SPARCS XI

The Rise of the Sky Surveys

(21st-25th November 2022)

List of Presentation Abstracts

This document lists the abstracts of invited and contributed talks at the SPARCS XI workshop. Abstracts are grouped by the theme of the session in which they are presented (see table of contents below) and then listed alphabetically by surname of the presenter.

Contents

Surveys

SKA Update

Anna Bonaldi

The Square Kilometre Array Observatory (SKAO, the largest radio facility in the world once built) is now under construction. In this talk, I will review the SKA design and its potential for transformational science on a wide range of science cases. I will also give an update on the current status of the project and on the path to full construction and commissioning.

The LOFAR LBA Survey at 54MHz

Francesco de Gasperin

The LOFAR Low Band Antenna (LBA) system makes LOFAR a case-of-study for the exploration of ultra-low frequencies (¡100 MHz). Understanding how to collect, store, reduce and analyse LOFAR LBA data, is key to have a fast track towards SKA-low science.

In this talk I will present the first release of the LOFAR LBA Sky Survey (LoLSS). The survey aims to cover the northern sky in the frequency range 42-66 MHz, reaching the sensitivity of 1 mJy/b at the resolution of 15 arcsec. These frequencies are unique testbed for exotic science cases such as low-efficiency phenomena, pulsars, exoplanet detections and absorption mechanisms. Thanks to this experience we have now a set of proven working multi-beam observing schemes, as well as simulation and data reduction

codes that can be directly applied to SKA-low observations.

The Rapid ASKAP Continuum Survey
Stefan Duchesne

Surveys of the sky at myriad wavelengths provide a complete view into the large-scale and bulk properties of the Universe while also allowing studies of individual and also unique and heretofore unknown astrophysical objects and processes. The Australian SKA Pathfinder (ASKAP) is completing a series of shallow surveys under the title "Rapid ASKAP Continuum Survey" (RACS) in three bands centered on 888, 1367, and 1632 MHz. RACS covers the Southern Sky and continues up to a declination of +49 degrees. RACS provides a combination of sensitivity ($\sim 150 - 300\,\mu$Jy/beam), resolution ($\sim 10 - 25$ arcsec), and the potential for multiple epochs that fills a niche while complementing existing data in the current ecosystem of all-sky surveys. The first of these surveys at 888 MHz has already been released with over 2M sources detected, and further data releases are expected over the coming year. On behalf of the team behind RACS, I will describe the surveys, highlight a selection of science results so far, and report on the progress of current and upcoming RACS releases across the three bands.

The MeerKAT International GHz Tiered Extragalactic Exploration (MIGHTEE) Survey
Catherine Hale

The MIGHTEE Survey (Jarvis+ 2016, Heywood+ 2022) is a MeerKAT survey to uJy/beam depth at 1.4 GHz over 20 sq. deg. This survey combines both continuum, polarization and HI spectral line information and will cover four deep extragalactic fields (COSMOS, XMM-LSS, ELAIS-S1 and E-CDFS). These fields are chosen to combine these radio observations with some of the best multi-wavelength ancillary data available. This will allow us to maximize the science goals of MIGHTEE, namely (i) to study AGN and star formation (ii) to trace the evolution of neutral hydrogen and (iii) to study cosmic magnetic fields. Recently, MIGHTEE release its Early Science Data (Heywood+ 2022) covering 5 sq. deg over the COSMOS and XMM-LSS fields combined. These images have been released at two resolutions, to reflect the limits on confusion within the images. These areas are being expanded upon with additional observations, with a total of 1000 hours of observations. In this talk, I will present the MIGHTEE survey, its key goals and present the observations to date including the Early Science data and the science which is coming out of this survey. I will go on to present information about the additional, expanded radio images (DR1) which have now been made, including an ultra-deep pointing in the E-CFDS field.

The Rise of Millimeter Sky Surveys
Matt Hilton

The past decade has seen ground-based millimetre-wave telescopes conduct deeper surveys than ever before of the southern sky at arcminute resolution. While the main goal of these surveys is to study the cosmic microwave background, as a by-product these surveys produce catalogs of thousands of massive galaxy clusters, AGNs, and high-redshift dusty star forming galaxies, which are interesting targets for the SKA precursors such as MeerKAT. In this talk I will briefly review the mm-wave data products produced by the Atacama Cosmology Telescope (ACT), which has surveyed more than 1/3 of the sky covering the frequency range 30 - 220 GHz, and look briefly at prospects for the upcoming Simons Observatory, due to begin survey operations in 2024. I will also discuss plans to mine the MeerKAT archive for serendipitous observations of galaxy clusters, with the aim

of charting the evolution of AGNs and star forming galaxies in and around clusters over the past 8 billion years.

The Evolutionary Map of the Universe
Andrew Hopkins

EMU, the Evolutionary Map of the Universe, is a planned ASKAP survey of the Southern three-quarters of the sky, aiming to achieve rms noise levels of 20 μJy. EMU will support a broad range of science, spanning star formation and evolution in our own Galaxy, galaxy evolution and the links between star formation and supermassive black holes, to cosmology. EMU has been allocated 8533hr in the coming 5 years of ASKAP operations to deliver this program. I will summarise the technical and scientific goals of the survey, the current status of and timeline for the survey, and highlight a selection of recent results

GLEAM-X: GaLactic and Extragalactic All-sky MWA survey - eXtended
Natasha Hurley-Walker

As the successor to the GaLactic and Extragalactic All-sky MWA (GLEAM) survey, GLEAM-eXtended uses the Phase II extended configuration of the Murchison Widefield Array to survey the low-frequency sky at twice the resolution and up to an order of magnitude higher sensitivity. In 2020 we completed our observing campaign, which is stretched across three years and $\sim 30,000$ individual observations, and covers the entire celestial sphere south of ~ 30 degrees. In this talk I will show the first data release, covering 1,400 square degrees, down to an RMS noise level of < 1.2 mJy/beam. The data and catalogue cover 72 — 231 MHz with 20 spectral channels, illuminating the low-frequency spectral behaviour of 70,000 radio sources. I will also describe the science prospects of and data release plans for GLEAM-X.

Decameter Observations with the Low-Frequency Array
Christian Groeneveld

The Decameter band (< 30 MHz) has been scarcily explored since the inception of radio astronomy, largely due to observational limitations. However, the decameter wavelength band is an important part of the electromagnetic spectrum. In particular, decameter observations of radio halos in galaxy clusters will allow us to constrain the particle reaccerlation mechanisms responsible for the bright and extended synchrotron emission. With the LOw Frequency ARray (LOFAR), we are able to observe the decameter wavelength band with unprecedented detail and sensitivity, opening up a new spectral window for observations. In this talk, we will present current LOFAR decameter observations, in particular of radio halos in galaxy clusters. We will specifically discuss how LOFAR corrects for the severe perturbing effects of the ionosphere at decameter wavelenghts, and the current plans for expansion to a full northern-sky survey.

The VLA Sky Survey – Overview and Current Status
Mark Lacy

The VLA Sky Survey is a synoptic radio survey of the whole sky visible to the VLA at 3-arcsec resolution. Observations are now complete for two of the three epochs, with the third and final epoch scheduled to begin observations in January 2023. "Quick Look" Stokes I image products are available for both of the first two epochs, and work has begun on producing higher quality "Single Epoch" image products in both Stokes I wide-band continuum and as cubes in I, Q and U polarization. In this talk I will give an update on the progress of the survey, discussing both some of the new science that has already been enabled by the survey and the steps taken to validate the Single Epoch products prior

to the start of production. Finally, I will discuss plans for combined imaging of all three survey epochs.

Apertif continuum source catalog
Alexander Kutkin

The first data release from Apertif survey contains 3074 radio continuum images, covering a thousand square degrees of the sky. The observations were performed between August 2019 and July 2020. The continuum images were produced at a central frequency 1355 MHz, with a bandwidth of 150 MHz and angular resolution of up to 10". We present the continuum catalog for this data release containing quarter a million sources. We discuss some scientific applications and plans for future Apertif data releases.

e-MERLIN Overview and Update on Future Development Plans
Tom Muxlow

The University of Manchester e-MERLIN radio imaging array occupies a unique position in the Northern sky radio imaging parameter space with antennas spacings lying between 10km and 220km – intermediate between the JVLA and VLBI arrays allowing seamless combination imaging across the arcsecond to mas angular scales at centimetric wavelengths. Recent developments have enabled routine EVN+e-MERLIN combination imaging together with many joint JVLA+e-MERLIN combination imaging programmes, providing wide-ranging radio imaging capability in the Northern Sky. A significant digital upgrade to e-MERLIN has been funded to upgrade and replace aging electronic equipment across the e-MERLIN array – together with plans to move to larger bandwidths and to replace the existing (and aging) WIDAR hardware correlator with a software equivalent. In addition to technical developments, some examples of new science results from recent combination imaging programmes are presented.

