MAYA 2023

Meeting for ALMA Young Astronomers

SOC

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List of Abstracts

Surfing long waves to discover old dusty treasures on unexplored SHORES

Meriem Behiri

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Most studies on dust-obscured galaxies at high redshift have been conducted in the sub-millimetre, possibly affected by dust temperature biases. An approach complementary to this is using a radio selection, as Talia et al., 2021 and Behiri et al., submitted. In the COSMOS field, taking advantage of the panchromatic coverage, Talia et al., 2021 and Behiri et al., submitted, show the efficiency of this method at selecting galaxies obscured in the NIR bands, namely the Radio Selected NIR-dark galaxies (RS-NIRdark). Moreover, thanks to the ALMA data from the A3COSMOS catalogue, they can substantially improve SED-fitting results, particularly the dust properties. On this path, we will introduce a newborn radio serendipitous survey of 15 deg^2 in the H-ATLAS field, SHORES. We have recently targeted a patch of this wide area with ATCA up to 20 GHz. Moreover, SHORES is rich in ancillary data from Herschel, Spitzer and ALMA. In this talk, we will discuss the possibilities for galaxy population selection and SED reconstruction, the perspectives offered by ALMA archives, and the follow-up of our detected sources.

A rich population of young high-mass proto-stars unveiled by the emission of complex organic molecules detected with ALMA-IMF

Mélisse Bonfand

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The detailed processes involved in the formation of high-mass stars have been long-standing issues in astrophysics. The new capabilities of state-of-the art radio-interferometers have recently opened a new window on the study of high-mass star-forming sites, which have become prime targets of large observing programs. The high-sensitivity wide-bandwidth observations delivered by ALMA, coupled with wide field mosaic mapping, give access to a large population of dense clumps, of which we are able to probe the structure and the chemical content, over scales from clouds to individual proto-stellar envelopes.

The ALMA-IMF observing program targets 15 of the most massive star-forming regions in the Galaxy. The observational data give access to the innermost part of high-mass star-forming sites that contains hundreds of compact cores, providing an instantaneous view on Galactic star formation, at different scales and different evolutionary stages. The systematic and deep analysis of the dataset reveals a striking diversity among the investigated star-forming regions, as well as within each region, where cores show completely different spectral features. While some cores show an extremely rich chemical content, other nearby sources are poor or devoid of any molecular lines, such that chemistry plays here a key role in diagnosing physical properties and their evolution. Based on the emission that arises from complex organic molecules we built an unprecedented catalog of more than 50 hot cores, that contributes to enhance the number of candidates of known high-mass star progenitors. From this catalog, we perform life-time estimates by comparing the hot core candidates with the list of pre- and proto-stellar sources identified based on the thermal dust continuum emission.

Complex S-bearing molecules towards high-mass star forming regions

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During the process of star formation, the molecular gas undergoes significant chemical evolution with the emergence of dense cores, harboring hot cores and hot corinos, rich in complex organic molecules (COMs). The formation pathways, even for simple molecules, are still debated. In particular, recent detections of sulfuretted ions and long carbon chains are raising new questions on the missing sulfur mystery and the lack of robust candidates for the sulfur reservoir towards star-forming regions. The ALMA-IMF large program offers a unique opportunity to study the complex S-bearing species: CH3SH and C2H5SH towards high-mass star forming regions. Thanks to the sensitivity and resolution of ALMA-IMF, we were able to resolve the emission. We will present our results on the excitation conditions of these molecules and pin down their physical origin in the envelope surrounding the protostars. Finally, we will show a comparison between the emission of O-bearing and S-bearing COMs in the sample.

Sulphur-bearing species in NGC 253: What do they trace?

Mathilde Bouvier

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Sulphur-bearing (S-bearing) species are known to be highly reactive in the gas phase of the interstellar medium. Their abundance depends greatly on the thermal and kinetic properties of the gas (Viti et al. 2004), which makes S-bearing species extremely useful in the reconstruction of both the chemical history and dynamics of the studied objects. Various processes can participate to increase the abundance of these species in the gas phase, such as (i) thermal evaporation and (ii) sputtering and/or shattering of dust grains in shocked regions. As a consequence, in our Galaxy, S-bearing species are relatively ubiquitous and are detected in various environments, from diffuse clouds to star-forming regions.

What do S-bearing species trace in nearby external galaxies? What is their sulphur budget? Do the processes dominating the release of S-bearing species into the gas phase depends on the type of galaxy? Thanks to the advent of powerful interferometers such as ALMA, it has now become possible to address such questions by performing molecular line surveys of nearby galaxies with a resolution down to scales of Giant Molecular Clouds (GMCs; i.e. tens of pc). In particular, the ALMA Comprehensive High-resolution Extragalactic Molecular Inventory (ALCHEMI) is the first ALMA large programme which provides a most complete unbiased molecular survey towards the nuclear region of the starburst galaxy NGC 253 (Martín et al. 2021), at an unprecedented angular resolution of 1.6” ($\sim$27pc).

Within the ALCHEMI frame, we investigated the region of emission of H2S, CS, SO, SO2, CCS, H2CS and OCS towards the centre of NGC 153 with the aim of understanding their region of emission and, hence, the main processes at play in this region. We detected several transitions for each species which allowed us to perform a first radiative transfer analysis assuming LTE. I will present these first results and show why non-LTE analysis is mandatory to pursue this work.

Can Molecular Ratios be used as Diagnostics of AGN and Starburst activity? The Case of NGC 1068.

Joshua Butterworth

Affiliation: Leiden Observatory

The Interstellar Medium (ISM) of gas and dust present with galaxies is not consistent on universal scale. As a result of the extreme activities of particular regions such as Active Galactic Nuclei (AGN) and Starburst (SB) regions the ISM may be greatly disrupted and altered (Bayet et al. (2009), Watanabe et al. (2014)). These regions and their effects on the ISM have been observed at a galactic scale (∼kiloparsecs), but also with the availability of interferometric instruments, such as ALMA, observations of these variances in the ISM at a scale of dozens of parsecs within external galaxies have been observed across many molecular species and transitions (Scourfield et al. (2020)). Molecular line ratio diagnostics are often used to investigate the physics and chemistry of the ISM. For example, as the gas chemistry located in the central/nuclear regions of galaxies is believed to be dominated by X-rays emitted from the AGN, this greatly affects the conditions of the ISM in the surrounding regions, especially compared to regions located in starbursts (Usero et al. (2004), Garcia-Burillo et al. (2010)). Hence, line ratios of specific molecules have been proposed as indicators of certain energetic or physical processes e.g. HCN/HCO+ as a tracer of AGNs; HCN/HNC as a 'thermometer', HCN/CO as a density tracer (Loenen et al (2007), Leroy et al. (2017), Hacar et al. (2020)).

In order to investigate these molecular line ratio diagnostics we have performed a global investigation into the use of molecular line ratios as tracers particularly of AGN versus SB activity. As a Seyfert 2 barred spiral galaxy that contains significant SB activity within a prominent SB ring, NGC 1068 is the perfect source to be used a 'laboratory' for a study of this kind. Making use of radiative transfer modelling we are able to both delve into the respective properties of these regions as well as testing the reliability of the ratios themselves.

ALMA multi-band, multi-scale dust study of L1527: evidence for (sub-)millimeter dust grains in the envelope of a Class I YSO

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Protoplanetary discs around both young (class 0/I) and more evolved (class II) stars display substructures thought to be carved, among other effects, by planets. Late-stage discs, though, seem to show a lack of solid mass when compared to the known exoplanet population, as opposed to their younger counterparts. This deficit could be explained by the early conversion of small dust grains into large, undetectable planetesimals at Class 0 and I stages of stellar and disc formation. A potential early grain growth in protostellar envelopes in-falling on young discs has been suggested in recent studies, supporting the idea that solids start to agglomerate already during the Class 0/I phase. We aim to indirectly determine the maximum dust grain size in the envelope of the Class 0/I source L1527, located in the Taurus star-forming region (140 pc). Probing grain sizes in the envelopes of such young objects is an ongoing quest, the findings of which might ultimately set the initial conditions of planetesimals formation. Using ALMA and ACA observations in four bands and extending the spatial range of previous studies, we place tight constraints on the spectral and dust emissivity indices in the 70-2000 AU radial scales range. We find alpha$\sim$2.7 at all envelope scales. The dust emissivity index (0.8 ¡ beta ¡ 1.6) shows a positive outwards gradient consistent with ISM-like grains at 2000 AU and with the presence of (sub-)millimeter-sized dust grains in the inner envelope. These findings are discussed against possible caveats such as the assumed temperature profile of the envelope and the effects of chemical and physical composition of the dust. The low betas suggest that either (sub-)millimeter grains have already grown at large (10^2 AU) scales in the envelope of L1527, or they have been transported from the disc to the envelope, perhaps by its outflow, recently beautifully imaged by JWST.

