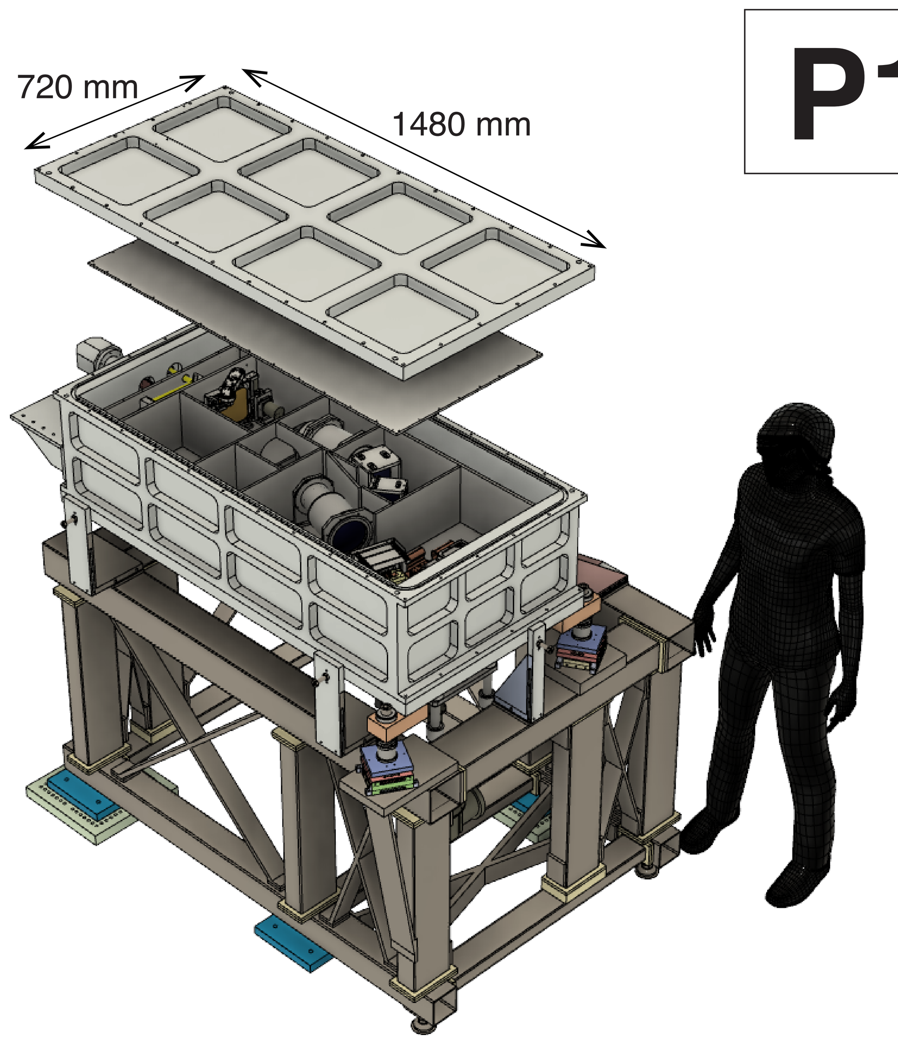

P16

NINJA: the wide-band spectrograph optimized for the Laser Tomography Adaptive Optics

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NINJA is designed to optimize for the Laser Tomography Adaptive Optics (LTAO) for the Subaru Telescope. NINJA will obtain both the optical and NIR spectra simultaneously. It will be designed, manufactured, assembled, and tested in Mitaka, and transported to the Subaru. We plan to develop the NIR spectrograph first, followed by the optical one. Science observations in NIR will be planned to start in 2026. If you are interested in science, development, or observation, please join us!
This work is supported by Japan Society for the Promotion of Science (JSPS) KAKENHI, Grant-in-Aid for Scientific Research (S), Grant Number 21H04997. Part of the development is supported by the ATC/NAOJ.

SCIENCE OBJECTIVES

The main scientific objective of NINJA is to reveal origins of elements through observations of kilonovae as well as supernovae. Especially, through the observations of the kilonova AT2017gfo followed by a double neutron star merger discovered by the gravitational wave event GW170817, it has been confirmed that r-process elements are synthesized in double neutron star mergers. However, AT2017gfo remains to be the only kilonova identified with gravitational waves. Many more observations of kilonovae are required to understand the general nucleosynthesis properties of double neutron-star mergers. In order to estimate how much r-process elements are synthesized in a double neutron star merger, it is required to conduct spectroscopic observations in the optical and NIR of a kilonova at least for a week after its merger. Indeed, VLT/X-Shooter spectra of AT2017gfo that covered the optical and NIR simultaneously played essential roles in revealing its nucleosynthesis signatures. During the O5 of the gravitational wave observatories starting in 2027, about 50 neutron star mergers out to 200 Mpc are expected to be discovered by gravitational wave events in a year. **To conduct spectroscopic follow-up observations of kilonovae at 200 Mpc for a week after the mergers, we require a spectrograph with a limiting magnitude of 22 mag in the NIR** (Figure 1). By reaching 22 mag with NINJA, we can significantly increase the observational constraints on the nucleosynthesis in neutron-star mergers during O5 and obtain general nucleosynthesis properties in neutron star mergers.

