

**PhD Student:** Cristina Nanci

**PhD Cycle:** XXXVI

**Tutors:** Dr. Roberta Zanin (CTA Observatory), Dr. Marcello Giroletti (INAF-IRA)

**Research Project:** Synergies SKA-CTA: jet-accretion process across the mass scale

**Context** - Arising close to the accreting black holes of stellar to supermassive size, relativistic outflows are known to be the site where particles get accelerated to relativistic speeds. These mechanisms result in the release of radio waves and very high energy (VHE) photons. Allowing a very high resolution, the Very Long Baseline Interferometry (VLBI) in the radio band, and the Major Atmospheric Gamma-ray Imaging Cherenkov Telescopes (MAGIC) at VHE are very effective facilities in investigating the physics of the jets and the particle acceleration processes occurring here. Moreover, we will further improve our capabilities with the advent of the Square Kilometer Array (SKA) in radio and of the Cherenkov Telescope Array (CTA) at VHE. In this prospect, in order to take full advantage from the next generation instruments, it is important to characterise the properties of relativistic jets across the mass scale, mostly stressing on a multi-wavelength (MWL) point of view.

Relativistic jets are largely investigated in the so-called blazars, a class of radio-loud Active Galactic Nuclei with the jets pointing to the observer. In September 2017, the first association of a cosmic neutrino with an astrophysical source, the gamma-ray blazar TXS 0506+056, boosted the idea of blazar jets as ideal astrophysical accelerators. Before this event, several theoretical and statistical studies predicted that astrophysical neutrinos can come from blazar jets as products of highly accelerated cosmic rays interactions with the ambient.

**1<sup>st</sup> year Goals** - Being the case of TXS 0506+056 the only reliable association to date, we aim to bring new radio-gamma rays observational constraints on the hypothesis of the neutrino-blazar connection by analysing recent neutrino events. In the meanwhile, we purpose to deeply investigate the parameters of known and well studied blazar jets structure, kinematics and evolution and to model the radio-gamma interplay in these objects.

**Methods** - Markarian 501 - Markarian 501 (Mrk501) is one of the best prototypes of blazar. Thanks to its brightness over all the electromagnetic spectrum, it is the ideal laboratory for jet physics from a MWL perspective. The beginning of my first year was devoted to the reduction of multi-frequency and multi-epoch VLBI data of Mrk501. These are part of a rich VLBI monitoring conducted during 2016 simultaneously with MAGIC observations. As a member of the MAGIC Collaboration, I can use the MAGIC proprietary data of Mrk501. Once reduced and analysed, the VLBI and MAGIC data together will allow a broadband characterization of the Mrk501 jet emission with improved accuracy with respect to the past.

Blazars-neutrinos connection - I produced the first interferometric collection of candidate neutrino counterparts. *1. The sample.* During 2019-2020, we carried out 4 neutrino-events VLBI follow-ups, including a total of 10 potential radio counterparts. 8 of them are associated with a gamma-ray source. Once performed the data reduction, I derived the radio luminosity (when the redshift is known) and the spectral properties of each source. By inspecting their arcseconds-scale properties with survey data, I determined the compact/extended nature. This preliminary analysis drives the selection of the most promising targets according to their similarity with TXS 0506. The final sample consists of 5 radio-gamma-ray blazars-like sources. *2. The detailed analysis.* (1) In order to determine the state of activity of the 5 sources in the radio band at the neutrino arrival, I analysed archival data in comparison to our new proprietary VLBI data. In particular, for each source, I measured the VLBI (milliarcseconds scales) flux density variability. This is done to reveal the presence of flaring states as observed in TXS 0506 in coincidence with the neutrino arrival. (2) By modeling the jets emission with discrete Gaussian components, I analysed the radio morphology of the jets. If the data quality and the nature of the source allow it, performing this analysis on multi-epoch data leads to infer the jet's kinematic parameters and the variation in the structures over the time. I finally compared all the findings with respect to the case of TXS 0506 and to the models proposed for neutrino emission in blazars.

**Results** - In this process, I identify **2 promising neutrino-emitter candidates**. A paper on this work will be soon submitted to A&A. Due to the considerable impact that the MWL information has on the neutrino-emitters identification, my work is part of a MWL campaign which resulted in two contributes to the ICRC conference (I am co-authors of one of them) and one manuscript in preparation related to one of these contributes (I will be co-author). The results on VLBI data reduction of Mrk 501 are still preliminary.

