub-filament systems and their fragmentation into star forming cores. I will present our recent theoretical and observational studies describing the evolution of the physical properties (turbulence, magnetic field structure, filament line mass, mass accretion rates) of hub-filament systems as star formation proceeds from early (weak stellar feedback) to evolved (strong feedback) stages. In addition to the previously reported matter flow along the dense filaments onto the hub, our recent studies identify matter flows from the the low-density inter- filamentary regions, with a fraction of the matter being accreted by the filaments and some flowing directly onto the hub. These new findings demonstrate the importance of the total available gas mass, both along the dense filaments and in the extended low-density inter-filament regions, to fully describe the history of star formation in hub-filament systems. I will also show observational signatures suggesting the formation of hub-filament systems through multiple collisions and filament coalescence, shaping the physical environment necessary for the formation of star-clusters with low- to high-mass stars.

34. Identifying Multiple Hub–Filament Systems in the Sh 2-284 Star-Forming Complex

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Harmeen Kaur, Saurabh, Sharma, Devendra K Ojha, Alok Durgapal

Hub–filament systems (HFSs), characterized by the convergence of multiple filaments into dense hubs, are considered fundamental structures in molecular clouds and important sites of clustered star formation. We present a study of the filamentary network associated with the Galactic H II region Sh 2-284, located at a distance of approximately 3.8 kpc, with the primary goal of identifying and characterizing multiple hub–filament systems. This work combines far-infrared observations from Herschel and molecular line data from the FUGIN survey to investigate the morphology and connectivity of dense gas within the cloud. Herschel-derived column density maps are used to trace the filamentary structures, while FUGIN CO observations provide information on the distribution and large-scale organization of the molecular gas. To identify and characterize the filament network, we employ the getsf and DisPerSE algorithms, which detect both prominent filaments and finer sub-filamentary structures. In addition, CuTEx is used to identify compact dense condensations associated with the filaments and hub regions. Our analysis reveals a complex system of interconnected filaments extending across the molecular cloud, with several locations exhibiting the characteristic morphology of HFSs. Multiple candidate hubs are identified at filament junctions, suggesting that Sh 2-284 hosts a hierarchical network of filamentary structures. By combining continuum and molecular gas tracers with complementary structure-identification techniques, this study aims to provide a comprehensive view of the filamentary architecture of Sh 2-284 and to assess the prevalence of multiple HFSs within the region. The results will contribute to a better understanding of the role of filamentary networks in organizing molecular gas and regulating star formation in Galactic molecular clouds.

35. 67805 Discovery of a rich population of compact hub-filament systems in a single star-forming complex

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In recent years, hub-filament systems (HFSs) have emerged as key structures characterized by a network of filaments converging toward a central hub-typically the birthplace of massive OB stars (> 8 Msun) and young stellar clusters. Despite growing observational evidence, their typical number, spatial scale, formation mechanisms, and overall impact on star formation within a single cloud remain poorly constrained. To address these issues, a comprehensive multi-scale, multi- wavelength investigation of the filamentary structures in the W33 complex was conducted. A rich population of 45 compact hub-filament systems, with a median size of ~2.4 pc, is investigated toward dark filamentary structures in the W33 complex. The hub-filament systems are preferentially located at the intersections of elongated infrared dark substructures and exhibit clear signatures of massive star formation and active protostellar clustering, while largely lacking radio continuum emission. To our knowledge, this is the first report of such a high concentration of small-scale hub-filament systems within a single star-forming complex. These results support a scenario in which cloud/filament fragments form compact hub-filament systems that promote efficient, clustered star formation, frequently leading to massive star formation. In this symposium, I will discuss these observational findings and their implication for underlying phyiscal processes.

36. A Rich Population of Hub–Filament Systems in Cygnus X and Evidence for Hierarchical Star Formation

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Hub-filament systems (HFSs) are widely believed to play a crucial role in the formation of massive stars and young stellar clusters. Numerous observational studies have revealed longitudinal gas flows along individual filaments toward dense central hubs, suggesting that filaments actively channel material into hub regions where star formation is taking place. Although single or double hub-filament systems have been reported in the literature, the identification of a large population of such systems within a single star-forming complex remains relatively rare. An important question is whether the presence of multiple hub-filament systems within a molecular cloud complex can enhance overall star formation activity. To investigate the role of filaments in star formation, a detailed multi-wavelength study of the Cygnus X complex, which is one of the most active star-forming regions in the Galaxy and a well-known site of massive star formation, is carried out. Infrared images reveal >140 hub-filament systems distributed throughout both Cygnus North and Cygnus South. In addition, several large-scale, extended hub-filament systems are associated with infrared dark clouds and exhibit corresponding 13CO emission detected in the Purple Mountain Observatory survey. The identified hub-filament systems span a wide range of sizes, from compact systems with radii of ~0.4 pc to extended systems with radii of ~1.1 pc.

In selected regions of Cygnus X, many of these hub-filament systems are associated with previously reported 1.2 mm continuum clumps. Some HFSs also appear to be linked with massive dense cores (MDCs) and radio continuum emission, indicating ongoing or recent massive star formation. Furthermore, Minimum Spanning Tree (MST) analysis reveals that protostars are strongly concentrated within the HFSs, with typical protostellar separations of less than 0.4-0.7 pc, demonstrating a high degree of clustering within these fragmented structures. Many hub-filament systems host their own embedded stellar groups, while neighboring hub-filament systems are often separated by only ~1.9 pc.

Collectively, these results support a hierarchical, tree-like scenario of star formation in which filamentary clouds fragment into clumps, each hosting an HFS that facilitates active star formation. Cygnus X therefore represents another notable example, similar to the W33 complex, where a rich population of compact HFSs is found within a single star-forming complex. The presence of numerous HFSs in such environments provides important insights into the physical processes that regulate clustered and intense star formation.

