

Activities with Brazil

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1 Topics

In general, the scientific collaboration between ICRAANet and Brazil is based on the following activities:

- Production of scientific research;
- IRAP Ph.D. and the Brazilian doctorate programs;
- Postdoctoral programs;
- Professors/researchers visitor programs;
- Organization of conferences, meetings, and workshops.

The research collaboration between ICRAANet and Brazil encompasses a series of topics in relativistic astrophysics mainly connected to the physics and astrophysics of compact objects such as white dwarfs, neutron stars, and black holes. Some topics of research include:

- Equation of state (EOS) of compact stars (white dwarfs, neutron stars, hybrid stars, quark stars).
- Temperature effects on compact star EOS and structure.
- Magnetic field effects in compact stars EOS and structure.
- Rotation effects in compact stars structure.
- White dwarfs in astrophysical systems: binaries, mergers, type Ia supernovae.
- Neutron stars in astrophysical systems: binaries, mergers.
- Radiation mechanisms of compact stars, such as electromagnetic emission, neutrino emission, gravitational waves, accretion disks, compact object magnetospheres, etc.

Below, we summarize and highlight the main activities and results achieved in all the above areas in 2023.

2 Participants

Below, we list professors, senior researchers, postdocs, and graduate students from ICRANet and Brazil who are in active scientific collaboration.

2.1 ICRANet

- J. A. Rueda (ICRANet, Italy)
- R. Ruffini (ICRANet, Italy)

2.2 Professors/senior researchers in Brazil

- U. Barres de Almeida (Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil)
- R. Camargo (Universidade do Estado de Santa Catarina, Florianópolis, Brazil)
- G. A. Carvalho (Universidade Tecnológica Federal do Paraná, Brazil; Universidade do Vale do Paraíba, Brazil)
- J. G. Coelho (Universidade Federal do Espírito Santo, Brazil)
- J. C. N. de Araujo (Instituto Nacional de Pesquisas Espaciais, Brazil)
- E. O. da Silva (Universidade Federal do Cariri, Brazil)
- G. de Barros (Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil)
- R. C. dos Anjos (Universidade Federal do Paraná, Brazil; Universidade Federal da Fronteira Latino-Americana, Brazil; Universidade Federal do Paraná, Brazil)

- M. M. Guzzo (Universidade Estadual de Campinas, Brazil)
- S. O. Kepler (Universidade Federal do Rio Grande do Sul, Brazil)
- M. Malheiro (Instituto Tecnológico de Aeronáutica, Brazil)
- R. M. Jr. Marinho (Instituto Tecnológico de Aeronáutica, Brazil)
- D. P. Menezes (Universidade Federal de Santa Catarina, Brazil)
- C. V. Rodrigues (Instituto Nacional de Pesquisas Espaciais, Brazil)
- F. Rossi-Torres (Universidade Estadual de Campinas, Brazil)
- C. A. Z. Vasconcellos (Universidade Federal do Rio Grande do Sul, Brazil)

2.3 Postdocs

- R. V. Lobato (Universidad de Los Andes, Bogotá, Colombia; Texas A&M University-Commerce, Commerce, USA)
- J. P. Pereira (Universidade Federal do Espírito Santo, Brazil)
- M. F. Sousa (Universidade Federal do Paraná, Brazil)

2.4 Graduate Students

- S. V. Borges (University of Wisconsin-Milwaukee, USA)
- K. Kianfar (Instituto Tecnológico de Aeronáutica, Brazil)
- T. Ottoni (Universidade Federal do Espírito Santo, Brazil)

3 Summary and Highlights 2023

This year has seen a particularly intensive collaboration with Brazilian professors, researchers, and graduate students from Universidade Tecnológica Federal do Paraná, Instituto Tecnológico de Aeronáutica, Universidade Federal do Espírito Santo, Instituto Nacional de Pesquisas Espaciais, and Universidade Federal do Paraná.

From the scientific publication viewpoint, the collaboration with Brazil has led to the publication of two articles and a chapter in a book (more details are presented below).

Professor Jorge A. Rueda from ICRANet performed a scientific visit to the Instituto Tecnológico de Aeronáutica (ITA) from 26 February to 12 March 2023, granted by *Programa Institucional de Internacionalização- PRINT* of Brazil. The visit has aimed to set up a series of scientific activities with ITA for the years 2023 and 2024 within the proposed research project *White Dwarf Binary Mergers as Progenitors of Fast Rotating Highly-Magnetized Neutron Stars*, under the coordination of Prof. Manuel Malheiro at ITA and Prof. Jorge A. Rueda at ICRANet. The research on this topic is ongoing, and the first article related to this activity is being prepared for publication.