The LOFAR Two meter Sky Survey
Tim Shimwell

PENDING

SPICE-RACS: Spectra and Polarisation In Cutouts of Extragalactic sources from RACS
Alec Thomson

Despite the fundamental nature of cosmic magnetic fields, many questions remain regarding their origin, evolution, and structure. We are able to illuminate these otherwise invisible fields through observations of background polarised radio sources. By measuring the Faraday rotation this polarised emission experiences along the line of sight, we are able to reconstruct the magneto-ionic structure of foreground features, such as the Milky Way Galaxy. This technique would also be applicable to smaller foreground objects, such as galaxies and clusters, however, we are typically limited by the on-sky density of background sources detected by a given radio survey. Through a collaboration between the ASKAP observatory and the Polarisation Sky Survey of the Universe's Magnetism (POSSUM) survey team, SPICE-RACS will catalogue linearly polarised sources from the Rapid ASKAP Continuum Survey (RACS) and deliver a background polarised source density 3-5x higher than the current state of the art. I will present the first data release of SPICE-RACS. This catalogue contains 6000 polarised radio sources, imaged at 25", over 1300 square degrees towards the nearby Spica HII region. I will describe our first science results derived from this catalogue, and the future plans for SPICE-RACS.

the upgraded GMRT: Overview and Surveys
Dharam Vir Lal

The MeerKAT International GHz Tiered Extragalactic Exploration (MIGHTEE) is one of eight approved Large Survey Projects on the MeerKAT Square Kilometre Array (SKA) precursor telescope. Next, the increased bandwidth and sensitivity of the upgraded Giant Metrewave Radio Telescope (GMRT) SKA pathfinder telescope provides capability identical the MeerKAT to achieve noise levels of a few microJy.

These two instruments complement one another. More specifically, for the MIGHTEE project, the MeerKAT will devote a total of 1950 hours of time to secure deep imaging at $\sim$2 micro-Jy sensitivity covering 20 sq. deg. over a bandwidth of 0.9-1.6 GHz. Similarly, the GMRT, with baselines almost four times larger than those of MeerKAT, offers similar imaging angular resolution at low frequency (250-850 MHz) as the MeerKAT at high frequency, will match MIGHTEE project at the low frequency.

In my presentation, we will provide a status report of this (technical and scientific) collaboration, namely, a joint MeerKAT and upgraded GMRT project, or the super-MIGHTEE project.

MALS – Homogeneous Continuum Catalogues Towards a Measurement of the Cosmic Radio Dipole
Jonah Wagenveld

The MeerKAT Absorption Line Survey (MALS) is a blind search for absorption lines with pointings centred on bright radio sources. With the sensitivity and field of view of MeerKAT, each MALS pointing yields thousands of sources observed in continuum, and with a thousand pointings planned for the full survey the final catalogue is expected to contain millions of sources. With these number counts we aim to measure the cosmic radio dipole, an anisotropy in the number counts of radio sources with respect to the cosmic background. Results have shown a tension between the radio dipole and the dipole as measured from the cosmic microwave background (CMB), presenting an intriguing puzzle as to the cause of this discrepancy. We present the observations, calibration, processing, and analysis of the first ten MALS pointings, focusing on mitigating and characterising systematic effects that could lead to an inhomogeneous catalogue, and compile a continuum catalogue with 16,269 sources covering 35.7 square degrees of radio sky. We show that we can effectively homogenise the catalogues and properly account for systematic effects down to $100 - 200\,\mu$Jy, which will give us sufficient sensitivity for a dipole measurement with only 100 MALS pointings. This deep analysis on source characteristics and counts in the pointings will enable us to perform the most complete dipole estimate of a radio survey thus far.

The POSSUM Survey
Jennifer West

I will present the Polarization Sky Survey of the Universe's Magnetism (POSSUM), one of eight large survey science projects that will take place over the next 5 years using the Australian Square Kilometre Array Pathfinder (ASKAP) telescope. POSSUM will provide Faraday rotation measures (RM) for at least an order of magnitude more radio sources than ever before observed. The RM reveals information about the physical properties of the intervening magnetic field and can answer many scientific questions such as: What is the nature of the magnetic fields of the Milky Way and nearby galaxies? And what is the role of cosmic magnetic fields in the evolution of galaxies and large scale structure? I will discuss the current status and future plans for the survey and give a

brief overview of the survey science.

Pipelines and Imaging

Recovering diffuse extended emission with LOFAR
Luca Bruno

The study of extended sources in the sky involves many different areas of radioastronomy. These targets require a dense sampling of short baselines to be properly recovered by radio interferometers and avoid flux density losses due to inadequate uv-coverage. In galaxy clusters, extended (Mpc-scale) diffuse synchrotron emission can be found in the form of radio halos. The absence of radio halos may be not intrinsic, but due to extrinsic instrumental and observational effects. In both cases, upper limits to the radio power of a possible halo can be derived and compared with the power of detected radio halos in statistical studies to investigate the origin of these sources.

The Second Data Release of the LOFAR Two Meter Sky Survey (LoTSS-DR2) includes ~ 140 Planck galaxy clusters lacking a detected radio halo. We exploit targets from this sample to test the capabilities of LOFAR to recover diffuse extended emission through the injection of mock visibilities simulating radio halos into the observed uv-datasets. We show that the unprecedented density of the uv-coverage of LOFAR at short spacings allows to recover $\sim 90\%$ of the flux density of targets with sizes up to $\sim 15'$. We find a relation that provides upper limits based on the image noise and extent of the mock halo. This relation can be safely adopted to obtain upper limits without the injection process; nevertheless, the presence of artifacts still requires injections and visual inspection of the images to determine more reliable limits. Through these methods, we obtain upper limits for 75 clusters to be exploited in ongoing statistical studies.

IDIA processMeerKAT pipeline: v2.0 and outlier imaging
Jordan Collier

The IDIA processMeerKAT pipeline has been developed as a scalable, user-friendly parallel processing software package, designed to efficiently deal with the onslaught of MeerKAT data. Recently, we released v2.0 of the pipeline, which implements CASA 6 and Python3, self-calibration and science imaging. This talk will cover the pipeline's design and results, and present the experimental implementation of outlier field imaging, an algorithm to improve imaging performance without the need for the computationally-heavy process of creating very large images.

The SKA DATA Challenge 1 Hack
Eslam Hussein

There are four data challenges which SKA planned for, all of which are designed to get scientific community familiar with the challenges that the SKA will present. However, those data challenges are difficult to walk through for absolute beginners. Therefore we at IDIA redesigned Data challenge 1 into more beginner hack friendly. The hack into total has two tutorials. One tutorial is for data pre-processing and the other is for source classification. The idea of the presentation is to show the audience the benefits of the newly designed data challenge.

EMUcat
Josh Marvil

This talk will review the design and developmental progress of the EMU Value-added Catalog (EMUcat). The primary aim of the EMUcat project is to digest the pipeline-processed data products from each ASKAP-EMU observation and prepare them for use

by the EMU science teams and the broader community. The first stage of EMUcat processing is to consolidate the individual observations into a full-sensitivity, all-sky radio component catalog. The next stages group components together into physical sources of radio emission, and for extragalactic sources identify the host galaxy producing this emission. Further stages assemble a suite of multiwavelength photometry and other value-added information for each source, compute derived properties, and assign textual labels to aid in source selection and classification.

Asynchronous on-the-fly (OTF) mosaic imaging with MeerKAT
Kristof Rozgonyi

Interferometric scanning or 'on-the-fly' mosaicking (OTFM) mode enables a high survey speed by removing some of the slew-and-settle overhead time from the observations. This mode, in particular, is ideal for multi-epoch, shallow, large-area surveys, carried out with a sensitive interferometer with a small field of view. OTFM also enables commensal single-dish intensity mapping with interferometric observations. However, this mode is currently only available on the VLA.

MeerKAT and the upcoming SKA-mid would greatly benefit from implementing the OTF observing mode for both continuum and spectral-line large-area surveys. Although the current hardware is capable of OTF mode observations, developing a dedicated data reduction and imaging pipeline is required. As such, in the first step towards demonstrating the feasibility of the OTF mode on MeerKAT, we conducted a series of scanning observations to probe cosmology by intensity mapping in autocorrelation mode (standard observing mode) while additionally performing crosscorrelation for a fixed delay centre in the observer's reference frame. Ergo no geometric delays were introduced to track the dish movements. While such an observation strategy introduces a small phase error on the observed visibilities, synthesis imaging can be carried out by phase-rotating the correlated visibilities to the antenna pointing.

In this presentation, we report on the first results from these 'asynchronous' MeerKAT OTF observations. We present the calibration and imaging methods used, and our results from the scans processed to date. Furthermore, we touch on possible synergies with a commensal single-dish intensity mapping experiment.

VLBI and High Resolution

VLBI coverage of MeerKAT extragalactic surveys

Roger Deane

High angular resolution radio astronomy has undergone several major advancements over the past decade at metre, cm, and mm wavelengths through the Very Long Baseline Interferometry (VLBI) technique. Increased VLBI sensitivity, capabilities, and algorithm development enable wider area surveys that detect orders of magnitude more sources, while sophisticated imaging and Bayesian modelling enables higher and more robust scientific yield from individual sources of interest. This is set to dramatically accelerate over the course of the next decade as new stations are added and as the SKA-MID and and LOW arrays become operational. Increased wide-field VLBI survey capability and usage is timely given the survey-driven focus of SKA pathfinders and more generally the impetus on wide-area synoptic surveys across the electromagnetic spectrum. In this talk I present the design, processing, and basic data products of several wide-field VLBI surveys over legacy extragalactic fields, and their synergies with the MeerKAT MIGHTEE survey, in particular. Novel survey design, imaging, and source-finding approaches will help broaden the discovery space for future wide-field surveys with upcoming arrays like Square Kilometre Array (SKA-VLBI).

