STAR CLUSTER FORMATION: MAPPING THE FIRST FEW MYRS

PROGRAMME

29-31 AUGUST 2018
GRENOBLE

The SFM project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687528.

WELCOME TO GRENOBLE

We welcome colleagues to this 2.5-days workshop on the formation and early evolution of star clusters held in Grenoble, 29-31 August 2018. This workshop will provide a forum for the star formation community to discuss the big issues of this field. Combining observation and theory, and with a particular emphasis on results obtained from Gaia DR2, topics will include: initial conditions of stars and gas in stellar cluster formation; spatial and kinematic properties of newly formed/active massive star cluster regions, open clusters and stellar associations; and early dynamical evolution and simulations of massive star cluster regions.

This is the second workshop hosted by the StarFormMapper (SFM) project, an EU Horizon2020 funded collaboration between the University of Leeds, University of Cardiff, University Grenoble Alps and Quasar Science Resources SL. The key aim of the project is to combine state-of-the-art numerical simulations with data from Gaia and Herschel and ground based surveys to constrain the mechanisms that underlie massive star and star cluster formation. Taken collectively, these facilities cover all stages from the formation of molecular cores, through the formation of stars, to the dispersal of the gas in young clusters. We are developing new automated statistical techniques to extract the full scientific value of these combined data, that will eventually be released as common user tools to the community. Our scientific results will underpin the study of how all galaxies evolve.

COMMITTEES

LOCAL ORGANISING COMMITTEE

- Pouria Khalaj (IPAG, France)
- Estelle Moraux (IPAG, France)
- Patricia Grant (University of Leeds, UK)

SCIENTIFIC ORGANISING COMMITTEE

- Emilio Alfaro (IAA, Spain, Co-Chair)
- Estelle Moraux (IPAG, France, Co-Chair)
- Pouria Khalaj (IPAG, France)
- Anne Buckner (University of Leeds, UK)

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VENUE

The IMAG building located on the Grenoble University campus (one of the most beautiful in France). To go there from downtown, you can either take the tramway B or C and stop at the tram station "Gabriel Fauré" (see map below). The tram tickets can be bought at any tram station (for about 1.50 euros each).

PROGRAMME

Wednesday 29 August

Workshop Venue: Bâtiment IMAG – Université Grenoble Alpes, 700 avenue Centrale – Domaine Universitaire, 38401 St Martin d'Hères – France

08:45 – 09:15	Registration
09:15 – 09:30	Introduction (Estelle Moraux)

Session 1: Molecular Clouds and Protoclusters Observations

09:30 – 10:05	**A Galaxy-wide View of Star Formation (James Urquhart)**
10:05 – 10:25	The role of spiral arms in Milky Way star formation (Sarah Ragan)
10:25 – 10:45	Complex dynamics at the edge of the Monoceros OB1 molecular cloud (Julien Montillaud)
10:45 – 11:15	Coffee break
11:15 – 11:35	An ALMA view of Sagittarius B2: a progenitor of a super star cluster? (Alvaro Sanchez-Monge)
11:35 – 11:55	Characterizing the high-mass protoclusters in NGC 6334 (Mahya Sadaghiani)
11:55 – 12:15	Challenging the relation between cores masses and stellar masses: from W43-MM1 to the ALMA- IMF large program (Frédérique Motte)
12:15 – 13:00	Discussion
13:00 – 14:30	Lunch

Session 2: Modelling and Hydrodynamical Simulations of Stellar Cluster Formation

14:30 – 15:05	**Star cluster formation: structure, kinematics, and stellar properties (Matthew Bate)**
15:05 – 15:25	Galactic Flows and the formation of stellar clusters (Ian Bonnell)
15:25 – 15:45	Volume-Density-Driven Star Formation in the Galaxy (Geneviève Parmentier)
15:45 – 16:15	Coffee break
16:15 – 16:35	Simulating photoionization and radiation pressure feedback from massive stars in clusters (Ahmad Ali)
16:35 – 16:55	The binary fraction and CMF in star-forming regions (Christian Boily)
16:55 – 17:15	Establishing Star Formation Scenarios Using Protoplanetary Disc Fractions: The Case of Cygnus OB2 (Andrew Winter)
17:15 – 18:00	Discussion

18:30 – 19:30	Public talk (French): *La naissance des étoiles et des planètes (J. Bouvier)* Venue: Maison du tourisme

Thursday 30 August

Workshop Venue: Bâtiment IMAG – Université Grenoble Alpes, 700 avenue Centrale – Domaine Universitaire, 38401 St Martin d'Hères – France