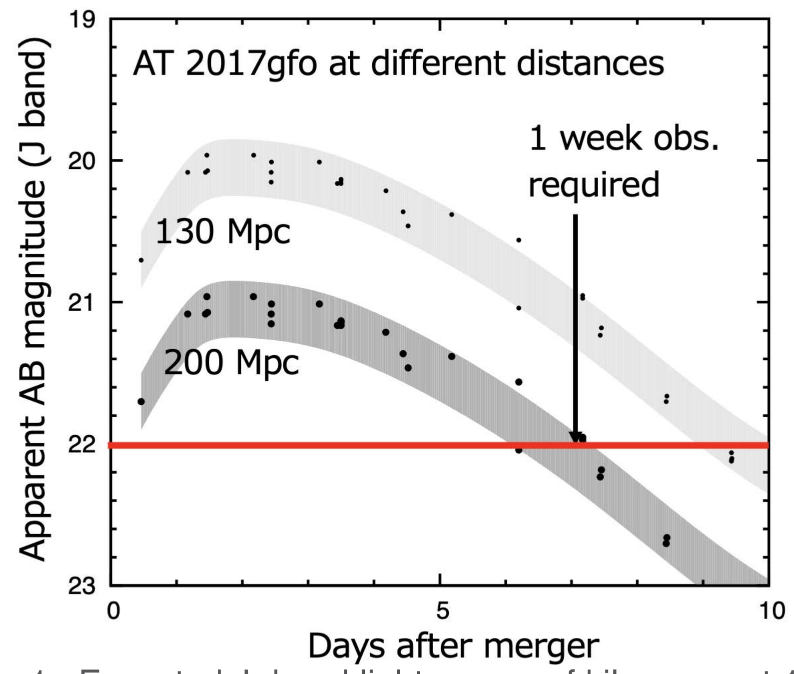

Figure 1 : Expected J -band light curves of kilonovae at 130 Mpc and 200 Mpc. In order to observe a kilonova at 200 Mpc for one week after its merger, limiting magnitude deeper than 22mag is necessary.

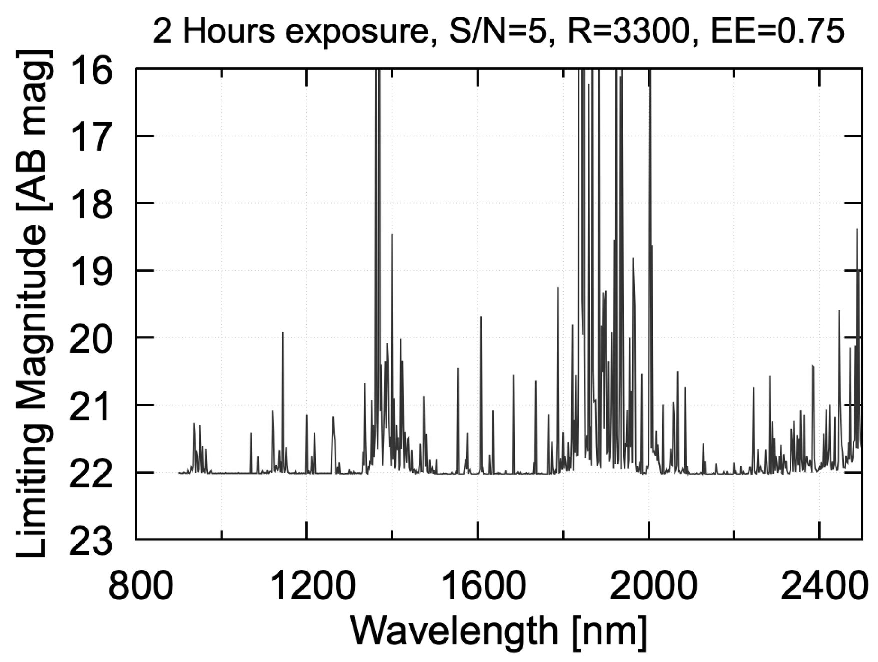

Figure 2 : Expected LTAO+NINJA limiting magnitude. This estimate does not include thermal radiation.

