

Astronomical Spectroscopy with Skipper CCDs: First Results from a Skipper CCD Focal Plane Prototype at SIFS

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New Perspectives 2024
09 July 2024



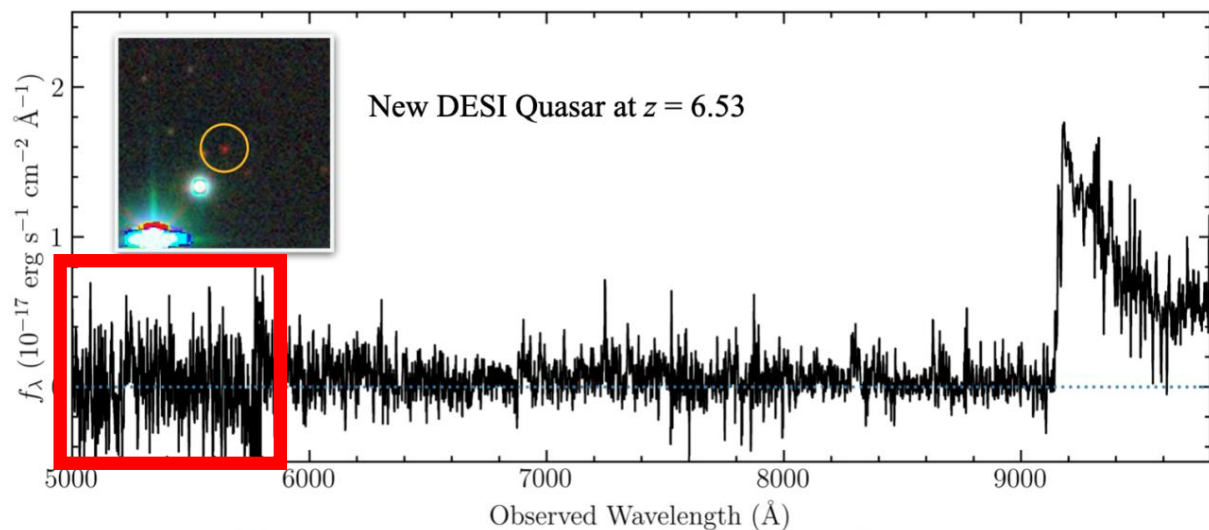
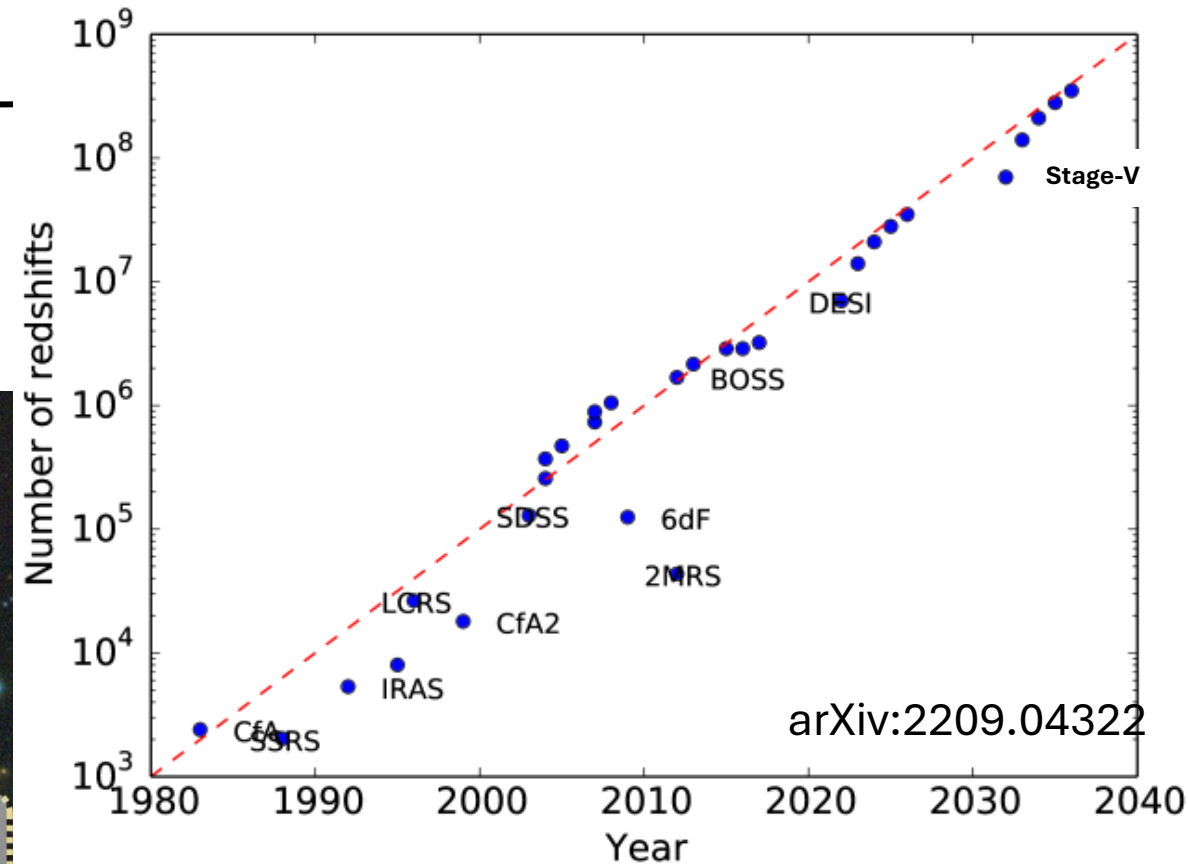
 **Fermilab**

 **THE UNIVERSITY OF
CHICAGO**

Cosmological Surveys

Improved Detector Technology for Cosmic Surveys

Spectroscopic survey speed has increased by a factor of 10 each decade.



