# A Centenary of Astrophysical Jets: Observation, Theory and Future Prospects

# Abstract Booklet

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# 1 Oral Contributions

# 1.1 General Overview

### 1.1.1 Jet Theory: Some Key Questions

Despite great progress in modeling certain aspects of jet physics, the basic mechanisms of jet launching, acceleration, collimation, and dissipation are far from established. I will outline some key questions that still need to be answered and discuss some possible new directions.

Mitchell Begelman (University of Colorado, USA)

# 1.2 Launch & Acceleration: Theory & Observations

### 1.2.1 Jets and their connection to the accretion flow

I will review how the changing jet behaviour observed in Galactic Black hole binary systems is connected to a change in accretion mode from a standard disc to some sort of hot flow. A similar change in accretion flow is implied by the difference in jet spectra seen in BL Lacs compared to FSRQ. The FSRQ plainly have an inner standard disc which produces a strong source of UV ionising photons to light up the BLR, giving the external Compton dominated jet spectrum. Conversely, the SSC jet spectrum of the BL Lacs shows that their inner disc is replaced by a hot flow with very few UV ionising photons. Nonetheless, both these clearly have highly relativistic (bulk Gamma 10-15) jets, while the galactic black holes have only mildly relativistic (bulk Gamma ; 2) jets which collapse in the standard disc states. I will propose a simple model to explain this where the hot flow launches an accretion powered jet with moderate Lorentz factor in both AGN and stellar mass black holes, but this is augmented by a faster Blandford-Zdnajek powered jet in objects with high spin. Measuring spin is currently controversial, but low spin for stellar remnant black holes is in line with current gravitational wave data, while I will show evidence for high spin in the highest mass black holes in AGN.

Chris Done (University of Durham, UK)

### 1.2.2 Numerical simulations of black hole jet

Accreting black holes produce relativistic jets via an interplay between magnetized accreting plasma and general relativistic frame-dragging near the black hole horizon. Numerical simulations are a powerful technique to study how this central engine works. Jet power is largest when the black hole spins rapidly and a strong ordered magnetic field is present around the spinning hole. Jets form easily in the presence of geometrically thick accretion disks, but can be present even with thin disks under certain conditions. The observational dichotomy between jetted and non-jetted sources is not yet fully understood, but is likely correlated, at least in part, with disk thickness.

Ramesh Narayan (Center for Astrophysics, Harvard & Smithsonian, USA)

# **1.3** Launch and Acceleration + VLBI: Observations

### 1.3.1 Comparing radio-loud Swift/BAT AGN with their radio-quiet counterparts

We compare the radiative properties of radio-loud (RL) and radio-quiet (RQ) AGN selected from the Swift/BAT catalog with similar black hole (BH) masses and Eddington-ratios. As we have found the only significant difference concerns the hard X-ray luminosities, which are about two times larger in RL-AGN than in RQ-AGN. One might speculate that this difference comes from having in RL-AGN X-ray contribution not only from the innermost, hot portions of accretion flow, but also from a jet. However, this interpretation is challenged by our findings that hard X-ray spectra of RL-AGN have similar slopes and high-energy breaks to those of RQ-AGN and that hard X-ray radiation is in both RQ and RL-AGN quasi-isotropic. Hence we argue that production of hard X-rays in the RL-AGN is like in the RQ-AGN, dominated by hot, central portions of accretion flows, and that larger X-ray production efficiencies in RL-AGN may result from larger radiative efficiencies of the innermost portions of the accretion flows around faster rotating BHs.

Maitrayee Gupta (Nicolaus Copernicus Astronomical Center, Poland)

#### 1.3.2 Strong lensing reveals jets in a sub-microJy radio quiet quasar

Despite their discovery in the radio, most quasars produce relatively little radio emission. Consequently, the emission mechanism within so-called radio quiet quasars (RQQs) has been difficult to observe directly, and continues to be hotly debated. For the SKA, this means that the phenomenological description of the one of the largest future source

populations remains incomplete. For galaxy evolution models, feedback processes during the most common state of existence of an AGN are not understood. Historically, the problem has largely been investigated using statistical studies, which variously cite either starburst or AGN jet activity as the dominant emission mechanism. By using strong gravitational lenses as cosmic telescopes, we can instead constrain the emission mechanism by directly imaging it. To this end, I present observations of a lensed RQQ at z=1.5 which show twin parsec scale jets in what is the faintest radio source ever imaged. I will also raise tentative implications for the reliance on the radio-FIR correlation to separate starburst regions from low-power radio jets.

Philippa Hartley (SKAO, UK)

#### 1.3.3 Effects of Numerical Resolution and Disc Tilt on Jet Properties

Using the GRMHD code Athena++, we study a number of accretion flows in the magnetically arrested disc regime. A comparison of different resolutions shows most simulations in the literature resolve most disc properties of interest, and preliminary results indicate the same holds for jet properties. By independently tilting the matter angular momentum and initial magnetic field direction with respect to black hole spin, we find the orientation of the outgoing jet to have some dependence on all angles in the problem. The plasma and fields at the base of the jet show substantial differences varying the initial field, even with the disc orientation held fixed.

Chris White (KITP, University of California, USA)

#### 1.3.4 VLBI studies on AGN jets

Formation, acceleration and collimation mechanism of active galactic nuclei (AGN) jets are still not fully understand yet, while it has passed for 100 years since the first discovery of the extragalactic jet in M87. Very Long Baseline Interferometry (VLBI) have been one of the powerful and unique tools in order to probe the innermost region of the AGN jets, and have been provided interesting and important clues, such as topology of the magnetic field, collimation and velocity field profile, and so on to address those questions. In this talk, I would like to summarize contribution of VLBI studies.

Keiichi ASADA (ASIAA, Taiwan)

### 1.3.5 Synthetic VLBI Imaging of Relativistic Jet Simulations: Applying Polarized Radiative Transfer Through 3D RMHD and 3D PIC Jet Calculations

Constraining: (i) the plasma content of a relativistic extragalactic jet, and (ii) the location(s) within the jet of the site(s) of high-energy emission production, remain two of the most sought-after questions in high-energy jet astrophysics. I will present my recent efforts in applying full-Stokes polarized radiative transfer (via ray-tracing) through 3D relativistic magnetohydrodynamic (RMHD) and 3D relativistic particle-in-cell (PIC) jet simulations. These complimentary numerical techniques are aimed at better understanding the macro and micro physics that drive the dynamics of the jet and produce the resultant non-thermal jet emission. In particular, I will present radiative transfer calculations that highlight the unique ability of deep polarimetric imaging in answering these two fundamental questions through the use of global very long baseline interferometric (VLBI) arrays (i.e., a phased ALMA in concert with the GMVA and the EHT).

Nicholas MacDonald (Max-Planck-Institut für Radioastronomie, Germany)

#### 1.3.6 A mechanism for triple-ridge emission structure of AGN jets

Recent radio VLBI observations of the relativistic jet in M87 radio galaxy have shown a triple-ridge structure that consists of the conventional limb-brightened feature and a central narrow ridge. Motivated by these observations, we examine a steady axisymmetric force-free model of a jet driven by the central black hole (BH) with its electromagnetic structure being consistent with general relativistic magnetohydrodynamic (GRMHD) simulations, and find that it can produce triple-ridge images even if we assume a simple Gaussian distribution of emitting electrons at the base of the jet. We show that the fluid velocity field associated with the electromagnetic field produces the central ridge component due to the relativistic beaming effect, while the limb-brightened feature arises due to strong magnetic field around the jet edge which also induces the electrons to be dense there. We also show that the computed image strongly depends on the electromagnetic field structure, viewing angle, and parameters related to the electrons' spatial distribution at the jet base. We will also discuss the extension of our force-free model to GRMHD model, which will help constraining the non-thermal electron injection mechanism of BH jets. This study will be complementary to theoretical analyses of the upcoming data of Event Horizon Telescope.

Taiki Ogihara (Tohoku University, Japan)

# 1.4 VLBI + Small-scale: Theory and Interpretations

#### 1.4.1 Modelling relativistic jets via evolutionary algorithms

We developed a numerical scheme based on evolutionary algorithms which allows us for the first time to directly model Very Long Baseline Interferometric (VLBI) observations of jets with state-of-the art relativistic magnetohydrodynamical (RMHD) simulations. During the modelling process we consider besides the macro and radiation micro-physics the limitations of the observing array and the image reconstruction algorithms. We successfully applied this new end-to-end pipeline to Event Horizon Telescope observations of M87 and to multi-frequency VLBI observations of NGC1052. In the talk I will present the results for M87 and NGC1052 and provide an outlook to future applications of the pipeline.

Christian Fromm (Goethe University, Germany)

# 1.4.2 Powerful blazar jets dissipate their kinetic power to radiation from a single location: the molecular torus

The location of gamma-ray emission, which traces energy dissipation, in blazars is a matter of active debate: is it within the sub-parsec scale broad-line region, the further parsec-scale molecular torus, or beyond these at the location of the VLBI radio core? This is a very important question, with implications regarding jet formation, jet collimation, particle acceleration, and energy dissipation in blazars. We have developed a diagnostic, called the seed factor, for the gamma-ray emission location in powerful blazars in the case of leptonic models. This diagnostic, which is dependent on only observables, is unique to the photon population of the gamma-ray emission location. Using 2 samples of well-sampled, quasi-simultaneous SEDs, along with a sample of SEDs taken from literature for 2 well-observed sources, we find that the seed factor distribution peaks very sharply at a single value. This indicates that there is a single gamma-ray emission location in powerful blazars. Furthermore, applying a few common, welljustified assumptions about the broad-line region and the molecular torus, our results indicate that the molecular torus is very strongly preferred as the gamma-ray emission location.

Adam Harvey (University of Maryland, Baltimore County, USA)

#### 1.4.3 Resolving the Enigma: Half a Century of VLBI Studies of Relativistic Jets

The centennial year of the discovery of extragalactic jets marks also the fiftieth anniversary of the first detection of a superluminal speed in an extragalactic jet. This detection revolutionized the entire field of jet and AGN studies, opening the avenues to localizing and tracing the radio emitting material down to the finest angular and linear scales. Decades of dedicated VLBI studies of jets have changed dramatically our understanding of this phenomena, taking the long stride from explosive expansions in the nuclear region of AGN to ballistic superluminal blobs, to curvilinear trajectories and planar shocks, and all the way to the present, most detailed picture of magnetized, accelerated flows manifesting rich and stratified internal structure and velocity field. Most of these advances fully take their roots in the VLBI imaging and polarimetry of radio emission down to microarcsecond scales. This presentation will review briefly the major milestones in the VLBI studies of extragalactic jets and outline a number of the outstanding problems in jet physics, including the site and the mechanism of jet formation, acceleration of relativistic flows, structure of magnetic field in the vicinity of the central engine of AGN, and the fundamental question of the physical nature of the central massive objects in galaxies. These problems will be further discussed in the context of prospects for VLBI studies in the coming decade, focusing specifically on the advances expected in millimetre- and space-VLBI observations and on the potentials of combining VLBI with multi-band and multi-messenger studies of the AGN phenomenon.

Andrei Lobanov (Max-Planck-Institut für Radioastronomie, Germany)

#### 1.5 M87: Theory and Observations

#### 1.5.1 Lessons Learned from M87 - Jet collimation break as a new unification in AGN jets

M87, "probably" the most studied relativistic jet in AGNs, has been spatially resolved from ten to tens of millions of gravitational radii; it gives a unique opportunity for understanding an AGN jet from birth to termination. Several key issues in AGN jets can be extensively discussed based on multi frequency VLBI observations and magnetohydrodynamic (MHD) jet theories toward M87. One of our remarkable findings in M87 is the "jet collimation break (JCB)", a structural change from parabolic to conical geometry at the sphere of influence, which coincides to a transition from increasing to decreasing in observed proper motions. In this talk, we review the JCB as a fundamental property in various AGNs under the interplay with the SMBH growth and evolution of host galaxies. We also discuss

about the jet launching in M87, which can be expected to unveil with the EHT project in coming years. This will provide further constraints on modeling the horizon scale properties of M87.

