Apply Lucky Image Technique on the Lulin One-meter Telescope

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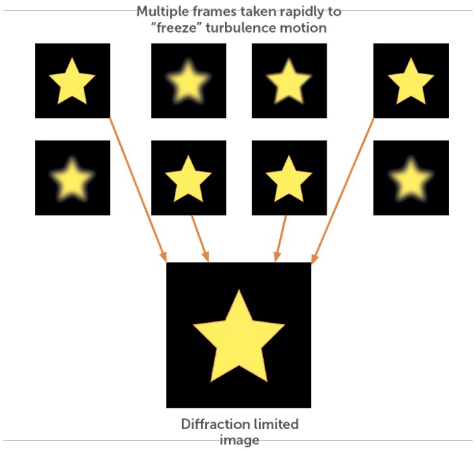
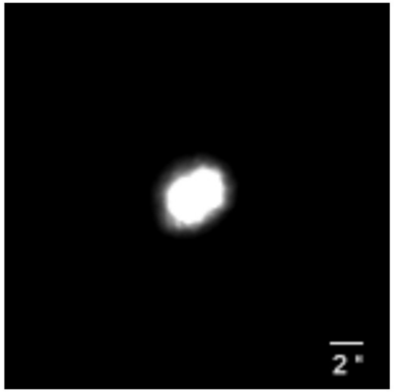
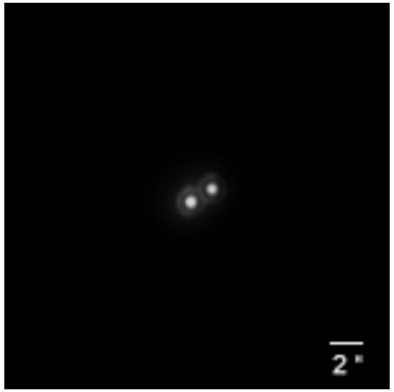
Lucky Image (LI): Inexpensive Way to Beat Atmosphere

- Taking many (~10^4 to 10^6) short exposure images for chances (or ``luck") of a small fraction of these images would be least affected by atmospheric turbulence → stacking the sharpest images it is possible to produce an image which is close to the diffraction limit of the telescope



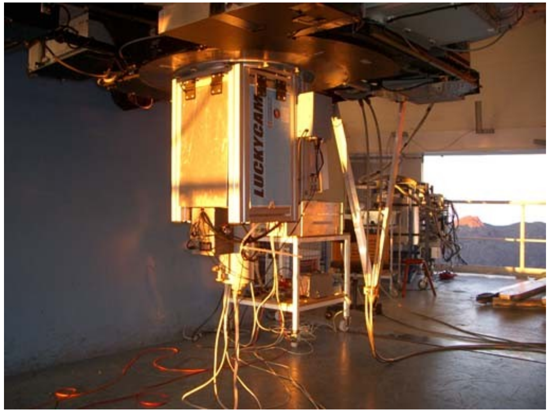




The Expected "Luck"

- r_0 = Fried parameter (diameter for RMS of phase distortion is 1 radian)