Nuclear regions of radio galaxies as seen by LOFAR international baselines: A high-resolution study of their recurrent activity

Nika Jurlin

Radio galaxies dominate the sky at radio wavelengths and represent an essential piece in the galaxy evolution puzzle. High-resolution studies focused on statistical samples of radio galaxies are expected to shed light on the triggering mechanisms of the active galactic nucleus in their centre, which alternate between the phases of activity and quiescence.

In this talk, I will present the first low-frequency statistical study of the sub-arcsec radio structures in the central regions of the 35 radio galaxies previously classified as active, remnant and restarted radio galaxies based on the LOFAR observations at 150 MHz. Our goal was to examine the morphologies and study the spectral properties of their central regions to explore their evolutionary stage and revise the morphological and spectral criteria used to select the initial sample. To achieve this, we used the newly available LOFAR image obtained using international baselines, yielding a resolution of 0.33 arcsec and higher frequency surveys up to 3 GHz, including VLASS. I will describe the various morphological and spectral properties of the sources in the sample, how we confirmed the nature of some sources and reclassified the others, and what this means for the duration of the inactive phase. Finally, I will briefly mention how this study expanded the development of automated criteria crucial for selecting and interpreting larger statistically-significant samples of restarted radio sources in the LOFAR Two-metre Sky Survey.

SPARCS-North Wide-field VLBI Survey: Exploring the resolved μJy extragalactic radio source population with EVN+e-MERLIN

Ann Njeri

The SKA PAthfinder Radio Continuum Surveys (SPARCS) are providing deepfield imaging with multiple SKA precursors such as the MeerKAT, LOFAR, ASKAP, eVLA and e-MERLIN. To characterize the relative contribution of radio emission associated with AGN from star-formation (SF) in faint radio source populations, a combination of sensitivity and high angular resolution imaging over a range of spatial scales (arcsec to mas) is

required. We present a multi-resolution (10–100 mas) view of the transition between compact AGN and diffuse SF through the deep widefield EVN+e-MERLIN, multiple phase centre survey of the centre of the Northern SPARCS (SLOAN) reference field at 1.6 GHz. This survey provides the first (and only) VLBI (+e-MERLIN) resolution observation of this field, and of the wider SPARCS reference field programme. We present a catalogue of 11 VLBI sources detected in the SPARCS-North field based on a sample of 52 known radio sources from previous observations with the e-MERLIN. We provide high spatial dynamic range coverage of these sources at $\sim$ 9 pc –0.28, further complemented by VLASS and e-MERLIN imaging at kpc and sub-kpc spatial scales. VLBI observations reveal compact emissions at parsec scales with one-/two-side jet structure appearing at sub-kpc scales. While the e-MERLIN resolves diffuse revealing extended radio structure associated with typical radio galaxies, the VLASS is important for source identification. Combining these spatial scales, we have made a serendipitous discovery of a binary SMBH candidate within the SPARCS-North field. It is expected that the occurrence of such sources are common but are however limited by sensitivity of our radio instruments and the FoV. Advances in the wide-filed VLBI technique and its application opens up possibilities for new discoveries of important astrophysical objects at mas scales over wide areas. An increase in the sensitivity of radio surveys and the increasing ability to probe the dynamic radio sky at VLBI mas scales, will directly probe the missing population of dual-AGN and binary SBMHs, which is crucial for SKA surveys. This VLBI+eMERLIN survey provides angular resolutions that will not be matched until SKA Phase 2. Therefore, this survey provides a source classification training set for the near-future deep-wide field VLBI surveys with instruments such as the MeerKAT and the SKA.

The next generation of high-resolution radio surveys with SKA-VLBI
Jack Radcliffe

The Square Kilometre Array (SKA) will be a truly revolutionary instrument that will provide us with profound insights into a broad spectrum of astrophysics. However, there is one factor that SKA will lack, and that is the resolution to see the inner workings of many phenomena. This gap can be plugged by using Very Long Baseline Interferometry (VLBI) arrays and the incorporation of the SKA into a VLBI array will provide exquisite sensitivity to these arrays. Through simulations, I shall show how SKA-VLBI will work, potential challenges that needs to be addressed, and how it can be used to investigate the feasibility of various science cases and SKA Science Working Groups.

Machine Learning, Citizen Science and Source Finding

The Semantically Meaningful Morphology Taxonomy
Micah Bowles

I will present and discuss the limitations of the terms used in radio galaxy morphology classifications. I will present the application of a novel natural language processing (NLP) approach to deriving English descriptors for science cases otherwise restricted by obfuscating technical terminology for radio astronomy. I will present the experiment and method used to derive a semantically meaningful radio morphology taxonomy. I present the taxonomy derived for RGZ EMU and the wider community. The derived tags are plain English. They constitute a morphology classification framework which is more flexible, more easily communicated, and more sensitive to abnormal combinations of features, which are otherwise not captured by the current framework of radio astronomy classifications.

Finding Double Radio Sources in Component Catalog Data with DRAGN-hunter
Yjan Gordon

Double Radio Sources associated with AGN (DRAGNs) frequently appear in component catalogs as multiple separate detections. This can lead to complications in determining the total flux and size of the full radio source, as well as host galaxy identification. To counter this problem, grouping together nearby radio detections seems like a reasonable first step, but will suffer high levels of contamination from random associations. Here, we present an algorithm, DRAGN-hunter, which first splits a source catalog into candidate lobes and candidate radio cores, before finding pairs of candidate lobes. Likely DRAGNs are then identified based on the angular separation and relative alignment of these candidate lobes. Once DRAGNs are identified, potential radio cores are searched for using the cataloged sources selected as candidate radio cores.

We have used DRAGN-hunter to create a catalog of $\sim 15,000$ DRAGNs with angular sizes $<$ 230" in the VLA Sky Survey (VLASS). Radio cores are identified for 2000 DRAGNs, and these are used to identify an AllWISE counterpart where possible. Where a DRAGN has no core identification, we use the maximum likelihood ratio method to identify an AllWISE counterpart. Overall AllWISE hosts are found for half of our DRAGNs. Visual inspection of a sample of 500 of these DRAGNs shows the false-positive contamination rate to be 10% for DRAGNs with a host or core identification, rising to 14% for those without. Comparisons with radio galaxy zoo estimate the sample completeness to be $\sim 75\%$ for sources larger than $\sim 30''$.

Enabling new discoveries with machine learning
Michelle Lochner

The next generation of telescopes such as the SKA and the Vera C. Rubin Observatory will produce enormous data sets, far too large for traditional analysis techniques. Machine learning has proven invaluable in handling large data volumes and automating many tasks traditionally done by human scientists. In this talk, I will discuss how machine learning for anomaly detection can help automate the process of locating unusual astronomical objects in large datasets thus enabling new cosmic discoveries. I will introduce Astronomaly, a general purpose framework for anomaly detection in astronomical data using active learning and overview some recent results, including discoveries made with MeerKAT data.

Machine Learning Approaches to Study Star Formation and Black Hole Accretion in the MeerKAT/MIGHTEE survey
Walter Silima

As a result of recent advances in astronomical and digital technologies, astronomy is rapidly becoming a data-rich science. The much-increased data rates from radio surveys with the MeerKAT telescope, ASKAP, and the SKA, require the adoption of machine learning (ML) techniques to automate most tasks previously carried out manually by astronomers. One such task is classifying radio sources as star-formation- or accretion-dominated. In this study, we implement and optimise five supervised machine learning techniques; Logistic Regression, Support Vector Machine, K-Nearest Neighbour, Random Forest and XGBoost, to classify radio sources detected in the MeerKAT International GHz Tiered Extragalactic Exploration (MIGHTEE)–COSMOS survey as star-formation or accretion-dominated. We adopt attributes used in literature to classify sources in the radio continuum, such as the mid-infrared (IRAC) colours, the infrared-radio correlation (qIR parameter), the optical indicator, stellar mass, etc. We found that the qIR is the essential attribute for classifying SFG or AGN in the radio continuum of all the adopted input attributes. We demonstrated that the supervised machine-learning model works very well in classifying SFGs and AGN detected from the MIGHTEE-COSMOS survey with the F1-scores $> 90\%$, even when only 20% of the data is used to train models. Four supervised machine learning algorithms yield scores above 90% when trained on each set of attributes and even when trained only with the qIR parameter. The traditional attributes are good enough to train our machine learning models.

The building of Radio Galaxy Zoo 2 - Evolutionary Map of the Universe
Eleni Vardoulaki

Radio Galaxy Zoo 2 EMU (RGZ2-EMU) is a direct spin off from the very successful RGZ citizen science project. The purpose of the project is to provide combined efforts from specialists and citizen scientists in order to 1) identify, 2) assemble and 3) classify radio sources, using tags, from the EMU survey. We will describe the building of the RGZ2-EMU platform, the functionalities and workflows, and how they relate to our three science goals above. The data we use are the Pilot EMU Survey data, for which Selavy automatic source identifier was used to create component catalogues. For the first time, we utilise the method of Segal et al. on anomaly detection to rank cutout regions centred at the Selavy radio components based on their complexity. We will present results from alpha testing, where over 40 citizen scientists were asked to test the workflows and report on their preference of functionalities. This feedback will be incorporated into beta testing and launching the citizen science project RGZ2-EMU. We expect a duration of a few years, which will generate several papers on classification, natural language processing, artificial intelligence, and cutout selection methods. We anticipate funding for the outreach and education program related to RGZ2-EMU to be offered to high-school students.

