

Abstracts

1. Light curve classification / statistical analysis

1

Marc Audard

University of Geneva

talk

Toward a new catalogue of variable young stellar objects in Gaia DR4

Gaia is a fantastic surveying machine to study the Milky Way in optical light. Apart from the exquisite astrometric data, variability in photometry and spectroscopy provides a powerful means to identify and classify sources: the Gaia 3rd data release included close to 10.5 million variable sources (9.5M stars and 1M AGN/quasars), and among them, close to 80'000 young stars are classified as young stellar objects (YSO). The upcoming Gaia 4th data release promises to expand much further the number of variable sources, notwithstanding the fact that all epoch and mean photometric and spectroscopic data will be released to the public for all Gaia DR4 sources; in addition the newly created work package on YSO analysis will characterise the photometric time series (periodicity, symmetry, color-magnitude slope) and propose sub-classes based on this analysis. I propose to give a summary of our Gaia variability analysis and showcase the power of Gaia in detecting and characterising variable sources, with the focus on the all-sky catalogue of variable YSO; I will describe new developments anticipated for DR4, in particular for the characterisation of YSO. I will present the above on behalf of the Gaia/CU7 team, and in particular the YSO WP team.

2

Máté Szilágyi

Konkoly Observatory

talk

Statistical characterisation of young stars in the Gaia Alert database

YSOs are intrinsically variable, and their photometric variability encodes key physical processes such as accretion, inner-disk dynamics, and dust production. Space-based monitoring campaigns have revealed distinct variability morphologies - such as dippers, bursters, and stochastic accretors- that map directly onto different physical mechanisms and evolutionary stage. However, our current understanding is based on isolated cases. We lack a statistically robust view of how common outbursts and extreme dimmings are, how they depend on evolutionary stage, and how they affect inferred stellar properties. The forthcoming Gaia DR4 will extend the temporal baseline and substantially enhance time-domain and spectro-photometric products, enabling a transition from descriptive variability studies to physics-driven population analyses. The goal of this project is to make a machine-learning based atlas of YSO variability, physically characterise outbursting and

dimming events, and determine the quiescent (baseline) brightness of each YSO and use this to refine the stars' positions on the Hertzsprung–Russell diagram in order to improve their age estimates and evolutionary classification. In this phase, we present our current results based on a testing sample of >1000 YSO (candidates) from the Gaia Alerts database.

3

Gábor Marton

HUN-REN CSFK Konkoly Observatory, Hungary

talk

Two halves, one star

We present a new machine-learning approach for exploring stellar variability directly from photometric time series, without requiring predefined classes or labelled training samples. Starting from a simple catalogue of light curves, the method automatically learns a compact representation of variability behaviour, allowing sources with similar temporal properties to naturally cluster together in a low-dimensional space.

We apply the method to nearly 45,000 Young Stellar Objects from the NEMESIS catalogue observed by ZTF. The learned representation independently recovers the main variability groups commonly identified in YSOs, including periodic, quasi-periodic symmetric, quasi-periodic dipper, aperiodic dipper, burster, and stochastic sources. Rather than separating these into rigid categories, the resulting latent space reveals smooth transitions between variability behaviours, reflecting the underlying physical connections between different accretion and obscuration processes.

The learned structure also captures variability trends that are difficult to identify using traditional variability descriptors such as the Q&M indices, including distinct regions associated with long-term brightening and fading behaviour. We further validate the generality of the approach on ~26,000 pulsating variables, including RR Lyrae, Cepheids, and δ Scuti stars, demonstrating that the method is not restricted to the YSO domain. Our results highlight the potential of unsupervised representation learning as a powerful new framework for analysing the rapidly growing photometric archives of modern time-domain astronomy.

4

Andrew Wilson

University of Exeter, UK

talk

Exploring the statistics of YSO variability

Large homogeneous samples provide the opportunity to determine robust statistics for the frequencies and characteristics YSO outbursts. We have therefore built a machine learning classifier (Wilson et al, 2023) for identifying Class II Young Stellar Objects from broad coverage photometric surveys. To identify YSOs without using variability, we created a special version of our classifier based on the four features of mid-IR excess, near-IR excess, H-alpha excess, and isochronal age from colour-magnitude diagrams. We ran the classifier

on a 1200 square degree region of the Galactic plane containing 14 million stars with well constrained Gaia DR3 parallaxes. At a posterior probability threshold of 0.5 we find ten thousand high confidence Class II YSOs. By comparing the results with the Gaia DR3 variability data and Zwicky Transit Facility light curves we identified three YSOs with variability amplitudes of 3-4 magnitudes and timescales much shorter than the larger-amplitude FUor stars. These appear to be the same class of object identified by Contreras Peña et al. (2019). We are preparing an all sky run of our classifier containing 127 million stars and this will provide sufficient data to explore FUor outburst statistics. The classifier posteriors will be independently calibrated using the WEAVE spectrograph on the William Herschel Telescope.

5

Lynne Hillenbrand

California Institute of Technology, USA

talk

A Heuristic Approach to Quantifying the Lightcurves of Outbursting Young Stellar Objects

We present a morphological study of the long-term lightcurves of outbursting young stellar objects (YSOs). Using analytic functions fitted to available optical and mid-infrared photometric time series data, we characterize the photometric rise, plateau, and decay properties of the outbursts. Our aim is to quantify outburst amplitudes and timescales in a uniform way, and enable comparison to theoretical models of episodic accretion. We first demonstrate the viability of our methods using an exemplar outburst that was well sampled during quiescence and then rose to reach a brightness peak, and then fully faded back to its faint state. We then apply our techniques to confirmed FU Ori objects, the majority of which have not been observed over their full evolution from quiescence to peak and back to quiescence. We identify several lightcurve families among the bona fide FU Ori class. The groupings may indicate that different flavors of heating and cooling physics can operate in accretion disk-dominated YSO systems.

6

Elisabeth Banks

University of Toledo, USA

talk

The 20-year Spitzer + WISE Large Amplitude Variability of YSOs within 500pc

Young stellar objects with dusty disks and envelopes exhibit mid-IR variability over orders of magnitude in amplitude and timescale. Significant changes in brightness, such as those greater than 1 magnitude, may be caused by changes in extinction or variations in accretion rate. To better characterize large-amplitude variability in nearby star-forming regions, we compile a 20-year baseline of observation with combined archival Spitzer and (NEO)WISE 3-5 micron data. Following the analyses of Kulkarni et al. 2026 and Zakri et al. in prep, we have three categories to describe YSO variability: bursts, fades, and fluctuators. We create combined Spitzer + (NEO)WISE light curves, color-magnitude diagrams, and Δm vs. Δt plots for each source. Here we will present the sample of high-amplitude variable YSOs (high-amplitude = greater than 1 magnitude in 3-5 microns) for star-forming regions within

500 pc, as identified with both Spitzer and WISE data. We then classify the light curves into the three categories defined by Kulkarni et al. 2026 and Zakri et al. in prep. One of the major caveats of this data set is its sparse and inconsistent sampling, with timescales of days, six months, and multiple years in between points. In order to develop statistics about the effects of our sampling on variability classification, we generate a grid of model light curves that resemble simple bursts and fluctuators. For each model light curve, we create sampled light curves at different cadences and generate Δm vs. Δt diagrams to see the effects of sampling on the tools we use to classify the sources. Supported by NASA ADAP grant 80NSSC23K0748.

7

Adolfo Carvalho

Center for Astrophysics | Harvard and Smithsonian, USA

talk

Unveiling the mass function of FU Ori objects

Eruptive accretion outbursts in young stars are proposed to be the mechanism by which young stars accrete large fractions of their final mass. The most extreme outbursts are those of the FU Ori objects, or FUOrs, which increase the disk-to-star accretion rate by 1000-10000 times and last for decades to centuries. The elevated accretion rate results in an accretion luminosity up to 100 times that of the star, making direct observations of the star impossible. The trigger mechanism of these outbursts, and whether all young stars undergo them, remain unknown, in part due to the difficulty of understanding the underlying stellar population. While individual measurements of masses exist for a handful of sources via fitting of models to the spectrum of the disk, they are too few to form a statistical sample. In this talk, I discuss a new technique to probe the mass distribution of FUOrs based on high resolution spectroscopy of 29 sources. Using this technique, I have found that the mass distribution of FUOrs is consistent with the solar neighborhood IMF, suggesting all young stars should, indeed, experience FUOr outbursts during their pre-main-sequence lifetime.

2. In-depth studies of individual objects

8

Aaron Labdon

ESO Chile

talk

The Dynamic Inner Disks of FUOrs with VLTI

The inner disks of FUOrs are poorly understood places that offer clues to both the causes and evolution of FUOr outbursts. These are not static places, but dynamic during accretion outbursts. By combining never-before-seen archival VLTI data with new GRAVITY data, we reveal the evolution of inner disks. We will present evidence of infalling material, disk depletion and new companions, which allow us to comment on potential triggering mechanisms and the effect of outbursts on planet formation processes. In particular, we find

multiple cases where inner disks are severely depleted as accretion outbursts end, for both FUor and EXor type outbursts.

9

Joe Ninan

Tata Institute of Fundamental Research (TIFR), India

talk

Probing the evolution of innermost disc during outbursts

The innermost region of the disc drives and regulates the episodic accretion. In this talk, I shall present our attempts to probe this region via high resolution spectroscopy. Specifically, we studied a magnetospheric accretion dominated source, V899 Mon, and a boundary layer accretion dominated source, V2493 Cyg using HPF on the 10-m HET over a multi-year campaign. We detected thermal inversion changes in the innermost region of the disc in V899 Mon, and its correlation with phases of the accretion outburst. In the boundary layer accretion source, V2493 Cyg, we detect long term evolution from a layer of gas screening the innermost edge of the disc. These observations provide direct measurement of the structure and dynamics of innermost regions of the eruptive systems.