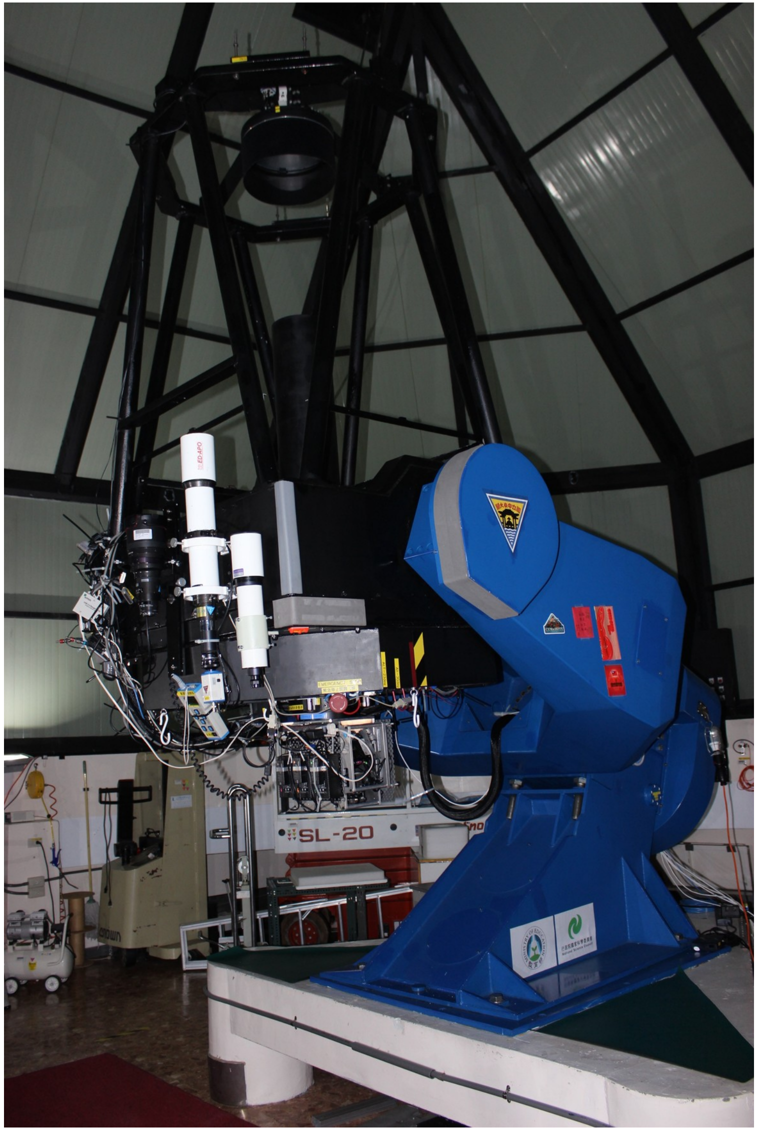
	Telescope	$\theta_{seeing}('')$	$r_0(cm)$
Lulin	LOT	1.5	8.3
La Palma	NOT	0.5	24.9



Fried (1978)

D/r_0	Probability
2	0.986 ± 0.006
3	0.765 ± 0.005
4	0.334 ± 0.014
5	$(9.38 \pm 0.33) \times 10^{-2}$
6	$(1.915 \pm 0.084) \times 10^{-2}$
7	$(2.87 \pm 0.57) \times 10^{-3}$
10	$(1.07 \pm 0.48) \times 10^{-6}$
15	$(3.40 \pm 0.59) \times 10^{-15}$

