



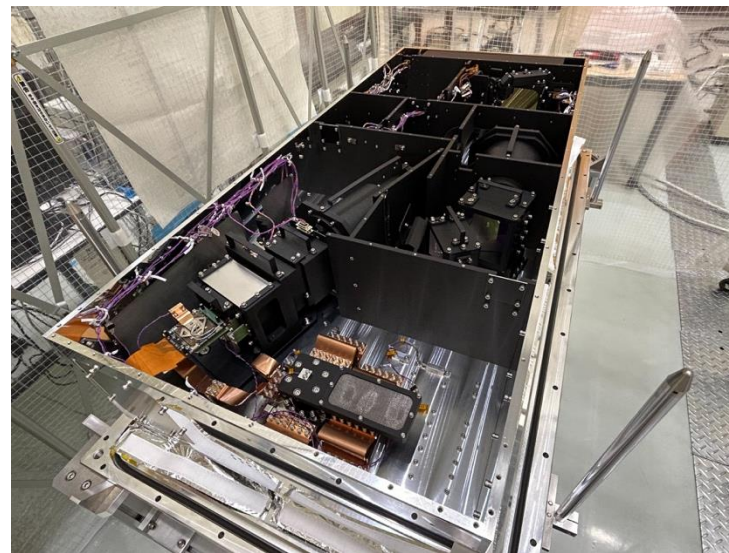
Sensitivity estimation of NINJA NIR-arm

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What is NINJA?

- NINJA is a new spectrograph for Subaru telescope covering the optical-NIR wavelengths
 - NIR-arm is now under development, Opt-arm in funding stage
 - NINJA will be connected to AO188 system (and LTAO in the future)
(LTAO → Tanabe-san, Narayama-san's talk)
 - Optimized for LTAO, equipped with a narrow slit
- **alignment is one of the key technical challenges** (Tomorrow, Yukino-san's talk)

Parameter	Specification
Wavelength Range	0.83 – 2.5 μm
Focal ratio	13.9
Slit Width (Spectral Resolution)	0.35" ($R \sim 3300$)
	0.21" ($R \sim 5500$)
	0.5" ($R \sim 2310$)
	0.7" ($R \sim 1650$)
Slit Length	5"
Detector	1 HAWAII-2RG (2048 x 2048 pixels)
Pixel Size	18 $\mu\text{m}/\text{pix}$
Sampling (0.35" Slit)	3.3 pix



Science cases and requirements

Origin of heavy elements

Kilonovae

**400-2500 nm, R ~ 1000,
22 AB (5 σ , 2h)**

Galaxy formation at z > 11

LAEs & LBGs at z > 11

800-2200 nm, R > 3000,
3E-18 erg/s/cm² (5 σ)