10

Victor Almendros-Abad

INAF, Osservatorio Astronomico di Palermo, Italy

talk

Episodic accretion at the bottom of the IMF: an EXor-like burst in a planetary-mass object

Episodic accretion is a defining feature of early stellar evolution, yet its behavior at the lowest masses remains largely unexplored. Brown dwarfs and free-floating planetary-mass objects extend the young stellar population into a regime where disks are smaller, and their lifetimes may be longer, offering a crucial opportunity to test whether the same accretion physics operates from stars down to planetary-mass objects. I will first present a homogeneous view of accretion across the substellar regime based on optical and near-infrared VLT/X-Shooter spectroscopy of young brown dwarfs and very low-mass stars in regions aged 1-10 Myr. These data show that accretion declines more rapidly at lower masses during the first few Myr. I will then report the discovery of the first accretion burst ever observed in a free-floating planetary-mass object. Multi-epoch X-Shooter and JWST spectroscopy reveal order-of-magnitude changes in accretion tracers, the development of line profiles consistent with magnetospheric infall, and contemporaneous variations in the mid infrared molecular spectrum, including the emergence of water vapour emission. This event demonstrates that EXor-like behaviour and accretion-driven chemical processing occur even in objects with masses comparable to giant planets.

11

Philipp Weber

Universidad de Santiago de Chile

talk

V960 Mon as a Multi-scale Laboratory for Eruptive Accretion

V960 Mon is a particularly compelling FUor system because it links an ongoing outburst to striking disk substructure on planet-forming scales: SPHERE polarimetric imaging reveals prominent spiral arms, and archival ALMA 1.3 mm continuum data show multiple compact clumps aligned along a spiral arm, consistent with spiral-arm fragmentation. Building on this motivation, we present the main results of Weber et al. (2025), a multi-wavelength study placing the disk and its spiral/clump morphology into a broader environmental context. We characterise several nearby compact millimetre sources and extended structures around V960 Mon that point to dynamical interaction and material transport on envelope/core scales. In particular, we report evidence for an elongated feature with a blue-shifted molecular counterpart consistent with a flow of material toward the V960 Mon system, suggesting a plausible route for replenishing the disk and promoting gravitational instability during the FUor phase. We discuss how the observations of several molecular tracers connect the large-scale reservoir to the destabilised disk, and what they imply for the longevity and recurrence of outburst activity in embedded, dynamically active environments. Finally, we highlight new VLT/ERIS L'-band high-contrast imaging (Dasgupta et al. 2025) that reveals a dust-embedded companion candidate at about 0.9" separation, located in the vicinity of the fragmented spiral structure, and thus suggesting that at least one fragment may currently be evolving toward a bound companion within this eruptive system.

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Anuroop Dasgupta

ESO Chile

talk (online)

V960 Mon: Ideal Laboratory for Gravitational Instability

V960 Mon is an FU Orionis object that shows strong evidence of a gravitationally unstable spiral arm that is fragmenting into several dust clumps. We report the discovery of a new substellar companion candidate around this young star, identified in high-contrast L-prime band imaging with VLT/ERIS. The object is detected at a projected separation of 0.898 ± 0.01 arcseconds with a contrast of $(8.39 \pm 0.07) \times 10^{-3}$. The candidate lies close to the clumps previously detected in the sub-millimeter (at 1.3 mm) and is co-located with extended polarized infrared signal from scattered stellar irradiation, suggesting it is deeply embedded. The object is undetected in the SPHERE H-band total intensity, placing an upper mass limit of approximately 38 Jupiter masses from the contrast curve. Using evolutionary models at an assumed age of 1 million years, we estimate a mass of approximately 660 Jupiter masses from the L-prime brightness; however, this value likely includes a significant contribution from a disk around the companion. The discrepancy between near- and mid-infrared results again suggests the source is deeply embedded in dust. This candidate may represent an actively accreting, disk-bearing substellar object in a young, gravitationally unstable environment.

13

Zhen Guo

Universidad de Valparaíso, Chile

online talk

A rejuvenation of a Class II accretion disk during an EXor type event

In this talk I will present our ongoing research on the eruptive YSO V557 Mon, a low mass class II object from the 2Myr Rosetta Nebula. In late 2024, V557 Mon went into an outburst and our group has been closely monitoring it during the fading stage of this event using data from Chilean facilities. Our near infrared spectroscopic data reveal a variable hot inner disk, co-evolved with the brightness of this object. We found abundant molecular emission bands resembling the accretion disk of a Class I YSO (V2492 Cyg). This intriguing event provides us insight on the evolution of an accretion disk during an EXor type event, leaving hints on the nature of outbursts on YSOs. In addition, this work belongs to a series of work we have done under the “caught on fire” regime led by Chilean scientists.

14

Carlos Contreras Pena

Seoul National University, South Korea
online talk

The long-term outburst(s) of GPSV16: from an intermediate to a FUor classification

In this talk, I present the analysis of the eruptive variable YSO GPSV16, a Class I object associated with the HII region G71.52–00.38, at a distance of 3.61 kpc. GPSV16 shows two outbursts, one with $\Delta K_s = 2.2$ mag (2005–2012) and a second one starting in 2016 with an amplitude of $\Delta K_s = 5.6$ mag. The luminosity of the second outburst is $\sim 300 L_{\odot}$, but with large uncertainties. The two outbursts exhibit distinct spectroscopic characteristics: the first shows emission lines associated with a hot inner disk, whereas the second shows absorption lines arising from the cooler upper layers of a viscously heated disk. These features likely arise due to the different accretion rates reached during each outburst. The mid-IR light curve of the second outburst shows a two-stage rise, requiring ≈ 8.4 years to reach peak brightness. The mid-IR brightening precedes the optical outburst by a similar amount of time. The wavelength-dependent light curve of the second outburst points to instabilities that are triggered at larger distances within the accretion disk and propagate inward. Assuming a propagation time of 8 years for the accretion wave, we estimate that the second outburst started at a distance of $r \sim 0.4$ AU. These results show the importance of long-term, multi-wavelength photometric monitoring to identify the disk instabilities that trigger FUor outbursts.

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Tarak Chand

Aryabhata Research Institute of Observational Sciences (ARIES)
talk

Decade-Long Evolution of the Young Eruptive Star V1180 Cas: Coupled Accretion, Extinction, and Outflow Activity

In this talk, I will present the results from a comprehensive analysis of our long-term photometric and spectroscopic variability of the young eruptive star V1180 Cas. The results are derived from multi-band optical-infrared light curves spanning 1999–2025 along with more than 30 epochs of optical to near-infrared spectra (0.5–2.5 μm). The light curves

revealed an evolution from sporadic early dimming events to a quasi-periodic variability pattern since 2018, characterized by eleven major asymmetric dips with stochastic sub-structures. Color-magnitude behavior during deep minima shows a clear UXor-like blueing effect, while near- and mid-infrared color changes indicate thermal evolution of the inner disk. Spectroscopy reveals persistent H, Ca II, He I, and forbidden emission lines throughout all the photometric states. Accretion tracers closely follow the photometric variability, with mass accretion rates ranging from $\sim 10^{-8}$ to $10^{-7} M_{\text{Sun}}/\text{yr}$. In contrast, forbidden lines often strengthen during photometric dips, suggesting a physical link between extinction and outflow. Altogether, the results indicate that V1180 Cas exhibits hybrid UXor/EXor behavior, combined with evolving disk signatures and persistent outflows, suggesting that the young stellar object is undergoing coupled accretion-extinction-outflow evolution.

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Péter Ábrahám

Konkoly Observatory, Hungary

talk

The outburst of V1647 Ori has ended (once again)

V1647 Ori is a young eruptive star whose 2004 outburst was among the first events to challenge the traditional FUor/EXor bimodal classification scheme, as it displayed characteristics of both classes. The associated McNeil's Nebula — a reflection nebula surrounding the embedded Class I/II source — is a famous feature of the system and motivated the proposed designation “MNor” for this intermediate class of eruptive objects. Optical and infrared light curves obtained over the past 25 years reveal two major outbursts: the first in 2003–2006 and the second in 2008–2019. The fading phase of an eruptive event is particularly diagnostic, as it traces the relaxation of the perturbed accretion system back toward quiescence and constrains the physical mechanisms in operation. Our group has extensively studied the late phases of the first outburst in 2006 (Acosta-Pulido et al. 2007, Mosoni et al. 2013). In order to investigate the termination of the second brightening in 2019 in similar details, we present new optical–infrared photometry, VLT/MUSE and SPHEREx spectroscopy, and infrared imaging of the nebula obtained with the Euclid Space Telescope. These data mainly cover the fading period and the subsequent quiescent phase. We will compare the 2018 fading event with the one in 2006, and discuss what we can learn from this spectacular object on the physics of the eruptive phenomenon in general.

