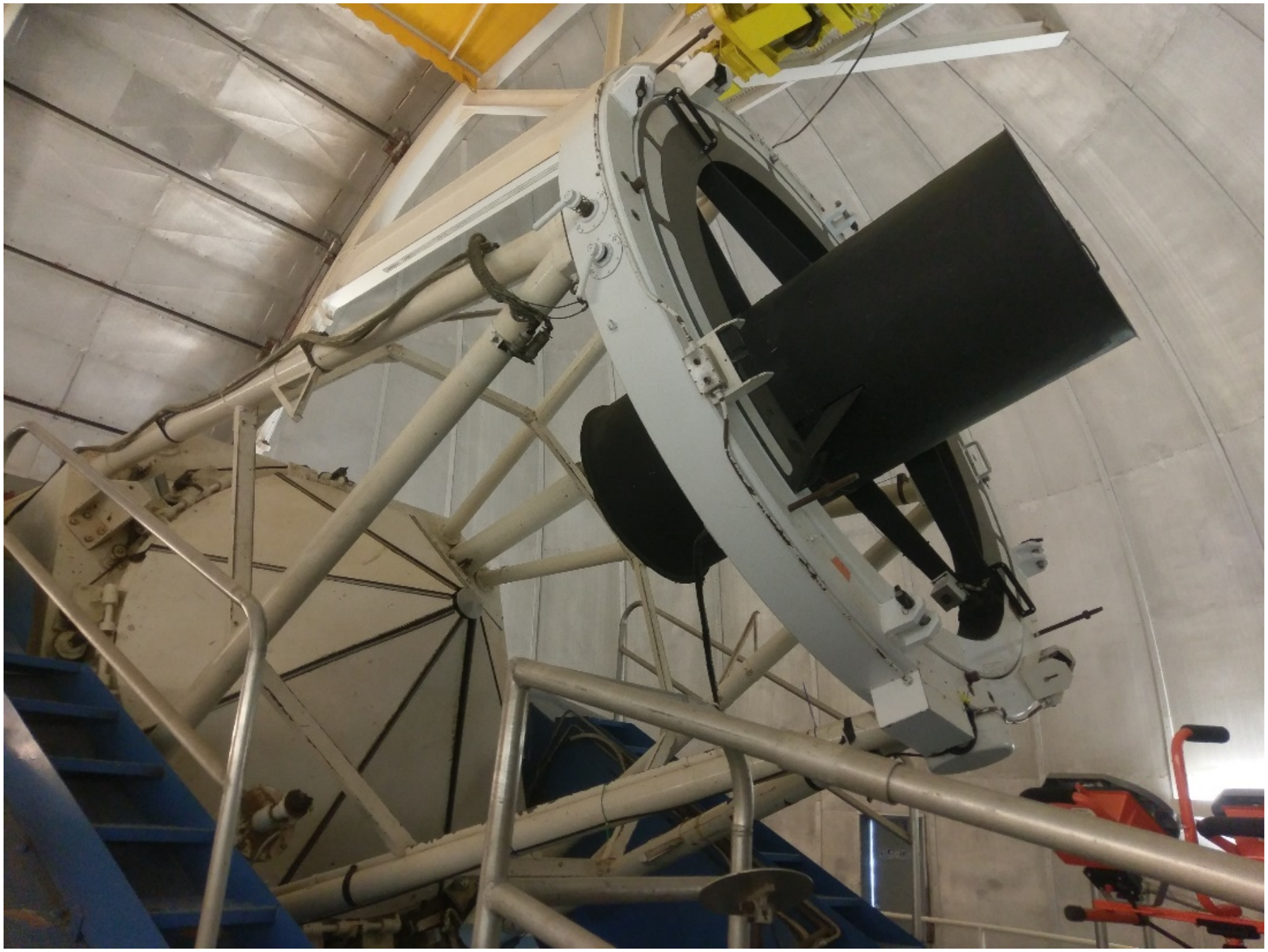
The Kitt Peak EMCCD Demonstrator (KPED)

The Kitt Peak 84 inch



Principal Investigator: S. R. Kulkarni
Project Scientist: M. W. Coughlin

The Kitt Peak EMCCD Demonstrator (KPED)

A sensitive, flexible, multi-spectral optical imaging capability for high-cadence follow-up of the transient universe.

Instrument

Hardware

1. EMCCD – Andor iXon 888
2. Filter Wheel – Finger Lakes (10 slot)
3. Filters – Johnson UBVRI, Sloan g and r
4. Corrector Lens
5. Mounting plates
6. Computer

Feeney/Riddle/Dekany/Coughlin

Software

1. EMCCD – Andor SDK + Python wrapper
2. Filter Wheel – FLI SDK + Python wrapper
3. Telescope Control – Robo-AO
4. Reductions – Robo-AO + Chimera

Riddle/Duev/Coughlin

Telescope/Camera

1. F/# = 4.864
2. FOV = 4.4 x 4.4 arcmin
3. 2.1 meter primary

Feeney/Riddle/Dekany/Coughlin

Science

- ZTF transient follow-up (GWs, SGRBs, TNOs) *Ahumada/Coughlin/Dekany/Kulkarni*
- WD Binaries – PTF and ZTF *Burdge/Coughlin/Prince/van Roestel*
- Gravitational Lens Time Delays *Coughlin*
- Astroseismology *Fuller*
- Calibration/Technical *Coughlin*

Instrument: Coughlin, Dekany, Feeney, Kulkarni, Riddle
Science: Ahumada, Burdge, Coughlin, Dekany, Fuller, Kulkarni, Prince, Riddle

Example Science Cases

Science

WD Binaries - PTF, ZTF and ATLAS

- Monitoring of the WD binary systems identified in the original PTF data.
- Follow-up of potential ZTF WD binary systems
- Follow-up of potential ATLAS WD binary systems

ZTF transient follow-up (GWs, SGRBs)

- Monitoring of the ZTF transients identified in the SGRB follow-up work.
- ZTF transients, especially those identified as fast fading, in preparation for SGRB and GW follow-up, is important.

