MAYA 2022 ABSTRACT BOOKLET

— *Wednesday, March 2nd* —

Tracing pebble dynamics with chemistry in protoplanetary disks

Ardjan Sturm (Leiden Observatory)

Carbon plays a crucial role in the thermal balance of planetery atmospheres and the formation of life. Besides, observations of the carbon abundance in protoplanetary disks may reveal planetesimal formation and dynamical dust processes. Drifting icy pebbles transport carbon from the outer regions of the disk towards the inner disk, unless the pebbles end up in a dust trap or planetesimal. Recent modeling shows that the amount of carbon that is depleted of the gas in the outer disk may be dependent on the evolutionary stage of the system. To look for an evolutionary trend, we observed the illusive [C I] line at 492 GHz in seven T Tauri disks using the ALMA ACA and modeled three of these disks using 2D thermo-chemical DALI models. We compare the carbon abundance in the outer disk with literature values of the inner disk carbon depletion for these three T Tauri disks and a sample of younger protostellar disks and warmer Herbig AeBe disks. The outer depletion increases as a function of stellar age in a manner consistent with theoretical dust dynamics models. Using literature values for the inner disk, we find that the dust rings in DL Tau are likely inefficient dust traps, and that the compact systems DR Tau and DO Tau may harbour hidden planets.

The complex multi-scale structure in simulated and observed emission maps of the proto-cluster cloud G0.253+0.016 ('the Brick')

Maya Petkova (ARI/ZAH, Heidelberg University)

The Central Molecular Zone (CMZ; the central ~ 500 pc of the Milky Way) hosts molecular clouds in an extreme environment of strong shear, high gas pressure and density, and complex chemistry. G0.253+0.016, also known as 'the Brick', is the densest, most compact and quiescent of these clouds. High-resolution observations with the Atacama Large Millimeter/submillimeter Array (ALMA) have revealed its complex, hierarchical structure. In this contribution I will compare the properties of recent hydrodynamical simulations of the Brick to those of the ALMA observations. To facilitate the comparison, the simulations are post-processed to create synthetic ALMA maps of molecular line emission from eight molecules. We correlate the line emission maps to each other and to the mass column density, and find that HNCO is the best mass tracer of the eight emission lines within the simulations. Additionally, we characterise the spatial structure of the observed and simulated cloud using the density probability distribution function (PDF), spatial power spectrum, fractal dimension, and moments of inertia. While we find good agreement between the observed and simulated data in terms of power spectra and fractal dimensions, there are key differences in the density PDFs and moments of inertia, which we attribute to the omission of magnetic fields in the simulations. This demonstrates that the presence of the Galactic potential can reproduce global cloud properties, but additional physical processes are needed to explain the gas structure on smaller scales.

Molecular spectroscopy across nearby star-forming disc galaxies

Ivana Beslic (Argelander Institute for Astronomy, Uni Bonn)

Gas flows with the surrounding enrichments, and star formation processes within galaxies regulate galaxy evolution. Stars form out within the densest, coldest parts of molecular gas. We need to constrain two fundamental drivers of star formation in the Local Universe: gas density and turbulence, to fully understand the ability of gas to form stars. Therefore we need to probe the densest molecular gas regime by observing high-critical density molecular lines in the 3 mm range (HCN, HCO+, HNC..). The key to understanding and constraining molecular gas physics lies in studying these ”dense gas tracers” within nearby galaxies that are an essential link to our Milky Way and the high-redshift Universe. In this talk, I will outline some of the key research directions in studying dense molecular gas using the new generation of telescopes: ALMA and NOEMA. I will present a cloud-scale study of dense gas tracers across the nearby star-forming galaxy NGC 3627, which represent the highest resolution observations of dense molecular gas covering a large portion of a nearby galaxy disc within the literature. This project bridges a gap in the Milky Way community and presents one of the essential steps toward probing star-forming regions in nearby galaxies. Next, I will introduce our view of dense molecular gas in the closest starburst galaxy NGC 253, obtained by ALMA. NGC 253 is an excellent example of objects we see in the high-redshift Universe. Therefore, understanding molecular gas content and its role in star formation within such an extreme environment is an essential benchmark to complete our understanding of star formation and galaxy evolution.

A 3D kinematic view of disc galaxies at $z \sim 4.5$ with ALMA

Fernanda Roman de Oliveira Kapteyn Astronomical Institute, University of Groningen

High-redshift galaxies are the progenitors of galaxies in the Local Universe and they hold the key to many of the open questions around galaxy formation and evolution. However, they come with their own set of challenges, particularly pushing the limits of our current observing capabilities. Given its unprecedented sensitivity and spatial resolution, ALMA is now a vital tool for carrying out resolved studies of the gas emission of high-redshift galaxies. This allows us for the first time to characterise the dynamical state of these early objects with enough detail to bring clarity to our understanding of turbulence and the formation of the first discs. I will present the 3D kinematics performed with the software 3DBAROLO on 4 of the most well-resolved galaxies by ALMA at $z \sim 4.5$, one of which has never been analysed before. We found that all of them are rotation supported at a mere 1.5 billion years after the Big Bang. We also observe a diversity of velocity dispersions that appear to be significantly lower than those predicted by state-of-the-art cosmological hydrodynamical simulations. This is evidence that disc formation can happen much earlier and with less turbulence than previously expected.

REBELS LP: Insights into the Physical Properties of Massive Galaxies during the Epoch of Reionization

Sander Schouws (Sterrewacht Leiden)

Achieving a physical characterization of galaxy build-up in the reionization epoch has been a long-standing goal in extragalactic astronomy. By using ALMA to spectrally scan 46 massive UV-bright $z > 6.5$ galaxies for [CII] in our REBELS Large Program and pilot studies, we have constructed a large sample of massive galaxies with [CII] and continuum detections. Here we will present the survey design and preliminary results, looking at the relation between [CII] and SFR, [CII]/Lir, dust, and kinematic properties and their possible evolution compared to local relations. This gives us some valuable initial insight into both the evolution of the physical properties and the formation of dust in these massive galaxies in the EoR. Finally we discuss the exciting future prospects for this survey ALMA, JWST and ground-based spectroscopy.

ALMACAL IX: Number counts in ALMA bands 47, and the resolved fractions of the cosmic infrared background

Jianhang Chen (ESO)

Wide, deep, blind continuum surveys at submillimetre wavelengths are required to prepare a full inventory of the dusty, distant Universe. However, conducting such surveys to the necessary sub-mJy depth, with sub-arcsec angular resolution, is prohibitively time consuming, even for the most advanced submillimeter telescopes. For this talk, I will present the most recent results from the ALMACAL project, which exploits calibration data from the Atacama Large Millimetre/submillimetre Array (ALMA) to map along the lines of slight towards and beyond the ALMA calibrators. ALMACAL has now covered 1,001 calibrators, distributed across the sky accessible from the Atacama, and accumulated more than 2,700 hr of integration time. We will first report the detection of 110 submillimetre galaxies (SMGs) in the most up-to-date ALMACAL database, considerably more than was found via any of the ALMA Large Programmes dedicated to this endevour, and where our derived number counts are considerably less susceptible to cosmic variance than those surveys. I will also report the number counts at five wavelengths, in ALMA bands 37, providing a benchmark for models of galaxy evolution. Besides, by combining all the blind surveys with ALMA, we are able to constrain the shape of CIB at (sub)millimeter range.

Do CO isotopologues point to IMF variation in starburst galaxies?