DESIGN

The optical system of the NIR spectrograph is shown in Figure5. A grating is used in a quasi-Littrow configuration. A collimator and cross-dispersing prisms are used in double path. A concave field mirror transfers a pupil image around the first element of a camera lens system. Efficiency of the spectrograph is estimated to be ~43% not including the detector.

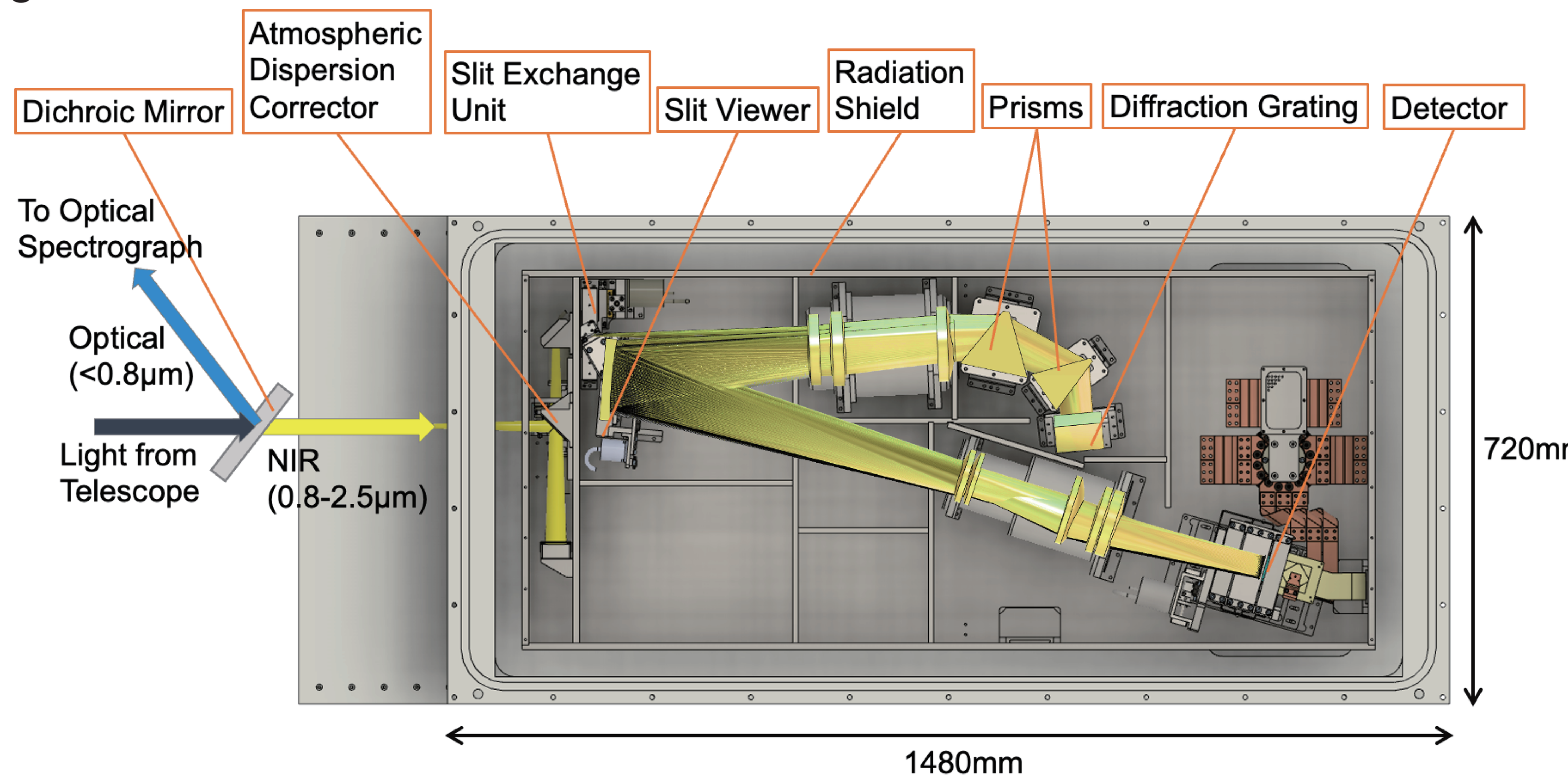

Figure 4 : The optical system of the NIR spectrograph in the cryostat.