37. 67844 A Massive Cloud, A Modest Cluster: Hierarchical Collapse and Filament-fed Cluster Formation in G148.14+00.41

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Star formation occurs in cold, dense molecular clouds through the interplay of gravity, turbulence, magnetic fields, and stellar feedback, with most stars forming in clustered environments. Rich and massive stellar clusters are not only important laboratories for understanding stellar evolution, but they also have a profound impact on the interstellar medium and the star-formation activity of their host galaxies. Despite their importance, the processes by which intermediate- to high-mass bound stellar clusters form within giant molecular clouds (GMCs), and the relative roles of different physical mechanisms in their formation and early evolution, remain yet to be understood. Molecular clouds with masses more than ~10^5 Msun are potential sites of massive cluster formation. Investigating the properties of such clouds during their early evolutionary stages provides an opportunity to test competing theories of cluster formation. G148.14+00.41 (hereafter G148) is one such cloud. We present a comprehensive observational case study of G148 through a multi-scale dissection of the cloud, systematically examining its physical properties and the governing processes across a wide range of spatial scales. Our analysis includes the dust and gas properties, the clustering structure of young stellar objects (YSOs), the filamentary and clump structures within the cloud, the mass-assembly processes of the clumps, the magnetic field properties of the hub, and the stellar cluster embedded within the hub. Using Herschel dust continuum map, near-infrared (NIR) dust extinction map from UKIDSS, and CO molecular line data from the Purple Mountain Observatory, the cloud was found to be of high mass (~10^5 Msun), low dust temperature (~14.5 K), nearly circular (projected radius ~26 pc), and gravitationally bound with a dense gas fraction of ~18%. Clustering analysis of YSOs reveals that the central region of the cloud exhibits a fractal substructure and primordial mass segregation, while the cloud itself is characterized by a shallow gas density profile. These properties contrast with the monolithic formation scenario, which predicts a more centrally concentrated density profile and radial density gradient clustering.

38. 67804 The Connection Between Filament Morphology and Star Cluster Formation

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Filamentary structure is ubiquitous across star forming molecular clouds. It is within such filamentary structure that we expect the seeds of star formation and eventual star cluster formation. However, the connection between the morphology of these filaments and the dynamics of the forming star cluster remains unclear. As dynamics play an integral role in the long term evolution of star clusters, it is important to understand how the natal gas environment of a cluster imprints itself on the cluster's dynamics. We introduce a novel method to convert observations of molecular gas distributions into simulation initial conditions and perform simulations of star cluster formation in the nearby Aquila Rift hub-filament system. We find that gravity dominates the evolution of the principal star forming filament (referred to as Serpens South) within less than 1Myr leading to the formation of small stellar clumps along its spine. Gas flows along Serpens South promote the merger of these stellar clumps and, after ~2Myr, a final collection of star clusters forms. We find that gas flows and filament dynamics directly affect the rotation and expansion of the forming star clusters and that these signatures are present even after gas is expelled from stellar feedback. We also show preliminary results from simulations studying the evolutionary parameters of hub-filament systems that may form as a result of colliding atomic gas flows and infer their ability to form bound star clusters. Overall, our research highlights the importance of hub-filament phase space morphology on the formation and long term evolution of star clusters.

39. NGC 2316: A Hub-Filament System in Formation

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Saurabh sharma et. al.

We present a multiwavelength study of the stellar cluster NGC 2316 and its parental molecular cloud. A prominent cold gas and dust lane extends westward from the cluster, with low-mass star formation concentrated at its western end and relatively older, more massive stellar populations located near the cluster. Molecular-line observations reveal an elongated cloud comprising several interconnected filaments. Their morphology and kinematics indicate filament coalescence and possible longitudinal gas flows feeding the cluster. The observed structure and dynamics are consistent with a Hub-Filament System (HFS), in which NGC 2316 represents the central hub and the dust lane forms the main filament. These findings suggest that star formation was initiated in the hub and subsequently progressed toward other filamentary nodes, highlighting the importance of filamentary accretion in cluster formation and evolution.

40. 67901 The Origin of Star Cluster Mass Functions in Molecular Cloud Evolution

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The majority of stars, particularly massive stars, are born and evolve in star clusters; therefore, elucidating the origin of star clusters is essential for understanding the evolution of galaxies and the Universe. Recent large surveys conducted with the HST and JWST have revealed a possible universality in star cluster mass functions, characterized by a power-law distribution with an index of -2. In contrast, recent observations with ALMA and JWST have identified more than 100,000 molecular clouds in nearby galaxies, indicating that the molecular cloud mass function can be described by a power-law distribution with an index greater than -2. These findings suggest that the bulk of molecular mass is concentrated in massive clouds, whereas stellar mass is more evenly distributed across star clusters spanning a wide range of masses. The origin of this difference remains poorly understood.

In this study, we construct a semi-analytic framework to investigate the origin of this difference. We first consider the simplest scenario, in which a single molecular cloud forms only one star cluster. This leads to two possible explanations: (1) the star formation efficiency in more massive molecular clouds is lower than that in less massive clouds, or (2) more massive star clusters are disrupted more rapidly than lower-mass clusters. However, both possibilities are inconsistent with the observed universality of star formation efficiency and with the current understanding of the dynamical evolution of star clusters. We therefore explore more complex scenarios in which a single molecular cloud forms multiple star clusters, as suggested by recent observations of multiple star cluster progenitors (so-called hub–filament systems) within a single molecular cloud. We formulate a coagulation equation to investigate the formation conditions of star clusters within each cloud, thereby reproducing the observed star cluster mass functions. Our results show that, in typical cases, more than three star clusters form within a single molecular cloud. Moreover, the mass ratios among these clusters follow a probability distribution with a power-law index close to -2.

In this presentation, I will introduce these results and discuss possible observational strategies for testing them in future studies, which will play an important role in connecting our understanding of local star-forming regions in the Milky Way to those in external galaxies.