Masanori Nakamura (ASIAA, Taiwan)

#### 1.5.2 Probing signature of black hole spin in M87 shadow in flaring state

The Event Horizon Telescope (EHT) has detected the black hole (BH) shadow in M87, whose BH mass is estimated to be 610<sup>9</sup> solar masses The BH spin, however, has not yet been determined. This is because the dependence of the BH spin on the size and morphology of the BH shadow is very weak, e.g., the diameter of the black hole shadow changes only less than 5% from 10 gravitational radius when optically thin plasmas surround the BH. We, therefore, calculate the partially thick plasma against the synchrotron-self absorption in the vicinity of BH, which will appear in a flaring state with a relatively high mass accretion rate in M87. We have found that a dark-crescent structure is generally produced between the photon ring and the SSA-thick ring at the innermost stable circular orbit (ISCO) in the BH shadow image. The scale size of the dark crescent increases with BH spin: its width reaches up to 2 gravitational radius when the BH spin is 99.8% of its maximum value. The dark crescent is regarded as a new signature of a highly spinning BH. This feature is expected to appear in flaring states with relatively high mass accretion rate rather than the quiescent states. We have simulated the image reconstruction of our theoretical image by assuming the current and future EHT array, and have found that the future EHT including space-very long baseline interferometry in 2020s can detect the dark crescent.

Tomohisa Kawashima (National Astronomical Observatory of Japan)

#### 1.5.3 Long-term, deep millimeter VLBI observations of M87 down to 7Rs and larger spatial scales

Recent Event Horizon Telescope (EHT) observations of M87 have finally revealed detailed morphology of the eventhorizon-scale structure around the central supermassive black hole. Detailed theoretical analysis of the M87 black hole images, performed by the EHT collaboration, have also brought immense impact on the BH accretion/ejection astrophysics. Nevertheless, detailed physical mechanisms controlling formation of the large-scale edge-brightened M87 jet, and how such jet of remarkable morphology is connected to the central BH, still remain as a subject of further studies and observations, largely due to limited sensitivity of the current EHT array to the larger and extended jet structure.

In this talk, we will discuss implications of the EHT M87 results in the context of (i) previous decadal Global millimeter VLBI Array (GMVA) M87 observations performed at 7 Schwarzschild radii (Rs) resolution and at 86GHz, and also (ii) long-term and high-cadence millimeter VLBI flux monitoring of M87 at 22, 43, 86, and 129 GHz with submilliarcsecond (i100Rs) resolution, performed by the Korean VLBI Network. We will also briefly show several observable signatures of different theoretical models of jet formation in M87, which can be captured by future GMVA+ALMA polarimetric observations. Finally, we will present and discuss preliminary results from a new ultra-deep image of M87 at 7mm wavelength – newly obtained from a global 43 GHz VLBI observations in Spring 2018 with VLBA+phased JVLA+GBT+EB+ other EVN stations at 14Rs resolution. We will particularly focus on its possible implications for the expected EHT 2018 results for M87.

Jae-Young Kim (Max-Planck-Institut für Radioastronomie, Germany)

# **1.6** VLBI + Small-scale: Theory and Interpretations

### 1.6.1 Internal structure of relativistic jets

In recent years, there has been a significant breakthrough in our understanding of relativistic jets from active galactic nuclei thanks to the possibility of spatially resolving their internal structure. This made it possible to check the numerous predictions that were formulated both analytically and numerically.

In my talk the main analytical results confirmed by numerical simulations will be presented. In particular, it will be shown that at large distances from the 'central engine' the jet must be strongly non-uniform. In addition, it will be shown how the how the knowledge of the internal structure of jets can help in explaining their observable properties.

Vasily Beskin (Lebedev Physical Institute & MIPT, Russia)

#### 1.6.2 The Overall B Field Configuration of AGN Jets

There is now considerable observational evidence that the magnetic (B) fields of AGN jets form a "nested helix" structure, with two regions of B field having oppositely directed azimuthal and poloidal components at different distances from the jet axis. The different directions of the azimuthal fields in these two regions can give rise to changes

in the observed Faraday rotation patterns, in particular, to different directions for Faraday rotation gradients across the jets, which come about due to the systematic change in the azimuthal B field across the jets. This overall B-field structure gives rise to a system of currents that is similar to that for a co-axial cable, with currents flowing along the jet in opposite directions close to and farther from the jet axis. The collected observational evidence points toward the action of some sort of "battery" mechanism, since the directions of these poloidal currents are not random: they are predominantly inward toward the central black hole close to the jet axis and predominantly outward farther away from the jet axis. Recent observational and theoretical/computational work on this type of global B-field model for AGN jets carried out in the radio astronomy group at University College Cork and elsewhere will be reviewed.

Denise Gabuzda (University College Cork, Ireland)

#### 1.6.3 Hot, Pair Dominated Relativistic Jets

Estimates of the energy content of radio lobes in FR II sources, whether based on their luminosities or on their confinement by the external medium, yield comparable results. This seems to exclude the possibility that the energy of radio lobes is dominated by the protons. Furthermore, large-scale relativistic jets that power the lobes are terminated at bright hotspots that show evidence for efficient acceleration of electrons, which would be difficult if the energy of jets was dominated by cold protons. Instead, we suggest that relativistic jets are energetically dominated by electron-positron pairs. Such a possibility is confronted against the constraints imposed by the jet formation scenarios and by the properties of jets on parsec and kiloparsec scales.

Marek Sikora (Nicolaus Copernicus Astronomical Center, Poland)

# 1.6.4 Numerical simulation of the polarization produced by recollimation shocks in jets with an initially disordered magnetic field

When simulating astrophysical jets, many recent models assume that the magnetic field within the jet plasma is predominantly ordered. This results in predicted levels of polarization much higher than observations imply. In this work we show simulated radio images produced from numerical simulations of steady, hydrodynamic jets, in which the magnetic field is, initially, fully disordered. The jets are overpressured at the inlet, producing a series of recollimation shocks at regular intervals along the jet. The polarization was obtained by monitoring the fluid deformation as it passes along the jet, using a method similar to that employed by Matthews & Scheuer (1990, MNRAS 242, 616). At present our method does not take account of radiative losses or particle acceleration at the shock fronts.

Our initial results show that the brightest parts of the jet are the pinch points, where the plasma is most compressed. The polarization fraction here tends to be low, less than 10%, and the polarization angles are spatially fairly uniform, becoming approximately radial in distribution as the line of sight angle increases. The recollimation shocks lie between the pinch points, and the fractional polarization from this fainter region can be as high as 30% in some models.

The recollimation shocks themselves are not readily apparent in emission, but can be traced in fractional polarization; the highest levels of fractional polarization are found near the projected outline of the shock surface.

Christopher Kaye (University of Central Lancashire, UK) Tim Cawthorne (University of Central Lancashire)

#### 1.6.5 Are BL Lac jets weakly magnetised?

The Spectral Energy Distribution (SED) of BL Lacs is usually modelled assuming that the momentum distribution of the non-thermal particles is isotropic. The modelling of the SED typically suggests the presence of strongly sub-equipartition magnetic fields in the emission region, which contradicts the paradigm of dynamically important magnetic fields in AGN jets. I will argue that the non-thermal electrons responsible for producing the observed radiation are instead primarily accelerated in the direction of the background magnetic field. The key point is that gyroresonant pitch angle scattering, which might isotropize the electron momentum distribution, can be effective only out to some electron energy that is typically smaller than the spectral break due to efficient cooling. I will present a simple phenomenological model that takes this effect into account. Using the new model, the physical properties of the emission region that are inferred from the observed SED change dramatically. In particular, allowing for an anisotropic electron distribution removes the need for strongly sub-equipartition magnetic fields in the emission region.

Emanuele Sobacchi (Ben Gurion University of the Negev, Israel)

#### 1.6.6 Optical AGN jets at milliarcsecond scales

Careful examination of VLBI/Gaia position offsets revealed a strong systematic pattern that can be explained only by the presence of optical jets at milliarcsecond scales, well below resolution of any existing optical instrument. Observed VLBI-Gaia offsets is the displacement of the optical centroid with respect to the most compact radio featureusually associated with a supermassive black hole. Optical jets were known at some galaxies before, but we found thatthey are ubiquitous. We discuss how measurements of VLBI-Gaia offsets can be used to deduce property of optical jets that are too short to be directly visible at optical images, but long enough to be detected with high precision astrometry.

Leonid Petrov (NASA GSFC, USA)

#### 1.6.7 Coupling between the small and large scale magnetic field configuration in the relativistic jet of OJ 287

The blazar OJ 287 is one of the best candidates for hosting a binary supermassive black hole (SMBH) system, with a secondary SMBH crossing the accretion disk of a more massive SMBH every 12yrs. Driven by this prediction, we initiated a dense and long-lasting monitoring program at different radio frequencies between 2.6 and 43 GHz using the Effelsberg 100-m radio telescope, to follow its evolution in total flux density, linear and circular polarization and test different facets of the binary SMBH model. Within the first year of observations, the source showed flaring activity, complex linear and circular polarization behavior and an extremely long EVPA rotation. We analyzed the single-dish radio data together with concurrent VLBI and optical polarization observations, which showed a similarly long EVPA rotation populated by shorter, but much faster, repeated rotations. The coupling of EVPA rotations seen across the radio and optical bands is consistent with a polarized emission component moving on a helical trajectory modulated by a large scale jet bending. Based on that model we used the polarimetric observations to constrain a number of physical parameters of both the small and large scale jet structure and its magnetic field's geometry.

Ioannis Myserlis (Max-Planck-Institut für Radioastronomie, Germany)

### 1.7 Particle Acceleration: Theory

#### 1.7.1 Particle acceleration at shocks in astrophysical jets

Particles that are accelerated in astrophysical sources have energies ranging from mildy suprathermal to over  $10^{20}$  eV. Some of these particles are known to be directly associated with jetted sources from, for example, gamma-ray and radio observations, while in the case of multimessenger signals any associations are less direct. In this talk I will discuss how particles can be accelerated to high energies in and around astrophysical jets, focusing mainly on shock acceleration, second-order Fermi and magnetic reconnection. In the process, I will explore how power-law spectra are produced, describe some relevant plasma physics, discuss progress in numerical simulations and derive various constraints on the maximum particle energy. Finally, I will offer some perspectives on the origins of ultrahigh energy cosmic rays.

James Matthews (University of Oxford, UK)

#### 1.7.2 Plasmoid reconnection as a mechanism for rapid radiation flares from relativistic jets

Relativistic jets are launched as highly magnetized collimated flows. High luminosities of non-thermal radiation observed in blazars and similar sources, and especially episodes of its rapid variation, require an efficient mechanism of energy dissipation and particle acceleration. Relativistic magnetic reconnection has been recognized as a leading explanation of these phenomena (Sironi et al. 2015, MNRAS, 450, 183). Large-scale magnetic reconnection produces ubiquitous stochastic substructures called plasmoids or magnetic flux ropes, which capture particles accelerated in reconnection X-points (Sironi et al. 2016, MNRAS, 462, 48). Because of high particle densities, plasmoids appear as the dominant sites of high-energy emission, and their statistical properties may be reflected in the observed blazar lightcurves (Petropoulou et al. 2016, MNRAS, 462, 3325; Christie et al. 2019, MNRAS, 482, 65). We will present the results of kinetic simulations of relativistic magnetic reconnection with open boundaries, investigating the effect of the synchrotron radiation reaction on the evolution of individual plasmoids, acceleration of particles, and the resulting synchrotron lightcurves. We will demonstrate that plasmoid collisions are particularly important for producing rapidly variable radiation signals.