Physical process of quenching

Massive QGs at z > 2

1000-2500 nm, R ~ 4000,
A few E-19 erg/s/cm²/AA in K-band

Quasars in EoR

Quasars at z > 6

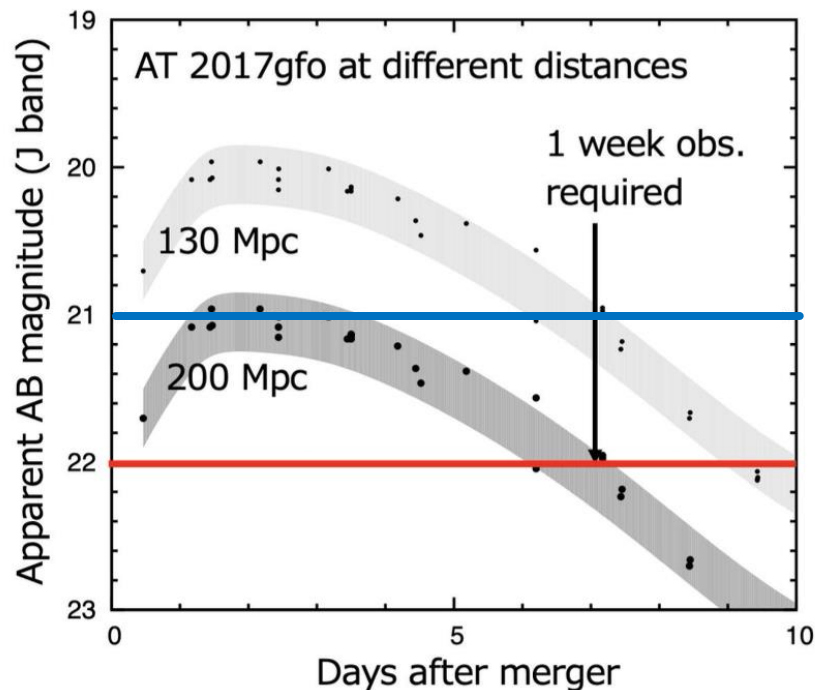
800-2500 nm, R ~ 1000-2000,
21AB (5 σ , 1hr)

IMF of EMPGs

EMPGs at z > 4

360-1300 nm, R > 5000
1E-18 erg/s/cm² (5 σ)

Requirement for Kilonovae observation



Expected J-band light curves of kilonovae

VLT/ X-shooter sensitivity (2h, SN=10)

Required sensitivity to observe kilonovae at ~200Mpc one week after merger (2h, SN=10)

Observation(s) up to 1 week after the merger

→ J-band limiting magnitude 22 magAB within 2 hours

→ **One magnitude deeper than VLT/X-shooter**

Characteristics of NINJA

8m-telescope + LTAO

Highest sensitivity
among 8m-telescopes

Simultaneous
wide wavelength coverage

Time-efficient
observation

realize

**Several 2-hour follow-up observations
within one week after the merger**

Motivation of this study

22 AB at the J-band with 2-hour exposure
→ One magnitude deeper than X-shooter



Sensitivity estimation

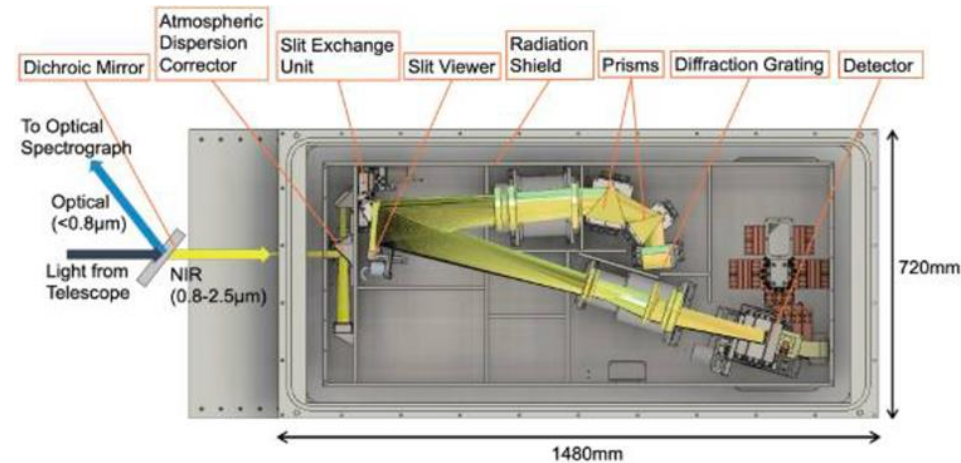
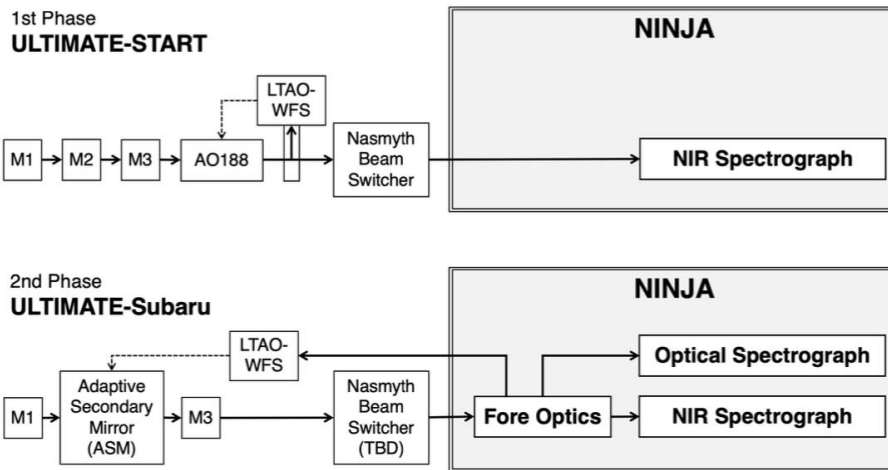