41. Accretion Network Theory: Connecting Cloud Assembly and Core Growth

Stefanie Walch-Gassner

Steffanie Walch

Models of (massive) star formation are based on core collapse, competitive accretion, global hierarchical collapse, or the regulation of accretion by turbulent and tidal flows. These approaches differ in what sets the mass supply and which gravitational scale controls the dynamics. I will present the Accretion Network Theory (ANT), a complementary framework that focuses on the evolving topology of that supply: gravitational potential basins are treated as nodes, while coherent mass-transport channels form the directed, weighted edges of a time-dependent network.

We apply this approach directly to three-dimensional adaptive mesh (AMR) colliding-flow simulations. An AMR-native potential dendrogram identifies nested gravitational basins, while moving potential surfaces define physically motivated control volumes for measuring mass fluxes, force balance, angular momentum and Eulerian virial terms. Temporal tracking follows cores through motion, mergers and changes in the refinement pattern. The analysis reveals a transition from a thermally assembled, non-gravity-directed molecular environment to compact potential-selected structures in which gravity becomes dynamically important. Accretion is spatially anisotropic, while rotation, residual motions and thermal pressure regulate how material crosses the core boundaries rather than simply halting inflow.

The inward mass flux increases systematically with enclosed mass. For progressively larger potential surfaces we find that the mass accretion rate of a structure depends on its mass to the power of p, with p ~ 1.11, 0.99, and 0.71 for the 30%, 60% and 90% potential surfaces, respectively. The approximately linear inner relations imply nearly constant fractional mass processing, whereas the sub-linear outer relation suggests geometrically or supply-limited capture. At the same time, mass alone does not determine whether a structure is gravity- or support-dominated.

These results motivate a network interpretation of core formation: future core growth depends not only on present core properties, but also on upstream reservoirs, connectivity, channel capacity and competition at shared junctions.

42. 67852 How ionising feedback restructures Hub-Filament Systems

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In the last decade, hub-filament systems have been increasingly recognised as the cradles of high-mass star formation. Once massive stars form, their evolution takes a drastic turn. Expanding into the parent cloud, their HII regions heavily restructure the medium, affecting gas flows and reordering the magnetic field geometry. Numerous observations and analytical studies have shown that this compression can create dense filaments and clumps, potentially triggering star formation. However, how both pre-existing and new structures respond to this feedback, and whether the resulting conditions still support the same mode of star formation, remain open questions. The outcome of this interaction on the star formation process depends on several physical conditions, including the pre-existing field strength and cloud topology, as well as the feedback energetics. Disentangling these parameters from observations alone is notoriously difficult. Numerical simulations are a valuable tool for gaining insight into this process, providing a controlled environment in which to isolate the role of each. To systematically probe the parameter space, we ran a suite of numerical simulations of a 10^4 M□ HFS, varying the ionising star's mass (20, 34, or 100 M□), its position relative to the central hub, and the cloud's initial magnetisation, which sets the overall morphology. Across this parameter space, we recover a wide range of outcomes, from flickering HII regions too weak to escape the gravitational potential well, to disruptive bubbles that disperse the central hub into the surroundings. In this talk, I will discuss how star-forming structures (the pre-existing filaments and central hub, and the newly formed ones) respond to intense feedback, focusing on magnetic field strength and alignment and their relation to the accreting gas flow. The expanding shell leaves distinct signatures that can be observed and compared with pristine structures unaffected by the HII region. This systematic analysis offers a framework for interpreting the impact of compact and extended HII

43. 67870 The role of gravity, turbulence, and protostellar feedback in star formation

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Sajay Sunny Mathew, Christoph Federrath, Amit Seta

The dynamics of gas within molecular cloud filaments play a key role in assembling dense star-forming regions and shaping the properties of the emerging stellar population. We perform a series of three- dimensional, magnetohydrodynamical (MHD) simulations of star cluster formation including gravity, turbulence, magnetic fields, stellar radiative heating and outflow feedback to study how each of these physical mechanisms affects the cloud morphology and star formation properties. We find that 1) stellar heating results in a higher fraction of high-mass stars by suppressing fragmentation and thus allowing existing stars to accrete to higher masses. 2) the inclusion of protostellar outflows reduces the star formation rate (SFR) by a factor of ~ 2, increases fragmentation, and shifts the IMF to lower masses by a factor of 2. 3) the filamentary structure, SFR, and IMF are significantly influenced by the turbulent characteristics of the cloud such as the mode of turbulence driving, Mach number, and virial parameter. We conclude that star formation is governed by the combined effects of gravity, turbulence, magnetic fields, radiation and outflow feedback.

44. 67880 Understanding the importance of magnetic fields in the “collect and collapse” model of star formation: a case study towards S104 using JCMT SCUBA2/POL2

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Rohit Chaudhary, Eswaraiah Chakali, Jessy Jose, Manash R Samal, Vineet Rawat, and Sandhyarani Panigrahy

