

ALMABO 2019



Views on the Interstellar Medium in Galaxies in the ALMA Era

**CONFERENCE
BOOKLET**

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ORAL CONTRIBUTIONS

Feeding and feedback in dusty galaxy nuclei and AGNs

Aalto Susanne - *Chalmers University of Technology* - **Invited**

Cold gas plays a central role in feeding and regulating star formation and growth of supermassive black holes (SMBH) in galaxy nuclei. Particularly powerful activity occurs when interactions of gas-rich galaxies funnel large amounts of gas and dust into nuclei of luminous and ultra luminous infrared galaxies (LIRGs/ULIRGs). Dusty, luminous galaxies are of key importance to galaxy mass assembly over cosmic time. The most active growth spurt is suspected to occur when the SMBH is deeply embedded in a dense, dusty ISM. Obscured AGNs can ultimately provide fundamental constraints on the AGN duty cycle, give the full range of environments and astrophysical processes that drive the growth of SMBHs, and help to complete the picture of connections between the host galaxy and SMBH. Understanding the molecular properties of local U/LIRGS and AGNs thus is essential both for defining the evolution of present day galaxies - and sorting out key astrophysical processes in their even more energetic, distant cousins and intermediate to high redshifts. It is also increasingly clear that feedback from star formation and AGNs is fundamental to regulating the evolution of galaxies in the nearby Universe as well as at earlier epochs. There is mounting evidence that massive amount of cold molecular gas is being expelled from galaxy nuclei and starburst regions by the feedback process. With the advent of ALMA and the NOEMA telescopes we can now study these outflows at unprecedented sensitivity and resolution. I will focus on recent ALMA and NOEMA studies of nearby enshrouded nuclei and AGN and their feedback. Recent ALMA studies (with resolutions of 20 milli arcseconds (1-7 pc) , reveal launch regions of molecular outflows and jets, inflows, and dusty nuclei of the nearby AGNs and LIRGs NGC1068, NGC1377 and IC860. The outflows are different from each other where NGC1068 shows gas carried out by a radio jet, NGC1377 has a 150 pc scale radio-quiet molecular jet, and the IC860 flow is exceedingly compact and dense and appears to be young. I will also discuss observational methods that reach behind the curtain of dust in the most obscured centres of U/LIRGs , allowing us to undertake new studies of heretofore hidden, rapid evolutionary phases of galaxy nuclei.

The new era of galaxy evolution studies from sensitive molecular and dust deep field surveys

Aravena Manuel - *Universidad Diego Portales (UDP)* - **Review**

This talk will present a brief review of the recent advances in our understanding of the evolution of galaxies enabled by molecular and dust continuum survey observations of cosmological deep fields with current radio/submm interferometers. In particular, recent results from the ALMA Spectroscopic Survey of the Hubble Ultra Deep Field (ASPECS) will be presented, including: measurements of the cosmic evolution of the molecular gas density, properties of the faintest gas-rich and dusty star forming galaxies, faint-end of the dust continuum number counts, and dust obscuration (IRX vs UV slope/stellar mass relations) at high redshift.

Feeding and Feedback in NUClei of GALaxies (NUGA)

Audibert Anelise - *Observatoire de Paris* - **Contributed**

The interaction between the nuclear activity in active galactic nuclei (AGN) and their host galaxies is crucial to understand the galaxy formation and evolution. Our aim is to explore the close environment of AGN and its connection to the host galaxy through the morphology and dynamics of the gas inside the central kpc in nearby AGN. Probing the dynamical structures leading to the fuel of the supermassive black hole (SMBH) from hundreds to parsec scales, the duty cycle of gas and the impact of molecular outflows on the star formation is crucial to understand how AGN are fueled in galaxies, and how the energy generated by the active nucleus can in turn regulate gas accretion. We report ALMA observations of a sample of 7 Seyfert/LINER part of the NUGA (NUclei of GALaxies) project, at the unprecedented spatial resolution of 0.06-0.09" (3-10 pc). We will present the observed molecular maps that have revealed the existence of molecular tori and show AGN feeding and feedback caught in action in some cases: trailing spirals observed inside the central 100 pc, efficiently driving the molecular gas into the SMBH and the detection of molecular outflows driven by the AGN.

Star Formation and ISM Properties in Local U/LIRGs at GMC scales: The Case of Arp 220

Barcos-Muñoz Loreto - *NRAO* - **Contributed**

Luminous and ultra luminous infrared galaxies (LIRGs and ULIRGs) are one of the best local laboratories to study physics at an extreme regime, potentially helping us understand similar processes happening in the early universe where high physical resolution observations are hard to achieve. U/LIRGs show star formation rates of up to a few 100 solar masses per year concentrated into their central kpc. Due to the large amounts of gas and dust surrounding their central regions, direct observations of the nuclei are often impossible at many wavelengths. Radio and sub-mm emission are key to study their star formation and ISM properties. I will show new high resolution (>40 pc), resolved ALMA Band 3 observations of the closest and most iconic ULIRG, Arp 220. I will show the distribution of dense molecular gas tracers (HCN and HCO+), and other gas tracers such as HC3N, H13CN, etc., from each nuclei of Arp 220, and the new challenges these detailed observations bring into the field. I will include results from cloud identification and analysis, along with kinematic modeling of the dense gas emission. With HCN and HCO+ in hand, I will show the distribution of their ratio as a function of radius and the implications of its use as an AGN diagnostic. Finally, I will present the first 3D morphology of the molecular outflow present in the western nucleus, and its properties.

Star Formation and Dense Gas in Extreme Environments with ALMA

Bemis Ashley - *McMaster University* - **Contributed**

We study the relationship between star formation and the dense gas content in a sample of ten nearby, extreme star-forming galaxies ($z < 0.03$) using archival ALMA data. Our sample includes systems with extreme environments (i.e. (U)LIRGs and starbursts) as well as normal star-forming galaxies for comparison. Analytic models of star formation (e.g. Elmegreen+2018) predict that gas tracers with high critical densities, such as HCN, should present a slope close to unity in the SFR-M_{gas} plane. We test this prediction for HCN and HCO+ in this sample and compare with the Kennicutt-Schmidt relationship of total gas (cf. Wilson+2019). Furthermore, we look for variations in depletion times and dense gas fractions across different regions within these systems (e.g. bars, spiral arms, nuclei). Recent work suggests that gas flow in systems that are interacting or barred can cause a build up of dense gas that eventually leads to a burst in star formation. We look for evidence of this by comparing emission of HCN, HCO+, and CO J=1-0 in these various regions, and we use a combination of continuum emission (from ALMA) and IR data (Herschel) to estimate the SFR and star formation efficiencies.

Exploring the [CII] and the dust continuum with the ALPINE survey: first scientific results

Bethermin Matthieu - *LAM* - **Invited**

ALPINE is an ALMA large program, which aims to build a first comprehensive picture of the obscured star formation and the properties of the interstellar medium in normal star-forming galaxies at the end of reionization. We targeted the [CII] line together with the 158-micron dust continuum in a sample of 122 $4 < z < 6$ normal star forming galaxies from optical spectroscopic sample. During the spring and summer 2015, 102 of our objects has been observed. At the abstract submission deadline (Feb 2018), we reduced all these data, built a first [CII] and continuum catalog, obtained first preliminary science result. The first science papers should thus be submitted or at least well advanced before the conference. The individual continuum detections at $z > 4$ are still rare and our new sample allow us to address if some obscured star formation is missed by dust-corrected UV estimates and in particular if the famous IRX-beta relation is valid at $z > 4$. With our data, we can also put first far-infrared constraints on the SFR-Mstar relation and the obscured star formation density at $z > 4$. We detected [CII] with $\sim 70\%$ success rate. A possible [CII]-deficit at high redshift has been recently discussed because of the low-metallicity, the high interstellar radiation field, and the high CMB temperature. I will present our new measurement of the SFR-L[CII] relation on this first $z > 4$ statistical sample. Finally, I will present our new constraints on the [CII] luminosity function. Finally, thanks to its depth and the its large number of non-contiguous pointing, ALPINE provides for free deep survey of galaxies at $z < 4$, which is much less affected by cosmic variance than usual observations. I will present the properties of these serendipitous continuum and line detections. I will show our new measurements of the deep continuum number counts, the dust luminosity function at $z \sim 2.5$, and the high-J CO luminosity function at $z < 2$.

The gentle monster PDS456 as seen by ALMA: implications for AGN feedback

Bischetti Manuela - *INAF Osservatorio Astronomico di Roma* - **Contributed**

We present the first ALMA observation of the nearby QSO PDS456 ($z=0.185$), mapping with unprecedented resolution (~ 700 pc) the molecular gas in the host-galaxy of a hyper-luminous QSO. With a bolometric luminosity $L_{\text{Bol}} \sim 10^{47}$ erg/s, it can be regarded as the local analogue of the QSOs shining at $z \sim 2$, i.e. the peak epoch of QSO luminosity density. We report on the discovery of a molecular outflow in PDS456, which also shows the most powerful, persistent, X-ray ultra-fast (0.25c) wind discovered so far. The exquisite ALMA resolution allows us to map this outflow in great detail, revealing a bright compact ($R < 1.2$ kpc) outflow component plus several extended ($R \sim 1.3-5$ kpc) clumps, characterized by blue-shifted bulk velocities up to -1000 km/s. For the first time, we get new insights on how multi-phase AGN-driven outflows expand outwards in the high-luminosity regime, finding that (i) the molecular gas may represent a minority fraction of the total outflowing gas mass, and (ii) the outflow in PDS456 can be explained as direct radiation-pressure on the ISM clouds or, alternatively, as an energy-conserving expansion with poor-coupling with the ISM.

The Central Engine and Outflows in the Nuclear Starburst of NGC 253

Bolatto Alberto - *University of Maryland* - **Invited**

Starbursts are a rare phenomenon in the present day universe, but they represent perhaps the most common mode under which stars form and galaxies grow during the $z \sim 1-2$ peak of cosmic star formation activity. Feedback, in the form of galaxy-scale outflows, is thought to be one of the main forms of regulation of galaxy growth. NGC 253 is the premier local example for a nuclear starburst, and has been targeted with several ALMA observations in order to study how these processes work. I will discuss the properties of the molecular outflow, including our best constraints on the mass and outflow rate, and the properties of the outflowing molecular gas. I will also present the results of our recent 1.7-pc resolution observations, including the detection and properties of 14 compact structures with properties corresponding to massive young star clusters and super star clusters, 13 of which are so embedded that are invisible in optical and NIR observations (the 14th is a known SSC). I will also discuss the evidence for feedback and disruption on the scales of these clusters. Finally, I will present a preliminary analysis of the 0.5-pc resolution observations recently obtained.

Dust Emission from $z \geq 2$ Lyman-Break Galaxies in the HUDF ASPECS Program

Bouwens Rychard - *Leiden University* - **Contributed**

For the past two decades, our view of star-forming galaxies in the distant universe has largely been limited to light in the rest-UV. Thanks to recent facilities like Herschel and especially ALMA, significant progress is being made in measuring the amount of star formation activity hidden by dust, through direct detection of the far-infrared continuum light. Several independent early studies with ALMA, most notably over the Hubble Ultra Deep Field, showed that dust obscuration was likely a strong function of stellar mass and not especially significant in the lowest mass galaxies. Now, further progress can be made in this area thanks to an even deeper set of ALMA observations over the Hubble Deep Field, from the ASPECS large program. The observations reach 1.4-3.5 times deeper than even in the ASPECS pilot program or Dunlop programs and over more than 3 times as much area as the pilot, allowing for arguably the most sensitive measurement of dust emission from distant galaxies achieved to date. Of considerable interest will be our new results on the infrared excess of galaxies as a function of stellar mass, as a function of the UV-color of galaxies (or beta), and as a function of redshift. The purpose of my presentation will be to summarize the new ASPECS answers to these and other related questions

The molecular gas content of obscured Quasars at high- z

Brusa Marcella - *DIFA - University of Bologna* - **Invited**

The standard merger-driven galaxy evolutionary scenario predicts a phase of deeply “buried” supermassive black hole growth coexisting with a starburst before feedback phenomena deplete the cold molecular gas reservoir of the galaxy and an optically luminous quasar (QSO) is revealed. We present measurements of the cold gas reservoir of a small sample of obscured and highly obscured QSOs at $z > 1$, including well studied objects such as XID2028 and GMASS953 for which the gas mass has been derived through CO SLED modelling. We compare the molecular gas conditions of our targets with those of other systems at $z > 1$, considering normal and SMGs, unobscured and obscured QSOs from the literature. From the comparison with literature data, we found that, on average, obscured QSOs are associated with high SFE and low gas fraction with respect to normal star forming galaxies and SMGs. We found comparable gas fractions associated with mildly and highly obscured active galaxies. Moreover, the SFE of CT and obscured systems are similar to those of unobscured quasars. These results could be in tension with the galaxy evolution scenario or, alternatively, might suggest that feedback effects are critical from the early phases of galaxy evolution

Scaling relations and interstellar dust mass budget in galaxies

Calura Francesco - *INAF-Osservatorio di astrofisica e scienza dello spazio, Italy* - **Invited**

Interstellar dust influences the spectral properties of galaxies across a wide wavelength range (from the UV to the FIR), as well as their chemical abundance pattern, as it contains large fractions of heavy elements. Dust can be produced by means of various processes, i. e. directly in cold stellar ejecta, it can grow in the interstellar medium and it can be destroyed by astration and interstellar shocks. In this contribution, I will show how chemical evolution models of galaxies which include dust production can be a useful tool to study the redshift evolution of a few basic galactic scaling relations. In particular, the analysis of the dust-to-stellar mass ratio of galaxies of different masses allows us to derive important constraints on some of their most fundamental parameters, including the stellar initial mass function. I will also present a new, direct assessment of the evolution of the cosmic dust mass budget up to high redshift.

ALMA witnesses assembly of first galaxies

Carniani Stefano - *Scuola Normale Superiore di Pisa* - **Contributed**

Characterising the primeval galaxies of the Universe entails the challenging goal of observing galaxies with modest star formation rates ($< 100 \text{ Msun/yr}$) and approaching the beginning of the reionisation epoch ($z > 6$). To date a large number of primeval galaxies have been identified thanks to deep near IR surveys. However, to further our understanding on the formation and evolution of such primeval objects, we must investigate their nature and physical properties through multi-band spectroscopic observations. Information on dust content, metallicity, interactions with the surrounding environment, and outflows can be obtained with ALMA observations of FIR fine structure lines such as the [CII] at 158 μm and [OIII] at 88 μm . ALMA observations reveal that the [OIII] and [CII] emission in $z > 5$ star-forming galaxies are partly clumpy and partly diffuse on scales larger than 1kpc. Our analysis reveal that 9 out of 21 galaxies having ALMA [CII] detection break into multiple components and only a fraction of which, if any, are associated with the primary rest-frame UV components, while the bulk of the [CII] emission is associated with fainter rest-frame UV components, or not associated with any UV counterparts at the current limits at all. By taking into account the presence of all these sub-components, we found that the L[CII]-SFR relation in the early epoch has a dispersion two times larger than that observed in the local population. This dispersion reflects the heterogeneous properties of the primeval galaxies. We find that the [CII] luminosity is lower in high Ly equivalent width (EW) sources than those with high Ly EW, suggesting that the metallicity plays an important role on the [Cii] emission as also expected by recent simulations. The angular resolution of ALMA observations has also allow us to investigate the relation between [CII] surface brightness and star formation rate density. Finally we discuss that the complex properties revealed by ALMA in $z > 5$ galaxies are consistent with expectations by recent models and cosmological simulations, in which differential dust extinction, differential excitation and different metal enrichment levels, associated with different subsystems assembling a galaxy, are responsible for the various appearance of the system when observed with distinct tracers.

Definitive view of the ISM in the Local Universe

Casasola Viviana - *INAF IRA Bologna* - **Contributed**

Understanding the interplay between the various components of the interstellar medium (ISM: dust, atomic and molecular gas) in galaxies of the Local Universe is of fundamental importance for studies of galactic formation and evolution. In the last decade, thanks in particular to Herschel, we made a considerable effort in the study of one of these components, the dust. In this framework, the European DustPedia project has been devised aimed at performing a complete characterization of dust in the Local Universe. However, we need information on all the phases of the ISM to draw definitive conclusions on it. Nearby galaxies are characterized by an intricate system of correlations between their global properties. These correlations form the basis of the so-called “scaling relations”, which are fundamental providing a quantitative mean to characterize how physical properties of galaxies relate to each other. Galaxy scaling relations also provide a tool to study the internal physics of galaxies, as well as their formation and evolutionary histories in different galaxy populations. I present the main scaling relations computed using uniformly homogenized data of molecular and atomic gas, dust, metallicity, stellar mass, and morphology for a sample of ~ 450 nearby ($z < 0.01$), late-type galaxies extracted from the DustPedia sample. These scaling relations have been tested under several physical assumptions (e.g., constant and metallicity-dependent CO-to-H₂ conversion factor). Only such a large and coherent dataset of all phases of the ISM can provide a definitive view of the ISM in the Local Universe and permit to link it with that at high redshift, tracing its evolution. ALMA is revealing the molecular gas component and the dust at (sub-)millimeter wavelengths, while telescopes as JVLA and, in future, SKA detect the atomic gas component (the 21 cm emission line). Our approach therefore represents an example of synergy between current and future IR/(sub-)mm/cm facilities which allows us to discuss, through the ISM, our understanding of galaxy evolution from nearby galaxies up to the early Universe.