**Confirm feasibility, derive parameter set,
ETC...**

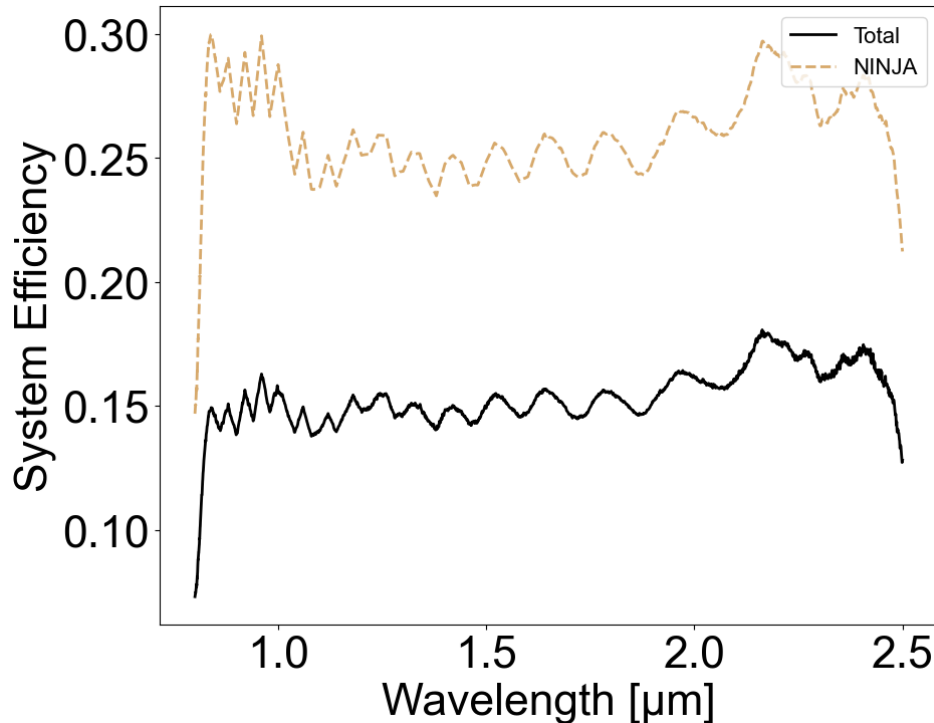
First phase system component

- Telescope (M1, IR-M2, IR-M3)
- AO188, LTAO
- Nasmyth beam switcher (NBS)
- NINJA NIR spectrograph

NsIR platform



System efficiency of NINJA



Component	Efficiency
M1, IR-M2, IR-M3	0.87
AO188	0.82
NBS	0.93
LTAO	0.91
NINJA	0.26
[Fore optics only]	[0.82]
[NIR spectrograph]	[0.32]
[NIR Spectrograph (w/o detector)]	[0.45]
Total	0.15

- Total system efficiency is about 15% on average
- Maximum efficiency of NINJA NIR spectrograph is high as 26%