Hunting for galaxy proto-clusters

Jianhang Chen

Affiliation: ESO

Distant proto-clusters of galaxies, prior to virialisation, remain a poorly understood phase of structure and galaxy formation. Proto-clusters were largely found by over-densities of Lyman-break galaxies (LBGs), Lyα emitters (LAEs), giant Lyα blobs and in the vicinities of radio galaxies and QSOs. The rare proto-cluster cores, with vigorous star formation ($>$ 6000Msun/yr and more than ten times denser than the field only began to emerge via the advent of large surveys with submm/mm telescopes. However, we still have a small number of confirmed proto-cluster cores, which prevents us from studying their origin and evolution statistically. Luckily, we are now making rapid progress in confirming proto-cluster cores spectroscopically. From our snapshot survey of the 3,083 reddest objects from the Herschel-ATLAS survey, we have collected 12 proto-cluster core candidates with multiplicity larger than three and photometric redshifts higher than 3. Then, subsequent ALMA band-3 spectral scans have recently confirmed four new proto-cluster cores. Our survey is one of the first systematic surveys for proto-cluster cores at z $>$ 3. I will also show their multiple galaxy populations with multi-wavelength observations.

2.1 GHz SHORES survey: Exploiting the synergy between ALMA archive and deep radio observations

Quirino D'Amato

Affiliation: Scuola Internazionale di Studi Superiori Avanzati (SISSA)

I will report on a large ($\sim$15 deg^2) and deep ($\lesssim$ 20 uJy at 5 sigma) survey of 30 fields carried with the ATCA in the H-ATLAS SGP area at 2.1 GHz. Each field is centered around a candidate submm-selected lensed galaxy (some of which are confirmed); as such, they feature high-resolution ALMA observations covering their innermost region, i.e. the most sensitive part of the survey. We expect to detect $\sim$12500 objects, $\sim$8850 of which ar RQ-AGN, SFGs or possibly a combination of the two. Thanks to the exceptional (both spectroscopic and photometric) multi-wavelength coverage of the H-ATLAS field, we will derive the basic quantities of the sources and investigate the relation between the SF and AGN activity in the framework of several evolutionary scenarios and in a large range of redshift. In the innermost and most sensitive part of the survey we expect to detect $\sim$100 distant (z $\gtrsim$ 1.5) SFGs, some of which are predicted to be UV/near-IR dark objects. These elusive sources are thought to provide a major contribution to the overall SFRD, but the obscuration at UV/Optical bands poses a serious challenge to their detection and investigation. In this respect, ALMA bands benefit from the negative K-correction of the dust thermal emission and represent the ideal wavelength at which detect and characterized the ISM of these objects. However, the small FOV at (sub)mm wavelength generally prevents the building of large surveys in a feasible amount of time. Thanks to the synergy between the ATCA and Optical/IR observations of HATLAS field, we can select high-z dark candidates and search for their counterparts in already existing ALMA data available in the archive, opening a new window on the study of obscured SFGs in the early Universe.

EP Aquarii: a new picture of its circumstellar envelope

Hoai DO

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New analyses of earlier ALMA observations of oxygen-rich AGB star EP Aquarii are presented, which contribute major progress to our understanding of the morpho-kinematics of the circumstellar envelope (CSE). The birth of the equatorial density enhancement (EDE) is shown to occur very close to the star, where the relative abundance of CO molecules with respect to SiO molecules is much higher than farther away. High Doppler velocity wings are seen to consist of two components, the front end of the global wind, reaching above ±12 km/s, and an effective line broadening, confined within 200 mas from the centre of the star, reaching above ±20 km/s and interpreted as caused by the pattern of shock waves resulting from the interaction between stellar pulsation and convective cell granulation. Close to the star, episodic and lumpy mass ejections are observed, and their interaction with the gas of the slowly expanding EDE is seen to play an important role in the development of the wind and the evolution of its radial velocity from 8-10 km/s on the polar symmetry axis to ∼2 km/s at the equator. It implies a very complex morpho-kinematics, which prevents making reliable interpretations with reasonable confidence. In particular, it sheds serious doubts on an earlier interpretation implying the presence of a white dwarf companion orbiting the star at an angular distance of ∼0.4 arcsec from its centre and currently west of it.

Reveal the chemical history of young protostars at low frequency

Marta De Simone

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The early stages of the formation of a planetary system are represented by Solar-type protostars. Recent research suggests planet formation may begin already at these stages. Thus, the chemical content of protostars can be directly linked to what future forming planets can inherit. However, protostars are far to be fully chemically characterized. Indeed, among various protostars, a chemical diversity in their millimeter spectra has been observed and it is not well understood yet. The gaseous chemical content of protostars depends on the composition of the icy dust grain mantles formed before the collapse begins. Directly measuring the ice mantle composition in these embedded objects is challenging, but it can be inferred indirectly by observing the ice major species once they are release into the gas phase during the warm protostellar stage.

In this contribution, I will show the results from our VLA high spatial resolution (∼300 au) observations of NH3 and CH3OH (critical ice mantle tracers). By comparing the NH3/CH3OH ratio with up-to-date astrochemical models, we were able to retrieve the chemical and dynamical history of the NGC1333 IRAS 4 protostars. The three protostars share the same history, characterized by a rapid collapse triggered by a brutal external event, which set the observed chemistry. These findings highlight the crucial role of low frequency observations in retrieving i) the dust contribution in absorbing the molecular emission, ii) the protostellar ice mantle history, and iii) the dynamics of the protostars' birth environment.

In this context, the upcoming ALMA Band 1 receiver (35-50 GHz) enables the observation of several complex species, with lower abundances than CH3OH, in a wavelength regime where the dust absorption is minimized. With its bandwidth and the high spectral and spatial resolution, it allows exploring a wide range of energy regimes at small angular scales (< 50 au) fully sampling the planet-forming protostellar region.

3D Modelling of the Mysterious Long Secondary Period of Evolved Stars Under a Binary Hypothesis

Davide Dionese

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Periodic light variations are ubiquitous among cool evolved stars, and so are intense stellar winds. Approximately one-third of evolved stars present long period oscillations (LSPs, long secondary periods) of a few 100 to 1,000 days, the origin of which is still debated. Although the light curves rule out a transiting optically thick obscurer, LSPs might be explained by a dusty wake trailing a dim body in orbit around the cool evolved star: in this scenario, the gravitational pull of this undetected companion focuses the stellar wind in its vicinity which forms an overdense tail where dust condensation is enhanced. Given its dimension and properties, the dust wake could scatter a significant amount of stellar light and be imaged with ALMA.

In this talk, I will present 3D hydrodynamical simulations of stellar wind deflection induced by a companion orbiting around a cool evolved star. We identified conditions favorable to the formation of a dense region in the wake of the companion. Based on its density and temperature, we evaluate the amount of dust produced and the typical grain size. We then perform radiative transfer computation to determine the observational signatures of such a cloud and show that it could fall within the grasp of ALMA. The cloud properties bear information on the engulfed object, particularly on its mass and orbital properties. Lastly, I will report on VLT/PIONEER near-infrared observations of a specific system where emission from the dust wake appears, bringing additional momentum to the binary origin of LSPs.

Observing and modelling the gas and dust of the most luminous galaxy known

Román Fernández Aranda

Affiliation: ESO & IA-FORTH

W2246-0526 is a Hot Dust Obscured Galaxy at redshift 4.6, and the most luminous galaxy known to date. It harbors a heavily obscured super-massive black hole that is accreting at or above the Eddington limit. Observations with ALMA of the brightest far-IR fine-structure emission lines as well as of their underlying dust continuum, in combination with a large grid of CLOUDY radiative transfer models, are used to constrain the interstellar medium of the central quasar and its host galaxy. We find that intense X-ray emission is required to reproduce observed emission line ratios.

Modeling the Sunyaev-Zel'dovich effect towards a distant galaxy cluster with the ALMA interferometer

Vanessa Frohn

Affiliation: AIfA (Uni Bonn)

Galaxy clusters have been extensively studied, as their properties offer insights into the evolution and history of structure formation in the Universe. Using the thermal Sunyaev-Zel'dovich (SZ) effect, the electron pressure distribution of a galaxy cluster can be determined, regardless of their redshifts which makes it possible to test structure evolution model by comparing fluxes from known high redshift and low redshift clusters. XMMU J2235.3-2557 is the most massive (M 500=$(4.4\pm1.0)\times10^{14}$ $M_\odot$) galaxy cluster at this high redshift (z=1.393) known to date. Given its high mass, we expect it to have a high electron temperature of 8keV and therefore a high thermal SZ flux.

By modeling the shape of the radio flux from the thermal SZ effect, we aim to characterize the electron pressure distribution of XMMU2235 to compare its characteristics like the core temperature to lower redshift clusters.

In this work, we used Band 3 ($\sim$100 GHz) continuum archival radio data from the Atacama Large Millimeter/sub-millimeter Array (ALMA). We wrote a Markov Chain Monte Carlo (MCMC) which was executed with Common Astronomy Software Applications (CASA) fitting data in the visibility space, tested it with Gaussian and β cluster profiles to then model the generalized Navarro-Frenk-White (GNFW) cluster profile.

We find the preliminary best-fit model parameters to be [P0, c500, γ, α, β] = [9.1$\pm$2.7, 1.17$*$, 0.22$\pm$0.05-0.18, 1.051$*$, 5.4905$*$] (marked($*$)=fixed) for the GNFW profile. This electron pressure profile is characteristic for a non-cool core cluster. These profile values are close to non-cool core clusters at lower redshift compared to the literature, suggesting that the cluster core characteristics are redshift independent and therefore time independent.

