New Directions in Radio Astronomy

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MPI für Radioastronomie

Book of Abstracts

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The role of gas in galaxy evolution (online)

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Our current understanding of galaxy evolution is centered around the cycling of gas in and out of galaxies, and the process of star formation out of the gas that settles in galactic discs. Observations of the cold interstellar medium at mm-to-radio wavelengths have been instrumental in firmly establishing the role of gas in regulating star formation and galaxy growth. In this talk I will review the current gas-centric galaxy evolution model, highlight important open questions, and discuss how future radio surveys will have the power to answer them.

Surveys II / 32

Cosmic magnetism with SKA Pathfinders (online)

Dr. MAO, Sui Ann[1]

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The broad bandwidth coverage, unprecedented sensitivity and angular resolution of radio polarimetric observations provided by SKA pathfinder/precursors and the eventual SKA will allow us to address many long-standing mysteries in cosmic magnetism science. In this talk, I will highlight new science opportunities enabled by these instruments in the field of magneto-ionic medium of AGN, the multi-scale multi-phase magnetized ISM of the Milky Way and magnetic fields beyond galactic scales.

Surveys II / 35

The Universe, Seen in the (Far-)Far-Infrared

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I will present an overview of observations, technologies, and facilities observing the evolution of the Universe in the (far-)infrared, from 2 to 2000 microns (μm) in wavelength. I will begin with current efforts to study the cosmic microwave background (CMB, 1000-4000μm), the relic radiation left over from the Big Bang. I will present an overview of the rich scientific questions currently being pursued by CMB experiments, which ties together the most disparate scales possible in science: quantum mechanics and cosmology; the beginning of the universe to the present day. I will transition to studies of high-redshift galaxy evolution with the Atacama Large millimeter/submillimeter Array (ALMA 450-3000μm) and the (very near!) future with the James Webb Space Telescope (2-30μm). Understanding the formation and evolution of galaxies is one of the foremost goals of astrophysics and cosmology today and these two facilities are, and will be, providing exciting new insights into these key questions. The far-infrared (50-500μm) portion of the electromagnetic spectrum provides a unique window into the evolution of the Universe and, while difficult, far-infrared spectroscopy is crucial for studies of the interstellar medium, galaxy evolution, and the high-redshift Universe. I will also discuss new instruments on the ground and in space which will significantly expand our discovery reach with the (far-)infrared into the coming decades.

Cosmology I / 33

Large-scale structure via intensity mapping (online)

Prof. LAGACHE, Guilaine[1]

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Intensity mapping measures the large-scale spatial fluctuations in the collective emission from all of the sources emitting in some convenient spectral lines. It is naturally sensitive to the radiation from faint sources and from the diffuse intergalactic medium. It has also the advantage of measuring fluctuations on large regions of the sky (few square degrees) in a large frequency, and thus redshift, range. Currently, considerable attention is being paid to intensity mapping using the neutral hydrogen HI 21cm line, the CO and the [CII] lines. Main goals are to constrain the cosmological model, the epoch of reionization, as well as structure growth. These large-scale structure surveys complement traditional galaxy surveys that are limited to studying only sources that lie above survey flux limits.
In this talk I will start by introducing line intensity mapping (IM) and discussing several aspects of using IM as a large-scale structure probe in order to better constrain the cosmological model and galaxy physics. I will then review its current and future observational status and the synergies of multiple IM tracers. I will finally briefly discuss some work on circumventing the contamination problem in such surveys, as well as the efforts to increase the precision of modeling.

Cosmology I / 37

Combining strong gravitational lensing with radio interferometers, a pathway to new physics

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Strong gravitational lensing is a powerful tool to address many interesting astrophysical questions. To this day, only a few hundreds strong gravitational lens systems are known. However, ongoing and upcoming surveys with, e.g. the SKA, will soon discover hundreds of thousands of new gravitational lens systems, marking a new beginning for strong gravitational lensing studies. In this talk, I will show how we can answer fundamental questions about the nature of dark matter, galaxy evolution and cosmic magnetism by combining the power of strong gravitational lensing, novel lens modelling techniques, and very long-baseline interferometry in the next five to fifteen years.

Cosmology II / 25

Massive Black Holes across cosmic time (online)

Dr. VOLONTERI, Marta[1]

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I'll discuss opportunities for radio observations to advance our knowledge of massive black hole evolution. In particular, I'll focus on jest at high redshift, and their possible link to super-Eddington accretion and to counterparts of gravitational wave detections of massive black hole mergers with LISA. I'll also discuss radio observations as gravitational wave experiments, with Pulsar Timing Arrays, and how they are already giving us information on low-redshift massive black holes at the high end of the mass spectrum.

