すばる望遠鏡広帯域分光装置 NINJA 検出器読み出し最適化
Optimization of NINJA detector system

田中健翔 (東京大学 修士2年)

柳澤顕史 (国立天文台), 森鼻久美子(国立天文台), 鎌田有紀子 (国立天文台),
本原顕太郎 (東京大学・国立天文台)

2025/11/10 可視赤外線観測装置技術ワークショップ 2025@京都産業大学

Outline

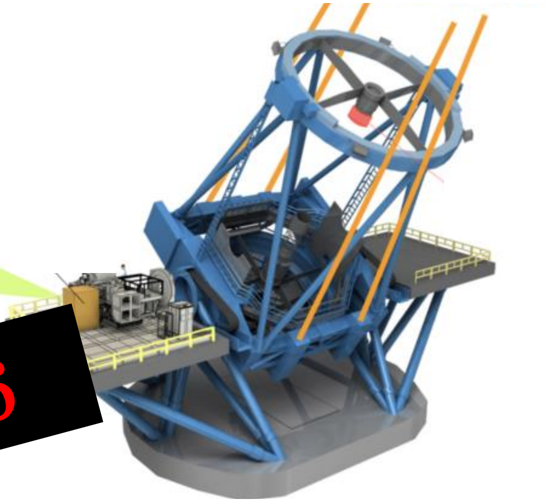
1. About NINJA
2. NINJA detector system
3. Requirements for developing NINJA detector system
4. Parameters of the detector system
5. Optimized Result
    - Readout noise and dynamic range
    - Persistence
6. Summary

What is NINJA?

Near-**IN**frared and optical **J**oint spectrograph with **A**daptive optics

- **IR spectrograph optimized for Laser Tomography Adaptive Optics (LTAO)**

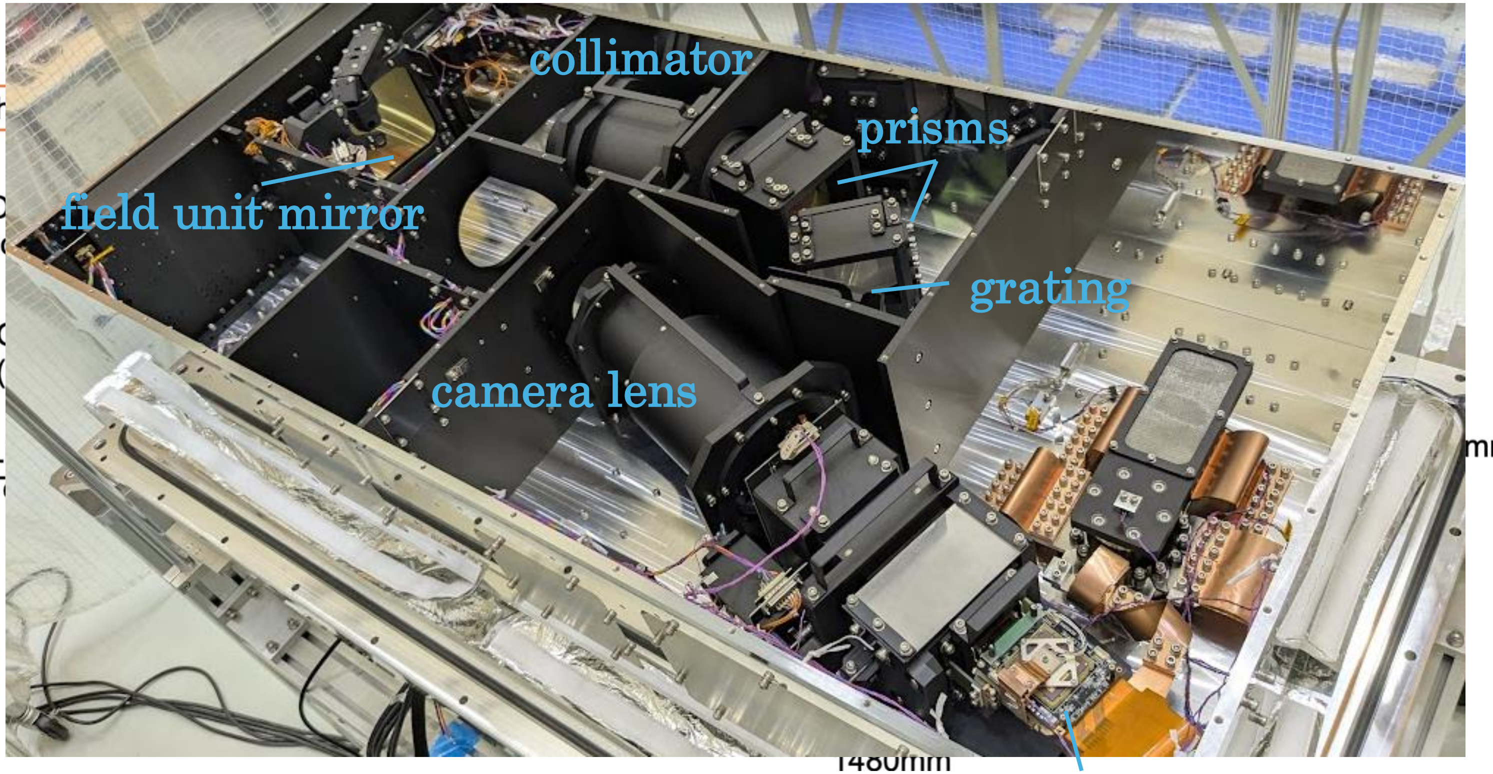
- **1 mag deeper** than present spectrographs (e.g. VLT/X-shooter)
- Aims for observing kilonova caused by neutron star merger within 200Mpc