Session 3: Star Formation from Stellar Clusters Observations

09:15 – 09:50	**Written in the stars: clues to the initial conditions of star formation (Richard Parker)**
09:50 – 10:10	Revealing the innards of a star cluster in the making (Morten Andersen)
10:10 – 10:30	Uncovering the Evolution of Clustered and Dispersed Star Formation Across the Serpens Molecular Complex (Marc Pound)
10:30 – 11:00	Coffee break
11:00 – 11:20	Gould Belt Clouds: Distances and Insights into YSO Kinematics (Lee Mundy)
11:20 – 11:40	Revealing kinematic substructure in young stellar clusters with Gaia DR2 (Tristan Cantat-Gaudin)
11:40 – 12:00	Not all stars form in clusters: measuring the kinematics of OB associations with Gaia (Jacob Ward)
12:00 – 12:45	Discussion
12:45 – 14:15	Lunch

Session 4: Characterisation of Spatial and Kinematic Structures of Star Clusters

14:15 – 14:50	**Star clusters in the Gaia second data release (Antonella Vallenari)**
14:50 – 15:10	Distance and kinematic of star forming regions (Sergio Dzib)
15:10 – 15:30	At the edge of molecular clouds: uncovering their 3D spatial structure with GAIA (Isabelle Joncour)
15:30 – 16:00	Coffee break
16:00 – 16:20	Quantifying velocity structure in star forming regions (Becky Arnold)
16:20 – 16:40	Modelling the structure of star clusters with fractional Brownian motion (Olivier Lomax)
16:40 – 17:00	Dancing Clusters: Quantitatively Tracing Spatial Evolution and the Morphological Features of YMCs (Anne Buckner)
17:00 – 17:45	Discussion

20:00	Dinner *Venue: Restaurant du Téléférique*

Friday 31 August

Workshop Venue: Bâtiment IMAG – Université Grenoble Alpes, 700 avenue Centrale – Domaine Universitaire, 38401 St Martin d'Hères – France

Session 5: Modelling and Simulations of Early Cluster Evolution

09:15 – 09:50	**Early cluster evolution (Pavel Kroupa)**
09:50 – 10:10	Observational constraints on clustered star formation: a more complete picture of clustered star formation emerging (Suzanne Pfalzner)
10:10 – 10:30	Constraining the birth conditions of star clusters by the present-day parameters (Hosein Haghi)
10:30 – 11:00	Coffee break
11:00 – 11:20	Simulation of binaries properties in a fragmented cluster (Timothé Roland)
11:20 – 11:40	A model for the environmental variation of the minimum cluster mass and its implications for globular cluster formation from Fornax to ultra-diffuse galaxies (Sebastian Trujillo-Gomez)
11:40 – 12:25	Discussion
12:25 – 12:35	Final remarks

ABSTRACTS

SESSION 1: MOLECULAR CLOUDS AND PROTOCLUSTER OBSERVATIONS

James Urquhart (Invited Talk)

A Galaxy-wide View of Star Formation

The strong correlation between star-forming regions and the spiral arms observed in studies of nearby spiral galaxies points to a strong connection between the large-scale dynamics of a galaxy and the star formation taking place on smaller scales. This has led to the view of galaxies being engines of star formation. In this invited review talk I will discuss the current state-of-the-art molecular line and dust continuum observational programmes that are providing a global view of star formation in the Milky Way. I will start by discussing how dust continuum surveys are being used to identify large representative samples of dense clumps (~1 pc) within giant molecular clouds (GMCs) where clusters begin their lives. I will then describe how molecular line surveys are being used to link these localised regions to their parent GMCs and investigate the connection between the large-scale dynamics of the Galaxy (e.g., spiral arms, Galactic bar) and the star formation taking place on smaller scales. We will also discuss how the results of these studies of the earliest stages of star-formation can provide constraints for cluster formation models.

Sarah Ragan

The role of spiral arms in Milky Way star formation

The Herschel Infrared Galactic Plane Survey (Hi-GAL) covers the peak of the spectral energy distribution of dense, cold dust and thus supplies an essential part of the observational description of the conditions necessary for star formation in the Milky Way. With a new catalogue of over 100000 compact Hi-GAL sources, we examine how star formation varies with Galactocentric radius and proximity to spiral arms. We revisit some long-standing questions about the effect Galactic properties have on star formation on parsec scales.

Julien Montillaud

Complex dynamics at the edge of the Monoceros OB 1 molecular cloud

Mon OB1 is one of the most massive (4x10^4 Msun) star forming complexes in the first kpc from the Sun. It hosts NGC 2264; an open cluster containing more than 1000 young stars; with age estimates scattered between 0.1 and 5 Myr; suggesting a sustained star formation activity. As part of the ""Galactic cold cores"" project, we have mapped the northern tip of the eastern molecular cloud of Mon OB1 with Herschel, revealing a complex network of intertwined filaments with decreasing star formation activity as one looks further from NGC 2264. A molecular follow-up at IRAM 30m revealed that the region is even more complex than suggested by dust continuum observations, and suggest possible collision or merging of different loops and filaments in the region also corresponding to the most active star forming clump in this area. We will present these results, and discuss the dynamics of this cloud in perspective with the general evolution of star formation in the Mon OB1 molecular complex.

