Nine Billion Years of Neutral Gas Evolution

29–31 July 2019

European Southern Observatory, Garching
Schedule — Monday, 29 July

09:00 – 09:05 opening remarks
— Session: HI surveys [chair: Jacqueline van Gorkom] —

09:05 – 09:35 Claudia Lagos
The origin and fate of H\textsc{i} in and around galaxies: the view from simulations

09:35 – 09:55 Michael Jones
\( \Omega_{\text{HI}} \) at \( z \sim 0 \) from ALFALFA

09:55 – 10:15 Baerbel Koribalski
WALLABY science goals and challenges

10:15 – 10:35 Apurba Bera
Atomic hydrogen and star formation in galaxies at intermediate redshifts

10:35 – 11:05 coffee

11:05 – 11:25 Natasha Maddox
The MeerKAT MIGHTEE-\textsc{Hi} survey: early science

11:25 – 11:45 Aditya Chowdhury
The Atomic Hydrogen Content of Galaxies at \( z \sim 1 \)

11:45 – 12:05 Elaine Sadler
An \textsc{Hi}-selected galaxy sample at redshift 0.4 \( \leq z \leq 1 \)

12:05 – 12:25 Neeraj Gupta
Cold atomic gas evolution at 0 < \( z \) < 3.5 using MeerKAT and uGMRT

12:25 – 13:25 lunch

13:25 – 13:35 one-minute/one-slide poster talks
— Session: Theory (and related observations) [chair: Romeel Davé] —

13:35 – 14:05 Dušan Kereš
From the ISM to the gas around galaxies: perspective from numerical simulations

14:05 – 14:25 Thorsten Naab
Modern simulations of the multi-phase ISM

14:25 – 14:45 Alex Richings
The effects of local stellar radiation on non-equilibrium ISM chemistry and ISM line diagnostics

14:45 – 15:05 Jorge Moreno
The evolution of the interstellar medium in merging galaxies

15:05 – 15:35 coffee

15:35 – 15:55 Rajeshwari Dutta
Prevalence of neutral gas in centres of merging galaxies

15:55 – 16:15 Pavel Mancera Piña
The startling dynamics of \textsc{HI}-rich ultra-diffuse galaxies

16:15 – 16:35 Federico Lelli
How can \textsc{HI} dynamics be used to probe the connection between galaxies and their dark matter halos over cosmic time?

16:35 – 16:55 Garima Chauhan
How \textsc{HI} populates haloes: simulations vs. observations

16:55 – 17:15 discussion
Schedule — Tuesday, 30 July

— Session: The circumgalactic medium [chair: Thijs van der Hulst] —
09:00 – 09:30 Mary Putman
The replenishment of H\textsc{i}
09:30 – 09:50 Snežana Stanimirović
Cold cloud formation and evolution with 21-SPONGE and GASKAP
09:50 – 10:10 Freeke van de Voort
The low-redshift circumgalactic medium with sub-kpc resolution
10:10 – 10:30 Katharina Lutz
Atomic gas morphology and kinematics in local galaxies
10:30 – 11:00 coffee
11:00 – 11:20 Erwin de Blok
Low column density H\textsc{i} and accretion
11:20 – 11:40 Michael Rauch
Accretion from the intergalactic medium at high $z$
11:40 – 12:00 Hsiao-Wen Chen
The origin of damped Lyman $\alpha$ absorbers at $z \lesssim 1$
12:00 – 12:20 Tayyaba Zafar
On the neutral hydrogen gas mass density of the universe
12:20 – 13:20 lunch
— Session: Outflow and inflow [chair: Céline Peroux] —
13:20 – 13:50 Sanchayeeta Borthakur
Looking for signposts of gas accretion and galactic feedback
at the disk-CGM interface
13:50 – 14:10 Antonino Marasco
Extra-planar H\textsc{i} and galactic fountain cycle in nearby late-type galaxies
14:10 – 14:30 J. Christopher Howk
Project AMIGA: H\textsc{i} and ionized metals in the circumgalactic medium
of the Andromeda galaxy
14:30 – 14:50 Vanessa Moss
Uncovering the hidden iceberg structure of the gaseous Galactic halo
14:50 – 15:20 coffee
15:20 – 15:40 Michael Michałowski
How to identify galaxies which have experienced recent inflow of gas?
15:40 – 16:00 Filippo Maccagni
Cold gas regulating the nuclear activity of Fornax A
16:00 – 16:20 Alessandro Loni
An H\textsc{i} survey of the Fornax galaxy cluster
16:20 – 16:40 Barbara Catinella
How can local H\textsc{i} surveys inform the analysis of higher redshift surveys?
16:40 – 17:00 discussion
Schedule — Wednesday, 31 July

— Session: Connections with star formation and environment [chair: Matt Jarvis] —

09:00 – 09:30 Linda Tacconi
How can we best – or most completely – characterize ISM mass at z > 1?

09:30 – 09:50 Deanne Fisher
High feedback and star formation efficiency in turbulent disk galaxies

09:50 – 10:10 John Wu
The multiphase ISM in Lyman break galaxy analogs

10:10 – 10:30 Aleksandra Hamanowicz
Molecular content of galaxies studied with ALMACAL

10:30 – 11:00 coffee

11:00 – 11:20 Tristan Reynolds
ASKAP/WALLABY early science: the NGC 7162 galaxy group

11:20 – 11:40 Alice Concas
The impact of the environment on the gas reservoir and star formation in local massive galaxies

11:40 – 12:00 Sheila Kannappan
Comparing apples to apples and apples to seeds between low- and high-redshift H I surveys

12:00 – 12:20 Lister Staveley-Smith
Traversing the H I desert

12:20 – 13:20 lunch

— Session: The multiphase ISM [chair: Martin Zwaan] —

13:20 – 13:50 Marcel Neeleman
The molecular content of cosmic gas reservoirs

13:50 – 14:10 Tirna Deb
Neutral hydrogen gas in a striking jellyfish galaxy

14:10 – 14:30 Sambit Roychowdhury
The gas-to-dust cycle in low-metallicity dwarf galaxies using spatially resolved measurements

14:30 – 14:50 Anne Klitsch
Molecular view on the cosmic baryon cycle

14:50 – 15:20 coffee

15:20 – 15:40 Luca Cortese
Challenging H 2 domination in high-redshift star-forming galaxies

15:40 – 16:00 Sergei Balashev
Measurements of the diffuse molecular gas at high redshifts

16:00 – 16:20 Erin Boettcher
Probing multiphase gaseous galactic ecosystems in absorption and emission

16:20 – 16:40 Maryam Arabsalmani
Neutral gas in the close environments of massive star explosions

16:40 – 17:00 Abhisek Mohapatra
Evolution of optically thin high-z C III absorbers associated with neutral hydrogen

17:00 – 17:15 discussion
Claudia Lagos (ICRAR)

The origin and fate of H\textsubscript{i} in and around galaxies: the view from simulations

In the last years, we have seen immense progress in the success of cosmological galaxy formation simulations in reproducing a range of observables. We are now at a point in which we have converged to approximately predict the correct evolution of the stellar mass growth of galaxies. However, the main challenge we currently face is that the latter is achieved for sometimes very different physical reasons, mostly associated to the different treatment of feedback. A crucial measurement to disentangle between different, plausible models, is to study the gas content of galaxies, which provide independent validation tests to the simulations. During this talk I will discuss recent relevant comparisons between simulations and H\textsubscript{i} observations, what different simulations tell us about the evolution of H\textsubscript{i} in and around galaxies, and how we expect to use the coming H\textsubscript{i} observations to improve galaxy formation modelling.

Michael Jones (Instituto de Astrofísica de Andalucía)

Martha Haynes (Cornell University), Kelley Hess (ASTRON), Riccardo Giovanelli (Cornell University), Lourdes Verdes-Montenegro (Instituto de Astrofísica de Andalucía)

Ω\textsubscript{H\textsubscript{i}} at z \sim 0 from ALFALFA

In the era of SKA it will finally be possible to detect H\textsubscript{i} in emission beyond z \sim 0 over medium and wide area surveys. This will allow us to constrain the redshift evolution of H\textsubscript{i} emission in much finer detail than what is currently possible with stacking experiments and pencil beam surveys. With this improved data we will be much better equipped to address the apparent disconnect that exists between the abundance of H\textsubscript{i} in emission and its inferred abundance traced by Ly\alpha absorption at higher redshift.

I will present the H\textsubscript{i} galaxy mass function (HIMF) estimated from the final ALFALFA H\textsubscript{i} source catalogue, which represents one of the most precise measurements of Ω\textsubscript{H\textsubscript{i}} at z \sim 0, based on well over 20,000 galaxies detected in H\textsubscript{i}. However, a thorough exploration of potential sources of uncertainty reveals that there is still a \sim 10 – 20\% uncertainty in this value driven primarily by cosmic variance and the absolute calibration of flux. In addition to these points, ALFALFA has also demonstrated that source confusion is likely to present a significant challenge for the deepest stacking experiments in precursor surveys, and that measurements of Ω\textsubscript{H\textsubscript{i}} and the HIMF in z bins will require the inclusion of priors on the relationship between H\textsubscript{i} mass and rotation velocity. I will discuss these points in the context of future H\textsubscript{i} galaxy surveys with SKA precursors, pathfinders, and the advent of SKA1.