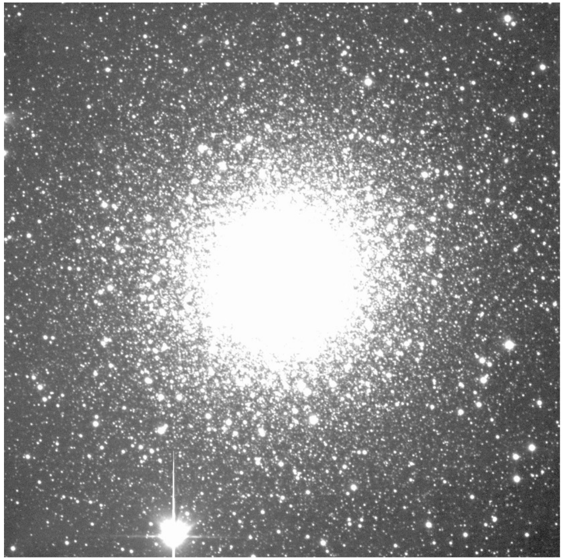
Custom-made high-speed CCD camera



LOT Test Observation

ZWO ASI294MM-Pro

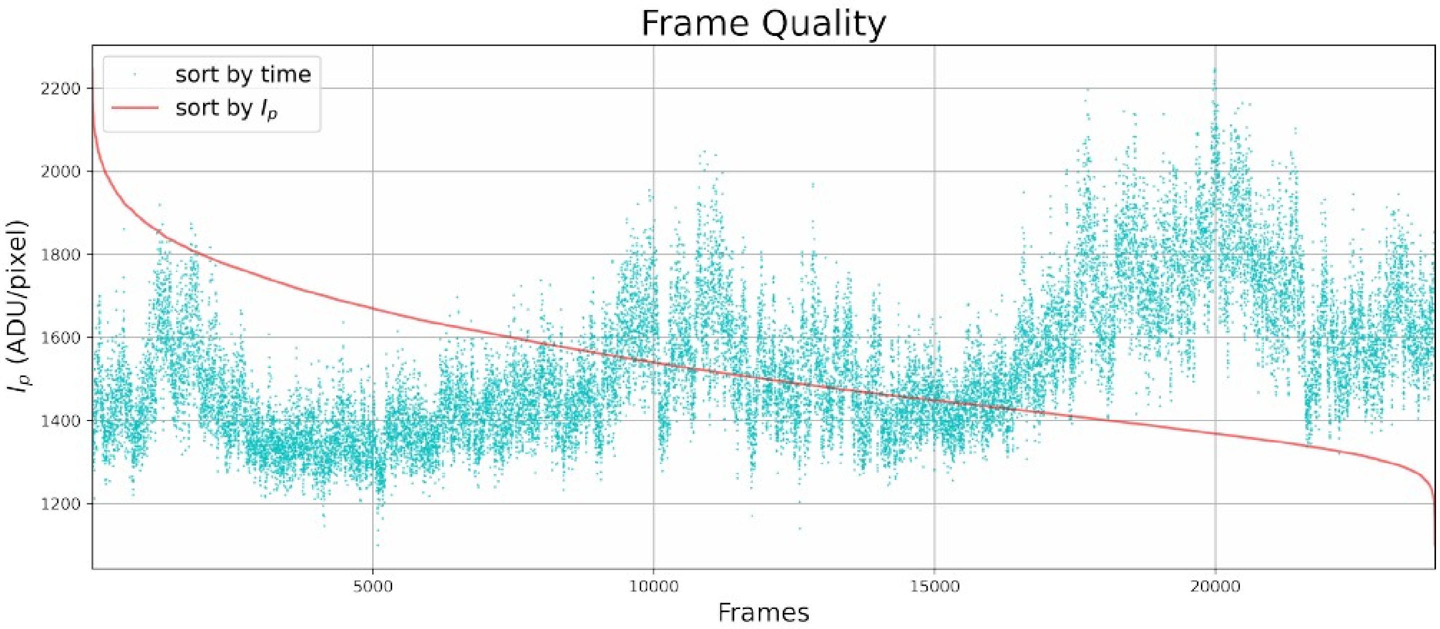
Image Sensor	SONY IMX492 BSI CMOS
Peak QE	90%
Readout noise	1.2e^- @High Gain
Dark current	0.002e^-/pix/s @ -20C
Pixel scale	0.12" /px (4.63μm)
Cool temperature	-35°C below ambient