SNR calculation

$$S/N = \frac{\tau\eta n_{\text{obj}} t_{\text{tot}}}{\sqrt{\tau\eta n_{\text{obj}} t_{\text{tot}} + m_{\text{pix}} \left(\eta n_{\text{sky}} + n_{\text{dark}} + \frac{2N_{\text{read}}^2}{t} \right) t_{\text{tot}}}}.$$

n_{obj} : number of photons emitted by the target object per unit time [photons/s],

τ : atmospheric transmission, η : system efficiency,

t : integration time per frame [s], t_{tot} : total integration time [s],

m_{pix} : number of pixels corresponding to the object's spatial extent [pix],

n_{dark} : dark current [e /s/pix], N_{read} : readout noise [e /pix],

n_{sky} : sky background photon count per unit time and per pixel [photons/s/pix].

- I_{λ} : sky background intensity [photons/s/arcsec²/μm/m²],

$$n_{\text{sky}} = \frac{I_{\lambda} S_{\text{tel}} A_{\text{slit}} \Delta\lambda}{m_{\text{pix,sky}}}$$

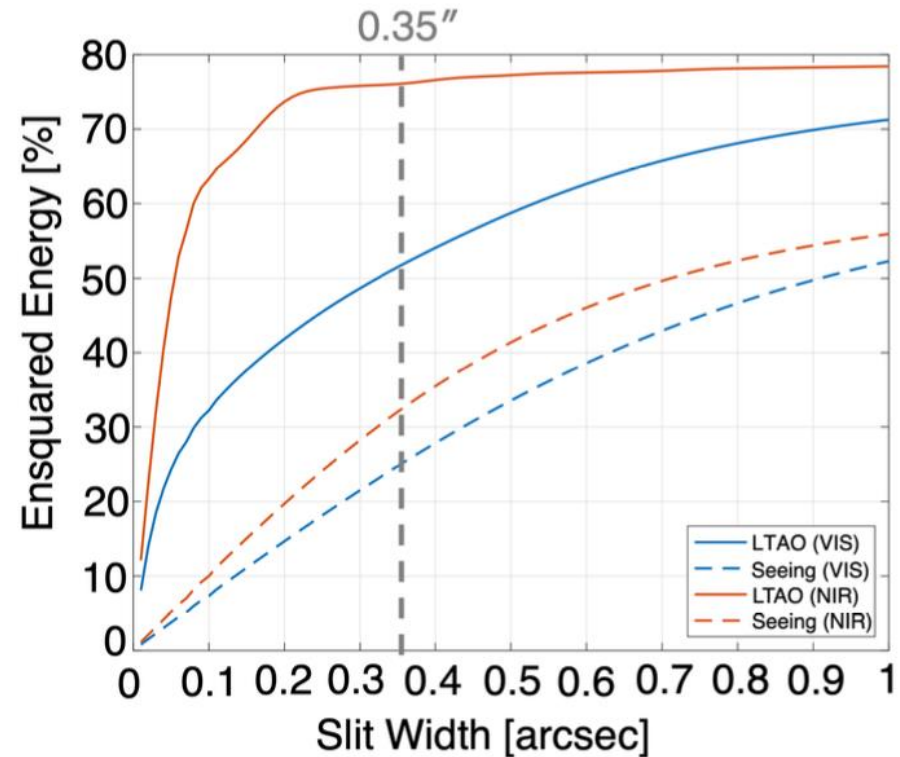
- S_{tel} : telescope mirror area [m²],

- A_{slit} : area on the celestial sphere covered by the slit [arcsec²],

- $\Delta\lambda = \lambda/R$: wavelength range.