Polarisation

Polarisation science with Apertif
Björn Adebahr

The Apertif surveys (AWES and AMES) were taken including full polarisation information. Here we show, using five independent datasets from the Science Verification Campaign (SVC) covering 56 square degrees, the reliability and potential of the Apertif polarisation data. We showcase our automatic approach to locate polarised sources in Apertif fields, cross-match them with their total power counterparts and their hosts in the infrared and optical regime and generate source catalogues using our polarisation analysis pipeline (Aperpol). We find that even the μJy polarised sky is dominated by radiation from Active Galactic Nuclei (AGN). The radio emission generated by star-formation is only on a few percent level for a minority of the sources and negligible for the majority. The amount of star-formation does not influence the degree of polarisation. We notice that the host galaxy type differs for the faint polarised sky compared to the bright one. The report of these first results will be complemented with an overview of ongoing and future polarisation related projects using Apertif data.

Mapping extended Faraday Rotation structure across radio galaxy lobes with ASKAP POSSUM
Emma Alexander

POSSUM, the Polarisation Sky Survey of the Universe's Magnetism, will use ASKAP, the Australian Square Kilometre Array Pathfinder, to perform a full continuum radio polarisation survey of the southern sky. In this talk I will present results from POSSUM Early Science and Pilot observations, with a focus on the polarisation properties of well-resolved radio galaxies. This work represents a significant increase in the number of well-resolved radio galaxies studied to this level of detail, with many of the sources being mapped in this way for the first time. In addition, I will outline the data analysis pipeline behind this work, which takes into consideration the continuing and future influx of data from ASKAP, paving the way for SKA-era levels of data processing.

Polarised Source Counts from GOODS-N field with Apertif
Anna Berger

We aim to study the nature of the faint polarised radio source population whose source composition and redshift dependence contain information about the strength, morphology and evolution of magnetic fields over cosmic timescales. Using 6 Apertif observations of the GOODS-N field, we cover $\sim 51\,\mathrm{deg}^2$, while reaching a central RMS down to 8 μJy. By using Aperpol, a semi-automatic routine, we generate a catalogue of polarised sources which also contains information of the total intensity in addition to information from NVSS, SDSS and allWISE. We end up finding 1364 polarised sources. Using the infrared data, we find that none of our sources show hints for star formation. In contrast to previous works, we do not find the fractional polarisation to be dependent on the total intensity flux density. By applying a completeness correction that is not dependent on the total intensity source counts, we find our Euclidean normalised differential source counts to have a steeper slope compared to the models. The source count models are highly dependent on the behaviour of fractional polarisation with total intensity. Thus we discuss possible origins of this steeper slope, such as the shift of source composition towards low flux densities.

Polarisation of faint galaxies in MIGHTEE
Leonnart Heino

this study explores the polarised radiation of the micro-Jansky population of radio sources in the MeerKAT MIGHTEE (MeerKAT International Giga-Hertz Tiered Extragalactic Exploration) survey in order to study the nature, origin and evolution of cosmic magnetic fields. MIGHTEE is a wide area survey targeting well known extragalactic deep fields with a wealth of multi-wavelength data, thereby providing an opportunity to chart the evolution of polarised emission from galaxies over cosmic time. The MIGHTEE survey detects polarised emission for a large number of radio sources down to total intensity flux densities of the order of 100 μJy At these flux densities the source population is increasingly dominated by star-forming galaxies (SFG) over active galactic nuclei (AGNs). We use multi-wavelength criteria to classify objects as SFGs and AGNs. We perform RM synthesis on the spectro-polarimetric data cubes and use the polarisation and RM synthesis spectra to search for polarised emission from SFGs. We also perform a comparative analysis of the polarisation properties of SFGs and AGNs. The multi-wavelength catalogs extend the study to the lowest possible flux densities using stacking techniques. I will show preliminary results of the MeerKAT polarisation studies of radio sources down to a sensitivity at the micro-Jansky level.

The detection of cluster magnetic fields via radio source depolarisation
Erik Osinga

It is well established that galaxy clusters have magnetic fields, which play a key role in many astrophysical processes. However, the exact properties and origin of magnetic fields in clusters are still uncertain. Various studies using Faraday rotation of cluster radio sources have derived the magnetic field strength and structure in clusters. These studies often rely on various assumptions that could be circumvented when using radio sources behind clusters. At the moment, such a study can only be done statistically due to the low amount of polarised radio sources behind clusters.

In this talk, I present a large study on the Faraday rotation and depolarisation of radio sources induced by the magnetised intracluster medium. With Karl G. Jansky Very Large Array observations of 124 massive clusters at $z < 0.35$, we detected with high significance, for the first time, the imprint of cluster magnetic fields through the depolarisation of radio sources. We studied the magnetic fields in more detail by combining the radio observations with ancillary X-ray data from Chandra and through the induced Faraday rotation measures. Because of the large sample size, we also investigated the magnetic field properties as a function of various cluster properties such as dynamical state, mass, and redshift. We found that the local interaction between the radio galaxies and the intracluster medium did not strongly affect the observed depolarisation trend, implying that cluster members and background sources can both be used to statistically probe magnetic fields. This study shows the potential of using statistical depolarisation in combination with Faraday rotation to probe cluster magnetic field parameters, which is particularly important in the context of the SKA and current pathfinders that are doing deep surveys.

Illuminating the magnetised cosmic web
Shane O'Sullivan

Radio galaxies can be observed throughout the majority of the history of the Universe and are thus excellent beacons for measuring the properties of the cosmic web and their evolution with cosmic time. Here I will highlight recent results from the ongoing LOFAR Two-metre Sky Survey (LoTSS), with a focus on the linear polarization and Faraday rotation measure (RM) data. The exceptional RM precision of LoTSS ($< 0.1\,\mathrm{rad/m^2}$),

in addition to unrivalled ancillary information such as the host galaxy redshift, has facilitated several new discoveries. In particular, our recent detection of the RM signature of cosmic web filaments shows how LoTSS is transforming our understanding of cosmic magnetic fields and providing a new way to study the properties of filaments and voids of the cosmic web in general.

A High-Dynamic Range Calibration of MeerKAT Observations of Pictor A at 21 cm

Athanaseus Ramaila

As one of the prominent radio sources in the southern sky, at a distance of 480 million light years, studying Pictor A provides a unique opportunity to understand radio galaxy jets, the termination shock environment of the radio lobes and the magnetic field structures. The primary purpose of our study was to conduct a deep and detailed analysis of Pictor A radio galaxy in full polarisation. We present high-resolution and high-dynamic range interferometric radio images of the Pictor A radio galaxy obtained using the MeerKAT telescope at L-Band and the techniques used to process the data. Our detailed polarimetric study of Pictor A will be discussed in Andati et al. in prep.

MIGHTEE-Pol: Everything but the kitchen sink

Srikrishna Sekhar

MIGHTEE is a MeerKAT Large Survey Project (LSP) designed to study the polarization properties of the microJy population of sources over a wide field of view. In this talk, we explain the details of MIGHTEE polarization calibration as implemented in the IDIA calibration pipeline. We discuss our strategy of using image-domain leakage corrections to deal with off-axis polarization leakage (as implemented in the 'plumber' package). Further, we detail our approach to polarization DQA for MIGHTEE. Finally, we present results from the early science data and preliminary results from the larger XMMLSS and COSMOS mosaics.

AGN, Remnants and GRGs

Probing the radio-loud/radio-quiet dichotomy of SDSS quasars
Marina Arnaudova

The most luminous representatives of active galactic nuclei (AGN) are quasi-stellar objects (QSOs), also known as quasars, which can outshine their host galaxies in the optical by several orders of magnitude. About 10% of these objects are found to produce strong radio emission in the form of relativistic jets, giving rise to the well-known radio-loud/radio-quiet dichotomy. This division raises the question of whether these two types of objects are physically distinct populations or whether they represent different evolutionary stages of a single one. We investigate this by performing spectral stacking on a sample of 73,401 SDSS quasars in the regions covered by the second data release of the LOFAR Two-metre Sky Survey (LoTSS). By creating high resolution composite spectra of the two populations–matched in redshift, absolute i-band magnitude and black hole mass–we are able to uncover spectral features otherwise indistinguishable in individual spectra, making a robust comparison. We find that radio-loud QSOs have a redder continuum with an enhanced [OII] emission, and discuss the potential physical interpretations of these results.

The MIGHTEEst radio galaxies
Jacinta Dalhaize

The perceived scarcity of giant radio galaxies (GRGs) is now being challenged thanks to the huge improvements in surface brightness sensitivity provided by SKA precursor and pathfinder telescopes. Understanding more about these systems will inevitably lead to a better understanding of radio-mode feedback, as well as the duty cycle of these enormous AGN. I will present a new study of several giant radio galaxies in the MeerKAT International GigaHertz Tiered Extragalactic Exploration (MIGHTEE) survey. The MeerKAT telescope provides exquisite sensitivity to the diffuse emission of the large-scale jets and lobes of GRGs. MIGHTEE L-band observations have therefore unveiled a number of GRGs across the target fields which were hitherto undetected, even by sensitive surveys with the VLA. We have performed a spatially-resolved spectral index study of the MIGHTEE GRGs, by comparing the L-band data with lower frequencies, including new MeerKAT UHF band observations of COSMOS. The good resolution of MeerKAT at both L and UHF bands allows us to examine spatially-resolved spectral ages across the GRGs. Our goal is to better understand these enigmatic systems, and to determine whether age is a primary driver of their huge sizes.