Since there are currently about 546 cluster observations in the ALMA Science Archive and our visibility space fitting method showed promising initial results, it could be applied to other massive cluster ALMA observations.

At the Frontiers of Cosmic History: How ALMA and JWST Team Up to Confirm High-Redshift Galaxy Candidates

Giovanni Gandolfi

Affiliation: SISSA

The James Webb Space Telescope's (JWST) ability to observe in the infrared range has pushed the limit of galaxy redshift to greater than 10, and the first data release has led to the discovery of over a hundred candidate galaxies at z > 11. Some of these candidates have been identified as being heavily extinguished and feature mature stellar populations; whereas other candidates, dubbed "blue monsters", are bright and dust-free objects characterized by blue UV slopes, challenging the current theoretical models. However, some of these candidates may also be low-redshift contaminants, making it crucial to confirm their nature. After a state-of-the-art review of these JWST high-redshift galaxies candidates, I will showcase how multi-band ALMA follow-up observations can provide crucial insights on the nature, physical properties, and redshift of such objects. ALMA, with its precise measurements, high resolution, and sensitivity, operating at millimeter and submillimeter wavelengths, is an essential instrument for confirming the redshift and physical properties of these JWST high-z galaxy candidates. Ultimately, I will show how the synergy between ALMA and JWST has the potential to lead to groundbreaking discoveries on the early Universe.

Radio-Selected NIR-Dark galaxies: the ALMA view behind the dust

Fabrizio Gentile

Affiliation: Alma Mater Studiorum - University of Bologna

Since the first (sub)mm observations, it has been clear that the cosmic census of high-z galaxies based on deep optical/NIR surveys is far from complete. The "darkest galaxies", in which significant amounts of dust absorb the stellar emission, are in fact missed by these surveys, even though their contribution to the cosmic Star Formation Rate Density and to the evolution of massive galaxies is thought to be significantly high. Due to their elusive nature - however - most of the studies regarding these extremely obscured sources still rely on low statistics and are potentially biased by cosmic variance. In this talk, I will illustrate the potentialities of a radio selection, paired to the lack of a NIR counterpart, to assemble the largest homogeneous sample of "dark" star-forming galaxies currently known. I will present the Radio-Selected NIR-Dark galaxies collected in the COSMOS field, their properties estimated through SED-fitting and their likely evolutionary path (Gentile 2023a, in prep.). Finally, I will discuss our first results on these sources obtained through a new series of ALMA observations and the future perspectives of this project (Gentile 2023b, in prep.).

ALMA resolves the first Optical/Near Infrared-dark lensing system

Marika Giulietti

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Co-evolutionary models between supermassive black holes and their host galaxies predict that processes in the early stages of galaxy formation, such as nuclear activity and star formation, are strictly related and coordinated in time. Dusty star-forming galaxies (DSFGs) are ideal laboratories to test this in-situ scenario, as they constitute the bulk population at the peak of cosmic star formation and they have been identified as the progenitors of massive quiescent early-type galaxies. Gravitational lensing offers the unique opportunity to access the details of the physical properties, morphology, and interstellar medium content, of these extremely compact and heavily dust-obscured objects which would be otherwise unattainable with the current instrumentation. In this talk, I will present ALMA high-resolution observations of a strongly lensed DSFG at redshift$\sim$3.1 (Giulietti et al., 2022, accepted by ApJ), first discovered in the Gama 12th field of the Herschel-ATLAS survey. ALMA observations confirmed the lensed nature of the object and shed new light on the features of this peculiar lensing system, showcasing a lack of a clear optical/NIR emission for both the lens and the background object. The high-quality ALMA data enabled to fully reconstruct the un-lensed morphology of the background source and resolve the compact ($\sim$500 pc) star-forming region and the gas distribution ($\sim$1 kpc) from the [CII] and CO(8-7) spectral line emissions. Furthermore, the analysis of ALMA-detected water vapor spectral lines revealed the presence of a hot and dense environment, with temperatures $\geq$ 100 K (Perrotta et al., in prep.). The analysis of the Spectral Energy Distribution revealed that the galaxy is a massive, young, and compact Eddington - limited dusty starburst, still growing its stellar mass content. These results are compatible with an object facing a "compaction" stage, as predicted by modern in-situ co-evolutionary models of galaxy formation and evolution.

Modelling molecular gas susceptibility to ram pressure stripping in Virgo cluster galaxies

Celine Greis

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By modelling the ram pressure and gravitational restoring pressure for a sample of 10 galaxies included in both the PHANGS and VERTICO surveys, we were able to estimate how much of a galaxy's molecular gas is susceptible to ram pressure stripping. Where the ram pressure exceeds the restoring pressure, we assume that the gas is susceptible to RPS. Our model uses high resolution CO data from PHANGS and stellar mass distribution maps from VERTICO. We find three galaxies where a significant percentage of the gas is susceptible to ram pressure stripping: NGC4254, NGC4548, and NGC4569. All three galaxies show very different molecular and atomic gas deficits, suggesting a first infall, currently undergoing RPS, and a second infall. Finally, we extend our sample to 50 Virgo cluster galaxies using the 720pc resolution of the VERTICO CO maps. The lower resolution data provide overlapping results with the higher resolution PHANGS CO data. We conclude that the small molecular gas structure is not as central to a galaxy's resistance to RPS as previously thought.

Star formation in the centre of NGC 1808 as observed by ALMA

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We present ALMA observations of free-free emission and hydrogen recombination line emission from NGC 1808, a nearby starburst galaxy. These forms of emission are ideal star formation tracers because they can directly trace photoionizing stars while being unaffected by dust obscuration, making them useful for probing the conditions within the centres of dusty star forming regions and for testing other more commonly used star formation metrics. The star formation rate for the central starburst derived from ALMA star formation tracers is comparable to that from total infrared emission and the mid-infrared emission but larger than that from the optical hydrogen line emission and the ultraviolet continuum emission, which has implications for the reliability and applicability of these star formation metrics in dusty starbursts.

Systematic search for late-stage infall of material onto Class II disks

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It is generally assumed that Class II sources evolve independently of their surroundings, but many of them are still located near their parent clouds and may continue to interact with them. This may result in late accretion of material onto the disk that can significantly influence disk evolution and planet formation. To systematically study this process, we examined whether proximity to reflection nebulae could be used as a criterion for identifying Class II sources that may be experiencing late-infall. Our results suggest that at least five Class II objects associated with a prominent reflection nebula, and for which adequate ALMA observations are available, have spirals or stream-like structures which may be due to late-infall. Moreover, a significant fraction of Class II disks in nearby star-forming regions may be undergoing this phenomenon. Finally, we explore ways to quantify the dynamics of infalling streamers to better understand their impact on the protoplanetary disks.

Cross calibration of CO and dust as gas mass tracers with [CI] in high-z lensed dusty star-forming galaxies.

Gayathri Gururajan

Affiliation: University of Bologna and INAF Bologna

In this work, we present Atacama large millimeter/sub-millimeter array - Atacama compact array (ALMA-ACA) observations targeting both the [CI](2-1) and [CI](1-0) line emission of 29 SPT-SMGs. Combining this with the ancillary mid-J and low-J CO observations and dust mass estimations, we test the ability of [CI], CO, and dust as a gas mass tracer. We cross-calibrate the CO-to-H2 conversion factor, CI abundance, and gas-to-dust ratio and find a good agreement between them. We also probe the ISM properties using the [CI] to mid-/high-J CO ratio and the [CI]/IR ratio. Our sample has similar radiation field intensities and densities as the sub-millimeter galaxies but higher than the main-sequence at z∼1 and local galaxies. We also constrain the kinetic temperatures of the ISM using the two [CI] transitions and find that the mean excitation temperature of our sample agrees with that of the SMGs presented in the literature. We also do not find any extremely high temperatures and the [CI]-excitation temperature is systematically lower than the dust temperature, advocating against dust models of high optical depth for our sample.

Comparison on GMC properties between observed and simulated mergers

Hao He

Affiliation: McMaster University

Giant molecular clouds (GMCs) in local starburst mergers are the key to study the driving mechanism of different star formation law and molecular gas properties in these extreme environments. However, these GMCs have been less well studied due to limited resolution and sensitivity of our instrument. In this work, we perform pixel-based analysis on ALMA CO 2-1 observations of two late-stage galaxy mergers, NGC 3256 and the Antennae, at GMC resolution ($\sim$100 pc) and conduct comparison with FIRE-2 simulated mergers to explore evolution of GMC properties at different merging stages. Comparing to normal spiral galaxies in PHANGS survey, GMCs in our observed mergers show significantly higher gas surface density and velocity dispersion, with peak surface density reaching 10^4 solarmass per parsec^2. Furthermore, GMCs in NGC 3256 show significantly higher virial parameter while the Antennae shows similar virial parameter value compared to PHANGS galaxies, potentially as a result of the different stages at which the two mergers are observed. In simulation, we also find similar enhancement in surface density and velocity dispersion by comparing GMCs in simulated mergers and control galaxies. Furthermore, we find that the virial parameters increases by a factor of 5-10 during the second pericentric passage, specifically for GMCs in the center. The rise and fall of virial parameter correspond well with that of global star formation rate (SFR), which suggests stellar feedback might play a role in making GMCs less gravitationally bound. The correspondence between high virial parameter and high SFR also suggests local environments (e.g. tidal field, hydrodynamical pressure) might help GMCs to collapse and form stars.