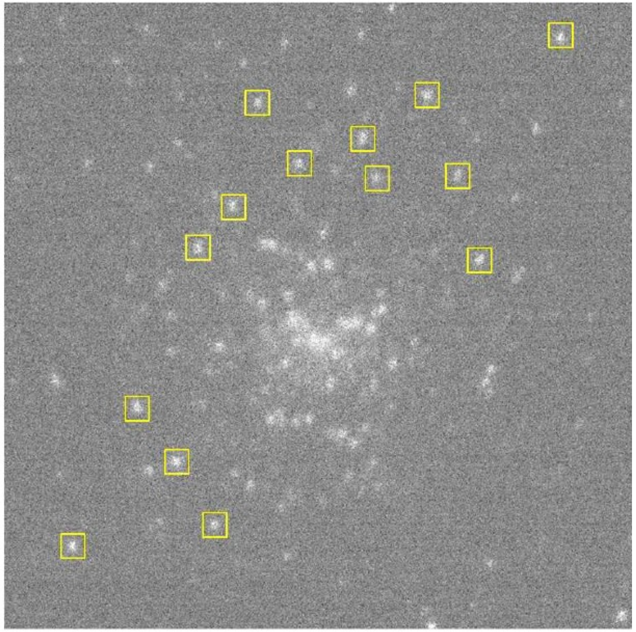


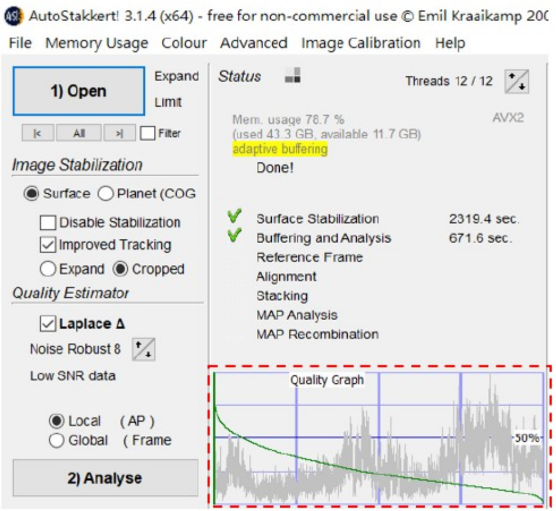
- One night at LOT, obs. core of M15
- Filter used: r-band → diffraction limit is 0.16''
- Using 20 FPS for 20 minutes = 24000 frames (or ~36 GB raw data)
- Field-of-view reduced from 13' x 13' to 2' x 2'