Deep Multi-frequency Radio Observations of Remnant Radio Galaxies
Sushant Dutta

The cessation of active galactic nuclei (AGN) activity in radio galaxies leads them into remnant phase. Remnant radio galaxies are believed to be rare objects as they can be observed over a relatively short period of time before the radio lobes with no supply of fresh plasma completely fade away due to radiative and dynamical energy losses. Remnants are characterized by an absent core, lobes of low-surface brightness and strong spectral curvature. The timescales of remnant phase and AGN duty cycle are vital to understanding the evolution of radio galaxies. In our recent work, we identify and characterize remnants using multi-frequency radio observations from the GMRT, LOFAR and JVLA. We estimate timescales of active and remnant phases by modeling their radio spectral energy distributions (SEDs) using a continuous injection-off model that assumes an active phase with continuous injection followed by a remnant phase. In this talk, I shall emphasize on the need of deep multi-frequency radio surveys to characterize and identify a much larger

and diverse population of remnants.

Cosmic evolution of jet-mode AGN feedback with LOFAR Deep Fields
Rohit Kondapally

Active galactic nuclei (AGN) can have a significant effect on their host galaxies by regulating their growth or suppressing star formation (known as AGN feedback). A crucial missing piece in galaxy evolution models is to understand the role of AGN feedback in shaping the observed galaxy population from early epochs to the present day. Of particular importance in the life-cycle of massive galaxies and clusters are the jet-mode AGN which display powerful bi-polar radio jets; recurrent feedback from these AGN is believed to keep galaxies 'red and dead' once quenched. However, the cosmic evolution of the jet-mode AGN and their feedback effect remains largely unconstrained beyond $z \sim 1$. The LOFAR telescope has been undertaking one of the deepest wide-field radio continuum surveys to date: this represents a novel sample to statistically study the growth of AGN activity and feedback across cosmic time. Using a sample of $> 10,000$ AGN, I will present the first robust measurement of the evolution of the jet-mode AGN population out to $z \sim 2.5$. I will model the evolution of the feedback effect from these AGN and compare these observational results with predictions from the latest cosmological simulations to draw conclusions of the evolving role of jet-mode AGN feedback across cosmic time.

Feedback and life-cycle of radio AGN
Pranav Kukreti

Radio AGN are known to affect the host galaxy's gas, by driving strong multiphase gas outflows. But, this has mostly been studied for powerful radio AGN ($L(1.4\,\mathrm{GHz}) > 10^{25} - 10^{26}\,\mathrm{W/Hz}$). However, low power radio AGN dominate the radio AGN population, and with SKA pathfinders, we will be able to detect such low power systems more than ever before, and investigate feedback in these sources. Radio AGN are also known to have a life-cycle and episodic activity. Young radio AGN are expected to show a peaked radio spectrum, with the spectrum getting steeper as the jets evolve. Thus, the spectral shape of the radio AGN can be used to classify them in different stages of their life-cycle. The effect of this life-cycle on the surrounding gas is also not well understood. Our aim is to investigate whether the outflows in radio AGN are mainly driven by radio jets, and whether the feedback evolves with radio jet's life-cycle. To do this, we use a sample of radio AGNs, with radio power ($10^{23} - 10^{26}\,\mathrm{W/Hz}$), and high resolution surveys like LoTSS (144 MHz), FIRST (1.4 GHz) and VLASS (3 GHz), to identify the spectral shape of their radio continuum emission. The high resolution of the surveys (3"-6") means we trace the radio spectra of the central few kpc, for which we also have the [OIII] emission line data from SDSS. This allows us to study the feedback effects in a systematic manner. By stacking the [OIII] spectrum of different groups of radio AGN, we find that gas kinematics evolves with the radio jet's life-cycle, with younger peaked spectrum sources showing an ionised gas outflow (velocity $\sim 600\,\mathrm{km/s}$) compared to older steep spectrum sources that do not show an outflow. We also find no dependance of the outflow on the Eddington ratios and ionisation states of the AGN, thus strengthening our result that the outflow is driven by radio jets and not radiation, and evolves with it. We identify candidate restarted radio AGN as well in our sample, and our results suggest that they have broader OIII profiles than adult/evolved radio AGN. Thus we are able to link the life-cycle of radio AGN to the short term feedback in the form of outflows.

New insights on classical radio galaxies from MeerKAT and uGMRT
Portia Legodi

The morphology of extragalactic radio sources of high and low luminosity has been the subject of a classification method for over four decades, leading to a comprehensive understanding of extragalactic radio sources. To date, the study of FR radio galaxies is still a hot topic. The advent of the SKA pathfinders and precursors has considerably improved the imaging sensitivity over broad range of angular scales and frequencies, leading to the discovery of many new features in the morphology of radio galaxies. We have selected a sample of 17 radio galaxies belonging to the FR0, FRI and FRII classes and are studying them with the current generation of radio interferometers. Our goals are both to revisit the morphological classification and investigate the properties and origin of the new filamentary features which are becoming common within and outside the radio lobes and which are suggestive of so far unexplored interactions between the radio plasma and the external medium. To this aim, we are using the μJy sensitivity offered by the combination of uGMRT and MeerKAT, covering the frequency range from 500-1712 MHz. Here we will summarise the status of our project and present our new results on two FR I and two FR II samples of radio galaxies from MeerKAT and uGMRT observation. We will show total intensity and polarisation images, as well as spectral index imaging and provide preliminary considerations on the results.

Uncovering the Faintest Peaked Spectrum Radio Sources
Fabio Luchsinga

Low-luminosity peaked spectrum (PS) radio sources are largely unknown. With the new generation of telescopes producing deep, wide-field radio surveys, we aim to increase the number of known luminosity PS sources manyfold. PS radio sources have been studied for decades. The physical processes underlying their peaked spectra and the relative scarcity makes them interesting. They are thought to be young radio galaxies, where the jets from their AGN only recently began to launch. It is thought that the precursors of Fanaroff-Riley Type I are amongst that population, but very few known examples exist. Our work focuses on fields with a deep and broad coverage across the electromagnetic spectrum, such as the XMM-LSS and ELAIS-N1 field. Within theses fields, we carried out radio spectral analyses and fit models to deduce the physical processes causing their spectral shape. Further exploration of PS sources in conjunction with VLBI are planned. I will present the latest theories, as well as our analysis workflow and preliminary results.

LOFAR giants: old, powerful, and lonely?
Martijn Oei

Giant radio galaxies, or colloquially giants, form a rare population of supersized radio galaxies with Mpc-scale extent. Among radio galaxies, they represent the old, the powerful, and the lonely – or so conventional wisdom holds. In this talk, we present substantial LOFAR progress on giants selected from four current and upcoming publications. We discuss the discovery of Alcyoneus, a 5 Mpc radio galaxy with suspiciously ordinary non-geometrical features. This giant is part of a LoTSS DR2 sample of almost two thousand new giants, which doubles the known population. In the second work (under review), we present this sample and perform a precision measurement of the giant length distribution. In a third work (under review), we use a 2.5 Mpc spiral galaxy-hosted giant from this sample to estimate the temperature at the boundary between a group and the WHIM, showing that giants are useful probes of filament thermodynamics. In the final work (to be submitted), we investigate giant growth as a function of Cosmic Web environment, using state-of-the-art density reconstructions. We find that, in contrast to common belief, radio galaxies grow larger in denser Cosmic Web environments. However, because dilute environments are much more common, the largest giants will still be found in the dilute

Cosmic Web.

MeerKAT follow-up of enigmatic radio sources in the G4Jy Sample
Precious Katlego Sejaki

The GLEAM 4-Jy (G4Jy) Sample, formed from the GLEAM survey, comprises 1,863 of the brightest extragalactic radio-sources in the southern sky, the vast majority of which are active galactic nuclei with powerful radio jets. However, 140 of these sources have uncharacterised/ambiguous host galaxies due to the inadequate resolution (of 25 to 45-arcsec) of existing radio images. In this talk, I present key results from studying these 140 G4Jy sources. These sources were observed with MeerKAT to assess their radio morphology and identify their likely host-galaxy through MeerKAT's higher resolution images. Our observations reveal a treasure trove of unusual radio sources: 5 of the 140 sources have X-, S-/Z-shaped morphology, 10 have head-tail morphology, and 14 have a wide-angle tail (WAT) morphology. We report finding host galaxies for 98 of the 140 sources, leaving 42 with no identified host galaxy. Of these 42 sources with no identified host galaxy, 24 sources still have ambiguous host galaxy even with higher resolution images from MeerKAT and 18 are candidate infrared faint radio sources.

Studying source properties with deep radio observations using uGMRT
Akriti Sinha

The synchrotron radiation dominates radio continuum emissions at low frequencies from the star-forming regions in the disk-galaxies and from the powerful active galactic nuclei (AGN) jets. To better understand the cosmic evolution in various source populations, deep radio measurements have created a new insight. We have extensively studied the Bootes field using uGMRT centered at 400 MHz. For these observation of 200 MHz bandwidth, we reached the central minimum off-source RMS noise of 18 μJy/beam, yielding a catalog of 4858 sources in 6 sq. degree of the sky. The resulting catalog is compared to other radio catalogs in order to measure flux accuracy, position accuracy and spectral indices. The normalised differential source counts are derived, and we observe flattening at lower fluxes implying an increase in the population of star-forming galaxies (SFGs) and radio-quiet AGN. For a better knowledge of the physical and evolutionary characteristics of the diverse source populations, a multi-wavelength investigation is necessary as radio measurements alone cannot present their full nature. The Bootes field is a widely studied extra-galactic field with a wealth of multi-band ancillary data. We thus classify the sources in SFGs, radio-loud AGN and radio-quiet AGN to investigate the source counts at low flux densities. The normalized source counts for the whole sample are in agreement with observations and simulations, while we observe an increase in these values for SFGs at faint flux densities.

