Job offer – PhD in Astro-Physics
(*For non-French scientists only*)

Research Project Short Title as Submitted to CEFIPRA: "Exploring the internal structure of neutrons stars with gravitational waves**"**
Principal Investigator contact (Name and email id): "Micaela Oertel, Observatoire astronomique de Strasbourg UMR 7550, micaela.oertel@astro.unsitra.fr"
Reference Number of the Job Offer: IFI_CEF_26_03

Project description

- **Keywords** : Gravitational waves, neutron stars, ultra-dense matter

- **Context** : Physicists have long been intrigued by the inner structure of neutron stars (NS) ever since its proposal by Walter Baade and Fritz Zwicky in 1934. They are the remnants left behind after the death of massive stars and are among the most compact objects in the universe with a mass of ~2suns in a radius of ~10km. The extremely high densities reached in the cores make their inner composition highly uncertain and intriguing, with the potential presence of "exotic" forms of matter other than neutrons, protons and electrons. Present observations do not definitively confirm the presence of exotic matter in the core. With the first detection of gravitational waves (GW) from a binary neutron star merger by LIGO and Virgo in 2017, they have become a promising tool to provide insights into the NS interior.

- **Abstract of the Research Project** : The interior composition of neutron stars is subject of extensive debate and can only be inferred from indirect evidence. Various individual models have been built considering different compositions and effective interactions which are consistent with current observational data on global NS properties such as mass, radius, and tidal deformability. The upcoming generation of ground-based gravitational-wave (GW) detectors, such as the Einstein Telescope and Cosmic Explorer, will provide observations with excellent precision, offering a unique opportunity to constrain the dense matter EoS. In this context, the collection of individual models is not sufficient to pin down the EoS and explore potentially the NS composition. Constructing a flexible and robust relativistic meta-model which allows for a systematic exploration of the allowed parameter space in model building is thus crucial and the first aim of the present project is to extent the purely nucleonic meta-model to include the possibility of an antikaon condensate. With the meta-model at hand, we will investigate the detectability of a phase transition to such a condensate from the GW signal from (i) quasinormal oscillation modes and (ii) the tidal deformability during binary neutron star (BNS) merger inspiral.

- **Scientific Objectives of the Project** : The main question we want to answer whether near future GW detections are able to confirm or infirm the existence of "exotic", i.e. non-nucleonic, matter in the NS. In order to be able to give this answer, several objectives have to be attained: (I) construct a flexible meta-model for the NS interior including the possibility of exotic matter; (ii) investigate detectability through BNS merger inspiral; (iii) investigate detectability from oscillation modes of mature NSs; (iv) investigate detectability through oscillation modes of the BNS post-merger remnant. The stay in Strasbourg concerned by the present offer will be mainly concerned by objective (ii), i.e. to investigate the detectability of an antikaon condensate with GWs from binary neutron star merger inspirals with current and future detectors on the basis of the flexible meta-model to describe NS matter built before.

- **Methodology and Timeline of the Project** : The present job offer for a one year stay in Strasbourg is part of a larger project with a duration of 36 months. The stay in Strasbourg shall take place during the second year of the project, the first being dedicated to constructing the flexible meta-model. In Strasbourg, the focus will be on the detectability of exotic matter from GWs during BNS merger inspiral. To that end, the response of current and future detectors to such events shall be simulated, assuming either a NS with or without exotic matter. The tidal deformablity values predicted from this response will then be compared with the allowed ranges from the metamodel with and without exotic matter. The study will be done for a few loud events as well as for multiple events. Several models for the distribution of the BNS population (with as main parameters the mass distribution and the distance) will be considered to assess whether

the expected precision of the measurements will allow us to tell apart a standard NS interior composition and a one with at least one exotic component. The last year of the project will be dedicated to the remaining objectives on NS oscillations.

Candidate profile

- Candidates can be all nationalities except French. In case of double nationality (French and another one), the candidate is not eligible. In the context of CEFIPRA, Indian candidates are preferred
- Applicants for PhD must have a master's degree (or be in the process of obtaining one) or have a University degree equivalent to a European Master's (5-year duration) to be eligible at the time of the deadline of the call
- No competences in French language is required, a very good level in English is expected.
- Candidate competences: Master in physics, programming languages (Python, C++, Fortran), numerical skills
- Candidate know-how: General knowledge in physics, and in the astrophysics of neutron stars is expected. A thorough knowledge of modeling of NS matter is required, in particular the techniques of covariant density functionals with nucleonic and strangeness ((anti-)kaons, hyperons) bearing degrees of freedom. In addition, knowledge of Bayesian methodolgies necessary in the construction of the meta-model is required.
- Expected starting date: 01/09/2026
- Expected duration: 12 months

How to candidate ?

Documents to be provided :

i. A cover letter (reasons for the candidature, professional project …) max 2 pages
ii. A copy of the master's degree or a proof of the program followed (and expected date of end) OR A copy of the PhD degree or a proof of the PhD program followed (and expected date of defense) max 1 page
iii. A copy of results for previous scholarship (max 3 pages)
iv. A copy of Passport
v. International curriculum vitae (max 2 pages)
vi. Two letters of recommendation: one from any Indian institution and one from the French institution planned to host the candidate –mandatory- (max 2 pages)
vii. All should be submitted within 1 pdf file of no more than 10 pages.

Applications should be submitted to the following email address: msi@institutfrancaisindia.in mentioning the reference number of the Job offer clearly.

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Candidates are requested to contact the French scientific principal investigator of the project before submission. A recommendation letter from the scientific principal investigator is mandatory.

Benefits:

- Monthly allowance of 1870 euros for PhD
- Travel allowance
- University fee
- Carte de séjour fee
- Campus France management fee
- Registration to the French social security scheme

Selection process:

Selection is made by a dedicated selection committee of at least 4 persons. Decisions will be transmitted by the Embassy of France to CEFIPRA. **No consideration will be given for candidates with no recommendation letter from the French institution.**

Criteria for applicants' selection:

Academic excellence

- Excellence of the Academic background, Academic records, Honors, Letters of support, Participation to international research projects, exchange programmes and conferences.

Motivation and qualities

- Academic maturity: appropriation of the thesis project (stakes and contexts) • Quality of the presentation (oral expression, skills for synthesis, English level) • Maturity of the professional project: capacity to project her/himself within five years in terms of career development.

About CEFIPRA:
Indo-French Center for the Promotion of Advanced Research (CEFIPRA/IFCPAR) is an Indian body which promotes scientific cooperation between France and India in advanced fields of Science and Technology. It is supported by the Department of Science and Technology, Government of India and the Ministry of Europe and Foreign Affairs of the French government