XIX IAG/USP Advanced School on Astrophysics

RADIOASTRONOMY

August 31 – September 5, 2025 – Bertioga/SP, Brazil

PROGRAMME

Topic I: "*Radio Telescopes and Fundamentals of observations"* **Alex Kraus** (Max-Planck-Institut-für-Radioastronomie, Germany)

Ia) Basic properties of radio telescopes

Ib) Observation methods of "single-dish" radio telescopes

Ic) Observations in the millimeter wavelength range

Topic II: "*An introductory course to the properties of the interstellar medium"* **Maria Teresa Beltran** (INAF, Italy):

IIa) The composition of the ISM and their properties

IIb) The star formation process of both low- and high-mass stars

IIc) Astrochemistry and molecular astrophysics

Topic III: "*Radio Interferometry: Principles, Practices, and Astrophysical Frontiers"* **Laurent Loinard** (UNAM, Mexico):

IIIa) Introduction to radio interferometry

IIIb) Very Long Baseline Interferometry (VLBI)

IIIc) The astrophysics of interferometry

Topic IV: "*Active galactic nuclei at radio wavelengths: properties, life and impact"* **Raffaella Morganti** (University of Groningen, The Netherlands):

IVa) Active galactic nuclei (AGN) and radio AGN: and introduction of their properties

IVb) Structure of radio AGN and their life cycle

IVc) Radio jets and their impact in galaxy evolution

Topic V: "*Spectral Line Astrophysics with interferometry: Techniques, Discoveries, and Future Horizons"* **Thomas Oosterloo** (University of Groningen, The Netherlands):

Va) Spectral line emission mechanisms and related science

Vb) Spectral line data processing/analysis and future instruments

Invited Talk 1: "*The LLAMA radiotelescope: present status, and perspectives"* - Jacques Lépine (IAG/USP)

Invited Talk 2: "*Simulating Black Hole Weather with AI"*- Rodrigo Nemmen (IAG/USP*)*

Invited Talk 3: "*The Radio Observatory Pierre Kaufmann"*- Zulema Abraham (IAG/USP)

Invited Talk 4: "*Solar Chromospheric Flares: A 165-year old mystery*"- C. Guillhermo Giménez de Castro (CRAAM & CONICET/UBA)

Invited Talk 5: "*Closing the feedback-feeding loop in radio galaxies*"– Thomas Oosterloo (University of Groningen)

Invited Talk 6: *"Modeling radio emission from bowshocks of high-velocity massive stars"*- Reinaldo Santos-Lima (IAG/USP)

Invited Talk 7: *The study of young stellar clusters with Gaia and VLBI astrometry"*- Phillip Galli (IAG/USP)

Invited Talk 8: *Astrophysical jets at the highest angular resolutions* - Ciriaco Goddi (IAG/USP)

SCHEDULE

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ABSTRACTS

Lecture I "*Radio Telescopes and Fundamentals of observations"*

Alex Kraus (Max-Planck-Institut-für-Radioastronomie, Germany)

The first lecture will cover the basic properties of radio telescopes. After a brief classification of radio astronomy as a subfield of astronomy, the properties of antennas, with a particular focus on reflector antennas, will be introduced and discussed. Several existing radio telescopes will be presented for illustration.
The second lecture will focus on the observation methods of "single-dish" radio telescopes. Special emphasis will be placed on calibration strategies. Examples of observations in the fields of radio continuum, spectroscopy, as well as pulsars and transients will be presented. Potential difficulties such as those caused by RFI (radio frequency interference) will also be addressed.
The third lecture will focus on observations in the millimeter wavelength range. The specific requirements of such measurements, particularly with respect to telescope location and calibration procedures, will be discussed. Examples of telescopes and their observational results will also be shown.