On the origins of X-shaped Radio Galaxies
Kshitij Thorat

SKA pathfinders and precursors have, over the past few years, uncovered radio galaxies with unforeseen morphological features and revealed unknown aspects of sources we thought we knew very well. We may expect with good reason that we'll find larger population of rarer populations of sources, shedding light on some of the current astrophysical mysteries. X or Z shaped radio galaxies are examples of such sources; inversion-symmetric and showing two axis of emission as compared to a single axis in the more usual radio galaxies, their origins a mystery, but possibly with wider astrophysical and cosmological implications. Recent broadband observations with MeerKAT, ASKAP and LOFAR have thrown more light on these sources allowed for spectral index analysis, a tool which

may help ascertain the mechanisms behind the formation of these sources. In this talk, I present an analysis of a sample of X and Z shaped radio galaxies formed from both archival and new observational data.

Investigation of the radio luminosity functions (RLFs) based on data from MIGHTEE survey

Nijin Thykkathu

We present an investigation of the radio luminosity functions (RLFs) based on data from MIGHTEE survey. The radio observations at 1.28 GHz with the MeerKAT telescope cover a 1 square degree area to a thermal noise limit of 1.8 μJy/beam. Using the Multinest sampling algorithm, we fit a redshift-dependent pure luminosity evolution model and a linear and power-law model to the total luminosity function and separate luminosity functions for star-forming galaxies and AGN based on the multi-wavelength classification of Whittam et al. 2022. We compare our results with other studies from VLA-COSMOS on individual populations of radio-selected star-forming galaxies (SFGs) and AGN.

Measuring cavity powers of active galactic nuclei in clusters using a hybrid radio/X-ray method

Roland Timmerman

As the intracluster medium (ICM) in galaxy clusters cools through the emission of X-ray radiation, it sinks down towards the central galaxy where it fuels the AGN. This AGN subsequently emits radio-mode feedback in the form of powerful jets of relativistic plasma which re-energize the ICM, completing the feedback cycle. Measurements of the energy injected by radio-mode feedback into the cluster environment have mostly relied on X-ray observations, which reveal cavities in the ICM excavated by the radio lobes. However, the sensitivity required to accurately constrain the dimensions of these cavities has proven to be a major limiting factor, and forms the main bottleneck on high-redshift measurements. In this talk, we describe a hybrid method based on a combination of radio and X-ray observations, which aims to enhance our ability to study radio-mode feedback. We present one of the first samples of galaxy clusters observed with the International LOFAR Telescope (ILT) with subarcsecond angular resolution at 144 MHz, and use this sample to test the hybrid method with low-frequency, high angular resolution observations for the first time. By comparing our measurements with results found in literature based on the traditional X-ray-based method, we find indications that the hybrid method can provide more reliable measurements thanks to the detailed view of the radio lobes provided by the ILT. In addition, we present preliminary results from the application of this method on a sample of galaxy clusters up to a redshift of $z = 1.2$.

Star Forming, Faint and Nearby Galaxies

LOFAR+GMRT+MeerKAT+VLA+JVLA: Radio spectral properties at 150-5000MHz of star-forming galaxies

Fangxia An

A well-determined radio spectrum for star-forming galaxy (SFG) is critically important for studies that are based on rest-frame radio power, especially those at high-redshift where k-corrections are generally extrapolated the most. In this talk, I will introduce two of our recently completed projects based on the MeerKAT+VLA+GMRT data in the COSMOS field and the LOFAR+GMRT+JVLA data in the ELAIS-N1 field. I will present our measured radio spectral indices between the observer-frame frequencies of 150-400, 400-610, 400-1300MHz, 1.3-3GHz, and 610-5000MHz and show the correlations between radio spectrum and physical properties of radio-selected SFGs. With these results, I will discuss the possible physical mechanisms that determine the radio spectrum of SFGs. I will also show how the adoption of these different radio spectral indices (from low- and high-frequency) in k-correction affects the study of far-infrared-radio correlation of SFGs.

The nature of the faint low-frequency radio population revealed by LoTSS deep fields and Prospector

Soumyadeep Das

A galaxy's star formation rate is a key metric we can use to understanding its formation and evolution. We performed SED fitting of over 130,000 $z < 1$ optically-selected sources in the ELAIS-N1 using the SED fitting code Prospector, and taking advantage of the excellent sensitivity and multiwavelength coverage of the assembled UV-FIR data alongside the exquisite 150MHz data from the LoTSS deep fields data release 1. By accounting for a possible contribution from AGN in our SED fitting, and considering the potential role of different star formation histories, we classified the galaxies into star-forming, radio-quiet AGN, low-excitation and high-excitation radio galaxy classes. For the vast majority of sources, our results and classifications agree with Best et al., who combined the results from four different SED fitting codes. However, at low star formation rates our SFR estimates differ, leading to different source classifications, and with potentially important impact on the 150 MHz radio luminosity - SFR calibration. Since Prospector can model photometry and spectroscopy simultaneously, our work with Prospector will be increasingly important in the near future once WEAVE-LOFAR begins taking data this year.

Highest Resolution and Sensitivity Radio Observations of the Eridanus Supergroup using ASKAP WALLABY

Joe Grundy

Radio continuum emission is produced in star-forming galaxies by massive young stars as they ionise their surrounding neutral hydrogen (HI) gas envelopes and then go supernova, producing shocks that emit synchrotron radiation. These young massive stars also heat the surrounding dust and molecular clouds which re-radiate in the infrared (IR). Hence both the radio continuum emission and the IR emission are linked to star formation resulting in the widely corroborated infrared-radio correlation (IRRC). Understanding how the radio continuum and IRRC are related to the physical properties of SFGs will be key to understanding future survey data that will be produced by the SKA and its pathfinders such as the Australian SKA Pathfinder (ASKAP). The Widefield ASKAP L-band Legacy All-sky Blind Survey (WALLABY) pre-pilot survey performed observations of the Eridanus supergroup. We utilise the $\sim 1.4\,\mathrm{GHz}$ radio continuum data to create the

highest resolution and sensitivity radio catalogue of this field to date. We investigated the total and resolved radio continuum and IRRC properties of the eight Eridanus supergroup galaxies, to probe the group environmental pre-processing which occurs before galaxies fall into clusters. We find that the total IRRC trends are reproduced with WISE W3 (12 micron) derived values following the previous far-IRRC measurements. Overall we find that the resolved IRRC can be used to observe group environment pre-processing effects in SFGs and used to easily discriminate between active galactic nuclei and SFGs as well as identify background radio sources.

A MeerKAT 1.28 GHz Continuum Study of Luminous Infrared Galaxies in the Southern Hemisphere: MeerLIRGs - an update

Lucia Marchetti

MeerLIRGs is a MeerKAT 1.28 GHz continuum survey of all the 298 southern galaxies selected among the brightest IRAS galaxies ($S(60\,\mu\mathrm{m}) > 5.24\,\mathrm{Jy}$). This campaign provides complete high-resolution L-band continuum coverage of the all-sky IRAS Revised Bright Galaxy Sample (RBGS) in the Southern hemisphere which also includes 201 luminous starburst galaxies (plus a few AGNs) parts of the Great Observatories All-sky Luminous Infrared Galaxies Survey (GOALS) and some merger systems. These new MeerKAT data, together with the complementary RBGS observations carried out with the VLA in the Northern hemisphere are providing the best (and complete) local reference to study AGN and Star formation activities in galaxies. In my talk, I will provide an update on the survey results obtained so far and how this survey will be extended in the near future with newly approved OT MerKAT projects.

Insights into cosmic-ray transport from radio halos in edge-on galaxies

Stein Michael

Through the analysis of radio continuum data from edge-on galaxies, we can gain a more comprehensive understanding of the influence of cosmic rays and galactic magnetic fields on the evolution of galaxies. Combining low- and high-frequency data sets, from two SKA pathfinder instruments (LOFAR & VLA), reveals the underlying transport mechanism of the cosmic ray electrons (CREs) and therefore gives insights into the galactic wind that is driven by stellar feedback. In this talk, I'll present the analysis of five edge-on galaxies (NGC 891, NGC 3432, NGC 4013, NGC 4157, and NGC 4631) with newly reduced data from VLA CHANG-ES L-band and LoTSS DR2. With these data sets it is possible to double (compared to previous studies) the extent of the analysed synchrotron radio halos and therefore strongly increase the reliability of the analysis. Therefore, the analysis sets new constraints on the morphology of radio haloes and the physical properties of galactic winds driven by stellar feedback. Additionally the transport mechanisms of CREs in these halos are analysed using a 1D cosmic ray transport model. The analysed radio halos show a large variety of wind velocities and derived magnetic field profiles tend to agree with equipartition measurements. By adding data from the uGMRT, I will further discuss the influence of thermal absorption on the low frequency radio continuum data set in the case of NGC 4631.