3. Gaia alerts / follow-up / classification

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Zsófia Nagy

Konkoly Observatory, Hungary

talk

Eruptive young stars found from Gaia Science Alerts: introducing the GLORIOUS (Gaia science aLerts tO find eRuptive yOUNg stellar objectS) collaboration

In 2014, only about 40 eruptive young stars were known, including candidates (Audard et al. 2014). The recent Outbursting YSOs Catalogue (OYCAT, Contreras-Pena et al. 2025)

reported 174 confirmed eruptive YSOs and 355 candidates. This improvement on the statistics of eruptive young stars is due to photometric monitoring by surveys such as Gaia, ZTF, Pan-STARRS, ASAS-SN, HOYS, VVV/VVVX, and WISE/NEOWISE.

Our GLORIOUS (Gaia science aLerts tO find eRuptive yOUNg stellar objectS) collaboration aims to find new eruptive YSOs from transient surveys such as the Gaia Science Alerts, and derive their physical properties based on optical and near infrared photometry and spectroscopy. We have identified more than 150 eruptive YSO candidates based on the Gaia Science Alerts, obtained spectroscopy for about 70 of them using various telescopes such as the NOT, TNG, GTC, LBT, VLT, and IRTF, and published the discovery of 11 eruptive YSOs: Gaia18dvy (Szegedi-Elek et al. 2020), Gaia19fct (Park et al. 2022), Gaia20eae (Cruz-Saenz de Miera et al. 2022), Gaia21elv (Nagy et al. 2023), Gaia20bdk (Siwak et al. 2025), Gaia23bab (Giannini et al. 2024, Nagy et al. 2025), Gaia21bkw and Gaia24beh (Giannini et al. 2026), Gaia20dsk (Nemeth et al. 2026), Gaia21bty (Siwak et al. 2023), and Gaia18cjb (Fiorellino et al. 2024). The analysis of several other eruptive YSO candidates is ongoing.

I will present a summary of our results on eruptive YSOs identified from the Gaia Science Alerts and our analysis on their follow-up spectroscopy.

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Ágnes Kóspál

Konkoly Observatory, Hungary

talk

Accretion, extinction, and outflow variability of the young eruptive star V346 Nor

V346 Nor is one of the earliest known FU Orionis-type (FUor) eruptive YSO and it provided the first observational evidence that FUor-type outbursts may be the consequence of a mismatch between the envelope-to-disk infall rate and the disk-to-star accretion rate. Around 2010, V346 Nor produced a deep minimum when the accretion rate dropped below $4 \times 10^{-7} M_{\text{Sun}}/\text{yr}$ and for a while this event seemed to signal the end of its outburst. However, the object later mostly recovered its former brightness. Recently, V346 Nor underwent a sudden optical brightening that even triggered an alert from the Gaia Photometric Science Alert system. Here we present results based on new and archival photometric, spectroscopic, and interferometric monitoring data from various optical, near-infrared, and mid-infrared instruments. We found that the recent brightening of V346 Nor was largely due to a decrease in extinction. Our accretion disk modeling revealed that the object currently accretes at a rate of $\sim 10^{-4} M_{\text{Sun}}/\text{yr}$, higher than ever before, placing it among the most strongly accreting FUors. The interferometric data along with the analysis of various spectral features suggest that not only the accretion rate, but also the outflow and wind activity of the central source is highly variable.

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Botond Máté Marosi

Konkoly Observatory, Hungary

talk

Variability of Young Stellar Objects with the SPHEREx Space Telescope

The study of star and planetary-system formation is a highly active field in modern astronomy. Particular emphasis is placed on investigating the dust and gas disks around

young stars, as these are the sites of planet formation. Changes in the star's illumination of the disk, as well as asymmetric structures or dynamical processes that temporarily alter the disk's geometry, can produce variability in the disk's mid-infrared emission. By studying this variability, we can learn more about the disk's structure and dynamics. Because the Earth's atmosphere absorbs much of this wavelength range, these objects are primarily observed with space telescopes, such as the recently launched SPHEREx mission. The goal of the SPHEREx is creating the first all-sky spectral survey in the optical and near-infrared range (0.75-5.0 micron). In this talk, I present the first results of a variability study of selected young stellar objects (YSOs) using new SPHEREx and earlier IRTF/SpeX spectra. As a first step, I checked the precision of the absolute flux calibration of the instrument using XXX standard stars. I determined the sensitivity and saturation limits and searched for any systematic offsets or biases. For the selected YSOs, I checked source confusion and determined the amplitude and wavelength-dependence of the variability, which informs us about the physical reason of the variability, such as changing accretion rate or changing circumstellar extinction. My results demonstrate that mid-infrared variability is a useful tool to study disk structure and these findings may reveal new insights into the formation of the Solar System and other exoplanetary systems.

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Roberta Carini

INAF, Italy

talk

Photometric and spectroscopic characterization of newly discovered eruptive variables alerted by Gaia

In recent years, thanks to surveys such as Gaia, the number of known eruptive young stars (EYs) has increased from a few dozen to more than a hundred. To classify a source as an EY, it is crucial to quantify key accretion parameters, the accretion luminosity (L_{acc}) and mass accretion rate (\dot{M}_{acc}) during both quiescent and burst phases.

In this talk, I present the results of an optical and near-infrared spectroscopic campaign conducted with the Large Binocular Telescope (LBT) and the Telescopio Nazionale Galileo (TNG). We analyzed several sources flagged by Gaia alerts between 2021 and 2024 due to significant photometric variability. Multi-epoch spectra reveal that all targets are accreting Young Stellar Objects (YSOs), characterised by prominent emission lines from accretion columns and, in some instances, atomic forbidden lines acting as signatures of outflowing gas.

By determining stellar parameters and accretion rates at different brightness phases, we found that during quiescence, these sources exhibit L_{acc} and \dot{M}_{acc} values typical of T Tauri and Herbig Ae/Be (HAeBe) sources, supporting the hypothesis that episodic accretion may be a universal stage in YSO evolution. When in burst, the sources with photometric variations exceeding 2 mag fall in the parameter space of EXor bursts or close to the upper end of the T Tauri locus, therefore being strong EY candidates.

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Fernando Cruz-Sáenz de Miera

Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse, France

talk

Discovery of accretion-driven photometric outbursts and the need for quick follow-up observations

As eruptive young stars are more easily discovered via a photometric brightening, the rise of multi-epoch all-sky surveys over the last decade has resulted in an outburst of newly detected events. Thanks to the photometric alert systems of these surveys, we can promptly carry out follow-up spectroscopic observations and increase our knowledge of the changes in the disk (due to the increase of temperatures) and the star (due to the enhanced accretion rate) throughout the timeline of the outbursts.

Here I will present the follow-up X-SHOOTER observations of multiple Gaia and ZTF alerts, including the confirmation of some new accretion (out)bursts. Likewise, I will show examples of how the quick discovery of an outburst can result in follow-up observations that are necessary to improve our understanding of the effects these events have on the star and planet formation processes.

22

Michal Siwak

Mt. Suhora Astronomical Observatory, Poland

talk

Spectroscopic and photometric search for new eruptive stars among USNO/Gaia candidates

Results of spectroscopic monitoring of YSOs from USNO/Gaia, as well as the ordinary Gaia Alerts sample, is presented. I will show IRTF spectra obtained for a few dozens of stars during 2024-2025, some of them turned out to be new FUors or EXors. In addition, I will show and describe light curves collected for the most promising targets by BHTOM observers.

23

Koshvendra Singh

Aryabhata Research Institute of Observational Sciences, Manora Peak, Nainital

talk

Gaia24ccy: An outburst followed the footsteps of its predecessor

Accretion-driven outbursts in young stellar objects remain poorly understood, largely limited by a statistically small sample of closely followed-up events. This underscores the importance of a thorough exploration of each outbursting object. We studied a peculiar outbursting system, Gaia24ccy, which exhibited two $\Delta g \sim 3.8$ mag outbursts in 2019 and 2024. The system consists of two unresolved, nearly identical, and rapidly rotating young stars: Gaia24ccy A (1.1419 days) and Gaia24ccy B (1.7898 days). Periodogram analyses just before the onset of the outbursts suggest Gaia24ccy B to be the outbursting component. Unlike any previously known EXor sources, the two outburst profiles show a very similar evolution: both rose at the same rate for the first 15 days, followed by many 'sub-bursts' on the timescale of 10–20 days. The 2019 outburst lasted 145–255 days, while the 2024 outburst persisted for 367 days. We infer the unstable region to lie at $r_{\text{trigger}} \approx 0.019 - 0.047$ au ($\sim 5-12.3R_{\text{star}}$). The accreted mass per event $M_{\text{acc}} \sim 10^{-5} M_{\text{Sun}}$ can be provided by a

compact inner-disk reservoir. The photometric rise/decay timescales and the mid-infrared color evolution favor a thermal-viscous trigger in a hot inner disk, while the appearance of rich emission-line spectra indicates concurrent magnetospheric compression — together best described by a hybrid picture. Finally, we explain the reddening of the mid-infrared color observed during the outburst as a consequence of the competing emission from the viscous disk and the photosphere.

4. Astrochemistry/mineralogy

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Lis Zwicky

Konkoly Observatory, Hungary

talk

Observational and Chemical Modelling of Molecular Line Diversity of FUors

One of the most valuable and unique features of FU Ori-type stars is their prominent effect on the disk chemistry. The extreme rise in the accretion rate significantly heats up the disk, allowing many molecular species to exist as gas in areas where they otherwise would remain predominantly in the ice phase. This phenomenon was confidently observed with water and methanol being detected much further than expected for classic T Tauri stars. Spectral scan observations of select few FUors revealed V883 Ori and V1057 Cyg to be extremely line-rich, while V1735 Cyg and V1515 Cyg showed much less line detections, despite their similar distance and accretion luminosity. The aim of this work is to investigate which system properties can explain the seen molecular line diversity or lack thereof. We use astrochemical model ANDES and radiative transfer code RADMC-3D to simulate the composition of outbursting objects and their molecular emission. We focus on 218-219 GHz frequency region, simulating 5 lines: 3 formaldehyde lines, a methanol line and an OCS line. We find that line emission is most sensitive to envelope mass, disk size, dust grain size and initial chemical composition of the disk. We explore a grid of models varying these four parameters to fully recreate line diversity and explain their effect on the lines.