Matthew Doherty (University of Hertfordshire)

The shape and universality of the initial mass function (IMF) is one of the most important questions in astronomy, being an integral part in both theoretical models and in deriving many key properties of galaxies. The most direct method to constrain the IMF, young stellar object counting, is impossible for cosmological distances and other traditional methods take advantage of UV, visible, and near- IR wavelengths making them inapplicable in the most extreme star forming galaxies due to the extreme dust extinction present in these systems. Many predictions of IMF variation occur within these systems, as such alternative methods to constrain the IMF are required, with one promising method being via the chemical signatures left by massive stars. Due to their different production routes the 13C/18O isotope ratio is thought to be one such signature. By observing the rotational transitions of the isotopologues 13CO and C18O and thus the 13C/18O ratio we can probe the IMF free from the effects of dust. Here we present a new ALMA band 4 spectral scan containing the CO isotopologues in 9io9, a strongly lensed sub-mm galaxy at $z = 2.6$. We find a global ratio an order of magnitude below that found in local spirals but in agreement with values in other SMGs and local ULIRGs. Using a state-of-the-art chemical evolution model, we probe the isotope ratio for a variety of IMFs and star formation histories finding that the low observed ratio in these extreme galaxies can be explained with a standard Milky Way IMF.

HCO+ and the effect of mixing in supernovae

Holly Davies (Cardiff University)

The molecular ion HCO+ commonly forms in molecular clouds and so it was a surprise to see significant amounts of it in SN 1987A in 2016 detected by ALMA. This surprise detection therefore comes with a question of where and how HCO+ forms in this young supernova. This study continues with investigations into this molecule by using higher angular resolution images of the ejecta with ALMA. Comparisons were made of the spatial distribution of HCO+ in the ejecta with those of CO and SiO to infer details of its formation. Furthermore, SN 1987A, which is a type II supernova, had a high-mass progenitor star with stratified nuclear burning zones, from heavier elements such as iron in its core, to the lighter elements such as hydrogen in its outer layer. For HCO+ to form in such quantities, the carbon and oxygen layers found deeper within the remnant, needed to mix with the outer hydrogen layer. Hence, the mere presence of this molecular ion in the ejecta of SN 1987A indicates that a form of mixing arising from Rayleigh-Taylor instabilities during the time of the explosion is responsible for this molecule to form.

Complex molecules in eruptive young stellar objects

Fernando Cruz Sáenz de Miera (Konkoly Observatory)

The chemical composition of planets is determined by the material they accrete from the midplane of their parent disks. Thus, understanding the chemical evolution of protostellar/protoplanetary disks is paramount for the study of planet formation. The detection of complex molecules is easily attainable in the youngest protostars due to their elevated temperatures. However, as systems evolve, they become colder and the molecules freeze onto the dust grains, complicating their detection. These frozen molecules are hard to detect, thus the chemical evolution of young stellar objects remains a mystery. A type of object that can shed some light on the chemical composition of cold disks are the FU Orionis-type objects (FUors).

FUors are low-mass young stellar objects experiencing brief periods of enhanced mass accretion rates, which raise the temperature of their disks, causing different chemical and mineralogical changes. In particular, the frozen molecules are desorped from the dust grains and become easily detectable. FUor-type events typically occur during the early phases of young stellar objects, when planets thought to be formed, and so present a great opportunity to analyze the chemical composition of disks as they are feeding gas and dust to the protoplanets.

Here I will present our ALMA observations with which we serendipitously detected several interesting complex molecules in the disks of a handful of FUors, along with the results of LTE modeling and kinematic diagnostics for our sample. The combination of two ALMA configurations and the ACA has allowed us to recover the extended emission with high angular resolution. I compare these with theoretical predictions of chemical evolution and with the chemical composition of other young stellar objects.

A study of sunspot 3 minute oscillations using ALMA and GST

Yi Chai (New Jersey Institute of Technology)

The Atacama Large Millimeter/sub-millimeter Array (ALMA) has been an extraordinary radio instrument for solar physics since the first solar commissioning campaign which took place in December, 2015. The high spatial and temporal resolution of the interferometer images has opened a new era of solar radio research. These data are unique in providing a time-series of direct temperature measurements in the solar chromosphere, making ALMA the perfect tool for studying chromospheric activities such as the well-known 3-minute sunspot oscillations. In our previous work, we combined the Hα data taken by the Goode Solar Telescope (GST) operating at the Big Bear Solar Observatory (BBSO) with the ALMA band 3 data taken from the solar commissioning campaign to investigate 3-minute sunspot oscillations in a large active region and discovered a phase relation between periodic ALMA temperature fluctuations and H sub-bands intensities. Combined with the solar atmospheric model (FAL S) and simulation tools (RH codes), we successfully tested a possible physical model for impulse-driven acoustic waves propagating in the gravitationally stratified medium developed by Chae & Goode (2015). This work demonstrates the capability of ALMA in the field of solar science and could lead to future developments related to frequency-dependent probing of the solar atmosphere using ALMA sub-bands.

V1309 Sco: A Rosetta stone in the study of stellar mergers

Thomas Steinmetz (Nicolaus Copernicus Centre for Astronomy)

Red novae have been established as a product of stellar mergers, producing a late spectral type (M) remnant. The red nova eruption produces intermediate luminosities between that of classical novae and supernovae. Such studies began with the discovery of V838 Monocerotis, but additional red novae have since been identified in the Milky Way, including V4332 Sagittarius and OGLE-2002-BLG-360. The most studied of these is V1309 Sco, partly due to it being the only Galactic red nova with data prior to the merger available. As a result of this, V1309 Sco is considered a significant object in understanding stellar mergers. All red nova remnants are rich in cool (30-300 K) gas and dust which is prominent at millimeter and sub-millimeter wavelengths. V1309 Sco has previously been observed using ALMA at multiple epochs, with the aim of measuring the physical parameters of the cool circumstellar component of V1309 Sco, which consists of material ejected before, during and after the merger. Such parameters we wish to constrain include the kinematics, gas excitation and chemical composition of this cool component, which features molecular lines such as CO, SiO and SO2. As we have ALMA data taken separated by 3 years, we can also monitor the evolution of these parameters over time, providing additional information on the physics going on within the red nova remnant. We wish to use this information to constrain the overall physics of stellar mergers, including the ejection mechanisms responsible at different phases, as well as the possible role of jets and the chemical processing responsible for the presence of unexpected species in the spectra such as CrO.

Evidence for Gaseous Halos Around AGN at Cosmic Noon from ALMA CO(3-2) Observations

Gareth Jones (University of Cambridge)

Gaseous outflows are key phenomena in the evolution of galaxies, as they affect star formation (either positively or negatively), eject gas from the core or disk, and directly cause mixing of pristine and processed material. Active outflows may be detected through searches for low-level, broad spectral line emission, but it is also possible to determine the presence of past outflows by examining the current brightness distribution of galaxies. In this work, we examine the CO(3-2) emission of a set of $z \sim 2.0 - 2.5$ AGN host galaxies (a subset of the SUPER sample), as observed with ALMA. By performing a three-dimensional stacking analysis, collapsing the resulting stacked cubes, and extracting radial brightness profiles, we find evidence for a gaseous halo of $r \sim 15$ kpc. This is verified by creating a model of one or two 2D Gaussian models, convolving them with the stacked PSF, and using the Bayesian inference code MultiNest to fit the Gaussian properties so that the extracted brightness profiles are matched. We extend this analysis to the HST/ACS i-band images of the SUPER sample, which show a complex small-scale ($r < 5$kpc) morphology but no evidence for an extended halo. Thus, the CO(3-2) data for the SUPER AGNs represents one of the best cases of gaseous halos at cosmic noon.

High-resolution gas and dust of the first QSOs

Roberta Tripodi (University of Trieste)

The cold ISM and dust properties are key elements to understand the assembly and nature of the first QSO at the Reionization Epoch. In particular, the [CII] and CO lines are bright tracers of the gas content that could be detected from distant galaxies. Measurements of the line widths, profiles and velocity maps of these emission lines reveal important information on the gas kinematics. Observations of the [CII] and CO emission lines from the young quasars hosts at $z \gtrsim 6$ at high resolution show a range of kinematic properties, including velocity gradients of ordered motion, large velocity dispersion/turbulence, gas outflows and mergers. Although the [CII] has been the main gas tracer up to now, the molecular gas component and the dust/gas ratio are still little explored. I will present results of the molecular ISM and dust based on CO, [CII] and continuum ALMA observations at high angular resolution in a sample of QSOs at redshift $\gtrsim 6$, partially drawn from the HYPerluminous QSOs at the Epoch of ReionizatION (HYPERION) Survey . These enable us to trace both the dust and gas components in our samples host galaxies and to accurately describe their kinematics and the relation between their distribution and their properties. Moreover, I will focus on the description of QSO J2310+1855, studying its dust emission properties thanks to the large number of ALMA observations available, discussing the information given by the analysis of its gas content in CO, [CII] and H2O, and finally exploring the environment of this QSO with new proprietary ALMA data.