Baerbel Koribalski (CSIRO Astronomy and Space Science)

WALLABY science goals and challenges
I will summarise the key science goals for the ASKAP H\(\text{I}\) All Sky Survey (WALLABY), aiming to survey three quarters of the sky ($\delta < +30$ deg) out to a redshift of $z = 0.26$. The WALLABY resolution will be $\sim 30$ arcsec and $4\text{ km s}^{-1}$. ASKAP has now started operating with the full array of $36 \times 12\text{ m}$ antennas, each equipped with a wide-field Phased Array Feed (PAF). I will present the latest H\(\text{I}\) results, including highlights from our five WALLABY Early Science fields targeting nearby galaxy groups and clusters. The huge field of view (30 square degrees), achieved by forming 36 beams using Checkerboard PAFs, makes ASKAP a fast 21 cm survey machine. All data products, obtained with the custom-build ASKAPsoft pipeline, will be publicly available in a dedicated science archive. Our WALLABY science goals, ranging from H\(\text{I}\) studies of the Local Group to scaling relations and cosmology, are much aided by sophisticated simulations and complementary multi-wavelength surveys. Essential to the success of WALLABY is our flexible 3D source finding application (SoFiA) as demonstrated in our series of WALLABY Early Science papers.

Apurba Bera (NCRA-TIFR)

Nissim Kanekar (National Centre for Radio Astrophysics), Jayaram Chengalur (NCRA-TIFR), Jasjeet Singh Bagla (IISER-Mohali)

Atomic hydrogen and star formation in galaxies at intermediate redshifts

Understanding the evolution of galaxies over cosmic time is one of the most important goals of modern astrophysics. In the recent past a number of deep optical studies of high-redshift galaxies have provided information on the evolution of the stellar mass, star formation rate, luminosity function and morphological properties of the galaxy population. However, these studies provide no information about the evolution of the neutral atomic hydrogen (H\(\text{I}\)) content of galaxies. Since atomic hydrogen provides the primary reservoir of the material required for star formation, understanding its evolution is fundamental for understanding galaxy evolution. The atomic hydrogen content of galaxies is best probed by their H\(\text{I}\) 21 cm emission. The upgraded Giant Metrewave Radio Telescope (uGMRT) with its L-band (1.0–1.4 GHz) receivers is an excellent instrument to measure the H\(\text{I}\) 21 cm emission from galaxies out to redshift of $z < 0.4$. Deep radio observations can also be used to estimate the star formation rates of high-redshift galaxies from their radio continuum emission using the well established radio-FIR correlation, which gives a dust-free estimate of the total star formation rate, unlike the optical/UV continuum or spectral lines which are subject to dust extinction. Comparing the radio-derived star formation rates to that estimated from optical/UV indicators, it is possible to study the dust extinction suffered by different indicators as functions of redshift and different physical parameters of the galaxies.

We are carrying out a deep uGMRT survey of the Extended Groth Strip with the L-band receivers to measure the H\(\text{I}\) content in the star-forming galaxies at redshifts of $z < 0.4$ in the field. In this talk I will present the preliminary results on H\(\text{I}\) mass measurements and radio-derived star formation rates from this study.

Natasha Maddox (USM-LMU)

The MeerKAT MIGHTEE-H\(\text{I}\) survey: early science

The successful commissioning of MeerKAT is opening new parameter space for observations of H\(\text{I}\), enabling large-area surveys spanning cosmological redshifts to be undertaken. MIGHTEE, the
medium-deep survey with the South African SKA precursor MeerKAT, will cover 30 square degrees commensally in both radio continuum and spectral line modes. Early science data products confirm the excellent sensitivity of MeerKAT. Incorporating the extensive ancillary data within the survey fields, MIGHTEE-H$^i$ is ready to produce results spanning many aspects of H$^i$ science at moderate redshift, and provide a link between the existing $z \sim 0$ observations and the upcoming deep H$^i$ surveys.

**Aditya Chowdhury** (National Centre for Radio Astrophysics, NCRA-TIFR)

Nissim Kanekar (National Centre for Radio Astrophysics), Jayaram Chengalur (NCRA-TIFR), Shiv Sethi (RRI), K. S. Dwarakanath (RRI)

**The Atomic Hydrogen Content of Galaxies at $z \sim 1$**

Atomic gas is a key component that impacts galaxy formation and evolution over cosmic time. A number of galaxy redshift surveys have firmly established that star formation in galaxies peaks at $z \sim 1 - 3$, with the cosmic star formation rate density being an order of magnitude higher than in the local universe. However little is known about the neutral gas content (i.e., the fuel for the star formation) of these galaxies at this epoch. We have used the upgraded Giant Metrewave Radio Telescope to conduct a deep ($\sim 100$ hour) search for the redshifted H$^i$ 21 cm emission from galaxies at $z = 0.75 - 1.45$ over a 2 deg$^2$ region of the DEEP2 survey fields. We have detected the H$^i$ 21 cm line emission from $z \sim 1$, by stacking $\sim 8000$ star-forming galaxies in the surveyed fields. This has allowed us to measure the average atomic gas mass and average atomic gas depletion time of star-forming galaxies at and just after the epoch of galaxy assembly.

**Elaine Sadler** (CSIRO & University of Sydney)

James Allison (University of Oxford), Vanessa Moss (CSIRO), ASKAP FLASH team

**An H$^i$-selected galaxy sample at redshift $0.4 \leq z \leq 1$**

We present the results of a pilot study using the Australian SKA Pathfinder (ASKAP) radio telescope to search for 21 cm neutral hydrogen (H$^i$) absorption in distant galaxies that lie along the line of sight to bright background radio sources. This has allowed us to identify a small sample of galaxies in the redshift range $0.4 < z < 1$ selected on the basis of their H$^i$ content alone, without reference to any of their optical properties. We discuss the nature of these distant H$^i$-selected galaxies, based on follow-up observations at other wavelengths, and show how our 21 cm data can set constraints on the typical H$^i$ spin temperature and CNM fraction at cosmological distances. We also provide a first 21 cm-based estimate of the DLA number density at redshift $z \sim 0.6$, and outline the prospects for the much larger ASKAP FLASH 21 cm H$^i$ absorption survey to be carried out in the near future.

**Neeraj Gupta** (IUCAA)

MALS collaboration
Cold atomic gas evolution at $0 < z < 3.5$ using MeerKAT and uGMRT

The MeerKAT Absorption Line Survey (MALS) will use MeerKAT’s L- and UHF-band receivers to carry out the most sensitive search of associated and intervening 21 cm absorbers at $0 < z < 1.5$. It will trace the relationship between cold atomic gas in galaxies, and the evolution of SFRD and AGN feedback. With uGMRT, we have recently completed a blind search of associated and intervening absorbers in a sample of $\sim 100$ IR-selected quasars at $2 < z < 3.5$. We have also obtained information on ionized and neutral gas along the sightline for all the quasars through our SALT/NOT optical observations. In this talk, I will present (1) results from the uGMRT search with constraints on CNM cross-section of galaxies and interpretations based on the optical/IR data, and (2) science goals and the current status of MALS.

Dušan Kereš (UC San Diego)

From the ISM to the gas around galaxies: perspective from numerical simulations

Understanding of physical processes relevant for the evolution of the ISM is crucial for understanding of galaxy evolution. Numerical simulations showed that several different physical mechanisms related to star formation play crucial role in the regularization and evolution of the ISM and that the same processes can also drive galactic outflows and affect the CGM. Stellar feedback via supernovae and radiation from young stars are main ingredients of successful models but several tensions with observations remain. Recently, additional physical processes such as feedback from cosmic rays started receiving more attention as a potential solution of some of these tensions. I will review the connection between the ISM physics and galactic gas flows and point out regimes where more work is needed to constrain the uncertain physical processes.

Thorsten Naab (Max-Planck-Institute for Astrophysics)

Modern simulations of the multi-phase ISM

I will present high-resolution simulations of the star forming multi-phase ISM investigating stellar feedback on all major thermal and non-thermal components like magnetic fields and cosmic rays. I will discuss the impact of stellar radiation, location of supernovae and cosmic rays on the distribution of molecular, neutral and ionized hydrogen. I will highlight limitations also of current galaxy formation simulations in accurately capturing the multi-phase ISM structure. The most recent galaxy formation simulations with feedback from individual massive stars and solar mass and sub-parsec resolution will be presented and future prospects will be discussed.