Alvaro Sanchez-Monge

An ALMA view of Sagittarius B2: a progenitor of a super star cluster?

The giant molecular cloud complex Sagittarius B2 (hereafter, SgrB2) is the most massive region with ongoing star formation in the Galaxy. It is located at a projected distance of about 100 pc along the plane to the Galactic Center and at 8.5 kpc from the Sun. The whole complex contains a total gas mass of 10^7 Msun, with the main sites of active star formation corresponding to the hot molecular cores SgrB2(N) and SgrB2(M), located at the center of the complex. They contain more than 50 high-mass stars with spectral types ranging from O5 to B0.

Recent high-spatial resolution ALMA observations have resolved the cluster population of SgrB2(N) and SgrB2(M). The two clusters have top-heavy core mass functions, with a lack of low-mass cores, and H2 volume densities of about 10^5-10^7 Msun/pc^3, one to two orders of magnitude higher than stellar densities of super star clusters. A network of converging filaments with large velocity gradients suggest that accretion of mass towards the center is still ongoing. In summary, SgrB2 may constitute an early stage of a protocluster that will evolve into a super star cluster like Arches or Qintuplet.

Mahya Sadaghiani

Characterizing the high-mass protoclusters in NGC 6334

Most of stars are born in clusters containing high-mass stars and therefore, their formation is strongly influenced by the feedback of high-mass stars. At the earliest stages of the cluster formation (i.e. protocluster) the interaction between the fragments may have a profound impact on the properties of the cluster such as the core mass function, the spatial distribution of the cluster members and the multiplicity fraction. With the aim of understanding the process of formation of stellar clusters and the properties of the surrounding environment, we investigate nearby star-forming clusters in NGC6334 filamentary cloud. The detailed observations conducted in the 3mm continuum and spectral line emission using the Atacama Large Millimeter/Submillimeter Array with a spatial resolution of ~1300 AU reveal: (i) about 140 compact mm sources towards the observed regions that were previously unknown, suggesting that the clusters are richer and more extended than the area which is surveyed in previous high-angular resolution observations. (ii) complex spatial and kinematic structures associated with the two clusters. Dense gas tracers like HCN and HCO+ show extended and elongated structures likely connecting the large-scale filaments to the clusters, which confirms the role of filaments as mass reservoirs. (iii) kinematically and spatially complex SiO stuctures distributed all over the clusters. While some of the structures are tracing outflows, there are other structures that could be caused by accretions shocks or cloud-cloud collision. The extension of the SiO emission suggests a strong star formation activity in a much larger area than just the central part of the clusters.

Comparing the cumulative mass functions with the shape of the IMF suggest that there is no dearth of the low-mass dense cores. Furthermore, the minimum spanning tree analysis performed down to the scales of ~800 AU indicates that the mean nearest neighbour separations of cores decreases as the cluster evolves. This ALMA dataset, together with the proposed observations at 1 mm will lead us to better characterize the observed protoclusters and investigate their environment.

Frédérique Motte

Challenging the relation between cores masses and stellar masses: from W43-MM1 to the ALMA- IMF large program

The ALMA-IMF large program (PIs: Motte, Ginsburg, Louvet, and Sanhueza) aims at investigating the origin of the IMF in 15 massive protoclusters. After introducing this on-going project, I will present the results of our pilot study on W43-MM1; the archetype precursor of galactic starburst clusters (~ 2 x 10^4 Msun within 6 pc^2, SFR = 6000 Msun/Myr). Thanks to the high angular resolution of ALMA, W43-MM1 images revealed about 130 cores with typical sizes of 2000 AU. The Core Mass Function (CMF) built from this sample covers an unprecedented mass range and contains cores forming solar-type stars up to the highest-mass stars. The CMF slope is quantitatively flatter than that of the reference IMF of Salpeter. This seriously challenges our understanding of the origin of the IMF.

SESSION 2: MODELLING AND HYDRODYNAMICAL SIMULATIONS OF STELLAR CLUSTER FORMATION

Matthew Bate (Invited speaker)

Star cluster formation: structure, kinematics, and stellar properties

I will present results from hydrodynamical simulations of star cluster formation, discussing the structure, evolution, and kinematics of the stars and gas, and the dependence of the resulting stellar properties on initial conditions and environment.