Subaru Telescope

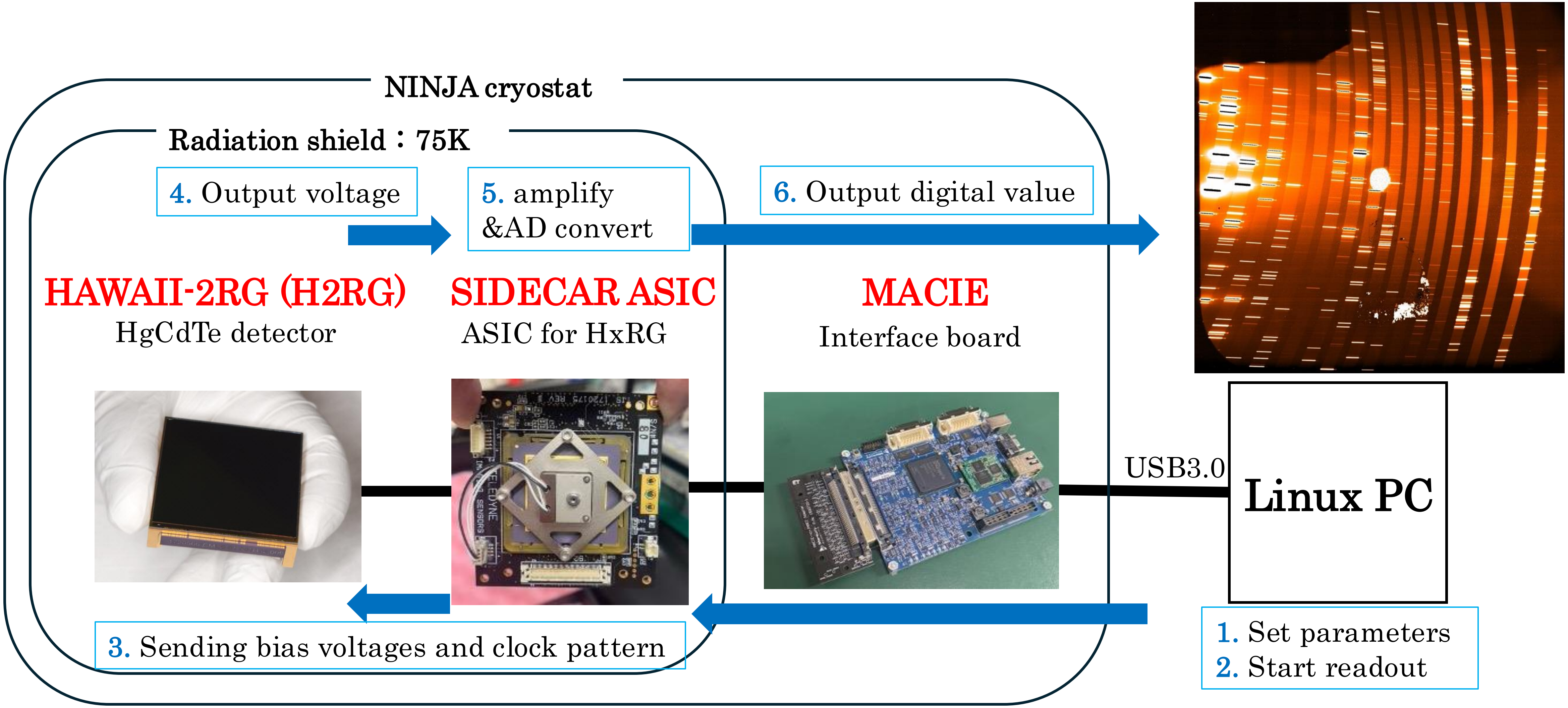
First light is scheduled in 2026

What is NINJA?



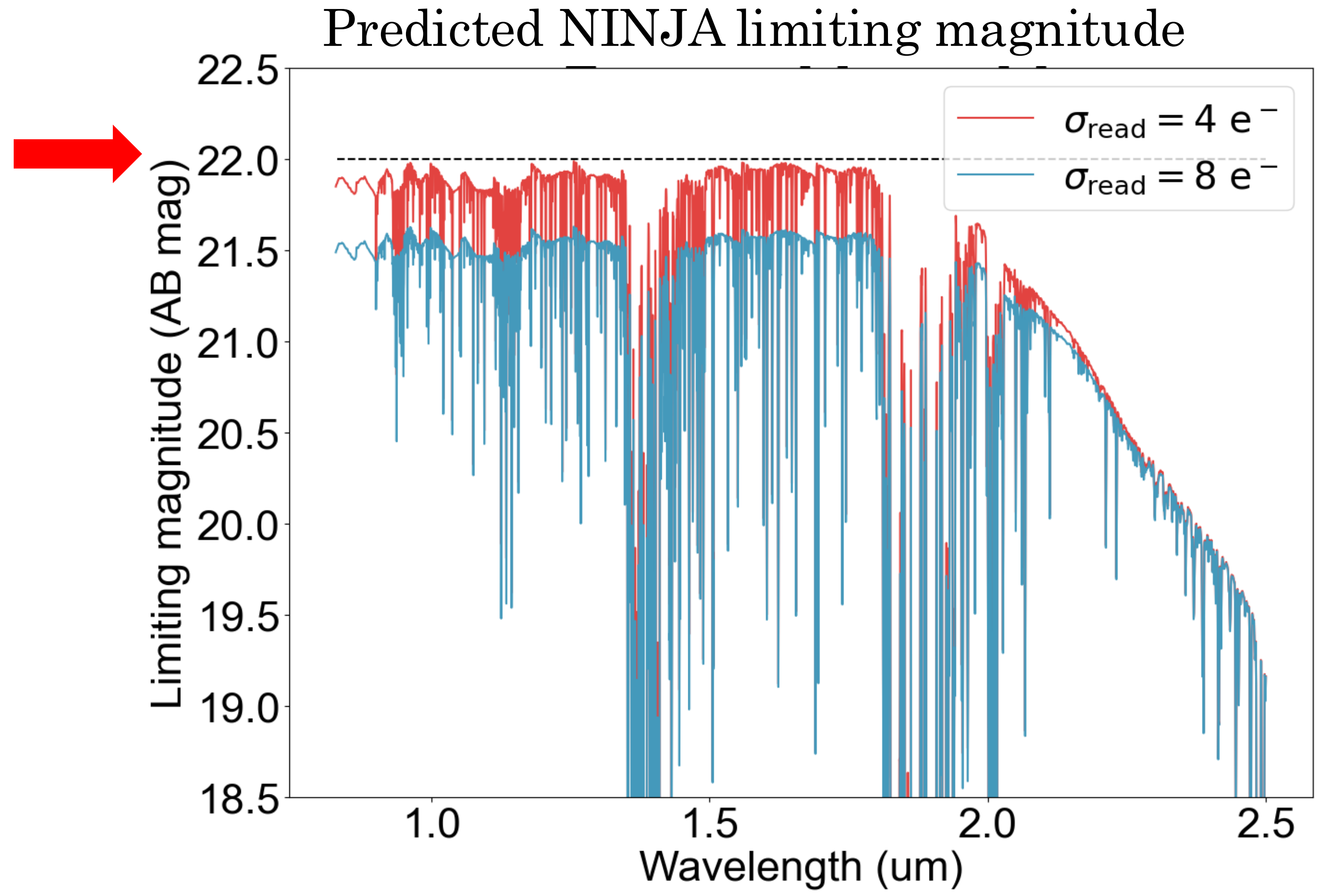
Spec	
wavelength	0.83-2.5μm
F ratio	13.9
Slit width, resolution	0.35″ R~3300 0.21″ R~5500 0.5″ R~2310 0.7″ R~1650
Slit length	5"
detector	HAWAII-2RG x 1 (2048 x 2048pix, 2.5μm cutoff)
Pixel size	18 μm/pix
Pixel scale	0.126”/pix
Limitting magnitude (J band)	22mag (S/N=10, 2hr)

NINJA detector system



Requirement for low readout noise

target



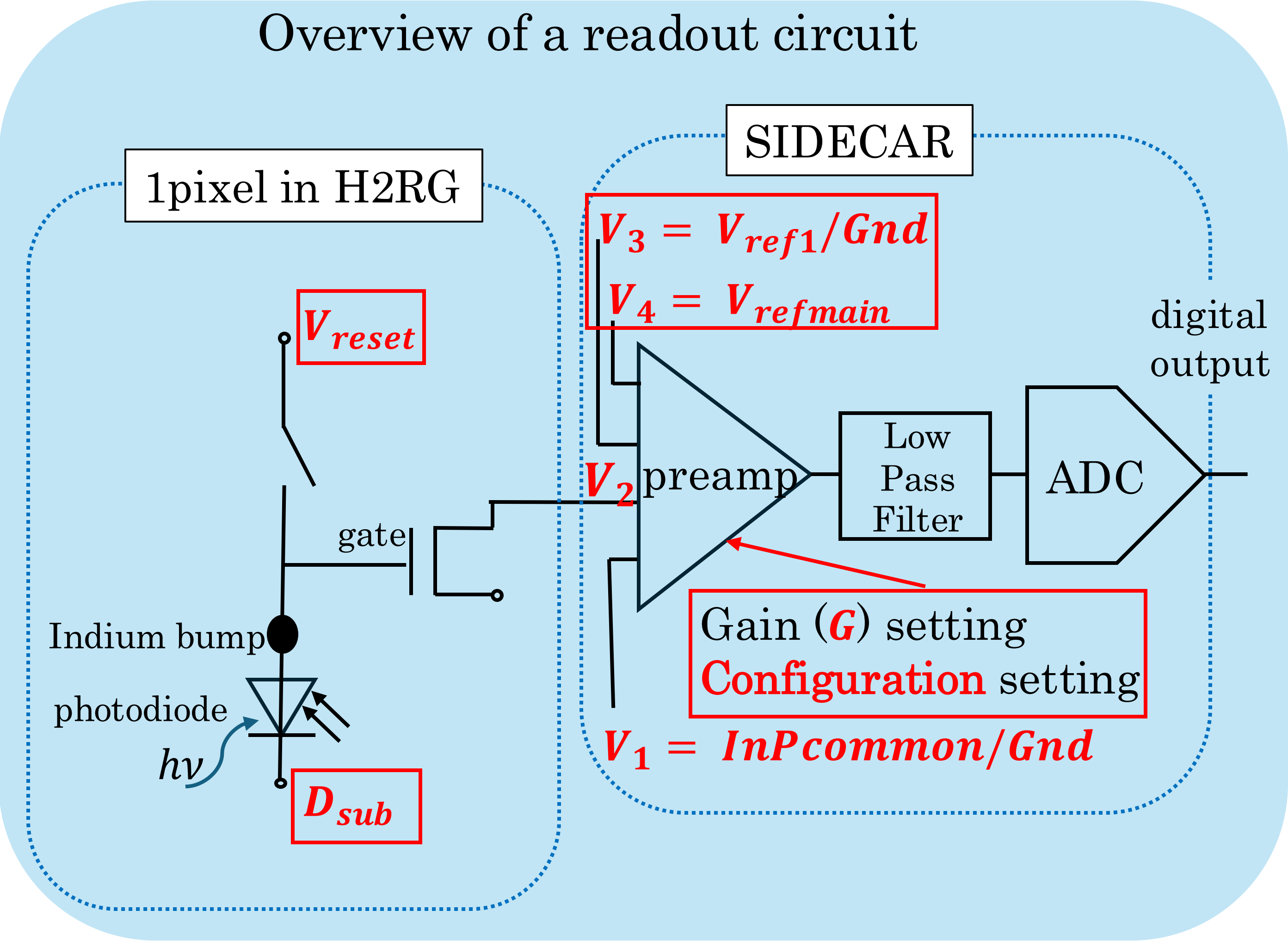
calculate parameters
Single exposure time = 900s
Total exposure time = 2hr
S/N=10
At Mauna Kea