The Ph.D. student from UFES, Tulio Ottoni, started a six-month academic visit at ICRANet-Ferrara from 15 November 2023 to 15 May 2024. This activity takes part within the context of the participation of ICRANet in the *International Ph.D. Program in Astrophysics, Cosmology, and Gravitation* (PPGCosmo) through the co-supervision of Ph.D. research. In the present case, student T. Ottoni's research work is supervised by Prof. Jaziel Coelho from Universidade Federal do Espírito Santo and Prof. Jorge A. Rueda from ICRANet-Ferrara. The thesis is entitled *Pulsar pulse profiles in scalar-tensor theories of gravity and some astrophysical tests*. The aim is to investigate gravitational theories in the strong field regime with the high energy light curve of pulsars. In addition, in collaboration with Prof. Piero Rosati at the University of Ferrara, the student is performing additional research on constraints of alternative theories of gravity using gravitational lensing data from galaxy clusters.

The organization, development, and success of our activities have led to

the full fruition of the collaboration agreements established by ICRANet over the years with Brazilian institutions such as universities, research centers, and national agencies for the promotion of research along the whole geographical territory of Brazil.

In 2023, ICRANet renewed collaboration agreements with the following Brazilian institutions:

- Instituto Tecnológico de Aeronáutica (ITA).
- Universidade Federal Fluminense (UFF).
- Universidade Federal de Itajubá (UNIFEI).
- Universidade Federal da Paraíba (UFPB).

In 2023, ICRANet signed new collaboration agreements with the following Brazilian institutions:

- Universidade Federal de São Carlos (UFSCar).
- Universidade Federal do Espírito Santo (UFES).

Therefore, as of this writing, ICRANet has active collaboration agreements with the following Brazilian institutions:

- Governo dello Stato di Ceará.
- Universidade Federal do Rio Grande do Sul (UFRGS).
- Universidade Estadual de Campinas (UNICAMP).
- Universidade do Estado de Santa Catarina (UDESC).
- Instituto Tecnológico de Aeronáutica (ITA).
- Universidade Federal Fluminense (UFF).
- Universidade Federal de Itajubá (UNIFEI).
- Universidade Federal da Paraíba (UFPB).
- Universidade Federal de São Carlos (UFSCar).

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- Universidade Federal do Espírito Santo (UFES).

ICRANet keeps expanding its activities in Brazil by establishing scientific cooperation with additional institutions. In 2023, ICRANet and the following Brazilian institutions started the procedure to sign new collaboration agreements or renew the existing expired ones:

- Universidade Tecnológica Federal do Paraná (UTFPR).
- Universidade Federal do Paraná (UFPR).
- Universidade Federal do Cariri (UFCA).
- Universidade do Estado do Rio de Janeiro (UERJ).
- Instituto Nacional de Pesquisas Espaciais (INPE).

For a summary of the collaboration agreements between Brazilian universities and research centers with ICRANet, please visit the dedicated page on the ICRANet website:

https://www.icranet.org/index.php?option=com_content&task=view&id=1427

See also:

https://www.icranet.org/documents/ICRANet_Brazil_Agreements_total.pdf

Special mention goes to the young Brazilian scientists to whom ICRANet has contributed to their academic formation via the IRAP Ph.D. Program, postdoctoral, and academic exchange programs, and that have obtained in the year 2023 permanent professorship positions in Brazilian universities. ICRANet keeps track of and encourages young professors' scientific careers. A report with this and additional information on the activities of ICRANet with Brazilian colleagues is continuously updated and publicly available on the ICRANet website.

For a summary of the collaboration activities of ICRANet with and in Brazil, including the scientific activities of Ph.D. students, postdocs, and professors, we refer to the following detailed report:

https://www.icranet.org/documents/ICRANet_activities_Brazil.pdf

4 Publications 2023

In 2023, two articles have been published, one in *The Astrophysical Journal* and one in *Universe*. The research topics have been in the context of the astrophysics of white dwarfs in binary systems and compact star theory in general relativity. In addition, a chapter about neutrino emission in gamma-ray bursts was published in a book edited by Brazilian Professor Cesar Zen Vasconcellos.

1. Sousa, M. F.; Coelho, J. G.; de Araujo, J. C. N.; Guidorzi, C.; Rueda, J. A., *On the Optical Transients from Double White-dwarf Mergers*, *The Astrophysical Journal* 958, 134, 2023.

Double white-dwarf (DWD) mergers are relevant astrophysical sources expected to produce massive, highly-magnetized WDs, type Ia supernovae (SNe), and neutron stars (NSs). Although they are expected to be numerous sources in the sky, their detection has evaded the most advanced transient surveys. This article characterizes the optical transient expected from DWD mergers in which the central remnant is a stable (sub-Chandrasekhar) WD. We show that the expansion and cooling of the merger's dynamical ejecta lead to an optical emission peaking at 1–10 d post-merger, with luminosities of 10^{40} – 10^{41} erg s⁻¹. We present simulations of the light-curves, spectra, and the color evolution of the transient. We show that these properties, together with the estimated rate of mergers, are consistent with the absence of detection, e.g., by The Zwicky Transient Facility (ZTF). More importantly, we show that the Legacy Survey of Space and Time (LSST) of the Vera C. Rubin Observatory will likely detect a few/several hundred per year, opening a new window to the physics of WDs, NSs, and SN Ia.