Asteroseismology

- Low-mass pulsating white dwarfs

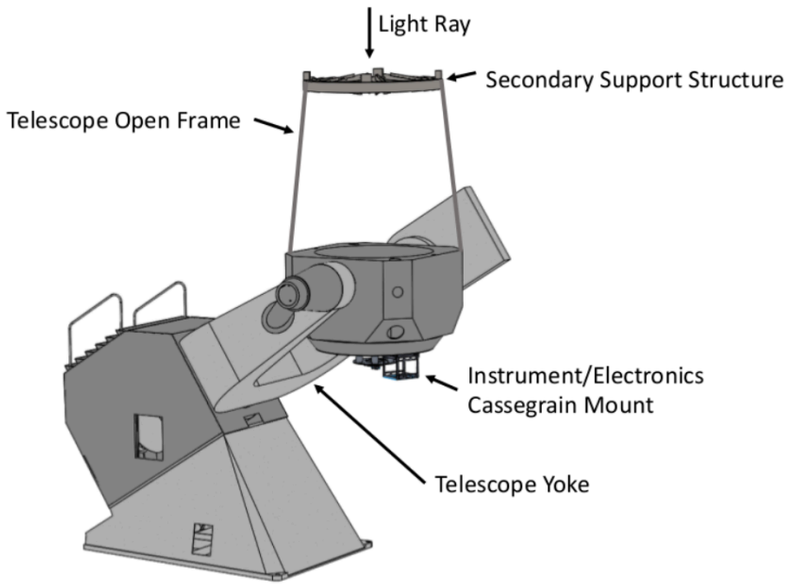
Gravitational Lens Time Delays

- Time delay measurement for GAIA + PS1 lens systems
- https://arxiv.org/abs/1803.07601

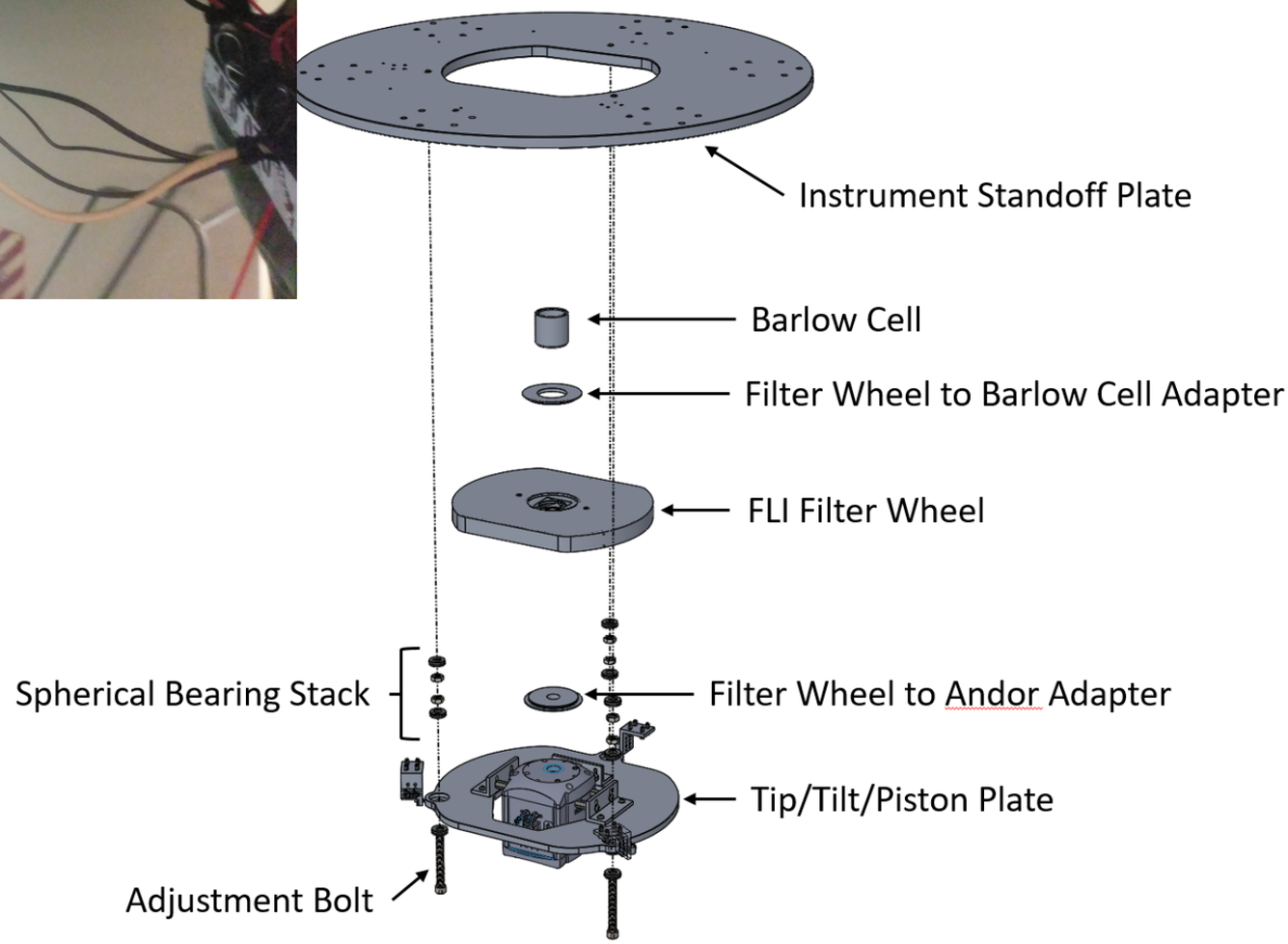
Calibration/Technical

- Photometric stability and performance of EMCCDs as a function of EM gain.
- Multiband colors in UBVRI of hot DA white dwarf stars from Gaia.

Instrument Breakdown



Instrument breakdown exploded view

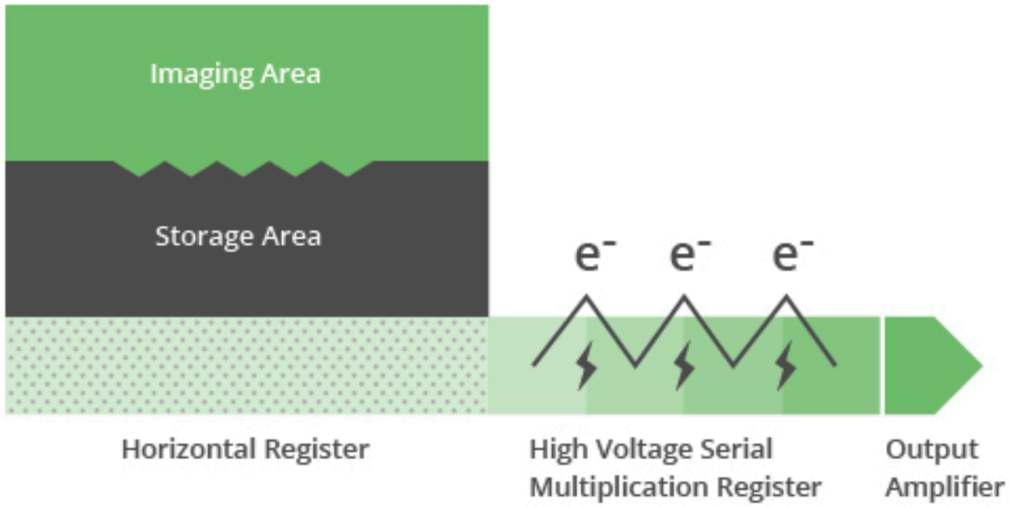


Electron Multiplying CCD (EMCCD)