**Future work** - The evolution of the radio properties of some of the sources will be investigated with VLBI observations scheduled for the next months. The second year of my PhD will be also devoted to the research for more neutrino-emitter candidates. This is part of a VLBI campaign that will be supported by VLBA data (one proposal is accepted, a second proposal to the European VLBI Network is currently under evaluation, I am the PI of both). Depending on the neutrino event relevance, also MAGIC data could be included in the study. The radio and gamma analysis of Mrk501 will be completed during the course of the next year and it will be followed by at least one dedicated publication.

## **WORKSHOPS, CONFERENCES & MEETINGS**

- 2 - 6 November 2020 - CASA-VLBI workshop 2020
- 1 - 4 December 2020 - 7th Annual Science At Low Frequencies (SALF) Conference
- 25 - 29 January 2021 - 8th MAGIC Stereo Analysis Workshop
- 15 - 19 March 2021 - The 2021 SKA Science Conference, "A precursor view of the SKA Sky"
- 12 - 17 April 2021 - Ninth International Fermi Symposium
- 14 - 18 June 2021 - Extragalactic jets on all scales - launching, propagation, termination
- 12 - 14 July 2021 - EVN Mini-Symposium & User's Meeting
  
- MAGIC Collaboration extragalactic (EGAL) monthly meeting
- MAGIC Collaboration Early Career Committee (ECC) monthly meeting
- VLBI group meeting (recurring every three weeks)
  
- Weekly PhD seminars (recurring)
  - 19 May 2021 - Talk: "Are gamma-ray blazars high-energy neutrino emitters? The parsec-scale view"
- EVN seminars (recurring once a month)
- Joint Astrophysical colloquia (recurring)
- DIFA/INAF/OAS/IRA Astrophysics talks (recurring)

Some relevant seminars:

- 12 February 2021 - IFPU colloquium: "Neutrino astronomy with IceCube" - Anna Franckowiak
- 23 February 2021 - Quid Ultra colloquium: "Gamma-Ray Astronomy: The Cross-Road Between Physics and Astrophysics"- Razmik Mirzoyan
- 11 March 2021 - Laura Bassi Colloquium: "The search for Galactic PeVatrons: gamma-ray and neutrino signatures" - Silvia Celli

## **PhD SCHOOLS**

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## **INTERNAL COURSES**

- 30 November - 2 December 2020 - Bologna, Italy - Remote - "The Interstellar Medium"
- 19 - 23 April 2021 - Bologna, Italy - Remote - "Gamma Ray Bursts: from observations to physical properties"

- 5 - 14 May 2021 - Bologna, Italy - Remote/in presence - Writing, talking and presenting Science

## ISA LECTURES

- 13 May 2021 - "Vaccini e sviluppo del farmaco tra Verità, Miti e Falsità"
- 10 June 2021 - "The Myth of Stockholder Ownership, and the new case for Workplace Democracy"

## COMPETITIVE TELESCOPE/COMPUTER TIME ALLOCATIONS

- Trigger Proposal to NRAO's North American (in particular to Very Long Baseline Array, VLBA, facilities, semester 21B-22A): Submitted as Principal Investigator and Approved with grade B (score = 3.75, where 0 is maximum and 10 is minimum)
- Trigger Proposal to European EVN Network (semester 21C-22A-22B): Submitted as Principal Investigator, under evaluation

## OTHER RELEVANT ACTIVITIES

Scientific divulgation activity during the event "La notte dei ricercatori -2021"  
- Bologna, 24 Sept. 2021

## PUBLICATIONS

- "Observing the inner parsec-scale region of candidate neutrino-emitting blazars", **Cristina Nanci**, Marcello Giroletti, Monica Orienti, Giulia Migliori, et al., in preparation
- Contribute presented at the 37th International Cosmic Ray Conference (ICRC 2021) "Fermi-LAT realtime follow-ups of high-energy neutrino alerts", Simone Garrappa, Sara Buson, Anna Franckowiak, Marcello Giroletti, Ioannis Lioudakis, **Cristina Nanci**
- Paper in preparation on the contribute presented at the 37th International Cosmic Ray Conference (ICRC 2021) "Multi-Messenger observations of the gamma-ray blazar 4FGL J0658.6+0636 consistent with an IceCube high-energy neutrino", Raniere Menezes, Sara Buson and other collaborators, for the VLBI data: **Cristina Nanci**, Marcello Giroletti