Giant molecular clouds in the bulge of the lenticular galaxy NGC1387

Eric Liang (University of Oxford)

Molecular gas is key to our understanding of star formation and galaxy quenching, but only over the past decade and with the capabilities of ALMA have spatially-resolved observations of giant molecular clouds (GMCs) beyond the Local Group become feasible. NGC1387 is an early-type galaxy (barred S0) in the Fornax Cluster, with a molecular gas-rich nuclear disc within its bulge revealed by ALMA CO(2-1) observations at 15 pc resolution. We have identified 1585 individual clouds and measured their fundamental properties (radius, velocity dispersion, gaseous and dynamical mass, etc). We found the NGC1387 GMCs to follow very similar scaling (e.g. Larson) relations as those of clouds in the Milky Way disc. On average, the GMCs are perfectly Virialised. Although the majority of cloud rotations do not follow galactic shear, a small subsample of inner large clouds do couple with galactic rotation.

The chemical nature of Orion protostars: Are ORANGES different from PEACHES?

Mathilde Bouvier (Univ. Grenoble Alpes, CNRS, IPAG, F-38000 Grenoble, France)

The protostellar stage is known to be chemically rich and diverse. Indeed, molecules that were trapped onto the ice mantles of grains during the prestellar core phase are released into the gas phase, resulting in the chemical enrichment and diversity of the protostar environment. Key pieces of evidence of this chemical diversity are hot corinos and Warm Carbon Chain Chemistry (WCCC) objects, two chemically distinct types of solar-mass protostars. On the one hand, hot corinos are compact (< 100 au), dense ($n > 10^7$ cm^{-3}) and hot (> 100 K) regions, enriched in interstellar Complex Organic Molecules (iCOMs; e.g. CH3OH, CH3OCH3). On the other hand, WCCC protostars have an inner region deficient in iCOMs but a larger zone ($\sim$ 1000 au) enriched in hydrocarbons (e.g. CCH, c-C3H2). This protostellar chemical diversity could reflect a difference in the chemical composition of the grains ice mantle set during the pre-stellar core phase. Whether the environment affects this diversity and how, is still an open question. In order to understand what causes the chemical diversity of solar-type protostars, we need to perform systematic studies of the chemical composition of solar-mass protostars at small scales located in different environments. In this context, two recent studies were performed. The first one is the Perseus ALMA Chemistry Survey (PEACHES) which targeted a relatively loose protocluster, containing only low-mass objects. The second one is the ORion ALMA New GEneration Survey (ORANGES), which targeted the Orion Molecular Cloud 2/3 filament, the nearest low- to high- mass star forming region, highly UV illuminated by nearby HII regions. While the PEACHES study showed that hot corinos were likely dominant in Perseus, I will present the new results obtained from the ORANGES, and answer the question of whether ORANGES are different from PEACHES.

Simulations of ALMA observations

Francesca Bonanomi (VISESS, University of Vienna)

ALMA provides with an unprecedented view of the filamentary structure of the ISM. In order to study the process of formation of high-mass stars, the EMERGE project will perform a sistematic study of > 30 filamentary network across the Milky Way using ALMA observations. The analysis performed in this work is based on interferometric observations, a kind of data presenting some critical issues. The emission properties of the sources observed with ALMA are strongly affected by the intrinsic filtering effects of their true sky brightness distribution. Adding the interferometric response to simulated data is therefore mandatory in order to compare simulations with observational data. To address this issue, the goal of this work is creating a simulation interface based on the CASA SIM tools (available in CASA), producing synthetic continuum and spectral ALMA observations. With that we aim to quantify the impact of extended emission on the recovery of the fundamental filamentary structure at different scales in the ISM using different tracers and continuum bands. In our analysis we compare and systematically quantify the effects of different configurations and arrays (i.e., ALMA 12m and ACA) and their potential improvements including data combination between arrays and with single-dish TP data. During my talk I will present the first results of this project for the analysis of different synthetic cloud geometries and configurations.

Charting Circumstellar Chemistry of Carbon-rich AGB stars

Ramlal Unnikrishnan (Chalmers University of Technology, Gothenburg, Sweden)

Asymptotic giant branch (AGB) stars contribute substantially to the chemical enrichment of galaxies. They produce heavy elements through nucleosynthesis, and release them to the interstellar medium through stellar winds. The chemical characterisation of the latter is crucial for understanding the astrochemical networks that lead to the formation of complex molecules and dust. However, the chemistry in circumstellar envelopes (CSE) of carbon-rich AGB stars remains poorly constrained and is currently almost exclusively based on observations of a single star, IRC+10216.

In this talk, I will present high-resolution ALMA Band 3 (84 - 116 GHz) spectral-line surveys of three carbon-rich AGB CSEs. With more than 200 emission lines detected per source, this survey offers one of the best tools for the detailed study of the molecular richness in carbon-rich CSEs. The three stars, with similar outflow properties and brightness, have been specifically chosen for the large spread in their 12C/13C isotopic ratio. This indicates their different nucleosynthetic histories, making them ideal candidates for a comparative study of variations in chemical evolution.

I will give an overview of the molecular content and the chemical structure of the three CSEs, and discuss the observed similarities and differences, as well as present initial abundance estimates and comparisons with corresponding single-dish observations. I will also provide an outlook of future work, including detailed radiative transfer analysis and updates to the existing chemical models for CSEs around AGB stars.

A search for Galactic Center transients in 230 GHz ALMA observations

Alejandro Mus (Universitat de Valéncia)

The Galactic Center presents one of the highest stellar densities in our Galaxy, making its surroundings an environment potentially rich in radio transients, such as pulsars and different kinds of flaring activity. In this talk, I present a first study of transient activity in the region of the Galactic Center based on Atacama Large mm/submm Array (ALMA) continuum observations at 230 GHz taken during the 2017 Event Horizon Telescope campaign on 2017 April 6,7 and 11. This search is based on a new self-calibration algorithm, especially designed to disentangle the variability of unresolved point source, in this case Sagittarius A*, from any potential transient emission in the wider field of view (in our observation of ~ 30 arcseconds, which includes the minispirals) and residual effects of the imperfect data calibration. Our algorithms are successfully tested against realistic synthetic simulations of transient sources in the GC field. Having checked the validity of the statistical criterion, we provide upper limits for transient activity in the effective field of view of the GC.

The chemical footprint of AGN feedback in the outflowing circumnuclear disk of NGC1068

Ko-Yun Huang (Leiden Observatory)

In the nearby (D=14 Mpc) AGN-starburst composite galaxy NGC 1068, it has been found that the molecular gas in the CND is outflowing, which is a manifestation of ongoing AGN feedback (García-Burillo et al. 2014). The induced interaction between the AGN ionized wind & jet with the molecular gas on the CND has produced large-scale molecular shocks on spatial scales of up to 400 pc from the AGN. The outflowing gas has a large span of velocities, which likely drive different shock chemistry signatures at different locations in the CND. In this talk we are presenting our recent ALMA multi-line molecular study (Huang et al. submitted; Huang et al. in prep.) using SiO, HNCO and methanol as tracers of chemical differentiation across the CND. With a radiative transfer analysis coupled with Bayesian inference processes, we are able to determine the gas properties of the potentially shocked gas in the CND.