Magnetic fields (B-fields) play a crucial role in regulating star formation by mediating the complex interplay between gravity, turbulence, and stellar feedback. However, their influence in feedback- dominated environments remains poorly understood, including in HII regions where expanding ionization fronts (I-fronts) interact with magnetized molecular clouds. HII regions created by massive stars provide ideal laboratories for studying how B-fields influence shell fragmentation and subsequent triggered star formation. We present the results based on high-resolution (14”) 850 μm dust continuum polarization observations using JCMT SCUBA-2/POL-2 towards two dense clumps located on the shell of the spherical HII bubble Sh2-104. These data are. complemented by JCMT HARP ^13CO and C^18O (J = 3–2) observations to investigate the connection between gas kinematics and magnetic fields. B-fields in clump 1 exhibit two distinct components – one with 0±24° orientation, aligning the I-fronts, while the other with 125±40° appears to be perturbed by the Ultra-compact HII region formed within clump 1. To further examine the influence of the expanding HII region on the surrounding clumps and B-field morphology, we produced offset angle maps (Δθ) between the tangential orientation of the I-front and the B-field position angle, revealing preferential alignment with the I-front in clump 1 (except those around UCHII) and radial configurations in clump 2. Using modified Davis–Chandrasekhar–Fermi techniques based on structure-function and autocorrelation-function analyses, we estimate magnetic field strengths of 49.7 ± 4.1 μG in Clump 1 and 61.1 ± 8.4 μG in Clump 2. The magnetic-to-turbulent pressure ratios indicate that magnetic pressure is comparable to or exceeds turbulent pressure in both clumps (PB/Pturb ≈ 1.5-2), while the derived Alfvénic Mach numbers remain sub-Alfvénic (MA ≈ 0.3-0.4), suggesting that magnetic fields are dynamically important in regulating turbulent motions. The estimated mass-to-flux ratios (λ = 1.16±0.20 and 0.8±0.18) imply that Clump 1 is transcritical to supercritical, whereas Clump 2 is subcritical to transcritical. Furthermore, most low-density regions within both clumps appear magnetically dominated. Our results suggest that the expanding ionization front of Sh2-104 has swept up molecular material to form dense shell condensations while simultaneously compressing and reorienting the magnetic field. The strengthened magnetic field provides significant support against gravitational collapse and may regulate the fragmentation of the swept-up shell. The embedded UCH II region in Clump 1 is likely a product of feedback-triggered, second-generation massive star formation.

45. 67693 Hypercompact H II Regions as Tracers of Massive Star Formation and Stellar Dynamics

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We present high-angular-resolution ALMA observations of hypercompact (HC) H II regions embedded within hot molecular cores, aimed at investigating the physical conditions and kinematic structure of the earliest stages of massive star formation. By combining molecular line tracers with ionized gas diagnostics, we examine the close interplay between dense molecular material and compact ionized regions surrounding young massive stars. Our observations reveal complex morphologies and kinematics that reflect the combined influence of accretion, rotation, stellar winds, and feedback operating on sub-parsec scales. We place these observational results in a broader context by considering recent studies that highlight the role of dynamical interactions in shaping massive stellar systems, including the formation of runaway and walkaway stars. In such scenarios, HC H II regions associated with hot cores provide a unique laboratory for probing how ionization and feedback proceed in dynamically evolving environments. Overall, our work demonstrates the power of ALMA observations in connecting the earliest ionized phases of massive star formation with the dynamical processes that govern the evolution of young stellar systems.

46. 67877 Tracing Star Formation Under Massive Star Feedback: A Multi-Wavelength Study of the Herbig Star PDS 255

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Understanding whether stellar feedback suppresses or triggers star formation remains an open question, especially in hub–filament systems where massive stars strongly reshape their environments. The Bochum 6 complex associated with the H II region S309, hosts a network of filaments and pillars around the O-type star LS 499, making it an excellent laboratory to study the impact of feedback on subsequent star formation. PDS 255, a Herbig Be star in the Bochum 6 region, is located at the tip of a pillar- like filament pointing toward LS 499. The location of PDS 255 within a filamentary structure and its unusual infrared and spectroscopic characteristics make it a promising candidate for examining whether feedback from nearby massive stars has influenced its formation. We present a multi-wavelength study of PDS 255 by combining multi-epoch spectroscopy from the Himalayan Chandra Telescope and the Devasthal Optical Telescope with optical, near-infrared, and mid- infrared archival observations. Multi-epoch spectroscopy of PDS 255 shows strong Balmer emission along with a very high mass accretion rate, placing it among the most active Herbig Be stars. Infrared images show an infrared bubble around LS 499 and an intricate network of hub–filament features across the region. Infrared color diagnostics and the Gaia photometry indicate that PDS 255 is younger than the surrounding Bochum 6 stellar population. The pressure estimates suggest that LS 499 can significantly influence its surroundings and likely trigger the formation of PDS 255. The observed morphology, age gradient, and feedback signatures are consistent with LS 499 influencing the formation of PDS 255 within a radiatively sculpted hub–filament environment. PDS 255 thus serves as a useful benchmark for testing theoretical models of star formation in feedback-dominated environments.

47. 68007 JWST Views of Protostellar Growth and Feedback in the Orion Filamentary Cloud

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Manoj Puravankara (TIFR, Mumbai) and the HEFE team

The High Angular Resolution observations of Stellar Emergence in Filamentary Environments(HEFE) is a 180-hour JWST Cycle 3 program that has obtained NIRCam, NIRSpec, and MIRI observations of the Integral Shaped Filament (ISF) in Orion A, one of the nearest and most active filamentary star-forming environments. Our observations focus on the OMC-2/3 region, a dense part of the filament containing 46 protostars and exposed to external UV radiation from nearby OB stars.

HEFE provides an unprecedented view of protostellar mass assembly and feedback in a clustered filamentary environment. Spectral imaging of 13 deeply embedded Class 0 protostars over 2.9–29 micron traces jets, wide-angle winds, and shocked gas through a rich suite of atomic, ionic, and molecular diagnostics, allowing us to probe how outflows are launched, how they interact with the dense infalling envelope, and how momentum and energy are injected back into the surrounding cloud. Complementary NIRCam imaging extends these observations from ~1000 au to parsec scales and provides a census of outflow activity across the larger protostellar population. The spectra also probe envelope ice chemistry and accretion diagnostics, enabling us to connect mass accretion, ejection, and chemical evolution during the earliest stages of star formation.

In this contribution, we will present the main results emerging from this large JWST program and discuss their implications for understanding the origin and evolution of protostellar jets and winds, and their role in regulating star formation in filamentary molecular clouds.