Ian Bonnell

Galactic Flows and the formation of stellar clusters

We present models of how star formation is triggered, and stellar clusters form, as the interstellar gas passes through spiral shocks. The spiral shock compresses gas into an 100 pc long main star formation ridge, where clusters form every 5-10 pc along the merger ridge. Final cluster masses at the end of simulation range between 1000 and 30 000 Msun with their characteristic half-mass radii between 0.1 and 2 pc. These clusters form by gathering material from 10-20 pc size scales. We investigate the gas accretion and merger histories of these clusters and make predictions of the resultant mass-radius relation, stellar age spreads and angular momentum content of young clusters. Late stellar mergers can form envelopes of isolated high mass stars around very high mass clusters.

Genevieve Parmentier

Volume-Density-Driven Star Formation in the Galaxy

I shall present a semi-analytical model of star cluster formation in which, locally, the gas of cluster-forming clumps is turned into stars with a constant star formation efficiency per free-fall time. This yields a density profile for the embedded cluster steeper than that of the residual star-forming gas; in agreement with the quadratic star formation relation observed in the Solar Neighbourhood. This physically-motivated set-up of cluster formation conditions yields a star formation efficiency threshold for cluster survival following instantaneous gas expulsion as low as 13%, i.e. more than a factor of two smaller than earlier predictions. Building on the same cluster formation model, I shall also discuss the pitfalls of interpreting star formation relations: (1) although nearby molecular clouds and distant molecular clumps behave differently in the star-vs.-gas-surface-density space, this per se cannot be taken as evidence for a change in the physics of star formation with gas density, (2) an observed linear relation between star formation rate and gas-reservoir mass does not necessarily imply that the star-formation activity is limited to the gas reservoirs for which the mass has been obtained.

Ahmad Ali

Simulating photoionization and radiation pressure feedback from massive stars in clusters

Massive stars can drastically alter their natal molecular clouds via radiative feedback. We simulate a self-gravitating, turbulent cloud of 1000 Msol evolving under photoionization and radiation pressure feedback from a 34 Msol star. We use a detailed Monte Carlo radiative transfer scheme alongside the hydrodynamics to accurately compute photoionization and thermal equilibrium with multiple atomic species and silicate dust grains.

We find that all material is dispersed from the (16pc)^3 grid within 1.6 Myr or 0.74 free-fall times. Mass leaves the simulation boundary with a peak flux of 2x10^{-3} Msol/yr, leading to efficient dispersal of gas from the cluster. 85 per cent of the volume, and 40 per cent of the mass, become ionized – dense filaments resist ionization and are swept up into roughly spherical cores with pillars that point radially away from the ionizing star. The impact of radiation pressure is negligible in our models.

Using the resulting temperatures and ionization states, we produce self-consistent synthetic observations of line and continuum emission. Free-free emission at 20 cm is used to estimate the production rate of ionizing photons, and dust continuum at 450 and 850 micron is used to probe the dust temperature. These usually underestimate the actual properties.

Christian Boily

The binary fraction and CMF in star-forming regions

Gravitational fragmentation modes would have massive stars sitting in denser knots of a star-forming region. While massive stars form efficiently (short hydrodynamical time-scale) the bulk of low-mass stars have not yet reached the main sequence and their intrinsic luminosity may yet be changing rapidly owing to uncertainties about their age and accretion rates. This, combined with interstellar extinction fluctuations (driven by turbulence) means that a solid fraction of ~ 30% of embedded low-mass cores may yet be missed. I argue that the later stages of the formation of stars are strongly affected by the combine effect of gas accretion and stellar dynamics.

Andrew Winter

Establishing Star Formation Scenarios Using Protoplanetary Disc Fractions: The Case of Cygnus OB2

In dense stellar environments protoplanetary disc (PPD) evolution is dependent on the feedback of neighbouring stars. In particular, external photoevaporation due to far ultraviolet (FUV) irradiation by massive stars can shorten disc lifetimes, with significant consequences for planet formation. Recent developments in the theory of FUV induced photoevaporation has made it possible to follow PPD evolution in regions of intense FUV field strengths. Such calculations allow us to take a novel approach to constraining the dynamical history of complex star forming regions. We combine dynamical simulations with observed disc fractions as a function of FUV intensity in the nearby OB association Cygnus OB2 to constrain initial cluster mass, gas expulsion history and underlying substructure. We further suggest the future fate of the stellar components of this massive star forming region.

SESSION 3: STAR FORMATION FROM STELLAR CLUSTERS OBSERVATIONS

Richard Parker (Invited speaker)

Written in the stars: clues to the initial conditions of star formation

Thanks to new and upcoming facilities such as Gaia, we are currently experiencing a revolution in terms of the quantity and quality of data available on the stellar content of young star-forming regions. In this talk I will summarise the latest observational progress on quantifying the spatial and kinematic distributions of young stars within star-forming regions. I will demonstrate how this is allowing us to place constraints on the past and future evolution of star-forming regions, and to predict whether star-forming regions will form long-lived bound clusters or whether they will disperse into the Galactic field. I will conclude by highlighting the implications of these studies on planet formation, and the Solar system in the overall context of exoplanetary systems.