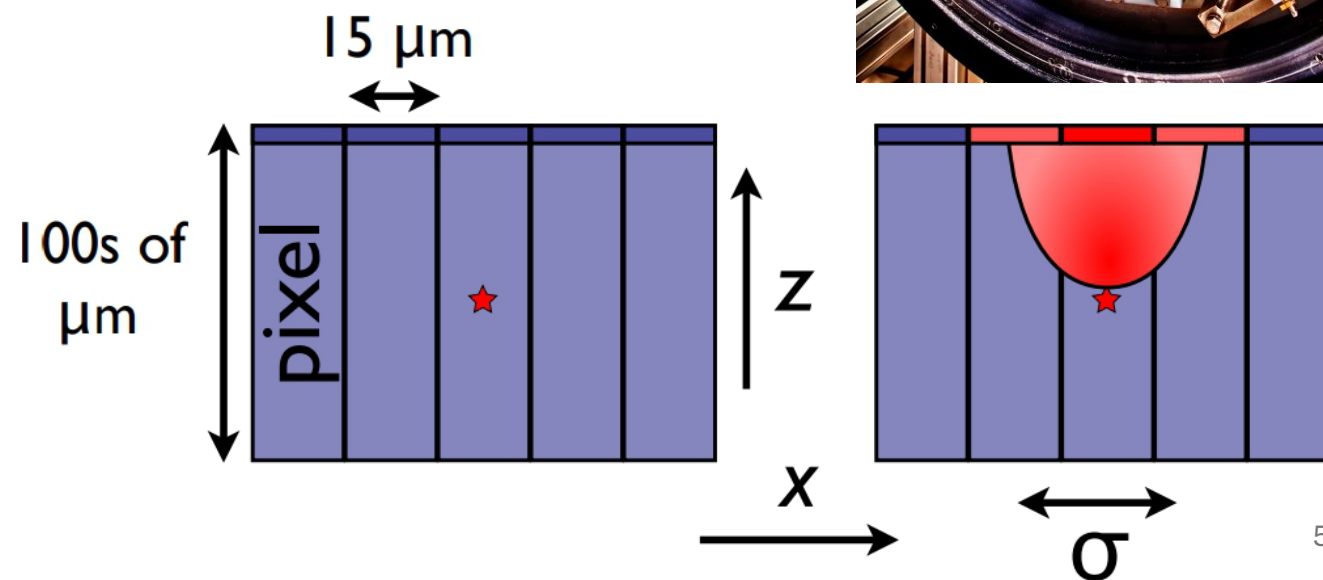
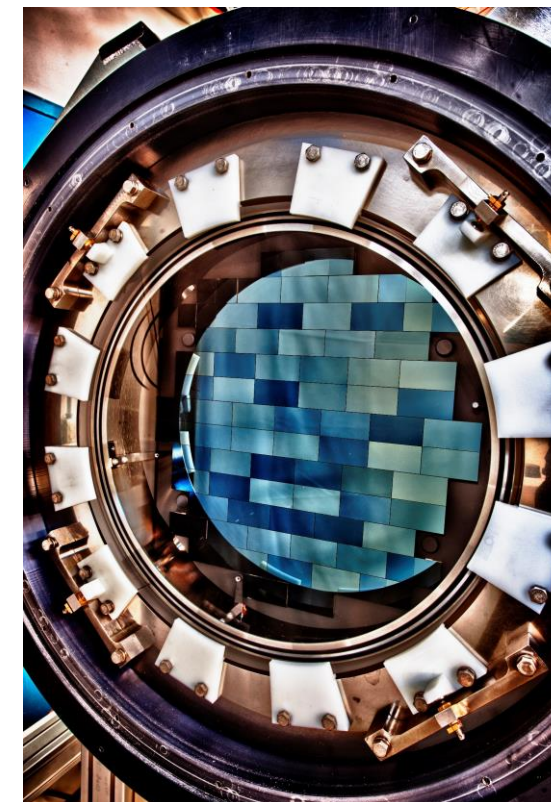
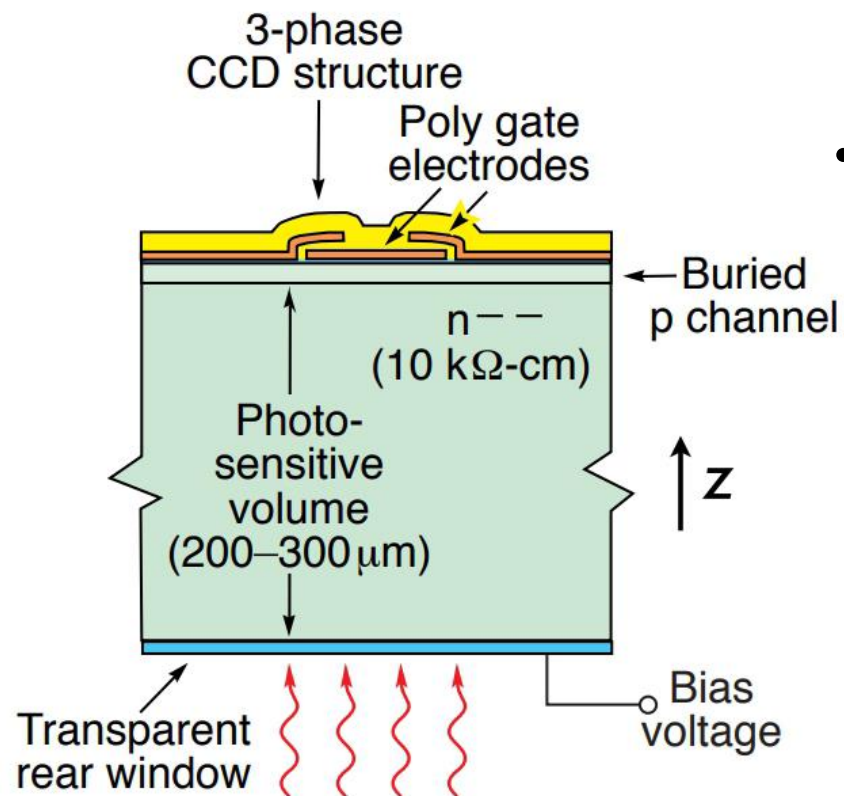
Future spectroscopic surveys (e.g., DESI-2 and a Stage-5 Spectroscopic Survey) need to be sensitive to fainter objects, particularly at blue wavelengths (Lyman-break galaxies and Lyman-alpha emitters at redshift $2 < z < 5$).

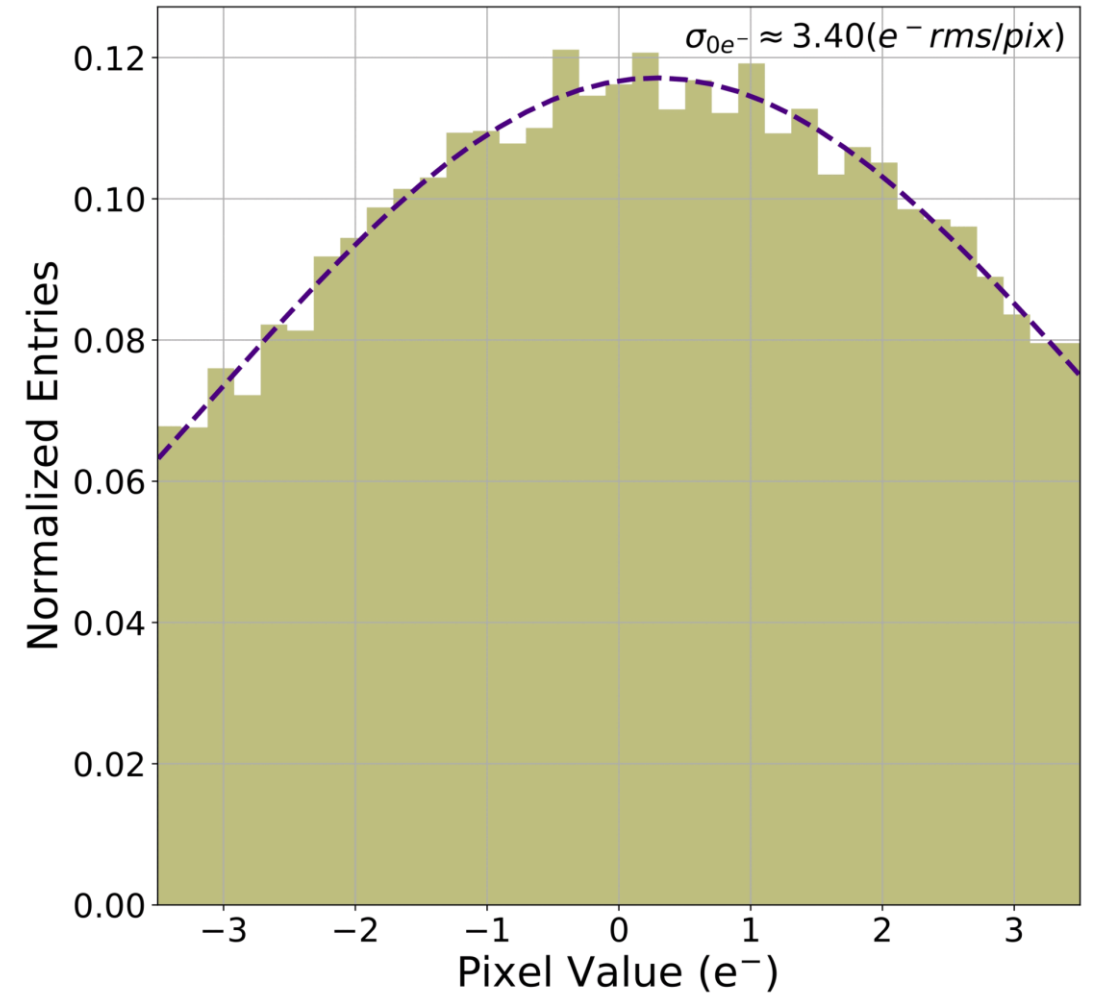
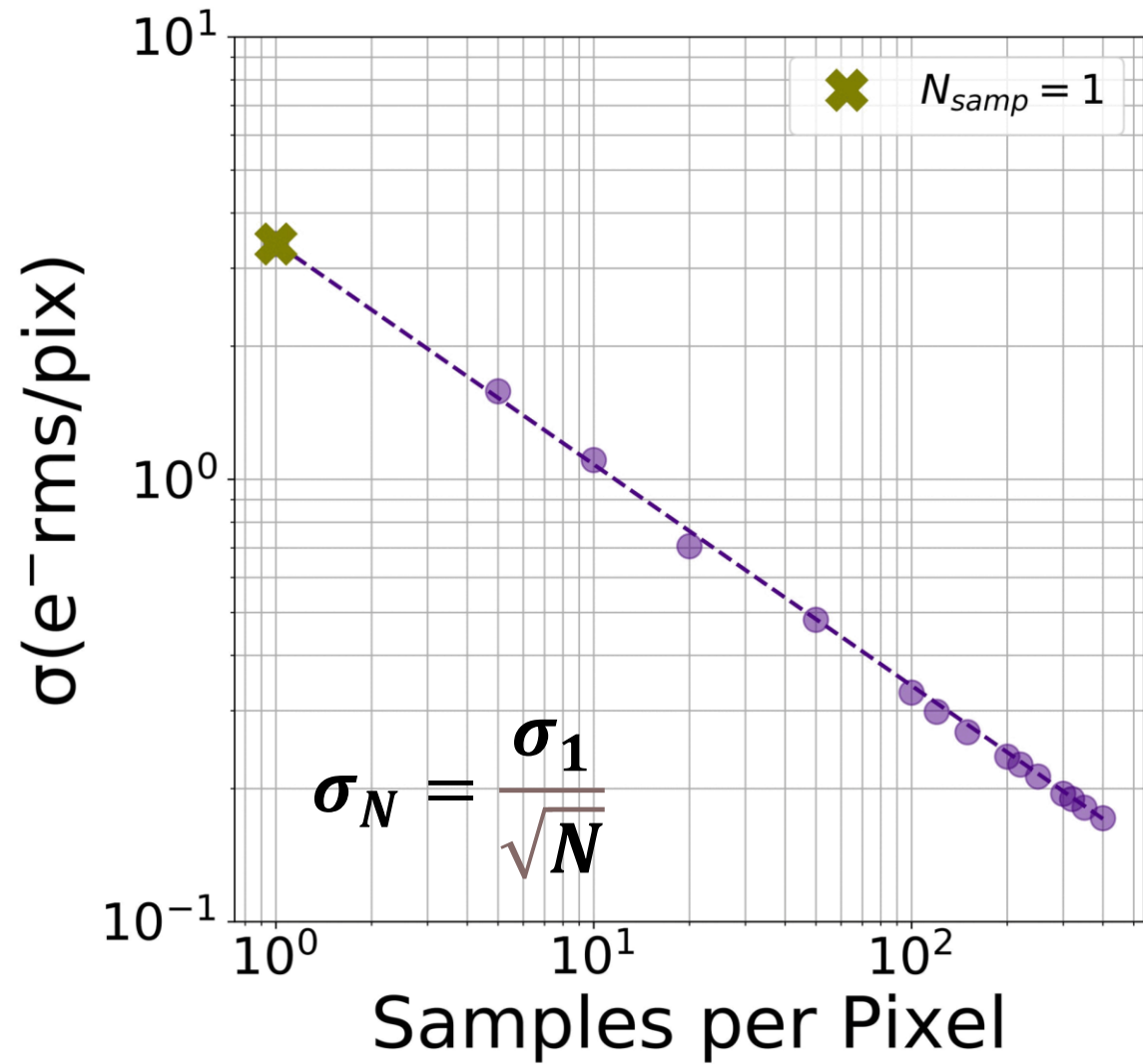
Skipper CCDs