48. Where Magnetic Fields Fit in the Hub-Filament Picture

Thushara Pillai

Thushara Pillai

Hub-filament systems have emerged as the leading architecture through which gravity assembles star clusters, channeling gas from clouds to hubs across a wide range of scales. The kinematic case is by now strong: velocity gradients have been shown to trace filaments accreting onto hubs, and the resulting picture of multi-scale, gravity-driven collapse is increasingly hard to argue with. What remains genuinely open is the role of the magnetic field — the third force, and by far the hardest to measure. Does it guide the flows, brake the collapse, or merely register motions it cannot resist? Drawing on a slowly but steadily expanding set of dust polarization observations across HFS, this review takes stock of what we can currently say about magnetic fields from the largest scales down to the hub, where the measurements stay sparse and the interpretations contested. Rather than force a premature consensus, I aim to map the trends that are starting to appear, the contradictions that persist, and the observations most likely to resolve them.

49. 67842 Evidence for the gravity-driven and magnetically-regularized gas flows feeding the massive protostellar cluster in Cepheus A

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The hierarchical interplay among gravity, magnetic fields, and turbulence in forming massive protostellar clusters remains elusive. We present high-resolution ($\sim$14 arcsec $\simeq$ 0.05 pc) 850 $μ$m dust polarization and C^{18}O line observations of Cepheus A using JCMT SCUBA-2/POL-2 and HARP. Our analysis reveals aligned gravitational (G), magnetic (B), and velocity fields (K), with an energy hierarchy of E_{G} > E_{B} > E_{K}. Gravity, as the primary driver, induces gas flows and drags in B-field lines. Magnetic tension, as a secondary force, regulates turbulence, enabling ordered flows with an accretion rate of $\sim$ 2.1 $\pm$ 0.4 $\times$ 10^{-4} M$_\odot$ yr$^{- 1}$. This challenges the conventional view of B-fields resisting collapse in the clump/hub scale, instead showing cooperation with gravity. The $\sim$0.6 pc clump-scale B-field (with mean PA $\sim$ 45°) aligns coherently with fields at cloud ($\sim$5 pc), core ($\sim$0.05 pc), and disk ($\sim$2000 AU) scales, offering new insights into the role of magnetic fields in multiscale star formation dynamics

50. 67825 Characterising magnetic fields at the onset of star cluster formation

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Gravity, turbulence, and magnetic fields are the three main factors thought to play a significant role in influencing star formation. Recent studies on the kinematics of infrared dark clouds – considered to be the birthplaces of stellar clusters – and their parent molecular clouds indicate that these stellar cluster progenitors are dynamically decoupled from their parent molecular clouds. This result may indicate that there is a preferred density and/or spatial scale on which the star formation process occurs; however, it is unknown as to the physical reason why this decoupling may take place. In this case, a transition in the properties of the magnetic field may be expected at a few parsec scales. I present my research using JCMT POL-2 and Planck polarisation data to derive the plane-of-sky magnetic field morphology of a sample of IRDCs and their parent giant molecular clouds respectively. A significant difference in morphology is seen in the magnetic field between these two scales for all samples, supporting the idea of a magnetic decoupling in the early stages of star formation as well. A clear link is also found between the alignment of the magnetic field with density structures and the kinematic properties - velocity dispersion and virial ratio - of the cloud/clump, suggesting that magnetic field morphology and the dynamic state of these density structures are strongly interlinked. Altogether, these results imply that magnetic fields play a significant role in guiding star formation, supporting clouds against collapse on larger scales while gravity and turbulence take over on smaller scales.

51. A numerical investigation of striations: The influence of magnetic fields and filamentary structures

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Rahul Khanna and Prof. Shantanu Basu

Molecular clouds exhibit hierarchical structure across all scales, with gas and dust arranged in intricate patterns. In the diffuse outer regions of molecular clouds, observations and polarimetric surveys have uncovered faint, thread-like structures known as striations, whose axes of elongation are well aligned with the surrounding magnetic field. Striations are typically connected to dense filaments, and recent observations have revealed gas flows along their long axes, feeding the filamentary structures. Therefore, striations represent the observable stage of a continuous mass assembly process: material from outer regions channeling through striations into filaments and then ultimately concentrating in central hubs fueling star formation. Understanding these structures will uncover the physical processes enabling mass accumulation within hub-filamentary structures.

We perform a series of 2D ideal MHD simulations to study the formation and evolution of striations using the ATHENA++ astrophysical code. Our models incorporate a stratified density profile and a sustained source of MHD perturbations to simulate the gravitational influence and stellar disturbances of a nearby filamentary structure. Small wispy striations emerge early in the evolution, which were absent in the previous numerical work. They are consistent with observations of small-scale striations observed in the Taurus and Musca molecular clouds. For relatively weak background magnetic fields, these small-scale structures persist throughout the simulation before gradually fading away. At higher magnetic field strengths, the wispy structures transform into large-scale ordered striations, well-aligned with the background magnetic field. Their density contrasts and spatial periodicity are in close agreement with observations. Power spectral analysis at successive evolutionary stages further reveals a systematic redistribution of compressive MHD wave mode power toward larger scales, affirming the involvement of magnetic fields in the formation and evolution of striations. We further identify an optimal ratio of magnetic to thermal pressure, expressed as the ratio of the Alfvén speed to isothermal sound speed, at which striations attain their maximum density contrast. Our simulations also recover velocity fields directed toward regions of higher density along the long axis of striations, consistent with observational signatures. We additionally demonstrate that the widely used Davis-Chandrasekhar-Fermi (DCF) and the Skalidis-Tassis (ST) methods used to measure magnetic field strengths perform inefficiently in outer diffuse regions with striations.

52. 67738 How important are magnetic fields to filamentary star formation?

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Professor | Australian National University

Mark Krumholz

Magnetic fields may be crucial ingredient of the star formation process, but their strength is notoriously hard to measure due to the indirect nature of the observational tracers to which we have access. In this talk I summarize recent work that attempts to resolve this problem using a full forward-modeling approach that combines high-resolution MHD simulations with rich physics with radiative transfer post-processing to generate synthetic observations of Zeeman splitting, dispersion, Faraday rotation, and similar observables that can then be compared directly to measurements. This technique offers a fresh window on magnetic field measurements, and provides hints that magnetic fields may be less important than previously thought in regulating the star formation process.