The promise of next-generation radio-continuum surveys: revealing the physics and evolution of faint radio sources

Isabella Prandoni

A wealth of new surveys from upgraded and new radio interferometers are rapidly improving and transforming our understanding of the faint extra-galactic radio sky. Indeed

the mounting statistics at sub-mJy and μJy flux levels is finally allowing us to get stringent observational constraints on the faint radio population, and on the modeling of its various components. In this talk I will present ongoing work based on LoTSS-Deep DR1 and EMU-Early Science GAMA 23 datasets. In particular I will highlight a) the benefit of wide-area deep samples to provide statistically robust constraints on radio source demography and evolution, and b) the added value of multi-frequency coverage and sub-arcsec resolution to address the role of AGN feedback in galaxy evolution. I will conclude with an overview of future plans and perspectives.

Clusters

Galaxy clusters with LOFAR: deep fields and samples
Andrea Botteon

LOFAR is the largest pathfinder of the SKA at low-frequency. In the very recent years, it showed the potential of high-sensitive observations at 50 and 150 MHz in different research areas, including in the study of diffuse synchrotron sources in galaxy clusters. The origin of these sources (radio halos and relics) is still not fully understood, and both observations of cluster samples and deep cluster fields can provide useful insights on the processes generating radio emitting electrons distributed on cluster scales.

In this talk, I will discuss the main results of our series of papers "The Planck clusters in the LOFAR sky". In this work, we used the largest statistical sample of galaxy clusters collected to date (309 objects detected by the Planck satellite and observed in the context of LoTSS-DR2) to study the properties of the diffuse radio emission in the intra-cluster medium. Moreover, I will also present recent constraints on the role of non-thermal components at large distances from the center of Abell 2255. In this case, results are based on deep 72h+72h LOFAR 50 and 150 MHz observations of the target, which unveil the presence of a giant envelope of radio emission embedding the cluster up to its virial radius. This discovery suggests that non-thermal components may contribute significantly to the pressure of the intra-cluster medium in the cluster periphery.

The Spectral Study of Halos and Relics of Massive Merging Clusters
Swarna Chatterjee

Galaxy clusters host Megaparsec scale diffuse radio structures in the form of radio halos and relics. These structures reflect the presence of large-scale magnetic fields and high-energy cosmic ray particles in the intra-cluster medium. Multi-frequency study of these sources provides insights into the spectral age, cluster merger dynamics, magnetic field, and particle acceleration process. At this conference, I will present our analysis of massive merging clusters that host giant radio halos and relics. Our discussion mainly focuses on the spectral property of the radio sources in the clusters using multi-frequency radio observations with uGMRT, MeerKAT, and VLA. Combining these with X-ray and optical studies, we will also discuss the merger and dynamical scenario of the clusters.

Deep calibration to study the A399-401 radio bridge
Jurjen de Jong

The detection of diffuse synchrotron emission in numerous clusters shows the presence of cosmic rays and magnetic fields in the intracluster medium. Recently, the Low-Frequency Array (LOFAR) reached the sensitivity required to detect for the first time Mpc-scale filaments (radio bridges) between pre-merging cluster pairs. In this talk, we present how we created the currently deepest radio maps for one of these pairs, Abell 399 and Abell 401, by using an advanced direction-dependent calibration strategy on top of the standard LOFAR calibration strategy. This helps us to study the morphology of the radio bridge and infer the origin and the mechanism behind the reacceleration of electrons. Our results are evidence for a scenario where past active galactic nuclei (AGN) activity injected plasma into the radio bridge, from where particles are re-accelerated by a Fermi-II re-acceleration to relativistic energies.

Star formation rates as a function of their environment using the MeerKAT Galaxy Clusters Legacy Survey
Kabelo Kasebonye

A new era of highly sensitive radio telescopes with large fields of view such as the MeerKAT telescope has opened a window to probe the star formation (SF) activity of clusters all the way from their inner cores to more than double their R_{200}. We use dust-unbiased radio luminosities from the MeerKAT Galaxy Cluster Legacy Survey (MGCLS) catalogue to investigate the star formation rates as a function of their environment in massive clusters ($M_{200} > 4 \times 10^{14} \mathrm{M}_{\odot}$) at $0.15 < z < 0.35$. Several studies in the last decade have presented contrasting results on the role of cluster mergers or unrelaxed clusters in the SF of their member galaxies. Some studies suggest an enhanced SF activity in merger clusters, some suggest suppressed SF activity while others find no difference between the SF activity of merger clusters and relaxed clusters. Using large-scale extended radio emission (haloes and relics) in clusters as an indicator for recent or ongoing merger activity, we note a significant difference in the star formation activity between clusters hosting radio haloes and relics and non-haloes/relics clusters. The fraction of star-forming (fSF) galaxies in clusters hosting large-scale extended radio emission in the form of haloes and relics $\approx 33\%$ higher than in non-radio-halo/relic hosting clusters within clusters R200 and rises to $\approx 43\%$ out to $2R_{200}$. We observe a 3-sigma difference between the total SFR normalised by cluster mass for non-radio-halo/relic hosting clusters and for clusters with radio haloes and relics. Our results support the suggestion that merger/unrelaxed clusters have enhanced SF activity compared to relaxed clusters. We highlight the need for extensive homogeneously selected cluster samples at varying stages of morphology to investigate the differences in SF activity of clusters noted by previous studies.

The MERGHERS Survey
Kenda Knowles

Diffuse cluster radio emission (radio halo, relics, mini-halos, etc) are found in a growing number of galaxy clusters thanks to the sensitivity of SKA pathfinder and precursor instruments. However, much of our statistical knowledge of these sources is based on low redshift, high-mass cluster samples. It is critical to expand statistical samples to higher redshift and lower mass clusters in order to understand the full nature of diffuse cluster radio emission and the contributing physical mechanisms. The MeerKAT Exploration of Relics, Giant Halos, and Extragalactic Radio Sources (MERGHERS) survey is an ongoing programme of SZ cluster observations with MeerKAT aiming at probing the radio properties of a well-selected statistical cluster sample covering previously unexplored redshift and mass ranges. We are currently building the first statistical sample at mid-to-high redshift, with the tier-one data showing a $\sim 40\%$ detection rate. I will present the results of the tier-one data and discuss the future of the project, leading into the SKA era.

MeerKAT-discovered AGN radio shock and large-scale relic emission
Isaac Magolego

AGN jets and outflows are key drivers of the evolution of massive galaxies over cosmic time, and Ultraluminous Infrared Galaxies (ULIRGs) can serve as an important snapshot thereof. However, diffuse large-scale radio tracers of relic AGN activity are a challenge to observe due to their steep spectra, low surface brightness emission at low-redshift, and the difficulty in decoupling morphological features at higher redshift, especially where higher-frequency observations are required to gain angular resolution. The study of exemplars in the nearby universe remain important laboratories for high-resolution comparison with hydrodynamical simulations and extrapolations to higher-redshift objects. MeerKAT observations hold a significant advantage in this endeavour, demonstrated in several published examples with early results. In this talk, I will present one of MeerKAT's novel early L-band discoveries, that of complex, multi-epoch, Mpc-scale radio emission centred

on the dual AGN, local-Universe ULIRG, NGC 6240. We detect what we argue to be a radio shock with an arc-like morphology with a radio power of $6.3 \times 10^{22}\,\mathrm{W\,Hz^{-1}}$ at 1.28 GHz. Our results show that even in low mass systems, MeerKAT is capable of detecting radio relic-like components.High-fidelity imaging and accurate spectral aging from these newly-discovered, multi-epoch radio lobes add important information to the holistic understanding of this postmerger, dual AGN system, and the links between the merger's dynamical, starburst, and jet triggering timescales.

Mining Mini-Halos with MeerKAT I: Calibration and Imaging
Keegan Trehaeven

Radio mini-halos are clouds of diffuse, low surface brightness synchrotron emission that surround the Brightest Cluster Galaxy (BCG) in massive cool-core galaxy clusters. They are difficult to image and only about 30 mini-halos are known to date. We describe third generation calibration (3GC), also called direction-dependent (DD) calibration, and point source subtraction on MeerKAT extragalactic continuum data in the context of studying radio mini-halos. To do this, we calibrate and image archival MeerKAT L-band observations of a sample of five galaxy clusters (ACO 1413, ACO 1795, ACO 3444, MACS J1115.8+0129, MACS J2140.2-2339). We use the CARACal pipeline for direction-independent (DI) calibration, DDFacet and killMS for 3GC and visibility-plane subtraction to directly image the underlying mini-halo. We show that our 3GC procedure drastically improves the field artefacts left after DI calibration. Then, using these spectrally deconvolved, wide-field, wide-band, Stokes I continuum images, we directly measure for four mini-halos the flux density, radio power, size and in-band integrated spectra unbiased by the BCG, and show in band spectral index maps of the mini-halo+BCG system. We present a new mini-halo detection hosted by MACS J2140.2-2339, an L-band detection of the southern extension to the ACO 3444 mini-halo and a direct detection of the MACS J1115.8+0129 mini-halo.