Charge-Coupled Devices (CCDs)

CCDs: Metal-Oxide-Semiconductor capacitors.

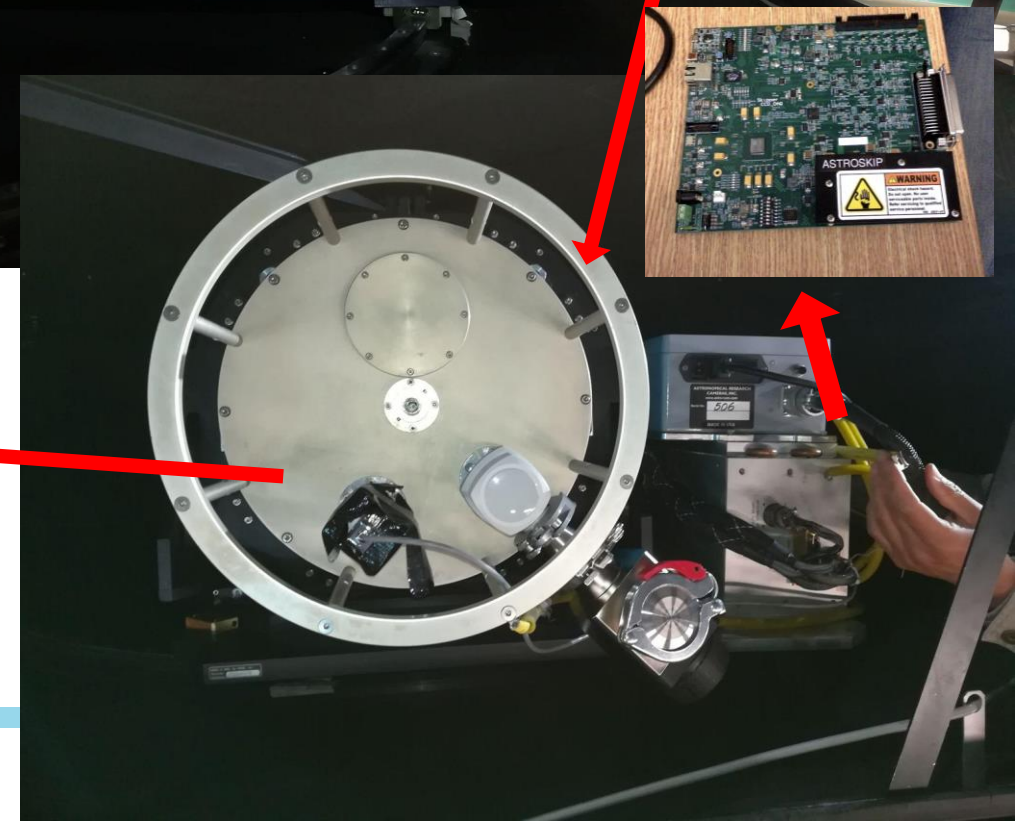
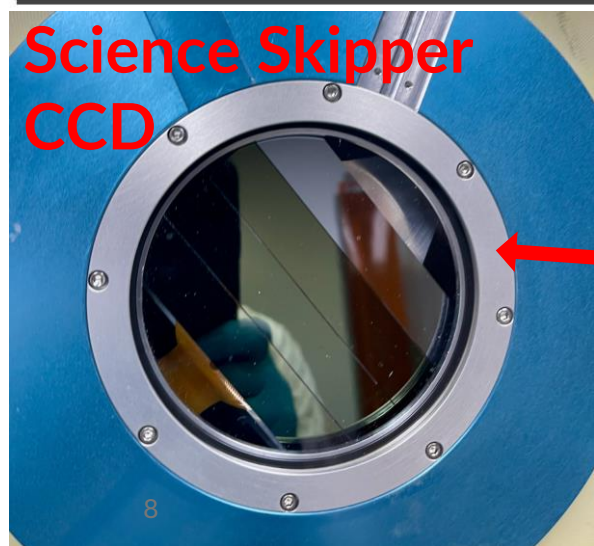
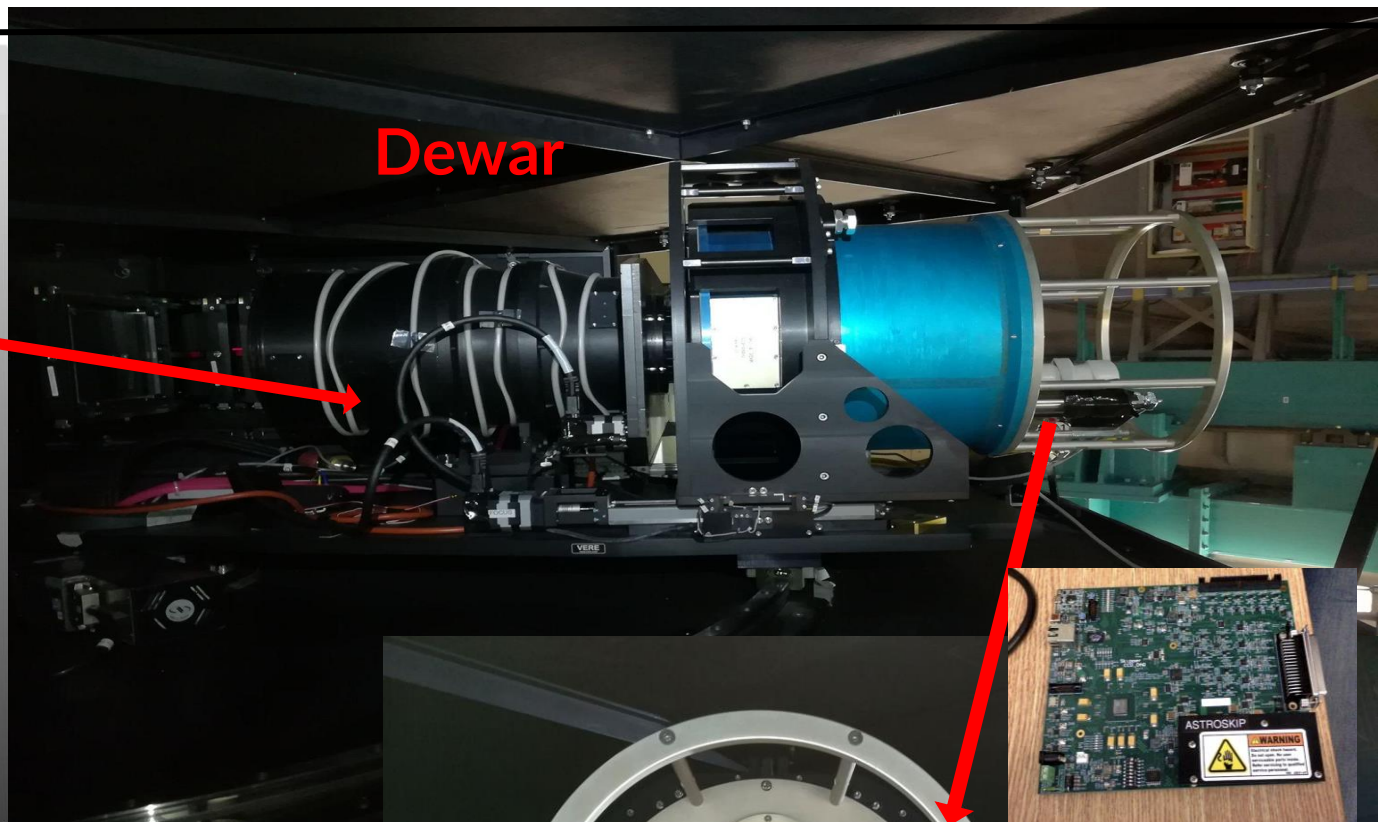
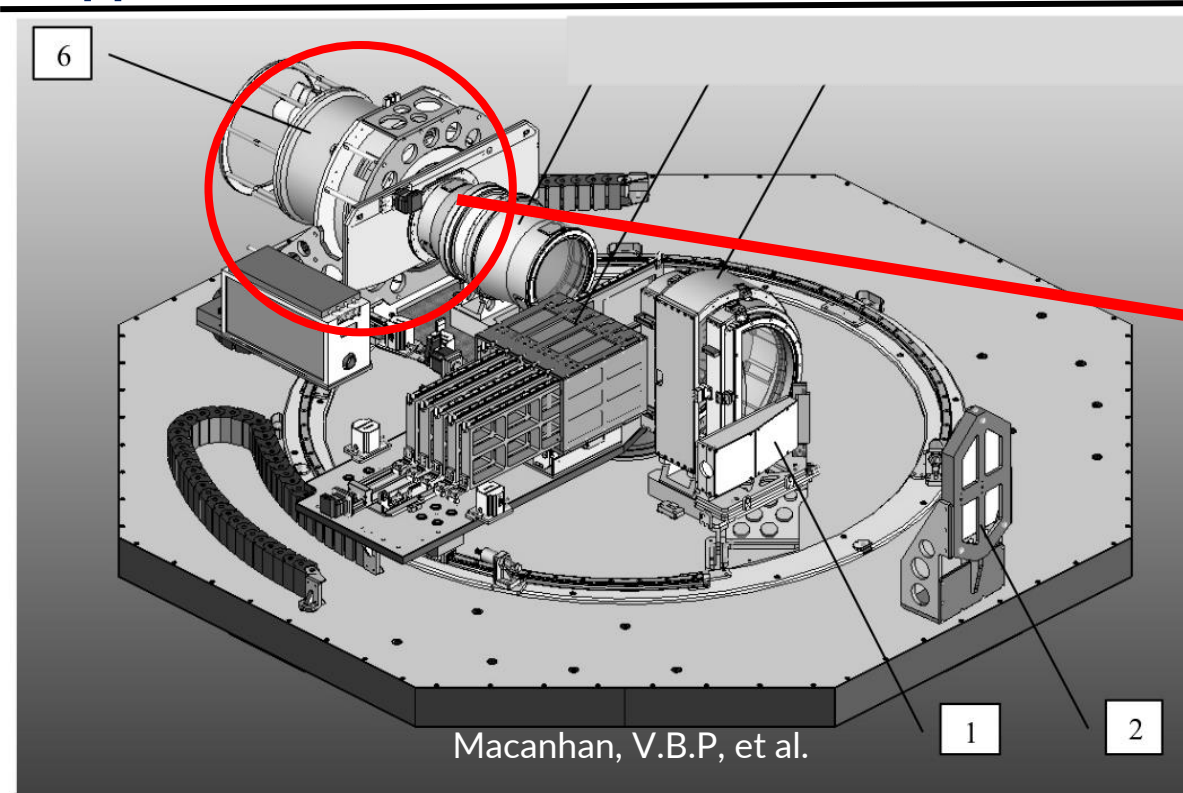
- Radiation interacting in the Si substrate (photoelectric effect) produces electron-hole pairs
- Charge is collected near the surface by applying V_{Sub}