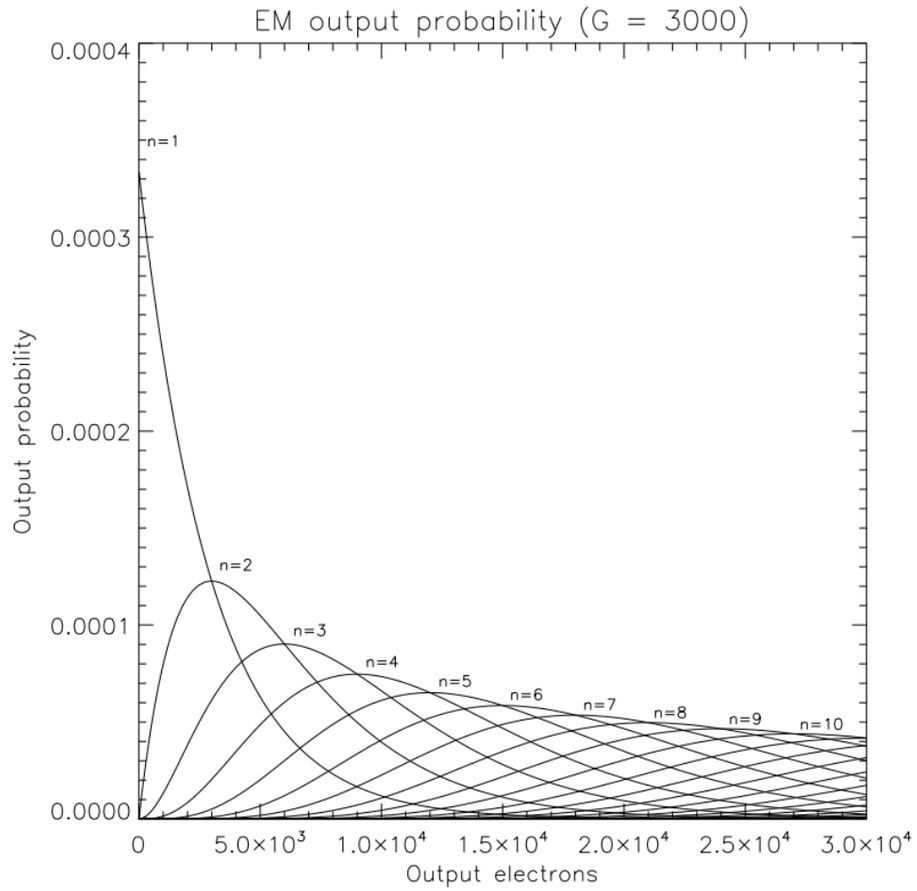
Enable sub-electron read-out noise!

but…

- Thermal noise: Cooling to -80 degrees Celsius
- EM Gain / Excess Noise Factor: The multiplication process involved is stochastic (square root 2 penalty, equivalent to half the quantum efficiency)
- Clock Induced Charges (CIC): Dominant over dark noise at high frame rate (at least an order of magnitude higher than the dark noise at 1 Hz).
- Charge Transfer Efficiency: Photoelectrons left behind during the charge transfer process, especially at high readout speeds



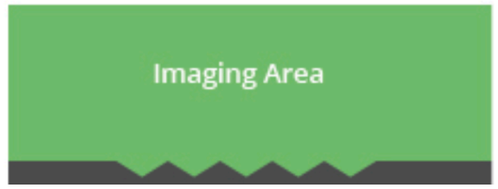
www.nuvucameras.com



Diagle et al. 2008 (0908.0528)

Electron Multiplying CCD (EMCCD)

Enable sub-electron read-out noise!