Resolving Cold Gas at Cosmic Noon

Melanie Kaasinen (ESO)

One of the major science goals driving the development of ALMA has been to map the star-forming, i.e. molecular, gas in distant galaxies. Yet, despite ALMA having been in operation for almost a decade, the resolution of molecular gas observations at $z \sim 2$ (now dubbed Cosmic Noon) remains significantly poorer than that of the stellar emission, leaving many fundamental questions unanswered. What were the main sites of star formation? And, what was the temperature, density and kinetic energy content of the gas out of which stars were forming? Answering these fundamental questions requires observations of the emission from ISM components that scale directly with the total molecular gas column and well as tracers of warmer/denser gas. To convince you, I will present some of the highest-resolution ALMA observations conducted yet of $z \sim 2$ galaxies and will highlight their limitations. I will explain why deep and high-resolution CO observations are still needed to understand how and where the bulk of stars formed, hopefully encouraging some interesting proposal discussions afterwards.

The role of major mergers in the galaxy mass-assembly as revealed by the ALPINE-ALMA [CII] survey

Michael Romano (National Centre for Nuclear Research, Warsaw, Poland)

How galaxies increase their stellar mass through cosmic time is still one of the most puzzling questions of modern cosmology. Galaxy major mergers and star formation have been proposed as the main drivers of the build-up of galaxies at different epochs of the Universe. Although star formation was considered as the favorite scenario for many years, recent works have suggested a possible increase in the fraction of major mergers in the early Universe, reviving the debate on which of the two processes dominates over the other.

To estimate the importance of major mergers in this context, we made use of the data collected by the ALPINE-ALMA [CII] survey, which observed the [CII] 158 m emission line in a hundred of star-forming galaxies one billion years after the Big Bang. We exploited, for the first time, both the morphological and kinematic information provided by the ALMA observations to identify major mergers at $z \sim 5$, and to assess their relevance in the framework of galaxy mass-assembly. We found that $\sim 40\%$ of normal galaxies at that redshift is undergoing a merging, providing the first constraint on the merger fraction from [CII] at this epoch. By combining our results with studies at lower redshift, we computed the evolution of the merger fraction through cosmic time, and compared the processes of merging and star formation as responsible for the growth of galaxies.

Our results reveal the presence of a significant merging activity at $z \sim 5$, that has to be taken into account in the overall process of galaxy build-up in the early Universe.

Characterisation of molecular outflows in ULIRGs using ALMA

Isabella Lamperti (Centre of Astrobiology (CAB,INTA-CSIC))

Local ultra-luminous infrared galaxies (ULIRGs) host the most intense starbursts in the local Universe and many of them host bright active galactic nuclei (AGN) as well. For this reason, they are the ideal places to study outflows and the feedback from AGN and star-formation. We use spatially resolved (~ 400 pc) CO(2-1) and continuum ALMA observations for a representative sample of 25 low-redshift ULIRGs ($z < 0.17$) to study their feedback properties. Taking advantage of the high spatial resolution, it is possible, for the first time, to map the outflow spatial extent and orientation, and to properly evaluate their effects on the host systems. I will present the first results of this study in terms of prevalence of the outflows, outflow energetics and quantify their impact on the host galaxy.

Galaxy formation, ICM heating and AGN feedback: the turbulent youth of a proto-

cluster at $z = 1.7$
Quirino D'Amato (University of Bologna, Italy)

Galaxy clusters are the largest virialized structures in the Universe, and most of their assembly takes place at the cosmic epoch where both star formation and black hole accretion peak ($1 < z < 3$). Exploring the interplay between nuclear activity, star formation and gas supply in such objects addresses the processes responsible for the build-up of present-day most massive galaxies. As prototype of similar investigations, I present the physical properties of a large-scale structure at $z = 1.7$ that is populated by star-forming galaxies and is assembling around a powerful FRII and characterized by extended X-ray emission, that seems to drive the distribution of the protocluster members. If this emission originates from the FRII jet interaction with the intracluster medium, promoting the star formation on nearby galaxies, this would be the first evidence of positive AGN feedback on multiple galaxies on hundreds-kpc scales. I will present ALMA CO(2-1) observations, that detected three new gas-rich galaxies, and a large molecular gas reservoir ($M_{H2} \sim 2 \times 10^{11} M_{\odot}$) around the FRII host galaxy. We predict that the system will evolve into a $\gtrsim 10^{14}$ $M_{\odot}$ cluster at $z = 0$ and that the FRII is the likely progenitor of the future BCG. I also present LOFAR (150 MHz) and JVLA (1.4 GHz) observations of the FRII, which revealed extended radio emission around its lobes, likely linked to the diffuse X-rays, and signatures of re-acceleration of the plasma in the outskirts of the lobes, possibly induced by interactions with the ICM.

The hunt for high-mass prestellar cores
Elena Redaelli (Max Planck for Extraterrestrial Physics)

The formation of high-mass stars, which have a deep impact on the evolution of the interstellar medium, is still highly debated. Different models have been developed, and one of the key parameters that distinguish among them is the mass of the cores that will later form massive stars. Are these prestellar cores already high-mass (tens of solar masses), or do they accrete a large fraction of their final mass in the protostellar phase? From the observational point of view, finding truly prestellar cores in dense and crowded high-mass clumps is challenging. We have developed a technique to identify genuine prestellar cores in high-mass star-forming regions, based on ALMA observations of ortho-H2D+. This molecule is a dense-gas tracer, which at temperature higher than 20K is efficiently destroyed by CO. It is hence an ideal probe of the prestellar gas. I will present our ALMA Band 7 data (resolution: 0.6") of the high mass clump AG14.49 (M $\sim$ 5200 Msun). Based on the o-H2D+ data, we identified 22 prestellar cores, with masses in the range 2-30Msun computed from the 0.8mm continuum flux. We used complementary Band 3 data, covering the N2H+ (1-0) line, to study the gas kinematics at larger scales. A spectral fitting of the data unveil a complex dynamic structure, with up to 3 velocity components on the line of sight. I will show how these data help us understanding the connection between filamentary, large scale gas and dense cores, also in terms of mass accretion.

The SVS 13 Protobinary System: Two Circumstellar Disks and a Spiraling Circumbinary Disk in the Making
Ana Karla Diaz Rodriguez (UK ARC Node, The University of Manchester)

We present VLA and ALMA observations of the close (0.3" = 90 au separation) protobinary system SVS 13. We detect two small circumstellar disks (radii 12 and $\sim$ 9 au in dust, and $\sim$ 30 au in gas) with masses of $\sim 0.004 - 0.009$ Msun for VLA 4A (the western component) and $\sim 0.009 - 0.030$ Msun for VLA 4B (the eastern component). A circumbinary disk with prominent spiral arms extending $\sim$ 500 au and a mass of $\sim$ 0.052 Msun appears to be in the earliest stages of formation. The dust emission is more compact and with a very high optical depth toward VLA 4B, while toward VLA 4A the dust column density is lower, allowing the detection of stronger molecular transitions. We infer rotational temperatures of $\sim$ 140 K, on scales of $\sim$ 30 au, across the whole source, and a rich chemistry. Molecular transitions typical of hot corinos are detected toward both protostars, being stronger toward VLA 4A, with several ethylene glycol transitions detected only toward this source. There are clear velocity gradients, that we interpret in terms of infall plus rotation of the circumbinary disk, and purely rotation of the circumstellar disk of VLA 4A. We measured orbital proper motions and determined a total stellar mass of 1 Msun. From the molecular kinematics we infer the geometry and orientation of the system, and stellar masses of ~ 0.26 Msun for VLA 4A and ~ 0.60 Msun for VLA 4B.

A New Window on Relativistic Transients with ALMA

Tanmoy Laskar (Radboud University Nijmegen)

As the most energetic explosions in the Universe, relativistic astrophysical transients provide a unique opportunity to explore physics at extreme energy scales that are otherwise impossible to investigate in Earth-bound laboratories. I will demonstrate the power of mm-band observations, combined with theoretical modeling, in teasing apart the physics of relativistic extragalactic transients. I will describe how unleashing ALMA's unparalleled sensitivity for photometric and polarimetric observations of transients is leading to new insights into the structure, composition, and magnetization of relativistic outflows from extreme explosions such as long gamma-ray bursts, short gamma-ray bursts, and tidal disruption events. I will conclude by highlighting the current and future role of mm-band facilities in the ongoing multi-messenger revolution in extragalactic time-domain astrophysics.