Constraints on the ISM dust-temperatures of galaxies across cosmic time

Casey Caitlin - *University of Texas at Austin* - **Contributed**

I will discuss ongoing work to characterize the ISM dust temperatures of galaxies from $z=0$ to the reionization era. There have been claims in the literature of ISM dust temperature correlation with SFR, with distance from the galaxy stellar mass-SFR relation, and evolution of the two with redshift. Comparisons between, e.g., local ULIRGs and $z \sim 2$ SMGs reveal that the latter have colder, more massive dust reservoirs that are physically more diffuse. Recent claims (Faisst+17, Behrens+18, De Rossi+18, Ma+19) further claim that dust temperatures of LIR-matched galaxies at $z > 5$ necessarily must be warmer due to the short time (< 1 Gyr) to form dust after the Big Bang, when dust may have been more silicate-rich and originating disproportionately from supernovae. Our recent work (Casey+18a,b and Zavala+18c) demonstrate that there is a dearth of observational evidence for this evolution toward warmer dust at these epochs. Instead, we find that evolution toward warmer dust SEDs is in tension with measured number counts of galaxies at 850 μ m-1.2mm from both single-dish (sub)mm and ALMA deep field surveys. This talk has relevance to the ISM content of galaxies, ALMA surveys, and very high-redshifts.

Probing the molecular gas content of normal star-forming galaxies at $3 < z < 3.5$ with ALMA

Cassata Paolo - *Università degli Studi di Padova* - **Contributed**

Although the evolution of the star-formation density of the Universe is now reconstructed up to the reionization epoch, the gas reservoir available for star formation and the efficiency of its conversion into stars are still largely unconstrained at $z > 3$, especially for galaxies on the star formation main-sequence (MS). Combining ALMA and VLA observations with different spatial resolutions ($\sim 0.6''$ to $0.2''$) we are sampling for the first time the CO emission line spectrum ($J=(1-0),(4-3),(5-4)$) for a sample of 5 massive ($M \sim 10^{10.5} M_{\text{sun}}$, $s\text{SFR} \sim 3 \text{ Gyr}^{-1}$) MS galaxies at $3 < z < 3.5$. This is the largest sample of main sequence galaxies at such redshifts with multiple CO detections, and it constitutes a golden sample with both sub-mm continuum and multiple CO transitions to calibrate the different methods to constrain the cold gas content of normal MS galaxies. The data allow to robustly measure CO luminosities and dynamical masses, and therefore to constrain the α_{CO} parameter. The galaxies turn out to be very gas rich, with gas fractions of 70-90%. By combining $0.2''$ and $0.6''$ ALMA CO(5-4) observations we robustly measure the total CO flux, as well as its spatial distribution down to 1.5 kpc scales, allowing to obtain resolved maps of gas depletion timescales and gas fractions. We find as well a variety of CO excitation SLEDs, indicating the the sources exciting the CO are diverse.

A systematic characterisation of the evolutionary cycling between molecular clouds, star formation, and feedback in nearby galaxies

Chevance Mélanie - *Heidelberg University* - **Contributed**

Star formation is one of the main drivers of galaxy evolution, but an understanding of this process remains elusive. This is caused by a lack of systematic observational constraints on cloud scales. Star formation in galaxies is expected to be highly dependent on the galactic structure and environment, as it results from a competition between mechanisms such as gravitational collapse, shear, spiral arm passages, cloud-cloud collisions, and feedback. A statistically representative sample of galaxies is therefore needed to probe the wide range of conditions under which stars form. I will present the first systematic characterisation of the evolutionary timeline of molecular clouds and star-forming regions, derived by applying the statistical method of Kruijssen & Longmore (2014) and Kruijssen et al. (2018) to homogeneous ALMA + optical observations at 50 pc resolution of a large sample of star-forming disc galaxies out to 17 Mpc (obtained in the context of the PHANGS collaboration). This method uses the multi-scale nature of the star formation relation to constrain the timeline and efficiencies for star formation and feedback on the cloud scale, across a wide variety of galactic environments. I will show that star formation is regulated by efficient stellar feedback, driving GMC dispersal on short timescales (1-5 Myr) due to radiation and stellar winds, prior to supernova explosions. This feedback limits GMC lifetimes to about one dynamical timescale (10-30 Myr), with integrated star formation efficiencies of only a few percent. Our findings reveal that galaxies consist of building blocks undergoing vigorous, feedback-driven lifecycles, that vary with the galactic environment and collectively define how galaxies form stars. These observations settle a long-standing question on the multi-scale lifecycle of gas and stars in galaxies, and open up the exciting prospect of studying cloud-scale star formation and feedback in galaxies across cosmic time.

PAHs trace the molecular gas in star-forming galaxies

Cortzen Isabella - *The Cosmic Dawn Center (DAWN), University of Copenhagen* - **Contributed**

We present new CO(1-0) line observations of 34 infrared-selected polycyclic aromatic hydrocarbon (PAH) emitters at intermediate redshift ($0.01 < z < 0.30$) to investigate the connection among PAH emission, the total molecular gas content, and the star formation rate in normal main-sequence and starbursting galaxies. Combined with observations of star-forming galaxies at low and high redshifts from the literature, our analysis reveals a universal, tight, and linear PAH-CO luminosity relation independent of redshift and star formation efficiency. This is in contrast with the PAH-IR luminosity relation where starburst galaxies appear as clear outliers. At odds with the classical picture of PAHs as SFR indicators, our results suggest the emission from PAHs can probe the molecular gas mass within a factor of 2, comparable with the CO and dust approach. This is further supported by the observed correlation between the emission from PAHs and cold dust, another reliable tracer independent of CO. Based on our results, we therefore propose the use of PAHs as a proxy for the molecular gas content in star-forming galaxies at all redshifts. As PAHs will be routinely detected with the upcoming launch of JWST, they will serve as a useful tool to investigate the cold gas properties of star-forming galaxies up to $z \sim 3$.

On the dust and gas content of high-redshift galaxies hosting obscured AGN in the CDF-S

D'Amato Quirino - *Istituto di Radioastronomia - INAF* - **Contributed**

Submillimeter Galaxies (SMGs) at high redshift are among the best targets to investigate the early evolutionary phases in the lifetime of massive systems, during which large gas reservoirs sustain vigorous star formation and efficiently feed the central, buried Super Massive Black Hole (SMBH), until it enters into luminous Quasar (QSO) phase, quenching the star formation. I will present the analysis of new ALMA band 4 (1.8-2.4 mm) data of six obscured QSOs ($\log N_H$ from X-ray spectra > 23) hosted by SMGs at redshift > 2.5 in the 7 Ms Chandra Deep Field South (CDF-S), and I will show their properties in terms of continuum emission and high-J CO transitions. Sizes and masses of the galaxies are measured to estimate whether and to which extent the host ISM may contribute to the nuclear absorption, under different geometry assumption. We found that these galaxies are massive ($\log M_{gas} \sim 10$, $\log M_{dust} \sim 8$) and compact (< 3 kpc) systems and that the ISM has column densities up to $\log N_H = 24-25$, comparable with those derived from the X-ray spectra, concluding that the galaxy ISM can substantially contribute to the AGN obscuration.

Witnessing galaxy assembly at the reionization epoch

D'Odorico Valentina - *INAF - Osservatorio Astronomico di Trieste / SNS Pisa* - **Contributed**

Damped Lyman-alpha systems are the highest column density HI absorbers observed in the spectra of high redshift QSOs. They arise in the overdense knots of the cosmic web and they trace galactic disks, or the dense clumps and filaments building primordial galaxies. They also provide the most accurate measurements of chemical enrichment of gas in the high redshift Universe. Up to now, only a small sample of $z > 2$, metal rich DLAs has been observed in emission with ALMA, to look for their galactic counterpart. I will report the detection of a pair DLA absorber/CO emitting galaxy at $z = 5.939$ and describe the interpretation of this system in the context of hydrodynamical simulations.

Impact of environment on molecular gas reservoirs probed in distant cluster and field galaxies

Dannerbauer Helmut - *Instituto de Astrofísica de Canarias* - **Contributed**

We know that environment has a critical impact on galaxy growth and evolution. What we do not know is when it starts to have an impact and how it does it. We are using the Australian Telescope Compact Array (ATCA) and ALMA to study the role of environment on the molecular gas content, the fuel of star formation, of distant star-forming galaxies. From our pilot study to search for low-surface brightness cold CO(1-0) molecular gas emission, I present the discovery of massive extended CO gas reservoirs in these star-forming galaxies that are located in the protocluster surrounding the radio galaxy, MRC1138-262 at $z=2.2$. The discovery is unexpected as gas truncation and stripping was predicted. Our results alter our view of the important topics of the development and gas phase distribution of the “proto-intracluster medium”: how ram-pressure stripping may operate in galaxy protoclusters, how the galaxies may contribute to enriching and heating the proto-intracluster medium, and how their star formation may be limited by their internal dynamics. Furthermore, I will present results of our on-going ATCA Large Program “CO ATCA Legacy Archive of Star-Forming Galaxies (COALAS)” based on our successful pilot study. Our sample consists of well-covered ‘field’-targets from the ALMA survey ALESS in the ECDFS and protocluster galaxies surrounding the Spiderweb. The ATCA CO(1-0) measurements of high- z star-forming galaxies at different environments complement our ALMA observations of mid-J CO lines and dust continuum of these sources. This survey significantly extends our study of how environment impact the cold molecular gas content, gas excitation and star-formation efficiency in cluster and field galaxies in the early universe.

Parsec scale views of the molecular gas in bulges with WISDOM

Davis Timothy - *Cardiff University* - **Contributed**

Gas rich mergers onto massive galaxies are a common occurrence as part of the cosmic baryon cycle. This gas typically falls deep into the potential well of the galaxy, forming a disc deep in the bulge. The bulge region of a galaxy is an extreme physical environment, with a deep potential well, high shear and harsh irradiation. Observationally this seems to decrease the efficiency of star formation, allowing the gas reservoirs to persist and act as a sink, slowing the baryon cycle. The physical mechanism causing this effect is less well understood. In this talk I will show that parsec scale ALMA observations, taken as part of WISDOM (the mm-Wave Interferometric Survey of Dark Object Masses), can shed light on this question. Our survey has revealed the GMC populations in a wide range of galaxy bulges across the Hubble sequence. We find that bulge dominated systems typically deviate radically from Larson’s relations, completely lacking high-mass GMCs. The mass surface density of GMCs appears to be regulated by the high external pressure in the bulge, while the lack of large clouds is due to shear (which tears large clouds apart, or stops them from forming). Thus the molecular ISM in these objects seems to be made up of very small clouds, which form a smooth disc with a very low velocity dispersion. These discs are typically shear- and Toomre-stable, likely leading to their low SFE (although stochasticity, sampling and IMF effects could lead us to underestimate the true SFR). This mechanism seems unlikely to quench galaxies directly, but shows that bulges do strongly impact the gas that lives within them, and can help explain low star formation activity in gas-rich massive galaxies.

Molecular clouds in a Milky Way progenitor observed 8 billion years ago

Miroslava Dessauges-Zavadsky - *Geneva Observatory* - **Contributed**

Thanks to the remarkable ALMA capabilities and the unique configuration of the Cosmic Snake galaxy behind a massive galaxy cluster, we could, for the first time, resolve molecular clouds down to 30 pc linear physical scales in a typical Milky Way progenitor at $z=1.036$ through CO(4-3) observations performed at 0.15" angular resolution. We identify numerous (17) individual giant molecular clouds (GMCs) that occupy the 1.7 kpc central region of the Cosmic Snake galaxy. These high-redshift molecular clouds are clearly different from their local analogues: with radii between 30 to 210 pc, they are two orders of magnitude more massive (8×10^6 - 1×10^9 Msun), one order of magnitude denser (with a median molecular gas mass surface density of 2600 Msun/pc²), and on average more turbulent (with internal velocity dispersions of 9-33 km/s). They thus are offset from the Larson scaling relations, well established for the local GMCs, and challenge the universality of molecular clouds. We argue that GMC physical properties are dependent on the galactic environment: GMCs must inherit their physical properties from the ambient ISM particular to the host galaxy. We find these high-redshift GMCs in virial equilibrium, and derive, for the first time, the CO-to-H₂ conversion factor from the kinematics of independent GMCs at $z \sim 1$. The measured large clouds gas masses demonstrate the existence of parent gas clouds with masses high enough to allow the in-situ formation of similarly massive stellar clumps seen in the Cosmic Snake galaxy in a comparable number to the GMCs. The comparison of the GMC masses and star cluster masses suggests a high efficiency of star formation, which anchors at $z \sim 1$ the recently proposed scaling of the star formation efficiency with gas mass surface density. Our results corroborate the formation of GMCs by fragmentation of distant turbulent galactic gas disks, which then turn into the stellar clumps ubiquitously observed in galaxies at cosmic noon.

ALMA Reveals the Interstellar Medium Dynamics of Hyper-luminous Obscured Quasars

Diaz-Santos Tanio - *Universidad Diego Portales* - **Contributed**

One of the most important results obtained from the WISE mission was the discovery of a previously unknown population of high redshift Hot, Dust Obscured Galaxies (Hot DOGs) at $z > 1$. The extreme bolometric luminosities of Hot DOGs, $L_{\text{bol}} > 10^{13}$ Lsun, are thought to be powered by accretion onto supermassive black holes (SMBH) buried under enormous amounts of gas and dust, effectively making them hyper-luminous obscured quasars. Depending on the time available, in this talk I will report the latest results of several follow up studies focused on the investigation of the interstellar medium and kinematic properties of Hot DOGs, including their SMBHs and host galaxies. I will pay special attention to the results of an ALMA pilot survey of the [CII] line at 158um in a sample of 7 Hot DOGs at $z \sim 3$ to 4.6. While these systems are thought to be at a key stage of their evolution, where the quasar is about to blow out its dusty cocoon, the ALMA observations show a diversity of morphologies and complex kinematic structures, surprisingly pointing to a non-unique dynamical state. In addition, ALMA has also provided us with a closer look to WISE 2246-0526, the most luminous galaxy known, where recent, deep observations of its FIR dust continuum emission reveal multiple companion galaxies and resolved filamentary structures connecting them to the central object, suggesting that accretion of neighbor galaxies may be a key mechanism through which the most luminous galaxies in the Universe grow their stellar mass, as well as feed and obscure their central SMBHs.

A magnified view of the ISM and star formation in a strongly lensed AGN hosting SMG at $z = 2.6$

Doherty Matthew - *University of Hertfordshire* - **Contributed**

Sub-mm Galaxies (SMGs) are among the most prolific star forming galaxies in the universe, with star formation rates (SFRs) up to 1000 Msun/yr. Our understanding of the nature of the dense star-forming interstellar medium (ISM) in these galaxies is still in its infancy, because it is difficult to access the spatial scales relevant for assessing the astrophysics of star formation in galaxies at high- z . “9io9” is a strongly lensed SMG at $z \sim 2.6$, with an intrinsic infrared luminosity exceeding $10^{13} L_{\text{sun}}$. The fact that it is strongly lensed allows us to examine the ISM on spatial scales of a few 100pc in a galaxy forming stars at several 1000 solar masses per year. We present new ALMA Band 4, 8 and 9 data tracing the molecular and atomic gas and thermal dust continuum in this object. We reveal evidence for a large star bursting molecular gas disc and possible molecular outflow, and present a study of the resolved dust temperature across the source (which also contains a radio-loud AGN). Our detection of both the 122 and 205um [NII] lines in 9io9, in combination with CI and CO(4-3), allow us to map the physical conditions of the ionised and molecular ISM across the source, providing a unique resolved insight into the nature of star formation at its most extreme at the peak epoch of galaxy assembly.