Alex Richings (Durham University)

The effects of local stellar radiation on non-equilibrium ISM chemistry and ISM line diagnostics

The chemistry of ions and molecules in interstellar gas plays an important role in galaxy formation, as the abundances of different chemical species determine how quickly the gas can cool. Furthermore, understanding the gas chemistry is important for interpreting a wide range of ISM
emission and absorption line diagnostics. Stellar radiation affects the ISM chemistry, as it ionises the gas and dissociates molecules. However, following the full 3D radiative transfer of stellar radiation in galaxy simulations can be computationally expensive. In this talk, I will present a suite of simulations of isolated disc galaxies, from dwarfs to Milky Way-mass galaxies, in which we couple an approximate treatment for the stellar radiation from individual star particles to a time-dependent chemical model that follows the evolution of 157 ions and molecules. I will compare these to simulations in which we assume a uniform interstellar radiation field, to demonstrate how including a local treatment for stellar radiation affects the evolution of the galaxy, the properties of the multi-phase ISM, and observable ISM line diagnostics. These simulations can also be used to test how ISM line diagnostics trace the physical conditions of the ISM, which is important for interpreting observations of these lines.

Jorge Moreno (Pomona College)

The evolution of the interstellar medium in merging galaxies

In this talk I will review the role of galaxy mergers in triggering star formation, and their effect on the interstellar medium. For many years, observations have suggested that star formation is enhanced in mergers. Recently, however, a number of IFU campaigns and HI surveys suggest that mergers also enhance the H$_2$ budget in galaxies, whilst leaving their HI content largely unaffected. Understanding how baryons migrate between ISM phases and/or become stars is a question that has eluded us, because of a lack of sufficient resolution in our simulations or lack of sophisticated models at scales both relevant to galaxies and the ISM. I will share recently published results where we employ a comprehensive suite of parsec-scale galaxy merger simulations using FIRE, the “Feedback In Realistic Environment” physics model. This framework allows us to resolve Giant Molecular Clouds and follow feedback physical processes that regulate star formation. I will describe the ISM as a pipeline where atomic gas can cool and compress into molecular gas, but the onset of star formation can turn these ISM components into warm ionized gas, or hot gas (with temperatures above 1 million Kelvin). The net result is the build-up of a molecular gas reservoir, hand in hand, with enhanced star formation — thus providing a physical picture to H$_2$ and HI observations. If time allows, I will describe the role of this baryon cycle in building up stellar bulges in galaxies.

Rajeshwari Dutta (European Southern Observatory, Garching)

Prevalence of neutral gas in centres of merging galaxies

Galaxy mergers can funnel large quantities of gas to the central regions of galaxies, triggering intense bursts of star formation and fueling Active Galactic Nuclei (AGNs). Feedback from AGNs, both positive and negative, can in turn have a strong impact on the evolution of the host galaxies and their environment. We have recently conducted a study of the neutral gas in the centres of $z \leq 0.2$ galaxy mergers that host strong radio sources, using HI absorption. We have found statistical evidence for the presence of large amount of neutral gas ($N$(HI) $\sim 10^{21-22}$ cm$^{-2}$) in the centres of such mergers, implying that mergers are efficient in channeling neutral gas to the galaxy centres. Using optical spectroscopy, we have identified both redshifted (inflowing) and blueshifted (outflowing) neutral absorbing gas components with respect to the AGN. Results from our multi-wavelength observations of low-$z$ mergers and their implications on the connection between AGN activity and the merger process will be presented in this talk.
Pavel Mancera Piña (Kapteyn Astronomical Institute & ASTRON)

Filippo Fraternali (Kapteyn Astronomical Institute), Tom Oosterloo (ASTRON & Kapteyn Astronomical Institute), Elizabeth A. K. Adams (ASTRON & Kapteyn Astronomical Institute)

The startling dynamics of H\textsuperscript{i}-rich ultra-diffuse galaxies

I will present our main discoveries regarding the dynamics of H\textsuperscript{i}-rich ultra diffuse galaxies (UDGs). Using a set of interferometric observations and a state-of-the-art 3D fitting technique we have derived reliable rotation velocities for a sample of seven isolated UDGs.

Surprisingly, these galaxies have very low circular velocities given their baryonic masses, which makes them shift off from the Baryonic Tully-Fisher relation (BTFR), suggesting fundamental differences between the formation of H\textsuperscript{i}-rich UDGs and other disc galaxies. Moreover, their position in the BTFR matches the expectations for galaxies with a baryon fraction equal to the cosmological value, making these galaxies compatible with having no missing baryons, which sets important constraints on feedback processes at dwarf scales. The rotation velocities we derive also allow us to make an estimation of the dynamical mass of our H\textsuperscript{i}-rich UDGs, revealing a low dark matter content. Yet, even with this set of unusual properties, they follow the same specific angular momentum-stellar mass relation as other galaxies.

Federico Lelli (European Southern Observatory)

How can H\textsuperscript{i} dynamics be used to probe the connection between galaxies and their dark matter halos over cosmic time?

I will summarize recent results from the Spitzer Photometry and Accurate Rotation Curves (SPARC) database. To date, SPARC is the largest collection of galaxies with both high-quality H\textsuperscript{i} rotation curves and NIR surface photometry. I will describe two classic methods to probe the connection between galaxies and dark matter (DM) halos: (I) fitting rotation curves with a prescribed DM halo profile, and (II) studying empirical relations between dynamic and photometric quantities, without a priori assumptions on DM halos.

The first approach leads to the following results: (1) cored DM profiles provide better fits than cuspy DM profiles, (2) the best-fit parameters from cored profiles naturally recover LCDM scaling relations (like the $M_{\text{star}} - M_{\text{halo}}$ relation), whereas cuspy profiles do not, and (3) the characteristic volume density of DM halos seem to be remarkably constant over 5 dex in luminosity.

The second approach enables us to identify and characterize three empirical laws of galactic rotation: (1) at large radii the mean velocity along the flat part of the rotation curve correlates with the baryonic mass with a slope close to 4 (baryonic Tully-Fisher relation); (2) at small radii the dynamical mass surface density from the rising part of the rotation curve correlates with the baryonic surface density (central density relation); and (3) at any radii the observed centripetal acceleration correlates with the expected baryonic acceleration (radial acceleration relation).

These relations are remarkably tight by astronomical standards, being consistent with no intrinsic scatter beyond the observational errors. They imply that the amount and distribution of baryons fully specify the amount and distribution of DM, and vice versa. Therefore, whilst the first approach is useful to link galaxy dynamics to cosmological expectations, it is effectively over-
constraining the observational problem: in general there is no freedom in fitting arbitrary DM halos to H\textsc{i} rotation curves.

Garima Chauhan (ICRAR/UWA)
Claudia Lagos (ICRAR/UWA)

How H\textsc{i} populates haloes: simulations vs. observations

All H\textsc{i} surveys are affected by selection effects, which in some cases can be quite complex. To understand these biases and how they affect our understanding of how galaxies populate dark matter halos, we have modelled H\textsc{i} emission lines of the galaxies in the semi-analytic model of galaxy formation SHARK, built on the LCDM SURFS suite of \textit{N}-body simulations. We use the latter to create a mock ALFALFA survey with the same selection function and instrumental effects as the real survey. We explored the long-standing problem of the over-production of low circular velocity galaxies, and found our simulated ALFALFA survey to reproduce the observed H\textsc{i} velocity width distribution very well, hence concluding that the discrepancies previously reported are due to the complex selection effects of H\textsc{i} surveys. We also found that these biases affect galaxies even at the dwarf galaxy regime. During this talk, I will present these results, and also show which biases might affect the upcoming H\textsc{i} surveys like WALLABY and DINGO, and how best to tackle them.

Abstracts — Tuesday, 30 July

Mary Putman (Columbia University)

The replenishment of H\textsc{i}

A galaxy needs to constantly replenish its H\textsc{i} reservoir in order to continue to form stars over cosmic time. The majority of the baryons in the Universe are in an ionized gas phase outside of a galaxy and therefore must somehow cool and settle on to the galaxy’s star forming region. I will discuss the observational evidence for the flow of gas between these two phases.

Snežana Stanimirović (University of Wisconsin)

Cold cloud formation and evolution with 21-SPONGE and GASKAP

Cold interstellar clouds are a necessary step on the way to star formation. Yet, understanding how these clouds form out of the warm diffuse medium, and what fundamental processes regulate their atomic and molecular fractions, has been largely unexplored. We have recently completed the first statistical study of the properties of neutral gas over the entire temperature range $10 - 10^4$ K. This project, “21 cm Spectral Line Observations of Neutral Gas with the (E)VLA” (21-SPONGE), is a large (58 lines of sight) survey of Galactic H\textsc{i} absorption with the Karl G. Jansky Very Large Array. Our exceptional sensitivity allows us to constrain the fraction of thermally unstable H\textsc{i} and place constraints on the importance of interstellar turbulence in the process of cold cloud formation. I will summarize key results from 21-SPONGE and also highlight several ongoing and future H\textsc{i}
absorption studies that focus on mapping the CNM in the vicinity of molecular clouds using the VLA, and expanding the H\textsc{i} absorption samples using the Australian SKA Pathfinder array.