Morten Andersen

Revealing the innards of a star cluster in the making

Stellar clusters are the birthplace of most stars. Yet we only have a rudimentary understanding of how they form, especially their evolution during the early, gas-dominated phases. This is due to a combination of short life times making them difficult to find and their dense embedded nature. Here we present work on a cluster still experiencing high molecular infall rate suggesting it is still in its formation stage. The total mass of molecular gas and dust suggests the forming star cluster may be a massive star cluster. Through HST near infrared imaging we are able to characterize the stellar content, deducing their age and spatial properties, which are strongly linked to the formation mechanism of star clusters. We further discuss the use of the stellar proper motions to further constrain the formation scenario of massive clusters.

Marc Pound

Uncovering the Evolution of Clustered and Dispersed Star Formation Across the Serpens Molecular Complex

We describe the motivation and scope of a new in-depth study of the distribution of YSOs and gas over approximately 6 square degrees of the Serpens Cloud Complex. The main goal of this study will be to characterize the star formation process over the full Serpens Cloud Complex on scales of 1000 AU to tens of parsecs, with focus on:

(1) the spatial distribution of YSOs
(2) the properties of YSOs in subclusters as a function of age and mass,
(3) quantifying how star formation progresses in space and time over the complex, and
(4) the detailed relationship between cloud material and YSOs.

Using data from many surveys, including Gaia, we will analyze the SEDs of potential YSOs to build a deep, uniformly selected, catalog. Our preliminary investigation suggests an increase of the YSO census in this region by 20-40%. Using star+disk+envelope models to gauge properties of the YSOs, we can estimate Classes and luminosity, and investigate other indicators of age.

We will use new statistical tools to quantify the clustering properties as a function of scale, extract dense substructures, and characterize them. We will determine the stellar hierarchical structure and its relationship to the present structure of the cloud material.

Lee Mundy

Gould Belt Clouds: Distances and Insights into YSO Kinematics

The GAIA DR2 data provide the opportunity to measure the distances to young stellar objects (YSOs) associated with local molecular clouds, and hence the distances to the clouds. For clouds closer than 500-700 pc, which includes most of the Gould Belt clouds, the distance and proper motion determinations can be sufficiently accurate to: (1) see if different star forming regions within a cloud are at different distances, (2) search for additional YSOs based on distance, proper motion, and color criteria, (3) examine the proper motion kinematics within clusters, and between YSOs and the surrounding cloud material. The proper motion kinematics can yield insights into the birthplaces of current Class II YSOs, which are typically more spatially dispersed than Class I or 0 YSOs.

Tristan Cantat-Gaudin

Revealing kinematic substructure in young stellar clusters with Gaia DR2

Young clusters and star-forming regions often show apparent substructure (e.g. NGC 2264; Venuti et al. 2018), possibly indicative of a time sequence of star formation events. Those substructures are sometimes only distinguished with kinematic information (e.g. radial velocities in Gamma Velorum, Jeffries et al. 2014), and might present compact or sparse distributions. Loose groupings such as OB associations might be the result of the expansion of a single once compact cluster (e.g. Mapelli et al. 2014 on the virial state of the two Gamma Velorum subgroups) or might have formed as low-density systems with substructured spatial distributions (e.g. Wright & Mamajek, 2018).

Applying cluster membership assignment tools (Cantat-Gaudin et al. 2018) to the astrometry of the Gaia DR2 catalogue allows us to distinguish kinematic structures in those complex regions and to further characterise the variety of mechanisms that drive cluster formation and disruption.

Jacob Ward

Not all stars form in clusters: measuring the kinematics of OB associations with Gaia

It is often assumed that star clusters are the fundamental units of star formation and that most (if not all) stars form in dense stellar clusters. In this monolithic formation scenario, low density OB associations are formed from the expansion of gravitationally bound clusters following gas expulsion due to stellar feedback. From N-body simulations, one would expect associations that formed in this manner to continue to exhibit positive radial velocities and elevated levels of anisotropy over 10s of Myr. However, recent theoretical and observational studies suggest that star formation is a hierarchical process, following the fractal nature of natal molecular clouds and allowing the formation of large-scale associations in-situ. Using the Tycho-Gaia Astrometric Solution (TGAS) catalogue, we quantify four key kinematic diagnostics for 18 nearby OB associations in order to determine whether the typical kinematic behaviour of OB associations are consistent with a monolithic star formation scenario. Comparing the distributions of each of these diagnostics with those derived from model associations with kinematics representative of random motions and expanding velocity fields, we find no evidence to support the notion that nearby OB associations are undergoing gas-expulsion driven expansion, either from a single cluster or multiple clusters. With the second data release (Gaia DR2), Gaia now allows the kinematics of all nearby OB associations to be probed with unprecedented precision. I will present the exciting new results from the expansion of our study to Gaia DR2, with which we implement clustering algorithms to independently identify over-densities of OB-type stars before measuring the kinematic properties of over 150 potential OB associations. I will discuss the implications of these results of these studies with particular emphasis on the unique potential of Gaia to distinguish between the monolithic and hierarchical star formation paradigms.