Krzysztof Nalewajko (Nicolaus Copernicus Astronomical Center, Poland)

#### 1.7.3 The Feasibility of Magnetic Reconnection Powered Blazar Flares

Order of magnitude variability has been observed in the blazar sub-class of active galactic nuclei on minute timescales. These high-energy flares are often difficult to explain with shock acceleration models due to the small size of the emitting region, with recent particle-in-cell (PIC) simulations showing that magnetic reconnection is a promising alternative mechanism. Here, we present a macroscopic emission model physically motivated by PIC simulations, where the energy for particle acceleration originates from the reconnecting magnetic field. We track the radial growth and relative velocity of a reconnecting plasmoid, modelling particle acceleration and radiative losses from synchrotron and synchrotron self-Compton (SSC) emission. To test the viability of magnetic reconnection as the mechanism behind rapid blazar flares we simultaneously fit our model to the observed light curve and Spectral Energy Distribution (SED) from the 2016 TeV flare of BL Lacertae. We find generally that, without considering external photons, reconnecting plasmoids are unable to produce Compton-dominant TeV flares and so cannot reproduce the observations due to overproduction of synchrotron emission. Additionally, problematically large plasmoids, comparable in size to the entire jet radius, are required to emit sufficient SSC gamma-rays to be observable. However, our plasmoid model can reproduce the rapid TeV light curve of the flare, demonstrating that reconnection is able to produce rapid, powerful TeV flares on observed time-scales. We conclude that while reconnection can produce SSC flares on the correct time-scales, the primary source of TeV emission cannot be SSC and the size of plasmoids required may be implausibly large.

Paul Morris (University of Oxford, UK)

# 1.8 Very High-Energy, Cosmic Rays and Neutrinos

#### 1.8.1 High-energy neutrinos from AGN?

With the advent of multi-messenger observatories, neutrino astronomy is turning into a helpful tool to investigate and put limits on the contribution of the known astrophysical objects to the diffuse neutrino background. Active Galactic Nuclei (AGN) have long been suggested among the candidate sources of cosmic high-energy neutrinos. If hadronic processes operate in the AGN jets, a lot can be learnt by combining neutrino observations with the putative accompanying electromagnetic information. This is motivated by the fact that both radiations may be pictured in the same astrophysical particle-cascades scenario, cascades that are ultimately originated by cosmic rays. While to date no neutrino point sources have been identified at high confidence, a promising ground for discovery could be the search for transient and variable neutrino/electromagnetic sources, in which case the atmospheric neutrino and muon backgrounds can be reduced by taking advantage of time- and space-coincidence. Recent outcomes in this field will be presented.

Sara Buson (University of Wuerzburg, Germany)

#### 1.8.2 The First Radio Polarization Measurement of a Gamma-ray Burst Jet

We present ALMA 97.5 GHz total intensity and linear polarisation observations of the mm-band afterglow of the Fermi/LAT and MAGIC/TeV-detected gamma-ray burst (GRB) 190114C spanning from 2.2 to 5.2 hours after the burst. We detect linear polarisation at the  $5\sigma$  level, decreasing from  $\Pi = (0.87 \pm 0.13)\%$  to  $(0.60 \pm 0.19)\%$ , and evolving in polarisation position angle from (105) degrees to (4412) degrees during the course of the observations. This represents the first detection of polarised radio emission in a  $\gamma$ -ray burst. We show that the optical and X-ray observations between 0.03 days and 0.3 days are consistent with a fast cooling forward shock expanding into a wind environment. However, the optical observations at 0.03 days, as well as the radio and millimetre observations arise from a separate component, which we interpret as emission from the reverse-shocked ejecta. Using the measured linear polarisation, we constrain the coherence scale of tangled magnetic fields in the jet to an angular size of  $\theta \approx$  1e-3 rad, while the rotation of the polarisation angle rules out the presence of large scale, ordered axisymmetric magnetic fields, and in particular a large scale toroidal field, in the GRB jet. We conclude by highlighting the potential of multiwavelength observations and radio polarisation measurements of GRBs in the SKA era to elucidate the processes responsible for forming, collimating, and accelerating relativistic GRB jets.

Tanmoy Laskar (University of Bath, UK)

#### 1.8.3 TeV Gamma-rays from jets

Teraelectronvolt gamma-ray emission is now a well-established feature of astrophysical jets on a wide range of scales and in a wide range of different systems. The most dramatic and well-studied case is that of the TeV blazars, with variability down to minute timescales and with huge luminosities, but more recently interesting cases are emerging of steady TeV emission on large scales, including extended emission from the large-scale jets of Centaurus A and in the case of the microquasar SS 433. I will provide a brief overview of the observational status of jets at TeV energies and the advances in instrumentation expected in the near future.

Jim Hinton (MPI-Heidelberg, Germany)

#### 1.8.4 Highlights from the VERITAS AGN Observation Program

VERITAS is an array of four 12m imaging atmospheric Cherenkov telescopes for Very High Energy (VHE; E¿100 GeV) gamma-ray astronomy that has been in full scientific operation for more than a decade. The VERITAS Collaboration has an extensive AGN program and conducts discovery, long-term monitoring and target-of-opportunity AGN observations. To date, 39 AGN have been detected by VERITAS, 36 of which are classified as blazars with the remaining three being radio galaxies. Recent highlights include the detection of VHE emission from TXS 0506+056 following a neutrino detection by the IceCube collaboration, and the first detection of VHE emission from 3C 264, the most distant VHE radio galaxy detected to date. An overview of the VERITAS AGN program will be presented with recent results highlighted.

John Quinn (University College Dublin, Ireland)

#### 1.8.5 Lepto-hadronic Blazar Modelling

Blazars are a kind of AGN characterised by their high luminosity. Due to their relation to galaxy evolution, extragalactic cosmic rays and neutrinos they are objects of great importance in high energy astrophysics. With the recent coincident observation of a neutrino and a gamma-ray flare coming from blazar TXS0506+056, the relation of neutrinos and blazars is tighter; and the necessity of explaining neutrino emission puts lepto-hadronic models as the main component for explaining their emission.

Until now, even though lepto-hadronic models existed and were successfully employed in simulating blazar emission, leptonic models were preferred. This was due to two reasons: leptonic models where good enough and usually lepto-hadronic models relied on a total energy that exceeded the Edington Limit. Now, with the neutrino detection by Ice Cube, we know that high energy hadrons are a necessary part of blazar modelling and thus, lepto-hadronic models are the way to go.

Even having settled the presence of hadrons in simulations, a number of assumptions about the geometry and the injection of high energy particles remain.

We show how, employing two different geometries and particle behaviours, the data available can be fitted. On top of that, we add an MCMC procedure that traverses a rich parameter space showing how the goodness of the fitting behaves and how parameters are correlated.

Bruno Jiménez Fernandez (University of Bath, UK)

### **1.9** High Energy Processes: Observations

#### 1.9.1 The importance of resolved X-ray data for understanding extragalactic radio jets

X-ray studies have addressed important questions pertaining to extragalactic radio jets over the last 40, and particularly 20, years. At the highest jet powers, X-rays were previously used to argue for very high bulk Lorentz factors persisting to hundreds of kpc. Recent evidence challenges some model assumptions, supports the detection of inverse Compton emission in quasar jets at the highest redshifts, and leaves the origin of particle distributions producing Xrays in powerful low-redshift jets at question. Jets of more typical power, those dominating the radio-power injection in the Universe as a whole, are amenable to study at all orientations to the line of sight. They are used to address a number of questions, and we find that the work done in driving shocks can exceed that in evacuating cavities.

Diana Worrall (University of Bristol, UK)

#### 1.9.2 Proper Motions from Radio to X-rays: New Results and Future Prospects

'Relativistic Expansion' was first posited by Martin Rees in 1966 as a means of explaining the then-bizarre variability behaviour of certain quasars which we now know to have relativistic jets. In the intervening decades, hundreds of measurements of proper motions of extragalactic jets have been made, chiefly by VLBI. These observations, which generally probe the sub-parsec to tens of parsec scale near the black hole engine, very frequently reveal superluminal motions, indicating that the bulk Lorentz factors of these jets can reach up to  $\sim$ 50. While observations of proper motions in the jet on larger scales (kpc to Mpc) are more rare (and difficult to observe), a number of exciting observations have been made in recent years, from the well-known result of up to  $\sim$ 6c superluminal motion in M87 seen with both the VLA and HST, to the subtle movements of X-ray knots in the flow of Cen A seen by Chandra. In this talk I will review where we stand as a field and what we can learn from these observations. I will discuss the exciting near-term possibilities for proper motions with new and archival data from long-running observatories like the VLA (35+ years) and HST (25+ years) and I will explore the possibilities for the proper motions studies of the future with existing (upgraded VLBA) and successor missions like ngVLA, SKA, JWST, Lynx, and AXIS.

Eileen Meyer (University of Maryland, Baltimore County, USA)

### 1.10 Propagation: Theory and observations

#### 1.10.1 The remarkable survivability of AGN jets

Fluid flows are known to be subject to various instabilities which is the reason behind their complex dynamics. For example, high Reynolds number jets studied in laboratory readily develop turbulence via Kelvin-Helmholtz instability and mix with their surrounding on the scale up to a hundred jet radii. In contrast, many cosmic jets and the AGN jets in particular manage to survive for much longer. If laboratory jets had such survivability they would be able to extend all the way to the Moon. On the other hand, AGN jets still show signs of instabilities on kpc-scale. We briefly review the issue of jet stability focusing on the role of magnetic fields and rapid expansion in the absence of efficient external confinement. We also discuss the conditions for the jet reconfinement at kpc-scale and how it promotes the onset of strong instabilities. In particular, we will discuss the potential importance of the centrifugal instability associated with the reconfinement process itself.

Serguei Komissarov (University of Leeds, UK)

#### 1.10.2 Large-scale jets: observations

I will review the subject of large-scale emission from relativistic jets, largely from the point of view of radio observation and phenomenological modelling. Deep, high-resolution radio imaging (in total intensity and linear polarization), modelled with simple physical assumptions, can provide a wealth of information about the geometry, velocity field, emissivity and magnetic structure of the jets. I will contrast the properties of jets in Fanaroff-Riley (FR) I sources - which flare, entrain, and decelerate - with those in FR II sources, which remain fast and narrow. A recent study of a transition case - NGC 6251 - has revealed transverse velocity structure persisting to at least 140 kpc from the central black hole (as long suspected for FR II jets, but never proven).

Robert Laing (SKAO, UK)

#### 1.10.3 Revisiting the Fanaroff-Riley dichotomy with the LOFAR Two-Metre Sky Survey (LoTSS)

We use the LOFAR Two-metre Sky Survey (LoTSS) first data release to revisit the relationship between radio galaxy morphology and radio power originally established by Fanaroff and Riley. LoTSS is the deepest wide-area survey to date, with sensitivity to both compact and extended structures, and an exceptional (73 per cent) host identification rate, allowing us to study radio galaxy morphology for sources spanning over five orders of magnitude in luminosity. We find that radio luminosity alone is not a reliable proxy for whether a source will appear as edge-brightened or centre-brightened. The LoTSS extended source population shows high diversity, and a large degree of overlap between FRI and FRII in terms of radio luminosity. In particular, we find a population of sources with FRII morphologies and luminosities spanning over two orders of magnitude below the FRI/II break, many of which show signs of ongoing activity. Despite the large overlap between populations, we observe the relationship established by Ledlow and Owen where the FRI/II break depends on the optical host magnitude, which is a proxy for small-scale environment. Our results highlight the complexity of the low-luminosity, extended radio source population, and the key role of the jet power/environment dependence. Ours is also a cautionary tale about interpreting the results obtained when using automated techniques to classify radio survey data.