Freeke van de Voort (MPA)

The low-redshift circumgalactic medium with sub-kpc resolution

Galaxies are intimately connected to the environments they live in: they grow by accreting gas from the circumgalactic medium (CGM) and they heat and enrich the CGM through galactic outflows. Most cosmological, hydrodynamical simulations focus their computational effort on the galaxies themselves and treat the CGM more coarsely, which means small-scale structure cannot be resolved. I will discuss how we get around this issue by running zoom-in simulations of a Milky Way-mass galaxy with standard mass refinement and additional uniform spatial refinement (0.5 kpc) within the virial radius. The improved spatial resolution does not strongly impact the central galaxy or the average density of the CGM. However, it samples strong overdensities (and underdensities) much better and therefore drastically changes the radial profile of the neutral hydrogen column density. Additionally, we find that metals are mixed less efficiently, reducing the average metallicity of the (ionized) CGM. We conclude that some of the properties of the CGM are strongly resolution dependent, while others are more robust. Our results show that future observations with telescopes such as ASKAP, MeerKAT, and SKA are likely to detect more H\textsc{i} 21 cm emission than predicted by standard-resolution cosmological simulations.

Katharina Lutz (CDS, CNRS, Observatoire astronomique de Strasbourg)

Atomic gas morphology and kinematics in local galaxies

We present the latest results from the HIX galaxy survey, which studies a sample of the most H\textsc{i}-rich (for their optical luminosity) and H\textsc{i}-massive spiral galaxies in the local universe. Given their large and massive H\textsc{i} discs, their high redshift counterparts might be among the first galaxies we will detect in H\textsc{i} beyond the currently observable redshift range. A detailed examination of the star formation activity, the spatially resolved H\textsc{i} morphology and kinematics, and the gas-phase metallicity of the HIX galaxies reveals that they have not recently accreted more gas than average local galaxies. Furthermore, they are also located on the star formation main sequence and are thus average star formers. However, large parts of the H\textsc{i} reservoirs of HIX galaxies are located outside the stellar disc, where no stars can be formed. This is due to a larger than average H\textsc{i} specific angular momentum, which allows HIX galaxies to stabilise their H\textsc{i} disc against more vigorous molecular gas and subsequent star formation. A comparison to semi-analytic models suggests that the elevated H\textsc{i} specific angular momentum is inherited from the elevated spin of the host dark matter halo.

During the examination of the HIX sample, the following questions arose: What do the average H\textsc{i} morphology and kinematics of an average local galaxy look like? How common are warped H\textsc{i} discs, H\textsc{i} tails, H\textsc{i} column density depressions in galaxy centres, ... ? The H\textsc{i} content of H\textsc{i}-rich galaxies is determined by the angular momentum properties of these galaxies; is this the case for all field galaxies at low redshifts? Does this allow us to predict H\textsc{i} masses of galaxies at higher redshifts solely from their kinematic properties? To understand these questions, we are currently compiling spatially resolved H\textsc{i} observations of an as large and diverse sample of galaxies as possible from the archives. We estimate that this will allow us to study the H\textsc{i} kinematics and morphology of a few
hundreds of galaxies in a consistent way. First results of this new project will also be presented at the workshop.

Erwin de Blok (ASTRON)

Low column density H\textsc{i} and accretion

I give an overview of recent observational results constraining the local H\textsc{i} accretion rate. These are mostly based on data from the WSRT HALOGAS survey, which recently had its public data release. Using the limits derived from HALOGAS data I discuss the parameter space that future H\textsc{i} surveys on SKA precursors and SKA itself must cover in order to further constrain the local cold gas accretion rate.

Michael Rauch (Carnegie Observatories)

Accretion from the intergalactic medium at high z

In principle, QSO absorption lines studies can provide the most sensitive approach to studying galactic in-and outflows of gas. In reality, it has remained difficult to distinguish between the two, and theoretical prejudices have often driven the interpretation of absorption line results.

I shall present recent observations of the intergalactic medium (IGM) and galaxies, partly combining absorption line measurements with observations of nebular emission, that allow us to more clearly probe the signatures of galactic accretion of gas at high redshift. We will further address the question as to what degree galaxies can establish a sphere of influence (a.k.a. the “circumgalactic medium”) genuinely distinct from the general IGM.

Hsiao-Wen Chen (The University of Chicago)

The origin of damped Lyman\(\alpha\) absorbers at \(z \lesssim 1\)

Damped Ly\(\alpha\) absorbers (DLAs) probe the neutral gas in the interstellar medium, extended rotating disks, and likely dense gaseous streams in galaxy halos. The large gas surface mass densities revealed in DLAs are comparable to what is seen in 21 cm observations of nearby star-forming galaxies, making DLAs a promising signpost of distant young galaxies. In this talk, I will present new damped Ly\(\alpha\) absorbers discovered in the Cosmic Ultraviolet Baryon Survey (CUBS), along with new observations that cast new insights into the physical origin of the gas.

Tayyaba Zafar (AAO)

On the neutral hydrogen gas mass density of the universe

Damped Lyman-alpha absorbers (DLAs) seen along the lines of sight of luminous quasars are a unique probe to select neutral hydrogen rich galaxies. These galaxies allow to estimate neutral gas mass over cosmological scales, which is a possible indicator of gas consumption as the star formation proceeds. The DLAs and sub-DLAs are believed to contain a large fraction of neutral gas mass in the Universe. A search for DLAs and sub-DLAs is made in the reduced archival
Ultraviolet Visual Echelle Spectrograph (UVES) dataset of 250 quasars. Because of a chosen redshift window a statistical analysis on 195 quasars is performed. For better statistics, the dataset of archival UVES quasars is analyzed in conjunction with other DLA and sub-DLA samples from the literature. Using the sample, redshift evolution of the number density and the line density are derived for DLAs and sub-DLAs and compared with the Lyman limit systems (LLSs) from the literature. Furthermore, the column density distribution down to the sub-DLA limit is determined. The redshift evolution of the column density distribution is also determined, indicating presence of more sub-DLAs at high redshift as compared to low redshift. The H\textsubscript{i} column density distribution is further used to determine the H\textsubscript{i} gas mass density between $1.5 < z < 5.0$. The complete sample shows that sub-DLAs contribute 10–20% to the total neutral hydrogen gas mass. In agreement with previous studies, no evolution of neutral gas mass is seen from low redshift to high redshift, suggesting that star formation solely cannot explain this non-evolution and replenishment of gas and/or recombination of ionized gas is needed.

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**Sanchayeeta Borthakur** (Arizona State University)

**Looking for signposts of gas accretion and galactic feedback at the disk-CGM interface**

While gas accretion and feedback are theorized to make significant changes to the state of the circumgalactic medium (CGM) at the disk-CGM interface, the observational evidence to support that is not conclusive. The need of the hour is to measure the properties of the gas in this highly sensitive interface region to connect them to the physics of accretion and outflow. I will discuss the results from our ongoing COS-Disk program, which probes the H\textsubscript{i} disk-CGM interface. I'll discuss our finding in terms of the signpost of gas accretion and galactic feedback. I'll also show evidence that structures such as high-velocity clouds and extraplanar gas that are thought to be pathways for gas accretion into galaxies are very common for most galaxies, thus strengthening our understanding of their role in feeding galaxies.

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**Antonino Marasco** (Kapteyn Astronomical Institute)

Filippo Fraternali (Kapteyn Astronomical Institute), Tom Oosterloo (ASTRON & Kapteyn Astronomical Institute), Erwin de Blok (ASTRON), George Heald (CSIRO Astronomy & Space Science)

**Extra-planar H\textsubscript{i} and galactic fountain cycle in nearby late-type galaxies**

In the last two decades, deep H\textsubscript{i} observations of nearby late-type galaxies have revealed the presence of extra-planar H\textsubscript{i} layers extending up to a few kpc above the galaxy midplane and accounting for $\sim 10\%$ of the total H\textsubscript{i} content. In the few cases studied in detail, these H\textsubscript{i} layers were found to be characterised by a slow-rotating, globally inflowing kinematics, which is expected by gas in a galactic fountain cycle triggered by stellar feedback.

We now present a homogenous and detailed analysis for a sample of 13 late-type galaxies with deep H\textsubscript{i} observations from the HALOGAS project. For each system we have masked out the H\textsubscript{i} emission coming from the rotating thin disk and produced synthetic data cubes to model the leftover extra-planar emission. Our model features 3 structural and 4 kinematical global parameters, which are fit to the data via a Bayesian MCMC method.
We found that extra-planar H\textsc{i} layers are ubiquitous in disc galaxies, with H\textsc{i} masses that are in excellent agreement with predictions from simple models of galactic fountain powered by stellar feedback. In most cases, the kinematics show a global inflow with speed of $20 - 30 \text{ km s}^{-1}$ in the vertical and radial directions, along with a vertical rotational lag of $5 - 20 \text{ km s}^{-1} \text{kpc}^{-1}$, suggesting an interaction between the material outflowing from the disc and the circumgalactic medium.