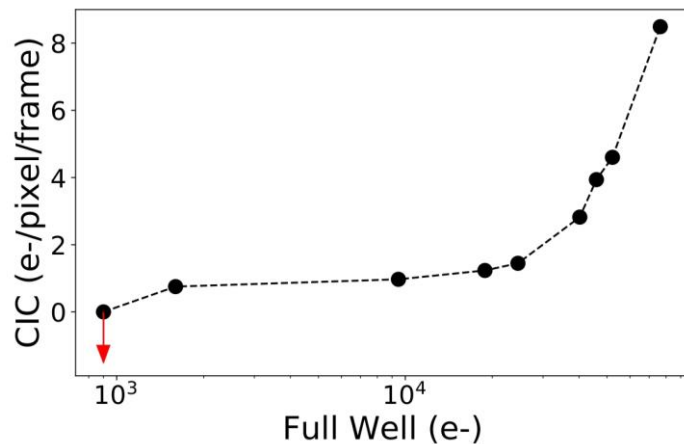
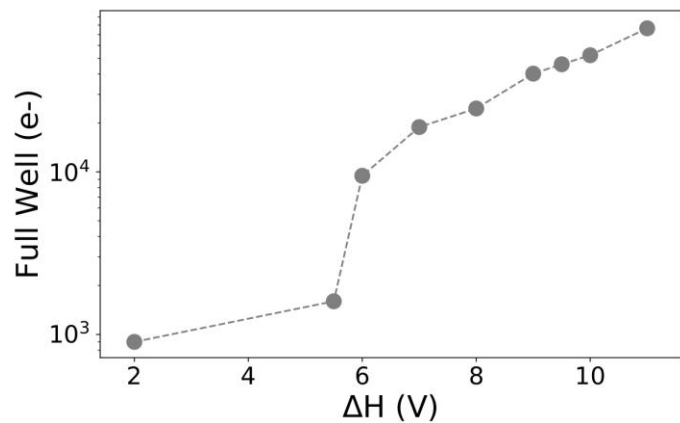
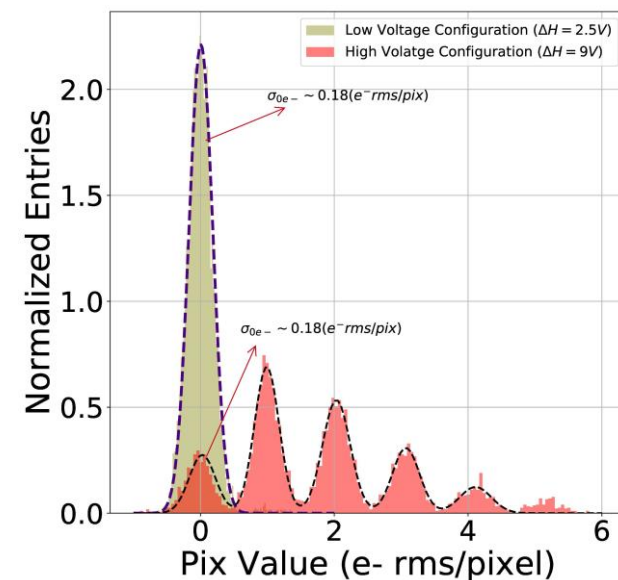
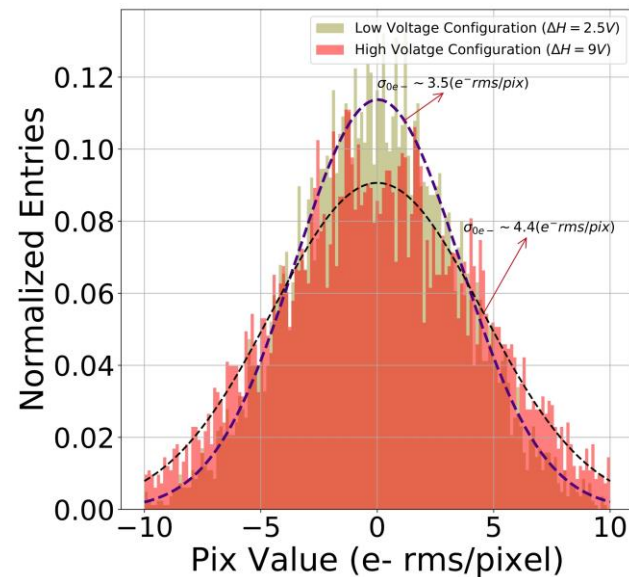
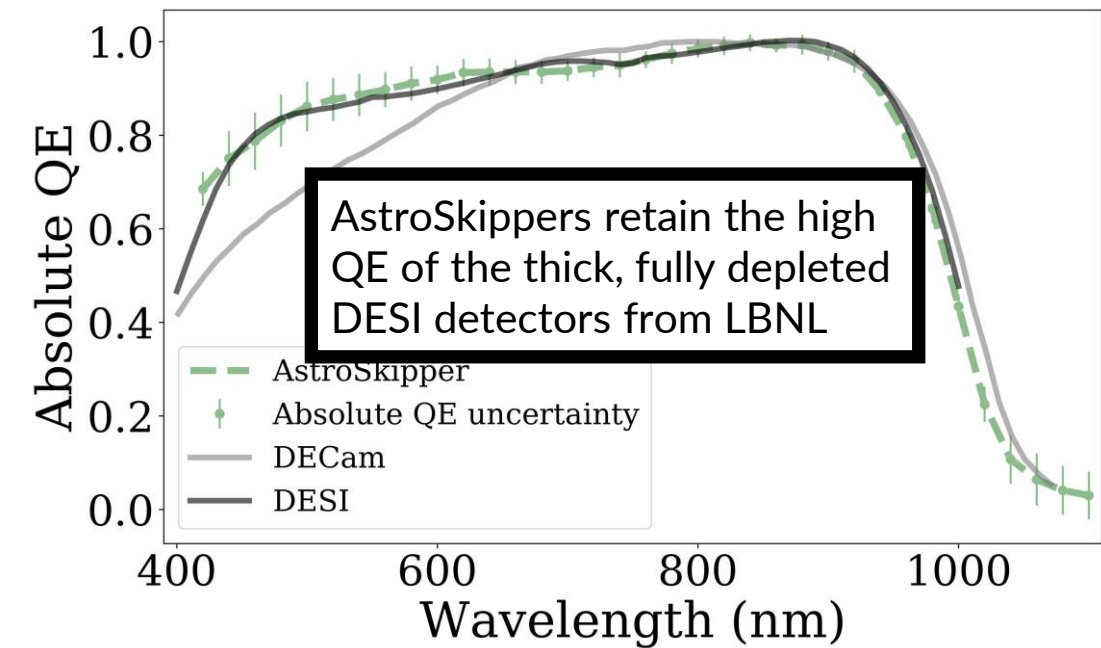