Beatriz Mingo (The Open University, UK)

#### 1.10.4 Unveiling the cause of hybrid morphology radio sources (HyMoRS)

While classical FR-I and FR-IIs comprise the majority of the radio galaxy population, a rare group of hybrid sources are also known to exist in which differing FR morphologies are observed in each of the two lobes. Despite potentially providing a wealth of information in to differing morphologies that are a result of just one central engine, studies of HYMORS have remained primarily limited to survey searches and investigations on VLBI scales. Where studies have used complementary arcsecond resolution data, they have tended to be archival, narrowband observations in a single array configuration, meaning the diffuse lobes are resolved out due to lack of uv coverage on short spacings. The morphology and spectrum of the diffuse emission of these sources therefore remains relatively unexplored.

In this talk we present results from a recent VLA study in to these unsual objects using modern, broad-bandwidth observations at arcsecond resolutions. Along with showing the large scale morphology of hybrid sources in significantly greater detail than previous studies, we reveal previously unknown structures and their spectrum on well-resolved scales. Using these results, we go on to establish the likely cause of hybrid morphology sources.

Jeremy Harwood (University of Hertfordshire, UK)

#### 1.10.5Jet propagation: energy dissipation and the FRI/FRII dichotomy

In my talk, I will describe the physical processes that may cause the morphological dichotomy in kiloparsec-scale jets, namely, growing instabilities and entrainment, also in relation with particle acceleration to very high energies, in terms of dissipation of magnetic or kinetic energy. On the one hand, supersonic, relativistic flows threaded by helical fields, as expected from the standard formation models of jets in supermassive black-holes, are subject to the development of a series of magnetohydrodynamical instabilities -which rises the natural question about the remarkable collimation and stability of some jets along hundreds of kiloparsecs. On the other hand, the interaction of the jet flows with stars and clouds of gas that penetrate the jets in their orbits around the galactic centers provides another deceleration and dissipation scenario. Within this frame, I will present results derived from time independent RMHD simulations, showing that mass-load from stellar winds can efficiently decelerate jets with typical FRI kinetic powers. I will finally discuss recent results on FRII long-term jet evolution from three-dimensional RHD simulations.

Manel Perucho (University of Valencia, Spain)

#### 1.10.6 The multi-band properties of FR0 radio galaxies

There is compelling observational evidence that an emerging group of compact radio galaxies, which lack of extended radio emission, dominate in number the radio-loud AGN population in the local Universe. We call these sources 'FR0' in opposition to the other Fanaroff-Riley classes to emphasize their lack of prominent extended radio emission. They are typically compact on a scale of i 5 kpc, within the host galaxy. Their host and nuclear properties are indistinguishable from the FRI radio galaxies, but more abundant and with smaller jets than classical FRIs. I will present high and low-resolution observations down to low radio frequencies (from EVN, eMERLIN, VLA, LOFAR and GMRT) to reconstruct the radio spectra and then the jet structure. Considering the whole properties of the FR0s, we discuss the jet properties, the possible origins of this class (short-lived radio sources or more exotic nature) and the possible cosmological scenarios they imply.

Ranieri Diego Baldi (University of Southampton, UK)

#### Numerical simulations of colliding jets in an external wind: Application to 3C 75 1.10.7

3C 75 is a complex radio source containing a pair of radio-loud active galaxies, each of which produces a two-sided jet. The jet beams on the west of the galaxies appear to collide and merge, producing a striking radio morphology. Motivated by 3C 75 we have conducted 3D hydrodynamic simulations of jet collisions. We simulate jets in a stratified atmosphere, and in the presence of an external wind to model the relative motion between the active galactic nuclei and intracluster medium. The simulations imply that direct contact between the jet beams on the west of the source is required to produce a morphology consistent with 3C 75. For a sample of different wind parameters (velocity and direction) we quantify the deceleration of the merging jets, the deflection of the jets and cocoons and show how the external wind impacts cocoon energetics. The unprecedented sensitivity and angular resolution of upcoming observatories will lead to the detection of many more complex sources at high redshift, where interacting jets are expected to be more numerous. The morphology of these complex sources can provide significant insight into the conditions in their environments.

Gibwa Musoke (Radboud University Nijmegen, Netherlands)

#### 1.10.8Jet-environment interaction as diagnostic of the central engine

Hotspots and radio lobes on scales of kpc to Mpc are prominent features of the jet environment interaction and contain a wealth of information. Using increasingly realistic models and observations of the environments, we can infer properties of the central engine. I will briefly review simulations, modelling and analysis and show that we can constrain mechanical power output and spin direction and stability of the driving supermassive black holes. Periodically varying spin directions point to close binary black holes in the most powerful sources. The Fanaroff-Riley morphological dichotomy may be primarily a consequence of a change of accretion disc structure. More powerful jets are likely injecting pair plasma at the jet base. If the Milky Way's Fermi bubbles have been produced by a powerful

jet episode of Sag A<sup>\*</sup>, one could explain the entire annihilation signal in the bulge region of the Galaxy by positrons mixed in from the gamma-ray bubbles. Detailed simulations could constrain this in the future.

Martin Krause (University of Hertfordshire, UK)

### 1.11 Microquasar Jets

#### 1.11.1 50 years of Microquasar Jets

It is around 40 years since the first radio jet was discovered in a radio-emitting X-ray binary star in our galaxy and 50 years since the first one was detected in the radio. The presence of collimated radio emission plus evidence for super-luminal motion led to the term 'microquasar'.by analogy with the more distant and much more powerful quasars. To date 84 galactic stellar mass X-ray binaries have been detected at radio wavelengths. They range from flat spectrum compact objects to sources with extended jets with moving components. All are variable, with radio outbursts and jet production associated with state transitions in the X-ray emission, with an energy source formed by accretion onto a stellar mass compact object. Stellar and accretion disk winds play an important part in the behaviour of these sources. I will discuss the objects in a historical context and also discuss some recent results.in particular a correlation of radio luminosity with orbital period. It is clear that the physical processes can be scaled to those around the much more massive black-holes in AGN.

Ralph Spencer (The University of Manchester, UK)

#### 1.11.2 Microquasar Jets

I will review the contributions that the discovery and research on microquasars have made for the understanding of relativistic jets in the universe. Furthermore, I will review the impact that research with SKA on microquasars may have on Cosmology and Gravitational waves Astrophysics

Felix Mirabel (IAFE-CONICET-UBA-Argentina)

#### **1.12** Feedback: Theory and Observations

#### 1.12.1 Feedback from relativistic jets in evolving galaxies

The discovery of the Magorrian and M-sigma relations has led to the convergence of two lines of research – the study of active galaxies and galaxy evolution. Silk and Rees proposed that these relations indicate a symbiosis between black hole and host galaxy formation in which black hole-driven outflows inhibit star formation. Our group is investigating relativistic jets as one agent of black hole interaction with the interstellar medium. A realistic log-normal distribution is adopted for the ISM and we have investigated both spherical and disk-like distributions of this gas. I will present several simulations showing that the jets process a large fraction of the ISM. For powerful jets in a spherical ISM a galactic fountain and ISM turbulence is produced both of which can contribute to quenching of star formation. For less powerful jets, the production of turbulence dominates. In the case of a disky ISM, the direct interaction of the jet with the disk leads to the ejection of clouds as well as buoyant radio bubbles on each side of the disk. The pressure of the jet-induced backflow disturbs the disk, tending to inhibit star formation. An incidental result in these investigations is that for a spherical ISM, the ionized gas surrounding the evolving radio lobes free-free absorbs the radio emission at low frequencies, leading to a natural explanation for Gigahertz Peak Spectrum and Compact Steep Spectrum radio sources. In this case the radio spectra inform us about the spectrum of density fluctuations in the ISM.

Geoffrey Bicknell (Australian National University, Australia)

#### 1.12.2 Is gas outflowing in a direction perpendicular to radio jets?

Optical integral field spectroscopy has opened a new window on the inner kiloparsec of galaxies. Our observations of the ionised gas have shown the existence of a puzzling and unexpected kinematical feature: a region of enhanced velocity dispersion in a plane approximately perpendicular to radio jets and radio extensions, seemingly the plane of the AGN torus. The spatial extent of the velocity dispersion enahncement is often sharply defined, and observed to extend over about 100 - 200 pc either side from the nucleus. Within this region, emission lines display complex profiles, suggesting the coexistence of multiple kinematical components. When feasible, detailed studies suggest the presence of ionised gas in rotation and/or outflow in a plane perpendicular to the axis of the radio jet. In this talk we will present an overview of our results and possible interpretations.

Davide Lena (SRON & Radboud University, Netherlands)

#### 1.12.3 A systematic multi-phase study of galactic feedback by jets in quasars

It is now well established that rapidly growing supermassive black holes are able to drive outflows into the interstellar medium of their host galaxies. However, to have a full picture of the impact that these outflows can have on star formation requires detailed studies at multiple gas-phases. Our Quasar Feedback Survey, aims to achieve this with sub-kpc scale mapping of the optical, sub-mm and radio emission in a sample of  $40 \ge 0.1$  powerful quasars. In this presentation I will provide the latest results of Type 2 quasars, the majority of which show low power (log L[1.4GHz]=23.3-24.4 W/Hz) radio jets and explore the impact of these jets over kpc scales on the warm ionised gas (MUSE; GMOS and VIMOS); molecular gas (ALMA) and, in a few cases, the hot gas as traced by Chandra observations. These results suggest that jets may be an important galaxy wide feedback mechanism even in 'quasar mode' AGN.

Miranda Jarvis (ESO, Germany)

#### 1.12.4 Varieties of interactions between radio galaxies and the intergalactic medium

High signal/noise radio mapping and high angular resolution X-ray images can be combined to study the varieties of interaction displayed by radio outflows from active galaxies. This talk will show some examples from recent mapping campaigns that appear to show jet-induced star formation and jet loops on kpc scales, magnetic filaments on Mpc scales, and other notable structures in low-redshift radio galaxies.

Mark Birkinshaw (University of Bristol, UK)

#### 1.12.5 Radio jets as driving mechanism of gas outflows

Radio jets have been long known to affect the surrounding gas in various ways. The energy that they release can couple well with the ISM and can prevent the gas from cooling, can produce fast gaseous outflows and/or can increase the turbulence of the gas, possibly preventing starformation. In this talk I will focus on what we have learned about the impact of jets by studying the kinematics and physical conditions of the gas on galaxy-scale and down to the inner kpc of the host galaxy. I will present recent results showing examples of radio jets covering a broad range of radio power and medium in which they are embedded. I will illustrate how we have traced these effects by study the kinematics of the warm ionised gas as well as the colder component of the gas (HI and molecular) with high spatial resolution observations. In this way we have derived the physical conditions of the gas (density, mass, mass outflow rate in the case of outflows, kinetic energy etc.). One interesting finding is that even low power radio jets can percolate through this medium and drive shocks into the ISM at distances much larger than their physical extent.