The Characterization of the Dust Content in the Ring Around Sz 91: Indications of Planetesimal Formation?

Karina Maucó (Instituto de Física y Astronomía)

One of the most important questions in the field of planet formation is how millimeter- and centimeter-sized dust particles overcome radial drift and fragmentation barriers to form kilometer-sized planetesimals. ALMA observations of protoplanetary disks, in particular transition disks or disks with clear signs of substructures, can provide new constraints on theories of grain growth and planetesimal formation, and therefore represent one possibility for progress on this issue. We here present ALMA band 4 (2.1 mm) observations of the transition disk system Sz 91, and combine them with previously obtained band 6 (1.3 mm) and band 7 (0.9 mm) observations. Sz 91, with its well-defined millimeter ring, more extended gas disk, and evidence of smaller dust particles close to the star, constitutes a clear case of dust filtering and the accumulation of millimeter-sized particles in a gas pressure bump. We compute the spectral index (nearly constant at ~ 3.34), optical depth (marginally optically thick), and maximum grain size (~ 0.61 mm) in the dust ring from the multi-wavelength ALMA observations, and compare the results with recently published simulations of grain growth in disk substructures. Our observational results are in strong agreement with the predictions of models for grain growth in dust rings that include fragmentation and planetesimal formation through streaming instability.

Resolving the COMfort zone of Sagittarius B2 (N1) with ReMoCA

Laura Busch (Max Planck Institute for Radio astronomy)

Many interstellar complex organic molecules (COMs) have first been detected in the vicinity of high- and low-mass protostars at temperatures higher than $\sim$ 100K. The production of many COMs is thought to happen via reactions between radicals on dust grains before the COMs desorb upon heating of the collapsing envelope by the nascent protostar. The characteristic temperature of $\sim$ 100K denotes the point when water, the main constituent of the dust grains ice mantles, desorbs from the grain surfaces, along with many other species, perhaps including the COMs themselves. This thermal co-desorption process of COMs with water has so far not been observationally confirmed, mainly due to the insufficient angular resolution of astronomical observations. Tackling the question of the COMs arrival in the gas phase is one of the objectives of the ReMoCA (Re-exploring Molecular Complexity with ALMA) survey that targets the massive star-forming region Sagittarius B2 (N) in the Galactic centre region. Thanks to the sub-arcsecond resolution of the survey, we resolve the COM emission

in the main hot molecular core of the region Sgr B2 (N1) and derive resolved profiles of rotational temperature, column density, and abundance of various COMs. Based on these profiles we resolve the desorption process of COMs in a hot core for the first time. The bulk of the COMs that are (partly) produced on dust grains desorb thermally at temperatures of about 100K likely alongside water. Moreover, we see indications for non-thermal desorption or another thermal desorption process at lower temperatures.

Exploring solar chromospheric dynamics with ALMA

Momchil Molnar (CU Boulder)

We present recent results from our studies of the solar atmosphere at high resolution with the Atacama Large Millimeter Array (ALMA). This allows for temperature measurements of the solar chromosphere, which has previously been an elusive task as the solar chromosphere is far from thermodynamic equilibrium and the interpretation of other chromospheric diagnostics is highly model dependent. Hence, ALMA uniquely provides us with a direct measurement of the chromospheric electron temperature. In this talk we present the novel relationship between hydrogen Balmer-alpha line width and the ALMA brightness temperature. We explain this correlation in the solar case as the coupling of the two diagnostics in the solar chromosphere. We additionally present avenues for its applicability for stellar studies and constraining stellar chromospheric modeling. We also present constraints on the wave heating in the solar atmosphere from ALMA observations. We use the hydrodynamic code RADYN to interpret our observations to show that acoustic waves in the solar chromosphere do not carry enough energy to maintain its quiescent thermal state, which has further implications for stellar chromospheric heating modeling.

GalaPy: a novel Python tool for modelling galaxy SEDs constraining the dust role with ALMA

Tommaso Ronconi (SISSA)

We present GalaPy, a new panchromatic python API for modelling the spectral energy distribution (SED) of galaxies at all redshifts, from radio to X-rays. Its hybrid C/C++/Python implementation allows for a flexible and modular framework with high extensibility capabilities, while reaching performances of an order of magnitude faster than current competitors in the worst scenario and up to two orders of magnitude in the best case.
Our implementation of the dust component is divided into two phases: the warm dust, coupled with the diffuse Inter-Stellar Medium, and the cold dust, coupled with the dense and cold gas phase (i.e. molecular clouds). It allows us to model with high precision the interplay by the contributions of these two components to the absorption of stellar light and to the emission in the IR, that strongly affect the SED of star-forming galaxies. Correctly modelling the contribution of cold dust is of paramount importance in the study of, e.g., high redshift Dusty Star Forming Galaxies (DSFG), which a constantly increasing number of studies are identifying as the progenitors of today's quiescent massive objects.
We probed the potential of our new fitting tool by modelling the photometric panchromatic SED of a collection of 11 DSFGs at the peak of Cosmic Star Formation History with extensively studied physical properties. For all of these objects we have the flux densities in the mm bands thanks to ALMA archival data. In particular, we demonstrated that the availability of similar continuum observations is of crucial importance for increasing the constraining power on our model parameters, in the range of wavelenghts more sensitive to the emission from the cold dust component.

The Morpho-Kinematic Architecture of Super Star Clusters in the Center of NGC253

Rebecca Levy (University of Arizona)

The bar-fed starburst in the center of the nearby galaxy NGC253 hosts a population of more than a dozen super star clusters (SSCs) revealed by submillimeter observations from ALMA and the VLA

(Leroy et al. 2018; Levy et al. 2021; Mills et al. 2021). These SSCs are massive ($M^* \gtrsim 10^5$ $M_\odot$), compact ($R \sim 1$ pc), and gas-rich ($Mgas/M^* \sim 1$), and at least three of them show spectral evidence of molecular gas outflows. In projection, the SSCs appear as a thin, almost linear, structure about 170 pc in length, reminiscent of the Central Molecular Zone (CMZ) of the Milky Way. The individual SSCs are connected by more diffuse dust and molecular gas emission. However, precisely how gas is flowing from the larger scale bar ($\sim$ 2 kpc) down to the nuclear region ($\sim$ 200 pc) to power the nuclear starburst and result in the formation of these SSCs is not well measured. In this work, we use the SSCs themselves as the tracers of the gas flows. We use ALMA observations of the dust continuum and molecular gas emission with a spatial resolution of 47 milliarcseconds (0.8 pc) to morpho-kinematically determine the arrangement of the SSCs in the context of the larger scale bar flows and orbits. From the ALMA spectra, we have precise measurements of the systemic velocities of each of the SSCs. By applying models developed for the CMZ to these observations, we find that the arrangement of the SSCs in NGC253 is consistent with an edge-on ring or crossing streams connected to the larger scale bar, both in terms of the morphology and the kinematics. From these constraints, we can make predictions for model-dependent cluster age gradients, which we will be able to test with our approved Cycle 1 JWST program.