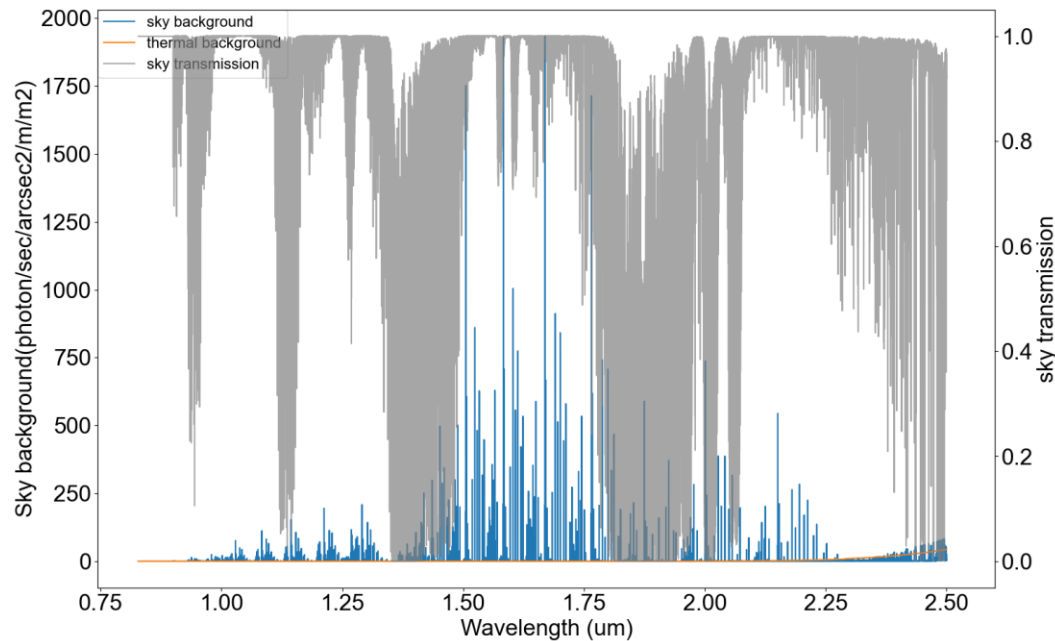
Parameters (1/2)

- Wavelength coverage: 0.9 – 2.5 μm
- $R \sim 3300$ (0.35" slit)
- Total exposure time: 2 hours.
- Single-frame exposure time: 900 s.
- A-B dithering pattern
- Assuming QE of H2RG = 70 %
- $N_{\text{read}} = 4.0 \text{ e- rms}$ and 8.0 e- rms
- Dark current = $0.05 \text{ e-}/\text{s}/\text{pix}$
- Spatial extent: 12.2 pix
- LTAO performance: good AO condition
- 75% of total energy is ensquared within the 0.35" slit