→ It is required to **achieve $\sigma_{read} < 4e^- \; rms$** for target sensitivity.

→ It is necessary to optimize parameters of the detector system.

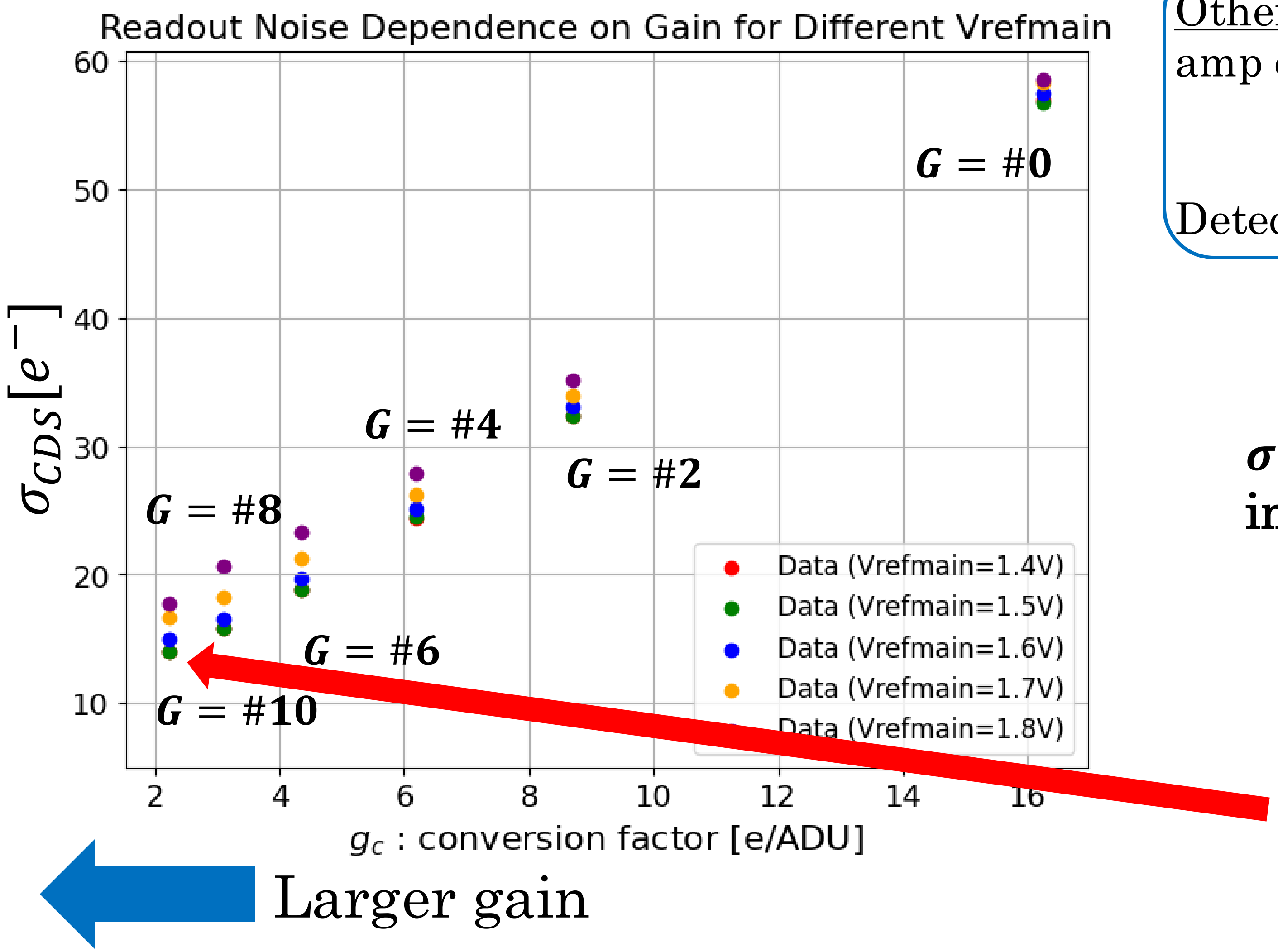
Parameters of the detector system

- bias voltages for H2RG detector :
  - ➢ V_{reset}, D_{sub}
- Preamp settings in SIDECAR :
  - Amplify the difference between $V_2 - V_1$ and $V_4 - V_3$ with gain setting
  - ➢ **Configuration**
    - Vrefmain mode
      - $V_1, V_3 = Gnd$
    - InPcommon mode
      - apply voltage to V_1, V_3
  - ➢ Reference voltages ($V_{refmain}, V_{ref1}$)
  - ➢ **Gain (G)**