SESSION 4: CHARACTERISATION OF SPATIAL AND KINEMATIC STRUCTURES OF STAR CLUSTERS

Antonella Vallenari (Invited speaker)

Star clusters in the Gaia second data release

In this presentation, I will review the properties of the Gaia second data release discussing the quality and the limitations with applications to the young stellar cluster science.

Sergio Dzib

Distance and kinematic of star forming regions

I will present an analysis of the astrometric results from Gaia DR2 and VLBA to Young Stellar Objects (YSOs) in star-forming regions related to the Gould Belt. The mean distance to the YSOs in each region is consistent with earlier estimations; though a significant improvement to the final errors was obtained. The mean distances to the star-forming regions were used to fit an ellipsoid of sizes (358+-77)x(316+-13)x(70+-4)pc, and centered at (-82+-15; 39+-7; -25+-4)pc from the Sun; consistent with the recently determined parameter of the Gould Belt. The mean proper motions were combined with radial velocities from the literature to obtain the three-dimensional motion of the star-forming regions, which are consistent with a general expansion of the Gould Belt. We estimated that this expansion is occurring at a velocity of 2.5+-0.1 km/s.

Isabelle Joncour

At the edge of molecular clouds: uncovering their 3D spatial structure with GAIA

In this work we use the Gaia data of stars located in the foreground of molecular cloud edges, to derive their extinction and spectral type in order to probe the 3D structure of the clouds.

As a benchmark, we first build empirical relative Spectral Energy Distribution (i.e. colors G- Bands) templates associated with different spectral type that we characterized by their G-K color. To do so, we select in GAIA dr2 archive, the stars located within 140pc and complement Gaia photometric bands (G, Gr,Gb) for each star with J, H and 2MASS (and SDSS) counterparts, to build empirical templates of relative SED. We show that these templates are not biased by extinction traces.

Becky Arnold

Quantifying velocity structure in star forming regions

Several methods have been devised for quantitatively analysing the spatial structure of star forming regions e.g. the Q parameter (Cartwright and Whitworth 2004), Λ (Allison et. al 2009), Σ (Maschberger & Clarke 2011). These methods have been valuable and well used by the field. However there are not similar methods of quantitatively analysing the velocity structure of star forming regions. With the advent of Gaia the field has access to an unprecedented quantity of high quality velocity data. In order to take full advantage of this new methods are required to quantitatively analyse it.

A new method for quantifying and investigating velocity structure in star forming regions will be presented. This method can be applied to data with any number of dimensions, and requires no assumptions about the size or morphology of the region.

The method will be applied to simple simulated clusters such as expanding and collapsing Plummer spheres and the results discussed. It will then be demonstrated that the method is robust against high incompleteness and large uncertainties in simulated datasets. To conclude the method will be applied to observational data and the results interpreted.

Olivier Lomax

Modelling the structure of star clusters with fractional Brownian motion

The degree of fractal substructure in molecular clouds can be quantified by comparing them with Fractional Brownian Motion (FBM) surfaces or volumes. These fields are self-similar over all length scales and characterised by a drift exponent H, which describes the structural roughness. Given that the structure of molecular clouds and the initial structure of star clusters are almost certainly linked; it would be advantageous to also apply this analysis to clusters. Currently; the structure of star clusters is often quantified by applying Q analysis. Q values from observed targets are interpreted by comparing them with those from artificial clusters. These are typically generated using a Box-Fractal (BF) or Radial Density Profile (RDP) model. We present a single cluster model, based on FBM, as an alternative to these models. Here, the structure is parameterised by H, and the standard deviation of the log-surface/volume density σ. The FBM model is able to reproduce both centrally concentrated and substructured clusters, and is able to provide a much better match to observations than the BF model. We show that Q analysis is unable to estimate FBM parameters. Therefore, we develop and train a machine learning algorithm which can estimate values of H and σ with uncertainties. This provides us with a powerful method for quantifying the structure of star clusters in terms which relate to the structure of molecular clouds. We use the algorithm to estimate the H and σ for several young star clusters; some of which have no measurable BF or RDP analogue.

arXiv link: arxiv.org/abs/1804.06844

Anne Buckner

Dancing Clusters: Quantitatively Tracing Spatial Evolution and Morphological Features

Despite considerable efforts, there is still little consensus on the formation of high mass stars. Forming almost exclusively in associations, groups and clusters, it is important to understand how high mass stars “cluster” together w.r.t their lower mass counterparts. Specifically analyses of the intensity, correlation and comparative spatial distribution of high and low mass stars in these regions is required to better distinguish between the different star formation models. As such, we have developed a novel clustering tool based on the Hopkins statistic, INDICATE (Buckner et al. 2018), to asses the clustering tendencies of stellar datasets. In this talk, we demonstrate its power for both 2D and 3D analyses and discuss the comparative differences between the spatial properties of high and low mass members in several star forming regions.