**J. Christopher Howk (U. Notre Dame)**

**Project AMIGA: H\textsc{i} and ionized metals in the circumgalactic medium of the Andromeda galaxy**

The Andromeda galaxy provides unique opportunities to study the structure of galaxies like our own Milky Way in great detail. I will report on the results from Project AMIGA (Absorption Maps In the Gas of Andromeda), which combines one of the most sensitive surveys to date for circumgalactic H\textsc{i} 21 cm emission with searches for metal absorption using HST/COS ultraviolet spectroscopy of $\sim 30$ background AGNs projected within $\sim 300 \text{kpc}$ (the virial radius) of M31. While the UV absorption measurements yield an extremely high covering factor of ionized metals about Andromeda, with $\sim 90\%$ covering factor of Si\textsc{iii}, H\textsc{i} emission is nearly completely absent to $N(\text{H}I) \sim 2 \times 10^{17} \text{cm}^{-2}$. Andromeda’s CGM shows weaker absorption and H\textsc{i} content than most samples of galaxies at $z \sim 0.2$. The 21 cm measurements, in particular, serve as both a guide and a warning for future proposed searches for CGM H\textsc{i} emission.

**Vanessa Moss (ASTRON/University of Sydney)**

**SWISH team**

**Uncovering the hidden iceberg structure of the gaseous Galactic halo**

How the Milky Way gets its gas and keeps its measured star formation rate going are both long-standing mysteries in Galactic studies, with important implications for the relationship of galaxies to their circumgalactic media throughout the Universe. I will present our discovery of two populations of neutral hydrogen (H\textsc{i}) in the halo of the Milky Way: 1) a narrow line-width dense population typical of the majority of bright high velocity cloud (HVC) components, and 2) a fainter, broad line-width diffuse population that aligns well with the population found in very sensitive pointings such as in Lockman et al. (2002). From our existing data, we concluded that the diffuse population could outweigh the dense H\textsc{i} by a factor of 3. This discovery of diffuse H\textsc{i}, which appears to be prevalent throughout the halo, takes us closer to solving the Galactic mystery of accretion and reveals a gaseous neutral halo hidden from the view of most large-scale surveys. We have carried out deep Parkes observations as part of the Survey of Weak Intensity of Southern H\textsc{i} (SWISH) to investigate these results further, in order to truly uncover the nature of the diffuse H\textsc{i} and determine whether our 3:1 ratio (based on the limited existing data) is consistent with what is seen when Parkes and the 140 ft Green Bank telescope are employed at comparable sensitivity. With these data, through a combination of both known and new sightline measurements, we aim to reveal the structure of the Galactic halo in more detail than ever before and connect our results to the recent studies of ionised UV absorption towards HVCs.
Michał Michałowski (Astronomical Observatory Institute, Adam Mickiewicz University)

How to identify galaxies which have experienced recent inflow of gas?

I will present observational evidence that galaxies hosting gamma-ray bursts (GRBs) and some types of supernovae (SN) can be used to study very recent inflow of metal-poor atomic gas from the intergalactic medium. This is supported by their high atomic gas content, irregular velocity fields, potential deficiency in molecular gas, and anomalous metallicity decrements at the position of the most vigorous star formation. Moreover, I will present the possibility that a fraction of star-formation in these galaxies is therefore fuelled by atomic gas, not molecular gas, as is usually assumed. This can happen in low-metallicity gas near the onset of star formation because cooling of gas (necessary for star formation) is faster than the H$^\text{I}$-to-H$_2$ conversion. These GRB/SN hosts have relatively low metallicity, so they can be used as local analogs towards the understanding of fuelling of star formation in the early Universe.

Filippo Maccagni (INAF-OAC)
Paolo Serra (INAF - OAC)

Cold gas regulating the nuclear activity of Fornax A

Observing neutral hydrogen gas (H$^\text{I}$) in well-resolved active galactic nuclei (AGN) is ideal to test how cold gas may fall onto the central super-massive black hole of a galaxy and regulate the nuclear activity. In the centre of several AGN, H$^\text{I}$ is typically found to be distributed in a circumnuclear disk, but sometimes it is found within in-falling clouds, that is likely fuelling the AGN or in outflows, possibly ejected by the expanding radio jets.

In this talk, I will focus on the study of the radio emission of the lobes and jets of Fornax A as well as its H$^\text{I}$ content. Fornax A is the third closest AGN in the Universe ($D_L \sim 20$ Mpc); its extended lobes ($\geq 200$ kpc) dominate its radio continuum emission and they are likely the product of nuclear activity triggered by a giant major merger. High resolution ($8''$) and high dynamic range (rms $\sim 20$ $\mu$Jy) MeerKAT commissioning observations of Fornax A allowed us to detect, for the very first time, H$^\text{I}$ in its centre, which is possibly interacting with the expanding radio jets. I will show how these broad-band continuum observations have been critical to unlock the history of the nuclear activity of Fornax A. I will relate the kinematics and physical conditions (mass, density and temperature) of the circumnuclear H$^\text{I}$ to the other phases of the ISM and to the evolution of the AGN.

Alessandro Loni (Istituto Nazionale di Astrofisica)
Paolo Serra (Istituto Nazionale di Astrofisica)

An H$^\text{I}$ survey of the Fornax galaxy cluster

We present a deep, blind, H$^\text{I}$ survey of the Fornax galaxy cluster carried out with the Australian Telescope Compact Array (ATCA). The Fornax galaxy cluster is significantly different from the well studied Virgo cluster, as the density of the intra-cluster medium and the velocity dispersion of Fornax are a factor of 2 lower, while the galaxy number is twice as large. These conditions enable
the H\textsubscript{I} in in-falling, gas-rich dwarf galaxies to survive longer than in other clusters, providing us with a good opportunity to measure the properties of the H\textsubscript{I} in the cluster including pre-processing mechanisms. Our images have an H\textsubscript{I} column density sensitivity of \(3 \times 10^{19}\) cm\(^{-2}\) at \(\sim \) arcmin resolution and an \(M(\text{H\textsubscript{I}})\) detection limit of \(10^{7} M_\odot\), which is an improvement of a factor of \(\sim 10\) in sensitivity and 15 in resolution compared to previous surveys. To date, we have detected 15 H\textsubscript{I} sources, which include many new detections. We are comparing the H\textsubscript{I} detections and upper limits to known scaling relations to measure the H\textsubscript{I} depletion in this cluster.

**Barbara Catinella (ICRAR/UWA)**

**How can local H\textsubscript{I} surveys inform the analysis of higher redshift surveys?**

In this talk, I will present recent results based on xGASS, the extended GALEX Arecibo SDSS Survey, as well as spectral stacking of a large stellar mass-selected sample with H\textsubscript{I} data from ALFALFA, and discuss implications for future H\textsubscript{I} surveys. In particular, I will focus on spatially unresolved, local H\textsubscript{I} surveys, both blind and targeted, and show how these are important not only to define the benchmark reference at \(z = 0\), but also to understand and quantify selection biases. I will also discuss ongoing work to investigate the shape of H\textsubscript{I} profiles, in order to extract more information from higher-redshift H\textsubscript{I} surveys.

**Abstracts — Wednesday, 31 July**

**Linda Tacconi (MPE Garching)**

**How can we best characterize the cold, dense ISM mass at \(z > 1\)?**

Comprehensive and systematic studies of star formation and the gas contents of galaxies during the epochs that are associated with the peak \((z \sim 13)\), and subsequent winding down \((z < 1)\) of star formation in the Universe are enabling us to illustrate the important role that cold gas, the fuel for star formation, has played in the assembly of galaxies across cosmic time. In this talk I will discuss various strategies and methods being used to determine the gas mass at high \(z\), and to present the statistically robust gas scaling relations with redshift, star formation and stellar mass.

**Deanne Fisher (Swinburne University)**

**High feedback and star formation efficiency in turbulent disk galaxies**

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\(^{-1}\)), 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 dominant 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 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, and discuss links between star formation efficiency and formation of clumps of stellar mass. The details of clumpy systems are a direct constraint of the results of simulations, especially on the nature of feedback in the high density environments of star formation that dominate the early Universe.

John Wu (Rutgers University)

The multiphase ISM in Lyman break galaxy analogs

The discovery of compact, UV-bright, $z \sim 0.2$ starbursts that strongly resemble Lyman break galaxies (LBGs) gives us the opportunity to study galaxy formation and evolution in far greater detail than would be possible at high redshifts. I will present VLT/SINFONI integral field spectroscopy of a sample of six LBG analogs, showcasing their diverse multiphase gas and dust properties. Intense star formation feedback is evidenced by high velocity dispersions, strong warm molecular gas emission, and hard ionizing spectra. LBG analogs also resemble high-redshift disk systems in terms of the stellar mass Tully-Fisher relation. I will discuss implications for the H$_1$ content of both LBGs and their low-redshift analogs.