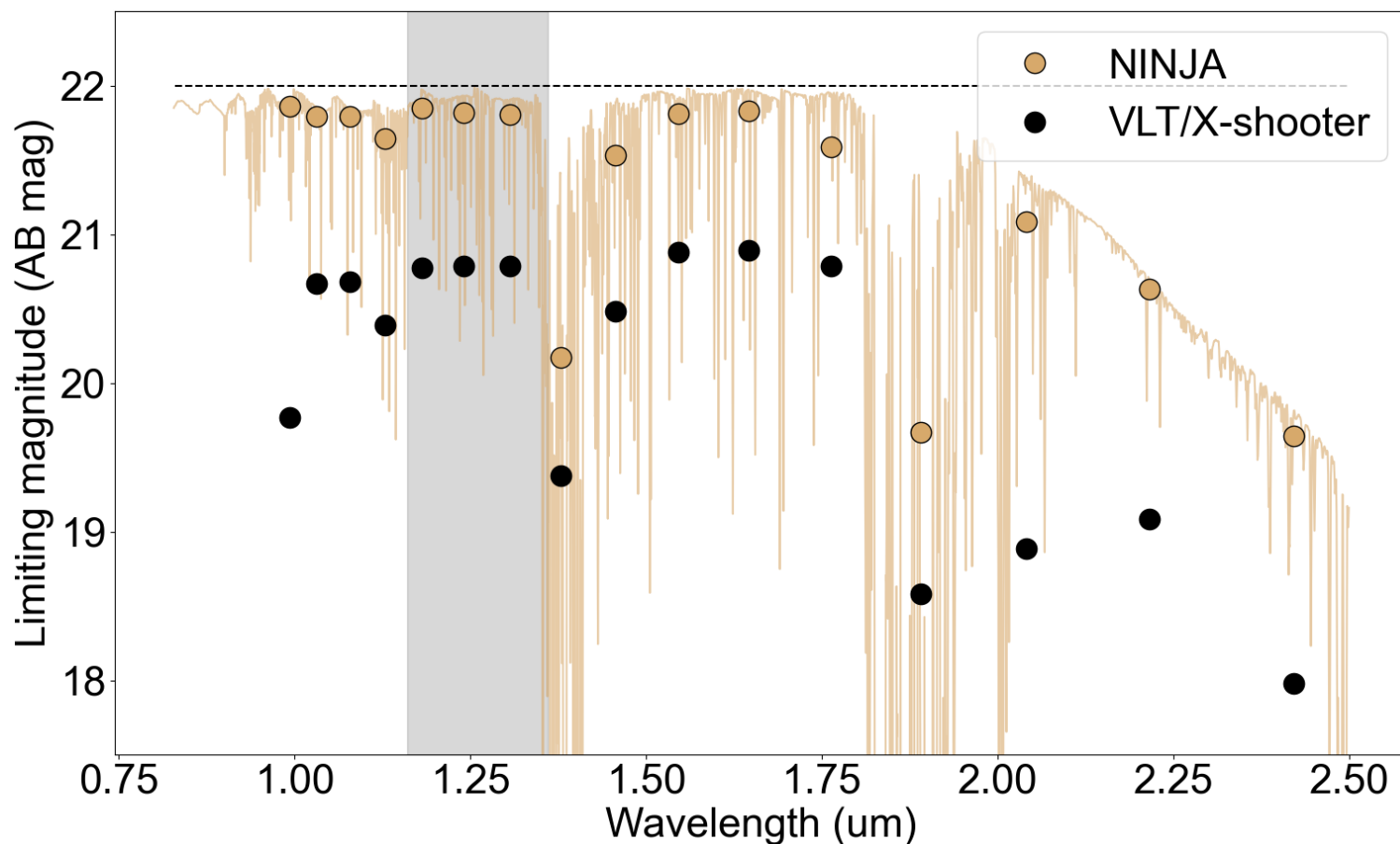


Parameters (2/2)

- Thermal emission from telescope: $T = 278 \text{ K}$, total emissivity = 0.37
- Atmospheric transmittance at @MK: Air mass 1.0, PWV 1.0 mm
- Airglow data taken from Gemini Sky Background Data
 - Air mass 1.0, PWV 1.0 mm
 - OH emission, O₂ emission, H₂O, continuum, thermal radiation from sky (273K)