The nature of the strongly lensed SMG J091043.0-000322

Enia Andrea - *Università degli Studi di Padova* - **Contributed**

Some of the most vigorous starbursts that have ever occurred are found in high-redshift, dust obscured submillimeter galaxies (SMGs). However, the physical mechanisms responsible for these extreme conditions are not yet fully understood in these systems. In order to shed some light into this mystery we take advantage of the effect of strong gravitational lensing, zooming into the ISM at a kpc-scale resolution. We use a plethora of archival data from various facilities (e.g ALMA, SMA, PdBI and HST) to study the properties of the ISM in the strongly lensed galaxy SDP.11, which were discovered in the H-ATLAS survey. We build a reliable lens model for this system from high-resolution ALMA observations and use the model to reconstruct the emission at various wavelengths and study its morphology. Furthermore, the detection of various molecular lines CO, CII allow us to reconstruct the kinematics of the lensed source, finding that the star-formation activity is spread across a few kpc rotating disks. Finally, correcting for differential lensing magnification we explore the intrinsic properties of the source and compare them with the population of SMGs and ULIRGs in the local Universe.

Star Formation in Turbulent, Clumpy Disk Galaxies

Fisher Deanne - *Swinburne University* - **Contributed**

Over 2/3 of all star formation in the Universe occurs in gas-rich, super-high pressure clumpy galaxies in the epoch of redshift $z \sim 1-3$. However, because these galaxies are so distant we are limited in the information available to study the properties of star formation and gas in these systems. I will present results using a sample of extremely rare, nearby galaxies (called DYNAMO) that are very well matched in gas fraction ($f_{\text{gas}} \sim 20-80\%$), kinematics (rotating disks with velocity dispersions ranging 20-100 km/s), structure (exponential disks) and morphology (clumpy star formation) to high- z main-sequence galaxies. We therefore use DYNAMO galaxies as laboratories to study the processes inside galaxies in the dominate mode of star formation in the Universe. In this talk I will report on results from our programs with HST, ALMA, Keck, and NOEMA for DYNAMO galaxies that are aimed at testing models of star formation. We have discovered of an inverse relationship between gas velocity dispersion and molecular gas depletion time. This correlation is directly predicted by theories of feedback-regulated star formation; conversely, predictions of models in which turbulence is driven by gravity only are not consistent with our data. I will also present results from a recently acquired map of CO(2-1) in a clumpy galaxy with resolution less than 200 pc. With maps such as these we can begin to study these super giant star forming clumps at scales that are more comparable to local surveys of GMCs. I will show results for the star formation efficiency of clumps, the boundedness of clumps of molecular gas.

Dust Attenuation of Star-Forming Galaxies in the First 2Gyr of the Universe

Fudamoto Yoshinobu - *Geneva Observatory* - **Contributed**

The development of sensitive mm/submm interferometers (e.g. ALMA, NOEMA) opened a new window to the far infrared (FIR) continuum and emission lines, which enable us to investigate the obscured star-formation activity of galaxies at high redshift. Based on the recent ALMA large program ALPINE (~ 118 galaxies at $z=4.5-5.5$), we present new results on the dust attenuation of a large sample of galaxies at $z \sim 4.5 - 6.0$, and compare them with results from archival ALMA observations at $z \sim 3$. In particular, we study the relationship between the stellar mass (M^*), the UV spectral slope (β_{UV}), and the infrared excess (IRX=LIR/LUV). We find that galaxies exhibit significantly lower infrared emission than expected from lower redshift relations, suggesting an evolution of dust continuum emission properties in the first 2 Gyr. Finally, we also discuss our recent NOEMA observations of the [CII] and dust emission of an especially luminous star-forming galaxy at $z \sim 11$.

First Identification of 10-kpc Scale [CII] 158um Halos around Star-Forming Galaxies at $z=5-7$

Fujimoto Seiji - *University of Tokyo* - **Contributed**

We report the discovery of 10-kpc scale [CII] 158um halos surrounding star-forming galaxies in the early Universe. We choose deep ALMA data of 18 galaxies each with a star-formation rate of $\sim 10-70$ Msun with no signature of AGN whose [CII] lines are individually detected at $z=5.153-7.142$, and conduct stacking of the [CII] lines and dust-continuum in the uv-visibility plane. The radial profiles of the surface brightnesses show a 10-kpc scale [CII] halo at the 9.2sigma level significantly extended more than the HST stellar continuum data by a factor of ~ 5 on the exponential-profile scale length basis, as well as the dust continuum. We also compare the radial profiles of [CII] and Lya halos universally found in star-forming galaxies at this epoch, and find that the scale lengths agree within the 1sigma level. The existence of the extended [CII] halo is the evidence of outflow remnants in the early galaxies and suggest that the outflows may be dominated by cold-mode outflows, which challenges current galaxy evolution models.

[CII]-Line Properties and Star Formation-driven Outflows in high- z Galaxies: early results from ALPINE

Ginolfi Michele - *Observatory of Geneva* - **Contributed**

The ALMA Large Program to INvestigate CII at Early Times (ALPINE) is an ALMA program designed to study the gas and dust properties of a representative sample of more than one hundred main sequence star-forming galaxies with spectroscopic redshifts between $4 < z < 6$, with $SFR > \sim 10$ MSun/yr and stellar mass $\sim 9 < \log(M_{\text{star}}) < \sim 11$. I will show some preliminary results of the survey, focusing on: (1) the observed [CII] emission and its connection with other physical quantities at high- z (e.g., the well known [CII]-SFR relation, [CII]-Mstar); (2) the overall spectral properties of CII spectra and their evolution with redshift; (3) early results obtained from the stacking analysis of [CII] spectra / data-cubes, providing new insights on star formation-driven outflows, precious for our understanding of the baryon cycle driving the evolution of high- z galaxies.

High resolution ALMA imaging of SMGs

Gullberg Bitten - *Durham University* - **Contributed**

Surveys of bright sub-millimetre sources with ALMA have provided the first unbiased view of intense star formation at high redshift and have allowed for detailed studies of their structures and star formation triggers. I will present a detailed analysis of high resolution ($0.18''$) 870um continuum maps of ~ 150 sub-mm galaxies (SMGs) selected from the ALMA-SCUBA-2 UDS survey. These observations resolve the dust which traces ongoing star formation within the interstellar medium of these galaxies, and typically have infrared light profiles consistent with exponential discs. The profiles also reveal an axis ratio distribution best described by triaxial shapes. This suggest that the sub-millimetre emission is tracing bars, which are funnelling cold gas from the outer part of the galaxies into the centres. Previous studies have suggested that SMGs may be the high-redshift analogs to local merger-dominated ultra-luminous infrared galaxies (ULIRGs). However, these results and other recent studies, suggest that SMGs instead have disc morphologies, and are accreting gas from the intergalactic medium, resulting in violent disc instabilities that trigger their star formation activity. This means that ALMA - once again - is revealing important differences between high-redshift SMGs and local ULIRGs.

Resolving chemistry and clouds on galactic scales

Gutcke Thales - *MPA, Garching* - **Contributed**

I present the preliminary results from a high resolution magneto-hydrodynamical moving mesh simulation of an isolated dwarf galaxy with 4 solar mass resolution that includes star formation and stellar feedback. With this simulation, we are able to look at the small scale effects on the multi-phase ISM run with a full chemical network and see how feedback energy is transported through the gas. This model provides an ideal testing ground for different physical processes like magnetic fields, cosmic rays, and radiation and the effectiveness of feedback on sub-parsec scales. This effort is a first step towards a comprehensive multi-physics ISM model that aims to be used in fully cosmological (zoom) simulations of galaxies. This will provide a consistent galactic scale framework that resolves the cloud scales necessary to compare with the highest resolution observations offered by ALMA.

Properties of galaxies at $z \sim 6 - 9$ revealed by ALMA

Hashimoto Takuya - *Univ. Osaka-Sangyo/NAOJ, Japan* - **Invited**

Understanding properties of galaxies in the epoch of reionization (EoR) is a frontier in the modern astronomy. With the advent of ALMA, it has become possible to detect far-infrared fine structure lines (e.g. [CII] 158 micron and [OIII] 88 micron) and dust continuum emission in star-forming galaxies in the EoR. Among these lines, our team is focusing on [OIII] 88 micron observations in high- z galaxies. After the first detection of [OIII] in the epoch of reionization (EoR) in 2016 from our team ($z = 7.21$; Inoue et al. 2016, *Science* 352, 1559), there are now more than ten [OIII] detections at $z \gtrsim 6$ up to $z = 9.1$ (e.g. Hashimoto et al. 2018, *Nature* 557, 392; Tamura et al. 2019, *ApJ*, 874, 27). Interestingly, high- z galaxies typically have very high [OIII]-to-[CII] luminosity ratios ranging from 3 to 12 or higher, demonstrating [OIII] is a powerful tracer at high- z . The high luminosity ratios may imply that high- z galaxies have low gas-phase metallicity and/or high ionization states. These ALMA observations also allow us to detect / place upper limits on dust continuum emission. I will show the dust-to-stellar mass ratios of these very high- z galaxies. In addition to these ISM properties, I plan to present our detailed SED fitting results at $z \sim 7 - 9$ taking ALMA data into account, which are useful to infer the star formation history of these objects.

ALMA twenty-six arcmin² survey of GOODS-S at one millimeter (ASAGAO)

Hatsukade Bunyo - *University of Tokyo* - **Contributed**

I will present the results of the ALMA twenty-six arcmin² survey of GOODS-S at one millimeter (ASAGAO). ASAGAO is a 1.2mm deep and wide area (26 arcmin²) survey on a contiguous field. By combining with archival data in the GOODS-South field, we obtained a deeper map in the same region ($1\sigma \sim 30-60$ uJy/beam), providing the largest sample of sources (45 sources at 4.5σ) among ALMA blank-field surveys. Multi-wavelength analysis of the ASAGAO sources found that the median redshift is 2.4 and they are located on the massive end of the main sequence. ALMA-detected K-band sources exhibit systematically larger IR excess (IRX) compared to ALMA-undetected sources, suggesting that they have different dust properties such as dust distributions or compositions. We created IR luminosity functions (LFs) at $z = 1-3$, and constrain the faintest luminosity of the LFs at $2.0 < z < 3.0$. The LFs are consistent with previous results based on other ALMA and SCUBA-2 observations, which suggests a positive luminosity evolution and negative density evolution with increasing redshift. We found sources without counterparts in deep H and K-band images, whose SEDs suggest $z \gtrsim 3-5$. Their contribution to the cosmic SFR density would be consistent with bright SMGs, demonstrating the importance of ALMA unbiased survey for detecting dust-obscured star formation activities in the early universe, which have been missed in previous optical/NIR surveys.

Molecular gas properties of typical galaxies and their outflows at $z\sim 1-3$

Herrera-Camus Rodrigo - *Universidad de Concepcion* - **Invited**

In this talk I will review our current knowledge on the molecular gas masses (from CO, [CI] and dust observations), depletion timescales, gas fractions, and demographics of outflows in galaxies at $z\sim 1-3$, the time when the cosmic star formation rate density and the frequency of nuclear activity in galaxies peaked.

ALMA dense molecular gas survey of nearby ultraluminous infrared galaxies

Imanishi Masatoshi - *National Astronomical Observatory of Japan* - **Contributed**

We present our ALMA dense molecular gas survey of nearby merging ultraluminous infrared galaxies (ULIRGs) to investigate luminous buried AGNs, by distinguishing from starbursts, based on (sub)millimeter molecular line flux ratios (Imanishi et al. 2016 AJ 152 218; Imanishi et al. 2018 ApJ 856 143; Imanishi et al. 2019 ApJS in press arXiv:1902.04124). Scrutinizing luminous AGNs deeply buried in dust and dense molecular gas in merging ULIRGs is of particular importance to understand how supermassive black holes (SMBH) grow in mass during gas-rich galaxy mergers in our universe. Observations at the almost dust-extinction-free (sub)millimeter wavelength are a very powerful tool for this purpose. Since an AGN and a starburst have different radiative energy generation mechanisms (a mass-accreting SMBH vs nuclear fusion inside stars), their feedback to the surrounding molecular gas should be different, producing different (sub)millimeter molecular rotational J-transition line flux ratios, depending on primary energy sources. We found that (1) ULIRGs with luminous AGN signatures in the optical and infrared tend to show molecular line flux ratios seen in optically selected AGN-important galaxies, (2) optically and infrared elusive, but (sub)millimeter detectable extremely deeply buried luminous AGNs are present, and (3) AGN-like molecular line flux ratios are seen particularly in the nuclear regions where the putative luminous buried AGNs should reside. We argue that ALMA (sub)millimeter dense molecular line flux ratios can be a very powerful tool to understand optically elusive, deeply buried luminous AGNs in merging ULIRGs, and our energy diagnostic can be applied to distant ULIRGs because only bright molecular emission lines are used.

The first large, unbiased ALMA survey of CO at parsec resolution in the Small Magellanic Cloud

Jameson Katie - *CSIRO* - **Contributed**

The Small Magellanic Cloud (SMC) at only 1/5 solar metallicity is the only galaxy near enough to study the effect of a low metallicity environment on the physics of star formation and the ISM on small spatial scales. Understanding the effects of low metallicity is crucial for understanding galaxies in the early universe and the evolution of galaxies over cosmic time. Initial ALMA observations in the SMC show similar compact CO clumps (Jameson et al. 2018), but only small areas targeting specific star-forming regions have been mapped to date and we lack a statistically significant sample of the CO structure throughout the galaxy. We used ALMA in ACA standalone mode to map a 1.0 deg x 0.5 deg (~ 1 kpc x 500 pc) area of the Southwest Bar of the SMC at $\sim 6.5''$ resolution and cover an unprecedented range in size scales from ~ 1.5 pc to 1 kpc. Our new map shows previously undetectable small (\sim pc) molecular gas clumps, similar to what is seen in WLM (Rubio et al. 2015) and NGC 6822 (Schruba et al. 2017), but across a much larger scale. I will discuss the properties of the CO-emitting gas and how it compares to the HI gas from our new ATCA HI absorption survey and GASKAP HI map and what that reveals about the atomic-to-molecular transition at low metallicity.

Extremely cold dusty galaxies at $z=4-6$: first direct evidence of CMB impact on high- z galaxy observables

Jin Shuowen - *Instituto de Astrofísica de Canarias* - **Contributed**

We report observations of $z=6-7$ galaxy candidates IR-selected from FIR/submm observations, that are spectroscopically confirmed to be at $z=3.62-5.85$ by ALMA 3mm line scans. These galaxies have extremely cold dust temperatures, which mimicked much higher redshifts, with respect to known galaxies at $z>4$. Their dust temperatures are moderately above CMB temperatures, which thus plays a non-negligible role impacting their RJ beta-slopes and observed CO fluxes. High resolution ALMA imaging shows compact morphologies and evidences for mergers. This work reveals a population of cold dusty star-forming galaxies that were missing in current surveys. The physical mechanism accounting for their cold dust temperatures could be either rapid metal enrichment or low star formation efficiency.

Kinematics of $z\sim 4-6$ Lyman Break Galaxies in ALPINE

Jones Gareth - *University of Cambridge* - **Contributed**

The past century has seen massive improvements in the study of galaxy kinematics. Early work focused on single nearby galaxies, while current studies probe the kinematics of many objects or single objects in greater detail. With the continued use of modern IFUs and interferometers (e.g., SINFONI, ALMA), we may now study the dynamics of galaxies at high redshift. However, the sample of galaxy observations at $z>4$ that featured the sensitivity and resolution for rotational analysis or resolved dynamical characterization has been small. Even with this limitation, multiple ongoing mergers have been detected at $z>5$, and slight evidence for ordered rotation is present for some main sequence and starburst galaxies. The ALMA Large Program to INvestigate CII at Early Times (ALPINE) targeted 122 LBGs at $z=4-6$, representing a vast increase in the sample size of possibly dynamically interesting sources. Initial analysis of this dataset has revealed multiple merging systems, and evidence for rotation in both targeted and serendipitous field galaxies. Current work focuses on simulated observations of model galaxies, in order to test whether intrinsic properties can be extracted from low resolution and low sensitivity observations. The characterization of both dynamically disturbed mergers and relaxed, rotating disks in the epoch between the end of reionization and cosmic noon will be useful for models of galactic evolution.

Comparing Molecular Gas Tracers at $z\sim 2$: Do CO and dust continuum emission trace the same regions of the ISM?

Kaasinen Melanie - *Max Planck Institute for Astronomy* - **Contributed**

We have compared resolved and unresolved observations of the CO and dust continuum emission from star-forming galaxies at $z\sim 2$ (taken with ALMA). The molecular gas phase of the interstellar medium is a crucial component of star-forming galaxies, hosting, and providing the fuel for, star formation. Constraining the total mass and spatial distribution of molecular gas is therefore critical to understanding the evolutionary state of a galaxy, which can be characterised by how efficiently, and where, star formation is occurring. To determine the total molecular gas mass of high- z galaxies, the community currently relies on two main approaches: measuring either (1) a CO line luminosity, or, (2) dust continuum emission. Thanks to ALMA, these molecular gas tracers have now been observed for large samples of high- z galaxies, and it is assumed that the two lead to equivalent measurements of the molecular gas content. In our recent work we showed that, at least for some galaxies, this assumption is indeed correct. However, recent low-resolution imaging indicates that the CO and dust continuum may trace different galactic regions, with the dust continuum emission being more centrally concentrated. We investigate this claim using matched, high-resolution observations of CO and the dust continuum in $z\sim 2$ main sequence galaxies. I will present our comparisons of the CO and dust-derived molecular gas properties of star-forming galaxies at $z\sim 2$, and, will discuss the implications for future molecular gas studies with ALMA.