→ Searching for the parameters which realize lowest readout noise

Result : lowest readout noise parameter set

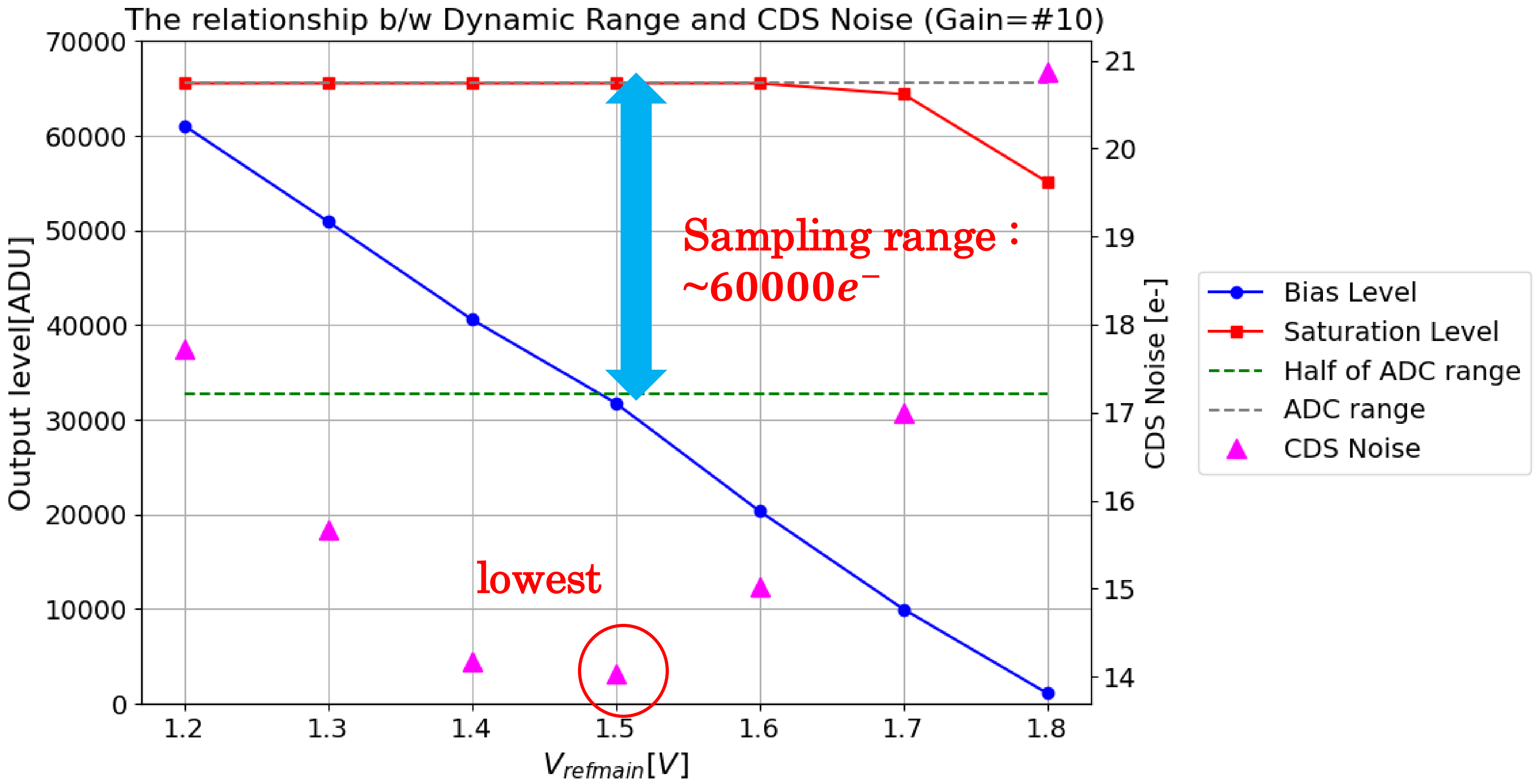


<u>Other parameters</u>
amp config : Vrefmain mode
$V_{reset} = 0.3715V$
$D_{sub} = 0.6215V$
Detector temperature : 80K

σ_{CDS} is calculated by two dark CDS images with variable G and $V_{refmain}$.

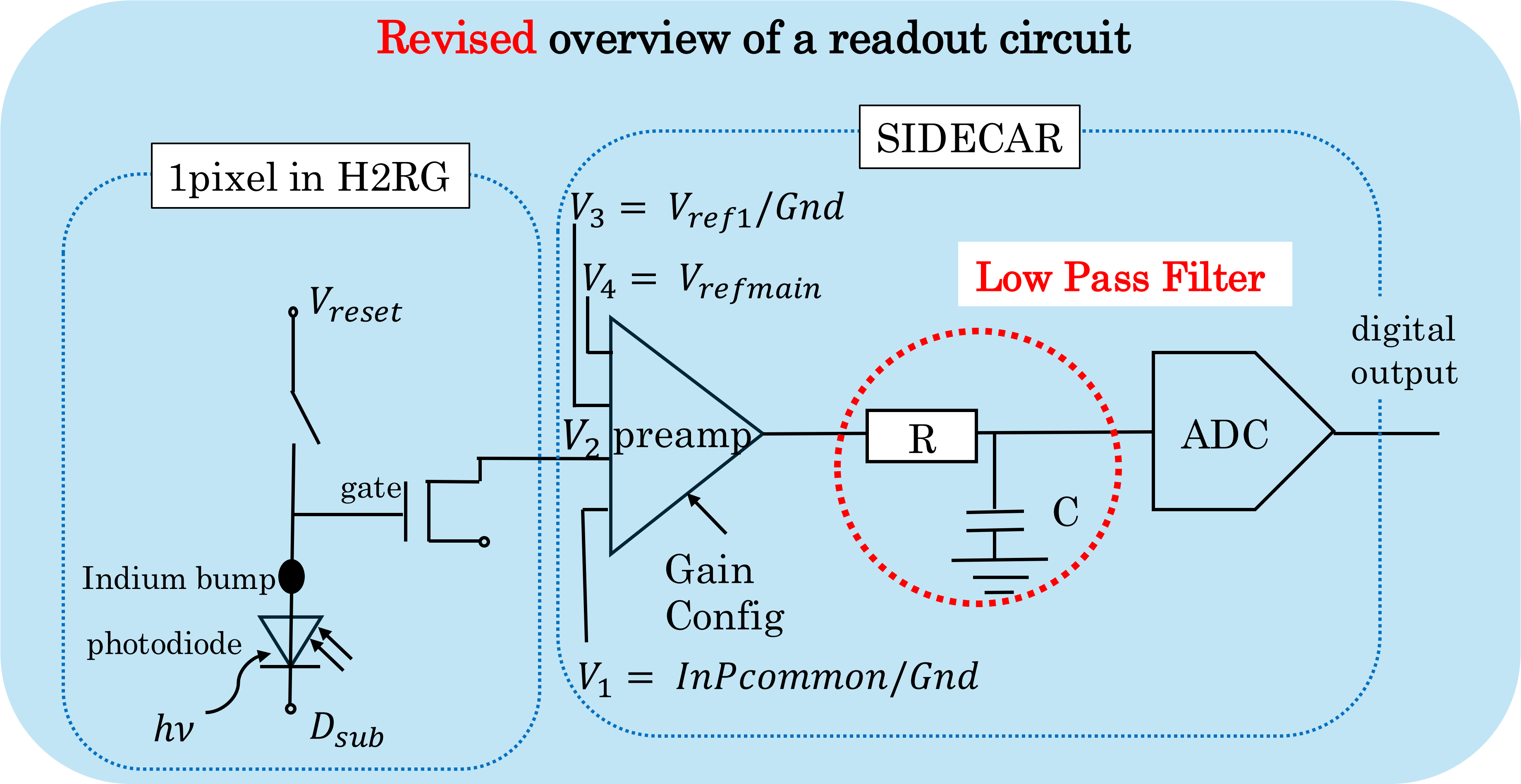
$V_{refmain} = 1.5V, G = \#10$
→ $\sigma_{CDS} = 14.0e^-$