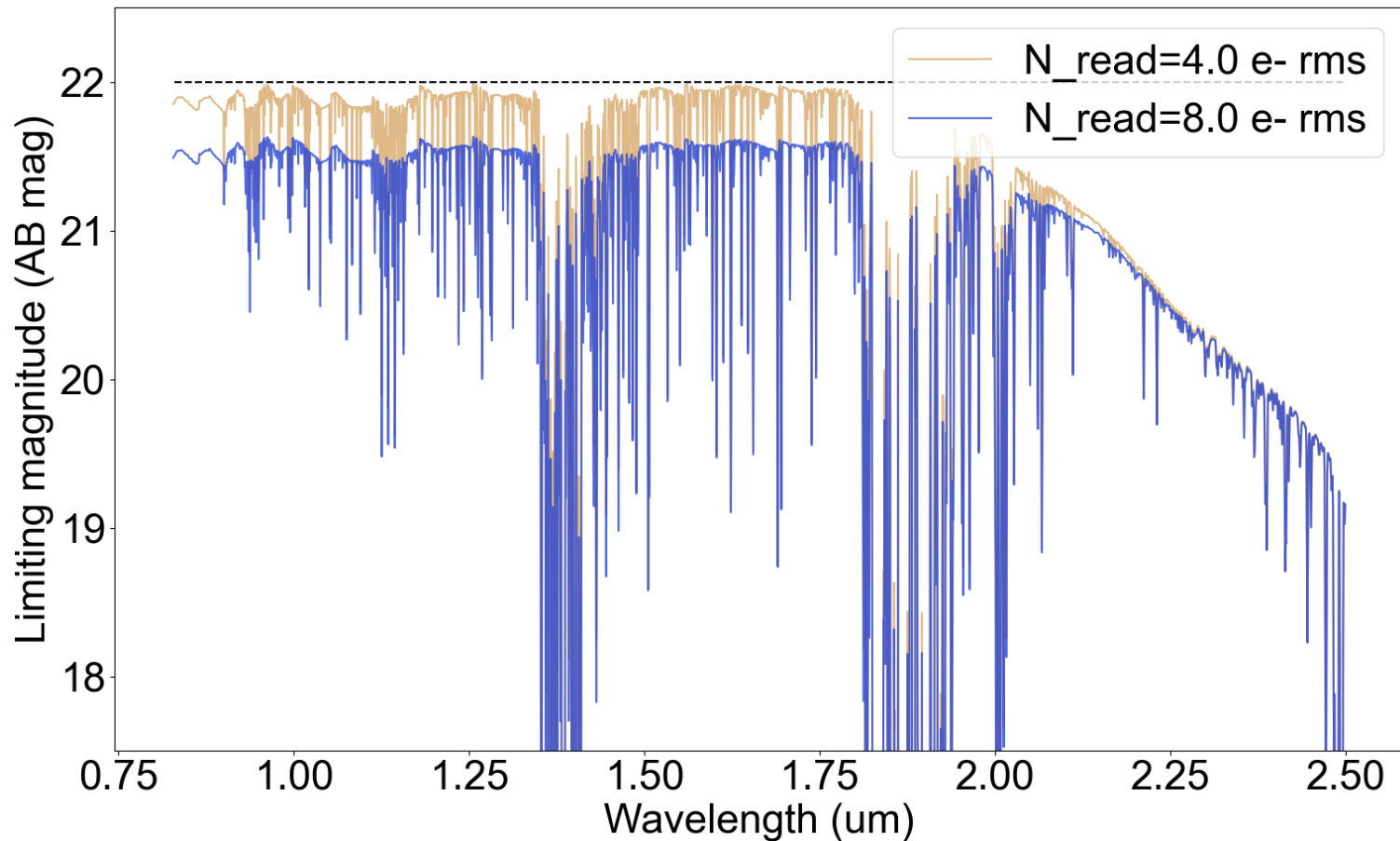


Result: Limiting magnitude in 2 hours



NINJA can achieve ~ **22 mag** in **J-band** in **2 hours**
→ **"one magnitude deeper"** than X- shooter

Result: Calculation in different parameter



N_{read} impacts the sensitivity in YJH
 $\rightarrow N_{\text{read}} \sim 4 \text{ e- rms}$ is required

Future work

- Better implementation of LTAO
 - PSF size
- Effect of “Detector slide” mechanism
- second phase optics
 - Integrate both into future NINJA ETC

Summary

- We confirm that the key requirement can be achieved:
Limiting magnitude of 22 ABmag in J-band with 2 hours.
→ one magnitude deeper than X-shooter NIR-arm
- To reach this performance, we require **$N_{\text{read}} \sim 4 \text{ e- rms}$**
→ next Tanaka-san's talk
- Future work: Effect of LTAO and detector-slide
→ NINJA ETC