SESSION 5: MODELLING AND SIMULATIONS OF EARLY CLUSTER EVOLUTION

Pavel Kroupa (invited speaker)

Early cluster evolution

Stars can be mathematically modelled as being formed as multiple systems formed at the same time in spherical embedded clusters. Observational constraints imply these to be very compact with half mass radii rh/pc = 0.1(M/Msun)^0.13 and a wide range of stellar masses M (10 to many millions). These embedded clusters need to expand within a few Myr to achieve the radii of open and globular clusters and this can only be achieved by the expulsion of a significant amount of residual gas. The stellar-dynamical processes within the embedded clusters shape the multiplicity properties of Galactic-field stars and low-mass dwarf galaxies ought to have a much higher binary fraction than massive elliptical galaxies. Massive stars, formed in the mass segregated embedded clusters, eject each other efficiently from their birth clusters. These stellar-dynamical processes may be important for the emergence of multiple populations in embedded clusters which are not older than a few Myr by modulating infalling molecular gas into the cluster along molecular cloud filaments. They result in a field-population of runaway and slow moving O stars which is largely consistent with the observed isolated O stars.

Susanne Pfalzner

Observational constraints on clustered star formation: a more complete picture of clustered star formation emerging

Stars form predominantly in groups, which display a broad spectrum of masses, sizes, and other properties. Despite this diversity there exists an underlying structure that can constrain cluster formation theories. Here we show that current data compilations of clusters in the solar neighbourhood show correlations among cluster mass, size, age, maximum stellar mass, etc. One of them is the by now well-proven mass-radius for young embedded clusters which follows M_c = CR^γ with γ = 1.7 ± 0.2. This relation can be directly related to the mass-radius relation of clumps, which shows a very similar slope. Another one is the dependence of the star formation efficiency on the gas density, which has been so far incorporated in only a few numerical models. We will show that applying those to simulations leads to overall lower star formation efficiencies necessary to reach the observed cluster masses and sizes. For the most massive clusters the entire evolutionary path over the first 10 Myr can be described making use of these two relations. The resulting evolutionary tracks will be discussed.

Hosein Haghi

Constraining the birth conditions of star clusters by the present-day parameters

The internal properties of star clusters can undergo significant changes at birth and also during the course of cluster evolution. For example the mass function and the mass-to-light ratios evolve at early stages and also during the cluster secular evolution as the stars are removed from the system through stellar and dynamical evolution. First, I will review which birth conditions match up with the present-day properties of a couple of distant star clusters, Pal 4 and Pal 14 and how the imprint of residual gas expulsion and primordial mass segregation might be visible in the present-day mass function. In the second part, I will address the discrepancy between the observed M/L ratios of of 163 GCs in the M31 galaxy and what is predicted from SSP models of GCs with a canonical IMF and will propose solutions which are mainly based on the depletion of low-mass stars either due to dynamical evolution, a metallicty- and density-dependent top-heavy IMF, and the relation between the age and the metallicity of the Gcs.

Timothé Roland

Simulation of binaries properties in a fragmented cluster

The binarity of newborn stars still begs lots of question, both in their formation and their impact on the dynamical evolution of the overall star forming region. In particular, the high number of binaries seen in dense regions contrasts with the low rate found in the field, and raises the problem of their evolution. Simulations can help to link these different stages, from a star forming regions (like the Orion Nebulae) to a young cluster (the Pleiades).

During the fragmentation process, stars are formed in small clumps with a potentially high rate of binaries. Using the software AMUSE (Portegies Zwart et al. 2009, 2013), we initialize a small clump with some binaries just after their formation. Then, we compute their evolution to analyze their properties in the first million years. Destroy these binaries is expected to be really difficult but some change on their properties could bring new insight on the observations.