Acoustic Waves in ALMA: An Epoch Analysis

Ryan Hofmann

Affiliation: University of Colorado Boulder / National Solar Observatory

Acoustic waves are a ubiquitous phenomenon in the lower solar atmosphere, and are commonly identified as velocity perturbations in time-series observations of spectral lines. These acoustic waves also heat the plasma they pass through, and these temperature perturbations are expected to be visible in the millimeter continuum. However, previous attempts to identify an ALMA counterpart of these shocks have been inconclusive. To that end, we present simultaneous time-series observations of the quiet sun, taken in both Band 3 (3 mm) and the Ca II 854.2 nm spectral line. Using epoch analysis, we examine the presence or absence of an ALMA counterpart to these 3-minute acoustic waves, using the relative amplitudes and phases of the temperature and velocity perturbations to constrain the effective heights of formation of the ALMA observations relative to the calcium line. This approach will allow a critical examination of both wave properties of the acoustic waves and our understanding of the formation of the millimeter continuum radiation.

Reconstruct the shock history in NGC 253 with ALCHEMI

Ko-Yun (Monica) Huang

Affiliation: Leiden Observatory

Multi-line multi-species molecular observations are an ideal tool for a systematic study of the physico-chemical processes in the ISM, given the wide range of critical densities covered, and the dependencies of chemical reactions on the energy budget of the system. In our recent work (Huang et al. submitted) we were able to characterize the gas properties (such as kinetic temperature, gas density) probed by the shock tracers, SiO and HNCO, in the nearby starburst galaxy NGC253 by ALMA multi-line imaging as part of the ALCHEMI large program at GMC-scale (∼30pc). From our modeling analyses, which includes radiative transfer as well as chemical modeling, we found that the gas components traced by these two species are indeed subjected to shocks with different shock strengths, and possibly with a variety of shock history.

CO Isotopologues in Galaxy Mergers

Naman Jain

Affiliation: McMaster University

I will present high resolution ALMA observations of 12CO(J=2-1), 13CO(J=2-1), and C18O(J=2-1) for the Antennae galaxies, an iconic nearby galaxy merging pair. I use isotopologue emission line-ratios to probe the physical conditions of molecular gas down to the scale of giant molecular clouds (GMC), and compare them with gas surface density. Preliminary tests show that the line ratio 13CO(J=2-1)/12CO(J=2-1) increases from $\sim$0.05 to $\sim$0.09 as the cloud-scale molecular gas surface density increases from $\sim 10^3$ to $\sim 10^4$ $M_\odot$ pc^2. Additonally, there an offset between trends at GMC and kilo-parsec scales, in the sense that line-ratios at GMC scales compared to kilo-parsec scales are smaller at low surface densities. I also correlate the line-ratios with star formation rate (SFR) estimates from total infrared luminosity (LTIR) at 500 pc scale. This ongoing work will reveal the change in molecular gas conditions in response to stellar feedback, which is expected to be very strong in merging galaxies.

Catching the Chemical Footprints of Accreting Planets in Protoplanetary Disks

Haochang Jiang

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Protoplanetary disks, the birthplace of planets, commonly feature bright rings and dark gaps in both continuum and line-emission maps. Utilizing data from the MAPS large program, we have identified a statistically significant spatial coincidence of line-emission rings inside a continuum gap in MWC 480. We propose that this spatial coincidence of molecular emissions is indicative of an accreting planet present within the D76 continuum gap of MWC 480.

Through multi-fluid hydrodynamical simulations accounting for evaporation fronts, we simulate the process of an accreting planet locally heating up its vicinity, opening a gap in the disk, and creating a site for C-photochemistry. The simulation output provides a potential explanation for the emission in organic molecular lines as witnessed by ALMA.

Our findings suggest a novel approach for searching for planets in disks through their chemistry signals.

Elucidating the origin of COMs during star formation : The necessity to use Artificial Intelligence

Nina KESSLER

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During the process of star formation, a wide variety of molecules can form. The use of ALMA interferometer has made it possible to detect a richness of complex organic molecules (COMs) towards hot cores and hot corinos by studying their rotational transitions. However, the analysis of such spectra is tedious work and actual technics are not optimal, especially for analyzing a large sample of spectra in a systematic way. Moreover, the amount of data related to these observations has increased considerably in recent years. Therefore, it becomes necessary to develop new tools based on Artificial Intelligence (AI) to automate line detection and identification. We have tested neural network architectures to facilitate the analysis of large samples of (sub)millimeter spectra, and as a first approach, we aimed to classify the molecular content based on relative abundances. In this talk, I will discuss how to build a training set and use Neural Network architectures. It will also be the occasion to present our first results.

Lessons learnt from observing a z∼13 candidate with ALMA

Melanie Kaasinen

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Over the last year, we have witnessed a mad dash as the community tries to confirm candidate z > 10 galaxies identified through HST and JWST photometry. Multiple ALMA DDT observations have been conducted, targeting the [OIII] (and [CII]) emission of these candidates, with the aim of securing their redshifts. But, at the time of this abstract submission, none of these candidates have been "robustly" detected in the [OIII] or [CII] transition. In this talk, I will discuss the statistical tests of the ALMA data that we performed for the observations of the z∼13 candidate, HD1, for which we found no credible evidence of any [OIII] or [CII] emission. I will also present the broader lessons learnt from performing these tests and put these in context of the other candidates targeted, but not confirmed, with ALMA.

Tracing the molecular gas in jellyfish galaxies with ALMA and IRAM 30m Telescope

Anežka Kabátová

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Galaxies in clusters suffer a number of environmental processes acting on their gas content, star formation history and even their morphology. One of the dominant mechanisms is a hydrodynamical interaction between the hot intracluster medium of the galaxy cluster and the interstellar matter of galaxies that move through the cluster with large velocities, called ram pressure stripping. Through this process, the gas content of a galaxy is gradually stripped, forming a multiphase wake of gas behind it. For the resemblance, these galaxies are sometimes referred to as jellyfish. We observed five Coma cluster jellyfish galaxies with IRAM 30m telescope and searched for molecular gas (traced by CO(1-0) and CO(2-1)) in their disk as well as their tails. We discovered an unexpectedly large amount of molecular gas in the disk of four of them suggesting that the process of ram pressure stripping temporarily enhances the formation of molecular gas from atomic gas before it is stripped and star formation is quenched. Now, we revisit the same galaxies with ALMA as a part of a Large Program ALMA JELLY. With the resolved high-resolution CO(2-1) observation, we are able to map the distribution of molecular gas within these galaxies and better understand the process of ram pressure stripping and galaxy evolution in clusters.

Isotopologues ratios across galactic environments from the 'eyes' of Atacama Large Millimeter/submillimeter Array (ALMA)

CHI YAN LAW

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One of the frontiers of the star-forming community focuses on the extent to which the local chemical architectures of massive stars and planets-forming regions care about the chemical settings of the larger-scale environment. The isotopologue ratios of carbon (12C/13C), nitrogen (14N/15N), and sulphur (32S/34S) in star-forming regions across the galactic distances provide a unique opportunity to quantify the scale at which the local chemical process becomes dominant. The high spatial/spectral resolving power and sensitivity of ALMA probe into these massive clumps in unprecedented detail. Here we report the galactic radial functions of the carbon isotope ratio from the 'eyes' of ALMA using a large sample of massive star-forming regions from the ALMAGAL survey. In contrast to many previous studies, the lack of a radial gradient hints that local chemical processes may already be shaping the chemical evolution of stars and planet formation regions at $\sim$0.1 pc scales. We also present how single-dish data are a crucial complement to interpreting the results. The findings of this work establish strategies for the upcoming follow-up observations.

An HST dark galaxy merger revealed by ALMA

Ivanna Langan

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Galaxy mergers are known to be one of the major paths through which galaxies evolve across cosmic time, therefore it is absolutely necessary to study such systems at different redshifts to further our understanding of galaxy evolution. Significant progress has been made in the last decades thanks to HST, although a remaining challenge is the presence of obscuring dust, which can make one or more individual components invisible and therefore, completely impossible to identify as a merger. This is where radio telescopes such as ALMA enter. Not only has ALMA recently opened a new window to observe rest-frame far-infrared emission, thus revealing dust obscured sources, but ALMA also provides high-resolution observations essential to distinguishing multiple components. While studying CO(5-4) and CO(2-1) emission of a massive star-forming galaxy part of the COSMOS field, we revealed an adjacent companion which was totally invisible to HST, uncovering an ongoing major merger of galaxies at z=1.17. This redshift makes this merger particularly interesting as it is happening at the end of the peak of star formation activity in our Universe, also known as cosmic noon, where this class of mergers still remains unexplored. In my talk, I will show our findings for this example of a so far poorly understood class of mergers, i.e., morphological and kinematics properties of the two galaxies, their stellar and gas budget as well as their ISM conditions. I will also discuss the importance of multi-wavelength studies to fully access all baryonic properties of galaxies, and include future plans to further explore similar systems.