Gas and star formation at sub-100 pc scales in lensed hyper-luminous SMGs at Cosmic Noon

Kamieneski Patrick - *University of Massachusetts Amherst* - **Contributed**

Submillimeter galaxies (SMGs), or dusty star-forming galaxies (DSFGs), are natural laboratories for studying the physical processes involved in the rapid growth and quenching of massive galaxies during Cosmic Noon ($z \sim 1-3$). Their short-lived, extreme starburst phase ($\text{SFR} \sim 100+ \text{ Msolar/yr}$) implies a need for converting large quantities of molecular gas into stars in a very efficient way. However, understanding the physical processes at work in SMGs requires multi-wavelength information at sub-kpc or better spatial resolution. While there is a growing body of data on SMGs, it is still very observationally expensive to reach this resolution with even the best man-made facilities and interferometers, and studies are drastically limited to small sample size by necessity. An increasingly popular alternative is to exploit the amplifying and magnifying properties of strong gravitational lensing. Lensing can enable sensitive studies of sub-kpc and even sub-100pc scales in high-redshift galaxies, with much reduced integration time. This is done by modeling the distortion due to lensing and reconstructing the source-plane with an improved resolution beyond the diffraction limit. Using our sample of lensed SMGs selected with Planck and WISE all-sky surveys, we are able to study the source-plane morphology, distribution, and kinematics of gas, star formation, and stellar light with our ALMA, JVLA, and HST programs. Because lensing is achromatic, the same mass model can be used to reconstruct all wavelengths in the same way. With ALMA in particular, we can study the structure of CO emission and 1mm continuum down to <100 pc scales in a sample of 15 objects. Simultaneously, with JVLA, we can explore the presence of AGN and their connection to their star-forming host galaxies. The lensing reconstruction method is a novel way to study the physical processes governing the ISM of distant galaxies at an unprecedented physical resolution similar to our view of nearby galaxies.

Kinematics of $z > 6$ galaxies from [CII] line emission

Kohandel Mahsa - *Scuola Normale Superiore di Pisa* - **Contributed**

We study the kinematical properties of galaxies in the Epoch of Reionization (redshift $z > 6$) via the [CII] line emission. The line profile provides information on the kinematics as well as structural properties such as the presence of a disk and satellites. To understand how these information are encoded in the line profile, we have first developed analytical models from which we identify disk inclination and gas turbulent motions as the key parameters affecting the emission line profile. To gain further insights, we use “Althaea”, a high-resolution (30 pc) simulated prototypical Lyman Break Galaxy, in a cosmological environment. At $z = 6-7$ Althaea shows a disk structure with radius ~ 0.5 kpc. Its evolution presents three main evolutionary stages: I) Spiral Disk, II) Disturbed Disk, and III) Merger. By comparing the [CII] spectral profiles in these stages with the analytical galaxy model, we identified the spectral signatures of spiral arms, outflowing gas, and merger events in both face-on and edge-on views of Althaea. Comparing the extremely structured synthetic spectra to the observed galaxies, we find that Althaea in low inclinations has a similar FWHM to the observed galaxies (~ 180 km/s). We generalize the form of dynamical mass function vs. FWHM of the [CII] line for various structure of a galaxy. By knowing the exact inclination of the galaxy, this function has the lowest errors in estimating the galaxy mass while assuming a fixed inclination can increase this error to a factor of ~ 4 . A Tully-Fisher like relation $L_{\text{[CII]}} \propto \text{FWHM}^{1.8}$ is found for the observed high- z galaxies. We derive the general form of such relation and find that the value of the empirical fit is consistent with the theoretical guess. In this relation, we see a bias in non detection of lines with large FWHM and low luminosity (higher inclinations of small galaxies). By re-binning Althaea’s spectra with channel width < 300 km/s, we clarified that edge-on views are more difficult to detect, suggesting this situation might be the cause of some of the non-detections in [CII] reported for the high- z observations.

A detailed ALMA look into the NGC253 starburst and its connection to the Galactic Center

Nico Krieger - *Max Planck Institute for Astronomy* - **Contributed**

We present high-resolution ALMA observations of the central star-forming region in the nearby nuclear starburst NGC253. The ALMA cycle 3 observations in band 7 offer unprecedented detail at 2.5pc (0.15") spatial resolution for the CO(3-2) line, as well as the dense gas tracers HCN(4-3), HCO+(4-3), CS(7-6) and the 350GHz dust continuum. This high resolution opens the nearby universe to studies previously limited to the Milky Way. As our spatial resolution approaches that of giant molecular clouds, we are able to directly measure the kinetic gas temperature: Molecular gas in the star-forming disk is typically warmer than 50K with a peak of 75K that coincides with the peak in the 350GHz dust continuum emission. Beside the prominent south-western gas streamer that has been studied in previous, lower-resolution imaging, we further identify a dozen kinematically distinct outflowing structures that are visible in CO(3-2). By fitting these features, we derive size, mass, velocity gradient, internal kinetic energy and kinetic energy relative to the launching site. The launching site is reconstructed in position-position-velocity space in the plane of the sky and radial velocity by tracing back the outflowing structures to the molecular gas disk. We find the launching sites to lie close to sites of current high-mass cluster formation. Exploiting the high resolution, we can directly compare the ISM properties in the center of NGC253 to the Milky Way Galactic center at the cloud scales relevant to star formation. Assessing the turbulent ISM through the linewidth-size relation shows that the molecular ISM in both systems is remarkably similar given the vastly different star formation rate and thus feedback strength. In NGC253, we determine the molecular mass outflow rate driven by the starburst to be $\sim 30 M_{\text{sun}}/\text{yr}$.

The baryon cycle from molecular clouds to galaxies

Kruijssen Diederik - *Heidelberg University* - **Contributed**

The baryon cycle between galaxies and the intergalactic medium (IGM) determines the composition of galaxies, but their ability to form stars and return mass, metals, and energy to the IGM through stellar feedback is set by molecular cloud-scale physics. I will present a unified picture of star formation and feedback in galaxies, by presenting a multi-scale description of the star formation relation between the gas mass (density) and the star formation rate (density), i.e. from individual giant molecular clouds (GMCs) to entire galaxies. I will show how the star formation relation exhibits a strong dependence on the spatial scale, environment, and interstellar medium (ISM) phase. I will demonstrate that this multi-scale behaviour represents a fundamental test for star formation and feedback models applied in numerical simulations of nearby and distant galaxies. This test enables current models to be falsified and improved, of which I will present key examples. I will use recent ALMA observations of nearby galaxies to demonstrate that the GMC-scale star formation relation underpinning the above processes is closely coupled to the galaxy-scale conditions. These GMC-scale physics set the structure of the ISM, which I will show has an important impact on the efficiency and mass loading of galactic winds feeding back into the IGM. Together, these results help unify the great variety of empirical manifestations of the star formation relation in observed and simulated systems, from nearby galaxies to the distant Universe, and quantitatively link the baryon cycle on super-galactic scales to that on sub-galactic scales.

Gas dynamics at $z=4.8$ with high-resolution ALMA observations

Lelli Federico - *European Southern Observatory* - **Contributed**

I will present fresh, high-sensitivity and high-resolution ALMA observations of the [CII] line in a massive galaxy at $z=4.8$. We reach a spatial resolution of 0.1 arcsec (corresponding to ~ 650 pc) which allows us to study the gas distribution and kinematics with unprecedented details at this cosmic epoch. The [CII] emission extends out to ~ 4 kpc and traces a regularly rotating disk with no indications of strong non-circular motions (inflows or outflows). This is remarkable considering that the galaxy is forming $1000 M_{\text{sun}}/\text{yr}$ and hosts an AGN. There is also a hint of a flocculent spiral structure in the disk. The rotation curve rises steeply in the inner parts, then displays a mild decline and becomes flat in the outer regions. This is similar to bulge-dominated disk galaxies at $z=0$. I will also present the first rotation-curve decomposition in luminous and dark matter components at these redshifts. Finally, I will discuss the prospects of using high-resolution ALMA observations of the [CI] and [CII] lines to study dynamical scaling laws (like the Tully-Fisher and Radial Acceleration Relations) from $z=2$ to $z=6$.

ALMA Brings Molecular Gas in Galaxies Into Focus

Leroy Adam - *The Ohio State University, Department of Astronomy* - **Review**

Over its first few years of operation, ALMA has dramatically sharpened our view of cold gas in galaxies. I will review highlights from these first few years. These include resolving cold gas disks and outflows from centers of active galaxies, discovering forming star clusters in dwarf and starburst galaxies, and directly imaging the dense, star-forming gas in other galaxies. I will also give an overview of ALMA's first Large Program targeting nearby galaxies. PHANGS ALMA is carrying out the first high completeness, wide area survey of individual molecular clouds across the whole nearby galaxy population. Using CO 2-1 emission, this survey traces the structure and kinematics of gas at ~ 100 pc resolution across more than 80 nearby star forming galaxies. These observations reveal a highly structured medium in which the distribution and properties of cold gas clouds are closely coupled to the host galaxy and galactic environment. When the cold gas seen by ALMA is contrasted with signatures of high mass star formation, these same observations show a violent cycle of cloud collapse and feedback. Based on what ALMA has done so far, I will also call out some of the major questions for the next five years.

Probing ISM conditions of high redshift galaxies with dust emission: A view from the FIRE simulations

Liang Lichen - *Institute for Computational Science, University of Zurich* - **Contributed**

Dust thermal emission is important tool for constraining ISM conditions of high redshift galaxies. However, the physical interpretation of its SED is very challenging as it is unclear how various galaxy properties shape the dust SED. Radiative transfer analysis of cosmological galaxy models provides many valuable insights. In the first part of my talk, I will discuss the method of using broadband fluxes in the Rayleigh-Jeans (RJ) tail as proxy for molecular gas mass (Scoville+2014; Scoville+2016; Liang+2018). Compared to the traditional CO method, this approach is time-efficient. Using a galaxy sample that is extracted from the high-resolution cosmological simulations from the Feedback in Realistic Environment (FIRE) project, I will show that sub-millimeter (submm) luminosity and molecular ISM mass are tightly correlated and that the overall normalisation is in quantitative agreement with observations (Scoville+2016) from $z \sim 2$ up to higher redshifts, including during starbursts. Our result supports the empirical approach of using broadband submm fluxes as a reliable proxy for molecular gas content in high- z galaxies. [arXiv: 1804.02403] In the second part of the talk, I will focus on the topic of dust temperatures. The RJ approach of dust/ISM mass estimates depends on an assumed dust temperature, which is close to the mass-weighted temperature (T_{mw}). I will show that the observationally-derived dust temperatures generally differ from, and are even poor proxy for T_{mw} . We find that dust temperatures based on the peak emission wavelength (T_{peak}) increase with redshift, in line with the higher star formation activity at higher redshift, and are strongly correlated with the specific star formation rate. In contrast, T_{mw} does not strongly evolve with redshift over $z = 2 - 6$ at fixed IR luminosity but is tightly correlated with LIR at fixed z . We also analyse an equivalent dust temperature (T_{eqv}) that is commonly used for converting single (sub)millimeter flux density to total IR luminosity, and provide a fitting formula as a function of redshift and dust-to-gas ratio. I will show that galaxies of higher T_{eqv} (or higher T_{peak}) (“warmer dust”) do not necessarily have higher T_{mw} . The rise of T_{eqv} with redshift, which is implied by recent observational evidence, including the low number counts of submm sources in ALMA blind surveys and the unusual IRX-beta relation of high- z galaxies (Bouwens+2016, Casey+2018), is not simply a sign of dust being physically hotter but rather a consequence of a change in SED shape. A two-phase picture for interstellar dust can explain the differences of the various dust temperatures, and is critical for proper interpretation of star-forming conditions of high- z galaxies. [arXiv: 1902.10727]

Cold gas across cosmic time from CO and [C II] serendipitous discoveries

Loiacono Federica - *Università di Bologna* - **Contributed**

Studying molecular gas in high-redshift galaxies is important to unveil the mechanisms regulating the cosmic star formation history. Molecular gas is indeed the fuel from which stars form and investigating its evolution across cosmic time is crucial to constrain the drivers of galaxy growth. Targeted observations of galaxies pre-selected based on their stellar mass, star formation rate and/or far-infrared luminosity have been instrumental to shape our understanding of the connection between the gaseous reservoirs and the build-up of galaxies; however, the pre-selection may introduce biases associated to our prior knowledge of the emitting systems. On the other hand, blind surveys, as well as serendipitous discoveries in observations targeting other sources, allow us to circumvent any potential selection bias, thus enabling a proper census of the molecular gas properties in a volume-limited region of the universe. Here I will present a study on the evolution of cold gas based on serendipitous discoveries in ALPINE, an ALMA large program intended to study the [C II] 158 μ m emission in 122 galaxies at high-redshift ($z \sim 4-5$). Our “blind” search revealed more than 70 serendipitous detections of high-J CO and [C II] line candidates, as well as continuum sources, in the redshift range $0.6 < z < 5$. These serendipitous sources allow us to investigate how the cold gas content of galaxies evolved across cosmic time. In particular, these line emitters allow us to place first constraints on the luminosity function of [CII] and high-J CO lines throughout a wide span of cosmic history.

Kinematics and dynamics of molecular gas in high redshift quasars

Lupi Alessandro - *Scuola Normale Superiore* - **Contributed**

Molecular hydrogen (H₂) is a fundamental component of galaxies, being the most abundant element in molecular clouds, where stars form, and an important source of radiative cooling at low temperature. With the advent of the ALMA telescope, we have started to collect data of the H₂ distribution in galaxies with unprecedented resolution. In particular, we are now starting to resolve the distribution of molecular gas in high redshift quasar hosts, and this is giving us important information about the kinematics and dynamics of these systems. However, the large majority of numerical simulations on galactic and cosmological scales still lacks the ability to directly follow the formation and dissociation of H₂, and must rely on pre-calibrated sub-grid models to compare the results with observations. I will present a numerical study of the H₂ kinematics and dynamics in a massive halo at $z=6$, expected to be a quasar host, in which I self-consistently follow the evolution of H₂ with non-equilibrium chemistry, including gas and dust shielding, H₂ self-shielding, star formation, supernova feedback, and extragalactic and local stellar radiation. I will discuss in particular the interplay between the central AGN and its galaxy host, and the launching of outflows, both in the ionised/neutral and molecular phase. I will also show that the apparent obesity of high-redshift massive black holes is due to the gas tracers employed, and not to different intrinsic properties of the systems.

Molecular outflows in the local universe

Lutz Dieter - *MPE* - **Contributed**

We have obtained new detections and limits from a NOEMA and ALMA CO(1-0) search for molecular outflows in 13 local galaxies with high far-infrared surface brightness, and combine these with local universe CO outflow results from the literature. I will discuss constraints from line ratios and spatial structure on optically thick/thin CO emission and the conversion steps from observables to physical quantities such as molecular mass outflow rates. There is good agreement between the two main methods for molecular outflow detection: CO mm interferometry and Herschel OH-based spectroscopic outflow searches, in particular for the Gonzalez-Alfonso et al. (2017) sample of 12 bright ULIRGs with detailed OH-based outflow modelling. This spells good news for OH outflow studies with ALMA at high redshift, or with future space facilities like SPICA. Outflow properties correlate better with AGN luminosity than with far-infrared surface brightness, supporting other indications for an important role of, likely intermittent, AGN driving of these outflows.

The role of AGN-feedback in the baryon cycle of $z\sim 2$ galaxies: what we learn from the ionized and molecular gas kinematics

Mainieri Vincenzo - *ESO* - **Contributed**

Theoretical models of AGN radiative feedback predict that AGN-driven, galaxy wide massive outflows are not a rare and peculiar phenomenon, but a fundamental process affecting the bulk of the baryons in the universe. I will report the results of our on-going studies to address three questions: a) demography of AGN driven outflows on a statistical sample of AGN; b) how the properties (e.g. energetics and geometry) of such outflows are connected with the properties of the central SMBH; c) which is the impact of such outflows on the gas content of the host galaxy. The studies are focused on $z\sim 2$ AGNs, and they are based on data taken with SINFONI (SUPER survey and archival data) to trace the ionized gas and ALMA CO observations to trace the molecular gas content.