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Tamara Molyarova

University of Leeds, UK

online talk

Modelling complex organic molecules in FUors with a dust trap

Luminosity outbursts in FUors reveal the composition of ices in protoplanetary discs. ALMA and NOEMA observations show a dichotomy in the detection of complex organic molecules (COMs): while some FUors are rich in COM emission, others show no detection of them. FUor outbursts typically occur in young objects, where the planet formation process is not expected to begin yet. In this work, we explore the effect of early formation of dust traps on the amount of gas-phase COMs during a FUor outburst. We use a one-dimensional model of a viscously evolving disc midplane that combines dust growth and transport with chemical evolution. We find that the presence of a dust trap significantly increases the abundance of

COMs in the disc midplane, due to ice accumulation in the trap. The high COM abundances observed in some FUor discs may be a consequence of early dust-trap formation.

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Ji-hyun Kang

Korea Astronomy and Space Science Institute, Republic of Korea

online talk

Origins of Complex Organic Molecules in L1551 IRS 5: Interplay of Thermal Heating and Accretion Shocks

We present a high-angular-resolution ALMA archival study of complex organic molecules (COMs) and SO toward the FU Orionis-type Class I protostellar binary L1551 IRS 5 to distinguish thermal versus shock origins of disk chemistry. While the extended COM emission in Source N is largely driven by ice sublimation from its outburst luminosity, our analysis reveals clear signatures of heterogeneous accretion shocks. Specifically, Source N exhibits a dual-mode accretion scenario: COM emission along a spiral arm traces steady equatorial circumbinary-to-circumstellar accretion, while a localized hot spot of high-excitation COMs and enhanced SO marks a violent vertical streamer impact from the envelope directly onto the protostellar disk. In contrast, COM emission in the companion, Source S, is purely shock-driven. In Source S, methanol is strictly confined to the streamer landing site, whereas SO forms a ring at the tidal truncation radius, reflecting their different post-shock survival timescales. These results demonstrate that the chemical inventory of FUor-type binaries is not solely defined by burst-driven thermal desorption, but is profoundly shaped by an intricate interplay with localized accretion shocks.

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Anastasiia Topchieva

Institute of Astronomy of the Russian Academy of Sciences, Russia

online talk

The Imprint of Past Luminosity Outbursts on the Chemistry of FUor Disks: A Case Study of HDO/H₂O in V883 Ori

The ratio of deuterated water (HDO) to normal water (H₂O) in protoplanetary disks is a key indicator of the origin and evolution of planetary system volatiles. Recent ALMA observations of the V883 Ori disk have measured a high HDO/H₂O ratio at large radii (40–100 au) and placed the water snow line at an unexpectedly large distance [1]. These findings challenge standard models, as the current luminosity of the outburst (~400 L_☉) is insufficient to explain the observed heating. I present a numerical modeling study using the ANDES astrochemical code to investigate how accretion outbursts of FU Orionis-type stars shape the distribution of HDO and H₂O in protoplanetary disks [2]. We constructed a physical model of the V883 Ori system, including a protoplanetary disk and envelope, and simulated its chemical evolution through different outburst scenarios: single outbursts with peak luminosities of 400, 2000, and 10 000 L_☉, as well as a sequence of two consecutive outbursts (10 000 + 400 L_☉). Our results show that the observed high HDO/H₂O ratio and the far-out snow line cannot be reproduced by a single outburst matching the current luminosity of 400 L_☉. Instead, the best agreement with the ALMA data is achieved in scenarios involving either a more powerful

past outburst (up to $10\,000 L_{\odot}$) or an alternative temperature profile for the disk midplane. The model with two consecutive outbursts demonstrates that the chemical imprint of a bright past event persists for over a century, preserving an elevated HDO/H₂O ratio even after the luminosity has faded to its observed level. This suggests that the deuterium enrichment in the V883 Ori disk is not a product of its current state, but a relic of more violent accretion events in its recent history. Our findings indicate that the chemistry of FUor disks acts as a memory of their thermal history. This work reinforces the connection between the deuterium fraction in protoplanetary ices, cometary compositions, and the volatile inventory delivered to forming terrestrial planets.

References

- [1] Tobin, J. J., van't Hoff, M. L. R., Leemker, M., et al. 2023, *Natur*, 615, 227.
- [2] Topchieva, A., Molyarova, T., & Vasyunin, A., 2025, *RAA*, 25, 12.

28

Foteini Lykou

Konkoly Observatory, Hungary
talk

Potential dust processing following an FUor outburst

Modern all-sky transient surveys, such as Gaia Alerts, have revealed numerous new eruptive candidates and/or refocused our interest to new (out)bursts from known sources. The FUor PR Ori B (Gaia21arx) is one of the latter, showcasing enhanced activity in the last decade. Prior to its recent outburst events, it was known for its spectacular HH outflow and for being a member of a triple system. We have now observed its protoplanetary disk at the highest-angular resolution possible (down to 0.6 au) with the VLTI instruments GRAVITY and MATISSE from the near- to the mid-infrared. Archival ALMA data suggest a compact disk in cold dust continuum with optically-thick CO gas, while GRAVITY in the near-IR helps us constrain the sizes of the innermost hot gas and continuum regions. We also noted changes in the silicate feature over two decades between MATISSE and archival data that may hint at dust processing within <25 au radii. In this talk, I will present our results, and discuss possible scenarios based on our latest modeling efforts.

5. Outburst theory / numerical simulations

29

Eduard Vorobyov

University of Innsbruck
talk

A cascade mechanism of FU Orionis outburst

FU-Orion-type objects are characterized by short (tens of years) episodic outbursts, during which their luminosity increases by orders of magnitude. A possible cause of such flares may be a gravitational perturbation of a circumstellar disk during close stellar flybys in young star-forming regions. To trigger a burst with characteristics like that of FU Orionis, a flyby

with a periastron as small as a few tens of AU is required. However, the separation between the two known components of FU Orionis amounts to several hundreds of AU. Considering that the burst due to gravitational perturbation occurs near the passage of the periastron, simple mathematical estimates show that the components of FU Orionis must have an extremely high relative velocity to account for a separation of several hundred AU. Using numerical hydrodynamics modeling we demonstrate that stellar flybys with a periastron on the order of 500 AU can still lead to luminosity bursts, but the gravitational perturbation of the protoplanetary disk serves only as an initial trigger to a cascade mechanism of alternating thermal and magnetorotational instabilities that finally lead to a burst. This is the first model of FU Ori outbursts that includes not just one but three burst mechanisms working in unison, and it relaxes strict requirements on the relative velocity of the FU Orionis components, raising the likelihood of such events. As a byproduct, we found the development of vortex-like features in the aftermath of outbursts, which may facilitate planet formation in the innermost disk regions.

30

Aleksandr Skliarevskii

Southern Federal University, Russia

online talk

Observational differences in morphology of FU-Ori type bursts with different ignition mechanisms

Despite that FU-Ori type bursts are widely studied, there is no single theory determining their origin. The several mechanisms have been proposed to explain how a burst would be ignited, however from the observational side it is hard to distinguish between these mechanisms. We present the results of theoretical work, comprising hydrodynamic and radiation transfer calculations in order to simulate synthetic observational characteristics. The morphological features of the disks with different burst triggering mechanisms are shown to compare and distinguish between them.

31

Johannes Jørgensen

Universität Innsbruck, Austria

online talk

Inferring past accretion bursts from asteroseismic imprints

Stars form during the collapse of dense molecular cloud cores. However, most of their final mass comes from the ensuing protostellar disk. Here, the protostar gains up to 50% of its final mass in episodic bursts of mass accretion, while having quiescent phases between the bursts. However, accretion burst events are short-lived phenomena, occupying only a tiny fraction of the stellar pre-main-sequence lifetime. In my talk I present a novel study of how the occurrence of such bursts may be inferred using asteroseismology - the study of stellar pulsations. Specifically, I show how these intense episodes leave a detectable asteroseismic imprint in the deep stellar interior.

32

Sergei Nayakshin

University of Leicester, UK
online talk

FU Ori outbursts from the youngest binary systems

Close binary systems are believed to form via circumstellar disc fragmentation. We show that the secondary star in the fragmented discs grows not only via smooth gas accretion from the disc, but also through many episodes of mergers with disc fragments. The resulting accretion outbursts on the secondary star may have larger magnitude outbursts in the NIR than those occurring in classical outburst models on single stars. We argue that such binary star accretion episodes may be promising candidates for some of the VVV survey outbursts with unusual properties.