Dust polarization observations of protostellar cores

Valentin Le Gouellec

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Class 0 protostars vigorously accrete from their collapsing envelope, such as most of the future star mass is built during this evolutionary stage. The magnetic field is thought to play a key role in the regulation of the angular momentum available for disk formation and in the infall dynamics of the inner core. However the method used to trace the magnetic field, i.e., observing the linear polarization of thermal dust emission, is subject to caveats in such environment, where the grain alignment mechanisms still remain to be fully identified, and understood. Recent ALMA observations revealed surprising polarized dust emission maps in Class 0 objects, which, compared with synthetic observations of MHD models, suggest that indeed, the grain alignment physics requires detailed analysis. In particular, the Radiative Alignment Torques (RATs) mechanism predicts that for grain alignment to be efficient enough in the dense environment of the inner envelope (¡ 500 au), large grains ($\geq 10\ \mu$m) must already be present at these scales. In addition, the radiative feedback from the accretion onto the protostellar embryo can favor efficient grain alignment in the protostar, up to the point where dust grains get rotationally disrupted. In the context of the accretion variability of protostars, we explore the impact of the accretion on the alignment of grains responsible for the polarized dust emission detected at submillimeter wavelengths.

Stored in the archives: Uncovering the CN/CO intensity ratio with ALMA in nearby U/LIRGs

Blake Ledger

Affiliation: McMaster University

The Atacama Large Millimeter Array (ALMA) is a next generation telescope with the ability to observe nearby galaxies with unprecedented angular resolution and sensitivity. ALMA gives us access to the densest molecular gas on detailed spatial scales, providing valuable insight into the physical and chemical processes that regulate star formation. ALMA has the added benefit of a robust science archive which allows observers to utilize previous observations from other astronomers. I will present my most recent results from a large sample investigation of the CN/CO line ratio in nearby Ultra-Luminous and Luminous Infrared Galaxies (U/LIRGs) utilizing the power of the ALMA archive. I identify 16 U/LIRGs which have been previously observed and detected in both the CN and CO (1-0) lines at $\sim$500 pc resolution based on nearly 20 different ALMA projects. I will discuss how the CN/CO line ratio varies both within individual U/LIRGs and between ULIRGs and LIRGs as independent samples. My main conclusion is that the CN/CO line ratio is higher in ULIRGs than LIRGs, with a larger spread in the ratio measured for LIRGs due to the variety of galaxy environments included in our sample; e.g., starburst nuclei and quiescent disks, nearby galaxy mergers, and active galactic nuclei (AGN) in Seyfert galaxies. Future work will consist of comparing the CN/CO ratio to measured infrared luminosities, [CII] luminosities, AGN strength, disk versus nuclei locations, merger class, and more.

Measurement of the dust removal timescale and its dependence on elliptical galaxies properties

Aleksandra Leśniewska

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Dust is a key component of the interstellar medium. The mechanism of dust removal from galaxies has not been completely understood yet. However, dust evolution is not only relevant in the context of interstellar medium, but is also one of the main factors defining the evolution of stars and the entire host galaxy. I will address this issue by the analysis of several thousand dusty galaxies, which are becoming passive. They are elliptical galaxies in which star formation has a much lower rate than what their masses could imply, yet an unnaturally large amount of dust is observed - comparable to the amount of dust in spirals. The analysis is conducted on a sample that differs from previous work not only in the number of objects, but most of all in a wider range of parameters. This will allow the determination of how galaxies get rid of dust and also the testing of the mechanism which is responsible for this.

Colder and Dustier! Probing Dust Properties of the Brightest Submillimeter Galaxies by ALMA Follow-up Observation at Cosmic Noon

Cheng-Lin (Ray) Liao

Affiliation: National Taiwan University (NTU)/Institute of Astronomy and Astrophysics, Academia Sinica (ASIAA)

Dusty star-forming galaxies, luminous in the infrared and often times called submillimeter galaxies (SMGs), are dust-rich galaxies at cosmic noon (z$\sim$1-3). The far-infrared part of the spectral energy distribution (SED) of these galaxies can be well modeled by a single temperature modified blackbody profile, where the slope in the Rayleigh-Jeans tail, characterized as the dust emissivity index (β), can help reveal dust grain properties. In this talk, I would like to share our findings about the dust properties of a sample of flux-limited ($S_{850\mu m} > 12.4$mJy) SMGs. They have a higher dust fraction (M_{dust}/M_*) due to the selection effect, with an average $L_{IR} \sim 10^{13}$ L_{sun} located at high redshift (z$\sim$2-5). Our SMGs are well sampled in far-infrared SED by the Terahertz data from Herschel as well as the millimeter data from ALMA. In addition, spectroscopic redshifts are measured by the ALMA blind CO survey in > 90% of the sample, which allows us to break the degeneracy between dust temperature (T_{dust}) and redshift. In this study, we investigated how the dust properties of these ALMA-selected brightest SMGs differ from the typical SMGs. Are there any significant features of this sample that make it so massive in dust? To answer the question, we fit the far-infrared and millimeter photometry with the modified blackbody model. Results show that, compared to the typical SMGs, our sample appears to have a lower T_{dust} at a fixed luminosity due to the high 850μm cut of the sample selection. However, β is broadly consistent to that of the typical SMGs, with a median β=2.1$\pm$0.1, inferring no significant difference in dust grain compositions between the brightest SMGs and the typical SMGs. Furthermore, together with the measurements of the local star-forming galaxies (z < 0.5), we find a weak evolution of β, suggesting that our very bright SMGs are extremely dust-rich but have similar dust grain properties compared to those of typical star-forming galaxies from local to high redshift.

Unveiling the high-velocity jet powered by the massive star MWC349A

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MWC349A is a massive star that presents a circumstellar disk which rotates following a Keplerian law, and an ionized wind that is launched from the disk surface. Recent ALMA observations of the strong, maser emission of hydrogen radio recombination lines (RRLs) obtained toward this system have provided a detailed picture of its ionized environment with an accuracy down to a few AU scales. In this work, we present the radiative transfer modelling of the H30alpha and H26alpha maser line emission, and of its adjacent radio-continuum, recently reported with ALMA. By using the 3D non-LTE radiative transfer code MORELI, we reveal the existence of a high-velocity jet launched from the MWC349A disk and engulfed within the ionized wind with a velocity of $>$ 200 km/s. In addition, thanks to the unprecedented accuracy provided by the ALMA data, we find that the already known ionized wind experiences a deceleration as it expands radially from the ionized disk with a terminal velocity of 60 km/s. Our results show the potential of using hydrogen RRL masers as powerful probes of the innermost ionized regions around massive protostars at scales of a few AU.

Differences in physical properties of coronal hole and quiet Sun coronal bright points and their ALMA counterparts

Filip Matković

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Coronal bright points (CBPs) are a fundamental class of solar activity phenomenon. They represent a set of small-scale loops in the low corona that have an enhanced ultraviolet (UV)/extreme-ultraviolet (EUV) and X-ray emissions, but also radio emission as well. With the construction of the Atacama Large Millimeter/submillimeter Array (ALMA), detailed studies of the chromospheric features of a CBP are now possible. This is of crucial importance for getting the whole picture of a CBP and physical mechanisms that govern there.

Using full-disk Band 6 (λ = 1.21 mm) radio data obtained by ALMA with EUV 193 Å and magnetogram data obtained by the Solar Dynamics Observatory (SDO), we report measurements of the mean intensity and projected area of CBPs within five coronal holes (CHs) and in the quiet Sun (QS) regions outside the CHs observed at different times near the centre of the solar disk. CBPs were firstly identified based on the EUV and magnetogram data and are then identified in the corresponding ALMA data. Measurements of the intensity and area of CBPs were conducted for both ALMA Band 6 and SDO EUV images. Then, an unequal variances t-test was conducted on randomly chosen CBP samples using a bootstrap technique to determine if CH and QS CBPs show any differences in the measured physical properties.

Statistical analysis of the measured physical properties revealed that CBPs within CHs have on average a significantly lower mean intensity as well as a lower area than the QS CBPs. This was seen not only in the coronal parts of the CBP loop structure observed by SDO, but also in the chromospheric parts observed by ALMA. Future studies will focus on the evolution of the physical properties (intensity, morphology, and magnetic field) of both CBPs and CHs in order to investigate possible reasons for the observed differences between CBPs situated in different regions, but also to study how the coronal and chromospheric parts of a CBP loop structure might be linked.

The first molecular detection of the protostellar disk of VLA 1623W and its streamers as imaged by ALMA

Seyma Mercimek

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More than 50% of solar-mass stars form in multiple systems (e.g., Chen+2013, Offner+2022). It is, therefore, crucial to investigate how multiplicity affects the star and planet formation processes at the protostellar stage. Remarkably, recent studies showed that dynamical interactions between protostars, ejection phenomena, and streamers are impactful in the processes that lead to the formation of low-mass stars and their disks in multiple systems. These streamers are stripping away or feeding gas and dust to the individual protostellar disks (e.g., Pineda+2020, Alves+2020, Valdivia-Mena+2022).