Raffaella Morganti (ASTRON, Netherlands)

#### 1.12.6 The impact of relativistic jets on the ISM of the host galaxies during the breakout phase

The feedback effect of the relativistic jets on the hot, X-ray emitting gas in the haloes of their host galaxies and clusters is well-known, but the jets also have an effect on the cooler phases of the ISM, potentially directly influencing the star formation histories of the host galaxy bulges via jet-cloud interactions. However, in the past it has been difficult to quantify the energetic significance of such jet-cloud interactions because of substantial uncertainties about physical properties (densities, radial scales etc.) of the emission-line regions. Here I present the results of deep VLT/Xshooter and HST observations of the warm gas in a sample of CSS/GPS radio sources, which represent objects in which the jets are breaking out of the dense inner regions of the host galaxies. The data allow the properties of the emission line gas in such objects to be accurately quantified for the first time, and reveal that the jet-induced outflows have sufficient mass and kinetic power to do substantial damage to the host ISM in the near-nuclear regions. These relatively high spectral resolution data also reveal the presence of sub-kpc gas disks in some objects that may be responsible for fuelling the nuclear activity.

Clive Tadhunter (University of Sheffield, UK)

#### 1.12.7 Jet-driven bubbles in Fanaroff–Riley type I source

Observations of several Fanaroff-Riley (FR) type I sources reveal outflowing bipolar bubbles of hot gas surrounded by a weak forward shock. We consider the possibility that these bubbles were driven by choked relativistic jets which failed to penetrate the ambient intracluster medium (ICM). Using new results on choked jets linking the geometry of the forward shock to the jet properties, we infer robust limits on the radius Rch at which the jet was quenched in 5 well-studied FRI sources, finding typically Rch10 kpc. We further show that, in order to reach this radius in less than the current age of the system, the jet must have been tightly collimated, with the jet head subtending an angle of  $\theta h < 2^{\circ}$ . The ambient pressure is not high enough to explain this collimation, suggesting that the jet was collimated by interaction with its own cocoon. Although the choking radius is well-constrained, we find a degeneracy between the initial jet opening angle before collimation,  $\theta_0$ , and the duration of jet activity, tb, with  $(tb/1Myr)(\theta_0/5^\circ)2 \sim 0.1$ . We speculate that the working time and/or opening angle of the jet may be important factors contributing to the FR type I/type II morphology in galaxy clusters, with short-lived or wide jets being choked to form bipolar bubbles filled with diffuse radio emission, and longer-lived or narrow jets successfully escaping the cluster core to produce cocoons with radio hotspots.

Christopher Irwin (Tel Aviv University, Israel)

### 1.13 Lifecycle: Observations

#### 1.13.1 Radio source lifecycles from the LoTSS survey

The LOFAR survey LoTSS provides us for the first time with the capability to generate large, relatively unbiased samples of local radio-loud AGN. These allow us to investigate the time evolution and dynamics of active sources as well as the properties of special classes of objects like remnant or restarting sources. At high radio luminosities, the distributions of sizes and radio powers of observed sources are in agreement with models with a simple distribution of source lifetimes, but at low radio luminosities this model breaks down. I will discuss our current understanding of these issues and some future projects.

Martin Hardcastle (Unversity of Hertfordshire, UK)

#### 1.13.2 Energetics and duty cycles of radio galaxies: insights from models

Recent deep, wide-area radio surveys complemented by optical/IR counterparts are providing an unprecedented census of radio jets, their host galaxies and large-scale environment. In principle, these observations encode a multitude of information relating to the physics of jet triggering, their energetics, evolution, and feedback. In this talk, I will describe models which can be used to understand the jet-environment interaction. I will introduce analytical radio source models, and give recent examples of their successful application to survey data. Numerical simulations of jet propagation are highly complementary to this analytical approach. In both sets of models, the observable radio sources properties are strongly environment-dependent. I will discuss the prospects of quantifying radio source environments through galaxy clustering observations, and test this idea using data from the citizen science project Radio Galaxy Zoo.

Stas Shabala (University of Tasmania, Australia)

#### 1.13.3 Probing radio restarting activity and duty cycle in high-energy selected giant radio galaxies

Cross-correlating the INTEGRAL/IBIS and Swift/BAT AGN population with radio catalogs (NVSS, FIRST, SUMSS), we found that 25% of extended radio sources are Giant Radio Galaxes (GRG), i.e. the largest individual objects in the Universe. This fraction is four time more abundant than what found in previous studies. In 2014, we observed a pilot sample of these soft-gamma ray selected GRG at low radio frequencies with the GMRT, with the aim of studying the morphological and spectral properties of these objects. Thanks to these data, we discovered the second known X-shaped GRG, and a previously unidentified radio galaxy. Another object, observed both at kpc and pc scales, showed an extreme jet re-orientation of about 90 degrees. Given these intriguing premises, we embarked on a radio and X-ray follow-up to probe the lifecycle of these soft gamma-ray selected GRG. We found that more than half of these GRG have a nucleus with typical properties of young radio sources, while the remaining ones show a restarting radio morphology from low-frequency radio surveys or literature data. Among these, four are candidate hosts of a supermassive binary black hole system, and another two could host up to three distinct radio phases, underlying how the high-energy selection can pick up object with peculiar accretion and jet launching properties.

Gabriele Bruni (INAF, Italy)

# 1.13.4 The LOFAR Two-Metre Sky Survey view of radio-AGN in the local Universe: The most massive galaxies are always switched on.

I will present a study of the local radio source population, focused on jet-powered sources. The first data release of the LOFAR Two-Metre Sky Survey (LoTSS) provides deep data (median rms noise of 71 Jy at 150 MHz) over 424 square degrees of sky. These data were cross-correlated with the Sloan Digital Sky Survey (SDSS) DR7 main galaxy sample and 10615 (32 %) galaxies were detected. An improved method to accurately separate Active Galactic Nuclei (AGN) from star formation-powered sources was developed and applied, leading to a sample of 2121 local radio AGN. The prevalence of radio AGN activity is confirmed to show a strong dependence on both stellar and black

hole masses, remarkably reaching a fraction of 100 per cent of the most massive galaxies  $(\iota 10^{11} M_{\odot})$  displaying radio AGN activity with L150 MHz  $10^{21}$ W Hz<sup>1</sup>; thus, the most massive galaxies are always switched on at some level. The full Eddington-scaled accretion rate distribution (a proxy for the duty cycle) was probed for massive galaxies, and it is found that more than 50 per cent of the energy is released during the  $\approx 2$  per cent of the time spent at the highest accretion rates. Stellar mass is a more important driver of radio-AGN activity than black hole mass, suggesting a possible connection between the fuelling gas and the surrounding halo, in line with models in which these radio AGN are essential for maintaining the quenched state of galaxies at the centres of hot gas halos.

Jose Sabater Montes (IfA, University of Edinburgh, UK)

#### 1.13.5 Numerical modelling of Mpc scale jets - Dynamics and Energetics

Powerful jets with relativistic speeds launched typically in direction perpendicular to the accretion disk are characteristic features of active galactic nuclei. Recent radio surveys (e.g. NVSS, LoTSS) have led to discovery of rare population of number of extremely large radio galaxies and quasars whose relativistic jets reach upto physical distances of 1 Mpc or more. The primary challenge is to understand the nature of central AGN capable of launching jets of such immense physical scales. Additionally, it is also crucial to decipher the role of environment in shaping the jets and how such large scale jets impact the surrounding environment. To compliment the multi-wavelength observations of these relatively rare galaxies, a parameter study using numerical simulations is essential. Three dimensional magneto-hydrodynamic simulations using adaptive mesh refinement are performed with an aim to understand the dynamical properties of very large scale jets. A parameter study of propagation of such jets in realistic cluster environments will be presented. In particular, we will discuss the range of ambient cluster and jet parameters that sustains a stable jet up to Mpc scales. In addition, we will highlight the evolution of various energies along with the distance and time within the cluster for a thorough understanding of feedback processes due to such large scale jets.

Joydeep Bagchi (IUCAA, India)

#### 1.13.6 Jet production efficiency in the youngest radio galaxies

Here we discuss the sample of the confirmed young radio galaxies with measured kinematic ages, black hole masses, and accretion rates. We investigate the distribution of our sample in the three-dimensional space of the Eddington ratio, the nuclear X-ray luminosity considered as a proxy for the emission of the accretion disk coronae, and the jet total kinetic power. We find that (i) the Eddington ratio is distributed within a narrow range from  $\sim 1\%$  up to  $\sim 20\%$ ; (ii) the jet power normalized to the accretion luminosity correlates with the accretion rate; (iii) the jet production efficiency is below the level expected for magnetically arrested disks around maximally spinning black holes; and (iv) there is an interesting diversification in the normalized jet power on the accretion disk hardness-intensity diagram, with the jets being produced the most efficiently during the high/hard states, and suppressed during the soft states. The latter finding could be analogous to the dependance that was established for Galactic X-ray binaries.

Anna Wójtowicz (Jagiellonian University, Poland)

#### 1.13.7 Giant radio galaxies as ideal laboratories to study megaparsec jets

Radio galaxies exhibit magnificent bipolar jets emanating out from the AGN and extending from sub-kpc scales to over hundreds of kpc. A relatively rare subclass of radio galaxies extending beyond about 0.7 Mpc are called the giant radio galaxies (GRGs). Their projected linear sizes extend to about 5 Mpc, which places them among the largest single astrophysical objects known. Unlike the thousands of radio galaxies catalogued in the past six decades, only about 600 GRGs are known till date. The cause of their large size, rarity and the course of their growth and evolution are currently widely debated. It is unclear if the large sizes of GRGs indicate the high efficiency of radio jets ejected from the central AGN, or they grow to enormous sizes due to their location in sparser environments, or a combination of both. GRGs are good probes of the IGM, interacting with the CMBR and transporting enriched material and magnetic fields from the host galaxy to vast distances via their jets. In this paper, we review earlier work carried out on GRGs, and then present our new work using the LoTSS and NVSS, from where we have found 250 and 100 new GRGs respectively. Using these samples, we have explored and quantified host AGN properties of GRGs. Many of these GRGs exhibit hundreds of kiloparsec long jets propagating in a variety of environments. With the help of these larger samples of GRGs and multiband data, we explore the physics of these large-scale jets of GRGs

Pratik Dabhade (IUCAA, India)

# 2 Poster Contributions

#### 2.1 Giant radio galaxies - high and low excitation galaxies

In our analysis we investigate the fraction of high and low excitation galaxies in a sample of giant radio galaxies (with LLS;0.7 Mpc). It is supposed that different accretion mechanisms are responsible for high and low-excitation galaxy division. Our sample consist of 59 giant radio galaxies in a redshift range of 0.07<sub>i</sub>z<sub>i</sub>0.76, with available spectra in the SDSS survey. We performed spectral analysis for galaxies from our sample and obtained that the large fraction of them (54%) are high-excitation radio galaxies. We compared our result with a control sample of smaller-sized Fanarof–Riley type II radio galaxies where only 16% are HERGs. We also show that high-excitation galaxies from our sample have on average lower stellar ages than low-excitation ones. The more frequent occurrence of strong emission lines in giant's host galaxies can be the evidence, that generation of large-scale radio jets require large amount of cold gas which is accreted with high efficiency.

Agnieszka Kuzmicz (CTP PAS, Poland)

# 2.2 Relation between parsec-scale structure and broad-band radio spectra of extragalactic radio sources from an unbiased sample

Theoretical models of AGN predict a relation between the source structure and its radio continuum spectrum. We present the joint analysis of the VLBA observations at 2 and 8 GHz and RATAN-600 simultaneous 1-22 GHz broadband spectra of a complete sample of extragalactic radio sources with NVSS flux density greater than 200 mJy at 1.4 GHz and declination above +75 degrees. From the VLBA data we obtained the statistics of detections as well as the correlated flux density, angular size and brightness temperature of the dominating component, spectral index, and morphology for detected sources. These parameters were compared with characteristics of the total RATAN-600 spectra: flux density, spectral index and variability. We confirm the presence of bright relativistic jets for almost 100% of the flat spectrum sources. We determined the fraction of sources with parsec-scale features among steep spectrum sources in the complete flux-limited sample: 25% at 2 GHz and 14% at 8 GHz (for the sample selection frequency of 1.4 GHz). On the average, these compact steep spectrum (CSS) radio sources have larger angular size and lower brightness temperature than flat spectrum ones. This indicates that in CSS sources the compact opaque radio core is absent or obscured by dusty torus, and the jets are directed at larger angles to the line of sight.