ALCHEMI: First Results from the ALMA Comprehensive High-resolution Extragalactic Molecular Inventory of NGC253

Mangum Jeff - *NRAO* - Contributed

The dramatic increase in sensitivity and frequency coverage of radio, millimeter, and submillimeter facilities in the last decade has made it possible for the first time to study the chemical complexity of the molecular interstellar medium (ISM) in galaxies beyond the Milky Way. Both spatially resolved observations in nearby galaxies (e.g., Meier & Turner, 2005; Meier+2015; Martin+2015, Izumi+2015) and unresolved surveys (e.g., Krips+2008; Costagliola+2011) have gathered substantial evidence of a great variety in molecular gas composition and excitation across galaxies. Spectral line surveys (e.g., Martin+2011, Aladro+2015, Costagliola+2015) reveal significant differences in the chemical properties of the ISM in starburst galaxies, and suggest that chemistry may be an important diagnostic of evolutionary stage. ISM chemical cycling and enrichment by star formation can be assessed through observations of molecular isotopologues and the derivation of isotopic ratios (e.g., the $^{12}\text{C}/^{13}\text{C}$ and $^{16}\text{O}/^{18}\text{O}$ ratios: Rangwala+2011, Henkel+2014, Falstad+2015). ISM energy exchange and mechanical feedback from the starburst process can be studied through other molecular species that trace shocked gas and dust (e.g., SiO, HNC, CH₃OH: e.g., Garcia-Burillo+2001, Usero+2006, Meier & Turner 2012). Ultimately, molecular tracers of ISM chemistry probe the fundamental regulation of the star formation process in galaxies. To this end, we are conducting a multi-band spectral line survey within the nearby starburst galaxy NGC253. The ALMA Comprehensive High-resolution Extragalactic Molecular Inventory (ALCHEMI), an ALMA Cycle 5 Large Programme, encompasses the entirety of ALMA Bands 3, 4, 6, and 7 (85 to 366 GHz). A complimentary ALMA Cycle 6 program adds imaging of the ALCHEMI field at ALMA Band 5. ALCHEMI images the central several hundred parsec area of NGC253 using both the 12m Array and the Atacama Compact Array (ACA) to cover most of the central molecular zone (50x20 arcsec field) at 1.5 arcsec (25 pc) spatial and 10 km/s spectral resolution, with sensitivity to spatial structure $< \sim 15$ arcsec. These measurements will allow us to resolve the molecular cloud structure on giant molecular cloud scales. As of March 2019 all observations are complete. Analysis to-date has focused on spectral line identification in order to assess the average chemical composition in NGC253 and compare this chemical composition to that within other galaxies and Galactic sources. A preliminary analysis using the MADCUBA (Martin et. al. in prep) line identification tool of the ACA observations has uncovered the surprisingly rich molecular complexity even at the relatively low spatial resolution (~ 10 arcsec) of our ACA measurements of NGC253. This MADCUBA analysis has revealed (1) Spectral line transitions with intensity greater than $1 \text{ mJy} = 3978$, (2) Identification of 50 molecular species and 33 isotopologues, and (3) Seven of these species are new extragalactic identifications. The ALCHEMI collaboration is currently completing its molecular inventory of the NGC253 CMZ and has started the process of studying the detailed physical and chemical environment within the GMCs of NGC253. In this presentation I will present results from a wide range of research projects currently being conducted with the ALCHEMI survey.

Investigating the ISM of local Seyfert galaxies by modelling their CO SLED

Mingozzi Matilde - *Università di Bologna - Osservatorio Astrofisico di Arcetri* - **Contributed**

I will present a coherent multi-band analysis of the CO Spectral Line Energy Distribution (SLED) of two local Seyfert galaxies, NGC 34 and NGC 7130. These galaxies are prototypes of systems where the star formation and the accretion onto supermassive black holes coexist. The goal of the proposed study is to assess the impact of the two mechanisms on the physics of the molecular gas. We carried out our investigation by modelling the observed CO SLED, taking advantage of ALMA, Herschel, XMM and NuSTAR data. X-ray data analysis confirmed the presence (and allowed us to measure the power) of a heavily obscured AGN in both systems, whereas ALMA high resolution allowed us to scan the nuclear region, where the influence of the accretion could dominate, down to a spatial scale of ~ 100 pc for the CO(6-5) transition. We considered Photo-Dissociation Region (PDR), X-ray-Dominated Region (XDR) and shock models. PDRs are regions whose physics and chemistry are mainly dominated by far UV radiation produced by OB stars, while XDRs are influenced by the presence of X-ray photons, possibly due to an AGN. UV and X-ray radiation causes a different luminosity distribution over the CO rotational lines, since X-ray photons have a higher gas heating efficiency and are capable of penetrating at a larger column density of the gas than UV photons, causing the resulting CO SLEDs to be peaked at higher-J rotational transitions. Shock waves, originating from the supersonic injection of mass into the interstellar medium by stellar winds, supernovae and/or young stellar objects, can compress and heat the gas above $T \sim 100$ K, making the high-J CO rotational energy levels more populated. Both in NGC 7130 and in NGC 34, we found that the low-J transitions can be explained by PDRs, whereas the high rotational ladder requires the presence of a separate source of excitation, that we identified with X-ray heating due to the AGN. Hence, the observed CO SLED can be reproduced by adopting a composite PDR+XDR model, demonstrating that also the influence of the AGN is needed to reproduce the observed molecular emission (Pozzi et al. 2017, Mingozzi et al. 2018). Our study clearly indicates the capabilities offered by the current generation instruments at different wavelengths in shedding light on the properties of nearby galaxies, adopting the state-of-the-art physical modelling. The future exploitation of the data in the ALMA archive will allow us to enlarge the sample and place the results of NGC 34 and NGC 7130 on a more statistically significant context. Moreover, we intend to extend the analysis performed on the CO to other molecules, such as HCN, HCO+, for which we have already required and obtained APEX data (P.I. Francesca Pozzi), and we aim to obtain ALMA observations. These molecules, characterised by higher critical densities ($\log(n/\text{cm}^{-3}) = 5 - 6$) than CO, allow to trace a different parameter space of the giant molecular clouds, and their flux ratios permit to envisage the presence and strength of an AGN.

A theoretical view of dust in galaxies near and far

Narayanan Desika - *University of Florida* - **Review**

I will present a model for cosmological galaxy evolution that includes the formation, growth, and destruction processes of dust in the interstellar medium. After reviewing the pertinent physics driving these processes, I will show how these can provide insight into the formation of the earliest dusty star forming galaxies in the Universe, the growth of the dust mass function over cosmic time, and the properties of extinction and attenuation at all redshifts.

Interstellar medium in the early universe: a multi-line ALMA survey of a redshift 7.5 quasar

Novak Mladen - *Max Planck Institute for Astronomy, Heidelberg, Germany* - **Contributed**

Observations of high redshift galaxies represent the frontier that pushes our understanding of the early universe. In this endeavour quasars can be of great assistance due to their extremely large luminosities powered by supermassive black hole accretion and their non-transient nature. I will present new ALMA observations of quasar J1342+0928 at redshift of 7.5, which currently holds the record as the most distant quasar detected. We have conducted a multi-line survey of this galaxy targeting multiple atomic fine structure lines and molecular lines in the far infrared regime. Such a line survey allows us to probe in detail the properties of the interstellar medium of the host galaxy such its density, radiation field, ionisation state and gas mass, when the universe was only 0.7 Gyr old. Given continuum detections across multiple ALMA bands we can now provide much tighter constraints on the dust mass of the host galaxy. We also have secure detections of [CII] 158um, [NII] 122um, and [OIII] 88um lines, yielding unprecedented amounts of information at these early cosmic epochs.

Molecular outflows in young AGN

Oosterloo Tom - *Netherlands Institute for Radio Astronomy (ASTRON)* - **Contributed**

AGN-driven gas outflows are thought to play an important role in the evolution of galaxies, through their impact on the evolution of star formation in galaxies as well as on the growth on the central supermassive black hole of the host galaxy. Much of the detailed physics of these gas outflows, what drives them, and their actual impact on the host galaxy, is still not well understood. We will present the results from recent ALMA observations of the nearby quasar PKS 1549-79. This object is one of the closest ($z = 0.1525$) examples of a young, radio-loud quasar where the AGN appears to be in the process of clearing the gas-rich surroundings in which it is enshrouded as the result from a recent merger. We detect a large reservoir of molecular gas ($\sim 10^{10}$ Msol) in PKS 1549-79. Most of the gas is in the form of large tidal tails, but we also see the formation of a circum-nuclear disk of a few hundred pc in size. In the very centre of PKS 1549-79 we detect a very fast, massive outflow of molecular gas driven by the AGN. Our observations clearly reveal the effect of the AGN on the ISM. While on kpc scales the observed line ratios suggest that the conditions in the ISM are normal, in the inner few hundred parsec they show that the conditions in the circum-nuclear disk are clearly affected by the AGN. We also present the results from detailed numerical simulations of a young radio jet moving through a clumpy ISM. Comparing these simulations with the observations allows us to build a 3D picture of the AGN-ISM interaction in PKS 1549-79. In addition, we compare the results on PKS 1549-79 with those obtained on the molecular outflow we earlier detected in the much less powerful Seyfert galaxy IC 5063. This comparison shows that some aspects of the jet-ISM interaction are very similar (e.g. line ratios), but there are also important differences. Interestingly, the physical extent of the region with fast outflowing gas is much smaller in the more powerful PKS 1549-79. This is consistent with the predictions from the simulations.

Dust polarization measurements in nearby galaxies to investigate magnetic fields in cold gas

Paladino Rosita - *INAF IRA Bologna* - **Contributed**

ALMA, with its unprecedented combination of resolution and sensitivity in polarization, provides a new tool to investigate the role of magnetic field in nearby galaxies. So far magnetic field structure in external galaxies has mostly been studied through synchrotron emission and its polarization. These observations though do not probe the magnetic field in the cold gas, which can be traced with dust polarization. Recent results in the Milky Way show that there is a poor correspondence between the polarization properties obtained from radio synchrotron and those obtained from dust polarization measurements. Observations of external galaxies are necessary to better investigate this issue and possibly put constraints on the models. I will present our project of observation of ALMA dust polarization in a small sample of nearby galaxies, showing the potential of such a study in the investigation of the role of magnetic fields in regulating star formation processes and influencing galaxy evolution.

The interstellar medium and radiation field of the galaxies in the Epoch of Reionization.

Pallottini Andrea - *Centro Fermi/Scuola Normale Superiore* - **Contributed**

The characterization of primeval galaxies represent some of the biggest challenges of current observational and theoretical cosmology. This kind of studies recently entered a golden era, thanks to the unprecedented capabilities of the Atacama Large Millimeter Array. Far InfraRed fine structure lines – [CII]158 μ m in particular – are exquisite tools to search for and characterize the most remote system in the Universe. These experiments can be combined with detailed galaxy simulations to achieve a solid theoretical understanding. I will present high-resolution (10 pc), cosmological, zoom-in, radiation hydrodynamic simulations of Lyman Break Galaxies in the Epoch of Reionization. Comparing our models to the most recent FIR observations allow us to characterize and constraint the properties of the interstellar medium and radiation field of LBGs forming and evolving in the EoR. In particular, I will give key insights regarding the [CII]-SFR relation and the differences between what is observed in the local and high-redshift Universe.

The ALMA view of quasars host galaxies at the dawn of cosmic time

Pensabene Antonio - *DIFA-University of Bologna, INAF-OAS Bologna* - **Contributed**

The unparalleled capabilities of ALMA have opened a new window to study galaxy formation even at the earliest cosmic times. High-resolution maps of bright ISM lines, such as [CII] or CO, allow us to map the gas kinematics in galaxies even at the largest redshifts. By surveying multiple ISM tracers, we can infer first quantitative constraints on the physical properties (density, temperature, ionization state, excitation mechanism) of the star-forming medium. In this talk, I will capitalize on both these approaches to study the early evolution of quasars and their host galaxies at $z > 4$. We infer dynamical masses for a sample of $z > 4$ quasar host galaxies observed at high angular resolution in [CII], and we compare them with the central black hole masses to test the onset of the black hole – host galaxy relations observed in the local universe. We then study the impact of the luminous accreting black hole on the ISM properties of the host, by comparing the emission of various gas tracers (OH, H₂O, [NII], high-J CO) in pairs of galaxies with and without a luminous quasar at $z > 6$. Finally, I will discuss how these results fit within the co-evolution scenario and highlight their impact for our understanding of the early evolution of massive galaxies.

AGN in dusty starbursts at $z=2$: feedback still to kick in

Rodighiero Giulia - *University of Padova* - **Contributed**

We investigate a sample of 152 dusty sources at $1.5 < z < 2.5$ to understand the connection of enhanced Star-Formation-Rate (SFR) and Black-Hole-Accretion-Rate (BHAR). The sources are Herschel-selected, having stellar masses $M_{\star} > 10^{10} M_{\text{sun}}$ and SFR ($\sim 100\text{-}1000 M/\text{yr}$) elevated ($>4\times$) above the star-forming “main sequence”, classifying them as Starbursts (SB). Through a multiwavelength fitting approach (including a dusty torus component), we divided the sample into active SBs (dominated by an AGN emission, SBs-AGN, $\sim 23\%$ of the sample) and purely star-forming SBs (SBs-SFR). We visually inspected their HST/UV-rest-frame maps: SBs-SFR are generally irregular and composite systems; $\sim 50\%$ of SBs-AGN are instead dominated by regular compact morphologies. We then found archival ALMA continuum counterparts for 33 galaxies (12 SBs-AGN and 21 SBs-SFR). For these sources we computed dust masses, and, with standard assumptions, we also guessed total molecular gas-masses. SBs turn to be gas rich systems ($f_{\text{gas}} = M_{\text{gas}} / (M_{\text{gas}} + M_{\star}) \sim 20\%\text{-}70\%$), and the gas fractions of the two SB classes are very similar ($f_{\text{gas}} = 43 \pm 4\%$ and $f_{\text{gas}} = 42 \pm 2\%$). Our results show that SBs are consistent with a mixture of: 1) highly star-forming merging systems (dominating the SBs-SFR), and 2) primordial galaxies, rapidly growing their M_{\star} together with their Black Hole (mainly the more compact SBs-AGN). Anyway, feedback effects have not reduced their f_{gas} yet. Indeed, SBs at $z = 2$, with relatively low bolometric AGN luminosities in the range $10^{44} < L_{\text{bol}}(\text{AGN}) < 10^{46}$ (compared to bright optical and X-ray quasars), are still relatively far from the epoch when the AGN feedback will quench the SFR in the host and will substantially depress the gas fractions.

Dissecting sub-millimeter galaxies: ALMA studies of dust and gas on (sub-)kpc scales

Rybak Matus - *Leiden Observatory, the Netherlands* - **Invited**

Sub-millimeter galaxies (SMGs) play a key role in the epoch of the peak star-forming activity of the Universe. With star-formation rates of a few hundred M_{sol}/yr , they constitute a major stage in the evolution of massive galaxies and provide an important laboratory for understanding intense star formation. Since the first studies in the 1990s, our understanding of SMGs has been hampered by the relatively low angular resolution and sensitivity of (sub-)mm telescopes and interferometers. The lack of resolved dust and gas observations has offered only very limited insight into the two main questions about the nature of SMGs: - What drives the intense star-formation in SMGs? - What are the physical properties of the star-forming ISM, and how do they vary across the galaxies? The last five years have seen massive progress in piecing together the answers. This has been mainly thanks to the long-baseline capability and superb sensitivity of ALMA, which now allows routine studies of dust continuum and molecular gas on (sub-)kpc resolution. I will summarize recent results from the high-resolution (sub-)kpc ALMA studies of submillimeter galaxies in both dust continuum and fine-structure and molecular emission lines. These have revealed robust evidence for complex, tidally-induced substructures in the dust continuum and spatial variations in ISM properties on (sub-)kpc scales.

Molecular gas and dust in the nearby Universe: the global perspective

Saintonge Amelie - *University College London* - **Invited**

State of the art facilities operating at submillimeter-to-radio wavelengths are allowing us not only to look at gas and dust in galaxies at remarkably high spatial resolutions, but also to probe very large, representative samples, giving us a thorough census of the local galaxy population. In this talk I will review results from surveys such as xCOLD GASS and JINGLE that are designed to provide an unbiased view of the cold ISM across the nearby galaxy population, and to connect it to the global physical properties of the host galaxies. The scaling relations that emerge from these studies allow us to test models of galaxy evolution and feedback, understand star formation and quenching, and highlight the multi-scale nature of the star formation process.