53. 67840 Investigation of Hourglass-shaped Magnetic fields in the G35.20-0.74 Star-Forming Complex

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To investigate the role of magnetic fields toward the G35N and G35S sub-regions in the G35.20-0.74 star- forming complex, we utilized multi-wavelength polarimetric observations from the SOFIA/HAWC+ at 154 μm and ACT at 220 GHz/1.3 mm. The ACT 220 GHz polarization data (resolution ~1′) show an hourglass- shaped plane-of-sky magnetic field morphologies toward both the sub-regions, although with distinct symmetry axes. SOFIA/HAWC+ 154 μm data (resolution ~13.6″) confirm an hourglass morphology in G35N, whereas G35S displays a different magnetic field configuration compared to the ACT observations. An hourglass morphology identified at clump scales (~pc) toward G35N is consistent with the previously reported B-field morphology at core scales (~0.05 pc), supporting the scenario of a magnetically regulated collapse. Using the SOFIA/HAWC+ data, we estimate magnetic field strengths of ~600 ± 200 μG in G35N and ~850 ± 310 μG in G35S. Energy balance analysis suggests that gravity and magnetic fields contribute comparably in G35N, while in G35S the gas dynamics are dominated by magnetic field, followed by gravity and turbulence. The higher field strength in G35S likely results from compression by the expanding HII region, highlighting the impact of stellar feedback. Overall, our results show that magnetic fields decisively regulate star formation, with G35N shaped by magnetically controlled collapse and G35S being strongly influenced by stellar feedback.

54. 67849 Magnetic field tomography in Protostellar Cores via Multiwavelength Dust emission polarization observations

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Nguyen Chau Giang, Doris Arzoumanian, Jihye Hwang, Nguyen Bich Ngoc, Paolo Suin, Thiem Hoang

Observations of polarized thermal dust emission are widely used to study the dynamical importance of magnetic fields (B) in generating star formation. The different sensitivities of dust emission at far-infrared and submillimeter wavelengths to dust temperatures may offer an opportunity to probe changes in the observed plane-of-sky magnetic fields across cold and warm dust layers along the line-of-sight (LOS). To test this possibility, we perform multiwavelength synthetic dust polarization maps from 89μm to 850μm toward protostellar cores formed within collapsing molecular clouds MHD simulations using the POLARIS code including Radiative Torque grain alignment theory. We consider two dust populations of sub-micron and micron-sized grains to explore the impact of grain growth on multiwavelength polarization observations. We find a clear polarization angle deviation between 89um and 850um up to ~30-90 degrees within 1 pc scale around protostellar core only in the case of sub- micron grains and stellar luminosity below < 1000Lsun. The narrow alignment size range inside the core in the case of inefficient grain growth, along with the presence of multiple structures along the LOS with clear density and temperature contrast, is found to be the reason for the polarization angle deviation. In this case, we find that in regions where dust is majorly heated by the stellar radiation field, observations at 89um and 154um can reveal the POS magnetic fields in the core center, while 850um tends to trace B in the surrounding. In contrast, for areas where dust grains are mainly heated by ISRF, observations from 89um to 850um reveal a transition of the POS B fields from foreground to dense inner structure. These results demonstrate the potential of multiwavelength dust polarization combined with the modeling of grain properties for probing magnetic field tomography in star-forming regions, which may further help clarify the relative roles of magnetic fields, gravity, and gas dynamics in driving infall during the early stages of protostar formation.

55. Kinematics of Young Stars in Hub-Filament Systems

Michael Kuhn

Michael Kuhn

Observations of gas and young stars in star-forming regions show that much of the gas is arranged in filamentary structures, with young stars preferentially found within massive molecular-cloud clumps. This clumpy structure is imprinted on the spatial distribution of young stars, where subclusters are often associated with hubs, with smaller numbers of non-clustered young stars forming in less dense parts of the cloud. It has recently become possible to investigate the motions of young stars within these systems. Gaia proper motions measure stellar kinematics to sub-km/s precision in massive star-forming regions within a few kpc, sufficient to detect motions within subclusters and relative motions between them. In observed star-forming complexes of ~1–5 Myr, there is no evidence that stellar subclusters coalesce to form more massive star clusters. This favours a picture in which massive clusters form from a single massive molecular clump, possibly fed by filaments, rather than being assembled later. Relative velocities between stellar subclusters can differ by several km/s, comparable to turbulent motions in their natal molecular-cloud gas. Most young clusters and associations studied with Gaia are also super-virial. This may be explained if stars inherit collapse-driven velocities as material falls into hubs, then escape as stellar feedback removes gas and makes the gravitational potential shallower. The stellar kinematics therefore suggest that massive clumps, possibly formed as hubs, may be required to form bound clusters, while the hub-filament structure remains imprinted on the spatial distribution of young stars.

56. The Kinematics of Young Stellar Objects in the Extended Solar Neighbourhood

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S. S. Singh, M. A. Kuhn

Stars form in dynamically cold molecular clouds that broadly follow Galactic rotation, but these clouds are organised into filamentary networks, hubs, spurs, and spiral-arm substructure that can retain coherent non-circular motions. Low-mass young stellar objects (YSOs) can therefore trace both recent star formation and the velocity field inherited from the star-forming interstellar medium, with ~100,000 YSOs having proper motions measured by Gaia DR3. We model the kinematics of the young stars using the Oort constants, fitted to Gaia parallaxes, proper motions, and (l,b) positions. Using Markov Chain Monte Carlo methods in R/STAN, we fit a Bayesian model with realistic velocity dispersions. Preliminary estimates of the Oort constants for the YSOs are: A = 15.29±0.19 km/s/kpc, B = -14.42±0.13 km/s/kpc, C = 2.83±0.22 km/s/kpc, and K = 4.74±1.7 km/s/kpc. The non-zero C and K values suggest statistically significant non-circular velocity components in the YSO sample. Residual velocity dispersions are 5.34 km/s in the Galactic plane and 3.96 km/s perpendicular to the plane, following Student's-t distributions. We find that this model is a better representation of the YSO sample than published Oort constants derived from more evolved stellar samples. We investigate YSO groups that deviate significantly from the model prediction and explore how these deviations impact the inferred Oort constants. We examine whether these residual motions are associated with spiral arms, spurs, and large filamentary star-forming structures, thereby linking Galactic-scale kinematics to the clumpy, filamentary spatial distribution of young stars.