33

Michael Cecil

Max Planck Institute for Astronomy
talk

The inner disk instability: Mechanism and Accretion Signatures

The structure and evolution of the innermost regions of protoplanetary disks pose a particular challenge for both modeling and observational efforts. The transition between the very inner, turbulent, gaseous region and the low-turbulence MRI-dead zone in particular can lead to complex dynamic behavior on various timescales. I will present 2D and 3D radiation hydrodynamic simulations of these elusive regions, which show the emergence of periodic, large-scale instability, leading to episodic accretion events. The consequential restructuring of the inner disk regions, where the majority of exoplanets are found today, can have significant consequences for the formation and migration of planets close to their host star. Recent developments show that the inner disk evolution and the magnitude and frequency of these eruptions is strongly dependent on a large number of disk parameters. In particular, the morphology of the accretion events is indicated to be mainly determined by the presence and strength of the magnetic fields in the young star and the disk. Using pseudo-MHD models, including non-ideal MHD effects, I will elaborate on the connection between the inner disk's architecture, the magnetic field configuration and the resulting accretion burst signatures. Our models show that the structure of the inner disk can intrinsically lead to a substantial variety of eruption frequencies and shapes, which can be used to draw connections between observed variability signatures and computational inner disk evolution.

34

Sirush Khachatryan

Byurakan Astrophysical Observatory, Armenia
talk

Jet Response to Short-Duration Accretion Outbursts in EXor-type Young Stellar Objects: 2D MHD Simulations with PLUTO

EXor-type young stellar objects undergo recurrent accretion outbursts lasting weeks to months, with mass accretion rates increasing by factors of 10–100. While the accretion dynamics and disk response to such events have received growing observational and theoretical attention, the impact on the associated protostellar jets remains largely unexplored. In particular, no dedicated MHD simulation study has investigated how short-duration EXor-like accretion pulses propagate into and modify the jet structure. We present 2D axisymmetric resistive MHD simulations performed with the PLUTO code, targeting the jet launched from an EXor-like T Tauri star. Using a Keplerian disk as a boundary condition, we inject a time-variable accretion rate mimicking the typical EXor outburst profile. A rapid rise over ~ 2 weeks followed by an exponential decay over ~ 3 months. We compare the resulting jet morphology, knot formation, and propagation speed against a quiescent baseline simulation. Our preliminary results show that the accretion pulse generates a distinct overdense knot propagating along the jet axis at velocities consistent with Herbig-Haro knot proper motions. The knot's internal structure, Mach number, and magnetic topology differ qualitatively from those produced by sinusoidal variability models commonly used in jet simulations. We discuss the implications for identifying the accretion outburst history of EXors from spatially resolved jet observations, and the potential of future JWST and VLA observations to constrain outburst recurrence timescales through jet knot spacing.

35

Yisheng Tu

University of Michigan, US

online talk

Triggering Fast-Rising FU Orionis Outbursts via Avalanche Accretion-induced MRI

FUor outbursts observed in young stellar objects (YSOs) are commonly associated with episodic rapid accretion events, yet their triggering mechanism remains uncertain. A leading candidate is magneto-rotational instability (MRI), in which magnetic stresses provide the heating for magnetic coupling and angular momentum transport required to achieve the high accretion rates. However, initiating an MRI-driven outburst is a complex process involving nonlinear magnetic field–gas coupling and radiative cooling, and is not yet fully understood. We perform radiative non-ideal MHD simulations of an initially magnetically “dead” disk, introducing a localized temperature perturbation within a radius where the elevated temperature can activate local MRI. In our model, the outburst develops in two distinct phases: (1) a gradual inward migration of the perturbed, hot, MRI-active zone over timescales of years, followed by (2) the rapid formation of a disk-surface avalanche accretion stream that ignites the inner disk in less than one year. The avalanche stream is strongly magnetically heated, and the associated MRI heating is sufficiently efficient that the triggering mechanism is robust against uncertainties in radiative processes. This avalanche-accretion–driven scenario provides a promising explanation for fast-rising, outside-in outbursts and may naturally account for the observed IR–optical delay.

36

Jinshi Sai

Kagoshima University, Japan

online talk

Disk Kinematics as Diagnostics of FU Orionis–Type Outburst Mechanisms

Several mechanisms have been proposed to explain FU Orionis–type outbursts, yet identifying which mechanism operates in individual systems remains observationally challenging. Vorobyov et al. (2021) demonstrated that distinct burst models produce characteristic gas kinematics in protoplanetary disks, suggesting that disk dynamics can provide observational diagnostics of the outburst mechanism. In this talk, I present synthetic C18O line observations of the same numerical burst models, incorporating radiative transfer and observational effects to assess realistic observable signatures. We examine three scenarios: MRI+GI–driven bursts, clump infall, and stellar intruders. The MRI+GI model produces no prominent localized features in residual velocity maps at typical distances of FU Orionis objects and a resolution of 0.1", as perturbations induced by GI remain modest in amplitude and spatial extent. In contrast, the clump-infall model shows clear expanding gas motion along a spiral arm, driven by angular momentum exchange between the infalling clump and the disk. The intruder model exhibits strongly asymmetric velocity structures relative to the systemic velocity in channel maps. These distinct kinematic signatures provide promising diagnostics for distinguishing the outburst mechanisms.

37

Han-Gyeol Yun

Seoul National University, South Korea

online talk

Dynamical Impact of Accretion Streamers on Circumstellar Disks

Recent scattered light and molecular observations reveal various instances of circumstellar disks receiving materials from nearby filamentary structures regardless of their evolutionary stages. These filamentary structures, which are also referred to as accretion streamers, highlight the importance of environmental effect during the star formation process compared to the classical theory that assumes the gravitational collapse of the isolated dense core. Using hydrodynamic simulations, we explore how much the accretion streamer impact the disk structure and kinematics and drive the disk accretion process compared to the classical spherical infall. Furthermore, we examine how these effects can be traced via ALMA molecular line observations.

38

Vitaly Akimkin

Institute of Astronomy, Russian Academy of Sciences, Russia

online talk

Time-dependent radiation transfer in protoplanetary disks during accretion luminosity bursts

Luminosity variability is a defining characteristic of young stars. However, the time-dependent thermal response of surrounding protoplanetary disks to such bursts remains poorly understood. In this talk, I will present time-dependent continuum radiation transfer simulations of three key types of accretion-related events - routine T Tauri variability, EX Lupi-type bursts, and FU Orionis-type outbursts - performed with the HURAKAN code

(Pavlyuchenkov & Akimkin 2025; Laznevoi et al., 2025). Our simulations reveal a clear hierarchy of disk responses. Routine T Tauri variability is both too low in energy and too short-lived to meaningfully heat the disk midplane, causing only disk surface temperature fluctuations. In contrast, FU Ori outbursts are so powerful and sustained that they drive a complete thermal restructuring of the disk over multi-year timescales. EX Lupi bursts occupy a critical intermediate regime: their duration and total energy are comparable to the disk thermal timescale and thermal energy content, meaning the disk never reaches equilibrium with the central source luminosity during the event. Time-dependent nature of radiation transfer creates anomalous temperature gradients in radial and vertical direction, which are distinct from those predicted by static radiation transfer models.

39

Kundan Kadam

Space Research Institute (IWF, ÖAW), Graz, Austria

Talk

Episodic accretion and planet formation in the inner disk

The sub-micron sized interstellar dust grows in the environment of protoplanetary disk and eventually forms a planetary system, resulting in configurations that we observe in various exoplanets. However, the effects of time-dependent and stochastic phenomena as well as the protostellar environment, on regulating the dust growth and planet formation are not well understood. In particular, FU Orionis-type outbursts are among the most disruptive of such events, dramatically altering the physical conditions of the inner disk. These eruptions can exceed 100 solar luminosities and last decades to centuries, while dynamically perturbing the innermost few au of the disk. This is not only the region where a large fraction of currently observed exoplanets are located, but this region is also most relevant for the formation of Earth-like planets in the habitable region. In this talk, I will focus on the dynamical behavior of dust and prospects of planetesimal formation in the inner disk, with respect to FU Orionis type outbursts. With the help of numerical experiments conducted using long-term, dust-gas coupled hydrodynamic simulations, we find that the inner regions may ubiquitously form dusty rings. Although such rings may be destroyed during outbursts, in certain conditions, the outbursts themselves may trigger Rossby vortices, potentially seeding planet formation rather than suppressing it.

6. Outbursting protostars

40

Doug Johnstone

NRC-Herzberg Astronomy and Astrophysics, Canada

talk

The JCMT Transient Survey and Beyond: Monitoring Protostars in the Sub-mm and Mid-IR

The James Clerk Maxwell Telescope has been monitoring eight nearby low-mass star-forming regions in the Gould Belt at submillimetre wavelengths for almost a decade to search for and quantify the time dependent brightness variability of the resident deeply

embedded protostars (see also abstract by Y-H Lee). Secular variability is common among these protostars; greater than 25% of the sample show measurable long-term brightness changes and 10% show burst behaviour lasting months to years. We interpret this variability as reflecting changes in the mass accretion rate from the disk onto the protostar, as predicted by theoretical models of (proto)stellar assembly. For a subset of our sample we have contemporaneous mid-IR light-curves, confirming that the submillimetre variability is driven by changes in the dust temperature profile of the envelope. Furthermore, for one source EC 53, we synchronized single dish and interferometric sub-mm monitoring which allowed us to unambiguously recover a time lag in the variability across angular scales and we use these results to confirm the envelope structure surrounding the embedded protostar. Additionally, a few of our prominent submillimetre variables show episodic knots in their protostellar jets, suggesting a link between mass accretion onto protostars and their powerful outflows.