We report continuum and C18O (2-1) observations of the VLA 1623-2417 protostellar system at 50 au angular resolution as part of the ALMA Large Program FAUST (Fifty AU STudy of the chemistry in the disk/envelope system of Solar-like protostars; 2018.1.01205.L, PI: S. Yamamoto). The 1.3mm continuum probes the disks of VLA 1623A (A1+A2 binary), B, and W, and the circumbinary disk of the A1+A2 binary. The C18O emission reveals, for the first time, the gas in the disk-envelope of VLA 1623W. We estimate the dynamical mass of VLA 1623W and the mass of its disk. C18O also reveals streamers that extend up to 1000 au, spatially and kinematically connecting the envelope and outflow cavities of the A1+A2+B system with the disk of VLA 1623W. The presence of the streamers, as well as the spatial (∼1300 au) and velocity (∼2.2 km/s) offset of VLA 1623W, suggest that either sources W and A+B formed in different cores, interacting between them or that source W has been ejected from the VLA 1623 multiple system during its formation. The streamers may funnel material from the envelope and cavities of VLA 1623AB onto VLA 1623W, thus concurring to set its final mass and chemical content.

A sensitive CO and Carbon line survey of local ULIRGs using APEX and ALMA

Isabel Montoya Arroyave

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We use high sensitivity, beam-matched APEX, ALMA, and ACA (sub)-mm observations to study the state of the cold molecular gas in a sample of ∼40 local ultra luminous infrared galaxies (ULIRGs), hence probing mostly galaxy mergers characterized by strong starburst and AGN activity. We aim to understand how such energetic feedback processes affect the kinematics and excitation of the molecular ISM of ULIRGs. To do so, we use proxy tracers such as low-J CO (up to J=3) and neutral atomic carbon ([CI](1-0)) emission lines, which allow us to study their different line ratios and in turn get insight on the physical properties of the ISM, such as its excitation temperature and density, which in turn allow us to constrain the H2 mass using two independent gas tracers. Additionally, by performing a multi-Gaussian component fit to the high S/N CO spectral line observations, we can study separately the spectral line components that are characterised by different line-of-sight velocities and velocity dispersions, comparing the CO line excitation of the quiescent and the fast-moving molecular gas. We find extremely high average line ratios, however no correlation with SFR, AGN luminosity or SFE, indicating that these low-J CO lines are poor tracers of ISM heating mechanisms in such IR luminous mergers. We, however, suggest that large gas velocity gradients caused by turbulence and/or massive molecular outflows are at the origin of the most extremely high CO line ratios measured the our sample. Lastly, we find that these sources are very bright in [CI](1-0) compared to other galaxies and this enhancement seems to correlate with the line widths (turbulence/outflows), which are on average narrower for [CI] than CO lines in our sample of local ULIRGs, which may suggest different behaviours for different gas tracers.

Gas fractions of undetected galaxies in ALMA between 1¡z¡3 in GOODS-S

Rosa María Mérida González

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The emission of galaxies between $1 < z < 3$ around 1.1 mm gives us information about the molecular gas and gas fractions of these systems. This information is usually available for massive galaxies ($M_\star > 10^{10} M_\odot$), but less massive galaxies remain undetected at this wavelength. Stacking the emission of galaxies at lower stellar mass bins, we are able to push the detection limit and, at least, provide upper limits for the expected gas fractions and molecular gas mass of these galaxies. We will study these quantities using the ALMA data presented in GOODS-ALMA 2.0 (Gómez-Guijarro et al. 2022) and the galaxies included in the ZFOURGE galaxy survey (Persson et al. 2013).

How do stars get their mass? Understanding the origin of the IMF from the mass distribution of cores.

Thomas Nony

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The origin of stellar masses is one of the most central open issues in astrophysics. In this talk, I will introduce the ALMA-IMF Large Program, whose goal is to determine if and how the origin of the Initial Mass Function (IMF) depends on the cloud characteristics. Its first results, obtained from a large sample of cores without significant bias, suggest that mass distribution of cores (CMFs) in high-mass proto-clusters generally do not follow the canonical IMF. I will also present our recent detailed study of the W43 molecular complex. Identification of outflows in CO(2-1) enables us to assess that a very large fraction of high-mass cores are protostellar, and thus that most cores in this region do not go through a high-mass prestellar core phase. We also find that the slope of the protostellar CMF is significantly flatter than that of the prestellar CMF, which questions the processes of core mass growth.

ALMA Pilot Study of Heavily Obscured Quasars with Young Radio Jets

Pallavi Patil

Affiliation: National Radio Astronomy Observatory

I present pilot ALMA observations of two targets belonging to a unique sample of 156 distant ($0.5 < z < 3$) heavily obscured, hyper-luminous quasars with sub-galactic, young radio jets. The parent sample was selected to have extremely red MIR-optical color ratios based on WISE data and the detection of bright, unresolved radio emission from the NVSS/FIRST Survey. Followup radio and IR observations find our sources consistent with a population of newly (re)triggered, compact jets caught in a unique post-merger stage in which they still reside within the dense gas reservoirs of their hosts. These two targets in focus show interesting (sub)arcsec structures in 10 GHz VLA snapshot images. Here, I present results from deeper multi-band, multi-resolution (1.4-30 GHz) VLA observations designed to obtain spatial and spectral mappings of the radio emission. ALMA Band 7 data with sub-arcsecond resolution have confirmed the presence of strong resolved 870 um continuum emission and broad CO lines in both sources. The CO fluxes yield molecular gas masses of log(MH2/Msun) $\sim$ 10 using standard conversions. The CO line profiles are broad ($\sim$500 km/s) and may be associated with turbulence and/or outflows. Finally, I discuss the implications of our study for understanding the impact of young jets on the ISM and star formation rates in powerful young AGNs.

High Resolution [CII] kinematics for a rotating disc candidate at z $\sim$ 7

Sian Phillips

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The earliest galaxies formed during the first billion years after the Big Bang, producing the energetic photons required to initiate the Epoch of Reionization. Characterizing these first galaxies is key to understanding the evolution of the Universe, with resolved emission line studies providing information on how mergers and smooth gas accretion contribute to galaxy growth, and on which mechanism is dominant.

I present high-resolution kinematics of the galaxy COS-3018555981, which has previously been identified using marginally-resolved ALMA observations as a candidate rotationally-supported disc due to its smooth velocity gradient. At this resolution, the alternative scenario that the apparent rotational field was caused by merging [CII]-luminous satellites could not be excluded.

We detect some substructure in the source that could be due to outflows or a minor merger. After separating this emission we review evidence including position-velocity diagrams, moment maps and the ratio of rotational velocity to velocity dispersion, finding that the initial rotating disc interpretation remains valid at higher resolutions. This result suggests that disc structure may be already established during the Epoch of Reionization, although this stable phase may be short-lived, with most early star forming galaxies expected to be chaotic and dynamically hot as a result of the extreme environment and astrophysical processes in the early Universe.

Revealing the circumnuclear star forming region in two nearby Seyferts 2

Francesco Salvestrini

Affiliation: INAF - Arcetri Astrophysical Observatory

The high-spatial resolution provided by ALMA is a unique opportunity to reveal the hidden structure and physical processed that takes place in the very central region of nearby active galaxy, down to the size of single giant molecular clouds. In this work, we present the results of the analysis of new high-spatially resolved ALMA observations of a molecular star formation tracer (C2H) in two nearby obscured AGN (NGC0034 and NGC7130) The new interferometric data allow us to reveal the previously unknown structure and kinematics of the circumnuclear disks (CND) in the two targets. By combining this with the information provided by the continuum emission produced by the dust embedded in the CND, as well as an extensive multi-wavelength characterisation of the two sources (from the X-rays to the far-infrared), we model the radiation fields taking place in the central few tens of parsecs of the both galaxies.

Detection of massive molecular and dust reservoirs around z∼2 extremely red quasars: CGM enrichment by quasar-driven outflows

Jan Scholtz

Affiliation: KICC, Cambridge

Large scale outflows are believed to be an important mechanism in the evolution of galaxies, as they can both suppress and enhance star formation as well as eject gas from their host galaxies and mix the pristine gas from the intergalactic medium and processed material from the galaxy in the circum-galactic medium (CGM). We can study the impact of these large-scale outflows either by tracing the current outflows (by studying broad emission line profiles), or by studying the impact of past outflows on the gas surrounding the galaxy.

In this work, we examined the CO(7-6), [CI](2-1), H2O (806 GHz) and dust continuum ALMA observations of 15 extremely red quasars (ERQs) at z∼2.3. By investigating the radial surface brightness profiles of both the individual sources and the stacked emission, we detect extended cold gas and dust emission on scales of ∼14 kpc in CO(7-6), [CI](2-1), and dust continuum. We have further confirmed our results by investigating the visibilities of individual targets and the stacked visibilities.

In this talk, I will compare the measured sizes and dust and cold gas masses of our detected halos with those from previous studies of cold gas halos around star-forming galaxies across redshifts 2-4 and discuss the impact of large scale outflows on the CGM around extremely powerful quasars.

A detailed study of the Radio-FIR correlation in the Large Magellanic Cloud.