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Extragalactic Science with SKA Pathfinders

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The suite of SKA pathfinders have made a wide range of impressive and in some cases, unexpected discoveries in the extragalactic radio sky. These include the most distant detections of HI emission and OH masers, previously unseen radio galaxy morphological features, and transformative new perspectives of previously well-studied cosmic laboratories. However, several attributes of these telescopes and the decimetre radio sky make their full scientific utilisation a challenge, necessitating significant algorithm development. I will give a practical overview of early experience with and extragalactic science results from MeerKAT, the SKA1-MID precursor, which makes up the first third of the SKA1-MID array. I will discuss emerging themes in the scientific opportunities that MeerKAT provides, alongside synergies with wide-field VLBI surveys, as we look ahead toward an increasingly results-orientated science case for the envisaged SKA2-MID array, spread across the African continent.

Compact objects, relativistic jets and feedback I / 31

Multi-wavelength astrophysics of Galactic jets (online)

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A major open question in high-energy astrophysics is how relativistic jets are launched, accelerated and collimated. The inner regions of jets from active galactic nuclei have recently been imaged in exquisite detail using high angular resolution radio observations from the Event Horizon Telescope and space VLBI. However, the long evolutionary timescales of supermassive black holes make it difficult to understand the detailed connection between the jets and the accretion flow that powers them. X-ray binaries provide a complementary view of the accretion and ejection processes, allowing us to observe in real time the causal link between inflow and outflow around a compact object. I will review recent multi-wavelength studies of X-ray binary jets, demonstrating how a combination of multi-wavelength timing studies and high angular resolution imaging can probe the details of jet launching, and how this can be linked to underlying changes in the accretion flow properties. I will conclude by discussing how next-generation radio observatories such as the ngVLA and ngEHT, together with upcoming multi-wavelength facilities such as CTA and JWST can make progress in this field.

Compact objects, relativistic jets and feedback II / 29

Observational studies of the jet formation region in Active Galactic Nuclei

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A century after their discovery, relativistic jets are still among the most studied and fascinating objects in the Universe. They represent a unique cosmic laboratory for investigating the physics of relativistic plasmas in extreme conditions, and are believed to play a crucial role in the evolution of galaxies and clusters. Much of the progress in radio interferometric techniques has been driven by the need to pierce into the cores of the active galaxies producing them. As evidenced by the recent, staggering images of M87 on event horizon scales, the development of wide-band receivers and of global arrays operating at millimeter and sub-millimeter wavelengths has now opened a new window for the understanding of the jet phenomenon around supermassive black holes. In my talk I will review some of the progress recently made in jet formation studies, as well as the still open scientific questions and future perspectives in the field.

Compact objects, relativistic jets and feedback II / 42

Radio Probes of Extreme Particle Acceleration in Extragalactic Jets

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Relativistic jets in active galaxies are key to scientific advance in a multitude of interrelated fields of modern astrophysics ranging from fundamental physics in strong gravity near supermassive black holes over astroparticle physics to feedback on cosmological scales. Advances in radio astronomy will provide unique observational data on jets across scales, methods and disciplines over the coming decades. In this talk, I will focus on relativistic jets in active galaxies as sites of extreme particle acceleration, which are the likely origin of very high-energy neutrinos and ultrahigh-energy cosmic rays. High-resolution Very-Long-Baseline Interferometric (VLBI) observations along with variability and polarimetric radio data provide the crucial observational input to constrain theoretical/numerical models of the underlying physical processes and address many burning questions and riddles such as the infamous Doppler crisis, the unknown localization of the (very-high-energy) gamma-emission sites and the processes leading to neutrino and cosmic-ray emission. Observational challenges in the past have been imposed by the faint radio emission of important source classes like extreme high-synchrotron-peaked BL Lac objects. Thanks to new high-sensitivity VLBI and high-frequency single-dish total-intensity and polarimetric receiver systems, radio astronomy is lifted into a pole position in the multimessenger exploration of relativistic jets in combination with new neutrino telescopes like KM3Net and IceCube-Gen2 and upcoming very-high-energy facilities like the Cherenkov Telescope Array (CTA). Specifically, a strong boost for synergies between astroparticle physics and radio astronomy will be given by upgrades to sensitive single-dish and VLBI instruments like the 100-m Effelsberg telescope, new short-wavelength VLBI facilities like the ngVLA and the development of advanced Southern-Hemisphere cm-band VLBI arrays in the SKA era.