Aleksandra Hamanowicz (European Southern Observatory)

Martin Zwaan (ESO), Céline Peroux (European Southern Observatory)

Molecular content of galaxies studied with ALMACAL

The Star Formation History of the Universe changes with time and has a clear maximum around redshift $z \sim 2$, but it is not clear what drives the decline after that peak. Recent studies suggest a possible link between the cosmic density of H$_2$ — the most abundant molecule in the Universe — and the Star Formation History (Decarli et al. 2016; Keating et al. 2016; Riechers et al. 2018). The second most abundant molecule, and a proxy for H$_2$, is CO, and its rotational transitions are bright and relatively easy to observe with ALMA over a large range of redshift. In my talk I will present a blind CO emission line survey making use of ALMACAL — a science project aiming to use ALMA calibration data for scientific purposes. Since every ALMA science observation is accompanied by several calibration measurements across all bands, ALMACAL provides a vast and diverse dataset applicable for multiple science cases. After removing the bright point source (calibrator), we perform a blind search over the cubes with the longest accumulated integration times. Thanks to the uniqueness of the ALMACAL dataset we are able to study galaxies over a much wider area, and hence we are much less affected by cosmic variance than deep pencil beam surveys.
Tristan Reynolds (International Centre for Radio Astronomy Research/University of Western Australia)

ASKAP/WALLABY early science: the NGC 7162 galaxy group

The wide field of view, fast survey speed and high resolution of the Australian Square Kilometre Array Pathfinder (ASKAP) will provide the ability to study neutral hydrogen (H\textsc{i}) in large numbers of galaxies. In particular, the Wide-field ASKAP L-band Legacy All-sky Blind survey (WALLABY) will produce H\textsc{i} images for half a million galaxies in the local Universe ($z < 0.1$). This will result in the ultimate zero-redshift reference for the gaseous properties of galaxies, and the dependence of their properties on local environment. Prior to the full survey commencing, four early science fields have been observed using 12 ASKAP antennas (ASKAP-12) for validation of ASKAP and the processing pipeline and to investigate H\textsc{i} in group environments. I will present results from the first ASKAP-12 HI spectral line observations of the NGC 7162 galaxy group, located in one of the early science fields. ASKAP data is found to be of excellent science quality, as validated against archival HIPASS and the Australia Telescope Compact Array (ATCA) data. The excellent data quality and wide field of view result in the detection of three new group members. This includes the first H\textsc{i} detections of two dwarf galaxies, providing the first redshift measurements for these galaxies. The high spatial and spectral resolution of ASKAP enables kinematic studies of resolved galaxies to derive rotation curves and dark matter mass estimates. Full WALLABY (36 antennas) will enable similar analysis to this over 75% of the sky.

Alice Concas (Kavli, University of Cambridge)

Paola Popesso (TUM)

The impact of the environment on the gas reservoir and star formation in local massive galaxies

The star-forming properties of galaxies that reside in dense cores of galaxy clusters are remarkably different from those in the field. Several observations confirm that quiescent early-type galaxies are more prevalent in clusters whereas star-forming spirals dominate in the field. The dominant mechanism responsible for this bimodal distribution of galaxies in different environments remains elusive. In this talk, I will present a new observational methodology to statistically explore the impact of the environment on regulating the molecular gas reservoir and star formation in local massive central galaxies (at $z < 0.3$ and stellar masses larger than $10^{10} M_\odot$). For this purpose, we use the exquisite statistics of the Sloan Digital Sky Survey to examine central galaxies across a wide range of host halo masses, from massive clusters to the lowest halo mass groups in the local Universe. I will show that central galaxies located in low-density environments tend to be more gas-rich with respect to the galaxies in high-mass halos. Such lack of cold gas supply above the $10^{12-12.5} M_\odot$ halo mass threshold might limit the fuel for the galaxy SF process and so lower the galaxy SFR. All our findings indicate that the environment plays a pivotal role in regulating the cold gas reservoir and so quenching the SF activity in massive central galaxies.

Sheila Kannappan (University of North Carolina – Chapel Hill)
Zack Hutchens (University of North Carolina – Chapel Hill)

Comparing apples to apples and apples to seeds between low- and high-redshift H\text{I} surveys

This talk will begin with an overview of $z \sim 0$ relations between galaxy properties/environments and H\text{I} masses as observed in the complete, volume-limited RESOLVE survey, which has adaptive 21 cm sensitivity probing down to 5–10% of stellar mass. The observed relations reveal galaxy and group mass dependence as well as trends with star formation history, AGN activity, metallicity, and interactions/mergers. The talk will go on to examine whether and how these relations would change — in the absence of evolution — for high-redshift data with flux-limited 21 cm sensitivity and various survey selection strategies, especially as relevant to developing cross-matched data sets built on the LADUMA survey. Finally, protocols for analyzing group evolutionary state in tandem with group identification will be explored, as a step toward developing group finding approaches that optimally reflect progenitor-descendant relationships between low and high redshift groups.

Lister Staveley-Smith (ICRAR/UWA)

Traversing the H\text{I} desert

The understanding of the role of neutral hydrogen in galaxy evolution is limited by radio sensitivity to $z < 0.4$ and by ultraviolet sensitivity to $z > 1.6$. This corresponds to a gap in temporal coverage of 5 billion years, and occurs right at the peak of the cosmic star formation rate. Recent advances in “intensity mapping” have begun to address this “H\text{I} desert.” Intensity mapping permits the measurement of the cosmic gas density at a redshift of unity, and is also able to be used to study of the geometry of the Universe via baryonic acoustic oscillations. Specialist instruments such as CHIME, Tian-Lai and BINGO are currently being built or commissioned to undertake such studies. However, existing radio telescopes such as Parkes, MeerKAT, ASKAP and FAST are also capable of scientific contributions in this area, as will the SKA in due course. This talk summarises the recent accurate measurements of intensity mapping signals using a phased array feed on the Parkes telescope, and the corresponding implications for our understanding of galaxy evolution.

Marcel Neeleman (MPIA)

The molecular content of cosmic gas reservoirs

Our current knowledge of the properties of neutral gas at high redshifts has been obtained predominantly through absorption spectroscopy. The strongest H\text{I} absorbers, DLAs, are the most conspicuous, and make up the bulk of the cosmic H\text{I} budget. Their large H\text{I} column density and metal enrichment strongly implies — although indirectly — a close link with galaxies. Numerous studies have therefore attempted (with varying success) to connect the H\text{I} seen in absorption with emission lines from the associated galaxy.

In this talk, I will present observations from ALMA and other sub-mm/radio facilities that aim to measure the molecular and H\text{I} emission lines from galaxies associated with DLAs. ALMA has been transformative in this field by detecting — with great efficiency — the galaxy counterparts of DLAs. These observations show that the molecular mass of these H\text{I} absorption-selected galaxies is large, much larger than for other galaxy samples. The range of impact parameters between the
molecular emission and the H\textsc{i} absorbers implies H\textsc{i} is extended far past the molecular emission of the galaxies. Finally, comparing the absorber kinematics with the kinematics of the molecular emission suggests a range of different physical origins of the H\textsc{i} detected in absorption, in some cases the gas seem to arise from an extended disk, whereas in other cases it arises from within the circumgalactic medium.

Tirna Deb (Kapteyn Institute)

Neutral hydrogen gas in a striking jellyfish galaxy

Jellyfish galaxies have tentacles of material that stretch tens of kpc beyond their disks. These tentacles show signatures of ram-pressure stripping that happens when the hot, dense and powerful ICM pressure blows the gas out of the gravitational potential of the galaxies and creates tail-like structures out of the disk, stimulating star formation within them. The GASP (GAs Stripping Phenomena in galaxies) survey is carried out with the MUSE Integral Field spectrograph on the VLT to observe over 100 of these galaxies over a wide range of masses, morphological asymmetries and environments. Five of the most striking jellyfish galaxies are observed with the VLA-C array. JO204 is one such spectacular jellyfish galaxy in the relatively low-mass cluster A957 that shows a tail of ionized gas extending up to 30 kpc. From APEX data, we found a lot of molecular gas in the disk and in the ionized gas tail. I present the VLA H\textsc{i} data that provides missing information about the neutral gas phase. From the VLA observation of JO204, the H\textsc{i} content of this galaxy and the interplay between various gas phases is studied in detail. The H\textsc{i} tail is much more extended than the ionized gas tail and its unilateral extension is a distinct signature of ram-pressure stripping. We have also detected H\textsc{i} in absorption for the first time in this jellyfish galaxy against the 11 mJy central continuum source, which is an AGN. The red-shifted absorption profile of JO204 suggests that ram-pressure is pushing the H\textsc{i} gas towards the central black hole and thus triggering the AGN activity.