41

Yong-Hee Lee

KIAA-PKU, China

talk

A segment-based analysis of the JCMT Transient Survey lightcurves: Assessing the role of variable accretion in early star formation

The mechanisms driving variable accretion onto the protostar are still not well understood. Stars are thought to gain the majority of their final mass while deeply embedded within dense envelopes which obscure optical and even near-infrared light from inside. In such systems, changes in the central luminosity are reprocessed by surrounding dust and more easily traced at longer wavelengths. Submillimeter variability is therefore an indirect probe of accretion activity during the embedded phase. To investigate such deeply embedded variability, the JCMT Transient survey has monitored 14 star-forming regions, covering environments from low- to intermediate-mass star formation, at submillimeter bands. The survey has accumulated six-year lightcurves for the point sources at the nearby star-forming regions, with the calibration errors of approximately 1% at 850 and $\sim 5\%$ at 450 μm . This combination of time baseline and the sensitivity of the dataset enables further statistical analysis than has already been done. In this work, we test a statistical approach for characterizing variability on multiple timescales by dividing each light curve into short, sliding segments spanning a few months to years, and by comparing the scatter and trend in each segment against the expected measurement and calibration uncertainties. By partitioning complex light curves in this way, we aim to make their physical interpretation more tractable. We then use the amplitudes and timescale of the detected variable segments to assess the contribution of time-variable accretion to protostellar mass assembly during the embedded phase.

42

Antonio Armeni

INAF Naples

talk

JWST Identifies a Low-Mass Protostar as the Driver of a Methanol Maser Flare in IRAS 18134-1942

Accretion-driven outbursts are a fundamental process in star formation, yet identifying their specific drivers within dense, dusty protostellar clusters remains a significant challenge. Radiatively pumped 6.7 GHz methanol maser flares are traditionally interpreted as exclusive beacons of episodic accretion in high-mass young stellar objects (YSOs). In this work, we present James Webb Space Telescope (JWST) NIRSpec and MIRI observations of the star-forming region IRAS 18134-1942, following a massive methanol maser flare detected in 2023. Contrary to the established paradigm, our results reveal that the central massive protostar is currently in a quiescent state. Instead, the maser flare was driven by a nearby low-mass companion, located at a projected distance of ~ 1700 au, undergoing a violent accretion outburst. During this event, the companion's accretion luminosity (L_{acc} approx. $3100 L_{\text{Sun}}$) increased to approximately 2.5 times that of the massive protostar, with an estimated mass accretion rate of $\sim (1-4) \times 10^{-4} M_{\text{Sun}}/\text{yr}$. Multi-epoch spectroscopy allowed us to characterize the physical and chemical response of the system to the luminosity pulse through various signatures. Specifically, a forest of rovibrational emission lines from H_2O and CH_4 traces the rapid heating of dense gas within the inner disk close to the protostar. Furthermore, the emission from CO and H_2 appears dominated by UV-pumped fluorescence, indicating that these lines originate from the outflow cavity walls illuminated by the accretion process. Finally, the detection of crystallized CO_2 ice at 15.2 microns provides a thermal fossil that marks the extent of the outburst's impact on the surrounding envelope. These findings demonstrate that methanol masers can be triggered by low-mass stars undergoing outbursts within massive clusters. This discovery challenges the assumption that such activity is limited to high-mass YSOs and highlights the potential of maser flares to reveal hidden populations of eruptive low-mass protostars.

43

Sam Federman

INAF OACN

talk

A Possibly Eruptive Outflow from an Embedded Low-Inclination Protostar with VLT-ERIS

We will present preliminary results from observations with the VLT-ERIS SPIFFIER integral field unit of a young, embedded protostar seen through its outflow cavity at a low inclination. Observations of the Orion protostar HOPS 66 with high spatial and spectral resolution in the H and K bands reveal shells or bubbles in the outflow traced by shock-ionized molecular hydrogen emission, similar to the outflow from the eruptive YSO XZ Tau. A lack of Br Gamma detection supports the idea that this protostar is in an FU Ori-style outburst, and the NIR lightcurve from Spitzer shows variability greater than 1.4 magnitudes in the IRAC 3.6 micron band on timescales of >1000 days. We will discuss the possible eruptive origin of the distinct outflow structures from this protostar, in contrast with similar outflow structures that have been hypothesized to originate in gaps in the circumstellar disk as for HL Tau.

44

Eleonora Fiorellino

Alma Mater Studiorum - Università di Bologna, Italy

talk

Gaia18cjb and eruptive accretion in Class I protostars

The GLORIOUS collaboration has recently discovered dozens of new eruptive young stellar objects. Among them, Gaia18cjb stands out as a particularly intriguing source, exhibiting a FUor-like light curve together with an EXor-like spectroscopic behavior. Gaia18cjb can also be classified as a Class I protostar, placing it at a critical evolutionary stage. In this talk, I will first present the main observational properties of Gaia18cjb and discuss its eruptive phenomenology. I will then place this object in a broader context, reviewing the growing observational evidence that episodic and eruptive accretion may occur more frequently during the protostellar phase than during the pre-main-sequence stage. Finally, I will highlight the key open questions raised by these findings and discuss the next observational and theoretical steps needed to investigate accretion variability in embedded protostars.

45

Tom Megeath

University of Toledo, USA

talk

Eruptive Variability in Orion Protostars

The Orion Molecular Clouds, which hosts over 300 well characterized protostars, is an important laboratory for understanding episodic accretion and its connection to infall and outflow. I will overview efforts to measure the evolution of episodic accretion using ALMA, Spitzer, JWST and near-IR spectroscopy of Orion protostars. These data show evidence for a decrease in the rate of decade-long, large-amplitude outbursts as protostellar envelopes are depleted and the rate of infall declines. We use near-IR spectroscopy to measure the fraction of the total luminosity from accretion and find values clustered around 50%, although with large scatter and an overall decrease as infall declines. Finally, we use multi-epoch Spitzer and single epoch JWST data to measure the motions and dynamical times of knots in the jets of Orion protostars. We find most knots are separated by time scales of decades, too short for a direct connection to outbursts, but we find evidence that the recent outburst of the Class 0 protostar HOPS 383 has modulated the flow of gas in its jet.

46

Mayra Osorio

Instituto de astrofísica de Andalucía CSIC, Spain

talk

Orion protostars undergoing flares

We present results from the observation of eight protostars in Orion that reveal variability in their observed emission on typical timescales of several years. Three of these sources (HOPS 383, HOPS 12, and HOPS 124) show significant variability in their infrared emission, while in HOPS 373 the variability observed at infrared wavelengths appears to be, in addition, correlated with the emission at submillimeter wavelengths, and (marginally) with the centimeter emission. Four additional sources are presented where their variability is inferred

from their radio spectra constructed from VLA data, obtained at different frequencies in different epochs. Instead of a smooth behavior with frequency, these spectra show large jumps (by a factor of 5-10) in the observed emission, which can only be explained in terms of variability, suggesting that episodic accretion events may be common in the star formation process. A simultaneous, multi-wavelength monitoring of these objects would undoubtedly provide much information about this process in young stellar objects.

47

Guillermo Blázquez-Calero

Instituto de Astrofísica de Andalucía, Spain

online talk

Bowshocks driven by the jet of the outbursting protostar SVS 13

We present high-angular and high-spectral resolution ALMA CO observations of the molecular jet driven by the outbursting protostar SVS 13. Thanks to the high sensitivity of these data, we are able to resolve faint shell-like structures connected to jet knots at their apex. The morphology and kinematics of these shells are in excellent agreement with predictions from an analytical bowshock model. This strongly supports the interpretation that jet knots provide a fossil record of ejection variability, further reinforced by the temporal coincidence of the most recent knot with the documented optical/IR photometric outburst of SVS 13 around 1990. These findings imply that accretion outbursts should be accompanied by changes in ejection speed, since variations in jet mass flux alone would not produce the observed internal shocks nor the observed bowshocks.

7. High-mass eruptive YSOs

48

Giseon Baek

Seoul National University, Republic of Korea

online talk

Infall streamer traced by a class II methanol maser discovered in ALMA Band 6 toward S255IR NIRS3

Streamers have recently been reported observationally as asymmetric inflows feeding disks and protostars in low-mass systems, while clear examples in the high-mass regime remain rare. In our ALMA Band 6 spectral line survey of the high-mass hot core S255IR NIRS3, which underwent an accretion burst, we identified a class II methanol maser transition that was first detected in S255IR NIRS3; this maser emission exhibits blueshifted velocity components with acceleration toward the continuum peak. We investigate the kinematic structure of the class II methanol maser to assess whether it traces an infall streamer. We discuss constraints on mass transport and the role of maser-traced inflow in accretion onto the protostar, with comparison to low-mass counterparts.

49

Dominique Meyer

Institute of Space Sciences (ICE, CSIC), Spain
talk

The burst mode of accretion in massive star formation

Massive stars form deeply embedded in dense molecular clouds and acquire most of their mass through disc-mediated accretion. While episodic, burst-like accretion driven by gravitational instabilities is well established for low-mass stars, its relevance for massive star formation has long remained unclear. Using high-resolution three-dimensional gravito-radiation-hydrodynamics simulations, I show that massive protostars also grow predominantly through burst-mode accretion. Gravitationally unstable discs fragment into spiral arms and dense clumps that migrate inward, producing short-lived but intense accretion outbursts. During these phases, massive protostars can gain a significant fraction of their final mass, while weaker bursts occur much more frequently. This burst mode naturally explains luminous infrared outbursts observed in massive young stellar objects, such as S255IR NIRS3, and provides a unified framework for the formation of close massive binaries. Strong accretion bursts drive rapid excursions in the Hertzsprung–Russell diagram and lead to intermittent variability of surrounding H II regions. Predicted disc substructures, including spiral arms and clumps, have been observationally confirmed with the Atacama Large Millimeter/submillimeter Array, establishing episodic accretion as a fundamental mechanism of massive star formation.