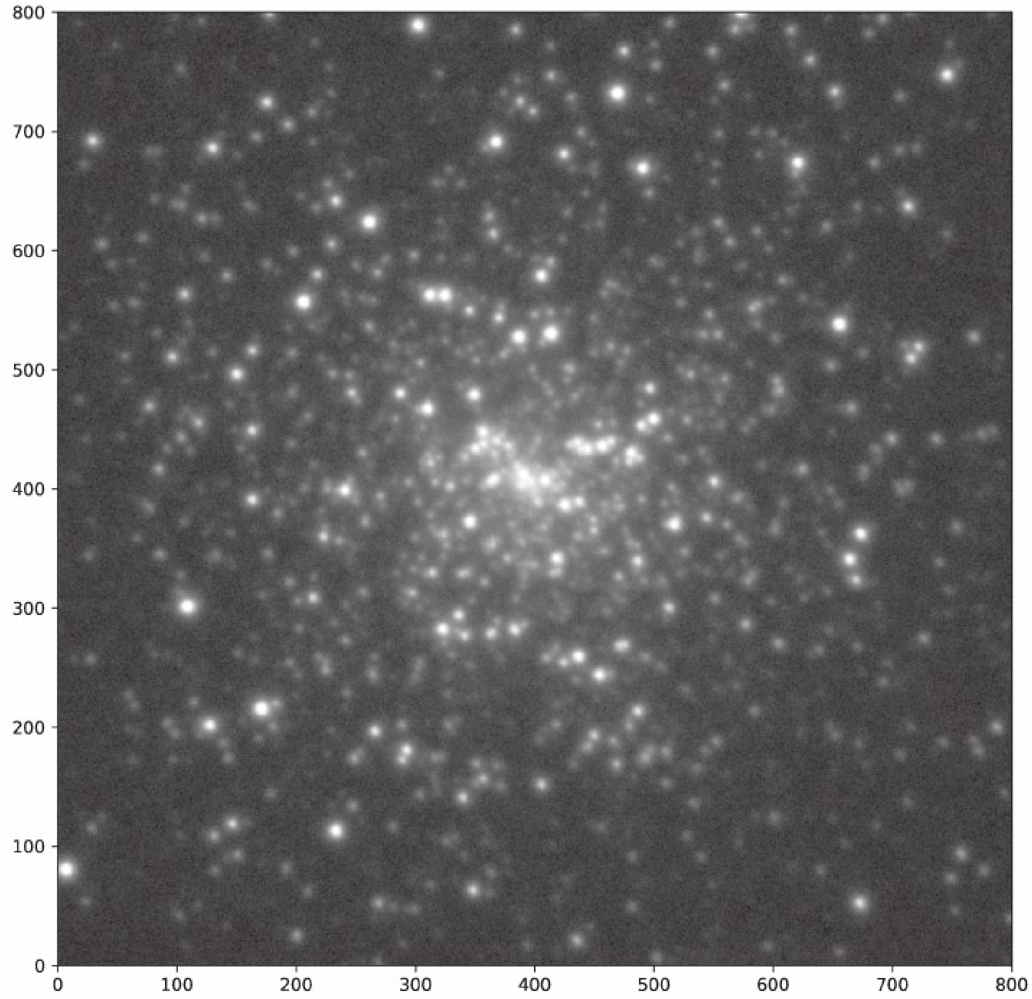
Best Frames Selection

- Select 14 bright reference stars, calculate I_p = mean ADU per pixel within 50 x 50 pixels from all reference stars