Lecture II: "*An introductory course to the properties of the interstellar medium"* **Maria Teresa Beltran** (INAF, Italy):

The first lecture will describe the composition of the ISM and the main properties of dust and gas (atomic, ionized, and molecular hydrogen), focusing on molecular clouds. The second lecture will describe the star formation process of both low- and high-mass stars, with special emphasis on the similarities and differences, the classification of young stellar objects, the properties of outflows, infall, and disks, and will give an overview on how to derive important parameters such as masses, momentum rates, and sizes. The third lecture will introduce astrochemistry in molecular clouds, in which basic aspects of interstellar chemistry and molecular astrophysics will be introduced. This includes detection and formation of molecules, chemistry of important species, deuterium, and complex organic molecules, maser emission, derivation of physical parameters, catalogues and databases, and line identification tools. The course will also present astrochemistry in low- and high-mass star-forming regions.

Lecture III: "*Radio Interferometry: Principles, Practices, and Astrophysical Frontiers"* **Laurent Loinard** (UNAM, Mexico):

This lecture series offers a structured exploration of radio interferometry and its application to modern astrophysics, blending theoretical concepts with practical insights and key scientific discoveries.
The first lecture provides an introduction to radio interferometry, beginning with an overview of the electromagnetic spectrum and atmospheric transparency. It covers the fundamental principles of angular resolution, the workings of a 2-element interferometer, and the Van Cittert-Zernike theorem. Participants will learn how the uv-plane and synthesis imaging enable high-resolution observations. The session concludes with a tour of major radio interferometers, showcasing the diversity and capability of current facilities.
The second lecture delves into the principles and practices of Very Long Baseline Interferometry (VLBI). It highlights the differences between connected and VLBI arrays, examining the full VLBI data chain from observation to calibration and imaging. Specific challenges and solutions for VLBI calibration will be discussed, along with advanced topics like VLBI astrometry and millimeter-wavelength VLBI. The lecture will also introduce the major VLBI facilities shaping cutting-edge astrophysical research.
The third lecture shifts focus to the astrophysical phenomena studied with interferometry. It explores emission mechanisms, the physics of active galactic nuclei (AGNs) and superluminal motions, and the role of VLBI in mapping the universe. Topics such as megamasers and their relevance to the Hubble constant tension, as well as groundbreaking results from the Event Horizon Telescope, illustrate the transformative power of interferometric techniques.

Lecture IV: "*Active galactic nuclei at radio wavelengths: properties, life and impact"* **Raffaella Morganti** (University of Groningen, The Netherlands):

During the life of a galaxy, the central (super) massive black hole can pass from a "dormant" to an "active" phase. In the latter, huge amount of energy is emitted, originated from the conversion of accreting matter in radiation. The amount of energy can highly outshine the radiation from the stellar component in the galaxy and can be emitted in different wavebands (from radio to gamma) and, therefore, be observed by different telescopes. The energy emitted by active nuclei is considered to be a key ingredient influencing the evolution of galaxies. This makes AGN extra relevant.
In the lectures I will start by giving an overview of the AGN phenomenon and the variety of the associated manifestations. I will then zoom-in into radio AGN. These are very special and fascinating objects with unique properties. I will describe the properties of the radio emission and how it is characterise by e.g. radio jets and lobes and where the radio plasma can reach up to many hundreds of kiloparsec to mega parsec distances from the host galaxy. The most advanced radio telescopes allow us to explore deep in the heart of these objects where the radio jets are originating as well as follow their expansion up to the intergalactic scales.
I will describe what we have learned about the life-cycle of radio AGN: we can identify just born radio jets as well as dying radio sources. This cycle is key for providing the necessary impact of the AGN on the evolution of the galaxy.
This will be the topic of the last lesson in which I will describe how we think the radio jets can impact their surrounding medium. Cavities in the distribution of the hot, X-ray gas produced by the expansion of the radio plasma are still one of the best evidence of such impact but others (like the presence of jet-driven outflows) are also being found. Finally, I will discuss how these phenomena are included in numerical and cosmological simulations.