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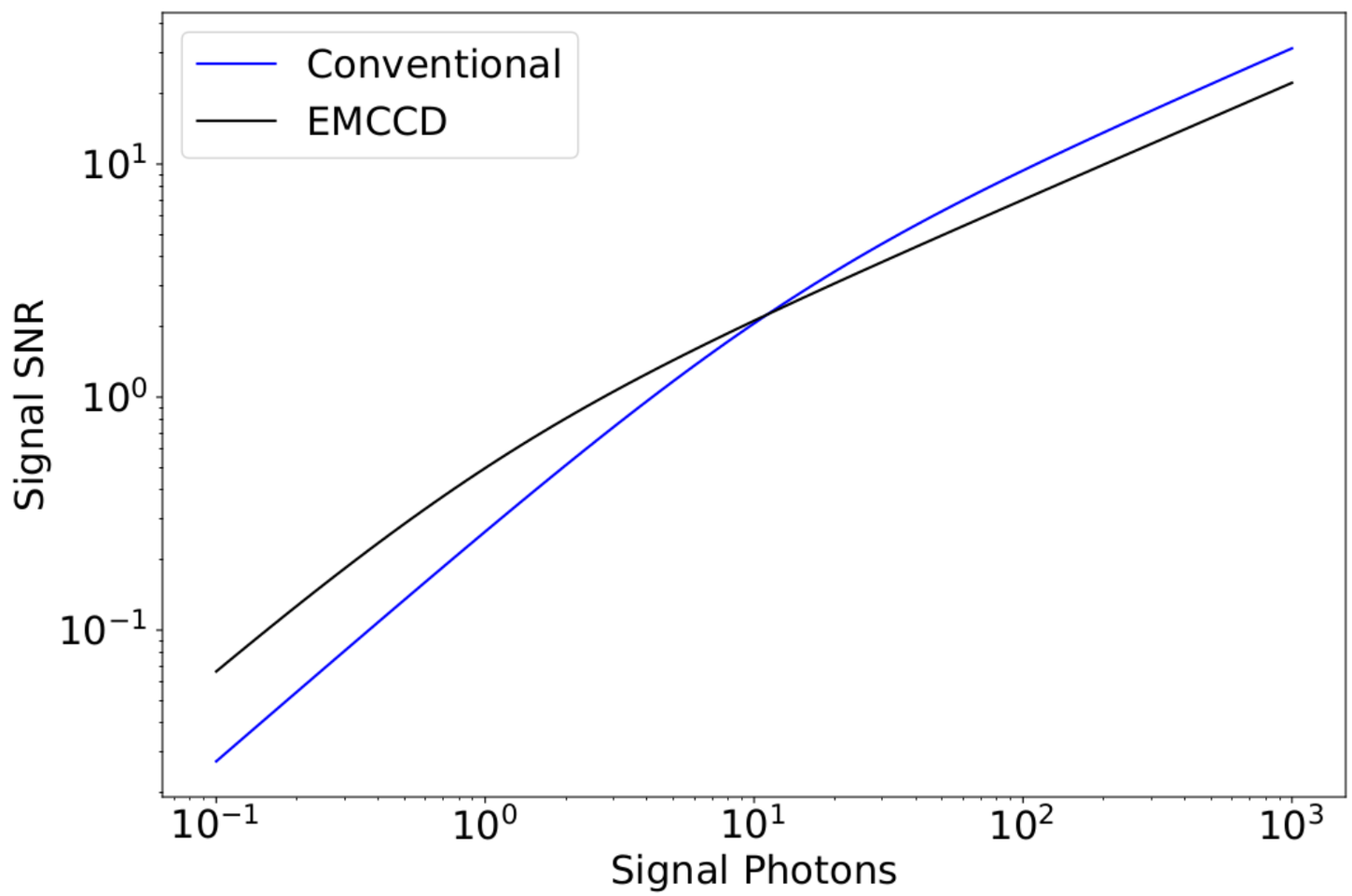
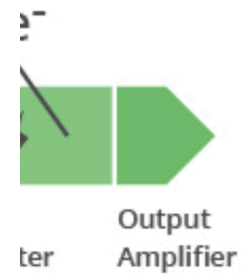
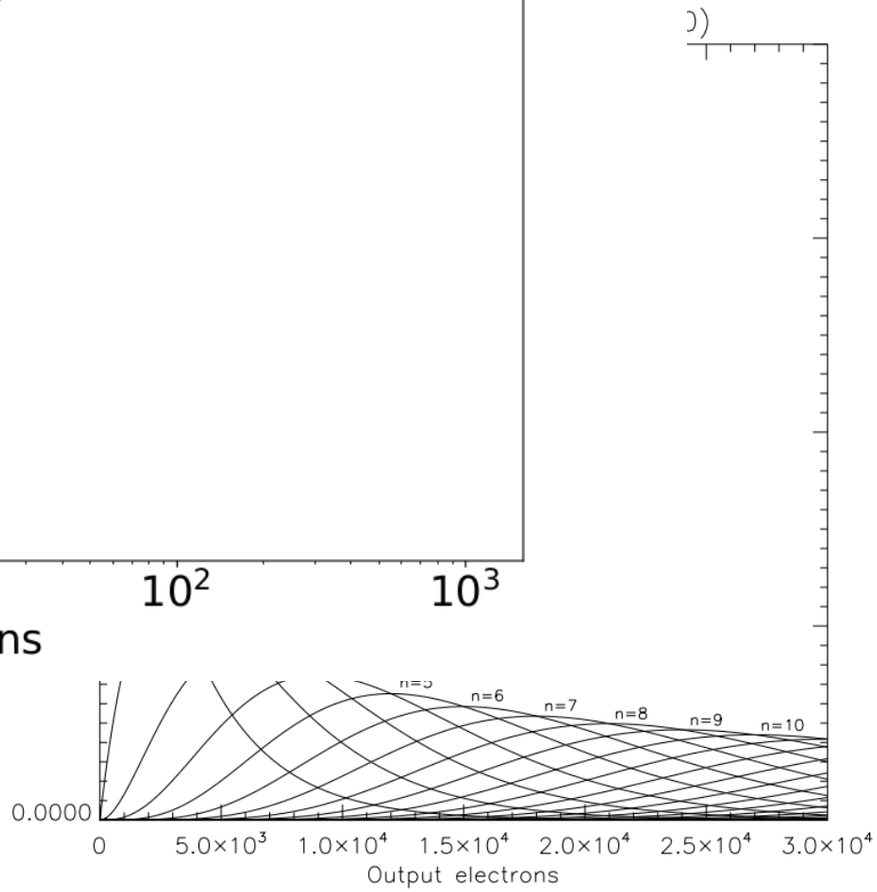






Diagle et al. 2008 (0908.0528)

Software

Telescope and Camera Control

- Based on Robo-AO and ZTF control system
- Simple, terminal based observation system
- Observation guide is documented here:

https://docs.google.com/document/d/14qMSYqB5meju1MuetaBHBBxcGyQp5c6Y1_-ECV-EBHU/edit#