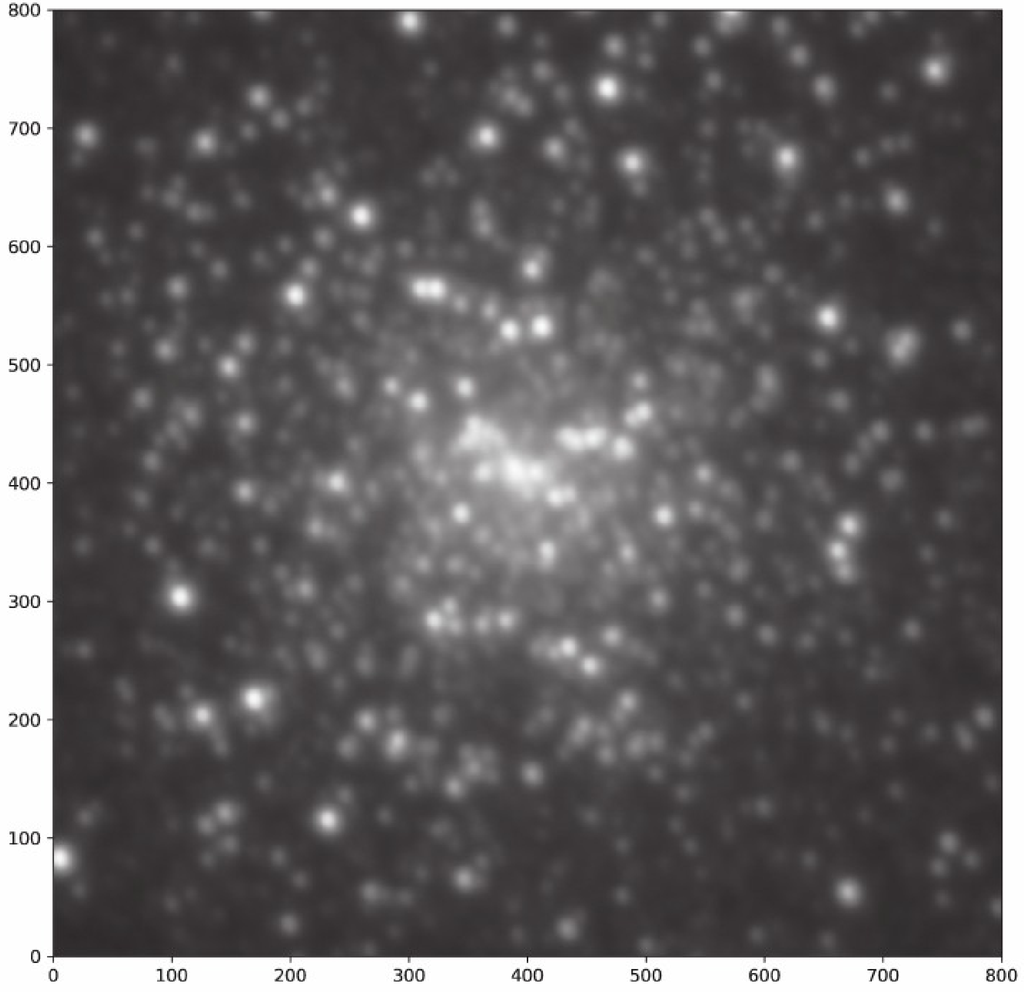




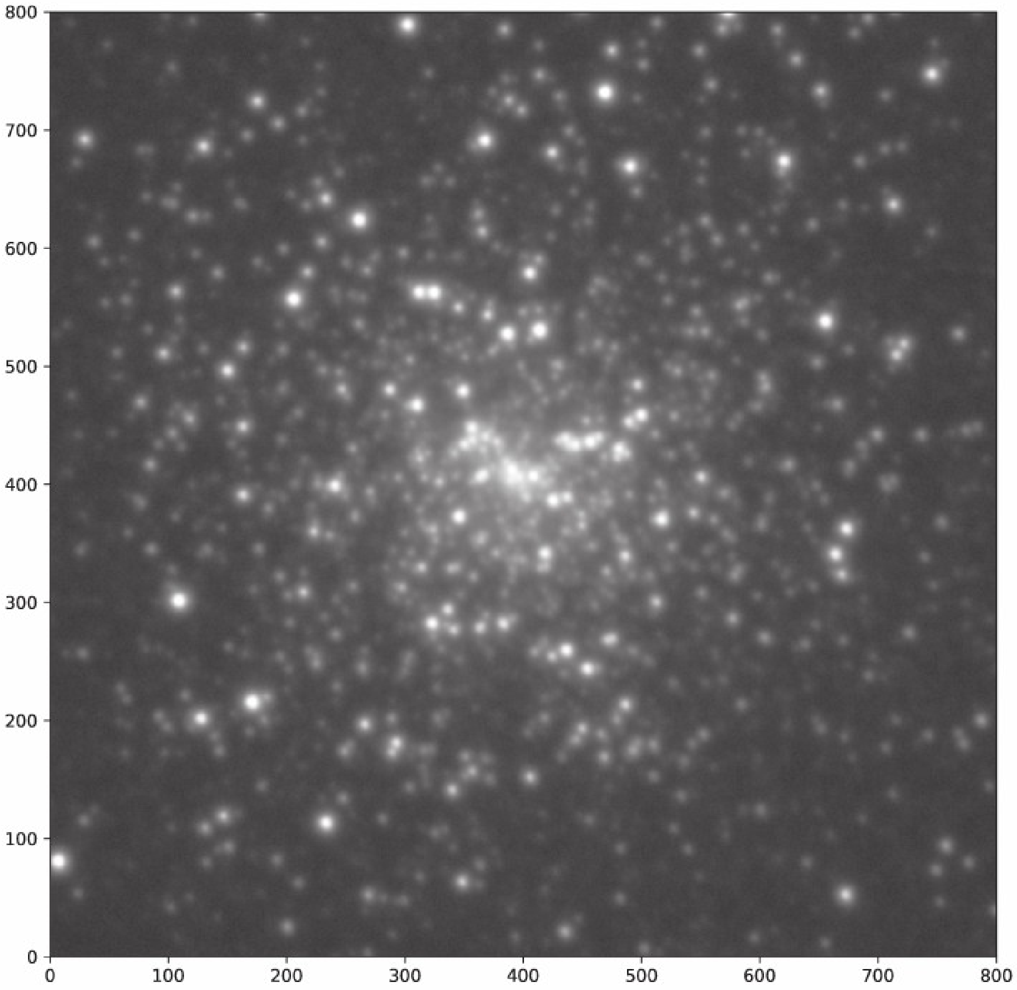