Lecture V: "*Spectral Line Astrophysics with interferometry: Techniques, Discoveries, and Future Horizons"*

Thomas Oosterloo (University of Groningen, The Netherlands):

This lecture series provides an introduction to the study of spectral lines in astrophysics, focusing on observational techniques, data analysis, and future opportunities in the field. We will examine the mechanisms driving spectral line emissions, such as atomic hydrogen's 21-cm line and molecular gas transitions, observed with leading facilities like MeerKAT, VLA, ALMA, and the upcoming SKA. An overview of the major scientific advancements achieved through spectral line studies will highlight their critical role in understanding the universe.
Technical aspects, including the operation of spectral line correlators and calibration requirements, will be addressed. The lectures will also cover essential data processing techniques such as continuum subtraction for broad and narrow bands, along with methods for visualizing and analyzing spectral line datasets using modern tools. Emphasis will be placed on strategies for source detection, balancing sensitivity with resolution, and employing image weighting techniques tailored to specific scientific goals. Attendees will learn about modeling kinematics from spectral line observations, exploring how data can yield insights into physical conditions and dynamics. Special considerations for absorption-line studies and their unique challenges will also be discussed.
The series concludes with a forward-looking perspective on next-generation facilities like the SKA and DSA-2000, examining their transformative capabilities and the groundbreaking spectral line science they will enable.

Invited Talk 1: "*The LLAMA radiotelescope: present status, and perspectives"* -
Jacques Lépine (IAG/USP)

The LLAMA Observatory, situated in the Argentinian Andes at 4800m altitude, in the Salta province, is aproject of Argentina and Brazil, which started in 2014 with an agreement between FAPESP (research foundation of Sao Paulo State), University of São Paulo, and MinCyt (Ministry of Science and technology of Argentina. The expenses will be equally shared. The 12m diameter antenna was constructed by VERTEX Antennentechnik GmbH (Duisburg, Germany). The surface precision of the dish will reach 15 microns r.m.s. deviations from an ideal parabola, after a period of fine adjustments, using holography technique. The antenna will perform observations at mm and sub-mm radio waves, like the international ALMA interferometer. The LLAMA antenna will be equipped with two lateral Nasmyth cabins, similarly to the APEX antenna installed in Chile. Initially, we will work with receivers for band 5, band 6 and band 9 (band names adopted from the ALMA observatory), constructed by NOVA Labs (University of Groningen, Holland). Brazil contributed to the acquisition of of those receivers, and to the construction in Brazil of sub-systems, like the optomechanical systems of mirrors to be installed inside the Nasmyth and Cassegrain cabins. Brazil also acquired , from Japan, the cryogenics, and a cryostat, in which the receivers will be installed. An additional receiver for bands 2 +3 is under construction at the Universidad de Chile , and a calibration loads system constructed by the Universidad de Concepcion, Chile.
The LLAMA antenna will be very competitive for observations going from Solar Physics, to the interstellar medium, and to extragalactic compact sources, and will participate in International VLBI observations. The rhythm of the construction of the LLAMA observatory and of the mounting of the radiotelescope has suffered variations along the years. It passed a phase of accelerated development, after the MinCyT attributed to the public company INVAP the task of installing the observatory and the radio telescope. Then, recently, the rhythm decreased again due to a decision of the Argentinian government economical to avoid expenses. We believe that the project will reach the situation of "antenna mounted" in 2025.

Invited Talk 2: "*Simulating Black Hole Weather with AI"*
Rodrigo Nemmen (IAG/USP*)*

Black holes accrete gas from their surroundings in a chaotic, turbulent manner, requiring complex simulations where fluid dynamics, electromagnetism, and general relativity collide. In this colloquium, I will introduce our pilot application of deep learning for black hole weather forecasting and explain how artificial intelligence (AI) can revolutionize these simulations. Along the way, I will also touch on traditional simulation techniques and clarify the differences between AI, machine learning, and deep learning.

Invited Talk 3: "*The Radio Observatory Pierre Kaufmann"*
Zulema Abraham (IAG/USP)

In this presentation I will discuss the evolution of the ROPK radio telescope instrumentation over the last 50 years and its association with scientific objectives, in the context of Brazilian and global reality. I will also discuss the current status and future prospects of the observatory.