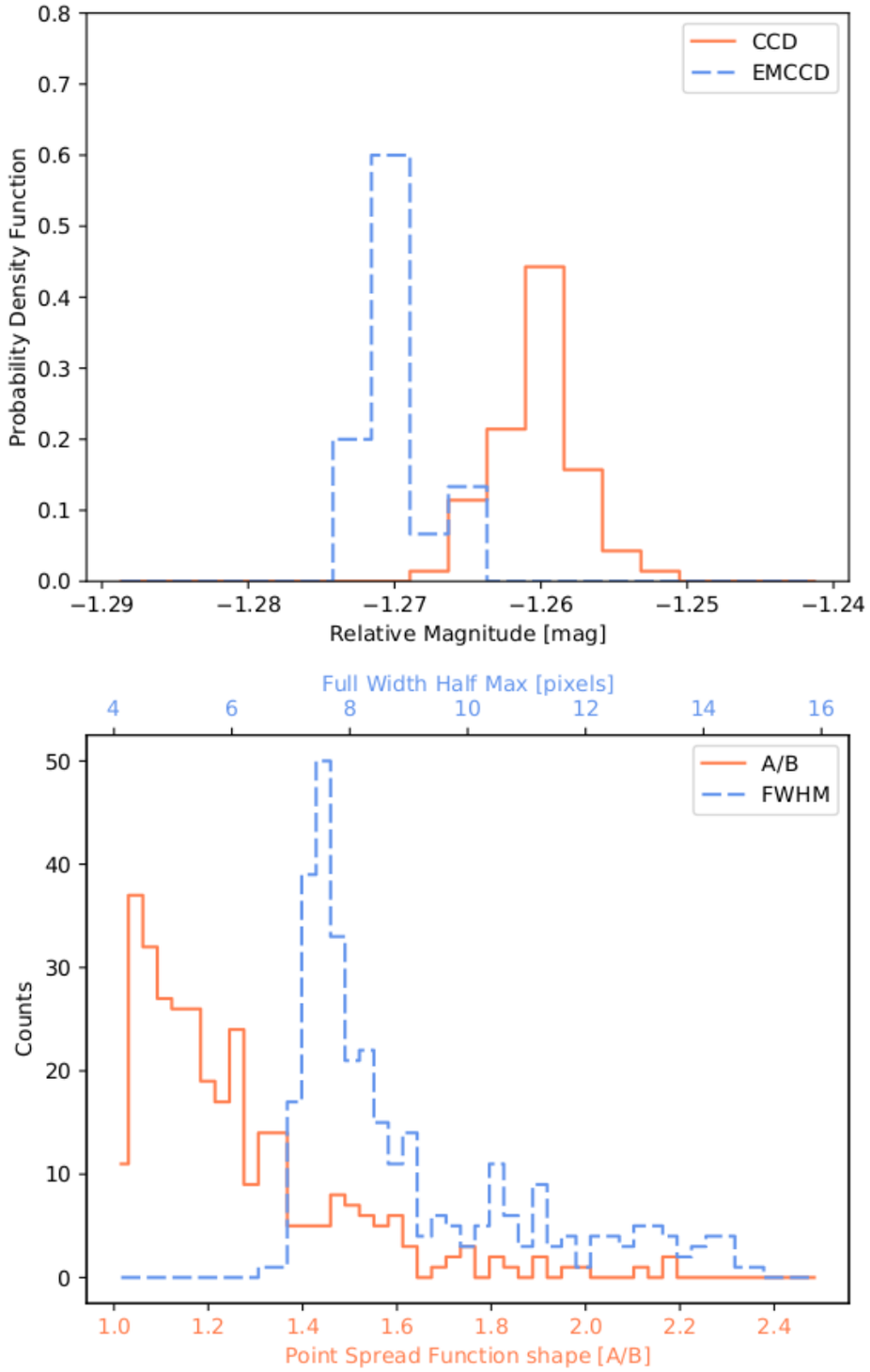
Photometric Reductions

- Based on SEDM and Chimera reduction packages
- Written in python, depending on standard packages including source extractor
- Software is self-documenting and publicly available on the KP84 GitHub

