平成30年度国立天文台滞在型共同研究報告書
Activity Report for NAOJ Visiting Joint Research in FY 2018

2018／10／30

申請者 Applicant	氏　名 Name	Hajime Sotani
	所属・職 Division・position	Division of Theoretical Astronomy Project Assistant Professor
研究課題名 Research Title	Pulse profiles from rapidly rotating neutron stars	
研究場所 Place	Mitaka Campus.	
共同研究者 氏名・所属・職名 Joint researcher's Name・Institution・Position/ Graduate Student year	Georgios Pappas Sapienza University of Rome Research Fellow	

1．研究概要（Summary of research）

The Neutron star Interior Composition ExploreR (NICER), that launched in 2017 and is currently on the International Space Station, will gather X-ray data on neutron stars and other high-energy sources. One of its scientific goals is to measure the masses and radii of non-accreting neutron stars via fits to the energy-dependent waveforms (pulse profiles) produced by the rotation of hot spots on their surfaces.

Modeling these waveforms has been a topic of great interest due to the relevance it has in probing the properties of neutron stars and the equation of state. To model the waveforms one first assumes that there is a hot spot on the surface of a rotating neutron star with some specific geometry assumptions on the location and characteristics of the hot spot. Then, for a given shape and size of the neutron star and a given spacetime geometry, one performs a ray-tracing calculation from the surface to the observer in order to produce simulated waveforms. This work has gradually evolved from the early Schwarzschild+Doppler model, where one assumes the spacetime geometry to be Schwarzschild and the shape of the star to be spherical and takes into account only the special relativistic effects of the emission from the rotating surface, to more sophisticated models like the oblate Schwarzschild, where one also takes into account the actual ellipticity of the neutron star surface due to rotation. A more sophisticated model would also include the effects of frame dragging and quadrupole of the background spacetime. Investigations along these lines could be performed using the Hartle-Thorne approximation, which is accurate for relatively slowly rotating neutron stars.

For this research project our aim is to extend previous work in order to model more accurately the observed waveforms by introducing a more accurate analytic model for the spacetime that can capture the properties of more rapidly rotating neutron stars, since the sources of interest are expected to rotate in the range of 600-800 Hz. The visiting researcher (Dr. Pappas) has worked on constructing analytic spacetimes that accurately describe the exterior of rotating neutron stars of any rotation rate, which can be used to model astrophysical phenomena that take place around them. These analytic spacetimes are parameterized by the multipole moments of the neutron star and can therefore make easier the connection between the observables and the neutron star properties. Since NICER is already operational and is preparing to start its observations, it is very timely to work on increasing the accuracy of the waveform modeling as well as to work on better understanding the various systematics, uncertainties and degeneracies of the parameter extraction process.

This research project will have three steps. 1) The first step will be to develop the formalism for producing simulated waveforms, reproducing work that has been already performed in the literature. 2) The second step will be the extension of previous work to incorporate the more accurate analytic neutron star and spacetime models, in terms of a small number of parameters, i.e., the mass, the angular momentum and the quadrupole of the neutron star. 3) The third and final step will be to explore how the various parameters affect the simulated waveforms. This step will have several different directions. One direction will be to use different background spacetimes, such as Schwarzschild and Hartle-Thorne backgrounds, and see how the results compare against the results from the more accurate analytic spacetime constructed by the visiting researcher (Dr. Pappas). A second direction will be to employ the full power of the fully analytic description in terms of mass, angular momentum and quadrupole moment and explore how each of these parameters affect the simulated waveforms, in order to better understand possible systematics and degeneracies in the waveform fitting.

２.研究成果(Research achievements)

During the length of the visit at NAOJ, the visiting researcher (Dr. Pappas) worked on the analytic modeling of the surface of a rapidly rotating neutron star. This is a necessary part of the accurate modeling of a waveform coming from rapidly rotating neutron stars, since these objects have a deformed shape that can deviate significantly from the spherical shape. Furthermore this analytic modeling of the surface of a neutron star is needed to complement an analytic description of the exterior spacetime in order to have a fully analytic modeling of the problem. The analytic modeling of the surface has been done in a new way, where the shape of the star is given as a perturbed ellipsoid, in contrast to the usual fitting ansatz used in the literature where the surface is fitted in terms of an expansion in Legendre polynomials of $\cos\theta$. The new fit introduces an eccentricity parameter and two additional perturbation parameters, and has been found to give consistently accurate fits for both slow and rapid rotation rates, performing better than the usual fit in the case of rapid rotation. This falls under the work assigned to the tasks 1 and 2 of the proposal.

The visit also included a colloquium seminar for the Division of Theoretical Astronomy titled, “Testing the Kerr hypothesis with QNMs and ringdowns”.

３．本制度に対する意見、要望など【申請者記載欄】
(Any comments on this program【For applicant】)

I think this program is good for making an international collaboration. I hope this program will continue.

４.本制度に対する意見、要望など【本事業で来訪した共同研究者記載欄】
(Any comments on this program【For joint researcher】)

Visiting NAOJ has been a great experience. The hospitality of the institute and the people here has made this visit memorable. The accommodation and the facilities provided have made working at the Mitaka campus effortless and productive. I believe these visiting fellowships provide an excellent opportunity for collaboration. On this note, I should mention that this visit also gave me the opportunity to collaborate with Dr. Hector Okada da Silva on some common aspects of our waveform modeling projects.

５.共同研究者の滞在日程(Joint research period)

氏名・所属 （Name・Institution）	Georgios Pappas Sapienza University of Rome	
滞在日程（Period of stay）		日数(days)
2018/09/27	～ 2018/10/24	28 days
年　月　日 YYYY/MM/DD	～ 年　月　日 ～ YYYY/MM/DD	日間(days)
合　計（Total）		28 days