Sambit Roychowdhury (Swinburne University)

The gas-to-dust cycle in low-metallicity dwarf galaxies using spatially resolved measurements

Star-forming dwarf galaxies are the most numerous galaxies in the nearby Universe, with many properties in common with the first galaxies that formed. They represent a goldmine in our own backyard for studying the baryon cycle in the smallest galaxies. Recent large multi-wavelength surveys of the Local Volume have made it possible to study these galaxies in considerable detail. Atomic hydrogen (H\textsc{i}) remains the primary tracer of gas in these systems as CO, the tracer of molecular gas, becomes harder to detect due to a decrease in the CO-to-H\textsubscript{2} ratio with decreasing metallicity. The atomic gas traces the total gas reservoir in dwarf irregulars — and consequently the whole ecosystem within which stars form. I will present our efforts to study the full baryon cycle in the lowest (< 20% solar) metallicity star-forming dwarf galaxies from the well-defined DustPedia sample, which has multi-wavelength coverage in 42 bands ranging from the ultraviolet to submillimeter. Adding resolved H\textsc{i} maps, and using SFR and dust properties derived from SED fits using a hierarchical Bayesian approach, we study the relations between various properties tracing the evolution of gas, stars and dust in the galaxies. While historically such studies have used single-dish H\textsc{i} fluxes, we compare the gas and dust properties within co-spatial regions using
interferometric H\textsuperscript{i} observations on a region-by-region basis within the galaxies. The results reveal rich and intriguing variation of dust properties within the disks of individual dwarf galaxies, and shows how the previous studies of the variation of gas-to-dust ratio with metallicity in dwarf galaxies erred by comparing metallicities measured in inner regions of these galaxies with global measurements of gas and dust. Our studies reveal how gas-to-dust properties actually vary within spatially resolved regions of low metallicity galaxies.

Anne Klitsch (European Southern Observatory)
Martin Zwaan (ESO), Céline Peroux (ESO)

Molecular view on the cosmic baryon cycle

Studying the multiphase circum-galactic medium (CGM) and its connection to the baryons in the host galaxies through the cosmic baryon cycle is an important step towards a better understanding of the evolution of galaxies. Large steps forward have been made in detecting the multiphase CGM through absorption line studies and connecting the CGM to its host galaxy. However, the link to the molecular gas phase from which the stars form is still missing. We have exploited ALMA calibrator observations to perform a novel (sub)mm survey, ALMACAL. We search for CO emission lines from the host galaxies of known Lyman alpha absorbers. We have detected three galaxies in multiple CO transitions indicating more excited ISMs than in normal star-forming galaxies. Furthermore, we find more evidence for intervening absorbers being connected to groups rather than isolated galaxies from our ALMA and follow-up MUSE observations.

In addition to the local baryon cycle, we also study the global baryon cycle by combining the cosmic star formation history with the evolution of $\Omega_{\text{H}1}$ and $\Omega_{\text{H}_2}$. By conducting a blind search for molecular absorption lines seen in the spectra of radio-bright quasars in ALMACAL, we measure the evolution of $\Omega_{\text{H}_2}$. The resulting measurement of the cosmic molecular gas density will serve as an independent comparison to the results of CO emission line surveys such as ASPECS and COLDz.

Luca Cortese (ICRAR/UWA)

Challenging H\textsubscript{2} domination in high-redshift star-forming galaxies

Cold hydrogen gas is the raw fuel for star formation in galaxies, and its partition into atomic and molecular phases is a key quantity for galaxy evolution. Observationally, it is still unclear whether at higher redshift atomic gas still plays an important role in the cold gas budget of galaxies, though the most common assumption is that H\textsuperscript{i} becomes negligible already at $z \sim 0.3$.

In this talk, we will present results from the HIGHz survey, i.e., the largest representative sample of star-forming galaxies with H\textsuperscript{i} information at $z \sim 0.2$. In particular, we combine ALMA and Arecibo data to estimate the molecular-to-atomic hydrogen mass ratio for some of the most massive gas-rich systems currently known. We show that the balance between atomic and molecular hydrogen in these galaxies is similar to that of local main-sequence disks, implying that atomic hydrogen has been dominating the cold gas mass budget of star-forming galaxies for at least the past three billion years. In addition, despite harboring gas reservoirs that are more typical of objects at the cosmic noon, HIGHz galaxies host regular rotating disks with low gas velocity dispersions.
suggesting that high total gas fractions do not necessarily drive high turbulence in the interstellar medium.

Sergei Balashev (Ioffe Institute)
Pasquier Noterdaeme (Institut d’Astrophysique de Paris)

**Measurements of the diffuse molecular gas at high redshifts**

We present the detection of the average H$_2$ absorption signal in the overall population of neutral gas absorption systems at $z \sim 3$ using composite absorption spectra built from the Sloan Digital Sky Survey III damped Lyman α catalogue. We present a new technique to directly measure the H$_2$ column density distribution function $f_{\text{H}_2}(N)$ from the average H$_2$ absorption signal. Assuming a power-law column density distribution, we obtain a slope $\beta = 1.29 \pm 0.06$ (stat) \pm 0.10 (sys) and an incidence rate of strong H$_2$ absorptions (with $N(\text{H}_2) \geq 10^{18}$ cm$^2$) to be $4.0 \pm 0.5$ (stat) \pm 1.0 (sys) per cent in H$_1$ absorption systems with $N(\text{H}1) \geq 10^{20}$ cm$^2$. Assuming the same inflexion point where $f_{\text{H}_2}(N)$ steepens as at $z = 0$, we estimate that the cosmological density of diffuse molecular gas (with H$_2$ in the column density range $\log N(\text{H}_2) (\text{cm}^2) = 18 - 22$) is $\sim 15\%$ of the total. We find one order of magnitude higher H$_2$ incidence rate in a subsample of extremely strong damped Lyman α absorption systems (DLAs) ($\log N(\text{H}1) (\text{cm}^2) \geq 21.7$), which, together with the derived shape of $f_{\text{H}_2}(N)$, suggests that the typical H$_1$–H$_2$ transition column density in DLAs is $\log N(\text{H}) (\text{cm}^2) \sim 22.3$ in agreement with theoretical expectations for the average (low) metallicity of DLAs at high $z$.

Erin Boettcher (The University of Chicago)
Hsiao-Wen Chen (The University of Chicago), Fakhri Zahedy (The University of Chicago)

**Probing multiphase gaseous galactic ecosystems in absorption and emission**

Combining QSO absorption-line spectroscopy with IFU emission-line observations provides a powerful probe of the multiphase gaseous environments of galaxies. We will discuss systems for which these observations have illuminated the co-evolution of galaxies and the circumgalactic medium and the promise of this approach in the era of 30m-class telescopes. We will then focus on the subset of QSO sightlines that reveal H$_2$-bearing DLAs, highlighting the detection of such a system at $z = 0.576$ towards J0111−0316. This system, observed with HST-COS as part of the Cosmic Ultraviolet Baryon Survey, has $\log (N(\text{H}_2)) = 17$ and $\log (f(\text{H}_2)) = -3.1$, with multiple velocity components resolved in both the atomic and molecular phases. We will discuss the kinematics, chemical properties, and ionization state of the system, and use the excitation state of the molecular hydrogen to probe the physical conditions in the cloud cores. Extensive ground-based spectroscopy from the Magellan Telescopes provides information about the galaxy population local to the DLA, and we will explore possible origin scenarios for the system. Pairing these and similar observations with IFU emission-line spectroscopy will allow the relationship between molecular cloud cores and their diffuse gaseous environments to be studied in a spatially-resolved sense.

Maryam Arabsalmani (University of Melbourne)
Neutral gas in the close environments of massive star explosions

Gamma Ray Bursts (GRBs) and Super Luminous Supernovae (SLSNe) are the brightest explosions in the Universe, originating in the core-collapse of massive stars, located in hearts of star-forming regions. Although the link between GRBs/SLSNe and massive stars is well established, the physical conditions for the formation of their progenitors remain speculative. A likely hypothesis is that they form in regions with high star formation rate density and high gas surface density. I will describe our ongoing survey of atomic and molecular gas in $z < 0.1$ GRB and SLSN host galaxies. This survey was designed to test the hypothesis mentioned above and to also investigate the structure of atomic and molecular gas in the close environment of these energetic events. I will in particular focus on three galaxies studied based on GMRT and ALMA observations. Our findings in three cases support the likely connection between massive star explosions and dense environments. Such a connection being commonplace would put strong constrains on the channels for the formation of bright explosions of massive stars.

Abhisek Mohapatra (NITR)

Evolution of optically thin high-$z$ C $\text{III}$ absorbers associated with neutral hydrogen

In this talk, I will present detailed photoionization models of well-aligned optically thin double ionized carbon (C $\text{III}$) absorption components at $2.1 \leq z \leq 3.4$. Our inferred number density and overdensity ($\Delta$) favor the absorption originating from gas associated with circumgalactic medium and probably not in hydrostatic equilibrium. We discuss statistically significant redshift evolution of our derived parameters. We show L vs. [C/H] can be well reproduced if L is governed by the product of gas cooling time and sound crossing speed as expected in the case of cloud formation under thermal instabilities. As noted in the literature survivability of such cloud over longer timescale is an issue. Therefore, studying the optically thin C $\text{III}$ absorbers over a large $z$ range and probably correlating their $z$ evolution with global star formation rate density evolution can shed light on the physics of circumgalactic medium formation and evolution.