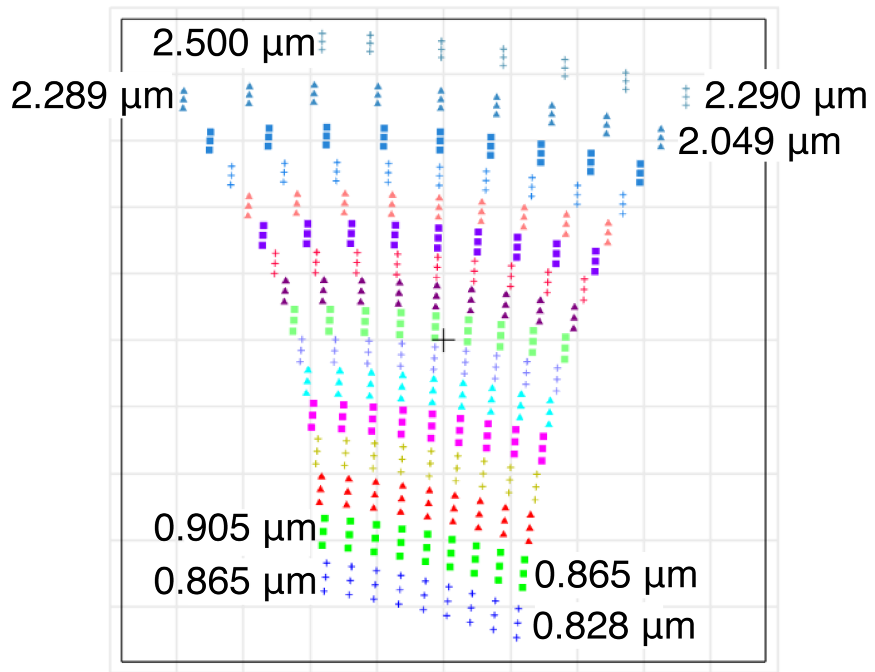

Figure 5 : Simulated Echelle format. The black solid square shows the detector area of the HAWAII-2RG.

Table 1 : NIR spectrograph parameters

Wavelength Coverage	0.83 – 2.5 µm
Input F Ratio	13.9
Slit Width (Spectral Resolving Power)	0.35″ (R~3300) 0.21″ (R~5500) 0.5″ (R~2310) 0.7″ (R~1650)
Slit Length	5″
Collimator Focal Length	597.7 mm
Pupil Diameter	43.0 mm
Detector	HAWAII-2RG (2048 x 2048 pix)
Pixel Size	18 µm/pix
Sampling for 0.35″ Slit Width	3.3 pix

LASER TOMOGRAPHY ADAPTIVE OPTICS

In the ULTIMATE-Subaru project, in addition to the wide-field ground layer adaptive optics (GLAO), the laser tomography adaptive optics (LTAO) mode is under development. Although the field of view is limited in the LTAO mode, it is expected to significantly improve spatial resolution both in the NIR and optical wavelength. Please see poster P14 (Akiyama et al.) for details on the LTAO.

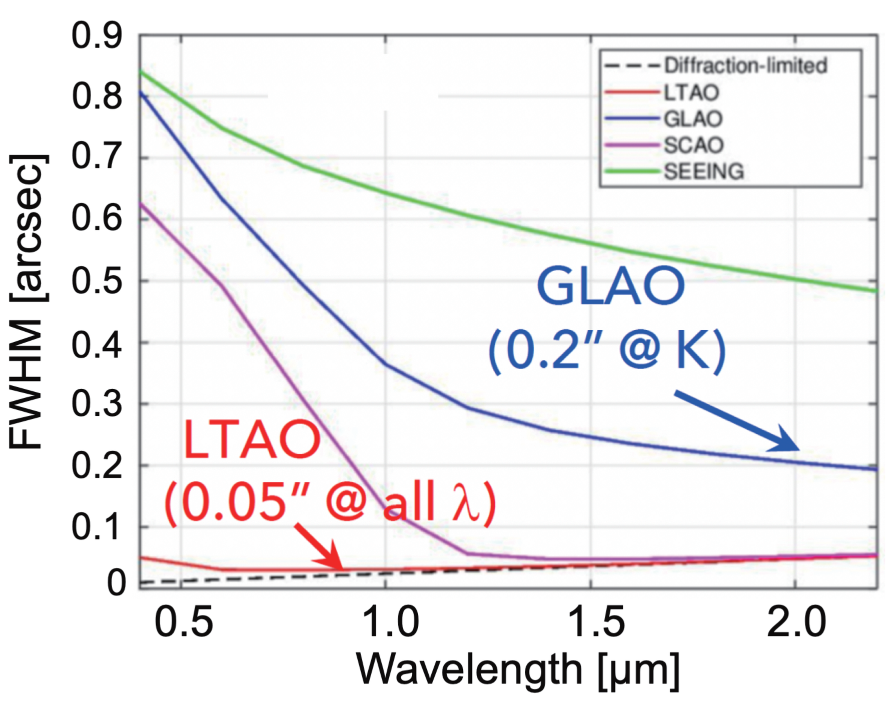

Figure 3 : Expected FWHM as a function of wavelength. LTAO performance (red line) achieve 0.05 arcsec of FWHM in entire optical and NIR band. (Terao et al. 2022)

DEVELOPMENT PLAN

The engineering **first light is planned in S25B** (TBD) and the start of science observation in S26B (TBD).