Sampling range problem



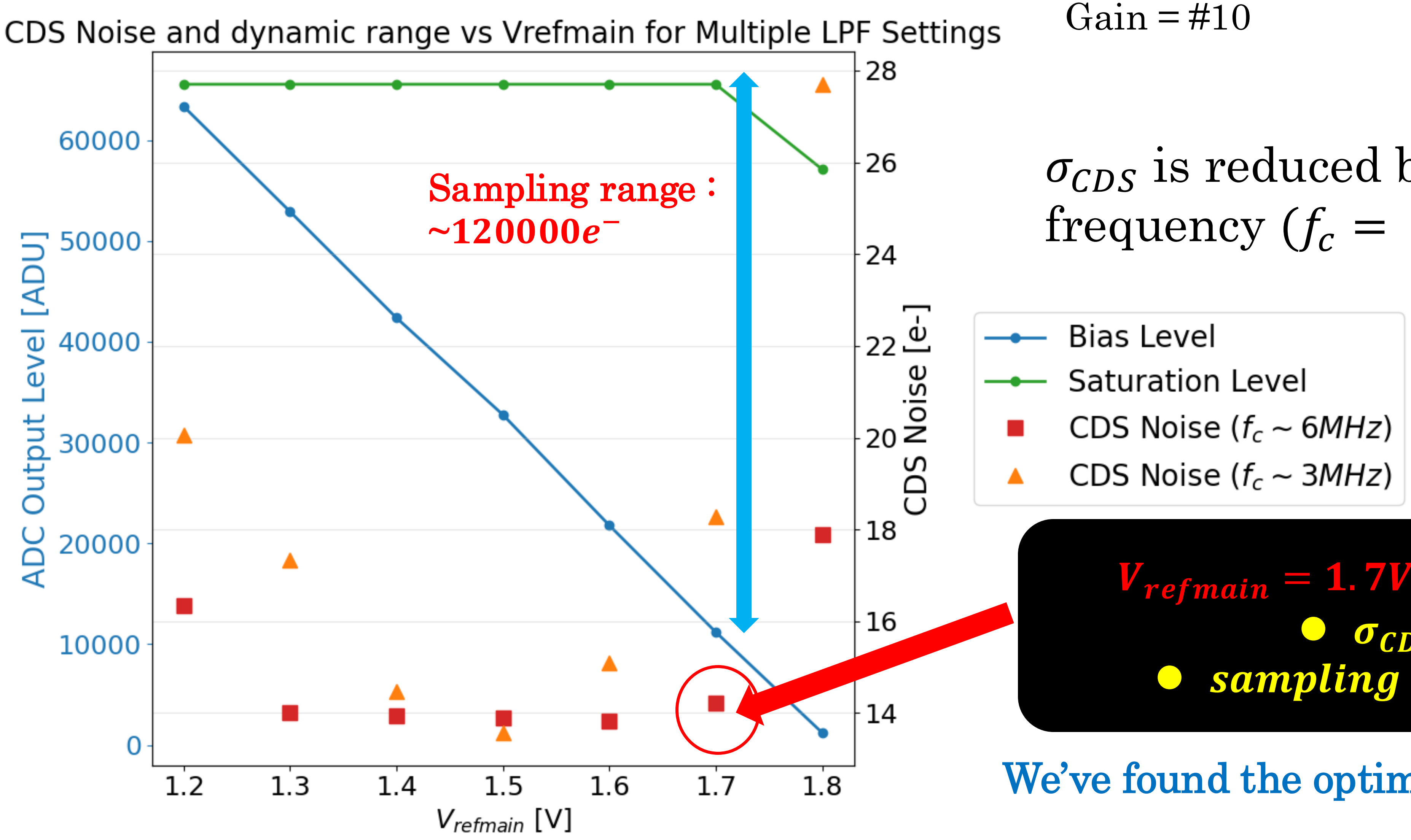
→ Sampling limited to ½ of the full well of the detector

A solution – Low Pass Filter setting



It is possible to **change the cutoff frequency of a low pass filter** varying resistance(R) and capacitance(C).

Optimization of LPF for both σ_{CDS} and sampling range



← default

Gain = #10

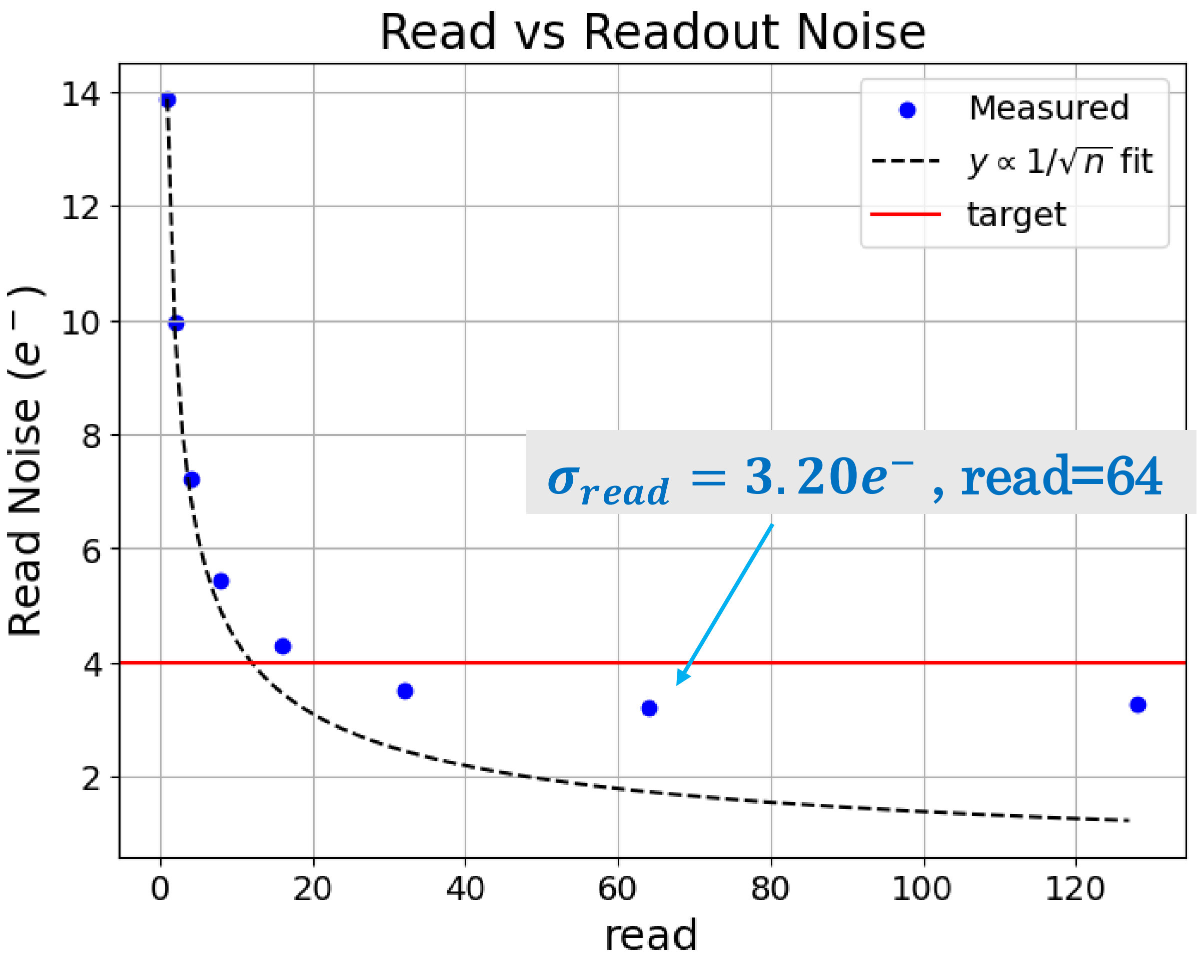
σ_{CDS} is reduced by changing cutoff frequency ($f_c = 1/RC$).

$V_{refmain} = 1.7V, G = \#10, f_c = 6MHz$

- $\sigma_{CDS} = 14.2e^-$
- $sampling \sim 97\%$ of $full well$

We've found the optimized parameter set !!