Abstracts — Posters

Ancor Damas (Instituto de Astrofísica de Andalucía (IAA-CSIC))

Lourdes Verdes-Montenegro (Instituto de Astrofísica de Andalucía (CSIC)), Michael Jones (Instituto de Astrofísica de Andalucía), Rainer Beck (MPIfR)

Evolution of galactic magnetic fields in H$\text{I}$ defined interaction stages

There is a deep connection between the evolution of a galaxy and its magnetic field, which can act in both directions; magnetic fields appear strongly dependent on galaxy interactions, whilst magnetic fields contribute significantly in many processes that occur in the interstellar medium. Thus it is crucial to understand how environment can affect magnetic fields of large scales. However, so far an evolutionary study of this kind has been impossible due to the lack of polarization radio observations of any type of galaxy groups, let alone those in well-defined evolutionary stages. In
this regard, we (the AMIGA team) have begun a pioneering project which will use our evolutionary model of Hickson Compact Groups (HCGs) of galaxies, together with new full Stokes continuum polarization studies from the JVLA, with the final aim of creating an evolutionary scheme for magnetic fields in HCGs, and to investigate how magnetic fields might modify or contribute to the morphology of H\textsc{i} in these interacting systems.

To perform such a study it is crucial to reach the deepest possible sensitivities in order to detect the faintest extended radio emission associated with the outskirts of galaxies and the IGM. The broadband receivers of the JVLA ($\sim 4$ GHz) can now reach sensitivities of the order of a few $\mu$Jy in our observations and make this study unique in terms of sensitivity and resolution in the field of interacting galaxies. However, the sensitivity needed to perform such study makes it challenging and needs new techniques and tools to calibrate and image radio observations.

Julia Gross (Columbia University)

Nick Luber (West Virginia University), Jacqueline van Gorkom (Columbia University), D. J. Pisano (West Virginia University)

Spin alignment in CHILES

The COSMOS H\textsc{i} Large Extragalactic Survey (CHILES) is a 1000-hour survey using the Very Large Array covering a continuous redshift range of $0 < z < 0.45$, a $40 \times 40$ arcmin pointing, and with 5 arcsec resolution ($z = 0$). The CHILES survey is studying the growth of galaxies as a function of location in the cosmic web. Luber et al. (2019) uses DisPerSE (Sousbie et al. 2011) to identify filaments in the cosmic web for the CHILES field of view. One of the predictions of galaxy growth in the cosmic web is that galaxies lower in mass assemble by accreting onto filaments, generating spins that align with filaments (Ganeshaiah Veena et al. 2018). CHILES is an ideal survey to test these predictions. We present preliminary results of ten nearby galaxies out to a redshift of 0.1, from the first epoch of the CHILES survey. Our results show preferentially parallel H\textsc{i} spin alignments with cosmic web filaments.

Zackary Hutchens (University of North Carolina at Chapel Hill)

Sheila Kannappan (University of North Carolina at Chapel Hill), Ella Castelloe (University of North Carolina at Chapel Hill)

A new perspective on group finding

Friends-of-friends is a simple yet powerful algorithm for identifying groups of galaxies that likely share a common dark matter halo. However, an evolutionary perspective on gas in galaxy groups would lead us to prefer an algorithm that can identify groups in an early stage of formation that may not yet share a common halo. To address this, we are developing alternative definitions of galaxy groups that are based on physical considerations, such as gravitational attraction or virialization state. In particular, we are testing alternative group definitions against conventional techniques using the complete, volume-limited RESolved Spectroscopy of a Local VolumE (RESOLVE) survey. RESOLVE has an existing group catalog based on friends-of-friends, spans a large volume containing groups at many stages of evolution, and offers a deep H\textsc{i} census reaching into the dwarf galaxy regime. We are also working to extend our tests to a new volume-limited sub-survey within the
Looking At the Distant Universe with the MeerKAT Array (LADUMA) survey, enabling direct evolutionary comparison across redshifts.

Aura Obreja (University Observatory Munich)

Andrea Maccio (New York University Abu Dhabi), Benjamin Moster (University Observatory Munich), Rahul Kannan (Harvard-Smithsonian Center for Astrophysics)

The impact of local photoionization sources on simulated galaxies: evolution of H\textsc{i} disks

Almost all cosmological simulations of galaxy formation include the effect of photoionization and photoheating only via a homogeneous and redshift dependent Ultra Violet Background (UVB). While on large cosmological scales, the UVB can be approximated as homogeneous, on galaxy scales the high energy photon sources (stars, hot gas, black holes) are distributed highly non-uniformly. In zoom-in cosmological simulations, where only a small region of the universe is modeled with high resolution, it is worthwhile and computationally feasible to explore the effects of the non-uniform galactic UV source distribution on top of a metagalactic homogeneous UVB. In this talk I will discuss an implementation of the local photoionization radiation from young stars, post-AGB stars and hot halo gas, in the \textit{N}-body SPH code Gasoline2. The simulated galaxies have been selected from the NIHAO suite. I will show how this physically-motivated feedback channel affects the evolution of the H\textsc{i} disks in terms of both global properties like total H\textsc{i} mass and disk extent, as well as small scale disk structure and dynamics, ultimately predicting how real galaxies will be seen by the upcoming exquisite radio facilities. Indeed I will show that the effect of the local radiation field starts to be visible in the galaxy structure only after \(z \approx 1.5\), which is precisely the redshift range (\(z = 0\) to 1.5) where SKA and its precursors will probe the distribution of neutral gas in the universe at best.

Daniel Rybarczyk (University of Wisconsin – Madison)

Snežana Stanimirović (University of Wisconsin – Madison)

Properties of AU-scale structure from 21-SPONGE observations

The 21 cm Spectral Line Observations of Neutral Gas with the VLA (21-SPONGE) survey detected H\textsc{i} absorption with exceptional optical depth sensitivity (\(\sigma < 10^{-3}\)) and matching H\textsc{i} emission with high angular resolution (\(\sim 4'\)) towards 47 extragalactic radio continuum sources to study the physical properties of neutral hydrogen in the Milky Way. 9 of the background sources have multiple components and offer a unique way of probing H\textsc{i} properties on spatial scales < 10\textsuperscript{4} AU. Cold H\textsc{i} features on AU-spatial scales, known as the tiny scale atomic structure (TSAS), have been observed since 1976. The origin of TSAS remains mysterious, and observations suggest that shocks and supernova remnants are likely important for the formation and survival of TSAS. All 9 of the multiple-component sources from 21-SPONGE are seen to undergo H\textsc{i} optical depth variations of at least 3\(\sigma\), with spatial separations between \(\sim 500\) and \(10^5\) AU. We compare the observed optical depth variations with predictions for turbulent fluctuations, and consider implications that TSAS has for heating of the ISM.
Predictions of detections of high-mass galaxies in CHILES

Hydrogen is the fuel for star formation, but relatively little is known about the role of cold gas in galaxy evolution. The COSMOS H\textsc{i} Large Extragalactic Survey (CHILES) is an on-going deep (1000 hr) H\textsc{i} survey being carried out with the Karl G. Jansky Very Large Array (VLA), probing a 0.5 degree region within the COSMOS field in the 21 cm line of neutral hydrogen. CHILES is the first survey to observe the H\textsc{i} 21 cm line in emission from $z = 0$ to $z \sim 0.5$, allowing us to observe the content, morphology and kinematics of the neutral hydrogen in relation to stellar disks, and how it may have evolved over this period. Here, we will present the results of a simulation of the galaxy detections possible with this survey, with an emphasis on the high-mass galaxies which should be detectable in the first 178 hours of the survey (epoch I). This will be compared with predictions of galaxy detections using artificial sources of similar scale inside of existing CHILES image cubes.

The results of our galaxy detections will be used to calculate and refine the high-mass end of the H\textsc{i} mass function (HIMF). The HIMF describes the intrinsic distribution of galaxies as a function of their H\textsc{i} mass. Because cosmological simulations make use of gas content and environmental factors, studying variations in the HIMF due to changes in redshift and environment can constrain the current models of galaxy formation. The HIMF has been well-studied in the local universe (e.g., Zwaan et al. 2005; Jones et al. 2018), and a Schechter function has been found to fit the data well. This function uses a power law to describe the low-mass slope and an exponential decline for the high-mass end. With the full 1000-hr CHILES data, we will be able to detect galaxies with H\textsc{i} masses of $10^{10} M_\odot$ out to a redshift of $z = 0.11$, and we will be able to detect galaxies with H\textsc{i} masses of $3 \times 10^{10} M_\odot$ at the highest redshift of the survey, $z = 0.5$, and use these to calculate the high-mass end of the HIMF as a function of redshift and environment, as well as to obtain the first measurements of cosmic H\textsc{i} density ($\Omega_{H\textsc{i}}$) derived from individual H\textsc{i} emission measurements at $z = 0.5$. 