【Grant-in-Aid for Scientific Research (S)】

# Elucidating Nucleosynthesis of Neutron Star Mergers using a Telescope at the World Highest Observatory

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## Purpose and Background of the Research

**●Outline of the Research**

We carry out systematic studies of nucleosynthesis of neutron star mergers using the TAO telescope at the world highest site. We improve sensitivity of an NIR instrument SWIMS by about three times, and will take spectra (0.9～2.5μm) of >10 neutron star mergers. We unveil origin of heavy elements by studying synthesized elements focusing on Lanthanum and Cerium.

**●Observations of neutron star mergers**

Neutron star mergers are very rare events, but recently Gravitational Wave (GW) was detected by aLigo and Virgo. Optical Infrared emissions are expected from thermal energy of radioactive decay due to nucleosyntesis of heavy elements. After localization of the merger with wide-field imaging in optical or X-ray, NIR spectroscopy can be carried out.

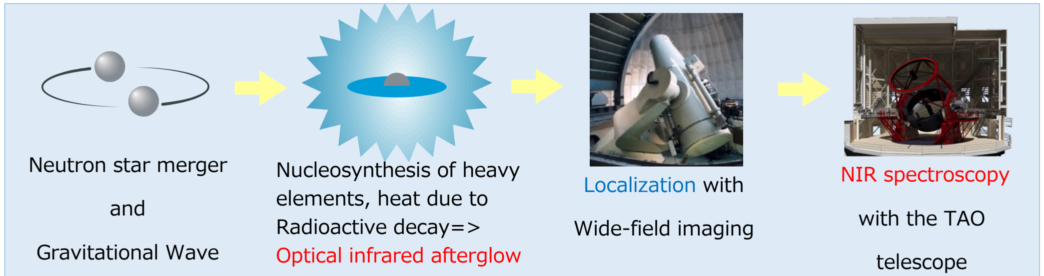


Figure 1 observations of neutron star mergers

**●NIR spectra and advantage of the TAO telescope**

Model calculations of NIR spectra of neutron star mergers（Domoto, Tanaka et al. 2022）predict that Lanthanum（La）and・Cerium (Ce) show specific features as shown in the lower panel of Figure 2. But atmospheric transmission of the expected wavelengths at the normal site is low. Hence we use the TAO telescope located at the world highest site (5640m) whose site has wide and high atmospheric transmissions.

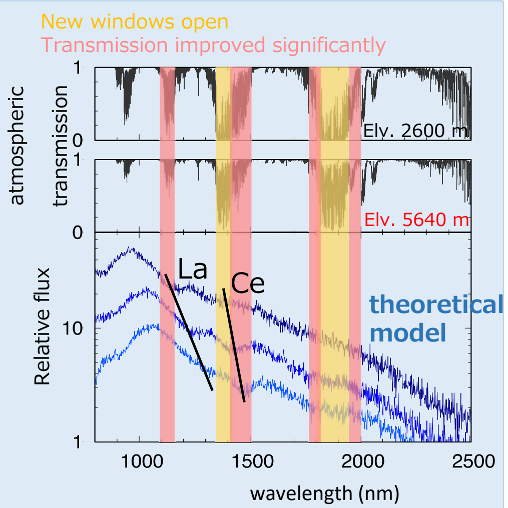


Figure 2（upper panels) Atmospheric transmission at elevation of 2600m and 5640m. (lower panel) NIR Model spectra of neutron star merges.

**●Sensitivity Improvement**

Sensitivity of GW telescopes is going to be improved, and during the fifth run (O5), neutron star mergers at about 200Mpc (630 million light years) can be found. Then NIR spectroscopy of neutron star mergers down to 21.5 mag is necessary.

Hence, we are going to introduce middle resolution spectroscopy mode for SWIMS instrument of the TAO telescope. By masking strong sky emission lines such as OH, sensitivity will be improved by about three times, as shown in Figure 3, and we can study spectral features such as Lanthanum and Cerium by a few hours observations.

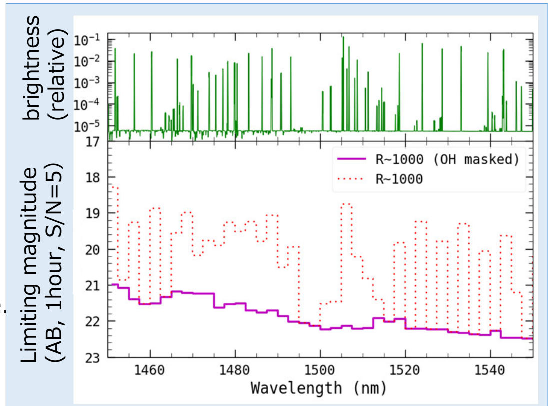


Figure 3 sky emission lines and limiting magnitude

**●Higher Dispersion Mode**

Wavelength Resolution of TAO/SWIMS is at the moment λ/Δλ~1000. In order to improve sensitivity by 3 times, spectral resolution need to be more than λ/Δλ~4000. To achieve this, we adopt an Echelle mode which uses orders (order=optical path difference / wavelength) from 4 to 6 instead of 1. We will add two detectors to cover all NIR wavelength range in this mode.

By adding two detectors, the field of view for imaging and for IFU spectroscopy will be increased, and more scientific topics can be carried out efficiently.

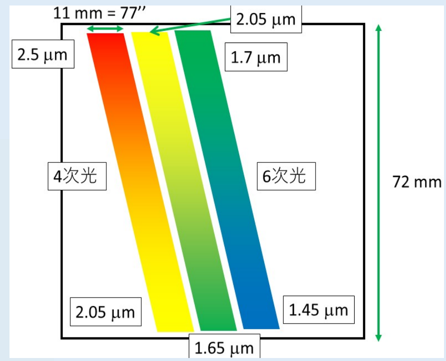


Figure 4 spectra on the detectors

## Expected Research Achievements

So far, detailed observations of neutron star mergers were successfully made only one case, GW170817, which was found by GW telescopes (aLIGO, Virgo).

In order to study nucleosynthesis of neutron star mergers and equation of state of neutron stars, at least 10 cases of neutron star mergers need to be observed, as we need to study dependence on mass of neutron stars or on line of sight of observations. Sensitivity of GW telescopes will be improved to find neutron star mergers up to about 200 Mpc (630 million light years), and about 10 per year will be found when the fifth run（O5) starts.

We improve sensitivity of SWIMS of the TAO telescope by introducing higher dispersion mode, and obtain NIR spectra (0.9～2.5μm) for more than 10 neutron star mergers at multiple epochs. We construct theoretical models which can explain those NIR spectra (especially focusing on Lanthanum and Cerium features) together with observational results of Gravitational Waves and other electro-magnetic waves, and understand how heavy elements (heavier than Fe) are synthesized. We also constrain equation of state of neutron stars by studying dependence of the radius of neutron stars on the ratios of heavy elements synthesized.

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| Homepage Address, etc. | TAO telescope：http://www.ioa.s.u-tokyo.ac.jp/TAO/en/<br>This work: http://www.ioa.s.u-tokyo.ac.jp/~doi/doi's_project.htm |