50

Bringfried Stecklum

TLS Tautenburg, Germany

talk

Revisiting the Infrared View on S255IR-NIRS3

The accretion burst of S255IR-NIRS3 was one of the first ever observed in a massive young stellar object (MYSO). Long-term far-infrared monitoring with SOFIA has enabled a revision of the initial burst parameters. A variety of observations point to a dust distribution that is more complex than the canonical YSO picture, possibly as a consequence of the burst. Our time-dependent dust-continuum radiative-transfer modelling reproduces key observational features, including wavelength-dependent emission time lags. The light echo associated with the accretion burst has now been detected. Nevertheless, some features remain unexplained.

51

Vardan Elbakyan

University of Duisburg-Essen, Germany

talk

Episodic Accretion in High-Mass Stars: Mechanisms and Observational Implications

Episodic accretion in high-mass young stellar objects (HMYSOs) arises from multiple, complementary physical processes that imprint distinct observational signatures. Using a combination of 1D, 2D and 3D radiation-hydrodynamic models and post-processing, we

show that thermal hydrogen-ionisation (TI) instabilities are ubiquitous in the hot inner discs of HMYSOs and naturally produce long (years–decades), quasi-periodic outbursts with moderate peak accretion rates — but they struggle to explain rapid, short (~1 yr) bursts. In contrast, gravitational instability and disc fragmentation generate dense, post-collapse clumps whose inward migration and tidal disruption (or merger) can produce the short, high accretion rate events and sharp photometric/IR signatures seen in some objects; the outcome depends sensitively on clump density/radius, inner-disc physics (viscous vs wind-driven transport), migration traps, and the numerical resolution of the inner few au. Disruption events can be non-periodic and, if sufficiently powerful, super-Eddington, driving episodic feedback. We conclude that multiple mechanisms are likely active: TI sculpts the inner disc and produces long, periodic bursts, while fragment/planet disruption explains rapid, high-luminosity events. Discriminating these channels requires high-cadence, multiwavelength monitoring (photometry, IR, jets/outflows) together with high-resolution, multi-dimensional modelling.

Posters

1

Lilit Darbinyan

Byurakan Astrophysical Observatory, Armenia

e-poster

On the absorption doses of UV radiation and CR particles by complex chemical species in low-mass star formation regions

Many complex molecules, such as formaldehyde, methanol, acetylene, etc, are observed in protostellar nebulae. Under favorable conditions, more complex species, precursors of pre-biomolecules, are possible, such as complex hydrocarbons, including isoprene, amino acids, sugars, and so on. This typically requires energy sources, which in the opaque depths of nebulae are cosmic rays with energies of several MeV and higher, capable of reaching depths with absorption characteristics of several stellar magnitudes and higher. High-energy particles play a dual role in this process. First, they directly react with molecules via nonthermal particles produced by the initial interaction with molecular hydrogen, which excites and ionizes it. These elementary interactions are accompanied by the emergence of new, secondary particles (primarily electrons) with lower energies, but still capable of ionizing H₂. Simultaneously, the excited H₂ molecules are deactivated, emitting photons in the Lyman and Werner series with energies of about 10-12 eV, providing the additional radiation dose necessary to initiate chemical reactions that form pre-biomolecules. This article is devoted to calculating the absorption doses of UV and CR radiation in nebulae with the formation of low-mass stars similar to the Sun and is the first in a series of articles on the combined irradiation of molecules (by photons and particles) with the possible formation of pre-biomolecules.

2

Lilit Darbinyan

Byurakan Astrophysical Observatory, Armenia

e-poster

Prebiotic Molecules in Low-Mass Star-Forming Regions: Modeling and Polarimetric Observations

We present a combined theoretical and observational study of prebiotic molecule formation in low-mass star-forming regions, addressing the role of molecular clouds, dust, radiation, and stellar feedback in shaping the chemical environment. Our focus is on carbon-containing pre-biomarkers such as formaldehyde (H_2CO), methanol (CH_3OH), acetylene (C_2H_2), and biomarkers like glycine and glycolaldehyde. Using astrochemical and physico-chemical modeling tools—including Pluto, Cloudy, UCLCHEM, and SNRPy—we investigate how the yields of these molecules depend on protostellar cloud properties, including mass, magnetic field, turbulence, cosmic ray flux, and dust composition (graphite versus silicate). The formation of molecules occurs both in the gas phase and on dust grain surfaces, with UV radiation, shocks, and cosmic rays providing additional energy for chemical reactions. For example, acetylene forms via methane photodissociation and surface reactions, formaldehyde arises from CO hydrogenation on cold dust grains, and methanol is produced through subsequent hydrogenation of H_2CO . Complex molecules such as glycine and glycolaldehyde are considered key biomarkers and potential precursors of amino acids and sugars, which may play a role in the emergence of life. To complement our modeling, we prepare polarimetric observations using the 2.6 m telescope at Byurakan Observatory. These observations aim to measure linear and circular polarization in selected protostellar nebulae and cometary globules, particularly in regions influenced by supernova remnants or shock waves. Polarization measurements are crucial for understanding the impact of circularly polarized light on asymmetric photochemistry, which may lead to molecular chirality relevant for prebiotic chemistry. This combined approach allows us to assess the dependence of pre-biomarker yields on stellar mass, cloud conditions, and dust type, providing insights into the physical and chemical evolution of molecular material from dense clouds to circumstellar disks and cometary bodies. Our results will help identify regions in the Galaxy favorable for the formation of life-related molecules and improve understanding of organic matter evolution across galactic timescales.

3

Lynne Hillenbrand

California Institute of Technology, USA

e-poster

Quantitative Spectroscopic Diagnostics for FU Orionis-Type Young Stellar Objects

FU Ori disks exhibit a distinct multi-temperature optical and infrared spectrum. Considering both the predicted spectrum from a disk atmosphere model, and existing spectral diagnostics from the literature, we identify key atomic and molecular features for characterizing FUOrs. Some of the chosen features are proxies for temperature, others are sensitive to surface gravity, and still others probe disk winds. Using the Palomar Observatory/Hale Telescope TripleSpec spectrograph, we gathered near-infrared spectrophotometry of 28 known FUOrs. We use standard equivalent widths to determine the strength of atomic lines and we design several band ratios for measuring molecular features. We compare the measurements between our spectra and a control sample of late-type dwarfs and evolved stars from the Infrared Telescope Facility Spectral Library. By

considering the relative distributions of these samples in our defined spectral diagnostics, we propose a number of parameter spaces that can distinguish FUOr disks from normal stars. The rate of discovery of FUOr candidates has increased significantly in recent years, largely due to the increasing prevalence of time-domain surveys. Our proposed diagnostics will allow new photometric candidates to be confirmed or refuted as such.

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Ágnes Kóspál

Konkoly Observatory, Hungary
e-poster

Time-resolved protoplanetary disk physics in DQ Tau with JWST

Accretion variability is ubiquitous in young stellar objects. While large outbursts may strongly affect the disk structure, the effects of moderate bursts are less understood. Our aim is to characterize the physical response of the disk around the eccentric binary system DQTau to its periodic accretion changes. We organized a multi-wavelength observing campaign centered on four JWST/MIRI spectra. We targeted three consecutive periastrons (high accretion state) and one apastron (quiescence). We used optical and near-infrared spectroscopy and photometry to measure how the accretion luminosity varies. We decomposed the multi-epoch spectral energy distributions into stellar, accretion, and rim components. In the MIRI spectra, we fitted the solid-state features using various opacity curves and the molecular features using slab models. We find the inner disk of DQ Tau to be highly dynamic. The temperature, luminosity, and location of the inner dust rim vary in response to the movement of stars and the L_{acc} variations. This causes variable shadowing of the outer disk, leading to an anti-correlation between the rim temperature and the strength of the 10 μm silicate feature. The excitation of CO, HCN, and hot H₂O molecules, as well as the luminosity of the [NeII] line correlate with the accretion rate, while the warm and cold H₂O components are mostly constant. CO emission, originating from a hot region likely within the dust sublimation radius, is the most sensitive to L_{acc} changes. We conclude that even moderate accretion rate changes affect the thermal structure in the planet-forming disk regions on short timescales, providing a crucial benchmark for understanding disk evolution.

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Mária Kun

Konkoly Observatory
e-poster

Long-term, multi-wavelength study of PV Cep

To understand the physical processes driving the variations of the young eruptive star PV Cep, we studied its long-term, multi-wavelength photometric and spectroscopic behaviour, based on our own, archival, and literature data, covering the time interval from 1996 to 2025, and the wavelength range from optical to far-infrared. We refine the stellar properties, determine the foreground extinction and variable circumstellar extinctions and accretion rates, and fit the spectral energy distributions with radiative transfer models to find out the most likely origin of the observed variations.

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Nathan Maindon

LUX - Observatoire de Paris, France

e-poster

Impact of variable jet bowshocks on protoplanetary disk structure

Protostellar jets often display time variability, producing a series of bowshocks as they propagate. In this contribution, we explore how such variable jet activity may influence the structure of nearby protoplanetary disks. Through hydrodynamical simulations, we study the interaction between jet-driven shocks and disk material, and we discuss possible consequences for disk morphology and evolution.