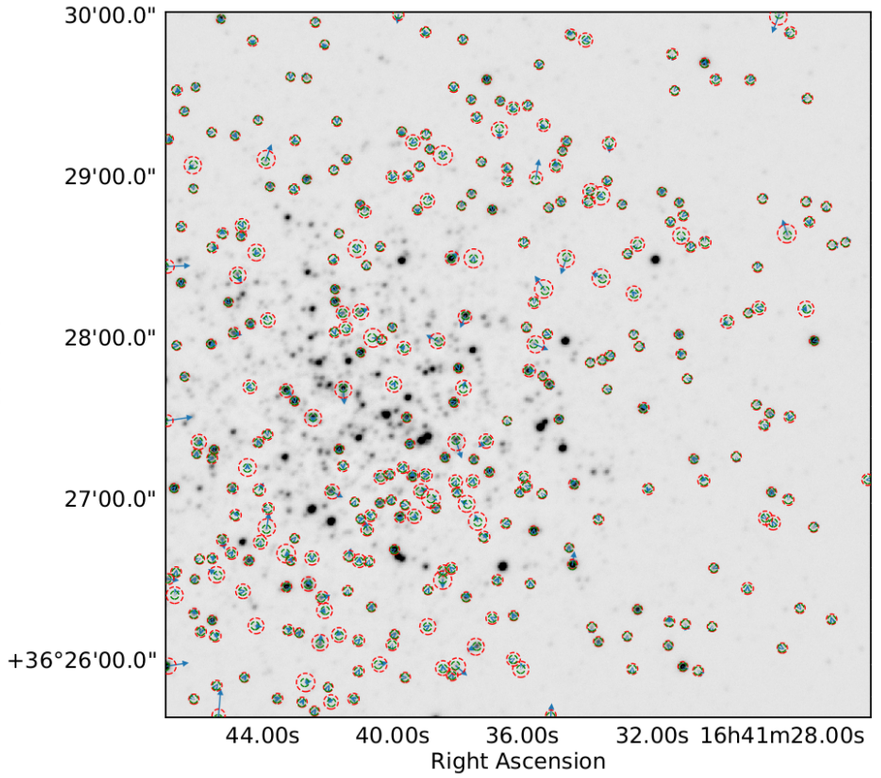
https://github.com/mcoughlin/kp84

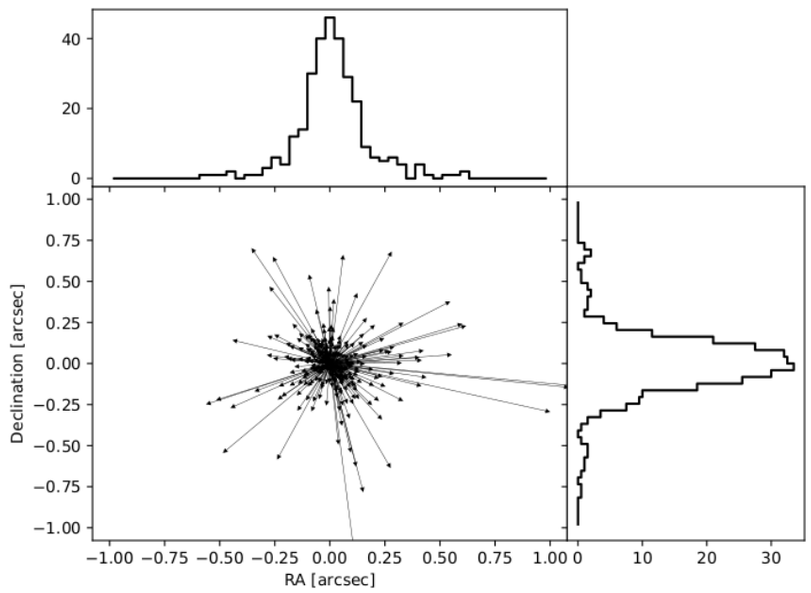
Instrument Performance

Photometric Performance



Pointing / Distortion





Instrument Sensitivity

Pointing / Distortion

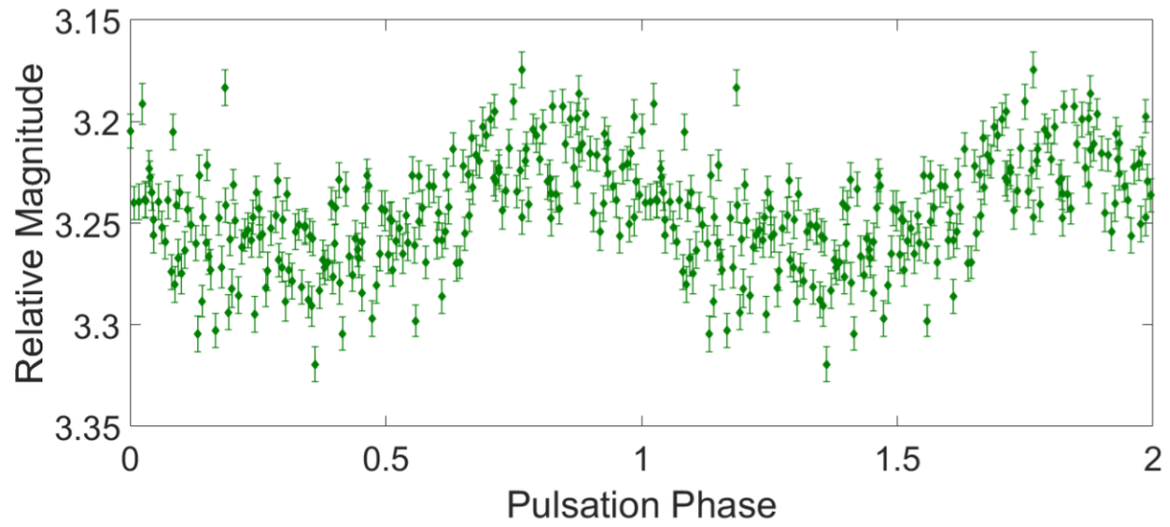
FITS WCS keyword	Value	Standard Deviation	Unit
CD1_1	-7.120×10^{-5}	6×10^{-8}	deg/pix
CD1_2	5.0×10^{-7}	8×10^{-8}	deg/pix
CD2_1	5.3×10^{-7}	6×10^{-8}	deg/pix
CD2_2	7.121×10^{-5}	8×10^{-8}	deg/pix
CRPIX1	512.019	0.003	pix
CRPIX2	512.002	0.002	pix
CCD_ROT	0.423	0.045	deg
PIXEL_SCALE1	0.2563	0.0002	arcsec/pix
PIXEL_SCALE2	0.2563	0.0003	arcsec/pix

Limiting / Zeropoint magnitude

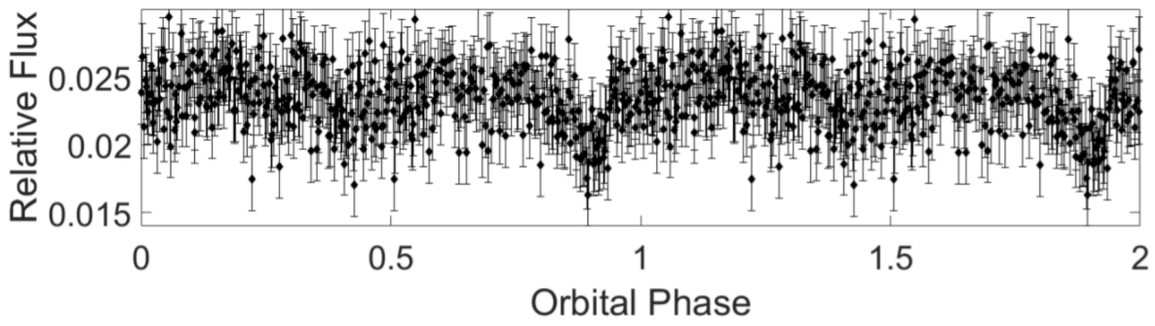
Band	Limiting mag.	$\sigma_{\text{Limiting mag.}}$	Zeropoint mag.
r	23.3	0.31	20.8
g	23.7	0.48	21.3
U	17.5	0.99	17.0
I	16.2	0.49	16.1