Astronomy-optimized Skipper CCDs

Skipper CCD Focal Plane for SIFS

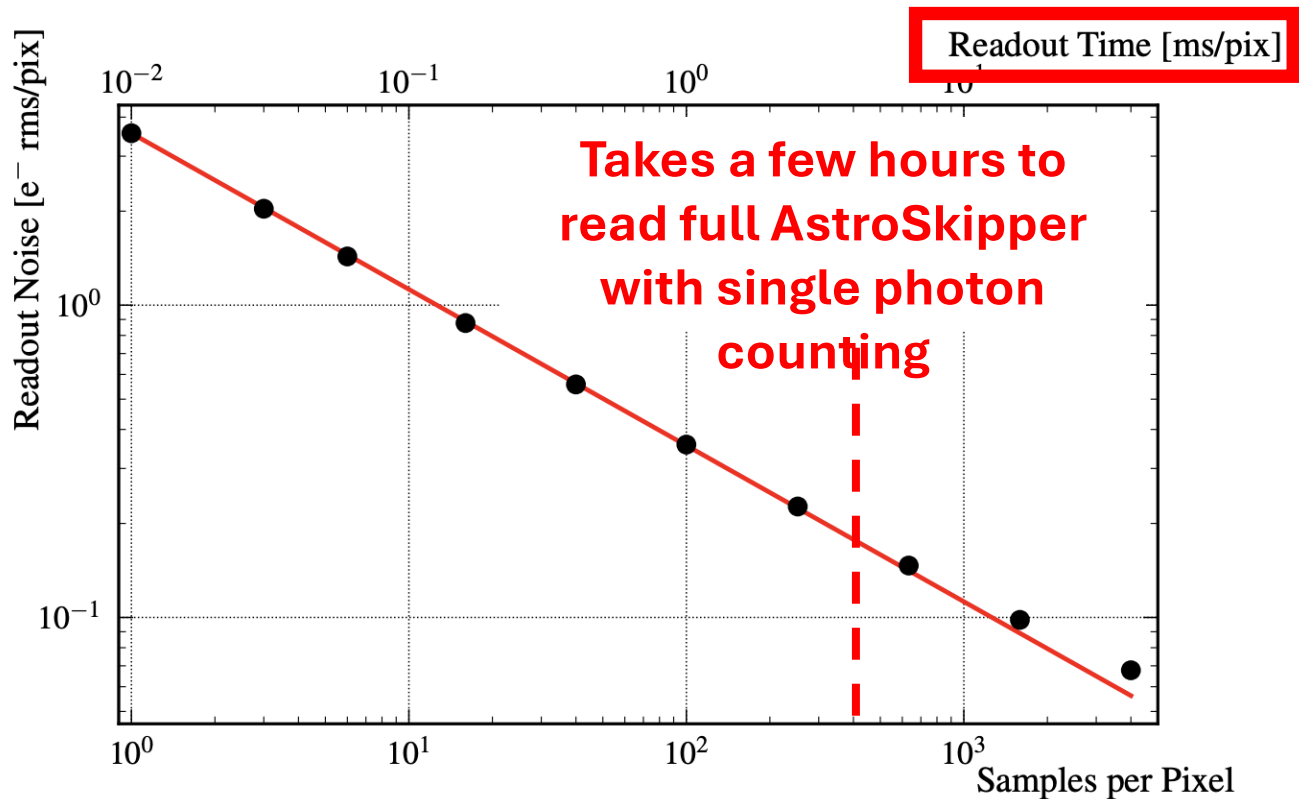


Skipper CCDs: Astronomy-Optimized

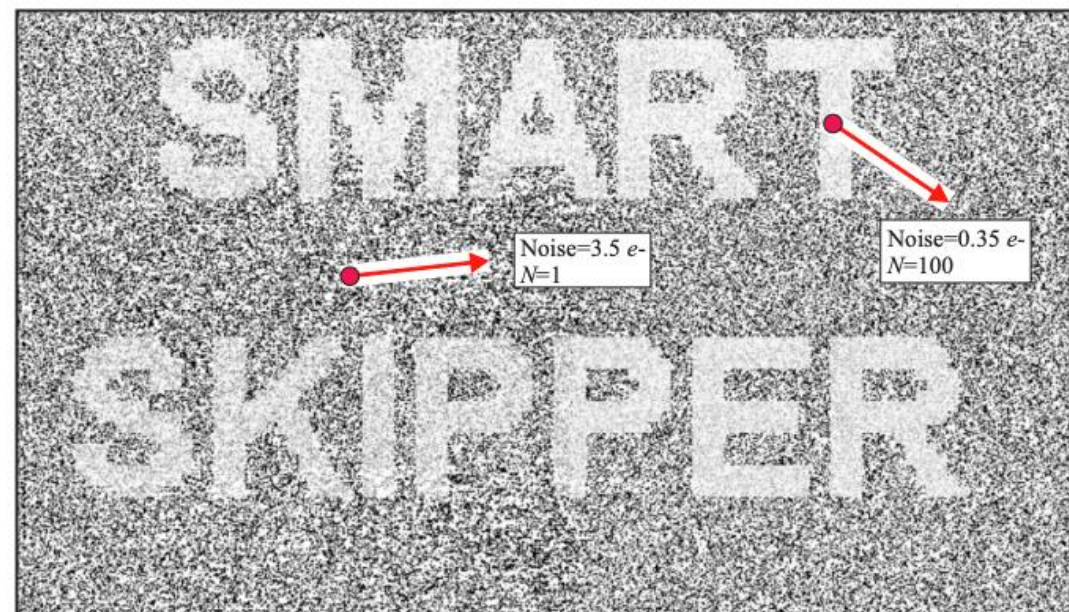
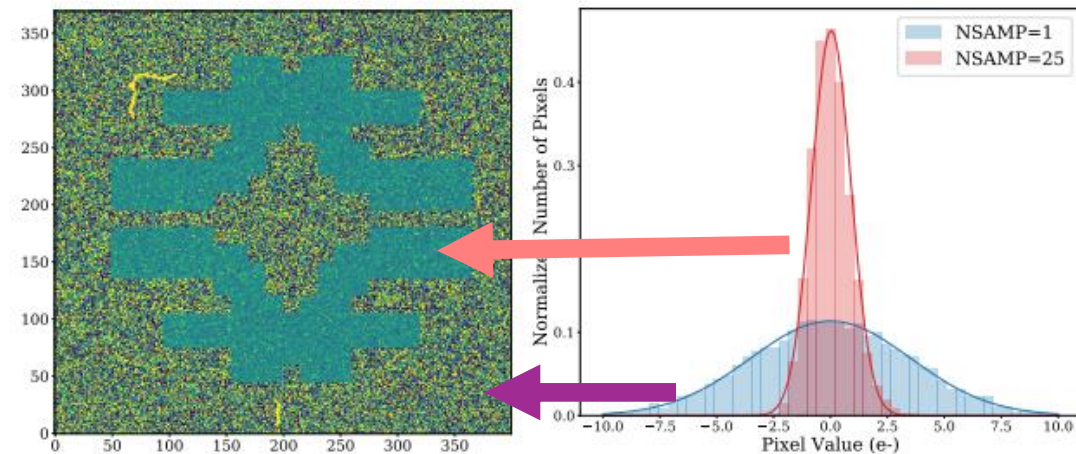