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Intermediate-mass black holes: current status and future prospects (online)

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Intermediate-mass black holes (IMBHs) of 100-1e5 solar masses formed at z>7 are currently the best candidates to being the seeds from which the first supermassive black holes formed. Studying this population of early Universe seed black holes has so far been only possible by investigating the possible local relics of those that did not become supermassive. These relic IMBHs should be found in globular clusters, in dwarf galaxies, and in the halo of massive galaxies that have suffered a merger with satellite dwarf galaxies. I will show how both single-dish and radio interferometric observations are key to identify and characterize IMBHs in the local Universe and out to z˜3. Single-dish observations with Effelsberg and APEX for instance can inform us about the gas availability and impact of IMBH feedback in dwarf galaxies, while continuum interferometric observations with the EVN or LOFAR can tell us about jet emission processes and black hole properties. The next generation of radio telescopes such as the SKA, in synergy with up-coming X-ray and gravitational wave observatories, will open a new window in detecting seed black holes at birth, probing the formation pathways of the first quasars in the Universe.

Compact objects, relativistic jets and feedback III / 22

New routes to galaxy formation and feedback

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Energetic outflows, by supposedly evacuating galaxies of their interstellar medium (ISM) gas reservoirs, are considered the main manifestation of negative feedback that can lead to galaxy quenching. Guided by the predictions of earlier cosmological simulations, which showed that extreme feedback events could lead to an almost sudden suppression of star formation in galaxies, the observational investigation of galactic outflows has focused - for the past 10 years - on the inner ISM of galaxies, with the aim of constraining their energetics (e.g. mass, outflow rate, kinetic power) and driving mechanisms (e.g. supernovae, AGNs, jets). Recent theoretical and observational developments in this field are however providing a much more complex picture of feedback. Besides clearly showing the multiphase nature of both galactic outflows and the circumgalactic medium (CGM) (both of which turned out to embed large masses of observationally elusive cold and dense neutral gas), these works prompt us to investigate feedback within the broader context of the baryon cycle in galaxies. This implies shifting our attention from the inner sub-kiloparsec regions of galaxy disks to the larger-scale ISM and CGM, where we can observe the cumulative effect of feedback processes across time scales of several 100s Myr. As an added bonus, on these scales we can study how galaxies accrete their fuel, and assess the role of the external environment in galaxy growth. These scientific questions translate into specific instrumental requirements for radio/sub-mm facilities and instrumentation, some of which appear to go in the opposite direction compared to the planned upgrades of sub-mm interferometers such as ALMA and NOEMA.

Gravitational Waves & Multimessenger Astrophysics I / 27

High-energy physics in the Galactic centre and beyond (online)

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It's been a fantastic decade for black hole studies, highlighted by the 2017 and 2020 Nobel Prizes in Physics. Multiple Galactic Center research groups, the Event Horizon Telescope, and LIGO/Virgo continue to bring rapid-fire new observations to sharpen our understanding of these exotic objects. I will discuss Sgr A*'s unique variability alongside other time domain phenomena in the Galactic Center, traced out over more than 20 years of observations from coordinated multi-wavelength campaigns. I will compare these detailed studies of Sgr A* to equally impressive multi-wavelength observations of M87*. I will also briefly explore how we can continue to push the frontiers of black hole research with existing and next-generation observatories.

Gravitational Waves & Multimessenger Astrophysics I / 11

Studies of transient phenomena (online)

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Radio transients: current results and future plans (online)

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The past decade has seen substantial improvements in our ability to study radio transients, largely due to new and upgraded telescopes such as ASKAP, MeerKAT, JVLA and, at low frequencies, LOFAR and the MWA. These instruments have started producing results, from the detection of long term synchrotron transients like gamma-ray burst afterglows and tidal disruption events, to more rapidly varying phenomena such as flaring stars and hints of exoplanetary-stellar interactions.

They have also discovered more mysterious objects such as a new Galactic Centre Radio Transient, and a long period magnetar. However, these discoveries are just the start of what we will find as we explore the radio transient sky in the SKA era. I will review the current state of radio transients, and discuss future plans and opportunities.

Transient Sky I / 26

Transient Radio Sky

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The transient radio sky is lit up on time scales ranging from nano-seconds to years by a diverse population of sources that are as close as the magnetic planets in our solar system and as distant as gamma-ray bursts on the edge of the visible Universe. Time variability is an important additional strategy for studying the underlying physics of astrophysical systems and is also essential for discovery in many cases. In this talk I will discuss how radio variability displayed by a wide range of source classes can be used to explore many areas in astrophysics, such as stellar evolution, source environments, magnetospheric physics, and the expansion of the Universe. For each of these science cases, I will highlight the role that fast radio bursts play. Finally, I will conclude with a few thoughts on future surveys.