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Calum Morris

Universidad de Valparaíso, Chile

e-poster

A statistical look at YSO variability in the Carina nebula across multiple age brackets

YSO variability is of high importance in understanding the true spread of masses and accretion behaviours present in a given cluster. This fact is even more pertinent concerning the phenomenon of eruptive variability, given the large role episodic accretion events may have in answering the 'luminosity spread problem' observed in young clusters. We examined the MIR light curves of over 1400 confirmed and candidate YSOs in the Carina nebula, as well as over 200 with additional NIR light curves from VVVX, with an aim to locate eruptive variables and characterise the differences in variability across the SED age classes. We noted that there was minimal eruptive variability in this cluster, and a far less clear separation of amplitudes and timescales, than we found in our previous study of the Cygnus-X region, pointing to differences in the make-up of the two clusters.

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Zsófia Nagy

Konkoly Observatory, Hungary

e-poster

Gaia21bja: pre-main sequence star with quasi-periodic brightenings

Episodic accretion is an important process in the formation of low-mass stars, however, it is not fully understood. We analyze optical and near-infrared photometry based on Gaia, CRTS, and (NEO)WISE data and spectra obtained using the IRTF and VLT in order to characterize the physical properties of the Gaia alerted young stellar object Gaia21bja. We investigate the stellar parameters and the mass accretion rate of the star as well as the gas excitation conditions. The 20-year-long light curve of the star shows at least seven bursts, which are quasi-periodic. A Lomb-Scargle periodogram analysis results in a most significant period of 916 ± 77 days. We estimated the mass accretion rate to be $(1.4 \pm 0.5) \times 10^{-9} M_{\odot} \text{ yr}^{-1}$ during the burst. Comparison to local line excitation calculations suggests that the fluxes of the Balmer series are consistent with a temperature of 10,000 K and an H density of 4×10^9

cm^{-3} . The fluxes of the Paschen series are consistent with either lower temperature and higher density (5000-7500 K and $n_{\text{H}} = 2.5 - 6.3 \times 10^{11} \text{ cm}^{-3}$), or higher temperature and lower density models (10,000-12,500 K and $n_{\text{H}} = 6.3 \times 10^{10} \text{ cm}^{-3}$).

Despite its large amplitude, long time scale variability, and EXor-like spectra, Gaia21bja cannot be classified as an eruptive YSO due to its low mass accretion rate. However, its accretion-related quasi-periodic variability suggests that episodic accretion occurs on lower scales in addition to eruptive YSOs.

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Patrik Németh

Konkoly Observatory, Hungary

e-poster

Gaia20dsk: A new MNor discovered by the GLORIOUS collaboration

Gaia20dsk is a Gaia-alerted young stellar object candidate that has exhibited two major non-periodic brightening events over the past five years, with a maximum optical amplitude of ~ 1.8 mag. We investigated its nature using publicly available optical and near-infrared photometry combined with an X-SHOOTER optical/NIR spectrum. The light curves reveal two prominent and one short-lived burst, while color–magnitude analysis supports variability driven by enhanced accretion rather than extinction changes. The spectral index classifies Gaia20dsk as a flat-spectrum source. The X-SHOOTER spectrum displays strong emission lines typical of actively accreting low- to intermediate-mass young stellar objects, including features characteristic of MNor-type eruptive stars. The derived mass accretion rate during outburst is $(0.5\text{--}1.8) \times 10^{-6} M_{\text{Sun}}/\text{yr}$. Our results confirm that Gaia20dsk is an eruptive young stellar object whose photometric behavior, spectroscopic properties, and accretion rates are consistent with MNor-like outbursts.

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Arianna Saba

Blue Skies Space, UK

e-poster

Mauve, BSSL's UV-Vis spectrophotometry smallsat

The Mauve satellite was launched in late 2025. Since January 2026, it has been providing NUV–visible observations of stellar objects as part of a detailed year-long observation programme that will answer questions about stellar activity and variability, exoplanet hosts, hot stars, exotic populations in binaries, and star-planet interaction. During the early science phase, Mauve observed multiple targets to characterise performance and understand the feasibility of the different science themes proposed by the survey members. In this talk, we will show how Mauve will address the original science themes proposed in the preliminary science programme, presenting analyses and interpretations of early datasets to demonstrate the satellite's performance across all stellar types and science themes. Mauve will run a collaborative three-year survey programme and provide thousands of hours of observations of bright stars. In this talk we will also explore how the wider research community can access Mauve year one data and identify opportunities to help develop the survey programme for years 2 and 3.

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Máté Szilágyi

Konkoly Observatory, Hungary

e-poster

Distance estimation of young eruptive stars using star clusters

To determine the basic properties of young stars, such as their accretion rates, reliable distance estimates are required. Thanks to the Gaia spacecraft, astrometric information is now available for more than 1 billion stars. However, many observed young eruptive stars are faint, and their astrometric measurements therefore carry large uncertainties. Since stars form in clusters and young stars are expected to remain close to their natal environments, cluster membership can be used to constrain their distances. In this poster, I present several case studies from our recent work demonstrating how more precise distances of YSOs can be obtained using star clusters and extinction maps.

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Gerry Williger

Konkoly Observatory

e-poster

Spectrophotometry of T Tau stars in Cha I

The mechanisms producing variability in T Tau stars are complex, and are influenced by accretion changes, dust in the surrounding disk, starspots etc. We analyse 25 years of spectra and photometry of 3 T Tau stars in the Cha-I complex, CT Cha, VZ Cha and WW Cha, to complete a set of six observed during a simultaneous campaign with ground-based telescopes and TESS. We will present the data, show results from Lomb-Scargle periodograms, describe emission line profile variability, colours and line fluxes, and interpret correlations between them. Results will be compared to the other program objects CR Cha, VW Cha and WX Cha (Zsidi+ 2022a,b ; Fiorellino+ 2022).

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Jiayi Zhang

Eberhard Karls Universität Tübingen, Germany

e-poster

Testing Unstable Magnetospheric Accretion at Late Disk Ages in TW Hya

The transition from vigorous episodic accretion in protostars to steady mass assembly at later evolutionary stages remains a key problem in YSO evolution. As a well-characterized system ($\sim 8\text{--}10$ Myr) with a massive, structured disk and a near-face-on orientation, TW Hya serves as a benchmark laboratory for late-stage accretion physics. In this work, we present a coordinated, multi-epoch analysis of TW Hya based on high-resolution VLT/ESPRESSO and CHIRON spectroscopy, complemented by (partially) simultaneous high-cadence TESS and ground-based AAVSO photometry. By analyzing the radial velocity variations of the He I 5876 Å narrow component (NC) in the spectroscopic data, we confirm the stellar rotation period and trace the kinematics of the post-shock line-forming region, thereby constraining

the magnetic-field geometry. Our joint photometric + spectroscopic analysis reveals that TW Hya exhibits clear signatures of unstable accretion, where photometric bursts directly correlate with mass accretion rate measured from near-daily CHIRON spectra. Comparisons with recent 3D MHD simulations allow us to constrain the spatial distribution of accretion hotspots and the star-disk geometry. These findings show that unstable accretion mechanisms persist even into the late protoplanetary disk stage, bridging the gap between early-stage eruptions and long-term variability in evolved systems.

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Yuting Zhou

High School Affiliated to Nanjing Normal University, 210024, Nanjing, Jiangsu Province, China

e-poster

Photometric Analysis of an Eruptive YSO in the Rosetta Nebula

In this poster, I will present the photometric analysis of an eruptive young star (V557 Mon) located in the Rosetta Nebula, using data from multiple facilities around the globe (ZTF, LCOGT, SOAR, SWOPE, LOT, DOT, etc). I performed aperture photometry on u, g, r, i-band data and described a 200 days eruptive event on this young star. We used the colour-magnitude diagram and pre-main-sequence isochrones to determine the stellar parameters (A_v , Mass and age). In addition, we measured the evolution of mass accretion rate throughout the event, based on the UV-band excess emission. We found that the energy released by the accretion front only counts 50% of the total extra energy generated by this eruptive event. This work is guided by Prof. Zhen Guo from Universidad de Valparaiso.

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Gábor Marton

HUN-REN CSFK Konkoly Observatory, Hungary

e-poster

Multi-modal identification and classification of YSOs

In the era of large astronomical surveys, young stellar objects (YSOs) are most commonly identified through infrared excesses observed in their spectral energy distributions (SEDs). Traditionally, YSO identification and classification relies on colours and brightness criteria tailored to specific datasets. While effective within individual surveys, this approach has led to wavelength-dependent methodologies and heterogeneous YSO catalogues, limiting the combined use of multi-wavelength data and hindering the construction of a truly homogeneous YSO sample for unbiased statistical studies. The primary goal of our work is to construct the largest and most accurate homogeneous catalogue of YSOs to date. In parallel, we aim to develop a classification framework that exploits the heterogeneous data available through the VizieR and IRSA archives, and to provide a robust, easily applicable tool for high-accuracy YSO identification across diverse datasets. Our approach is conceptually straightforward. We represent the spectral energy distributions, time-domain light curves, and local infrared environments of sources as images, and train deep learning models to distinguish YSOs from other astrophysical objects using this multi-modal

information. Specifically, we apply convolutional neural networks (CNNs) to these image representations, combining complementary observational domains within a unified binary classification framework. Using this method, we achieve YSO identification accuracies reaching 90%, while rejecting contaminants with accuracies above 99.9%. We apply the trained classifier to numerous YSO catalogues from the literature, both to validate the youthful nature of previously identified sources and to establish a consistently classified, homogeneous sample. The result is the NEMESIS General YSO (NGYSO) catalogue, representing the largest compilation of homogeneously identified YSO candidates assembled to date.