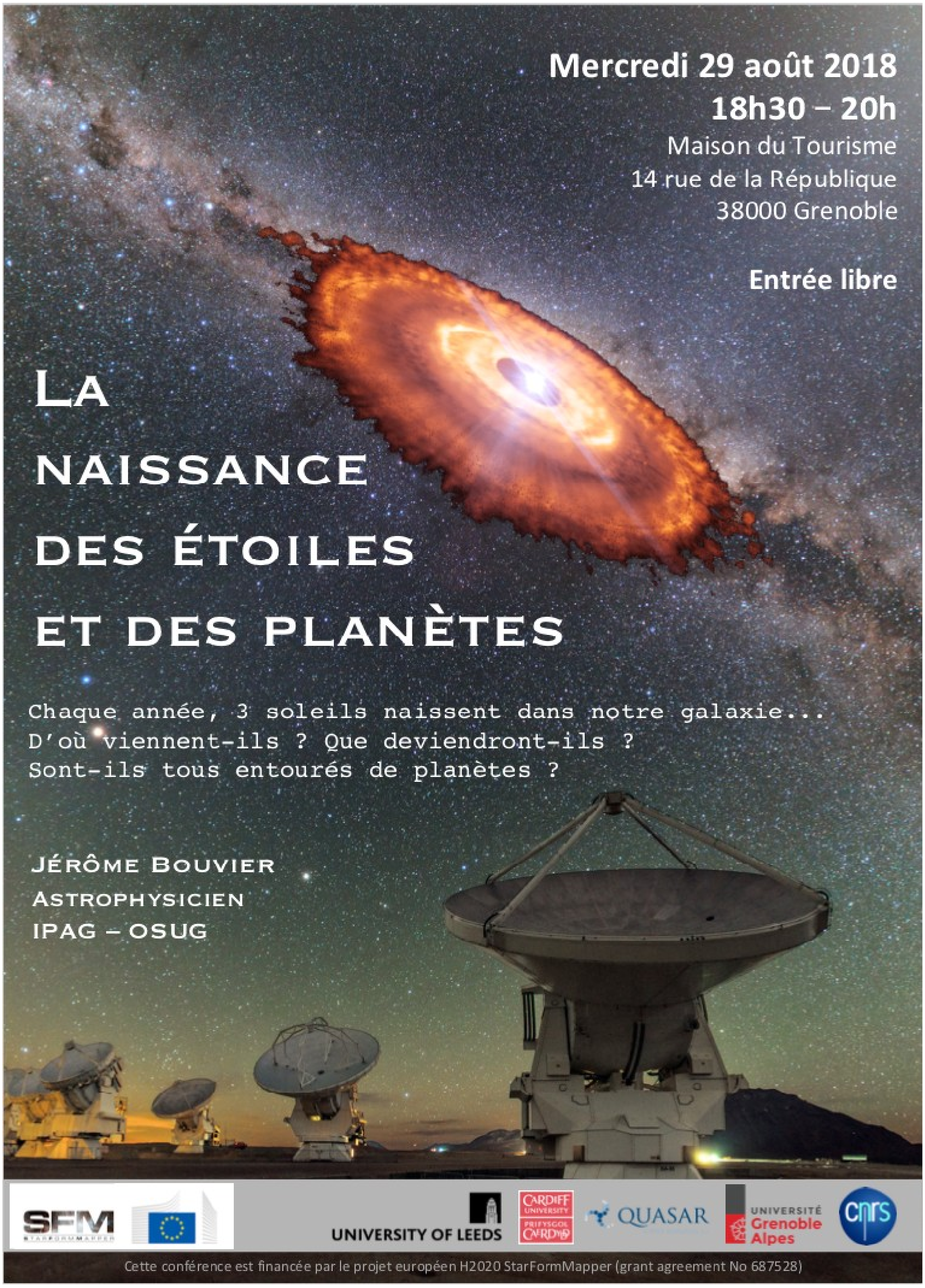
Sebastian Trujillo

A model for the environmental variation of the minimum cluster mass and its implications for globular cluster formation from Fornax to ultra-diffuse galaxies

We present a model for the minimum mass of stellar clusters in the context of galactic evolution across cosmic time. The model is based on the interplay between the timescales for star formation, stellar feedback, and galactic shear, and how these depend on the hierarchical structure of molecular clouds and on the global properties of their host galaxies. We use the model to predict the width of the initial cluster mass function (ICMF) across the full galaxy population in the local and high-redshift universe. These predictions agree well not only with observations in the solar neighborhood and nearby galaxies, but also with the mass functions observed in high-pressure ISM conditions typical of the Milky Way's Central Molecular Zone and the Antennae galaxies. By extending the model to globular cluster (GC) populations, we further show that the narrow predicted ICMF of dwarf galaxy progenitors could explain the large metal-poor specific frequency of GCs observed in Local Group dwarfs like Fornax, IKN, and WLM. Our results also suggest that ultra-diffuse galaxies like NGC1052-DF2 were highly compact systems when most of their stars and GCs formed, implying that they underwent a major transformation to become the low-density systems observed today.

PUBLIC TALK

La naissance des étoiles et des planètes par Jérôme Bouvier Mercredi 29 août 2018, 18h30-20h Maison du tourisme de Grenoble.



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