57. 67834 ROCKETS: Detecting the Rocket Effect in Massive Young Stellar Cluster Environments with Gaia

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Massive stars regulate the evolution of their natal environments through ionising radiation, stellar winds, expanding H II regions, and infrared bubbles. These feedback processes can disperse molecular material, but they can also compress dense clumps and trigger subsequent star formation. One important mechanism in this context is the Rocket Effect, in which ionising radiation photoevaporates the illuminated surface of a dense molecular clump and accelerates the remaining neutral material away from the ionising source. If stars form within such accelerated clumps, they are expected to inherit part of this outward motion. Stellar proper motions therefore provide a direct way to search for the dynamical imprint of feedback on young stellar populations. We present results from the Rocket-driven Cluster Kinematics and Triggered Star-formation (ROCKETS) programme, which uses Gaia astrometry to identify kinematic signatures of the rocket effect in young clusters and H II regions. We used a Gaia based method centred on the Relative Proper Motion Angle (RPMA) defined as the angular separation between the internal proper-motion vector of a star and the projected radial direction from the dominant ionising source. Stars with small RPMA values represent sources moving preferentially away from the ionising source. We also estimate a Rocket Effect Index (REI) to quantify the excess of outward-moving stars relative to other kinematic populations and a velocity gradient study to confirm our findings. We applied this framework to young clusters enclosed by mid-infrared bubbles, including Collinder 69 and IC 1396 (ROCKETS II), and extended the analysis to the W5 H II region (ROCKETS II). We selected co-moving stellar populations using Gaia astrometry, compared their proper motions with the locations of the central O-type stars, and examined their spatial relation to infrared bubble rims and bright-rimmed clouds. We find a significant excess of sources with RPMA below 15 degrees, consistent with preferential radial motion away from the ionising sources in all the above regions. This excess is particularly strong among Class I and Class II young stellar objects, suggesting that

58. Star formation and hub-filament systems in extreme environments

Adam Ginsburg

Adam Ginsburg

High-mass star formation ends when the gas reservoir runs out. The process of clearing out that reservoir is violent and bright. I will summarize the most extreme examples of HFS and their transition from accretion to evacuation, particularly focusing on the Galactic Center environment and the most massive star- and cluster-forming regions in the Galactic disk. The Sgr B2 and W51 clouds contain the star-forming regions we are most confident are presently forming stars up to the maximum mass in the modern universe. I will report on JWST and ALMA observations that reveal the age and mass distributions of YSOs around the still-forming massive stars.

59. The Extragalactic View of Star Formation: From HII Regions to Galaxy Assembly

Kathryn Grasha

Kathryn Grasha

In other galaxies, we cannot see the hubs and filaments that feed star formation. We see their end products instead: massive stars, clusters, and the HII regions they light up. Reading these products is hard. Integrated light hides the small-scale physics, and standard diagnostics often disagree by large factors because they ignore binary stars and real nebular structure. My work treats resolved HII regions as an empirical answer key. Spectroscopy of individual star-forming regions, paired with binary stellar models, recovers the true conditions inside them: the energy and metals massive stars inject, and how they mix into the surrounding gas. These chemical fingerprints form a fossil record of a galaxy's star formation and assembly history. I will use this framework to tour star formation across galaxies, from resolved nearby systems to unresolved ones at high redshift, and close with how JWST, ALMA, and MAVIS on the ELT will push this view down to the parsec scales where hub-filament structures themselves come into focus beyond our own Galaxy.

60. 68011 On the physical processes governing the multi-scale, filamentary network of star formation within galaxies

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Star formation is a multi-scale process in which single stars, stellar clusters, associations and kiloparsec-sized complexes, all form in a common hierarchy of stellar structure. Star formation in these structures, spanning a broad range in physical sizes, is facilitated by the filamentary networks of gas and dust. These multi-scale star-forming structures are believed to be sculpted by the scale-free processes of supersonic turbulence (induced by feedback, dynamics, spiral structure, shear) and gravitational interaction (collapse, instabilities, accretion). Infrared and longer wavelength observations with IRAS, Herschel, Spitzer, and more recently JWST, have revealed detailed maps of the filamentary structures in the ISM of our own galaxy Milky Way, as well as external galaxies of diverse morphologies. Hub-filament systems lie at the confluence of these filamentary structures, and are the birthplaces of massive stars and young star clusters. Therefore, studying the demographic of young star-forming regions can improve our understanding of the star formation (SF) process across scales, environments and galaxy morphologies. Young stellar structures (<~10 Myrs) also drive stellar feedback, which governs the organization of ionized gas in galaxies, disperses the parent molecular clouds and often triggers further star formation activity in the surrounding regions. In this work, we have studied the demographic and hierarchy of young stellar structures and their impact on the structure of ISM. To explore the hierarchical, multi-scale assembly of stellar aggregates and their dynamical evolution within galaxies, we constructed a catalog of ~25,000 recently formed (<400 Myrs) UV-selected star-forming clumps (SFCs) in 17 galaxies within 20 Mpc (Shashank et al. 2026a (under review in ApJS)). Our galaxy sample includes 8 grand-design spirals, 6 flocculent spirals, and 3 dwarf irregulars. Our SFC catalog leveraged full galaxy coverage far-UV and near-UV data from the UltraViolet Imaging Telescope (UVIT). We performed a clustering analysis (two-point correlation function) on our SFC catalog to study the stellar hierarchies in our 17 galaxies. The stellar hierarchies exhibit a characteristic maximum scale — the correlation length — which represents the largest scale up to which ISM turbulence sustains spatially correlated, hierarchical SF. The correlation length ranges from ~100 pc to ~5 kpc and comparing it with large-scale galaxy properties suggests that galaxy’s gravitational potential, shear and spiral structure set the sizes of the largest hierarchical stellar structures. The correlation length scale emerges as a direct consequence of the collapse of kpc-sized or larger filamentary networks of star-forming gas in galaxies. Connecting the correlation length with turbulence injection sources and scales implies that stellar feedback in dwarf irregulars, whereas disc instabilities and spiral structure in flocculent/classic spirals, dominate in setting their stellar hierarchies. The stellar hierarchies were found to disperse towards near-random distributions on timescales ranging from 15−160 Myr, owing to internal galactic dynamics (Shashank et al. (2025); 2026b (in prep.)). Additionally, to explore how young star cluster feedback affects the organisation of ionized ISM, we performed TPCF analysis on PHANGS-MUSE HII regions in 19 galaxies. This revealed that HII regions show weak signature of a hierarchical organisation, with only the brightest HII regions with high ionization parameter tracing the hierarchical structure of the ISM. This implies that feedback has a strong, dispersing impact on the hierarchical organization of ionized ISM (Shashank et al. (in prep.)). At the symposium, I will present an observational, extragalactic perspective about our efforts towards understanding the multi-scale nature of star formation and the physical processes governing it. Attending the symposium will be an exciting opportunity for me to learn more about the hub-filament driven star formation, in particular within the Milky Way, and connect it with my research.