Aleksandr Popkov (MIPT, Russia)

### 2.3 Blazar variability from decades to minutes timescales

The power-law form of variability power spectral densities, P(k) = A k, where k is the temporal frequency, A is the normalization and is the slope, indicate that the variability is generated by underlying stochastic processes which is of colored noise type (13). In this talk, I will present the results of our PSD analysis using both Fourier-domain and time-domain approaches on multiwavelength data sets (radio to TeV energies) covering a few decades to minutes timescales. The novelty is that at optical frequency, by combining long-term (historical optical light curves) and densely sampled intra-night light curves, the PSD characteristics are investigated for temporal frequencies ranging over 7 orders of magnitude. Our findings are: (1) nature of processes generating flux variability at synchrotron frequencies is different from those at Inverse Compton frequencies ( $\beta$ 2and 1, respectively); this could imply, that ray variability, unlike the synchrotron (radio-to-optical) one, is generated by the superposition of two stochastic processes with different relaxation timescales, (2) the main driver behind the optical variability is same on decades, years, months, days, and hours timescales ( $\beta \sim 2$ ), which argues against the scenario where different drivers behind the long-term flux changes and intra-night flux changes are considered, such as internal shocks due to the jet bulk velocity fluctuation (long-term flux changes) versus small-scale magnetic reconnection events taking place at the jet base (intra-night flux changes). Implications of these results are discussed in the context of commonly employed blazar emission models.

Arti Goyal (Astronomical Observatory of the Jagiellonian University)

# 2.4 GMRT unveils the longest uninterrupted ~600 Kpc jet of a Giant radio galaxy

The physics of the launching and propagation of relativistic jets in AGNs is a major area of research in radio astrophysics. While the mass of the black hole, it's spin and the rate of accretion of matter into the black hole are known to influence the formation of jets, the jet power, the environment and the age are the factors which decide how far the jet propagates. Here we present our interesting findings based on GMRT observations of GRG 2MASXJ10212421+1217060 (redshift z = 0.129), which reveal a very peculiar morphology. The giant source has

a total linear size of 2.2Mpc and shows an uninterrupted radio jet of length  $\sim$ 600kpc, making it the longest jet known so far. Uninterrupted jets of these scales are very rare and provide an ideal laboratory to study jet-medium interaction on longer length scales. The radio morphology shows clear signatures of episodic activity, and it appears that the jet from the second episode of activity is traversing through the diffused relics from the previous epoch. The influence of the age of the source, episodic activity, nature of the host galaxy, the jet power and the environment in the formation of this jet will be presented.

BIJU KG (WMO Arts and Science College)

## 2.5 Observing Magnetic Fields in Protostellar Jets

It is well established that magnetic fields are a fundamental ingredient in the formation, collimation and propagation of all astrophysical jets. Magnetic fields in relativistic jets are relatively easy to study through observations of the linearly polarized synchrotron emission. In order to understand the jet phenomenon, we would need to also study magnetic fields in protostellar jets, since these are probably the less energetic manifestation of jets. However, this has resulted extremely difficult, mainly because emission from protostellar jets is dominated by thermal emission which does not contain information about magnetic fields. In recent years, through very sensitive radio observations, we have learned that synchrotron emission is also present in some protostellar jets. This opens the possibility of studying magnetic fields in protostellar jets in a similar way than it has been extensively done in relativistic jets. However, it is not easy yet. Synchrotron emission from protostellar jets have revealed extremely weak, and even with the (expanded) Very Large Array, the detection of linearly polarized emission is possible in protostellar jets, and we have been able to study the conditions under which synchrotron emission is possible in protostellar jets, and we have performed some long observations of individual objects to detect polarization. Fortunately, all this previous experience will be very useful in the next years when new, more powerful instrumentation at radio will become available.

Carlos Carrasco-Gonzalez (Instituto de Radioastronomia y Astrofísica (IRyA-UNAM))

# 2.6 AGN jet-disk system revealed by the VLBI-to-Gaia position offsets and optical polarimetric data

An analysis of the disk-jet system on parsec and sub-parsec scales is important for our understanding of processes in nuclei of active galaxies. A new approach was suggested recently by utilizing VLBI-to-Gaia offsets taken together with optical color information (Plavin et al., 2019, ApJ, 871, 143). Using the Radio Fundamental Catalogue and Gaia Data Release 2, offsets for about 900 AGN turned out to be significant, the majority of them occur downstream or upstream the VLBI jet. It has been shown that the downstream offsets are due to strong parsec-scale optical jets shifting the Gaia centroid further away from the jet apex. Upstream VLBI-Gaia offsets occur when the accretion disk makes a major contribution to the optical emission while synchrotron opacity shifts radio away from the nucleus. In order to check this interpretation we have introduced optical linear polarimetric data into the analysis. We have found out that AGN with VLBI-Gaia offsets downstream the jet have a significantly higher fractional linear polarization than the upstream ones. It is indeed expected within the proposed scenario since optical synchrotron emission of jets is significantly more polarized than the thermal emission of the disk. We also note that many AGN with significant offsets show the optical polarization direction being aligned with the jet which supports models with a toroidal magnetic field.

Daria Zobnina (P. N. Lebedev Physical Institute of the Russian Academy of Sciences)

### 2.7 Determining the spatio-kinematic structures of jets in post-AGB binaries

Astrophysical jets are frequently observed phenomena in the Universe, ranging from high-energy jets in active galactic nuclei to low-energy stellar jets. In our recent studies, we have detected jets from a large fraction of binary post-AGB systems. The rich time-resolved optical spectroscopic data available for each of these post-AGB binaries with jets allows us to study the tomography of these jets. In Bollen et al., 2019, we have successfully developed a robust jet modelling code in order to determine the full spatio-kinematic structure of post-AGB binary jets. Jets from post-AGB binaries are diverse since these systems differ in terms of their orbital parameters and systems sizes. Therefore, in our on-going work, we apply our jet modelling code to the diverse sample of 15 jet-creating post-AGB binaries. Additionally, we also determine the mass accretion rates and jet outflow momenta, which give an insight into the changing conditions in the inflow and outflow that directly affect the launching of these jets and their environment. In this talk, I will present the results of our work which shed light on the nature of post-AGB binary jets, their launching mechanism, and their connection to jets from other astrophysical sources.

Dylan Bollen (Macquarie University)

# 2.8 Gamma-Ray Burst jet dynamics on a moving mesh and the origin of afterglow flares

Flares in gamma-ray burst (GRB) afterglow light curves provide an important clue to the jet-launching mechanism of GRBs and the nature of the remnant. The origin of these flares is still under debate and often attributed to late-time activity of the central engine. However, an alternative scenario solely based on jet dynamics was recently proposed. The scheme involves the passage of a long-lived reverse shock through a stratified ejecta, and thus avoids the need to invoke a long-lived neutron star remnant or late-time fallback accretion onto a black hole. In our work, we generalise this model to physically realistic conditions for long-duration GRBs and demonstrate the feasibility of this approach by running one-dimensional simulations using our novel moving-mesh relativistic hydrodynamics code. The enhanced efficiency of our numerical scheme relative to previous work allows us to explore a wider range of setups while introducing a more realistic treatment of the circumburst medium mass density. This, combined with an improved radiative prescription eventually enables the study of the dependencies between input parameters of the jet and flare properties, in particular the range of arrival times that can be obtained for the flares in this model.

Eliot Ayache (University of Bath)

# 2.9 VLBA observations of relativistic outflows from BL Lac objects at 6-22cm wavelengths

Data obtained with the Very Long Baseline Array (VLBA) at wavelengths of 6 13, 18 and 22cm are used to investigate the relativistic jets of a number of radio-bright BL Lac objects on scales of tens to hundreds of parsecs from the base of the jet. Theoretical models suggest that these jets should carry, and possibly be collimated by, helical magnetic (B) fields. The systematically changing line-of-sight B field across a jet carrying a helical B field should give rise to a Faraday rotation measure (RM) gradient across the jet, and we find evidence for such transverse RM gradients across several of the jets studied. The distributions of the fractional polarization and spectral index are also considered, and the results compared with earlier 18-22 cm VLBA observations obtained in 2004 and 2010.

Frederick Richardson (University College Cork)

#### 2.10 FERMI transient J1544-0649: a flaring radio-weak BL Lac

On May 15th, 2017, the FERMI/LAT  $\gamma$ -ray telescope observed a transient source not present in any previous high-energy catalogue: J1544-0649. It was visible for two consecutive weeks, with a flux peak on May 21st. Subsequently observed by a Swift/XRT follow-up starting on May 26, the X-ray counterpart position was coincident with the optical transient ASASSN- 17gs = AT2017egv, detected on May 25, with a potential host galaxy at z=0.171. We conducted a 4-months follow-up in radio (Effelsberg-100m) and optical (San Pedro Martir, 2.1m) bands, in order to build the overall Spectral Energy Distribution (SED) of this object. The radio data from 5 to 15 GHz confirmed the flat spectrum of the source, favoring a line of sight close to jet axis, not showing significant variability in the explored post-burst time-window. The Rx ratio, common indicator of radio loudness, gives a value at the border between the radio-loud and radio-quiet AGN populations. The CaII H&K break value  $(0.29\pm0.05)$ iscompatiblewiththerangeexpected for the long-sought intermediate population between BLLacs and FRI radiogalaxie ray band shows properties typical of a low-power BL Lac. As a whole, these results suggest that this transient could well be a new example of the recently discovered class of radio-weak BL Lac, showing for the first time a flare in the  $\gamma$ /X-ray bands.

Gabriele Bruni (INAF - Institute for Astrophysics and Planetology from Space)

### 2.11 GRB Afterglow jet analysis In The Multi-Messenger Era

Gamma-ray bursts (GRBs) associated with gravitational wave events are, and will likely continue to be, viewed at a larger inclination than their fellow GRBs without gravitational wave detections. As demonstrated by the afterglow of GW170817A, this requires an extension of the common GRB afterglow models which typically assume emission from an on-axis top hat jet. I present an updated characterization of the afterglows arising from neutron star merger jets, utilizing both trans-relativistic numerical calculations and simple analytic approximations of structured outflows. These will serve as a toolkit for both detailed and rapid qualitative modeling and interpretation of afterglows in the multi-messenger era. For example, in many cases, the afterglow temporal slope can be immediately connected to a ratio between the inclination angle and effective half opening angle of the jet. Our models, both numerical and analytic,

will be made publicly available as an open source Python package and are readily implemented in statistical analysis packages and population studies (Ryan & van Eerten, manuscript in prep; github.com/geoffryan/afterglowpy). This work extends the jet model that has been used to model GW170817A in a series of papers including our Chandra X-ray afterglow discovery paper (Troja+ 2017).