High resolution spectral imaging of CO(7-6), [CI](2-1) and continuum of three high-z lensed dusty star-forming galaxies using ALMA

Gayathri Gururajan (LAM, Aix-Marseille University)

High-redshift dusty star-forming galaxies with very high star formation rates (500 - 3000 Msun/yr) are key to understanding the formation of the most extreme galaxies in the early Universe. Characterising the gas reservoir of these systems can reveal the driving factor behind the high star formation. Using molecular gas tracers like high-J CO lines, neutral carbon lines and the dust continuum, we can estimate the gas density and radiation field intensity in their interstellar medium. We present high resolution observations of CO(7-6), [CI](2-1) and dust continuum of 3 lensed galaxies from the SPT-SMG sample at $z \sim 3$ with the ALMA. Our sources have high intrinsic star-formation rates (> 850 Msun/yr) and rather short depletion timescales (< 100 Myr). Based on the line and line-to-continuum ratios, our sample galaxies exhibit higher radiation field intensity compared to other SMGs but have similar gas densities. We perform visibility-based lens modelling on these objects to reconstruct the kinematics in the source plane. We find that the cold gas masses of the sources are compatible with simple dynamical mass estimates using ULIRG-like values of the CO-H2 conversion factor alphaCO but not Milky Way-like values. We find diverse source kinematics in our sample: SPT0103-45 and SPT2147-50 are likely rotating disks while SPT2357-51 is a probable major merger. The analysis presented in the paper could be extended to a larger sample to determine better statistics of morphologies and interstellar medium properties of high-z dusty star-forming galaxies.

RXC-J2014.8-2430, the strongest cool core galaxy cluster in REXCESS:How the hot intracluster medium affects the cold molecular gas in and around the brightest cluster galaxy

Joshiwa van Marrewijk (ESO)

ALMA has the unique capabilities to simultaneously observe the cold gas and hot thermalized intracluster medium (ICM) in distant galaxy clusters. The cold gas in distant galaxies is extensively studied with ALMA mainly through low-J CO and [CII] spectral line transitions, while the lesser-studied hot ICM can also be observed through the Sunyaev-Zeldovich (SZ) effect. With ALMA having access to both media, one can directly study their interaction which is crucial in understanding the multifaceted processes that drive galaxy evolution. In this study, we show via ALMA and ACA Band 3 CO(1-0) and SZ observations how bulk motions of the hot ICM within the cluster potential disturb the distribution of the molecular gas in and around the brightest cluster galaxy (BCG). With the CO(1-0) observations, we find filamentary structures around the core of the BCG. We estimate the free-fall time of the molecular gas in these filaments and find that the free-fall velocity of the molecular filaments matches the bulk velocities and orientation of the ICM. This case study indicates that the ICM as an environment for galaxies plays a strong role in determining the fate of the cold gas and by extension, star-formation. With ALMA, we can thus further explore how the ICM shapes the evolution of star-formation through SZ-observations and thus add another piece to solve the galaxy-evolution puzzle.

How well can we determine the kinematics of high-z galaxies?

Madeleine Yttergren (Department of Space, Earth and Environment, Chalmers University of Technology, Gothenburg, Sweden)

A significant portion of the star formation activity in the early Universe was heavily enshrouded in dust. Understanding the nature of this dusty star formation is required for understanding galaxy evolution through cosmic time, but it has so far been a challenge. ALMA is playing a crucial role in revealing the structure and processes in these distant galaxies. The resolution and sensitivity of ALMA allows us to see more details in distant galaxies than ever seen before, but the interpretation of their kinematics is uncertain.

ALMA has the capacity to reveal structures that show similarities to rotating disks and outflows, but can we with the spatial resolution available separate outflow from rotation, from a merger? In this talk I will discuss how ALMA has affected our relationship to distant galaxies and what limitations in particular spatial resolution pose on our kinematical studies. I will present a selection of kinematical studies and publicly available tools from the community to illustrate the current state of the field. I will discuss important considerations that have to kept in mind when studying high-z kinematics. And finally I will present our new project. A project that uses a combination of simulation and modelling tools to explore the limitations of the data and the abilities of the kinematical tools. Through this project we aim to answer the question of how well we can determine the kinematics of high-z galaxies. The project is new and ongoing, I will describe the outline and current state of the project and invite to further discussions and collaborations on the topic.

Rivers in the sky: streamers discovered towards two Class I sources in Perseus

Maria Teresa Valdivia Mena (Max Planck Institute for Extraterrestrial Physics)

Stars and planets are not born in isolation: the interaction with their surrounding medium drives their evolution. In the last few years, there has been a recent rise in the discovery of streamers, which are thin and long gas structures (on the order of 1000-10000 au and possibly longer) that feed the protostellar disk and/or pseudodisk region with material from outside their natal core. Streamers have been found in multiple phases of star formation, from Class 0 phase (protostars deeply embedded in the core) to the Class II phase (unveiled protostar and protoplanetary disk). These new observations go against the classical picture of star formation, where infall into the protostar and protoplanetary disk is azimuthally symmetric and relatively isolated from external influences. It is still unclear if (or how) these streamers connect the large scale filaments and fibers to the small scale protostellar disks. In this talk, I will present results of interferometric observations (ALMA and NOEMA) of 2 Class I objects in the Perseus Molecular Cloud to follow the flow of material from scales > 20000 au (~ 0.1 pc), down to the disk scales (~ 100 au). We study several molecular line transitions to map the gas kinematics using different molecular tracers. It is only thanks to this combination of several tracers that enables for a better understanding of the mass delivery process to disk scales.

Unveiling nascent stars with sulfur-bearing molecules

Tanya Kushwahaa ()

Sulfur depletion on its way from the diffuse interstellar medium to the cold dense, star-forming clouds is a long-standing problem. Despite its astrochemical relevance, its abundance and main repository in the dense clouds is still unknown. By observing the emission from molecules around infant stars we can better understand how they are made, what the physical conditions around them are, and what the composition of star and planet-forming material is. We derived H2S/OCS ratio for several low-mass stars which can be used as a tracer of the temperature of the birth cloud of these protostars and provide crucial information about the physical and chemical conditions around the birth cloud of these Solar-like stars. Such a chemical thermometer will show if the cloud is initially cold or warm and might help us in determining the unknown form of sulfur in their birth clouds. We used Atacama Large Millimeter/submillimeter Array (ALMA) Atacama Compact Arrays (ACA) Band 6, 7m dish observations to detect emissions from H2S and OCS and their isotopologues in two samples of Class 0/I protostars. By looking at the emission lines of these two molecules and their isotopologues, we analyzed the spatial distribution of these two molecules and derived their abundances by fitting synthetic spectra for the detected species using an LTE model. The H2S and OCS abundances in the sources vary by five orders of magnitude. H2S/OCS is found in the range 0.59-9.17, with IRAS 16293A having the lowest ratio and BHR71, the highest ratio. The ratio depends significantly on the environment of the cloud and the amount of photo-irradiation received prior to the formation of protostar. Sources such as IRAS 16293A, SMM3, IRAS 4B might have been exposed to more photo-irradiation or cosmic rays which resulted in greater conversion of H2S to OCS and hence, a lower H2S/OCS ratio while lesser photo-irradiation of H2S and isolation in BHR71 may have led to a higher H2S/OCS ratio.

Optical analysis of the ALMA Band 9 Front End for a possible upgrade

Sabrina Realini (University of Groningen)

The ALMA Band 9 (600720 GHz) receiver is a dual channel heterodyne system capable of detecting orthogonally polarized signals using a wire grid and a compact arrangement of mirrors. The existing receivers show a cross-polar level greater than -20 dB and a relatively large beam squint. By means of physical optics simulations, we analyze the possibility of improving cross-polarization performance by removing the grid and using an OMT to separate orthogonal polarizations. We also investigate the causes of the scatter in the beam squint, like tolerances of the grid mounting and aberrations in the current optics.

Chemical Substructures in Protoplanetary Disks: Results from the MAPS ALMA Large Program

Charles Law (Harvard University)

Planets form and obtain their compositions in dust- and gas-rich disks around young stars. Dust substructure at the 1-10 au scale is commonplace in these disks, but far fewer observations have probed gas substructure at similar scales. To address this, I will present results from the Molecules with

ALMA at Planet-forming Scales (MAPS) Large Program, which explores radial and vertical chemical structures at 10 au scales in five disks where dust substructure is detected and planet formation appears to be ongoing. The MAPS observations reveal a striking diversity in the radial morphologies of molecular line emission in protoplanetary disks. Chemical substructures are ubiquitous and extremely varied with a wide range of radial locations, widths, and depths. Here, I will discuss the implications of these findings in the context of interactions between gas and dust substructures, the volatile and organic compositions of incipient planets, and the general utility of using line emission substructures as probes of disk physical characteristics.