Transient Sky II / 23

Precision astrometry and its applications (online)

Prof. DELLER, Adam[1]

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The mundane task of measuring the positions of astronomical sources can, when carried out with sufficient precision, unlock transformative understanding of topics ranging from stellar evolution to cosmology. Most fundamentally, this springs from the provision of gold-standard, model-independent distance estimates for Galactic objects via the measurement of their annual geometric parallax. These measurements can amplify the power of individual systems (pulsars, masers, X-ray binaries, etc) to test astrophysical theories, but also underpin model-dependent distances for whole populations of such objects. Moving outside our own galaxy, the motion of the Earth around the Sun no longer provides a sufficiently large viewing angle change to discern annual parallax, but long timespans or relativistic source motion can nevertheless lead to discernible position change. Measurements of this positional change can be mapped back onto constraints on e.g. outflows and in turn to the physics of the accretion that powers them. I will review the current state of the art in precision astrometry at cm wavelengths and present a necessarily limited sample of recent science highlights at kpc to Mpc distances, as well as a look towards likely advances over the coming decade that will break new ground when paired with sensitive forthcoming facilities such as the SKA and ngVLA.

Transient Sky II / 41

The Space Weather and Magnetospheres of Extrasolar Planets

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Magnetic fields play a fundamental role in the formation, evolution and ongoing physical characteristics of both stars and planets. For example, the enhanced magnetic activity of the the young

Sun, powered by its rapid rotation, was a major factor in defining the atmospheric properties of the solar system planets. The enhanced radiative output at higher energies during flares leads to heating of the upper planetary atmosphere, resulting in photochemical reactions and significant atmospheric loss. Simultaneously, the stellar wind of an active star is potentially much denser and faster, compressing the magnetosphere, particularly during coronal mass ejections (CMEs), which are also presumed to be much more frequent, as well as associated solar energetic particle (SEP) events. Despite the potential impact, observational data are largely absent in this domain. No CME or SEP event on a main sequence star other than the Sun has been detected. Simultaneously direct detection of planetary magnetic fields has yet to be achieved and remains the most crucial ingredient in assessing planetary habitability in the context of stellar activity. The latest generation of radio telescopes, particularly at low frequencies, provide the best opportunity to directly detect these phenomena for the first time.

Gravitational Waves & Multimessenger Astrophysics II / 28

The computational challenge of black hole populations (online)

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The third gravitational-wave transient catalogue released by the LIGO-Virgo-KAGRA collaboration contains 90 event candidates, most of them associated with binary black hole mergers. This wealth of data opens new perspectives on the study of astrophysical black holes and poses new challenges to computational astrophysicists. What are the formation channels of binary black holes? What is their evolution across cosmic time? Can we use binary black holes to probe the first stars in the Universe? In my talk, I will review the state-of-the-art numerical models of binary black hole formation. On the one hand, population models of massive binary stars predict binary black holes with primary mass up to about 50 Msun and nearly aligned spins, but are affected by large uncertainties. On the other hand, dynamics of dense stellar clusters can trigger the formation of massive (>60 Msun) black holes via multiple stellar collisions and hierarchical mergers of low-mass black holes. The size of the relevant parameter space, the computational cost of current numerical simulations and the range of physical scales involved (from less than one solar radius to several hundred Mpc) represent the main challenges and affect both binary evolution and dynamical models. I will discuss these challenges and propose a new approach to tackle them. The proposed computational models, next-generation gravitational-wave detectors and future radio surveys will provide key results to shed light on black hole populations across the cosmic time.

Gravitational Waves & Multimessenger Astrophysics II / 40

New perspectives onto the Universe in the era of multi-messenger astrophysics

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Since the revolutionary discovery of gravitational wave (GW) emission from a binary black hole merger in 2015, the exquisite GW detectors LIGO, Virgo and KAGRA have detected more than 90 compact object mergers. Most notably, one of these mergers corresponds to the first binary neutron star merger, dubbed GW170817. This event has been transformative because it was observed in both gravitational and electromagnetic radiation, thus opening up a new era in multimessenger astrophysics. The multi-messenger characterisation of such an event has enabled major advances into diverse fields of modern physics from gravity, high-energy and extragalactic astrophysics, nuclear physics, to cosmology. In this talk, I will discuss my work in strong-field gravity astrophysics and how combining observations, theory and experiment is key to make progress in this field. I will present the opportunities and challenges that have emerged in multi-messenger astrophysics, and what the future holds in this new era.

Surveys III / 24

Sky surveys at long radio wavelengths (online)

Prof. HURLEY-WALKER, Natasha[1]

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Radio astronomy was first performed at low frequencies, but historically had seen a decline due to the sensitivity and resolution gains offered by moving to higher frequencies. Thanks to the search for the Epoch of Reionisation, low-frequency radio astronomy has undergone a renaissance, with instruments such as the Murchison Widefield Array, LOw-Frequency ARray, and the upgraded Giant Metrewave Radio Telescope being used to make many exciting new discoveries. An important component of this productivity is the ability to perform very large surveys at these frequencies, with increasingly large bandwidths. The future is bright, with further upgrades to these instruments and the Square Kilometer Array on the horizon. In this talk I will suggest some growth areas to watch over the next few years, and suggest strategies for the community to take advantage of the upcoming improvements in capability.