Hendrik van Eerten (University of Bath)

# 2.12 The X-ray Polarization Probe Concept Study

The X-ray Polarization Probe (XPP) is designed to be a follow-on to the Imaging X-ray Polarimetry Explorer (IXPE), deepening and broadening the field of X-ray polarimetry. IXPE is scheduled for launch in 2021 and will be the first instrument to measure the X-ray polarizations of dozens of sources of many types, such as Galactic X-ray binaries, supernova remnants (SNRs), magnetars, and active galactic nuclei (AGN). The IXPE instrument is sensitive in the 2-8 keV band with an imaging resolution of about 25", sufficient to resolve shock fronts of SNRs and separately measure pulsars and their wind nebulae. XPP would broaden the bandpass by including a polarimeter sensitive down to 0.1 keV as well as one for measuring polarization up to 60 keV. XPP would be more 3-10 times more sensitive than IXPE (in the 2-8 keV band) with larger focussing mirrors. In addition, the imaging resolution would be improved to 5-10", enabling more resolution of SNRs and resolving AGN jets. Other science goals of XPP will be presented, including measuring the spins of Galactic stellar-mass black holes, testing models of the geometry of AGN coronae, observing the polarization in the cyclotron resonant scattering features in Galactic accreting pulsars, and searching for axion-like particles.

Marshall Herman (Massachusetts Institute of Technology)

# 2.13 Relevance of jet magnetic field structure for indirect searches for axion-like particles with blazars

Many theories beyond the standard model of particle physics predict the existence of axion-like particles (ALPs) that mix with photons in the presence of a magnetic field. One prominent indirect method of searching for ALPs is looking for irregularities in blazar gamma-ray spectra caused by ALP-photon mixing in astrophysical magnetic fields. This requires the modelling of magnetic fields between Earth and the blazar and so far only very simple jet magnetic field models have been used. Theory, simulations and VLBI observations allow for more complicated models of the magnetic field structure in jets. Here we investigate the effects of jet magnetic field configuration on these spectral irregularities. SEDs of MRK501 with ALPs are simulated and fitted to no-ALP spectra, and the ALP and B-field configuration parameter space is scanned. We find that there is a region of unconstrained ALP parameter space around m 1-1000neV and g i 5e-12 GeV-1 for which mixing in the jet is important compared to other mixing regions and the magnetic field configuration at the base of the jet can have a large effect on the fits and so on potential ALP parameter constraints. This also means that in the event of an ALP discovery ALPs could be used as probes for this region of the jet.

James Davies (University of Oxford)

### 2.14 Radio bimodality of Swift/BAT AGNs and SDSS quasars

Comparison of properties of quasars with those of low redshift AGNs with similar BH masses but accreting at much lower accretion rates provides exceptional opportunity to study the dependence of the properties of these massive accretion systems on the specific accretion rate. This particularly concerns abilities of such systems to produce powerful jets. We present here results of comparison of radio-loudness distributions and discuss them in the context of investigated in literature scenarios proposed to explain the radio-dichotomy of AGN. Our preliminary results indicate that: (1) there is an explicit bimodality in the radio-loudness distributions in both populations; (2) the radio-loud fraction of AGNs accreting at moderate rates is larger than of quasars. These differences are consistent with predictions of the MAD (magnetically-arrested-disk) scenario for the production of strong jets and favor the model according to which central accumulation of magnetic flux proceeds prior to the AGN/quasar event.

Katarzyna Rusinek (Nicolas Copernicus Astronomical Center, Poland)

# 2.15 Orientation of the crescent image of M87\*

The first resolved image of black hole M87<sup>\*</sup> obtained by the Event Horizon Telescope has a form of a crescent oriented roughly along the southern side of the black hole shadow. However, the orientation of the crescent is not entirely consistent with the projected direction of the relativistic jet. In particular, emission from the SEE 'hotspot',

corresponding to the direction of the counterjet, is difficult to account for in the results of GRMHD simulations. We explore a range of simple geometric and kinematic models for the distribution of emission around M87<sup>\*</sup>, and we ray-trace the corresponding images. We suggest that significant departure from axial symmetry may be required to explain the SEE hotspot.

Krzysztof Nalewajko (Nicolaus Copernicus Astronomical Center)

# 2.16 Multiwavelength Analysis of the TeV-Gamma-Ray Emitting Radio Galaxy NGC 1275 (3C 84)

The radio galaxy 3C 84 is a well-studied source of radio emission and was detected as misaligned blazar NGC 1275 also in the TeV regime by gamma-ray detectors like MAGIC and Fermi-LAT. Radio images show multiple and variable emission regions within the core of the galaxy moving away from the innermost core component. In the gamma-ray regime, the source is known to be variable in flux and experienced some flaring activity in 2017. The Radio flux shows a slight but constant increase in radio emission until mid 2016. Since the origin of the gamma-ray emission is still unclear, multiwavelength studies are performed to explain the behavior of the source. In detail, we study the spectral indices of the radio emission, optical depth of the broad line region and temporal correlation of flux variability at different wavelengths. Our poster presents a multiwavelength analysis using data taken by MAGIC, Fermi, SMA, VLBA and optical telescopes from 2005 until 2019.

Lena Linhoff (TU Dortmund)

# 2.17 A detailed study of X-ray cavities in the environment of the cool core cluster Abell 3017

We present an in-depth analysis of a cool-core galaxy cluster Abell 3017 (z=0.219), which has been identified to be merging with its companion cluster Abell 3016. This study has made use of the Chandra X-ray and ESO VLT optical and infrared (IR) archival data of this cluster. Using various image processing techniques like, 2-d beta modeling, unsharp masking, contour binning and surface brightness profiling, we detect a pair of X-ray cavities (denoted as Ecavity and Wcavity) at a projected distance of 20 arcsec (70 kpc) and 16 arcsec (57 kpc), respectively from the core of Abell 3017. We also detect an excess X-ray emission towards the south which is at 25 arcsec (88 kpc) from the centre and relatively hotter than that of the surroundings, indicating that an in-falling galaxy group may be responsible for the hike in temperature at this region. We find that the radio lobes are responsible for carving the observed X-ray cavities detected in this system. The lower values of mid-IR WISE colour [W1-W2] and [W2-W3] imply that the central BCG of Abell 3017 is a star forming galaxy. The current star formation rate of central BCG estimated from the H and GALAX FUV luminosities are equal to be  $5.06 \pm 0.78 \text{ M}_{odot}\text{yr}^1$  and  $9.20 \pm 0.81 \text{ M}_{\odot}\text{yr}^1$ , respectively.

Mahadev Pandge

# 2.18 Radio Galaxies: The Great Gamma-Ray Hunt

Radio galaxies are relatively rare gamma-ray sources, but they can offer insights into jet physics. We use the Bologna Complete Sample of radio galaxies to search for new gamma-ray radio galaxies in the 10-year Fermi-LAT dataset. The galaxies selected are sorted by morphology, and regions of interest around the target galaxies are analyzed. Of the 79 galaxies, 5 are already present in the 4th Fermi (4FGL) catalogue, and we find point sources spatially coincident with a further 4 radio galaxies. A probability distribution is calculated to compute the look-elsewhere effect in this dataset, and we conclude that these are likely to be chance correlations. Upper limits on flux are calculated for the galaxies where no gamma-ray source is observed, and future work considered.

Max Harvey (Durham University)

# 2.19 The VLBI observations of jets in various AGN systems

The VLBI observations of relativistic jets in various AGN system are helpful in understanding the jet formation and the relationship between jets and accretion process. In this talk, we will present our VLBI observational results for the selected samples of radio galaxies and Narrow-line Seyfert 1 galaxies (NLS1s), covering a broad range of accretion rate. With bolometric luminosity manifested with Mid-IR emission in radio galaxies, we find that there is no single correspondence between the FR morphology and accretion mode and the higher accretion rate are likely able to produce more powerful jets. Moreover, we found that the relativistic jets may present in NLS1s with small black hole mass and high accretion rate. However, the jet speed in these sources is likely low, which is due to either the jet acceleration by the magnetic field and radiation force, or low spin in BZ mechanism. Finally, the case study of multi-band VLBA polarimetric observations on the GPS source, OQ 172, shows the jet bending, significant RM variations, Faraday depolarization, spectral turnover and broad line width of [O III]5007 could be closely related, likely caused by the same nucleus medium, presumably NLR.

Minfeng Gu

# 2.20 Catalogue with visual morphological classification of 32,616 radio galaxies with optical hosts

We present the catalogue of RadiO sources with Galactic counterparts and Unresolved or Extended morphologies I (ROGUE I), which is the largest handmade catalogue of visually classified radio objects and optical galaxies. It was created by cross-matching galaxies from the Sloan Digital Sky Survey Data Release 7 as well as radio sources from the First Images of Radio Sky at Twenty Centimetre and the National Radio Astronomical Observatory VLA Sky Survey catalogues. ROGUE I contains 32,616 galaxies with a FIRST core within 3" of the optical position. The results of our classification procedure are:

the majority of radio sources in the ROGUE I catalogue, i.e. 93%, have unresolved (compact or elongated) morphologies, while the rest of them exhibit extended morphologies, such as Fanaroff-Riley type I, II, and hybrid, wide-angle tail, narrow-angle tail, head-tail sources, and sources with intermittent or reoriented jet activity, i.e. double-double, X-shaped, and Z-shaped, most of the Fanaroff-Riley II radio sources in ROGUE I have low radio luminosities, comparable to the luminosities of Fanaroff-Riley I sources, our selection procedure allowed to discover or reclassify a number of objects as giant, double-double, X-shaped, and Z-shaped radio sources, the optical host galaxies in ROGUE I have elliptical (64%), spiral (16%), distorted (12%), and lenticular (7%) morphologies; the remaining 1% are ring galaxies and galaxy mergers. The presented sample can serve as a database for training automatic methods of identification and classification of optical galaxies and radio sources.

Natalia Zywucka (Centre of Space Research, North-West University, Potchefstroom, South Africa)

# 2.21 Optical variability modelling of newly identified blazars and blazar candidates behind Magellanic Clouds

We present results of optical variability study of 44 newly identified blazar candidates behind the Magellanic Clouds. The sample contains 27 flat spectrum radio quasars (FSRQs) and 17 BL Lacertae objects (BL Lacs). All objects possess high photometric accuracy and infrequently sampled optical light curves (LCs) from the long-term monitoring conducted by the Optical Gravitational Lensing Experiment in V and I filters. The LCs were modelled with the Continuous-time Auto-Regressive Moving Average (CARMA) process using the publicly available Markov Chain Monte Carlo sampler described by Kelly et al. (2014) and with the Lomb-Scargle (LS) periodogram.

The CARMA models allow to investigate variability features of irregularly sampled LCs, especially their power spectral density (PSD), to determine variability-based classification of astrophysical objects and to detect quasi-periodic oscillations (QPOs).

The power law PSD is indicative of a self-affine stochastic process characterised by the Hurst exponent H, underlying the observed variability. An estimation of the H values was performed with a wavelet lifting transform.

The power law PSDs of blazars are thought to be the result of synchrotron, synchrotron self-Compton, and external Compton emission. The higher-order CARMA fits suggest there are additional variations present in blazar jets and/or accretion discs that affect both the overall shape of the PSD, and can give rise to QPOs. The non-power law features are also visible in some of the LS periodograms, and signs of flattening of the PSD at low frequencies observed in some of the CARMA fits hints at the blazar nature of the objects.