Early KPED Results

- PTF1J214022.55+262124.4: period of 4.8 minutes

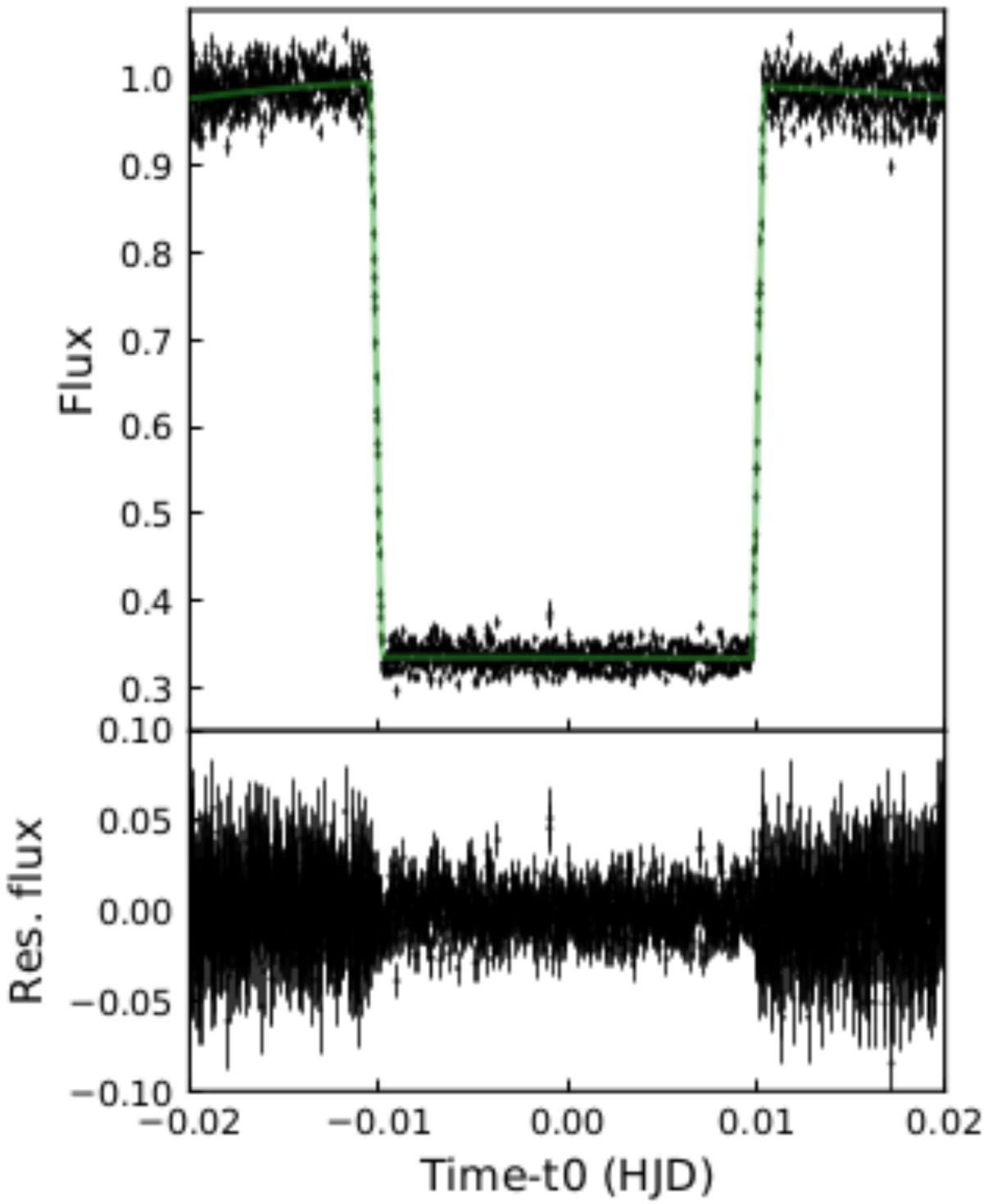


- J0651: period of 12.75 minutes

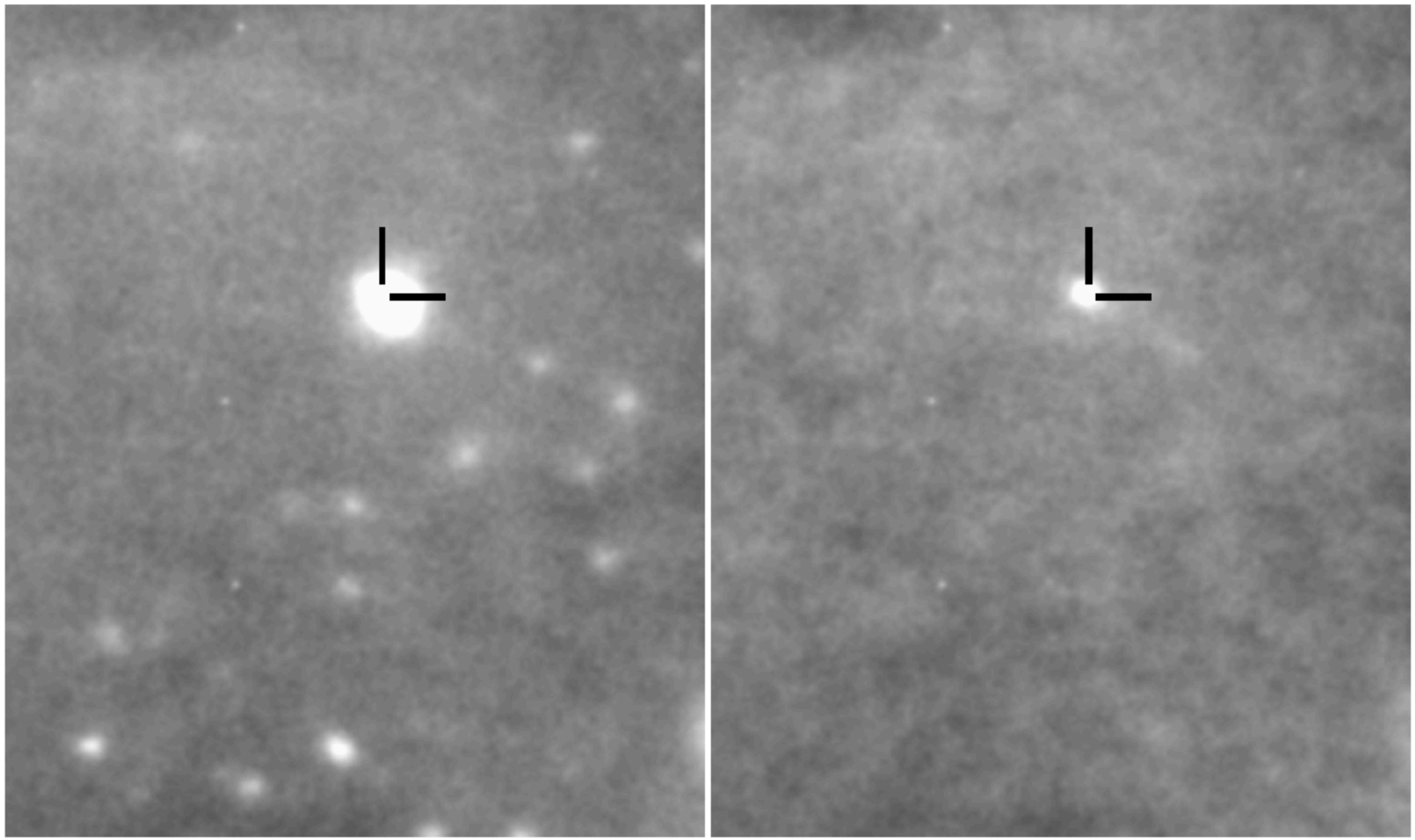


Lightcurve of PTF1J162528.61-003545.8

- PTF1J162528.61-003545.8: an eclipsing white dwarf--red dwarf system (g=16.0) identified by PTF with an orbital period of 7.8 hr.
- Eclipse timing uncertainty: 0.2 s
- Sum of the scaled radii ((R_1+R_2)/a) and the ratio of the radii: 1%