Galactic and Magellanic Clouds

Galactic science with LOFAR
Maria Arias

As part of its Two-Meter Sky Survey (LoTSS), The LOw Frequency ARray (LOFAR) will observe the Galactic plane between longitudes of 30 to 210 degrees. This will enable a wide variety of Galactic science, both of thermal and synchrotron-emitting extended objects, and of the ionised, free-free absorbing interstellar medium. In this talk, I will present some of the first LOFAR results in the field of supernova remnants (SNRs), showcasing the great diversity in science cases that the LOFAR observations have facilitated. Low-frequency observations have allowed us to probe (a) supernova explosion physics via the unshocked material in young remnants, (b) the last stages of the life of the progenitor star via its ionised environment, (c) shock physics via variations in the population of accelerated electrons, and (d) the Galactic SNR population by locating new sources that are too faint, or too extended, for other, higher frequency Galactic surveys to detect. Ongoing work as part of the LOFAR Galactic Plane Survey will enable similarly broad science in the fields of H II regions, planetary nebulae, and other Galactic objects, and in this talk I hope to highlight the great potential of this instrument for studies of the Milky Way.

Imaging science with the MPIfR MeerKAT Galactic Plane Survey (MMGPS)
Ancor Damas Segovia

The MPIfR MeerKAT Galactic Plane Survey is a 3000-hour full polarization survey that covers 900 and 300 square degrees at L and S band, respectively. his is the first SKA pathfinder survey where both continuum/imaging and time-domain surveys are observed commensally. This survey will have the broadest frequency coverage of the southern sky among the SKA pathfinder surveys. It will also produce a broadband Faraday rotation measure (RM) catalogue of extragalactic sources at a density of $25\,\mathrm{deg}^{-2}$. The use of this RM grid and Faraday tomography of the diffuse radio emission will give us access to study the small and large scale magnetic fields of the Milky Way and background polarized sources with a quality never seen before. The Pipeline used to calibrate and image the MMGPS full Stokes data has been developed at the MPIfR. The current state of the software can perform a full stokes calibration, multi scale imaging, and polarization cubes of L and S band data from MeerKAT. Currently, the L band part of the survey is almost finished and the initial results show 7" resolution images with an rms noise of $16\,\mu$Jy/beam at L band. We are currently conducting commissioning and science verification observations for the upcoming S band survey in collaboration with the South African Radio Astronomical Observatory (SARAO) with outstanding preliminary results. In this talk, we will present the first data products of both L and S band surveys.

A resolved study of the Radio and far-infrared correlation in the Large Magellanic Cloud
Mohammad Javad Shahhoseini

One of the most debated questions in astronomy is the origin of the correlation between the radio and far-infrared (FIR) emission which holds in different types of galaxies over 5 orders of magnitude. This correlation is traditionally linked to massive star formation, while recent studies show that it can hold even in non-star-forming ISM in normal spirals due to a balance between gas, magnetic field, and cosmic rays. We investigate this correlation in low mass systems such as the Magellanic clouds down to 15pc scales taking into account the heating sources of dust and the thermal and non-thermal origins of the radio continuum emission. By including the data taken with Spitzer, Herschel, ATCA,

and PARKES observations, we found that total RC emission has a better correlation with the dust heated by young massive stars (warm dust). The RC-warm dust correlation has mainly a thermal origin as the correlation with the thermal free-free component is better than that with the non-thermal synchrotron emission, although the correlation with the non-thermal is notable. Our results indicate that, in low-mass systems, a delicate balance between the gas, magnetic fields, and cosmic rays hardly holds in diffuse, non-star-forming ISM due to a relatively fast escape of cosmic-ray electrons, unlike the more massive normal spirals.

Orcs, Stars, Cosmology and More

Multi-frequency searches for stellar radio sources with ASKAP
Laura Driessen

I will present methods for and the early results of searching for radio stellar sources by cross-matching ASKAP continuum radio sources to archival X-ray and optical sources. The sensitivity and fields of view of new radio telescopes such as ASKAP and LOFAR are substantially increasing the number and type of known radio stellar sources. Recent searches for radio stars have been focused on searching for circularly polarised radio sources, which biases our searches towards coherent radio emission and coherent flares from stellar sources. However, many stellar radio sources are incoherent, particularly quiescent radio stars, and these sources cannot be found using circular polarisation searches. We can utilise X-ray matching as there is a known correlation between the X-ray and radio luminosity of stellar sources called the Guedel-Benz relation. I will present the initial results of our search, where we have found radio emission from stellar sources in ASKAP Polarisation Sky Survey of the Universe's Magnetism (POSSUM) observations. We are now learning a lot about stellar radio sources and searches using current instruments and SKA pathfinders, so I will also explore future prospects for stellar radio source searches with the SKA.

Characterizing low-latitude ionosphere using the SKA pathfinder: the GMRT
Sarvesh Mangla

In recent years, there has been a resurgence in low-frequency ($< 1\,\mathrm{GHz}$) radio astronomy, where the effects of the Earth's ionosphere can cause a positional shift of the cosmic radio sources. Many telescopes, including the Giant Metrewave Radio Telescope (GMRT), require detailed calibration procedures to mitigate the effects of the ionosphere; also, the same calibration data can be used to observe a wide range of phenomena, including traveling ionosphere disturbances (TIDs). Here, I will present my work on how GMRT dual-band observations (235 and 610 MHz) can be used to detect irregularities in total electron content (TEC) with a precision of about 10^{-3} TEC Unit (TECU), which is an order of higher sensitivity than the current GPS-based measurements. I will further discuss our novel methods to detect individual wave patterns associated with medium-scale to small-scale TIDs and estimate the speed and direction of individual waves. This study may bring insight into building pipelines where ionosphere-induced phase errors can be corrected in real-time for future telescopes like SKA-LOW in Australia and SKA-MID in South Africa.

Constraining radio galaxy bias and matter clustering based on LOFAR DR2 and CMB lensing
Szymon Nakoneczny

During my talk, I will show an ongoing cosmological project within the LOFAR collaboration. We combine radio continuum catalogs with gravitational lensing from the Cosmic Microwave Background (CMB) to place constraints on the bias evolution of radio galaxies, and on the amplitude of matter perturbations. We explore a variety of models describing the radio galaxy bias, discriminating between them through the combination of both auto- and cross-correlations with the CMB lensing. We then use these data to place constraints on the amplitude of matter inhomogeneities, parametrised by σ_8. We determine that a linear bias evolution of the form $b(z) = b_g/D(z)$ is able to consistently provide a good description of different sectors of the data. This allows us to measure

$b_g = 1.36^{+0.08}_{-0.09}$ for a flux-limited sample at 1.5 mJy, using only large scales $\ell < 200$. Freeing up the value of σ_8, we are able to constrain it to $\sigma_8 = 0.87^{+0.13}_{-0.11}$. With less conservative scale cuts, $\ell < 500$, the uncertainties on both parameters reduce by a factor ~ 2, and we obtain $\sigma_8 = 0.80 \pm 0.05$. In both cases we find a good agreement with the value of σ_8 found by Planck. We also present the first detection of the Integrated Sachs Wolfe effect in the LOFAR data, at the level of 2σ. The results give promise that the final data release of LOFAR will provide a successful test of the state-of-the-art cosmological constraints.

Odd Radio Circles: Giant explosions in distant galaxies?
Ray Norris

Two years ago, faint circles of radio emission (Odd Radio Circles, or ORCs) were found in the first quality images from CSIRO's new ASKAP radio telescope. Such circles had never been seen before and we had no idea what they were. The South African Meerkat telescope has now produced deep images showing structure within the ORCs, and also measurements of their magnetic field. From these and other observations, we now know they surround high-redshift galaxies, and may be shells of shocked gas, hundreds of kpc in diameter, resulting from a cataclysmic event in the host galaxies. However, other models are also possible. In this talk I will review the evidence, and discuss the possible models for the formation of ORCs

VAST fast imaging pipeline for rapid transients detection with ASKAP
Yuanming Wang

We developed a new pipeline (so called VAST fast imaging pipeline) dedicated to deep fields observed by Australian Square Kilometre Array Pathfinder (ASKAP), e.g. GW S190814bv field or the Evolutionary Map of the Universe (EMU) survey, to search for radio transients and variables on image domain at shorter timescales (seconds to minutes). The main scientific targets include enhanced scintillation, flaring stars, radio pulsars, and peculiar transients. The prototype pipeline resulted in the first discovery of a group of extreme scintillating AGNs in a linear arrangement on the sky - uncovering the existence of a Galactic plasma filament. We conducted a pilot survey on 40 deep fields from ASKAP archival data at a central frequency of GHz using the prototype fast imaging pipeline. The total area of the pilot survey footprint is ~ 1600 square degrees, revealing 34 highly variable and/or transient sources: 7 of them are known pulsars, including 3 millisecond pulsars, and 7 of them are flaring stars. We also detected an unknown transient with substantial polarisation. More follow-up investigations are underway to understand its nature.

LoTSS DR2 cosmology results
Jinglan Zheng

Here we present the work of the cosmology group in the LOFAR Surveys Key Science Projects, we have studied several different probes with LoTSS Deep Fields, LoTSS DR2 and other surveys in order to understand the radio sources better and create a comprehensive set of constraints on cosmological and astrophysical parameters. In particular, we look at: a) the auto-correlation and angular power spectrum of LoTSS (Hale et al.); b) the cross-correlation with CMB lensing and the Integrated Sache-Wolfe effect (Nakoneczny et al.); c) the cross-correlation with the optical spectroscopic survey eBOSS (Zheng et al.); and d) the joint cosmological parameter estimation with LoTSS combining a), b), c) and other surveys (Heneka et al.). We provide competitive constraints on the bias and redshift distribution of radio sources, BAO constraints and cosmological parameter constraints.