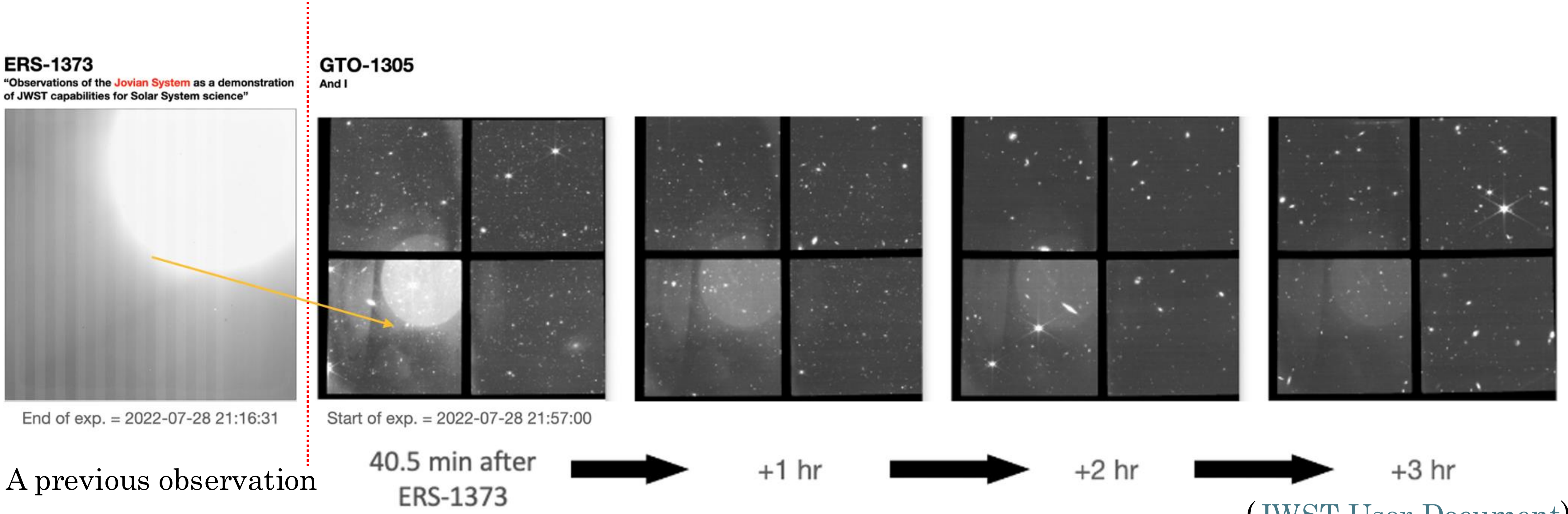
Multi sampling



Under the optimized parameter set

→Target $\sigma_{read} = 4e^- \ rms$ is achieved.

Persistence

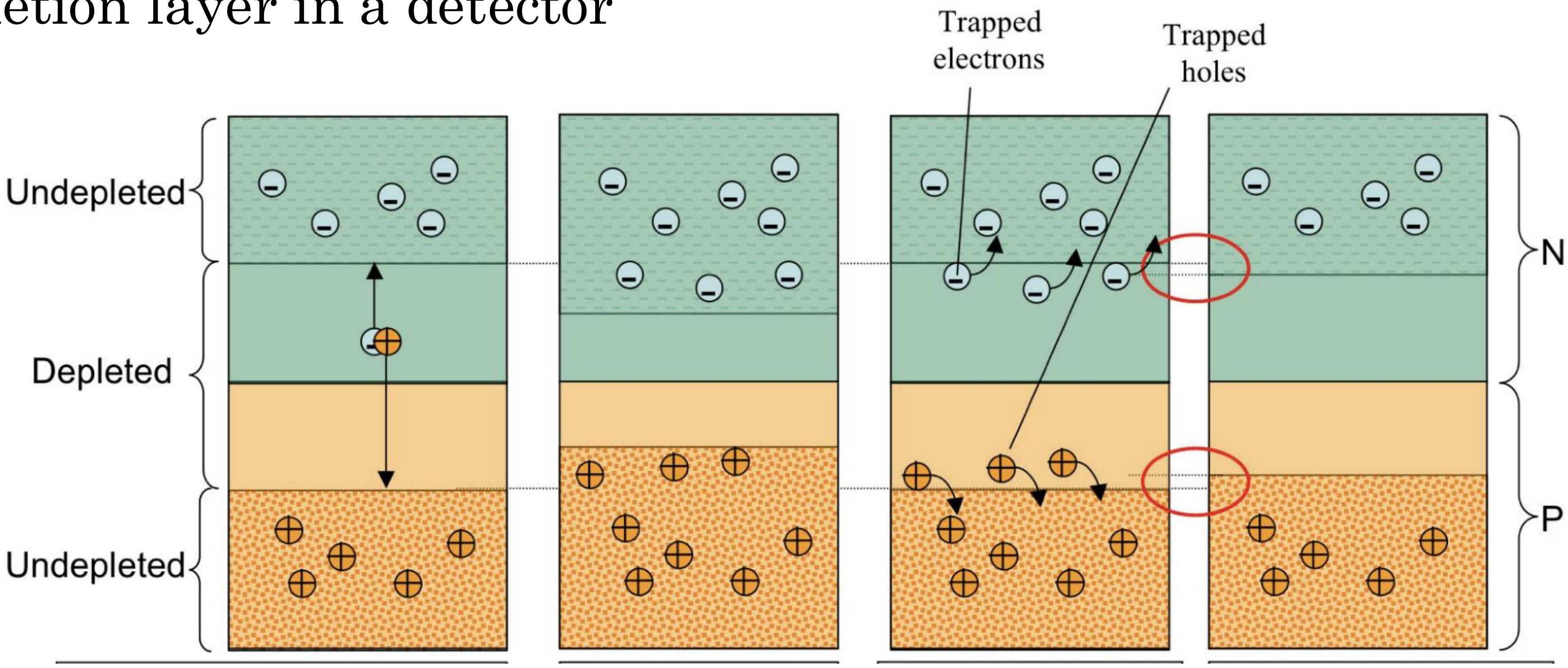


(JWST User Document)

- We can see **persistence** caused by bright objects **during previous observations**.
- Previous research have shown persistence tends to be reduced by **lowering the detector temperature** in some H2RG detectors (Mace et al. 2016).

Persistence model

A depletion layer in a detector



(Smith et al. 2008)