Skipper CCDs need to be optimized for large full-well capacities and low backgrounds

Skipper CCDs: Observation Optimization (Regions of Interest)



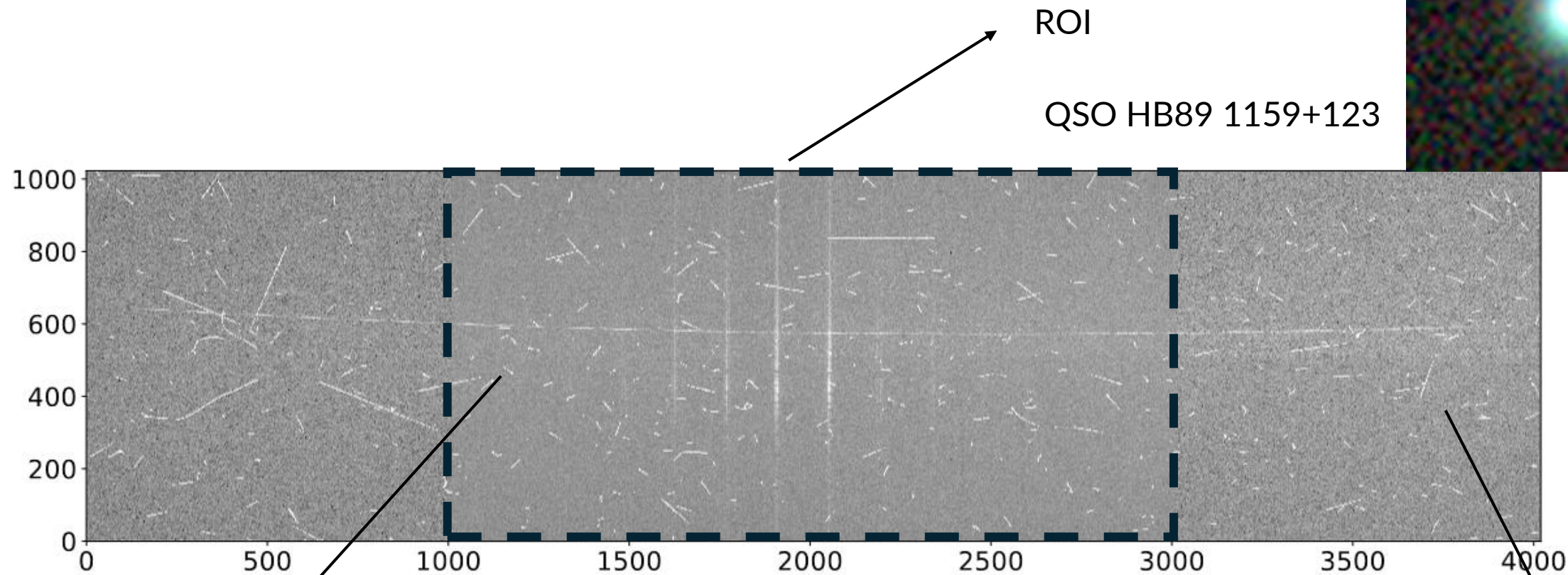
arXiv:1706.00028



arXiv:2012.10414

Results

Skipper CCDs: First On-Sky Demonstration (Sub-electron Noise)



ROI

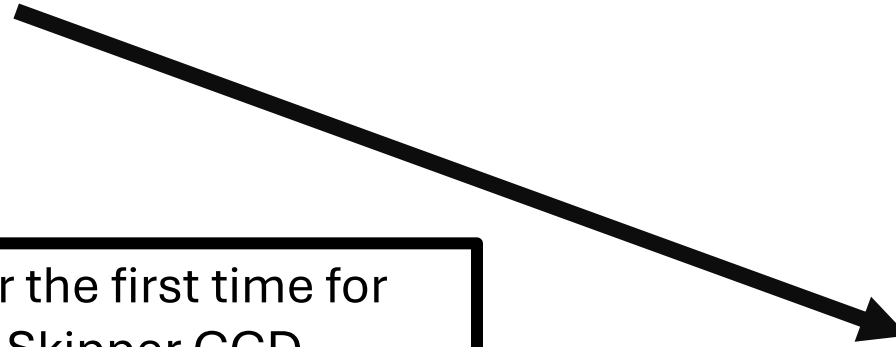
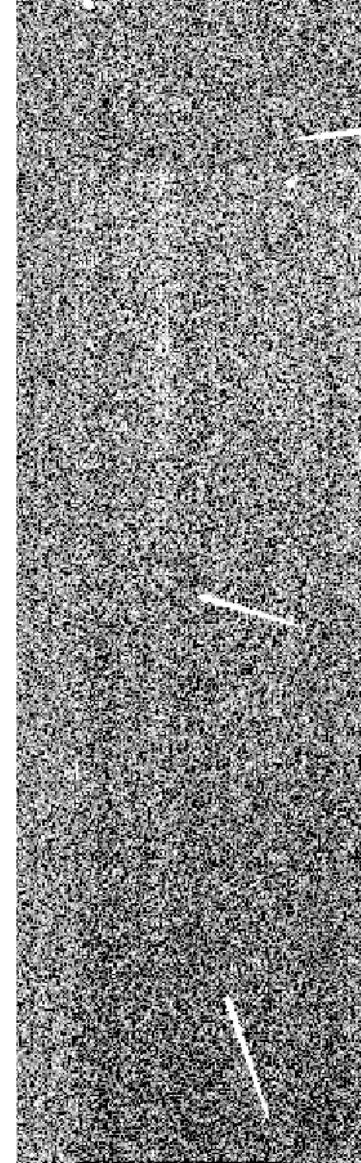
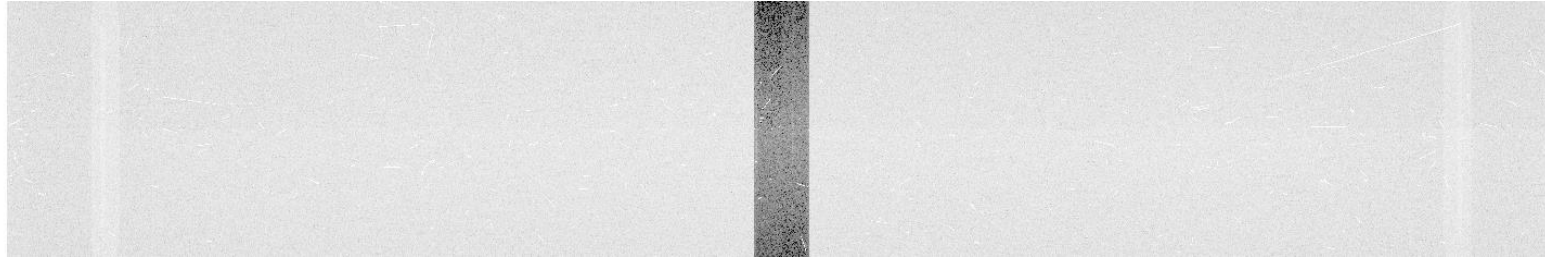
QSO HB89 1159+123

0.5 e⁻ rms/pixel

Achieved sub-electron readout noise (0.5 e⁻ rms/pixel) in science frames for an area 2k x 4k pixels. ROI minimizes readout time from ~55 min to ~15 min.