Mohammad Javad Shahhoseini

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One of the most debated questions in astronomy is the origin of the correlation between the radio and far-infrared (FIR) emission which holds in different types of galaxies over 5 orders of magnitude. This correlation is traditionally linked to massive star formation, while recent studies show that it can hold even in non-star-forming ISM in normal spirals due to a balance between gas, magnetic field, and cosmic rays. We investigate this correlation in low mass systems such as the Magellanic clouds down to 15pc scales taking into account the heating sources of dust and the thermal and non-thermal origins of the radio continuum emission. By including the data taken with Spitzer, Herschel, ATCA, and PARKES observations, we found that total RC emission has a better correlation with the dust heated by young massive stars (warm dust). The RC-warm dust correlation has mainly a thermal origin as the correlation with the thermal free-free component is better than that with the non-thermal synchrotron emission, although the correlation with the non-thermal is notable. Our results indicate that, in low-mass systems, a delicate balance between the gas, magnetic fields, and cosmic rays hardly holds in diffuse, non-star-forming ISM due to a relatively fast escape of cosmic-ray electrons, unlike the more massive normal spirals.

Quantifying the strength and nature of turbulence in star-forming regions using ALMA

Piyush Sharda

Affiliation: Leiden University

All modern star formation theories point out that turbulence in the molecular gas plays a major role in the interstellar medium (ISM). Large-scale galaxy/cosmological simulations also heavily rely on sub-grid recipes for modeling turbulence in the ISM. However, direct measurements of the strength and nature of gas turbulence are hard to come by, because they require excellent spatial resolution and targeting multiple chemical species that can trace the gas at different densities in a molecular cloud. As a result, ¡ 5 studies exist that can quantify the turbulent properties of star-forming gas, all of which are limited to the Milky Way. We use high-resolution (sub-pc) ALMA 12CO (J = 2-1), 13CO (J = 2-1), and C18O (J = 2-1) observations of filamentary molecular clouds in the star-forming region N159E (the Papillon Nebula) in the Large Magellanic Cloud (LMC) to provide the first measurement of turbulence driving parameter in an extragalactic region. We use a non-local thermodynamic equilibrium (NLTE) analysis of the CO isotopologues to construct a gas density PDF, which we find to be largely lognormal in shape with some intermittent features indicating deviations from lognormality. We find that the width of the lognormal part of the density PDF is comparable to the supersonic turbulent Mach number. This equivalency strongly indicates that turbulence in these clouds is highly compressive, which can explain the massive protostellar cores discovered in continuum emission. We speculate that the compressive turbulence could have been powered by H I flows that led to the development of the molecular filaments observed by ALMA in the region. This analysis can be easily adapted to ALMA data of different star-forming regions, a census of which will lead to a more thorough understanding of ISM turbulence and constrain gravo-turbulent models of star formation.

Binary progenitor systems of type Ic supernovae

Martín Solar

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Core-collapse supernovae (SNe) explosions mark deaths of massive stars. Detailed study of SNe environments are crucial to understand star formation history, host galaxy evolution, and nature of SN progenitors. Type Ic SNe (without hydrogen and helium lines in spectra) are believed to originate either from the core-collapse of very massive stars (> 30 $M_\odot$) or by the interaction of less massive stars in binary systems (10–20 $M_\odot$), in which the companion is responsible for stripping outer layers of hydrogen and helium.

In this talk, I will constrain type Ic SNe progenitor lifetimes using high-resolution CO(2-1) emission line observations, allowing us to measure the giant molecular cloud (GMC) environments. We used our own ALMA observations of type Ic SNe and archival PHANGS-ALMA data, both with very high resolution of ~ 100 pc, that are typical sizes of GMCs. We obtained observations for 28 type II SNe (with hydrogen lines) and 21 type Ic SNe.

We found that type Ic SNe are located in environments with similar GMC densities to type II SNe, suggesting that their progenitors have similar lifetimes and therefore similar zero-age main-sequence masses. The 2σ upper limit on the age difference between the progenitors of these SNe is 4 Myr.

Our finding support the binary model for type Ic SNe and argue that the lack of hydrogen and helium lines in their is due to the interaction with the companion.

Searching for signatures of gravitational instability in the AB Aurigae planet-forming disk

Jess Speedie

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Gravitational instability (GI) is a fundamental process that, when in action, plays a crucial role in both protoplanetary disk evolution and planet formation. GI occurs in disks with a sufficiently high disk-to-star mass ratio, and results in prominent spiral arms forming throughout the disk that can fragment into clump-like protoplanets. Despite the importance of GI to disk evolution and planet formation, it has been difficult to observationally confirm that GI is in action in real disks. To this end, we have obtained sensitive ALMA Band 6 line observations of 13CO and other molecular species towards the disk around AB Aur, which is a bright and well-studied young object that has shown strong signs of GI in multi-wavelength observations in the past. Our program was designed to provide clear and direct evidence that GI is in action in this planet-forming class II disk. With the recent discovery of the clump-like protoplanet AB Aur b, it is of great interest to determine whether this protoplanet could have formed by GI. While our analysis is still underway, I will describe our progress to search for GI signatures using newly proposed kinematic techniques.

Probing the Cool Sun with ALMA

Johnathan Stauffer

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As the only star we can spatially resolve with our telescopes, the Sun is key to advancing our understanding of stellar atmospheres. Magneto-hydrodynamical simulations reveal a highly dynamic solar atmosphere, with quickly evolving structures on a variety of spatial scales. Somewhat unexpectedly, some of these simulations predict the presence of very cool ($< 3{,}000$ K) gas well into the solar chromosphere, which should have a mean temperature of around 10,000 K. Unfortunately, many of the spectral diagnostics traditionally used to study the chromosphere (mostly of neutral or singly-ionized atoms) are only sensitive to plasmas of moderate-to-high temperatures, leaving any cooler regions of the Sun invisible to observers – especially when complicated inversion techniques are needed to infer atmospheric parameters from the detailed spectral profiles. In contrast, the millimeter continuum acts as a "linear thermometer" for these layers , remaining a sensitive diagnostic of the solar atmosphere even at low temperatures. ALMA can provide temperature maps at (sub)arcsecond resolution, making it the ideal instrument to search for and study cool gas in the solar atmosphere. Here, I present a set of wide-field mosaics at 1.3 mm (Band 6) and 0.9 (Band 7), showing a variety of solar features. I will discuss the appearance of cool structures in these data, while comparing them to those seen in the infrared vibrational spectrum of carbon monoxide (observed simultaneously with Band 6), which is another seldom-used probe of cool gas in the upper photosphere and low chromosphere.

ALMA observations of QSO MUSEUM

Maria Babakhanyan Stone

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The QSO MUSEUM catalog describes the extended Lyman-alpha emission around over 60 z$\sim$3 quasars, from MUSE observations (Arrigoni Battaia 2018, MNRAS). I am working on obtaining ALMA observations of the same set of quasars, to complement the MUSE observations by zooming in on the host galaxy. Similar work has been done for a few extremely luminous quasars at higher redshift (Fan 2018).

Hidden Gems on a Ring: ALMA Reveals Infant Massive Clusters in a Central Starburst Galaxy

Jiayi Sun

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I will present 0.1″ (∼5 pc) resolution ALMA observations of the central starburst region in a nearby barred galaxy, NGC3351. These Cycle 8 observations reveal over a dozen compact sources with strong 93 and/or 350 GHz continuum emission, distributed along a starburst ring with galactic radius of ∼300 pc. These sources are estimated to each host 10^4-10^5 solar masses of stellar and/or gas content, which means they are forming massive clusters still in their infancy. The majority of them have no counterpart in HST optical images, again implying extremely high extinction and very young age. Most clusters are associated with massive, dense molecular gas reservoirs (as traced by HCN and HCO+ emission), which are themselves embedded in complex, multi-scale gas structures (as revealed by deep CO imaging). The clusters are preferentially located near the two "contact points", where the large-scale, bar-driven gas inflow runs into the starburst ring. Such spatial pattern appears more consistent with models of dynamically triggered massive cluster formation than with the "popcorn" model of random gravitational collapse.

How to find needles in a stack (of protoplanetary discs): comparison between ALMA models and observations

Claudia Toci

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Protoplanetary discs are the place where planets accrete and evolve. It is of pivotal importance to characterise their evolution to fully understand the emerging exoplanetary population. Thanks to ALMA, we now have astonishing images of the dust and gas emission of protoplanetary discs, showing a large number of gaps and ring-like structures, often connected to the presence of one or more planets embedded in the parental disc. Moreover, results from surveys of star forming region are available, allowing demographic studies of populations of discs of different ages.

Frontier research is to study disc evolution and the interaction between the disc and the planets that are forming inside, using observational result in synergy with current theoretical models and numerical simulations. The main goal is to understand which are the mechanisms responsible for the substructures as well as predicting new observables to confirm or reject the presence of candidate protoplanets. In this talk, I will describe results from the modelling of single, bright sources (e.g., HD169142, PDS70, HD100546, GG Tau A), and will underline the information we can obtain by comparing multi-wavelengths observations with results from hydrodynamical models. In particular, I will focus on how simulations can help in constraining the mass and position of the candidate proto-planets that may be responsible for the ALMA observational results, as well as how they can support future observational strategies.