I. Before exposure

II. During exposure

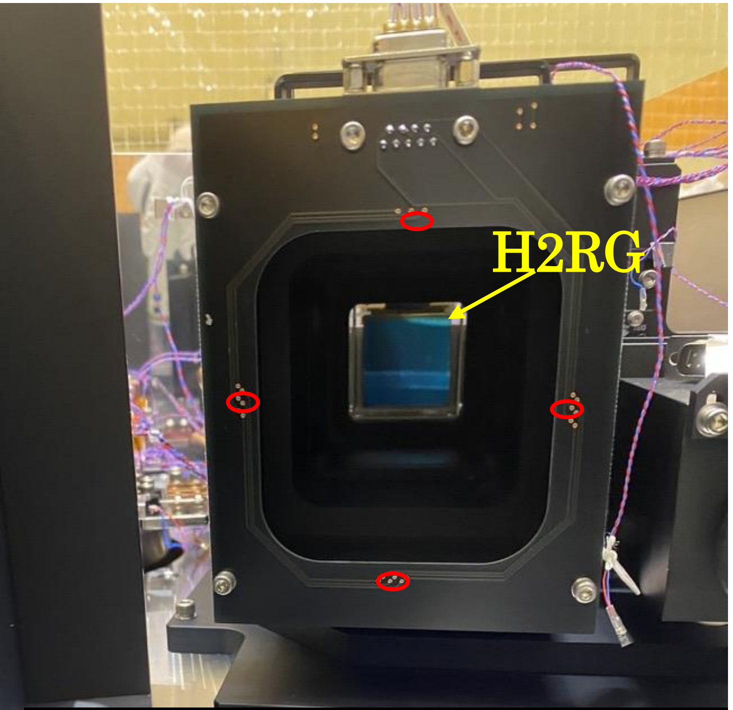
III. After reset

IV. Next exposure

Phase

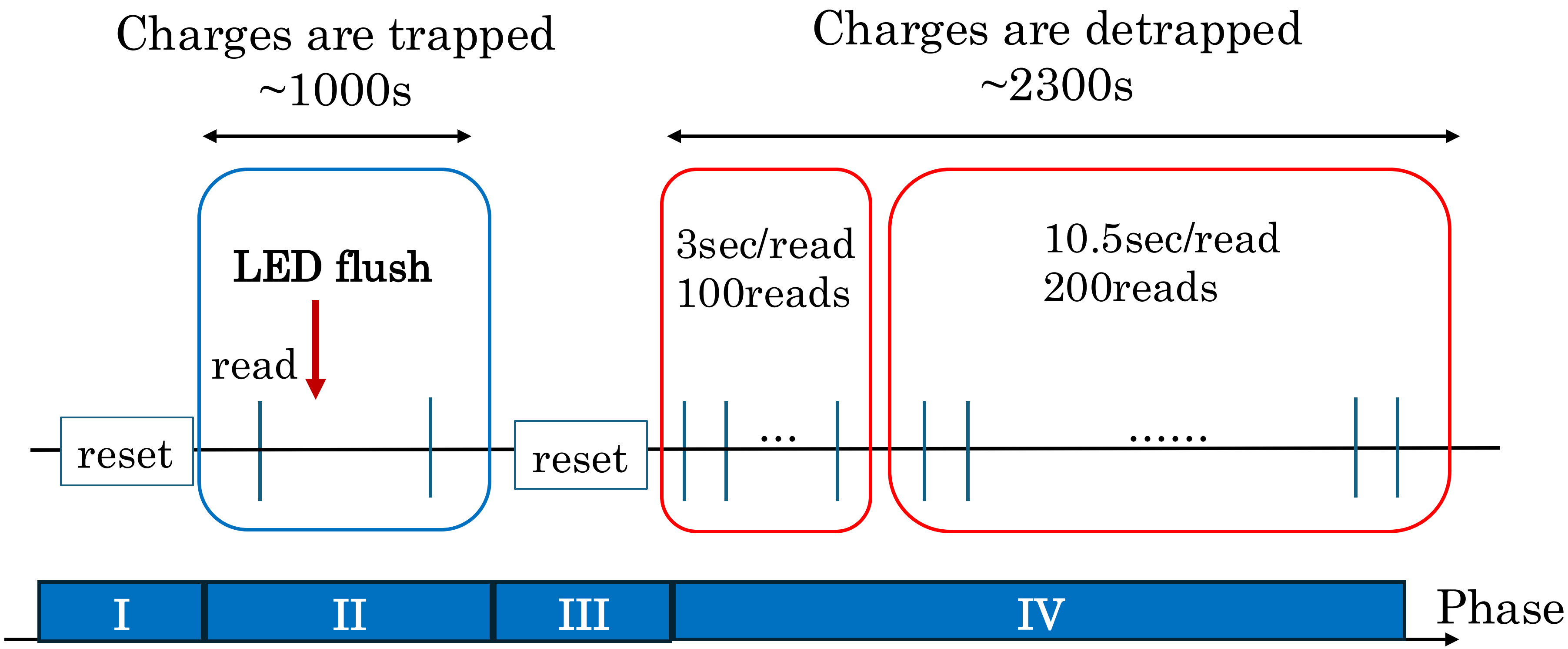
How to evaluate persistence

A picture in NINJA cryostat



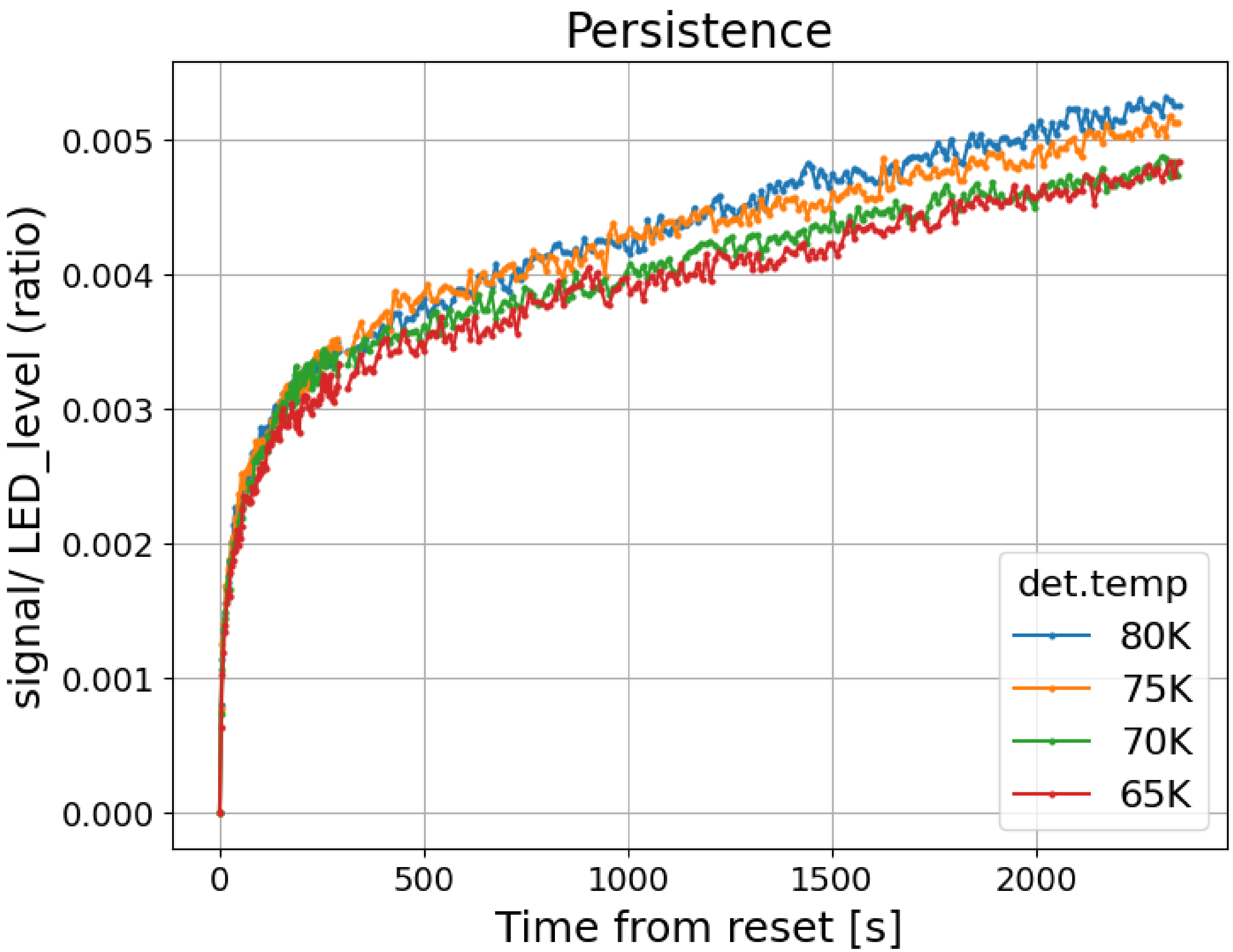
→ 4 LEDs can illuminate the H2RG detector.

The readout sequence



→ We tracked the temporal evolution of detrap signal during Phase IV.