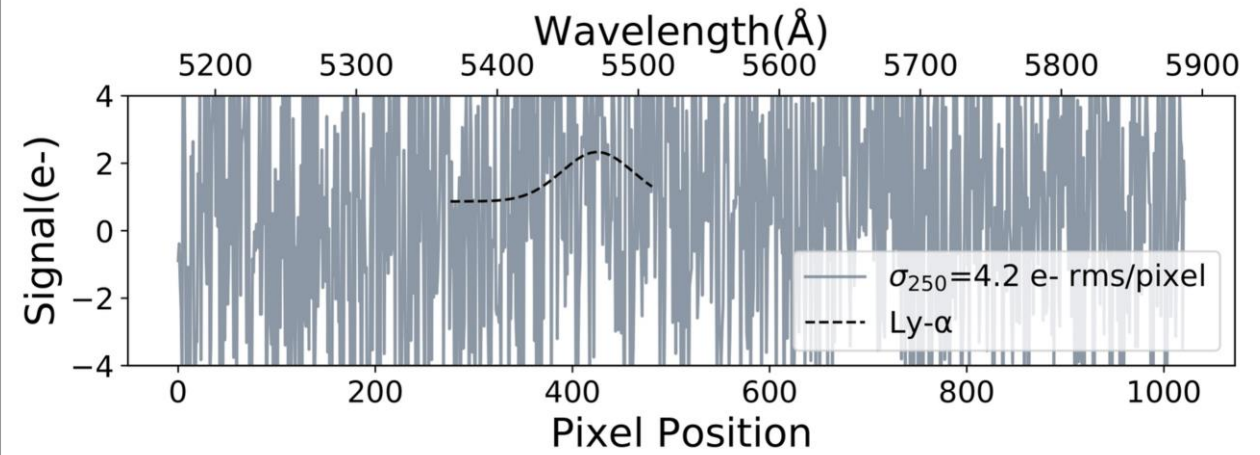
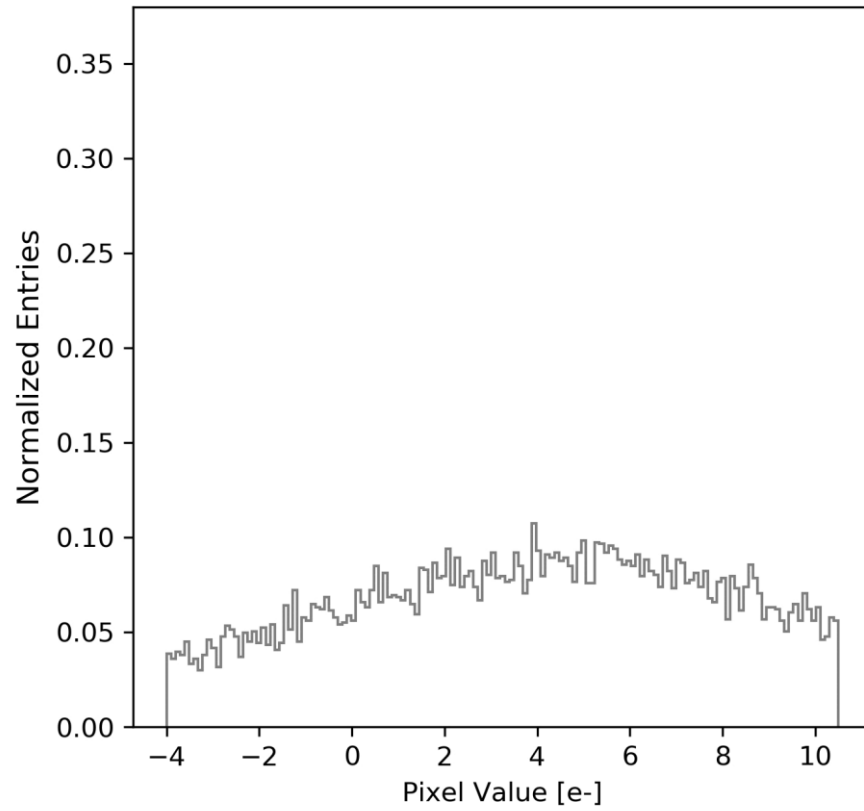
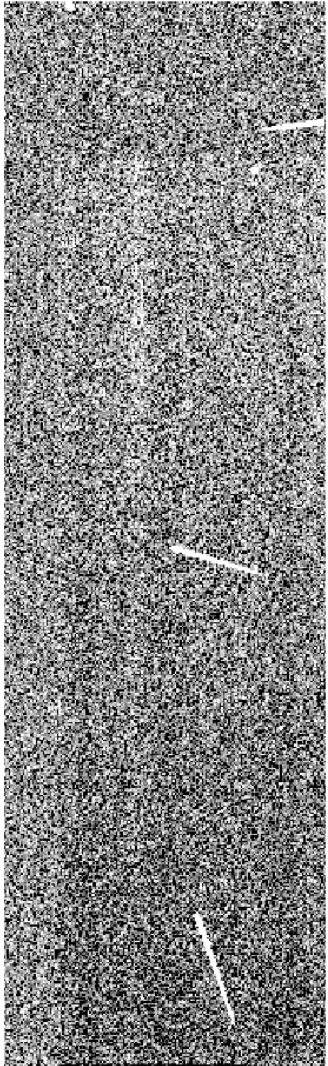
4.2 e⁻ rms/pixel

Skipper CCDs: First On-Sky Demonstration (Photon-Counting)



Photon-counting was achieved for the first time for astronomical observations with a Skipper CCD (charge quantizing read out noise on a CCD).

Skipper CCDs: First On-Sky Demonstration (Photon-Counting)

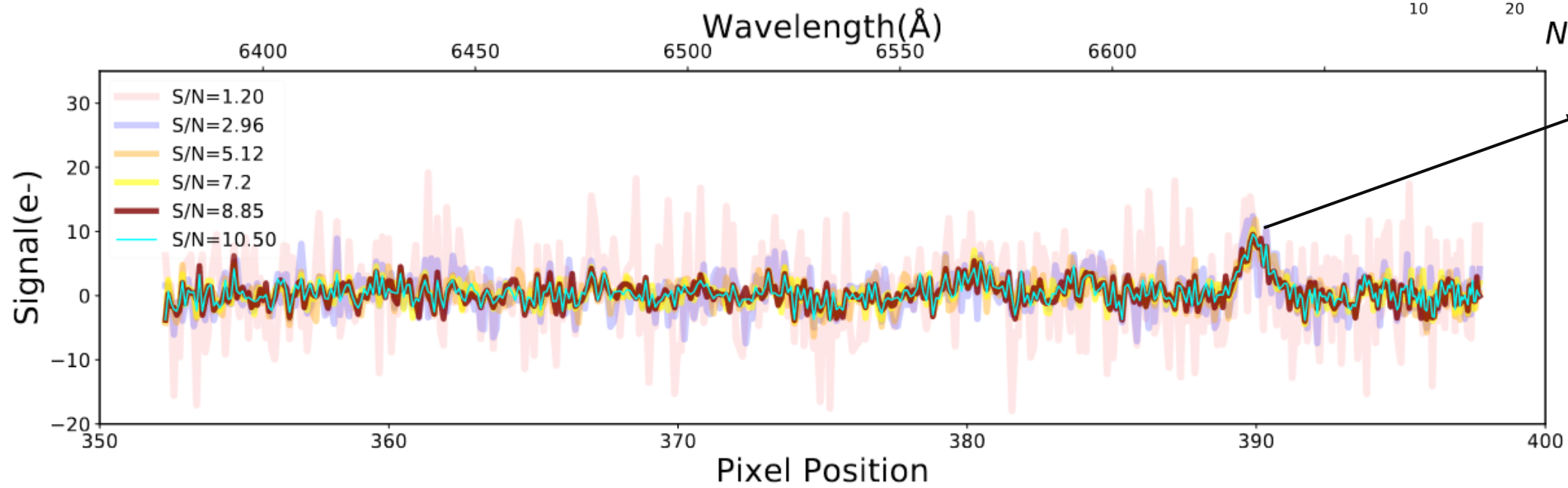
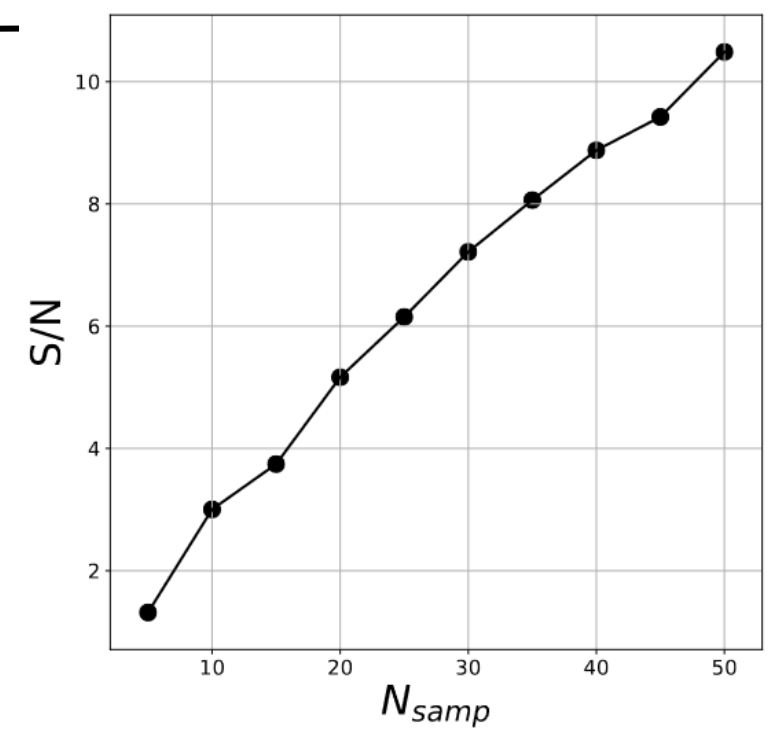


Signal-to-Noise (Read Noise Dominated Regime)

Region of interest N_{samp} is optimized to minimize backgrounds and demonstrate S/N improvements for SIFS.

$$\frac{S}{N} = \frac{R_{\text{src}} t_{\text{exp}}}{\sqrt{(R_{\text{src}} + R_{\text{bkg}} + R_{\text{dark}}) t_{\text{exp}} + N\sigma^2}}$$

$$N\sigma^2 \geq (R_{\text{src}} + R_{\text{bkg}} + R_{\text{dark}}) t_{\text{exp}}$$
$$R_{\text{src}} < R_{\text{bkg}}$$