Stacking in the UV-plane strongly-lenses high-z DSFGs observed with ALMA

Martina Torsello

Affiliation: Sissa

Nowdays stacking is a popular technique in radio interferometry for detecting spectral lines and studying the composition of galaxies. Stacking data directly in the visibility UV-plane instead stacking images, which is most common method, can reduce the holes interpolation problems and allows us to analyse fainter sources. However, this technique has several caveats, particularly when applied to a large range of high redshift galaxies. In this talk I will briefly present the software I am actually working on, which will be able to rest-frame visibility data and perform stacking on a large number of sources regardless of their redshift. The purpose of our research group is to perform stacking on a sample of strongly-lenses high-z DSFGs, featuring ALMA observations, to detect dust tracking lines and study the physical conditions of the ISM.

Dual constraints with ALMA: new [O III] 88 μm and dust-continuum observations reveal the ISM conditions of luminous LBGs at z $\sim$ 7

Joris Witstok

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I will present new [O III] 88 μm observations of four bright z $\sim$ 7 Lyman-break galaxies spectroscopically confirmed by ALMA through the [C II] 158 μm line, unlike recent [O III] detections where Lyman-α was used. This nearly doubles the sample of Epoch of Reionisation galaxies with robust (5σ) detections of [C II] and [O III]. We perform a multi-wavelength comparison with new deep HST images of the rest-frame UV, whose compact morphology aligns well with [O III] tracing ionised gas. By contrast, we find more spatially extended [C II] emission mainly produced in neutral gas, as evidenced by the high [C II]/[N II] ratio constrained by a [N II] 205 μm non-detection in one source. We find a positive correlation between the equivalent width of the optical [O III] and Hβ lines and the [O III]/[C II] ratio, as seen in local metal-poor dwarf galaxies. Cloudy models of a nebula of typical density harbouring a young stellar population with a high ionisation parameter appear to adequately reproduce the far-infrared lines. Surprisingly, however, our models fail to reproduce the strength of [O III] 88 μm, unless we assume an α/Fe enhancement and a near-solar nebular oxygen abundance. On spatially resolved scales, we find [O III]/[C II] shows a tentative anti-correlation with infrared excess, L_{IR}/L_{UV}, also seen on global scales in the local Universe. Finally, I will present a newly-developed, far-infrared spectral energy distribution fitting code to show that dust-continuum measurements of one source appear to favour a low dust temperature coupled with a high dust mass. This implies a high stellar metallicity yield and may point towards the need of dust production or grain-growth mechanisms beyond supernovae. Employing the code on all ($\sim$17) EoR galaxies with well-sampled far-infrared spectral energy distributions available in the literature, I will place these results in perspective by presenting an observational overview of dust properties in the early Universe.

Dust properties from multi-wavelength ALMA observations: single sources and disc demographics

Francesco Zagaria

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In planet-forming discs, knowledge of the physico-chemical properties of dust grains (size, density, temperature and composition) is pivotal to characterise the environment where planets form. Attempts to observationally infer these quantities rely on collecting interferometric data in the dust continuum at different wavelengths to study the spectral behaviour of the disc emissivity (a function of the previously cited dust properties). ALMA proved to be transformational in this context, providing high sensitivity and resolution images that allowed to grasp grain properties at the scale of the routinely observed rings and gaps. Because obtaining such high-quality data at several wavelengths is challenging, grain size, density and temperature have been conclusively characterised only in two cases. I plan to present preliminary results in the case of a third disc, CI Tau, whose high-resolution data cover a waveband wide enough (0.9 mm to 9.0 cm) to assess its dust properties. However, only targeting few bright sources is not informative of the population of (mainly faint, compact) discs in nearby regions. A recent work targeted a family of Lupus discs observed with ALMA at medium resolution between 0.9 and 3.1 mm, suggesting that grains could be (much!) larger than few mm in these sources. I plan to discuss how these results change where dust self-scattering is considered, showing that more conservative estimates can be obtained. I will also discuss the role of the forthcoming ALMA Band 1 to answer the open question on dust properties in planet-forming discs.

AGN driven winds and gaseous discs in local Seyfert galaxies: high resolution study of the multiphase ISM with MUSE, ALMA and JVLA

Maria Vittoria Zanchetti

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In this talk I will discuss the physics of the multiphase gas in local active galaxies and the impact of the Active Galactic Nucleus (AGN) on the host galaxy evolution. AGNs can generate winds and jets that interact with the host galaxy interstellar medium (ISM), potentially altering both the star formation and the nuclear gas accretion. I will focus on the cold molecular and warm ionized phases of the ISM, using ALMA and MUSE/VLT data to probe the kinematics and interaction of the different gas phases, over a broad range of physical scales. I will present a detailed dynamical modelling of the gas component through which we can reconstruct the distribution and kinematics of the multiphase discs, winds and their interaction, from nuclear out to several kpc scale. By exploiting spatially resolved optical and sub-mm emission lines, we are able to derive the best estimate of the velocity field, the spatial distribution, and electron density and therefore properly quantify both the ionized and molecular mass across the disc, narrow line region (NLR) and outflow, and their relative weight. I will present the application of our approach to a sample of local hard-X-ray selected Seyfert galaxies, including NGC2992 and others. In this peculiar object ALMA data allows to resolve a dust reservoir co-spatial with the molecular disc, therefore we are able to quantify the gas-to-dust ratio. JVLA data shows the presence of two components, one due to expanding radio bubbles and the other due to star formation in the disc. By exploiting radio and sub-mm emission we are able to derive the spatially resolved star formation law on scales of $\sim$200 pc.

Porous Grains in Protoplanetary Disks: Application to the Outer Region of the HL Tau Disk

Shangjia Zhang

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Grain sizes constrained from dust continuum and polarization observations by radio interferometry are inconsistent by at least an order of magnitude. Motivated by porous grains observed in small Solar System bodies (e.g., from Rosetta mission), we explore how the dust grain's porosity affects the estimated grain sizes from these two methods. Porous grains have lower refractive indices which affect both opacity and polarization fraction. With weaker Mie interference patterns, the porous grains have lower opacity at mm wavelengths than the compact grains if the grain size exceeds several hundred microns. Consequently, the inferred dust mass using porous grains can be up to a factor of six higher. The most significant difference between compact and porous grains is their scattering properties. The porous grains have a wider range of grain sizes with high linear polarization from dust self-scattering, allowing mm-cm-sized grains to explain polarization observations. With a Bayesian approach, we use porous grains to fit HL Tau disk's multi-wavelength continuum and mm-polarization observations from ALMA and VLA. The moderately porous grains with sizes from 1 mm-1 m can explain both continuum and polarization observations, especially in the region between 20-60 au. If the grains in HL Tau are porous, the porosity should be from 70% to 97% from current polarization observations. We also predict that future observations of the self-scattering linear polarization at longer wavelengths (e.g., ALMA B1 and ngVLA) have the potential to further constrain the grain porosity and size.

Dust-obscured star formation at z $\sim$ 6 from [CII]-selected companion galaxies

Ivana van Leeuwen

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One of the most exciting frontiers in extragalactic astronomy is understanding how rapidly galaxies formed stars in the Early Universe. This involves us constraining the Star Formation Rate Density (SFRD) at z $\gtrsim$ 6. Estimating the Star Formation Rate Density (SFRD) at z $>$ 4 is more difficult given the much greater ease in surveying the z $>$ 4 universe in the rest-UV. This biases our view of the SFRD to focus on the unobscured sources. Recent work shows that the dust-obscured sources could contribute quite meaningfully to the z $>$ 6 SFRD. Here we present a new method for deriving a measure of the SFRD at z $\sim$ 6 correcting for dust-obscured galaxies missed by rest-UV surveys. This method uses serendipitous sources that are found through [CII] (158 μm) emission which is equally sensitive to both dust-obscured and unobscured star formation. Using a sample of these sources detected by ALMA, we characterize the obscuration in galaxies as function of their total star formation rate and derive a corrected UV luminosity function and SFRD at z $\sim$ 6.

Resolved z=2 observations of a bonafide galaxy cluster via ALMA and the Sunyaev-Zeldovich effect

Joshiwa van Marrewijk

Affiliation: ESO

In recent years there have been an increasing amount of studies on the overdensities of galaxies in the distant Universe, even beyond a redshift of $z > 4$. However, how these so-called protoclusters evolve from a structure stretching several hundreds of Mpc to a bonafide galaxy cluster and how these distant clusters of galaxies differ from local ones are still open questions in modern astronomy as there are only a handful of observational constraints of clusters at intermediate, $z \sim 2$, redshifts.

Furthermore, many sub-mm observations focus only on the cluster members, but even though galaxy clusters are named for their visible galaxy constituents, the main baryonic matter component of a cluster can be found in the intra-cluster medium (ICM). Therefore, observations of the ICM in distant clusters of galaxies are key to answering the above-mentioned questions.

In this talk, I will show you how to use ALMA to detect diffuse extended gas from the ICM via the Sunyaev-Zeldovich (SZ) effect through a bayesian forward-modeling technique implemented in the uv-plane. With this routine, we detect and characterize the ICM of the most distant galaxy cluster found in current SZ-cluster catalogs. This case study will be the start of a high-resolution era for observations of the ICM in high-z systems as single-dish telescopes start finding more and more high-z galaxy clusters, which can be followed up with ALMA Band 3 and future Band 1 and 2 observations.