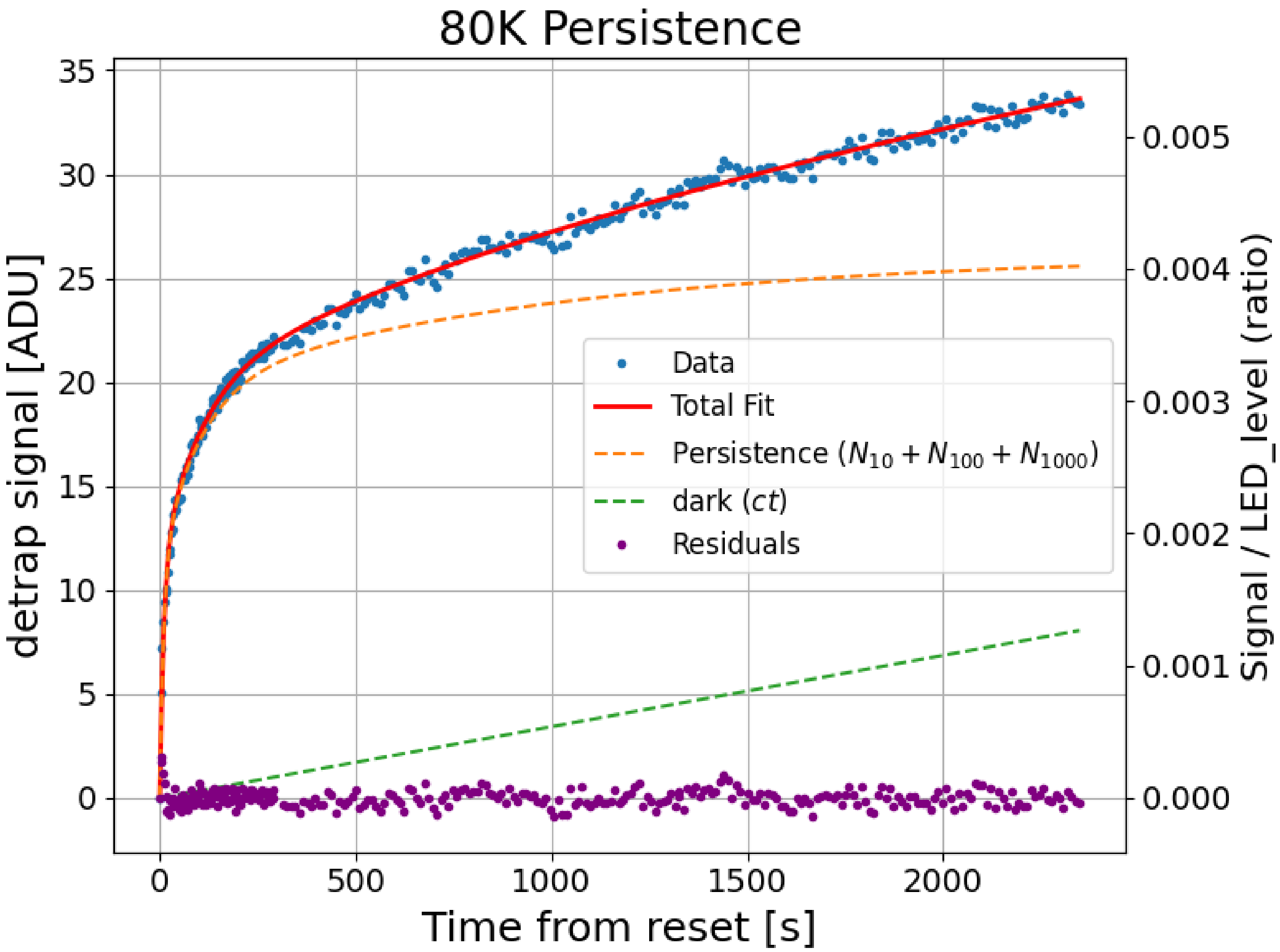
Temporal evolution of persistence



- Electrons are released as time goes on.
- Steeper release rate in the first ~300 s than afterward.

Necessity of eliminating dark contribution

Extraction of persistence contribution



<u>Assumption</u>

Detrap electrons have various time constants τ of release.

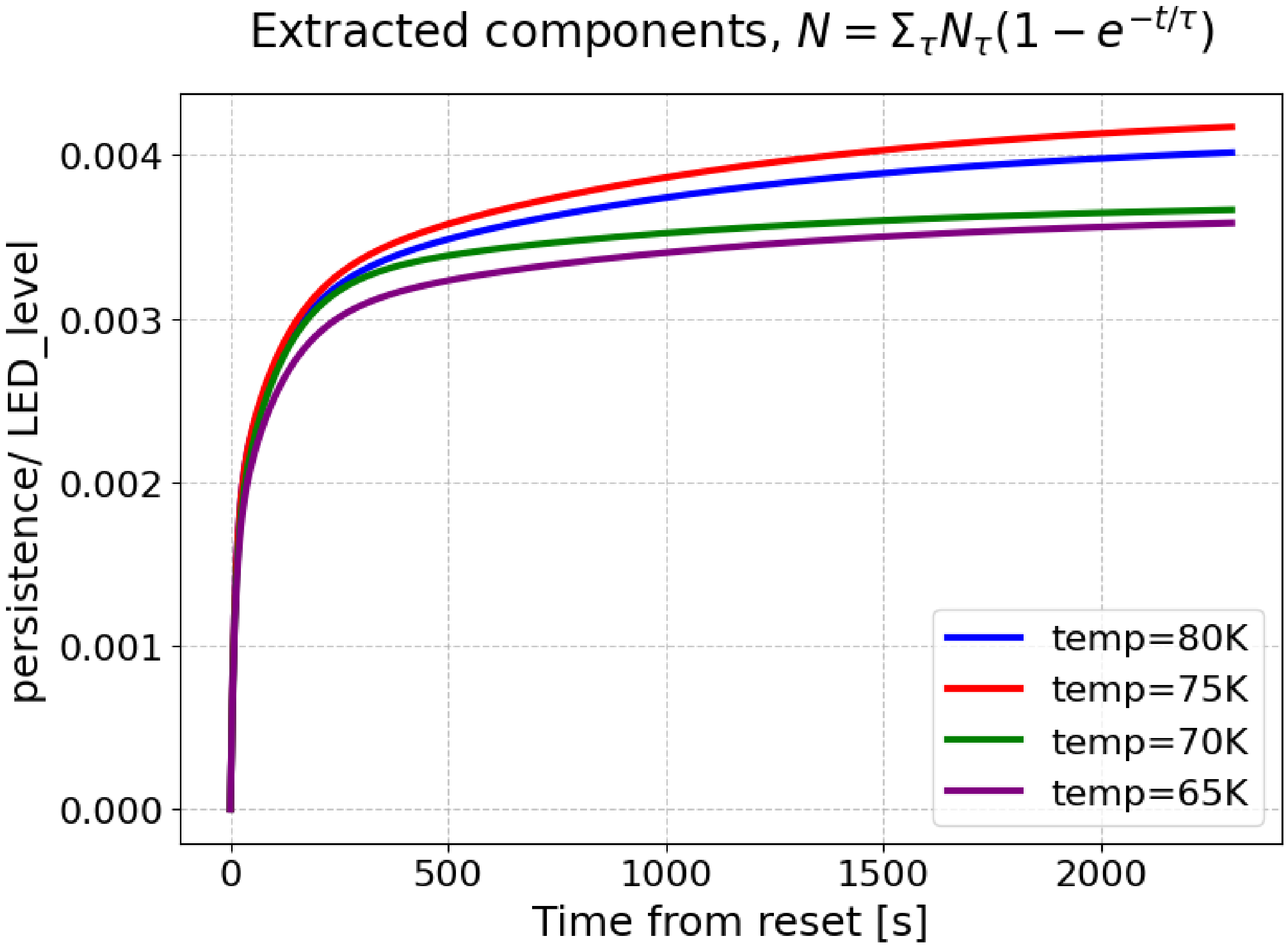
→ Fitting the signal by the equation below.

$$N = \Sigma_{\tau} N_{\tau}\left(1 - e^{-t/\tau}\right) + ct$$

$$(\textit{time constants}: \ \tau = 10s, 100s, 1000s)$$

→ Extracts the persistence component.

Persistence dependence on detector temperature



→ NINJA H2RG detector shows **little dependence of persistence on detector temperature.**

The optimized result

Preamp config	Vrefmain mode
G	#10 (2.23 e/ADU)
$V_{refmain}$	1.7V
D_{sub}	0.6215V
V_{reset}	0.3715V
Low pass filter setting	#6 ($f_c \sim$ 6MHz)
Detector temperature	80K
σ_{CDS} ($\sigma_{read=64}$)	14.2e$^-$ (3.2e$^-$)
Sampling range	~120000e$^-$

Summary

- NINJA is LTAO-optimized spectrograph covering 0.83-2.5μm.

- $\sigma_{CDS} = 14.2e^{-}$ and full-well sampling are achieved simultaneously by optimizing the parameter sets of bias voltages, preamp settings and low pass filter setting.
- $\boldsymbol{\sigma_{read} = 3.20e^{-}}$ is achieved with 64 read multi sampling under the optimized result.

- There is little dependence of persistence on detector temperature for the NINJA H2RG detector

- We are now preparing for transporting NINJA to Subaru Telescope.
- **NINJA first light is scheduled in 2026.**