61. 67812 Environmental Dependence of Star Formation in the Outer Milky Way

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Star formation is a fundamental process governing the evolution of galaxies and is strongly influenced by environmental parameters such as metallicity, radiation field, and gas density. The outer regions of the Milky Way provide a unique laboratory for investigating these effects, as they exhibit significantly different physical conditions compared to the solar neighborhood. In this presentation, we discuss a comprehensive study of a large sample of young clusters associated with star-forming regions in the outer Galaxy and compare their star formation properties with those of nearby Galactic environments. Using multi-wavelength observations obtained from several national and international facilities, along with archival datasets, we investigate how environmental variations influence the star formation process. The study focuses on key outcomes of star formation, including protoplanetary disk accretion and evolution, as well as the stellar initial mass function (IMF), for a statistically significant sample extending down to a mass limit of ~0.1 M⊙. This represents one of the most sensitive and extensive observational studies of star- forming regions in the outer Milky Way to date. Our analysis suggests that the protoplanetary disk fraction is significantly lower in low-metallicity environments, while the mass accretion rates do not show substantial differences compared to solar- metallicity regions. In addition, the characteristic mass distribution of the IMF appears to vary with metallicity, in agreement with theoretical predictions. We also find evidence that the overall gas mass distribution differs under low-metallicity conditions. These results provide important insights into the role of environmental conditions in shaping the star and planet formation process across the Galaxy.

62. Filaments, the IMF, and Star Formation Efficiency Across Metallicity: Clustered High-Mass Star Formation in Turbulent Clouds

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Takashi Hosokawa

Filamentary and hub-like structures are among the most prominent features of present-day star-forming molecular clouds. They are widely discussed as channels for assembling dense gas, promoting clustered star formation, and feeding the growth of high-mass stars. However, an important question remains: is this filamentary mode of star formation universal, or does it depend on the thermal and chemical state of the gas? This question is closely related to how high-mass stars form in different environments, and how the stellar initial mass function (IMF) and star formation efficiency (SFE) are regulated.

We investigate this issue using radiation hydrodynamics simulations of initially turbulent star-forming clouds over a wide range of metallicities, from 10^−4 Zsun to 1Zsun, spaced by one dex. This broad metallicity coverage allows us to follow the transition from present-day Galactic conditions to chemically young environments far below 10^-2 Zsun. The simulations follow the formation of stellar clusters, including high-mass stars with masses up to ~100Msun, and allow us to examine how gas morphology, the IMF, and the SFE vary together across metallicity.

We find that the mode of star formation already changes substantially once the metallicity drops below ~10^−2 Zsun. At solar and near-solar metallicities, efficient cooling promotes filamentary cloud structures and clustered fragmentation. Star formation proceeds through dense filaments and clumps, broadly resembling nearby Galactic star-forming regions, and the resulting IMF remains close to a present-day, Salpeter-like form. As metallicity decreases, the cloud structure changes qualitatively: the gas distribution becomes less filamentary and more spatially smooth. At the same time, high-mass star formation becomes more prominent, and the IMF gradually shifts toward a more top-heavy distribution. The SFE also decreases in the top-heavy regimes, because the increased number of massive stars produces stronger ionizing radiation and expanding H II regions that disrupt the parent cloud more efficiently.

The position of the IMF peak in these simulations is primarily determined by protostellar radiative heating of dust, following the physical picture of present-day star formation proposed by Krumholz (2011). Since the dust abundance decreases with metallicity, this mechanism should eventually become ineffective in extremely metal-poor gas. In the simulations, however, this limiting metallicity is not easy to identify, because the SFE also decreases as the IMF becomes top-heavy and the cloud is disrupted earlier by massive-star feedback. To isolate this effect, we construct a semi-analytic model that combines metallicity-dependent thermal evolution with irradiated accreting protostellar envelope structures. This model suggests that the regulation of the IMF peak by protostellar dust heating begins to break down around Z~10^-3 Zsun.

These results suggest that filamentary clustered star formation at high metallicity and top-heavy high-mass star formation in metal-poor clouds are different regimes of metallicity-dependent star formation. In this talk, I will discuss how filaments, the IMF, and the SFE evolve across metallicity in turbulent clouds, and how this framework may help connect high-mass star formation in the local Universe with that in chemically young, high-redshift galaxies now being revealed by JWST.