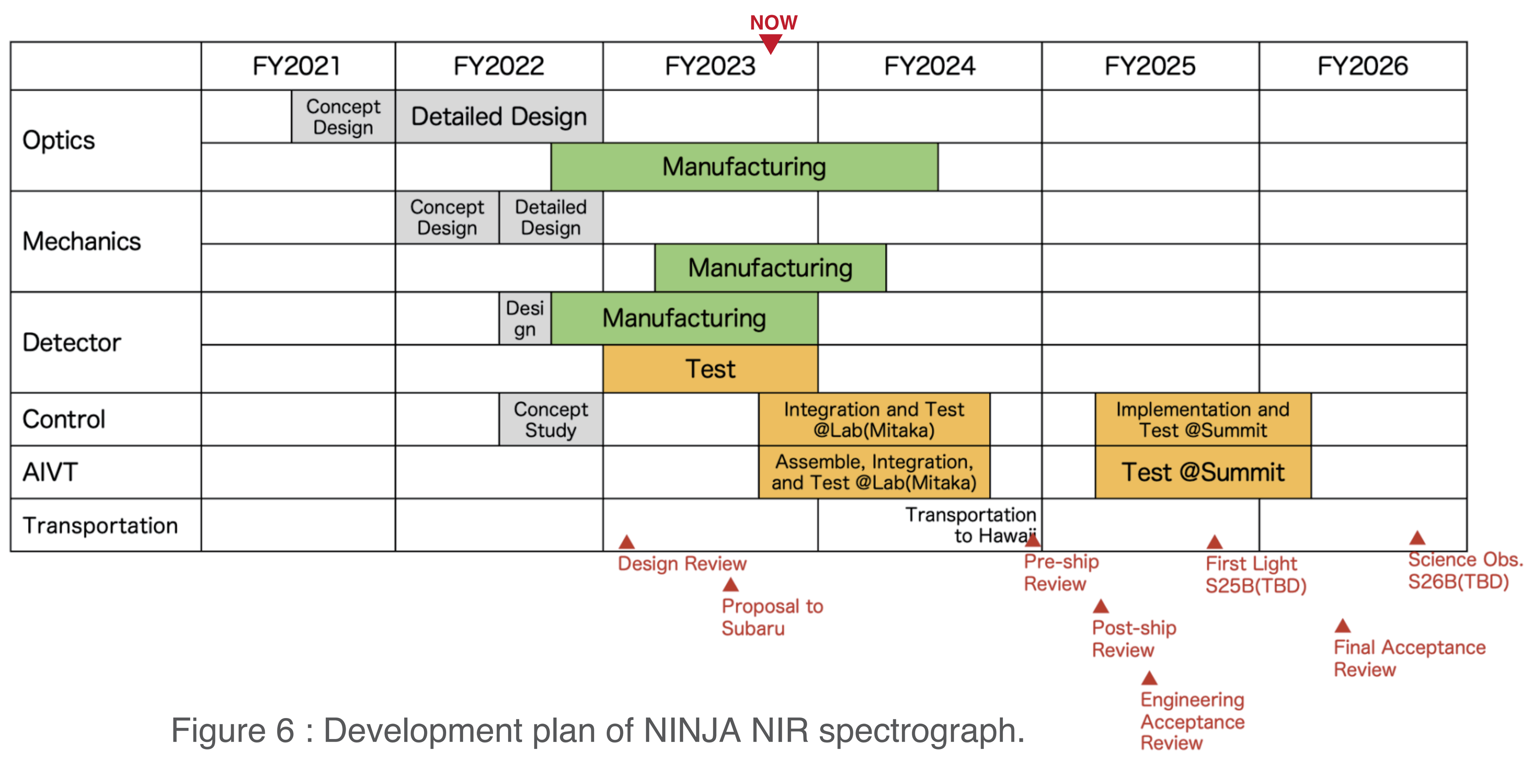

Figure 6 : Development plan of NINJA NIR spectrograph.