New observations of Dust and [CII] in the Epoch of Reionization

Schouws Sander - *Sterrewacht Leiden* - **Contributed**

Achieving a physical characterization of galaxies in the reionization epoch has been a long-standing goal in extragalactic astronomy. Fortunately now significant progress is being made thanks to advances made possible by ALMA. Recent results have shown detection of bright like [CII]158um and [OIII]88um and also dust continuum in a number of sources. These observations offer a unique and powerful insight into the physics governing these extreme objects. Thanks to new ALMA observations from two programs over extremely luminous $z \sim 7-8$ galaxies identified from wide-area fields, we have gained a better understanding of the physical properties of bright galaxies in this epoch. We have detected 4 new galaxies in the dust continuum, doubling the number of dust detections in the epoch of reionization, while allowing us to put interesting constraints on the obscured star formation and dust properties of these bright galaxies. We have furthermore detected 3 new luminous [CII]158um lines and a number of [CII] line candidates, including the most distant [CII] detection to date, allowing us to gain better insight into dynamical masses, redshift distributions, and physical properties of the interstellar medium in galaxies during the first billion years of the universe.

The Cloud-scale Baryon Cycle of Nearby Galaxies

Schruba Andreas - *Max Planck Institute for extraterrestrial Physics* - **Contributed**

A detailed understanding of the physical processes driving the baryon cycle in galaxies is paramount to understand galaxy evolution. In the past decade, surveys of the interstellar medium (ISM) and young stellar population have constrained the balance between atomic and molecular gas and star formation rate at kpc-scales in nearby galaxies, but remained inconclusive on the underlying physical processes. Today, observatories like ALMA, JVLA, VLT/MUSE, and HST can overcome these limitations by resolving nearby galaxies at the fundamental scale of star formation: individual star-forming regions. I will summarize recent results from the PHANGS ALMA and MUSE Large Programs and extensive surveys of Local Group galaxies that provide a detailed characterization of ISM properties, star formation process, and stellar feedback with unparalleled statistics and range in host galaxy properties. These include the finding of a strong metallicity dependence of the atomic-molecular gas transition as suggested by shielding-based theories. The finding of ubiquitous diffuse molecular gas. A common self-regulated dynamical state of molecular gas in gas-rich galaxies, which however is altered by host galaxy properties in low-density environments. Then, I will explore how the efficiency of star formation depends on cloud properties and galactic environment, and contrast this with analytical theories. In summary, these surveys deliver a detailed observational description how the star formation process on cloud-scales connects to host galaxy properties and play a vital role in advancing our understanding of the physical processes controlling the baryon cycle in galaxies.

The Close AGN Reference Survey: Discovering a [CII] line excess in a multi-phase AGN-driven outflow

Smirnova-Pinchukova Irina - *Max-Planck-Institut für Astronomie, Heidelberg* - **Contributed**

I present the first results from the Close AGN Reference Survey (CARS, www.cars-survey.org) of 39 nearby ($0.01 < z < 0.06$) Seyfert 1 galaxies. The survey consists of spatially-resolved multi-wavelength observations from X-ray to radio including an extensive VLT/MUSE IFU dataset. Feedback processes from the nuclear activity can substantially affect the interstellar media (ISM) of the host galaxy via photoionization and jet-driven shocks and turbulence. The main aim of the CARS project is to map the multi-phase ISM to quantify the AGN impact on the host galaxies. In particular the [CII] 158-micron far-infrared (FIR) emission line is linked to different gas phases of the ISM including neutral and molecular gas and became an important ISM diagnostic for high-redshift galaxies in the ALMA era. We have observed five CARS targets with the Stratospheric Observatory For Infrared Astronomy (SOFIA) to check how reliable the [CII] line can be used as a star formation rate tracer for AGN hosts. The results reveal an unprecedentedly high [CII]/FIR ratio of $\sim 4\%$ in a mildly starforming (SFR ~ 2 Msun/year) AGN host galaxy HE 1353-1917. The synergy with the multi-wavelength observations helps us to connect the [CII] emission with the physical processes in the host galaxy. HE 1353-1917 is an edge-on disc galaxy with the AGN ionization cone passing directly through the disc and producing a prominent extended narrow-line region (ENLR) photoionized by the AGN on kpc scales. Additionally, HE 1353-1917 contains a fast multi-phase jet-driven outflow with speeds up to 1000 km/s at ~ 1 kpc distance from the nucleus. The [CII] line excess of an order of magnitude is apparently linked to the outflow in which the [CII] line is boosted due to the interaction of the powerful outflow with the molecular gas in the disc. Our new SOFIA data gives us an opportunity to guide the interpretation for the origin of the [CII] emission for high-redshift AGN host galaxies.

An ALMA view of galaxies in the Epoch of Reionisation

Smit Renske - *Cavendish Laboratory, University of Cambridge* - **Review**

In the past decade hundreds of galaxies have been identified in the Epoch of Reionisation, selected from their rest-frame UV light, using HST and ground-based optical/NIR observatories. Only a handful of these sources, however, have spectroscopic redshift determinations and we have limited understanding of their physical properties. ALMA is currently transforming this field by confirming the redshifts of galaxies out to $z=9$ and providing the first view of the dust obscured star-formation, the kinematics of these sources, the cool gas traced by [CII] and highly ionised gas traced by [OIII]. In this talk I will discuss new and recent results on the UV-bright galaxy population during the first billion years of cosmic time and what they imply for their observational and physical properties. Finally, I will discuss what might be expected from the upcoming REBELS ALMA large program (approved for Cycle 7) that aims to perform the first systematic ALMA line survey in galaxies within the Epoch of Reionisation.

Introducing the Cloud Factory: How galactic scale forces affect cloud morphology and dynamics

Smith Rowan - *University of Manchester* - **Contributed**

I present a new suite of simulations that resolve individual molecular clouds down to ~ 0.1 pc scales while they are embedded within a Spiral Galaxy. This uniquely enables us to study fragmentation and star formation within the resolved clouds in their true galactic context for the first time and is a perfect point of comparison to ISM observations in the ALMA era. Our Arepo simulations include a time-dependent chemical model, gas self-gravity, the ISRF and gas self-shielding, magnetic fields, sink particles, supernova feedback, and photo-ionisation from sinks. Using an analytic Milky-Way like spiral potential as our base, we turn on these effects step-by-step in a series of simulations to create a laboratory for testing the physics of the ISM and star formation from kpc scales to cold cores. The molecular clouds formed in our galaxy scale simulations consist of networks of velocity coherent filaments, as seen in observations. In regions with high turbulence from supernova feedback the filaments within the clouds are shorter and less aligned than those in more quiescent regions dominated by the galactic potential. Stars form in all cases, but are more likely to form at the junctions of filaments in the feedback dominated case. To investigate how the turbulence driven by the large scale forces compares to observations we perform non-LTE line transfer to calculate the CO emission, and then compare to observed data using PCA and the Turbustat package. A good match to observed size-linewidth relations is found only when there is both self-gravity and previous turbulent mixing from supernova. I will then investigate how different magnetic field strengths impacts on the formation of molecular clouds, the star formation rate given by sink particles, and the orientation of filamentary structures. Finally I will show early results extending our Cloud Factory simulations to low metallicity dwarf galaxies.

PHANGS-ALMA: Demographics and Environment-dependence of Molecular Cloud Properties

Sun Jiayi - *The Ohio State University, Department of Astronomy* - **Contributed**

I will show what PHANGS-ALMA tells us about the demographics and environment-dependence of the cloud-scale properties of molecular gas. PHANGS-ALMA is an ALMA large program obtaining arcsecond resolution CO imaging of ~ 80 nearby, star-forming galaxies. With its linear resolution (40-120 pc) matching the typical size of individual giant molecular clouds (GMCs), PHANGS-ALMA is providing the most detailed and complete view of GMC properties across the local galaxy population. The first set of CO imaging data reveals a wide range of molecular cloud surface density and mass, velocity dispersion, and turbulent pressure. Combing these CO maps with multi-wavelength data, we conduct one of the first quantitative and complete study on the correlation between cloud-scale molecular gas properties with their local environment (characterized at kilo-parsec resolution). Both molecular cloud surface density / mass and velocity dispersion correlate strongly with the local average gas abundance, stellar mass distribution, and strength of star formation activity. By comparing molecular gas turbulent pressure to the the kpc-scale average ISM pressure expected from vertical hydrostatic equilibrium, we find that molecular gas is over-pressurized (by a factor of ~ 3) relative to its ambient environment. Self-gravity appears to govern cloud-scale molecular gas dynamics over a wide pressure range, whereas stellar gravity and ambient pressure only become important in low density / pressure environment. The observed relations between ISM pressure and SFR surface density agree well with predictions from the self-regulated star forming disk model.

A survey of atomic carbon [CI] in normal main sequence galaxies at high redshift

Valentino Francesco - *Cosmic Dawn Center / Niels Bohr Institute* - **Contributed**

Tracing the bulk of the molecular gas in galaxies is a task of paramount importance in extragalactic astrophysics, but historically hard to achieve. Dust and CO emission have been playing a major role to access the secrets of gas reservoirs in galaxies, but both these proxies are hampered by degeneracies and uncertainties. Therefore, exploring alternative tracers is highly desirable. In this talk, I will present the first results of an ALMA survey of the lower fine structure line of neutral atomic carbon [CI](3P1 - 3P0) - a potentially superior tracer of molecular gas - in main-sequence galaxies at $z \sim 1.2$. This sample is further detected in several far-IR and sub-mm bands and one or multiple CO transitions, allowing for a comprehensive comparison with starbursting systems and quasars reported in the literature so far. I will show that the [CI] luminosity correlates on global scales with the infrared luminosity LIR similarly to low-J CO transitions, with possible systematic variations of $L[\text{CI}] / \text{LIR}$ as a function of the galaxy type. I will further highlight the relation among [CI], dust, and low-J CO transitions, showing that their luminosity ratios are remarkably constant among main-sequence galaxies and local and high-redshift starbursts. This suggests that [CI] is a good tracer of the molecular gas as dust and CO in all these systems, and it offers new opportunities to systematically study the ISM and to model its properties in detail, e.g., via PDR modeling. Finally, by comparing [CI] with dust and CO, I will estimate the CI abundance - the fundamental ingredient to calibrate this gas tracer. We find lower [CI] abundances in main-sequence galaxies than in starbursting systems and sub-millimetre galaxies, as a consequence of the assumed classical alpha-CO and gas-to-dust conversion factors. This cautions against the application of a universal [CI] conversion factor and it stresses the importance of accessing multiple molecular gas tracers for every galaxy population.

(Sub)millimetre observations of ~ 6 quasar hosts: massive galaxy formation in the epoch of reionisation

Venemans Bram - *MPIA Heidelberg* - **Review**

Quasars are the brightest (non-transient) objects observed at the highest redshifts, $z > 7$, which makes them unique probes of the evolution of black holes, massive galaxies and the intergalactic medium. While at (observed) optical and near-infrared wavelengths the central point sources outshine the host galaxies of these bright quasars, observations in the millimetre can constrain the gas and dust content in these galaxies. In recent years numerous quasars at $z > 6$ and up to $z = 7.5$ have been discovered. In this talk I will review the results of a number of ALMA and NOEMA programmes to study the host galaxies of $z > 6$ quasars. I will discuss the implications of the findings on massive galaxy formation, the black hole - galaxy coevolution and the environment of high redshift quasars.

On the nature of HST-dark sources revealed by ALMA

Wang Tao - *University of Tokyo* - **Contributed**

A few recent studies reveal a significant population of ALMA-detected, yet missed in even the deepest HST images ($\text{WFC3/F160W} > 27 \text{ mag}$), most of which are likely at very high redshifts with $z > \sim 4$. Here I will present a census of redshift, stellar mass, and sizes of a statistical sample of 50 such sources detected in both blind ALMA surveys and our own dedicated ALMA observations. I will show that these galaxies make up the bulk of the most massive galaxies at high- z , which have been missed so far. I will also discuss what are their differences with bright SMGs that were found in previous studies.

Dense gas and star formation in nearby galaxies with a range of morphologies

Wilson Christine - *McMaster University* - **Contributed**

I will present the results of a large ALMA archival survey of nearby galaxies ranging from normal spirals to ultra-luminous infrared galaxies. The data reveal enhanced HCN/CO and CN/CO line ratios in starburst regions, implying higher dense gas fractions in these environments. Similar central enhancements are only seen in galaxies with AGN when the maps have sufficiently high spatial resolution, showing the energetic effects of the AGN are confined to a smaller volume than in starbursts. The nearest luminous infrared galaxy in the sample, NGC 3256, shows a significant regions with low HCN/CO line ratios, which a diversity of physical conditions across this merging system. Although models predict that CN should trace UV or X-ray illuminated dense gas, I find an extremely constant CN/HCN ratio for all the galaxies despite a range of nearly 3 orders of magnitude in the star formation surface density. This constant ratio suggests that CN is a good tracer of the dense star-forming gas and opens the path to much larger surveys taking advantage of the proximity of the CO and CN 3mm spectral lines.

Studying the ISM in high-redshift strongly gravitational lensed galaxies in the ALMA era

Yang Chentao - *European Southern Observatory (Chile)* - **Contributed**

The discovery of a population of high-redshift dust-obscured submillimeter galaxies (SMGs) has revolutionized our understanding of galaxy evolution and star formation in extreme conditions, yet their nature remains hotly debated. Recent wide-area extragalactic surveys at submm/mm bands have discovered hundreds of strongly gravitational lensed SMGs. The boosted angular resolution and brightness of the lensed SMGs opens new exciting opportunities for observing the interstellar medium in these exceptional objects. We have thus carefully selected a sample of the brightest strongly lensed SMGs based on the Herschel-ATLAS sample. Using IRAM telescopes, we observed multiple transitions of the CO lines and analysis the physical conditions of the molecular gas. The first multiple transitions of the submm H₂O line survey at high-redshift was also conducted within our sample. Through these lines, we have studied the properties of the far-IR radiation fields that they trace primarily, which provide us new constraints of the warm dense, extreme dust-obscured regions. ALMA 0".2-0".4 follow-up of one of the brightest sources (G09v1.97) in our sample shows very well agreement of the spatial distribution and kinematics between the CO(6-5), H₂O(211-202) and H₂O+(202-111) lines. Interestingly, this merger shows a mismatch between the cold-dust continuum peak and the peak of the line emissions, suggesting a significant amount of cold gas is in the interacting region, similar to the local merger prototype, the Antennae galaxies. In parallel, we have conducted a line survey in Band 3 and 4 using ALMA, which resulted in detections of a rich family of molecules including HCN, HCO⁺, CCH, 13CO, C₁₈O, C₁₇O, C₁₈O, CS, NH₂, and including the first detection of the 448GHz H₂O emission at high-redshift. The rich detections of molecules in multiple transitions enable us for the first time to have a detailed view of the astrochemical process and reveal rich information about the physical properties of the molecular gas, the radiation field, and their interactions at high-redshift.

How the cluster environment affects the baryon cycle

Zabel Nikki - *Cardiff University* - **Contributed**

The effect of environment on the baryon cycle is a crucial area of research in modern day astrophysics. It has been known for some time that galaxies in cluster environments have smaller atomic gas reservoirs than their counterparts in the field. There are several environmental processes that can remove this gas from galaxies and deposit it into the intra-cluster medium. These include galaxy-galaxy interactions, ram pressure stripping, and tidal interactions. Whether these environmental processes also affect the more tightly bound (and centrally distributed) molecular gas is much less obvious. Because molecular gas is the direct fuel for star formation, the effects of the cluster environment on this phase of the ISM has immediate consequences for the star formation rates within the host galaxy. If molecular gas is indeed directly affected by the cluster environment, this has important implications for the quenching of star formation in cluster galaxies and, with $\sim 40\%$ of the galaxies living in groups or clusters, for galaxy evolution as a whole. The ALMA Fornax Cluster Survey is a complete survey of all 30 galaxies in the Fornax cluster across the Hubble sequence that appear to host a cold ISM (based on HI and dust observations). The Fornax cluster is one of the nearest galaxy clusters (at ~ 17 Mpc) and is therefore an ideal laboratory to study the effects of the cluster environment on the gaseous reservoirs of its member galaxies. CO(1-0) was observed as a proxy for the cold molecular gas, allowing us to create resolved maps of its morphology and kinematics, and calculate H₂ masses and deficiencies (compared to field galaxies). The combination of these data with H α maps from MUSE allows us to investigate whether these cluster galaxies follow the Kennicutt-Schmidt relation, and to make detailed maps (~ 250 kpc scales) of depletion times within these galaxies. I will show that the tightly bound molecular ISM is indeed directly affected by the cluster environment, especially in low mass galaxies. Ram pressure stripping/tidal interactions are found to be removing cold gas from these objects, forming spectacular tails in some instances, and directly affecting the star formation efficiencies. The detection of these disturbed molecular gas reservoirs reveals the importance of the cluster environment, which is affecting the baryon cycle directly, even when considering the tightly bound molecular gas phase.