Invited Talk 4: "*Solar Chromospheric Flares: A 165-year old mystery*"
C. Guillhermo Giménez de Castro (CRAAM & CONICET/UBA)

Since Richard Carrington observed a white-light flare through his four-and-a-half-inch telescope in September 1859, the mystery of the origin of chromospheric flares has not been settled. The Solar Chromosphere has historically been studied from spectral lines in the visible and UV, notably Hα, Ca II, Mg II and Lyα. Observations at long UV wavelengths (304, 1600 and 1700 ̊A) from space have been recently added. However, the Chromosphere can also be studied in the infrared, both in the continuum and lines. Studies in this spectral band, which by definition extends from 1 μm to 1 mm, are scarce and recent, and its advantages have been little explored. The Center for Radio Astronomy and Astrophysics Mackenzie, CRAAM, played a leading role in the development of new instrumentation with the Solar Submillimeter Telescope for 1400 & 700 μm (1999), the Solar-T balloon experiment for 100 and 43 μm (2016), the High Altitude THz Solar Photometer (HATS) for 20 μm (2024) and the telescopes for 10 μm (AR30T & SP30T) that are contributing to our understanding of the Solar Chromosphere. This talk reviews what we learned and describes how much can be done with ground-based instruments.

Invited Talk 5: "*Closing the feedback-feeding loop in radio galaxies*"
Thomas Oosterloo (University of Groningen)

Invited Talk 6: *"Modeling radio emission from bowshocks of high-velocity massive stars"*
Reinaldo Santos-Lima (IAG/USP)

Massive stars modify their surroundings through their intense ultraviolet radiation field, violent mass-ejection episodes, or the continuous injection of mechanical energy from their powerful winds. These wind-interstellar medium (ISM) interactions produce shocks, the perfect scenarios for energizing cosmic rays via the diffusive shock acceleration mechanism. A particular case of stellar wind collision with the ISM comes from runaway massive stars, which move through the interstellar medium with V > 30 km/s. The outer shock, called the bow shock, propagates through the ambient medium cooling efficiently and compressing the gas. The bow shocks of a few massive runaway stars were detected at radio wavelengths with a high level of non-thermal emission, most probably

synchrotron radiation. These systems are also interesting because they provide a laboratory for studying many aspects of cosmic ray transport and acceleration around shocks. In this talk, I will present our modeling of the bow shock structure of massive runaway stars using plasma simulations (MHD), the distribution of cosmic ray electrons obtained from solving the transport equation for locally accelerated particles and those from the galactic background, and the production of synthetic maps of radio emission and polarization from these systems at frequencies of ~GHz, which can help interpret current and future observations.

Invited Talk 7: *The study of young stellar clusters with Gaia and VLBI astrometry"*-
Phillip Galli (IAG/USP)

Significant progress has been made in recent years to discover and characterise young clusters thanks to the state-of-the-art astrometry provided by the Gaia satellite. Ground-based Very Long Baseline Interferometry (VLBI) surveys in the radio domain also played an important role to complement the Gaia catalogue in regions of high extinction which are ubiquitous to young clusters and dramatically affect optical observations. These projects combined together delivered proper motions and parallaxes for a large number of young stellar objects making it possible, for the first time, to construct a 3D map of the nurseries to which they belong. In this talk I will review important results on the study of young stellar clusters and individual stars obtained from Gaia and VLBI astrometry.

Invited Talk 8: *Astrophysical jets at the highest angular resolutions*
Ciriaco Goddi (IAG/USP)

Astrophysical jets are a ubiquitous and powerful phenomenon in astronomy, ranging from young stellar objects (YSO) to super-massive black holes (SMBH) and Active Galactic Nucleii (AGN). Jets are believed to play a central role in regulating protostellar and black hole mass-accretion as well galaxy growth via AGN feedback. Despite their significance, their driving mechanisms remain elusive, primarily due to the observational challenges of probing the inner regions where jets are launched and collimated. Achieving the required resolution to test theoretical models demands cutting-edge techniques like Very Long Baseline Interferometry (VLBI) at (sub)millimeter wavelengths, which provide the highest angular resolution available in ground-based astronomy. In this talk, I will highlight key findings from ALMA, the EHT, and global VLBI networks, emphasizing their impact on our understanding of mass-accretion and mass-loss processes in Galactic star formation, the role of magnetic fields in launching relativistic jets, and black hole physics. I will also discuss future prospects, including planned expansions and technological innovations, poised to unlock transformative discoveries in jet astrophysics and SMBH science over the coming decade.