The link to the publication in *The Astrophysical Journal* website is:

<https://iopscience.iop.org/article/10.3847/1538-4357/ad022f>

2. Pereira, J. P.; Rueda, J. A., *Matching Slowly Rotating Spacetimes Split by Dynamic Thin Shells*, *Universe* 9, 305, 2023.

We investigated within the Darmois–Israel thin-shell formalism the match of neutral and asymptotically flat, slowly rotating spacetimes (up to second order in the rotation parameter) when their boundaries are dynamic. It has several important applications in general relativistic systems, such as black holes and neutron stars, which we exemplify. We mostly focused on the stability aspects of slowly rotating thin shells in equilibrium and the surface degrees of freedom on the hypersurfaces splitting the matched slowly rotating spacetimes, e.g., surface energy density and surface tension. We show that the stability upon perturbations in the spherically symmetric case automatically implies stability in the slow rotation case. In addition, we show that, when matching slowly rotating Kerr spacetimes through thin shells in equilibrium, the surface degrees of freedom can decrease compared to their Schwarzschild counterparts, meaning that the energy conditions could be weakened. The frame-dragging aspects of the match of slowly rotating spacetimes are also briefly discussed.

The link to the publication in the Universe journal website is:

<https://www.mdpi.com/2218-1997/9/7/305>

3. Uribe, J. D.; Rueda, J. A., *Neutrino Flavour Oscillations in Gamma-Ray Bursts*, published on February 2023 as a chapter in the book *New phenomena and new states of matter in the Universe: from quarks to Cosmos*, Edited by Peter Hess, Thomas Boller, and Cesar Zen Vasconcellos, World Scientific.

In the binary-driven hypernova model of long gamma-ray bursts, a carbon-oxygen star explodes as a supernova in the presence of a neutron star binary companion in close orbit. Hypercritical (i.e., highly super-Eddington) accretion of the ejecta matter onto the neutron star sets in, making it reach the critical mass with the consequent formation of a Kerr black hole. We have recently shown that fast neutrino flavor oscillations occur during the accretion process onto the neutron star. Numerical simulations of the above system show that a part of the ejecta keeps bound to the newborn Kerr black hole, leading to a new hypercritical accretion process. We address here the occurrence of neutrino flavor oscillations given the extreme conditions of high density (up to 10^{12} g cm⁻³) and temperatures (up to tens of MeV) inside this disk. We estimate the evolution of the electronic and non-electronic neutrino con-

tent within the two-flavor formalism ($\nu_e\nu_x$) under the action of neutrino collective effects by neutrino self-interactions. We find that neutrino oscillations inside the disk have frequencies between $\sim (10^5-10^9) \text{ s}^{-1}$, leading the disk to achieve flavor equipartition. This implies that the energy deposition rate by neutrino annihilation ($\nu + \bar{\nu} \rightarrow e^- + e^+$) in the vicinity of the Kerr black hole is smaller than previous estimates in the literature not accounting by flavor oscillations inside the disk. The exact value of the reduction factor depends on the ν_e and ν_x optical depths but can be as high as ~ 5 .

The link to the book chapter on the World Scientific website is:

https://www.worldscientific.com/doi/10.1142/9789811220913_0002

The first paper in the above list has received attention from the scientific community and media. It has presented the relevant and concise prediction that the forthcoming Vera Rubin Observatory will be able to pinpoint a new class of ever-detected astrophysical sources at a pace of thousands a year: the merger of binary systems of white dwarfs. These results open the way to new research on these astrophysical sources, and the Vera Rubin Observatory and the Zwicky Transient Facility research teams are already collaborating with ICRANet scientists to prepare the observational campaigns of these sources.

Below, we report some of the press releases reporting the results of our research team:

On the ICRANet website:

http://www.icranet.org/index.php?option=com_content&task=view&id=1032&Itemid=920

Press releases in Italy:

On the University of Ferrara website:

<https://www.unife.it/it/notizie/2023/scienza-cultura-e-ricerca/origine-stelle-na>

On Ansa.it

<https://www.ansa.it/emiliaromagna/notizie/2023/11/02/unife-in-team-per-scoprire-75f3c2be-3992-4df0-80a8-49db4a4d8fcd.html>

On Ferraratoday.it:

<https://www.ferraratoday.it/cronaca/astrofisica-unife-icranet-brasile-scoperta-o.html>

On Ultimometro.it:

<https://www.ultimometro.it/uncategorized/unife-in-team-per-scoprire-origine-delle-235580/>

On 30scienze.com:

<https://30science.com/2023/11/news/unife-icranet-e-brasile-insieme-per-scoprire-lo>

On Estense.com:

<https://www.estense.com/2023/1047157/astrofisica-unife-icranet-e-brasile-insieme-p>

Press releases in Brazil:

On the Universidade Tecnológica Federal do Paraná website:

<https://portal.utfpr.edu.br/noticias/geral/divulgacao-cientifica/fusoes-estelares->

On the Universidade Federal do Espírito Santo website:

<https://www.ufes.br/conteudo/estudo-conduzido-por-pesquisador-da-ufes-preve-observ>