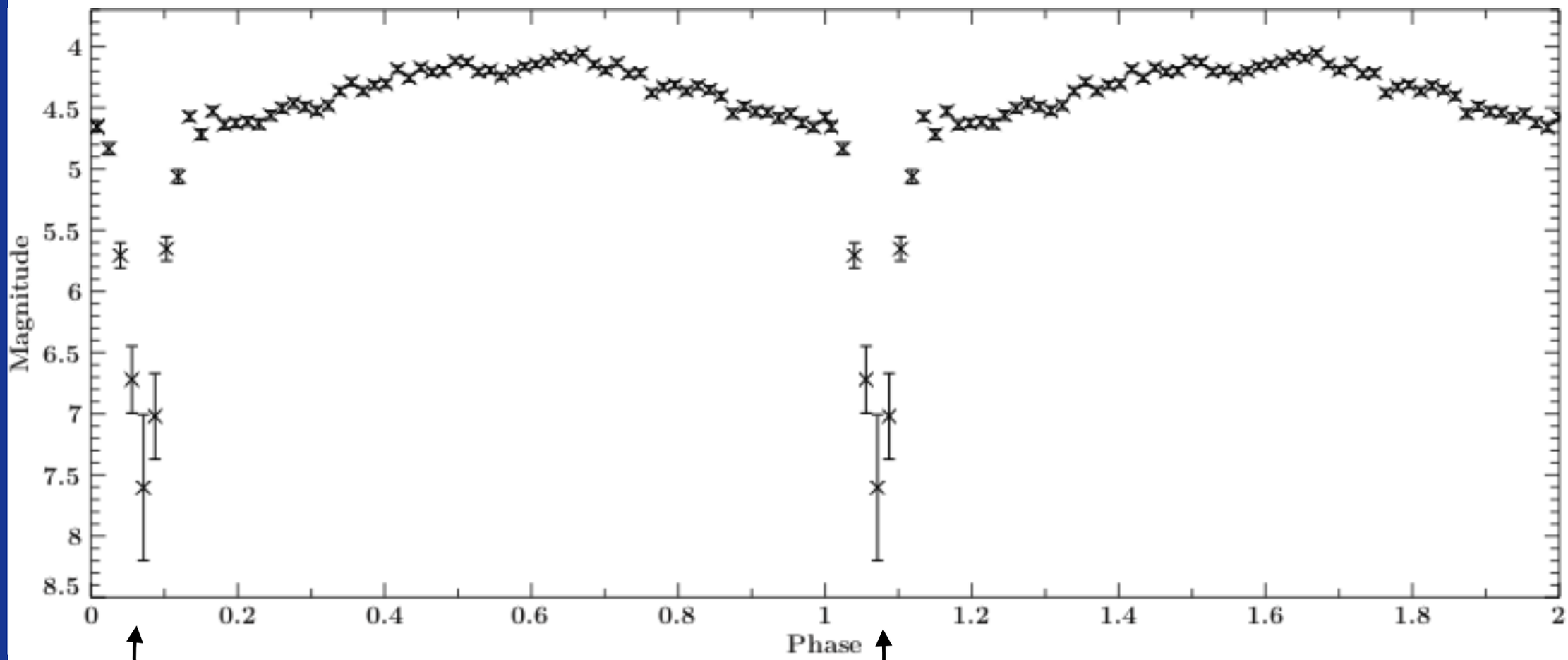
Transient Follow-up



- Example of difference imaging with KPED: ZTF18aalrxas in r-band

A 7 minute system

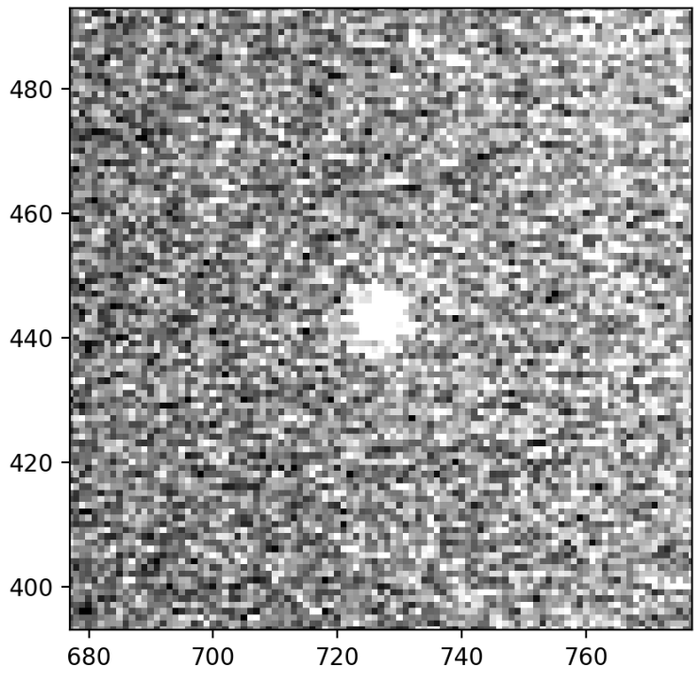
- **Folded Lightcurve of the 7 minute binary eclipsing white-dwarf binary from KPED**



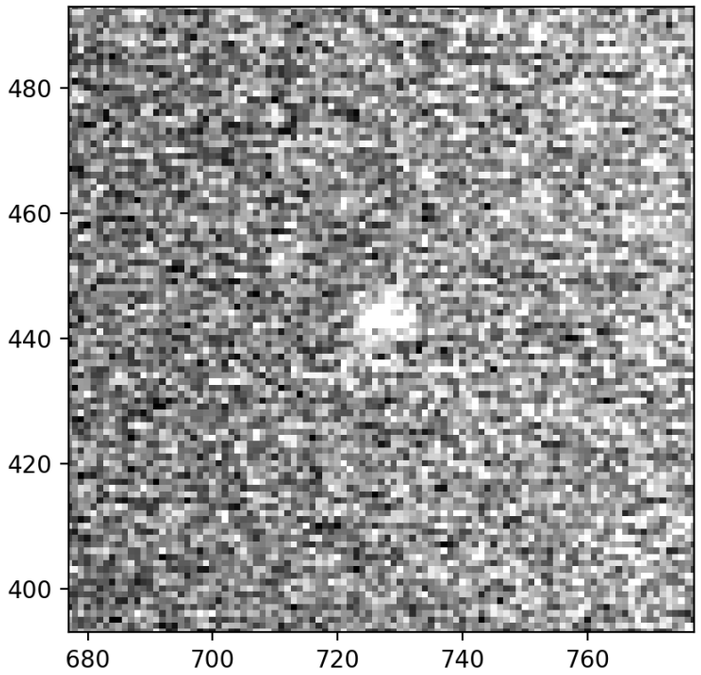
Two eclipses; 7 minute period

A 7 minute system (continued)

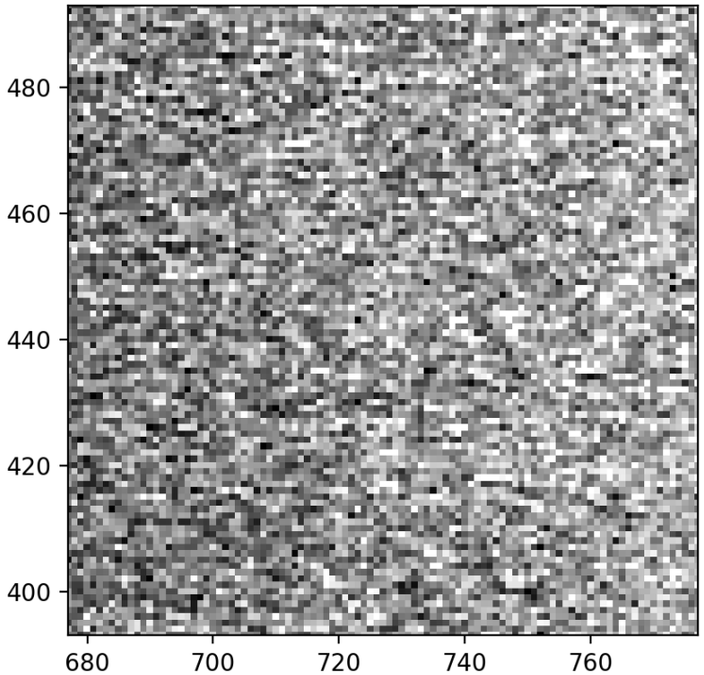
Peak Brightness



Eclipse Ingress



Eclipse



- **Low flux level during the eclipse prioritizes the use of the EMCCD, which is designed for low light level observations**

LISA Verification Binaries