Formaldehyde deuteration in the VLA1623-2617 protostellar cluster with ALMA

Seyma Mercimek (INAF Arcetri Observatory, University of Florence, Institute Radio Astronomie Millimétrique (IRAM))

Understanding how molecular complexity evolves in Sun-like star-forming regions is mandatory to comprehend whether the chemical composition of the protostellar stages is inherited by protoplanetary disks and planets. Molecular deuterium enrichment occurs in cold environments, such as prestellar cores, therefore, high D/H values in comets are believed to be a ""fossil"" record of the early phases of our Sun. Following a single-dish study on deuterated formaldehyde in a sample of Class I protostellar sources suggests that the D/H values are inherited from the pre-stellar phase (Mercimek+2022). The follow-up work is to test this scenario with interferometric data since we need high angular resolution to measure deuteration on Solar System scales in the different components, i.e. the accretion streamers, the outflow, the envelope, and the disk. We present H2CO, HDCO, and D2CO emission at 50 au resolution obtained in the framework of the FAUST (Fifty AU Study of the chemistry in the disk/envelope systems of Solar-like protostars) ALMA Large Program towards an embedded protostellar cluster, VLA1623-2417, which consists of the close binary A1+A2, source B, and source W with the present data. The lines probe several components of the protostellar cluster: The extended envelope (traced by low-velocity H2CO and HDCO emission), an X-shaped outflow cavity associated with the binary A1+A2 (detected also in D2CO), the accretion streamers (detected in H2CO and HDCO), and the rotating disk/inner envelope (seen at high-velocities towards both Source A1+A2, Source B, and Source W). We will compare the H2CO deuteration measured in these components. More specifically, the detected lines will allow us to estimate for the first time the deuterium fractionation in the Class 0 and I sources of the protostellar cluster at the disk scale ($\sim$ 50 au) and to compare the obtained D/H with estimates at earlier prestellar phases as well as in comets.

Morpho-kinematics around cool evolved stars: unveiling the underlying companions

Ileyk El Mellah (IPAG - CNRS)

Stellar multiplicity has been recognized as a ubiquitous feature: stars seldom live an effectively single life. In the late stellar evolutionary stages, mass loss plays a major role. Interaction with an orbiting companion too dim to be directly detected can leave remarkable imprints in the wind up to distances much larger than the orbital separation. Thanks to its high spatial and spectral resolution, ALMA has shed unprecedented light on the complexity of the physico-chemistry at work in the circumbinary envelope around cool evolved stars like red and asymptotic giant branch stars.

In this talk, I will present simulations of dust-driven winds from cool evolved stars in a binary system. We designed 3D numerical setup to solve the wind dynamics beyond the dust condensation radius and follow the flow up to several hundreds of stellar radii. Non-uniform grids enable us to capture small scale features such as shocks and disks forming around the orbiting object. We reproduced typical non-spherical features such as arcs, spirals, petals and orbital density enhancements, and identified patterns associated to eccentric orbits. I will show how synthetic multi-channel molecular line emission maps can be obtained from these simulations for different orbital inclinations, to be compared to ALMA observations. These results suggest that we can set constrains on the mass and orbital properties of the companion from the morpho-kinematics of the circumbinary envelope.

Unveiling the nature of 11 DSFGs @ $z \sim 2$: the crucial role of spatially-resolved ALMA images

Lara Pantoni (CEA Paris-Saclay)

The build-up of massive galaxies across cosmic time constitutes one of the main issues of modern astrophysics. In this talk (based on Pantoni et al. 2021b, 2021MNRAS.507.3998P), I will present a pilot study on a sample of 11 spectroscopically-confirmed Dusty Star Forming Galaxies at the peak of Cosmic Star Formation History ($z \sim 2$), thought to be the star-forming progenitors of massive quiescent galaxies at $z < 1$. The galaxies are selected from (sub-)millimetre surveys with ALMA, APEX and LABOCA, in the Great Observatories Origins Survey South (GOODS-S; Dickinson & GOODS Legacy Team 2001; Giavalisco et al. 2004) field and their panchromatic spectral energy distribution (from the radio band to the X-rays) was extensively studied in Pantoni et al. (2021a, 2021MNRAS.504..928P).
I will focus in particular on the crucial role of ALMA spatially-resolved continuum maps and data cubes to gain a better insight on the processes that lead massive dusty galaxy evolution, e.g. gas condensation, star formation, AGN feedback and interactions with galaxy environment. In Pantoni et al. (2021b, 2021MNRAS.507.3998P), we succeed in addressing these issues by using ALMA Science Archive products at the highest resolution currently available (< 1 arcsec or comparable), through the analysis of our galaxy millimetre continuum maps and CO spectral line emission.
Even if, thanks to ALMA, we have been able to look into these galaxies in greater details, I will finally stress the need of images at higher resolution, both in space and frequency, to definitely constrain the evolution of high-z DSFGs.

Uncovering the physics of star formation in the Epoch of Reionization with [CII] 158 m and [OIII] 88 m

Joris Witstok (Kavli Institute for Cosmology, University of Cambridge)

Recent ALMA detections of the [C II] 158 m and [O III] 88 m emission lines allow some of the first explorations of the interstellar medium in the early Universe. In this talk, I will present new [O III] observations of four bright 7 Lyman-break galaxies spectroscopically confirmed by ALMA through the [C II] line, unlike recent [O III] detections where Ly was used. This nearly doubles the sample of EoR galaxies with robust [C II] and [O III] detections. We present a multi-wavelength comparison with new deep HST images of the rest-frame UV, whose compact morphology aligns well with [O III] tracing diffuse ionized gas as opposed to the more spatially extended [C II] emission mainly produced in neutral gas. This suggests we are witnessing intense star formation which locally shows extreme [O III]/[C II] ratios indicative of leaking ionizing radiation. Other regions might be more metal-enriched and obscured by dust, as indicated by the dust continuum. Probing the continuum at two wavelengths furthermore allows us to constrain key dust properties such as its temperature and yield, both largely unknown for high-redshift galaxies. One source appears to require surprisingly cold dust which, if confirmed, would have important implications for the formation mechanisms of dust.

PHANGS-ALMA: Vertical Scale Height of the Molecular ISM in Nearby Disk Galaxies

Jiayi Sun (McMaster University)

I will present my latest research based on PHANGS-ALMA, an ALMA large program providing wide-field, arcsecond resolution CO(2-1) imaging data for ~ 90 nearby galaxies. Utilizing CO kinematics on individual molecular cloud scales, we estimate the vertical scale height of the molecular gas disk from cloud-to-cloud velocity dispersion assuming hydrostatic equilibrium. We show that this novel method yields more accurate measurements of the scale height compared to existing methods that use kpc-scale observations. Our new measurements have broad implications on the 3D gas distribution, volumetric star formation laws, and turbulence driving mechanisms in nearby disk galaxies. If time permits, I will also showcase Cycle 8 ALMA observations of a nearby ringed galaxy at ~ 5 pc resolution, which offer an unprecedented view of the molecular gas reservoir feeding forming young massive clusters and the central supermassive black hole.