O III

Extra Slides

Planned Science

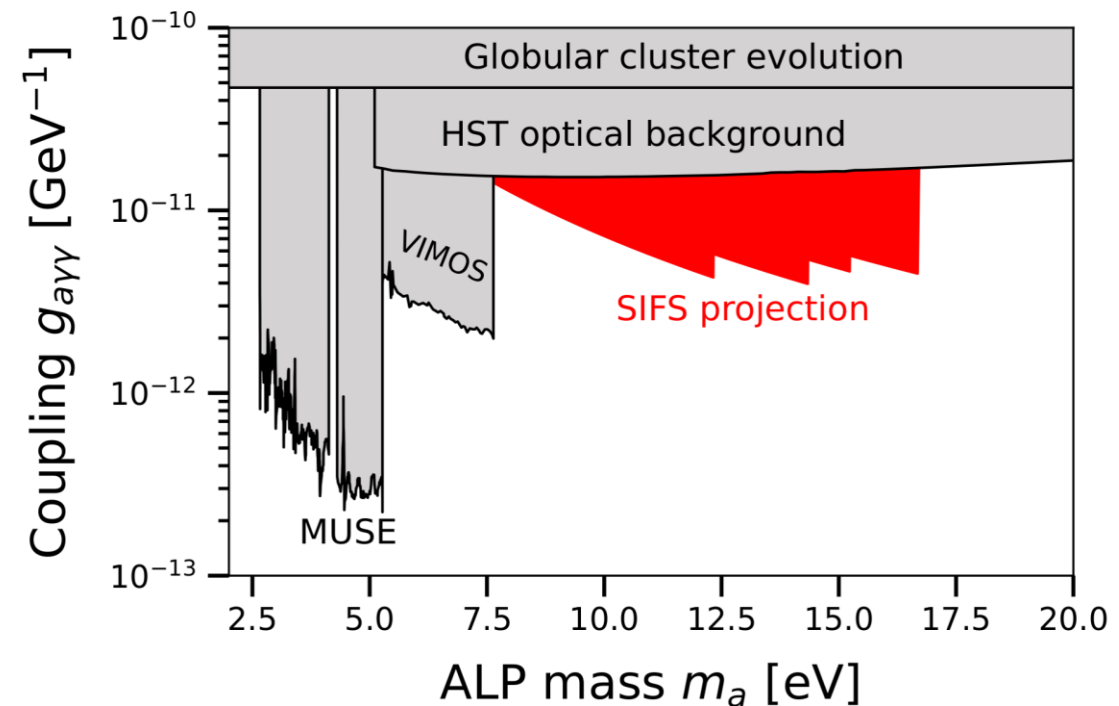
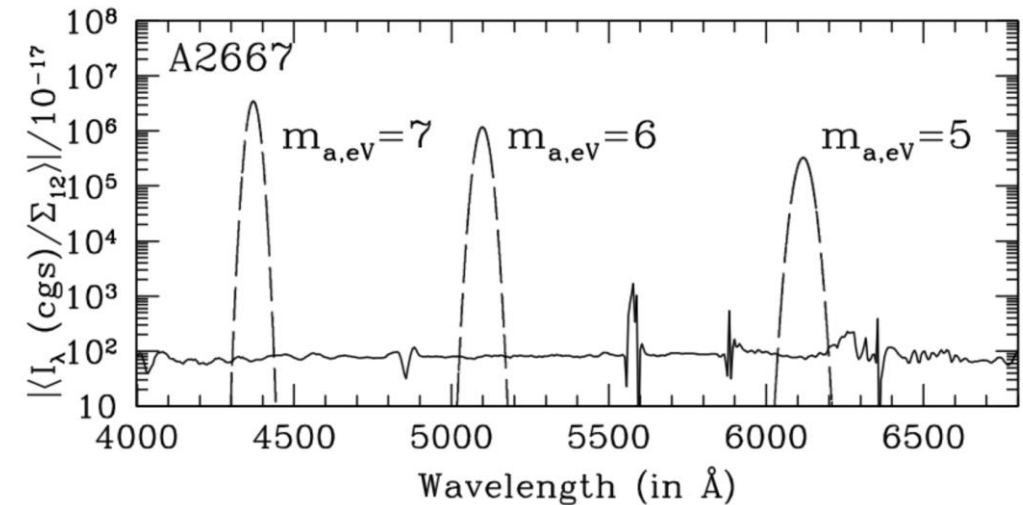
Axion-like-Particle Dark Matter in Galaxy Clusters

ALPs or other eV-scale DM may decay into mono-energetic photons, producing a spectral line.

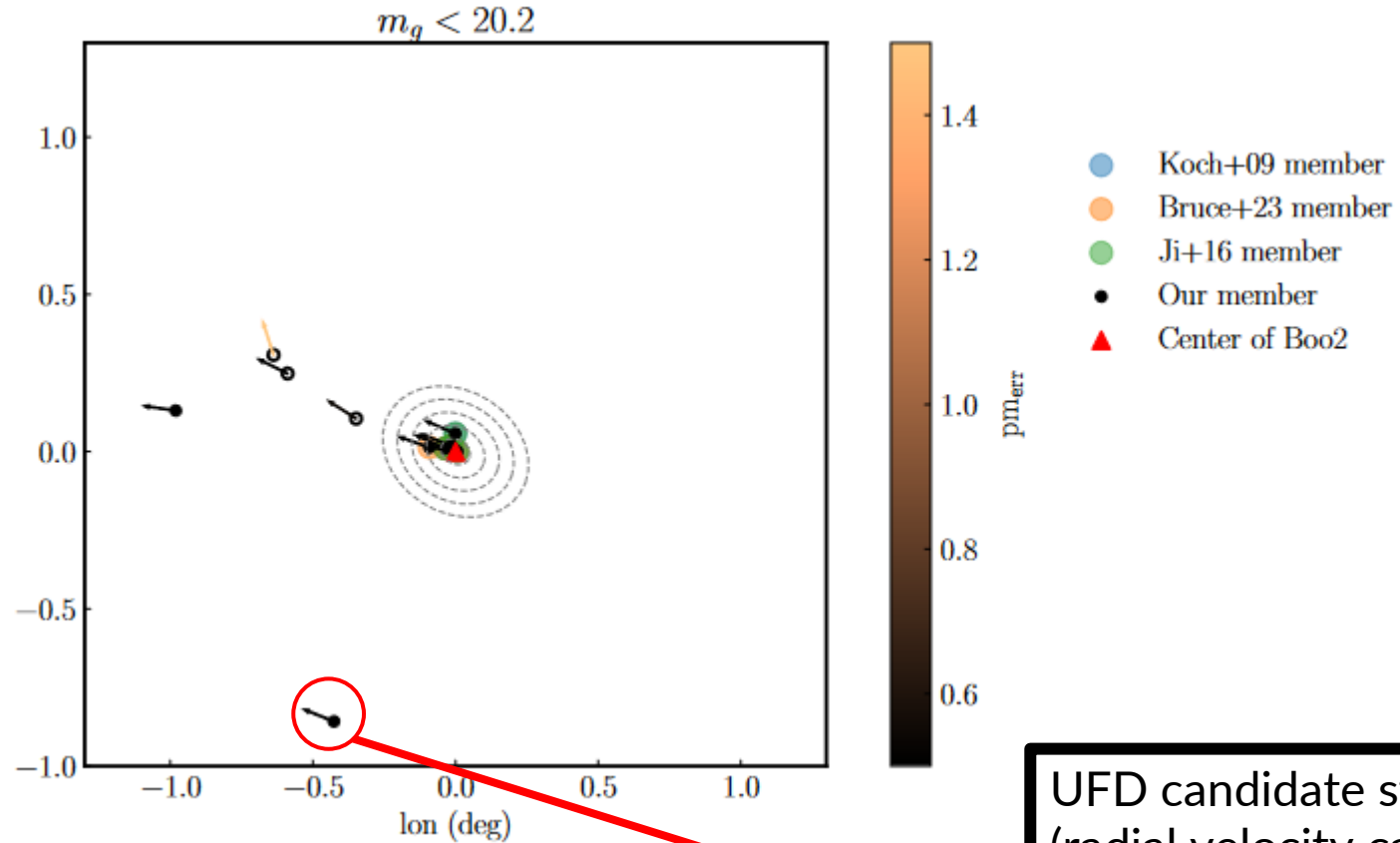
For two-photon decays, each photon has observed wavelength $\lambda = 2480 \text{ \AA} * (10 \text{ eV}) * (1+z)$.

Moderate-redshift ($z \sim 1-2$) galaxy clusters have several advantages for ALP searches:

- Large DM masses constrained by SZ observations (e.g., ACT or SPT)
- Increases ALP mass reach for a given wavelength bandpass by a factor $(1+z)$.



Ultra-faint-Dwarf Galaxy Candidate Member Star



UFD candidate star member confirmation (radial velocity calculations).

Extend the mapping of stellar population of UFDs to larger distances (galaxy evolution and their small dark matter halos).