Natalia Zywucka-Hejzner (North-West University, Potchefstroom, South Africa)

# 2.22 Variations of Sub-Parsec-Scale Jet Orientation in PKS B1144-37

Understanding variability in supermassive black hole accretion is important for studies of black hole growth and, through any accretion disk re-orientation, jet dynamics and feedback on the surrounding gas. We have studied the evolution of the morphology of the sub-parsec-scale jet in the BL Lac object PKS B1144-379. Changes in the structure of the core (on scales of 10s microarcseconds) were investigated using high-cadence flux density monitoring of interstellar scintillation with the University of Tasmania Ceduna 30m radio telescope at a frequency of 6.5 GHz. We find that the angular size of the core varies between 10-30  $\mu$ as (0.08- 0.23 parsecs) and is at its most compact during two flares in the total flux density, which were observed in 2005 November and 2008 August. A complementary kinematic study of the sub-parsec-scale jet of PKS B1144-379 has been undertaken, using 8.6 GHz Very Long Baseline Array (VLBA) data obtained between 1997 January and 2017 June. Over the 20 year interval, the jet shows significant changes in position angle, ranging from 171 to -145 degrees. We detected rapid changes and large jumps in position angle (south-east to south-west) just before the flares occur, indicating a correlation between the flux density changes and the ejection of superluminal knots. Quasi-periodic flarings with a period of 3-4 years were observed. We suggest that these rapid changes and large jumps may be caused by perturbation of an accretion disk whose spin is misaligned with the inflowing gas.

Noor Masdiana Md Said (University of Tasmania)

# 2.23 Blazars in the LOFAR Surveys Data

I will present results from our studies that examine the blazar populations within the LOFAR Two-Metre Sky Survey (LoTSS) and the Surveys KSP Deep Fields. Blazars are active galactic nuclei which have relativistic jets aligned towards Earth. While blazars emit broadband radiation, the population is poorly understood at low frequencies because survey sensitivity and angular resolution limitations have made it difficult to determine the MHz counterparts.

In the LoTSS 1st Data Release (LDR1) we identified radio counterparts to all 98 sources from the 3rd Fermi-LAT Point Source Catalogue (3FGL) or Roma-BZCAT Multifrequency Catalogue of Blazars (5th edition) that fall within the LDR1 footprint. We studied the radio properties (e.g. the spectral index and luminosity) of our sample, performed a correlation analysis of the radio and -ray flux densities, and examined the infrared colour distributions of the sources; these results were recently published as part of the LoTSS AA special issue. I will showcase our preliminary analysis of the LDR2 data, which contains 1000 blazars. The increased sky coverage and improved calibration will allow us to compare the qualities of the blazar subpopulations and to examine their spatial properties.

I will present new results from our analysis of ¿20 blazars in the Deep Fields dataset. The 20–40 Jy/beam sensitivity of these data allow us to accurately characterise the arcsecond-scale diffuse (i.e. MHz) emission around the beamed blazar cores for the first time. I will highlight our efforts to identify new blazars from the sources in the Deep Fields lacking optical counterparts.

Sean Mooney (UCD)

# 2.24 Evidence for Helical/Toroidal B Fields in AGN Jets on Kiloparsec Scales from Faraday-Rotation Mapping

Helical magnetic fields in jets from AGN are predicted theoretically and many examples of helical B-fields have been inferred on parsec scales using VLBI. For AGN jets on larger kiloparsec scale jets observable with the VLA, for example, a comprehensive study has yet to be performed. To probe the line of sight magnetic field component in the vicinity of an astrophysical jet, observations of the Faraday rotation measure (RM) are required. The RM is directly proportional to the line of sight magnetic field component and electron density in the Faraday rotating medium. A gradient in the observed RM transverse to the jet indicates the line-of-sight magnetic field is behaving similarly across the jet, plausibly due to a toroidal or helical field. A review of results for observed transverse gradients on VLA scales will be presented, including results for Coma A, 3C465, NGC6251, and IC4296. Possible origins of slanted RM "stripes" observed in two sources will be considered.

Sebastian Knuettel (University College Cork)

# 2.25 Two-temperature MHD study of sub-relativistic jet propagation into the Intracluster medium

Jet feedback from active galactic nuclei(AGN) plays a fundamental role in the evolution of galaxy clusters because jet provides energy to the intracluster medium(ICM) by shock heating and turbulence. The observed X-ray cavities in the center of clusters, which is formed by the interaction between jet and ICM, is indirect evidence that the jetted gas is low-density hot plasma. Thus, because of weak Coulomb collisions under such high-temperature condition, the jet is expected to have an electron temperature that is distinct from the ion temperature. Also, because an accretion disk which is the origin of the jet formation becomes two-temperature disk, jet also needs to treat by twotemperature uid. However, previous studies ignored this treatment. Therefore, We have simulated the propagating of the sub-relativistic jet using two temperature magnetohydrodynamics code, CANS+. Our simulations implement the effect of Coulomb coupling and the electron heating in a viscous shock that is based on the results of particle-in-cell simulations by Matsukiyo (2010). We find that the ion and electron temperatures separate through the terminal shock, and thermal electron energy becomes one-order of magnitude less than ion energy in the cocoon. The ion gas, which can be regarded as a heat bath, can be heating the electron gas about a few hundred Myr. Furthermore, it is argued that the gas cooling time is ten times longer than that of one temperature simulation. In conclusion, our results indicate that two-temperature plasma physics could not be ignored for investigating between the jet and ICM interaction.

Takumi Ohmura (Kyushu University)

# 2.26 Constraining the -ray emission location and the magnetic field strength of the blazar TXS 2013+370

Astrophysical jets emanating from accreting supermassive black holes often show strong variability across the electromagnetic spectrum. The combined kinematical monitoring of the VLBI jet and its broadband flux density variability addresses the jet physics and the origin and spatial location of the variable emission. Here we present the results of a case study of the blazar TXS 2013+370. On the basis of mm-VLBI and single-dish observations, performed over a period of 10 years, we obtained a detailed description of the morphological evolution and the variability properties of its radio jet emission. The combination of the sub-pc scale kinematics and flux density variability in the centimeter to millimeter radio bands and in the -ray regime allowed to search for correlations between the different light curves and with structural changes in the inner VLBI jet. Through such correlation analysis, we constrained the location of the -ray production region with respect to the jet base, the overall jet inclination.

Thalia Traianou (Max Planck Institute for Radio Astronomy)

# 2.27 FSRQ/BL Lac dichotomy as the magnetized advective accretion process around black holes: a unified classification of blazars

The Fermi blazar observations show a strong correlation between -ray luminosities and spectral indices. BL Lac objects are less luminous with harder spectra than flat-spectrum radio quasars (FSRQs). Interestingly FSRQs are evident to exhibit a Keplerian disc component along with a powerful jet. We compute the jet intrinsic luminosities by beaming corrections determined by different cooling mechanisms. Observed -ray luminosities and spectroscopic measurements of broad emission lines suggest a correlation of the accretion disc luminosity with jet intrinsic luminosity. Also, theoretical and observational inferences for these jetted sources indicate a signature of hot advective accretion flow and a dynamically dominant magnetic field at jet-footprint. Indeed it is difficult to imagine the powerful jet launching from a geometrically thin Keplerian disc. We propose a magnetized, advective disc-outflow symbiosis with explicit cooling to address a unified classification of blazars by controlling both the mass accretion rate and magnetic field strength. The large scale strong magnetic fields influence the accretion dynamics, remove angular momentum from the infalling matter, help in the formation of strong outflows/jets, and lead to synchrotron emissions simultaneously. We suggest that the BL Lacs are more optically thin and magnetically dominated than FSRQs at the jet-footprint to explain their intrinsic -ray luminosities.

Tushar Mondal (Indian Institute of Science, Bengaluru)

# 2.28 Asymmetric jet launching in magnetospheric star-disk interaction

In our numerical simulations of the star-disk magnetospheric interaction in a regime relevant to Young Stellar Objects, we obtained pairs of axial jets launched from the close vicinity of a star. The two jets moving in the opposing directions do not have identical properties. We measure the propagation and rotation velocity of these jets, and estimate the angular momentum extracted from the system.

Milenko Cemeljic (Copernicus Astronomical Center)

# 2.29 The Temporal Variability of the Radio Structure of B2 1420+32 in its High State

QSO B2 1420+32 was a gamma-ray detected FSRQ with inverse radio spectrum. Recently, its g-band magnitude reaches it maximum value of 15.55 from it low state of about 19 mag. It might be not a coincidence that the gamma-ray emission was not detected until in the third Fermi-LAT AGN catalogue. Such a dramatic brightening, by more than a factor of 10, is unprecedented for this object. We will present the newly vlvi imaging results with VLBA at multi-frequencies, and discuss what is happening in the innermost region of the object over a period of more than one year.

Yongjun Chen (Shanghai Astronomical Observatory, Chinese Academy of Sciences)

# 2.30 The polarization imaging in M87 jet by general relativistic radiative transfer simulation with GRMHD models

Spectacular images of the M87 black hole taken by the Event Horizon Telescope (EHT) have opened a new era of black hole research. One of the next issues is to take polarization images around the central black hole (BH). Since radio emission is produced by synchrotron emission, polarization properties should vividly reflect the magnetic field structures at the jet base and thus provide good information regarding the magnetic mechanism of jet formation. With this kept in mind we perform general relativistic (GR) full polarimetric radiative transfer calculations based on the GR magnetohydrodynamic (MHD) simulations of low-luminosity AGN jet M87, to obtain polarization images in the BH horizon-scale. We found that the linear polarization components originating from the jet experience Faraday rotation and depolarization when passing through the accretion flow, so that the resultant distributions of polarization vectors should depend on the BH spin. We conclude that a fast-spinning model with aBH=0.9MBH gives the best fit to the reported 230 GHz polarization measurement of the M87 jet core, and that it is also consistent with the horizon image by the EHT observation. We also find in all models that the circular polarization component originating from the counter jet is amplified in the counter jet by Faraday conversion within the inner flow, and so this can be a good tracer of linear polarization components before depolarization. We will be able to specify field configuration through the comparison between such simulated polarization images and future polarimetry with EHT and other VLBI observations.

Yuh Tsunetoe (Department o Astronomy, Kyoto University)

### 2.31 Study on temporal and spectral behaviour of 3C 279 during 2018 January flare

We have carried a detailed temporal and spectral study of the blazar 3C 279 using multiwavelength observations from Swift-XRT, Swift-UVOT, and Fermi-LAT during a flare in 2018 January. The temporal analysis of  $\gamma$ -ray light curve indicates a lag of 1 d between the 0.1–3 GeV and 3–500 GeV emission. Additionally, the  $\gamma$ -ray light curve shows asymmetry with slow rise–fast decay in energy band 0.1–3 GeV and fast rise–slow decay in the 3–500 GeV band. We interpret this asymmetry as a result of shift in the Compton spectral peak. This inference is further supported by the correlation studies between the flux and the parameters of the log-parabola fit to the source spectra in the energy range 0.1–500 GeV. We found that the flux correlates well with the peak spectral energy and the log-parabola fit parameters show a hard index with large curvature at high flux states. Interestingly, the hardest index with large curvature was synchronous with a very high energy flare detected by H.E.S.S. Our study of the spectral behaviour of the source suggests that  $\gamma$ -ray emission is most likely to be associated with the Compton up-scattering of IR photons from the dusty environment. Moreover, the fit parameters indicate the increase in bulk Lorentz factor of emission region to be a dominant cause for the flux enhancement.

Zahir Shah (The Inter-University Centre for Astronomy and Astrophysics, Pune, India)

# 2.32 Probing the relativistic jet structure through multiwavelength analysis

Although VLBI radio observations are still the only direct tool to study the structure and evolution of parsec scale jets, multiwavelength observations are being used to understand the physical processes involved in their emission. In this presentation I will discuss the implications of the different assumptions involved in the determination of the physical parameters of the jets based on multiwavelength observations, like Lorentz factor of the jet bulk motion, nature of the processes that originate the high energy emission and where they occur in the jet. I will base my conclusions on multiwavelength observations of several well studied blazars, as well as in polarimetric results.

Zulema Abraham (University of Sao Paulo)