Top-heavy IMF found in dusty starburst galaxies across cosmic time

Zhang Zhiyu - *University of Edinburgh* - **Contributed**

All measurements of cosmic star formation must assume an initial distribution of stellar masses - the stellar initial mass function (IMF) - in order to extrapolate from the star-formation rate (SFR) measured for typically rare, massive stars to the total SFR across the full stellar mass spectrum. The shape of the stellar IMF in various galaxy populations underpins our understanding of the formation and evolution of galaxies across cosmic time. Classical determinations of the IMF in local galaxies are traditionally made at ultraviolet, optical and near-infrared wavelengths, which cannot be probed in dust-obscured galaxies, still less so in distant starbursts selected at submillimetre (rest-frame far-infrared) wavelengths, exactly the type of galaxies for which galaxy evolution models often predict an IMF biased towards massive stars. The $^{13}\text{C}/^{18}\text{O}$ abundance ratio in the cold molecular gas - which can be probed via the rotational transitions of the ^{13}CO and C^{18}O isotopologues - is a very sensitive index of the IMF, with its determination immune to the pernicious effects of dust. We determine this IMF-type index for a sample of four dust-enshrouded starbursts at high redshifts, with ALMA observations, finding unambiguous evidence for a top-heavy stellar IMF in all of them (Zhang et al. 2018, *Nature*, 558, 260). A globally low $^{13}\text{CO}/\text{C}^{18}\text{O}$ ratio for all our targets and local starbursts - alongside a well-tested, detailed chemical evolution model benchmarked on the Milky Way - implies that top-heavy IMFs are inevitable for starburst events compared to ordinary star-forming spiral galaxies. I will also present our new ALMA observations of spatially resolved $^{13}\text{CO}/\text{C}^{18}\text{O}$ ratios in starburst galaxies.

POSTER CONTRIBUTIONS

Poster # 1

Linking molecular cloud properties with arcsecond, mm-wave spectroscopy of dense gas tracers across the nearby galaxy NGC 3627

Bešlić Ivana - *Argelander Institute for Astronomy*

To fully understand the star formation process in galaxies that happens in the cold, dense parts of molecular clouds, most large scale extragalactic studies have been focused on the brightest observable emission lines, such as the ground transition of ^{12}CO . However, in order to study the denser and colder molecular gas associated with star formation, higher critical density tracers are required. The cloud scale work is currently being expanded to many nearby galaxies from PHANGS, giving access to cloud properties across 70 nearby galaxies. At the same time, kpc-scale work, e.g. from our EMPIRE survey, provides wide-area, multi-line mapping data targeting tracers of dense gas (HCN , HNC and HCO^+) and the CO isotopologues ^{13}CO , C^{18}O , across the entire molecular disks of 9 nearby star-forming galaxies. However, what is critically missing currently are high-resolution observations linking both, molecular cloud properties and density structure and physical conditions on individual cloud scales. I will present new results from a NOEMA program targeting the EMPIRE galaxy NGC3627, where we map the entire star forming disk of this galaxy at 1 arcsec resolution (~ 43 pc) in key dense gas tracers and CO isotopologues also studied in EMPIRE. These observations will be used to study the physical conditions of the dense gas within molecular clouds, and fill in the gap between Galactic and extragalactic dense gas observations by isolating individual molecular clouds. I will place this work in context with EMPIRE, extragalactic molecular cloud surveys and ongoing efforts in the Milky Way, surveying large parts of local clouds in the same molecular lines.

Poster # 2

A census of molecular gas in NGC 3256, the closest luminous infrared galaxy

Brunetti Nathan - *McMaster University*

We present the molecular gas properties in the merging pair of galaxies NGC 3256 as observed with ALMA in CO J=2-1 at a resolution of $\sim 0.2''$ (43 pc). NGC 3256 is the closest luminous infrared galaxy at 44 Mpc with a bolometric luminosity of 4×10^{11} L_{sun} making it an ideal target for a giant molecular cloud (GMC) scale study of a massive starburst system. In addition to enhanced star formation, this system boasts additional extreme environments such as outflows and possible inflows which can contribute to variations in GMC dynamics. We present both a “blind” pixel-by-pixel characterization of the gas kinematics and density as well as a giant molecular cloud catalogue with derived sizes, line widths, and luminosities. We compare these to the molecular gas properties in both “normal” disk galaxies and other starbursting galaxies.

Poster # 3

An extended H α over the compact cold dust continuum in submillimeter galaxies - New insights into dust distributions and star-formation rates at $z \sim 2$

Chen Chian-Chou - *ESO*

Star-formation rates (SFRs) are among the most fundamental measurements to galaxy formation models, yet there is still a lack of agreement between measurements made using different methods, especially when it comes to accounting for dust-obscured SFRs from nebular emission lines at $z \sim 1-3$, the epoch when over 80% of the cosmic SFR density is obscured by dust. Part of the problem is hinged on a lack of knowledge with regard to the spatial distributions of dust relative to star-forming regions traced by optical emission lines, which requires both near-infrared IFU and sub-arcsecond far-infrared continuum observations that are only available recently. In this talk I will present results from our ongoing program to study dusty star-forming galaxies at $z \sim 2$ that are detected in H α by the IFU from KMOS/SINFONI, as well as in far-infrared continuum by ALMA with a matched spatial resolution. I will present the relative spatial distributions of these two tracers of SFRs and their sizes. I will discuss the impact of our findings on galaxy formation models in general, as well as on the planning of future IFU observations by ALMA, JWST, and ELT.

Poster # 4

The effects of bars and interactions on the relationship between molecular gas and star formation in CARMA-EDGE galaxies

Chown Ryan - *McMaster University*

Recent surveys of spatially resolved CO in galaxies, such as CARMA-EDGE (Bolatto et al., 2017), have enabled multiwavelength studies (e.g. from optical to radio) of galaxies on \sim kpc scales. I will first present recent results using CARMA-EDGE and optical integral-field data from CALIFA (Sanchez et al., 2012) where we find that galaxies with centrally enhanced star formation are either barred or interacting and have relatively high molecular gas concentrations (Chown et al., 2019). I will then show our ongoing work on the same sample of galaxies, where we explore the correlations between WISE 12 μ m emission and CO (1-0) from EDGE, and compare global SFR-CO correlations to resolved correlations on \sim kpc scales. Our goal is to understand the extent to which bars and/or galaxy interactions impact spatially resolved SFR-CO correlations, using both optical (CALIFA) and infrared (WISE 12 μ m) star formation indicators.

Poster # 5

The environmental effect on galaxy evolution at $z=2$: merger-driven star formation, AGN, and the ISM of sub- M^* galaxies.

Coogan Rosemary - *University of Sussex*

Thanks to the large over-density of galaxies in cluster Cl J1449+0856, we have uncovered a diverse range of galaxies - from a massive assembling BCG to populations of low gas-phase metallicity and early-type galaxies at $z=2$. Cl J1449+0856 is an excellent case to study the development of environmental trends seen at low-redshift a galaxy cluster at redshift $z=2$ with an already virialised atmosphere. Using ALMA and the VLA, we have obtained a wide range of observations of cluster members, including multiple transitions of CO and dust continuum emission. With these data, we study how obscured star-formation, ISM content and AGN activity are linked to environment during this crucial phase of cluster and mass assembly. Probing beyond the massive population, we place our $z=2$, sub- M^* galaxies on αCO and G/D ratio scaling relations at low-metallicity, and compare with those relations calibrated in the local Universe. We also quantify the effect of low enrichment on both low- and high-J CO transitions, investigating this so-far poorly probed ISM regime at $z=2$, and motivating this growing area of research.

Poster # 6

A Machine Learning Approach for Categorising Galaxies Based on Kinematics Alone

Dawson James - *Cardiff University*

We merge the use of machine learning techniques with hydrodynamical simulations to predict the kinematic behaviour of molecular gas in galaxies and test these models on both simulated and real ALMA data. Using the power of convolutional autoencoders, we cluster latent velocity map features, unattainable by the human eye or standard tools, and discriminate between levels of ordered rotation of molecular CO(1-0) structures. Using simulations has advantages over collecting real data including larger sample sizes and the ability to calculate empirical truths in the data. This has allowed us to begin exploring gas kinematics in a Big Data way, helping us prepare for future survey instrument science -primarily, SKA science. Recent work in this field has shown that kinematic properties of galaxies hold valuable information regarding their evolutionary histories, including origins of bulge and disk structures and explaining gas deficits in post star-burst galaxies. Expanding on this direction of work, we develop models that categorise galaxies quickly in order to identify both disturbed and highly ordered gas structures. Doing so may lend further insight as to which processes dominate periods of morphological evolution of galaxies. The full scope of how well these processes are correlated with galaxy kinematics is not fully understood, meaning these studies could be a source of untapped information in bridging large-scale events (such as galaxy mergers, AGN activity, and environmental feedback) to small scale processes (such as star-formation and local ISM dynamics). Our methods can be tuned to reflect observations of other molecular gases thanks to the use of a kinematic molecular simulator, which allows us to generate mock interferometric cubes and therefore could be used by the wider Astronomy community to help explain local-scale kinematics in other wavelength regimes.

Poster # 7

Kennicutt-Schmidt Star Formation Law at GMC Scales in the Dust Lane of the Elliptical Galaxy NGC 5128 (Centaurus A)

Espada Daniel - *National Astronomical Observatory of Japan*

We present high resolution ($\sim 1''$, or ~ 18 pc) CO(1-0) observations along the dust lane of the nearest elliptical galaxy and radio galaxy, NGC 5128 (Centaurus A), taken with the Atacama Large Millimeter/submillimeter Array (ALMA). We calculate gas mass surface densities at giant molecular cloud scales, and derive for the first time the Kennicutt-Schmitt star formation (SF) law using the star formation rate (SFR) surface densities obtained from Spitzer/IRAC $8 \mu\text{m}$ at a resolution of $2.4''$ (~ 50 pc). We checked the correlation between the Spitzer/IRAC $8 \mu\text{m}$ and MIPS $24 \mu\text{m}$ fluxes (to the coarser resolution of $6''$ for the latter) and found that they scale almost linearly. Although the SF law and depletion times are in general similar to “normal” disk galaxies, there are regions that deviate from the standard relations such as the circumnuclear disk and the outermost parts of the disk. This is the most detailed view of the SF law within an elliptical galaxy, and also in regions close to a powerful radio jet. We discuss the case of Centaurus A in the evolutionary sequence for the gas properties in elliptical galaxies.

Poster # 8

Dynamically-regulated star formation in the colliding Taffy galaxies

García-Rodríguez Axel - *Observatorio Astronómico Nacional (OAN), Spain*

Galactic interactions are efficient mechanisms to inject gas from galaxy discs into the Inter-Galactic Medium (IGM). A fine example of such process is the Taffy galaxy pair (UGC 12914/5), where a high-speed head-on collision drew out of the galaxies as much molecular gas as in the entire Milky Way. This created a massive and turbulent 20 kpc-long intergalactic bridge. We have studied the effects of such extreme gas dynamics on the molecular IGM and how it affects its ability to form stars. Unlike in other interacting/merging systems like (U)LIRGs, Star Formation in Taffy is not enhanced but rather inhibited. In order to understand the connection between large-scale environment and molecular cloud properties, we carried out a multi-species survey of the molecular line emission across Taffy using the IRAM 30-m telescope. Our study included tracers of the bulk molecular gas ($12/13\text{CO}$), the dense star-forming phase (HCN, HCO+) and shock-driven chemistry (SiO, HNCO). Combining these tracers, we found out that not only the bulk of the molecular gas is inefficient at forming stars, but also that the efficiency of its dense phase is abnormally low. Furthermore, the dense gas fraction in the bridge is considerably low (2%), suggesting that the gas density is lower than in other interacting/merging systems and even in most normal galaxies. On the other hand, the first direct detection of shocks via SiO, together with the broad line profiles, supports the idea that an enhanced turbulence is inhibiting the star formation in such low-density clouds. Finally, we combine our observations with literature data to place constraints on a set of well-known analytic models of star formation. The extreme conditions found in Taffy expand significantly the region of the parameter space covered by extragalactic observations, which cannot be easily explained by several of those models.

Poster # 9

ILLUMINATING THE DARK SIDE OF STAR FORMATION AT $z > 3$

Giulietti Marika

DiFA - Università di Bologna

One of the key open questions in galaxy evolution is how efficiently galaxies form stars as a function of cosmic time. In order to solve this problem, it is crucial to reconstruct the star formation rate density (SFRD) and its integral (the stellar mass assembly history) to the highest possible redshifts. However, the available information at $z > 3$ is limited and biased towards UV-luminous galaxies. One approach is to search for star-forming galaxies (SFGs) at $z > 3$ missed by optical/NIR surveys because of dust obscuration, and detect them in the FIR/mm. However, this is not trivial because of the limited sensitivity at $z > 3$ and/or the source blending issues of current data. Another possibility is offered by radio surveys with excellent sensitivity and angular resolution. In this project we have used radio data from the VLA-COSMOS survey (Smolcic et al., 2017a) to search for dusty SFGs at $z > 3$. We selected a subsample of 286 galaxies without optical/NIR counterpart in COSMOS2015 photometric catalog (Laigle et al., 2016). We reconstructed the median Spectral Energy Distribution (SED) of this sample (Giulietti et al. in preparation) performing a stack in each band from the optical to 24 μ m and combining the results with FIR data (Herschel+SCUBA from Jin et al., 2018). The median SED shows no detection in optical bands, while significant emission emerges from NIR to sub-mm. Moreover the SED fitting allow us to provide an estimate of a photometric redshift of ~ 2.6 and to derive an infrared luminosity (LIR; 8-1000 μ m and combining the results with FIRm) of $10^{12.2}$ L/Lsun, consistent with ULIRG's range luminosity. For a subsample of 169 (out of 286) galaxies it was possible to recover a few detections from NIR-to-FIR and to construct the individual SEDs. From the individual SED-fitting we derived a distribution of photometric redshifts that peaks at $z \sim 3$ with a tail at $z > 4$ and combining the results with FIR and a mean extinction value $A_V = 5$ mag. These results suggest the existence of a significant population of obscured high redshift galaxies completely missed in the available NIR surveys, and that our approach based on radio selection is very efficient to find them.

Poster # 10

ISM PROPERTIES AND CIRCUMNUCLEAR STARBURST OF A QUASAR HOST AT $z=4.4$

Gonzalez Lopez Jorge - *Universidad Diego Portales*

The $z=4.4$ quasar BRI 1335-0417 provides the unique opportunity to study the ISM of a quasar host galaxy in unprecedented detail. Strong star-formation activity together with a large reservoir of perturbed molecular gas hints an ongoing gas-rich ('wet') merger. Our ~ 1 kpc resolution imaging of the CO(2-1), [CII] and continuum emission reveal a galaxy with a dynamically complex molecular gas, an extended [CII] disk resembling a warped disk and a cuspy continuum emission. The disturbed rotating disk support the idea of an early galaxy assembly, where the gas accreted during the merger is funneled towards the central region fueling the AGN as well as a circumnuclear starburst as proposed by cosmological simulations. The central region around the AGN shows signal of a strong central radiation field with dense and hot gas. BRI 1335-0417 could be described as the combination of two phases, one corresponding to an extended disk and other linked to the circumnuclear starburst and/or AGN. I will discuss what are the mechanism in play in the formation of early galaxies and how is the interplay of star formation, central black hole accretion and the molecular gas reservoir in a quasar host at $z=4.4$

Poster # 11

Molecular Gas Properties in the Early Merger System Arp 240

He Hao - *Dept. of Physics and Astronomy, McMaster University*

I present results of an ALMA study that explores the physical properties of the molecular gas in the early merger system Arp 240. I use spectral line data of 12CO1-0, 13CO1-0 and 12CO2-1 for both spiral galaxies in the system, NGC 5257 and NGC 5258. The molecular gas distribution estimated from 12CO 1-0 shows the gas to stellar mass ratio is high where the gas is concentrated, which suggests the inflow of molecular gas towards the center in merger system. I further determined the geometrical properties of these galaxies based on 2D velocity fitting. Both galaxies follow the normal rotational pattern of spiral galaxies, but NGC 5257 has tidal tails and perturbed outer regions. The perturbed regions show high velocity dispersion, which could be an interesting region to study the effect of turbulence on star formation activity. I further studied the molecular gas properties based on a RADEX multiline analysis. The major effect on the results comes from the varying 12CO/13CO 1-0 ratio, which shows a downward trend from the outer region to the inner region. This may suggest that gas with a high [12CO]/[13CO] abundance ratio is flowing inwards from the outer region. I will further explore the influence of the gas properties on the star formation activity in different regions as traced by the 33GHz radio continuum map.