Gas Kinematics around the High-Mass Prestellar Core Candidate G11.92-0.61 MM2

Suinan Zhang (University of St Andrews)

We report deep ALMA observations towards the high-mass prestellar core candidate G11.92-0.61 MM2. Located in the G11.92-0.61 protocluster, MM2 is a strong, compact dust continuum source that shows no molecular line emission or other star formation indicators in SMA and VLA observations. Our ALMA observations, targeting H2D+ (11 , 0 - 11 , 1) and N2H+ (4-3), were designed to trace dense and depleted gas, to test whether MM2's unusual properties were due to extreme physical conditions such as low temperature and high density. In the ALMA images, extensive N2H+ emission is detected around MM2 with a 0.54" beam (1800 AU), while H2D+ is undetected at an rms noise level of 2.7 mJy/beam (Tb 0.06 K) with a resolution of 0.65". The morphology of the N2H+ emission differs markedly from that of the 0.8 mm continuum, with a clear offset between the peak of the integrated N2H+ emission and the continuum peak. The N2H+ spectra are complex, due to a combination of the hyperfine structure of the transition and multiple velocity components within the cloud. To analyze the kinematics of the gas surrounding MM2, we apply Gaussian decomposition to the N2H+ spectrum at each pixel using SCOUSEPY (Henshaw et al. 2016a) and then conduct hierarchical clustering of the extracted velocity components using ACORNS (Agglomerative Clustering for Organising Nested Structures, Henshaw et al. 2019). We find that eight velocity- and position-coherent sub-structures in the N2H+-emitting gas describe $> 60\%$ of the fitted velocity components. These sub-structures contain smaller-scale structures and display velocity gradients. The kinematics and hierarchically structured composition of the clouds appear consistent with the superposition of multiple gas streams in the hub of a hub-filament system.

ALMA and Spectroscopic Inversions: What Can We Learn?

Ryan Hofmann (NSO / CU Boulder)

Studies of the thermal structure of the solar chromosphere are typically hampered by the complexities of non-LTE radiative transfer. This issue can be addressed using observations of the millimeter continuum, which directly probes the electron temperatures in the chromosphere. In recent years, the Atacama Large Millimeter/submillimeter Array (ALMA) has made it possible, for the first time, to obtain millimeter observations of sufficient spatial resolution to supplement spectral line observations and inversions. Here, we present observations of a plage in the 3.0 mm and 1.2 mm continua with ~ 2 arcsecond resolution, combined with simultaneous imaging spectroscopy observations from the Interferometric Bidimensional Spectrometer (IBIS) at the Dunn Solar Telescope. We compare the observed ALMA brightness temperatures with temperatures inferred from spectroscopic inversions using the Na D1 5896 and Ca II 8542 lines, and investigate the wide range of physical heights probed by the millimeter continuum. In addition, we examine the effects of including ALMA data in the inversions. We find that the millimeter emission arises from a range of heights both above and below the chromospheric calcium line, depending on the local temperature profile and electron densities. Furthermore, we identify several problems that arise from the technical limitations of hydrostatic 1.5-D inversion codes, particularly when inverting mm-continuum and spectroscopic diagnostics with similar heights of formation, such as ALMA Band 6 and the Ca II infrared triplet.

Survival of ALMA rings in the absence of pressure maxima

Haochang Jiang (Tsinghua University)

Recent ALMA observations have revealed that a large fraction of protoplanetary discs contain bright rings at (sub)millimetre wavelengths. Dust trapping induced by pressure maxima in the gas disc is a popular explanation for these rings. However, it is unclear whether such pressure bumps can survive for evolutionary time-scales of the disc. In this work, we investigate an alternative scenario, which involves only dust-gas interactions in a smooth gas disc. We postulate that ALMA rings are a manifestation of a dense, clumpy mid-plane that is actively forming planetesimals. The clumpy medium itself hardly experiences radial drift, but clumps lose mass by disintegration and vertical transport and planetesimal formation. Starting from a seed ring, we numerically solve the transport equations to investigate the ring's survival. In general, rings move outwards due to diffusion of the clump component. Without pressure support, rings leak material at rates$\sim$ 40 ME Myr^{-1} and in order for rings to survive, they must feed from an external mass reservoir of pebbles. In the case where the pebble size is constant in the disc, a cycle between ring formation and dispersion emerges. Rings produce large quantities of planetesimals, which could be material for planet formation and explain the massive budget inferred debris disc. Mock images of ALMA observations compare well to the rings of Elias 24 and AS 209 from DSHARP's sample.

ALMA variability study in YSOs: First systematic search for millimeter flares in protostars

Jaime Vargas González (University of Hertfordshire)

Here I present a radio variability study in protostars as part of a larger project aimed to better understand the high-energy processes at the earliest stages of protostellar evolution. Following the results of our systematic search for intense centimeter radio flares over a large sample of YSOs and motivated by the few available examples of strong millimeter flares, we have conducted a systematic search for such variability in the Orion Nebula Cluster (ONC) using ALMA. Radio variability in protostars at these wavelengths is associated with nonthermal (gyro-)synchrotron emission from magnetospheric activity and thus, together with thermal X-ray emission from heated plasma, probes the high-energy processes in YSOs, differing from mm-variability associated with mass accretion events which has an impact on longer timescales. In the former case, electrons at higher energies (MeV) are responsible for synchrotron radiation into the millimeter range. Our ALMA variability study in the ONC sets the first systematic constraints on the occurrence of such events in a large YSO sample, finding a wide range of variability up to a factor of ~ 5 on timescales of hours to days. Finally, in order to quantify systematic effects, we made use of simulated ALMA observations and find an upper limit for spurious variability of up to a factor of ~ 2. The main factor for these systematic effects comes from the constantly changing shape of the synthesized beam and its impact on flux measurements of resolved sources together with the effects of a complex background in regions such as the ONC.

The ALMA (sub-)kpc scale view of local radio galaxies

Ilaria Ruffa (Cardiff University)

The unprecedented resolution and sensitivity provided by ALMA have opened up a new era in the study of active galactic nuclei (AGN) at low redshifts ($z < 0.1$). The level of detail at which nearby AGN can be observed indeed enabled us to resolve the key scales over which nuclear feeding and energetic outputs operate, uncovering a number of physical phenomena (e.g. nuclear bars, massive cold gas inflows/outflows) and providing clear evidence of a connection between the AGN fuelling/feedback processes and their host galaxy evolution. In this talk, I will present the results obtained by analysing multi-wavelength, high-resolution ALMA observations of a small but complete sample of nearby low excitation radio galaxies (LERGs), which are a class of AGN accreting gas at low rates ($<< 1\%$ of the Eddington limit) and producing almost entirely kinetic (i.e. jet-induced) feedback. I will show how the obtained results provide important constraints on the details of jetcold gas interactions, fuelling and feedback processes in these systems. I will then particularly focus on ALMA observations of multiple molecular gas tracers in one sample source, NGC 3100, clearly demonstrating jet-induced modifications in the physics and kinematics of the molecular gas on sub-kpc scales. Finally, I will also highlight the crucial synergy with high resolution radio continuum, neutral hydrogen, optical and X-ray observations to understand the origin of the observed cold gas reservoirs and ultimately get a comprehensive view of the mechanisms regulating the life-cycle of LERGs.

High resolution ALMA study of CO(2-1) line and dust continuum emissions from cluster galaxies at $z = 1.46$

Ryota Ikeda (NAOJ)

How did massive elliptical galaxies in nearby clusters form their structure is still an open question. To shed a light on this problem, it is crucial to probe the star formation of high-z cluster galaxies around the peak of cosmic star formation. We present a result of spatially resolved CO(2-1) line observations of cluster galaxies in XCS J2215 at $z = 1.46$. Our sample comprises 17 galaxies at the cluster core, all of which have been detected in CO(2-1) previously in lower resolution. For nine galaxies, the effective radius of both CO(2-1) line (~ 0.4" resolution) and 870 m dust continuum (~ 0.2 resolution) emissions are robustly measured by modeling visibilities. We find that CO(2-1) line emission in all of the galaxies is more extended than dust continuum emission by factors of ~ 2. We also investigate the spatially resolved Kennicutt-Schmidt relation and reveal that the inner region of galaxies tends to have higher star formation efficiency (SFE) compared to the extended region. Overall, our result indicates that star formation is concentrated and enhanced at the central part of the galaxies, supposedly resulting in the formation of a bulge structure. Furthermore, we notice the consistency between the stellar radius of passive members and the dust radius of our galaxies, and discuss our galaxies will likely turn into passive members within 1 Gyr. Finally, we do not find any difference between galaxies with close companions and without them.