Poster # 12

Resolving the molecular gas in the ram pressure stripped tail of the Norma jellyfish galaxy with ALMA

Jachym Pavel - *Czech Academy of Sciences*

We present 1" (350 pc) angular resolution map of the cold molecular gas distribution in a prominent ram pressure stripped tail of the Norma cluster galaxy ESO 137-001. With ALMA we found a rich distribution of mostly compact CO regions extending out to nearly 60 kpc distance from the galaxy and over 25 kpc in width. In total about 10^9 Msun of molecular gas was detected. Most of the detected CO clumps are larger structures with masses of Galactic GMCs and GMAs, but with sizes and linewidths that are larger than is typical of those found in the Galaxy. The CO features are found predominantly at the heads of numerous small-scale (~ 1.5 kpc) fireballs (i.e., star-forming clouds with linear streams of young stars extending toward the galaxy) but also of large-scale (~ 8 kpc) super-fireballs. The new data help to shed light on the origin of the molecular tail via in-situ formation and direct stripping scenarios. The ALMA observations of ESO 137-001, together with observations from HST, Chandra and VLT/MUSE, offer the most complete view of a spectacular ram pressure stripped tail to date.

Poster # 13

Dust production in galaxies at $z > 6$

Leśniewska Aleksandra - *Adam Mickiewicz University in Poznań*

Dust production is a very important issue in galaxy evolution. Unfortunately, we are still unable to determine its formation mechanism. I will present the investigation of dust production in nine galaxies at the redshift of $z > 6$, for which dust emission has been detected. In recent years, more accurate measurements were made using the most powerful instruments, eg ALMA, which contributed to better estimates of luminosities and sizes, and thus to determine the masses of gas, dust and stars in the studied galaxies. I conclude that asymptotic giant branch (AGB) stars did not contribute to the dust formation significantly in these Early Universe galaxies, and that supernovae are unlikely to produce the bulk of the dust mass.

Poster # 14

Characterizing the ISM Using Fine-Structure Lines in a $z=5.7$ Hyper-Starburst Galaxy Merger

Litke Katrina - *University of Arizona*

SPT0346-52 is a gravitationally lensed dusty star forming galaxy at $z\sim 5.7$. It is an extremely luminous hyper-starburst system with intrinsic far-infrared luminosity $> 10^{13}$ Lsol and star formation rate density ~ 4200 Msol/yr/kpc². Based on ALMA observations of [CII]158 emission, I have determined the prodigious star formation rate density is likely driven by a major merger of two components. Continuing this work, I have ALMA Bands 6, 7, and 9 observations of five fine structure lines in this dusty star-forming galaxy: [CII]158, [NII]122, [NII]205, [OI]145, and [OI]63. I use a pixellated, interferometric lensing reconstruction code to model the visibilities observed by ALMA and “de-lens” emission to obtain the spatially resolved interstellar medium (ISM) in the source-plane. With these reconstructed lines, I will map physical properties of the ISM, such as electron density, metallicity, and dust temperature, as well as explore the ionized versus neutral phases of the gas in the ISM.

Poster # 15

X-ray, mm and radio wavelength observations of the nuclear activity in lensed dusty star forming galaxies

Massardi Marcella - *INAF-IRA / Italian ARC*

According to co-evolutionary scenarios, nuclear activity and star formation play relevant roles in the early stages of galaxy formation. I will show how it is possible to exploit high-resolution and high-sensitivity X-ray, millimeter and radio-wavelength data to confirm the presence or absence of star formation and nuclear activity in high redshift galaxies and describe their relative roles in shaping the spectral energy distributions and in contributing to the energy budgets of the galaxies. I will overview the possibilities for lensed galaxies science offered by the ALMA Science Archive. In particular, I will present the data, model, and analysis in the millimeter (mm) and radio bands for a sample of strongly lensed galaxies, selected in the Herschel-ATLAS catalogs at redshift 1. For these sources, we analyzed the data that are available in the ALMA Science Archive and followed-up with ATCA radio band observations. Furthermore, we observed two of them with Chandra ACIS-S in the X-ray regime: by combining the information available in mm, optical, and X-ray bands, we reconstructed the source morphology. By taking advantage of the lensing magnification, we identify weak nuclear activity associated with high- z galaxies with high star formation rates. This is useful to extend the investigation of the relationship between star formation and nuclear activity to two intrinsically less luminous high- z star-forming galaxies than was possible so far.

Poster # 16

ALMA view on GASP jellyfish galaxies at $z\sim 0.05$

Moretti Alessia - *INAF/Padova Astronomical Observatory*

Within the GASP project, aimed at studying with MUSE the ionized gas properties of ram-pressure stripped galaxies in nearby clusters, we started an observational campaign with ALMA devoted to the detailed study of the baryon cycle in these peculiar objects. I will present the results that we have obtained so far by studying a sample of 4 jellyfish galaxies with band 3 and band 6 observations, that have allowed us to map the extent of the molecular gas phase around gas stripped galaxies as well as to characterize the Star Formation Efficiency on kpc scales thanks to the match with MUSE data.

Poster # 17

The WISDOM from molecules about Galaxy-black hole co-evolution

North Eve - *Cardiff University*

Supermassive black holes play a crucial and controlling role in the baryon cycle, their co-evolution with their host galaxy is integral part of our modern theories of galaxy evolution. Our understanding of this vital process is hindered, however, by a lack of direct dynamical black hole mass measurements. The use of molecular gas as a tracer of the gravitational field in a galaxy has been used to make several direct super-massive black hole mass measurements. With fewer morphological biases than previous methods, and the possibility of pushing towards high redshift observations, this method has the potential to advance our understanding of the evolution of supermassive black holes and their hosts. In this talk I will present the latest results from the mm-Wave Interferometric Survey of Dark Object Masses (WISDOM). I will show that the molecular gas method can probe the same material as megamasers, deep in the molecular torus, clearly resolving the Keplerian increase in rotational velocities close to the black hole and providing high precision black hole mass estimates. I will support this with tests conducted on a simulated galaxy, which allow us to identify the strengths (and observational limitations) of the molecular gas method.

Poster # 18

Results from the EMPIRE survey

Puschnig Johannes - *University of Bonn, AIfA*

EMPIRE is a ~ 600 hr IRAM-30m large program to observe high-critical density molecular lines (e.g. HCN, HCO+, HNC) across entire star forming disks for a sample of nine nearby spiral galaxies. I will present key results from this survey, focusing on relations of dense gas fractions (HCN/CO) and dense gas star formation efficiencies (IR/HCN) with local conditions across the sample galaxies. One of our key findings is a variable dense gas fraction and efficiency: while the dense gas fraction increases as expected with hydrostatic pressure, stellar and molecular gas surface density, star formation seems less efficient in such environments. I will discuss these results, which are at odds with a whole class of models triggered by Milky Way work. In addition, I will present dense gas tracer line ratios across galaxies and constraints on their optical depths using optically thin isotopologues. To first order, EMPIRE demonstrates that the conditions in a galaxy disk set the gas density distribution and that the dense gas traced by HCN shows an environment-dependent relation to star formation. Motivated by that finding, we have developed a comprehensive RADEX-based radiative transfer modeling approach to constrain physical quantities (e.g. density and temperature) from dense gas observations, taking into account that at \sim kpc scale emission lines of CO and HCN emerge from a mixture of gas densities rather than from a single-density medium.

Poster # 19

Witnessing the early stages of the formation of Super Star Cluster in the nucleus of NGC253

Rico Villas Fernando - *Centro de Astrobiología (CAB, CSIC-INTA)*

Starburst galaxies efficiently convert large amounts of gas and dust into stars in their nuclei in very short time scales, 10^7 - 10^8 years. A large fraction of the star formation is believed to occur in Super Star Clusters (SSC). SSCs are compact, with sizes of ~ 1 pc, massive ($\sim 10^5$ Msun) and young (from few to 100 Myears). Understanding the formation and evolution of SSCs is crucial to determine the conditions leading to the emergence of the starburst and also to evaluate the effect of their associated radiative and kinematic (superwinds) feedback on the evolution of Galaxies. In the Galaxy, the earliest phase ($< 10^5$ years) of massive star formation in clusters (protoclusters) is commonly recognised as very compact (0.02 - 0.1 pc), hot (200-300 K), and dense condensations (10^7 cm $^{-3}$), known as Hot Cores - HCs. We have used 0.2" ALMA images of the HC3N vibrational excited emission (HC3N*) to reveal the Super-Hot Core (SHC) phase associated to Super Star Clusters (SSCs) in the nearby starburst galaxy NGC253. HC3N* emission is a direct probe of unobscured mid-IR emission since it is radiatively pumped by the dust heated by the protostars. The detected 6 unresolved SHCs with temperatures ≥ 230 K and high densities are tracing the proto-SSC phase just before massive stars ionise their surroundings. We estimate that proto-SSCs account for more than 1/3 of the total luminosity of the galaxy. However, our estimates are still very rough and better resolution and sensitivity are required to make robust estimates of the luminosities.

Poster # 20

Deuteration in galaxies: Breaking ground with ALMA

Rivilla Victor M. - *INAF-Osservatorio Astrofisico di Arcetri*

Since the detection of unexpectedly high deuterium fractionation in the Galactic Center almost 20 years ago, many follow up observations were carried out in different Galactic environments which showed deuterium abundances well above the elemental ratio $D/H \sim 1.5 \times 10^{-5}$. These observations have been well reproduced by chemical models and showed that deuteration is an excellent tracer of the degree of chemical processing of the gas by star formation, and therefore a tracer of pristine material feeding the future star formation events. Though models have been proposed for different extragalactic environments, only now, with the superb sensitivity of ALMA, observations are possible. We present for the first time the D/H ratio in the starburst galaxy NGC 253. We have simultaneously observed DCN, DCO+ and N2D+. This data have allowed us to confront models and observations in uncharted regions of the parameters space, and constrain chemical evolution models of star-forming regions. Given the key role of deuterated molecules, our study makes an important contribution in understanding the cosmic chemical enrichment.

Poster # 21

The AGN fueling/feedback cycle in nearby radio galaxies through ALMA observations

Ruffa Ilaria - *INAF-IRA/University of Bologna*

Galaxy formation theories struggle to explain the role of Black Hole accretion in shaping galaxies over cosmic time. Radio feedback, associated to radio jets, is accepted as a fundamental component of the lifecycle of the most massive radio-loud early-type galaxies (ETGs) in the local Universe ($z < 1$). The many details of such process, however, still remain poorly understood. Here we present the results obtained so far by analyzing ALMA CO(2-1) and 230 GHz continuum observations of nine nearby ($z < 0.03$) low excitation radio galaxies (LERGs), with spatial resolution of few hundreds of parsecs. LERGs are a class of radio-loud AGN characterized by low accretion rates (0.01 Edd), mostly low 1.4 GHz radio power ($< 10^{25}$ W/Hz) and their feedback is almost entirely kinetic (i.e. jet-induced). In Ruffa et al. (2019) we show that (sub-)kpc rotating molecular gas discs are very common in LERGs (six out of nine targets were detected in CO(2-1)). Whenever possible, we also demonstrate that the CO discs are co-spatial with dust discs/lanes. In a couple of cases the gas shows kinematic misalignment with respect to the stellar body of the galaxy, pointing towards an external origin of the gas. Continuum emission from the radio cores was detected in all objects. Six sources also show mm emission from jets on kpc/sub-kpc scales. In four of the six galaxies with CO detections, the gas rotation axes are roughly parallel to the radio jets in projection; the remaining two cases show large misalignments. In one case (NGC 3100) the gas disc clearly shows a disturbed morphology that seems to suggest an interaction with the radio jets. The 3D modeling of the six CO detections allowed us to identify signs of gas perturbations, such as warps or gas asymmetries (e.g. gas that has not yet settled into the host galaxy potential) in almost all the cases, as well as indications of the presence of non-circular motions (e.g. inflows/outflows, streaming) in the plane of the CO disc of one object.

Poster # 22

How reliable is CO as kinematical tracer in star-forming regions?

Sabatini Giovanni - *INAF-IRA/ARC/DiFA, UniBO*

CO is the most abundant molecule after H_2 and it is commonly used as kinematical tracer of interstellar gas. Because ^{12}CO is virtually always optically thick, less abundant/optically-thin CO isotopologues (e.g. $C^{18}O$) are habitually used to probe the denser and colder regions of molecular clouds. However, in this environment, where densities are $>$ a few $\times 10^4$ cm^{-3} and the temperature is $<$ 20 K, the effects of CO-depletion can alter the amount of $C^{18}O$ in the gas phase and thus its usefulness as a kinematic tracer. We present a study of the depletion of $C^{18}O$ in the IRDC G351.77-0.51 (G351). A key parameter is the radius within which the $C^{18}O$ is depleted (R_{dep}). To derive a map of the depletion across the cloud, we used the dust continuum emission (Herschel Hi-Gal), combined with APEX $C^{17}O$ and $C^{18}O$ J(2-1) line observations. We built a simple chemical model to investigate the size of the CO-depleted regions in G351. The model suggests that $R_{dep} < 0.15$ pc where $n(H_2) > 2 \times 10^4$ cm^{-3} . From this we conclude that in a quarter of the volume of G351, about 90% or more of the $C^{18}O$ could be frozen onto dust grains. This lack of $C^{18}O$ in the gas phase reduces its usefulness for the study of the kinematics of the gas in the inner regions of molecular clouds, and suitable alternatives will have to be sought.

Poster # 23

The complex gas kinematics in the nuclear region of NGC 7213

Salvestrini Francesco - *DiFA - Università di Bologna*

The nature of the symbiotic relation between star-formation (SFR) and Active Galactic Nuclei (AGN) accretion is still matter of debate and strictly related to understanding if and to which extent the AGN affects the SFR. A multi-wavelength approach, aimed at tracing the different physical mechanisms and emission processes, is mandatory to face this problem. For instance, the X-ray spectral analysis provides information on the BH accretion, the optical and IR lines on star-formation and accretion, the mm emission on the molecular gas morphology and kinematics, while the broad-band SED decomposition allows us to estimate the relative contribution of stars, AGN and star-formation. The 12 Micron Galaxy Sample provides the perfect candidates for this study, thanks to the extensive collection of available data at all frequencies, from the X-rays to sub-mm and radio wavebands. In this work, we focused our attention on NGC 7213, as a test case for this multi-wavelength approach. We present the study of the molecular gas kinematics (using the archival ALMA Band 6 observation), the X-ray spectral analysis (using archival NuSTAR and XMM-Newton observations), and we provide a complete source characterization in terms of different gas components.

Poster # 24

Dust and star formation in hyper-luminous dust-obscured galaxies, and spectral energy distribution modeling using CIGALE

Suleiman Nofoz - *Eötvös Loránd University*

The interstellar medium and star formation of distant galaxies may be revealed using advanced spectral energy distribution modeling. Such models however require a knowledge of the mid- and far-infrared luminosities. Our research is based on catalogued AKARI measurements, and the latest all sky” photometry of Herschel point sources systematically and homogeneously extracted from thousands of observations. Besides a brief introduction of the Herschel point source catalogues, I will review our results on dust and star formation in galaxies in the Local Universe and at cosmological distances. I will flesh up our results on the relationship of star formation and the polycyclic aromatic hydrocarbons (PAH) content in a variety of galaxies in the ELAIS N1 field based on AKARI and Herschel detections, and photometric data collected from other publicly available archives. Spectral Energy Distributions (SEDs) were fitted using the Code Investigating GALaxy Emission (CIGALE) software package. The total and relative PAH densities were compared to the star forming rate (SFR) and differences between galaxies at various distances will be shown. I will also present our results for a selected sample of AGN host galaxies dominated by dust based on similar data sets and CIGALE SED fitting. I will especially demonstrate the ability of extracting the luminosity related to the AGN.

Poster # 25

A search for [CII] emitters in the ALMA Spectroscopic Survey (ASPECS) in the Hubble Ultra Deep Field

Uzgil Bade - *Max Planck Institute for Astronomy, Heidelberg, Germany*

We present results of a [CII] 158 micron line search in the blind spectral scan performed from 212-272 GHz, corresponding to observed [CII] redshifts at $z = 6-8$, by the ALMA Spectroscopic Survey (ASPECS) in the Hubble Ultra Deep Field (HUDF). With a [CII] line luminosity depth (1-sigma) of 4^{07} solar luminosities, and expansive volume coverage of 12,600 comoving cubic Mpc, ASPECS provides the deepest limits to date on the [CII] luminosity function (LF) at $z > 6$, and places the first direct constraints on the evolution of the [CII] LF until the current epoch ($z \sim 0$). In addition to the blind search, the wealth of optically-selected galaxies in HUDF with spectroscopically and photometrically determined redshifts enables a targeted line search at spatial positions corresponding to the locations of both Lyman-alpha emitters and Lyman-break dropout galaxies. Finally, we discuss the results of this prior-based line search in the context of the [CII] luminosity-star-formation rate relation.

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Cover image: ALMA view of the Seyfert galaxy NGC 5135 (from G. Sabatini et al. 2018)