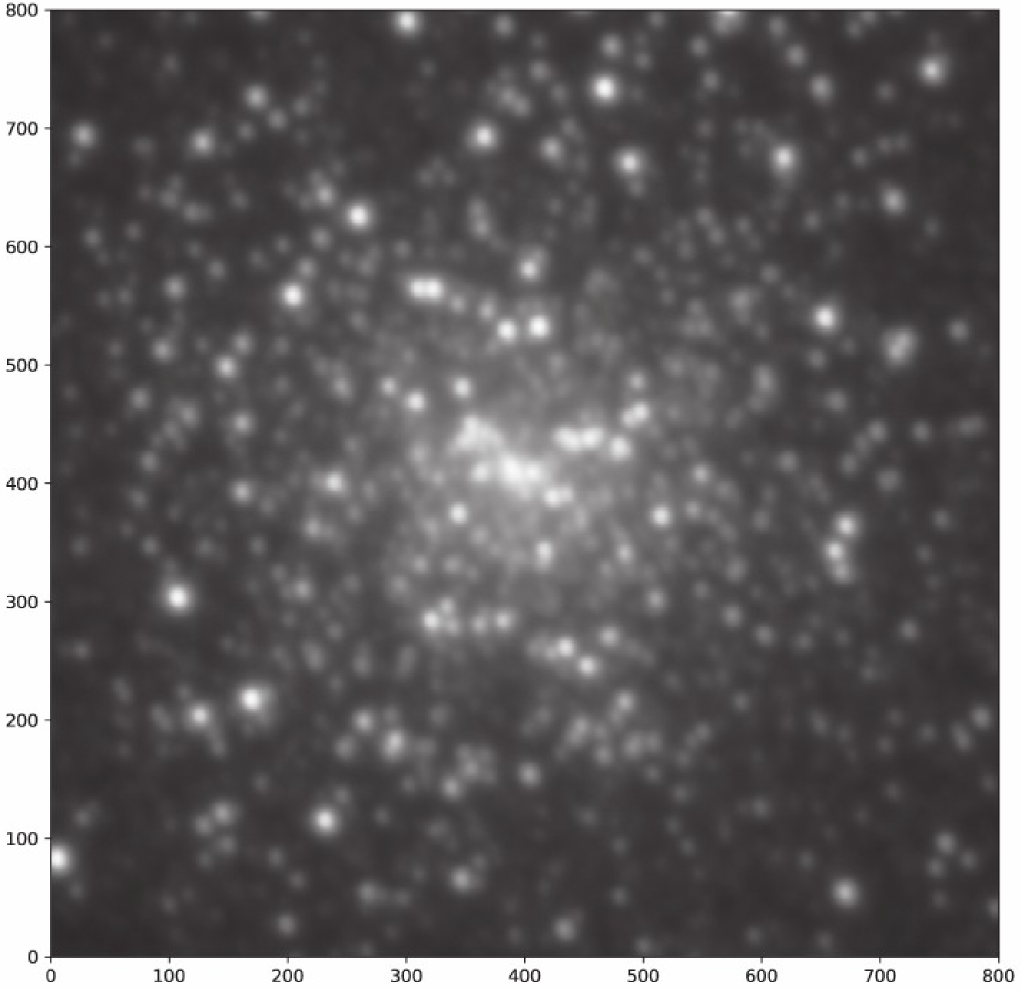
(a) Best 1% selection.



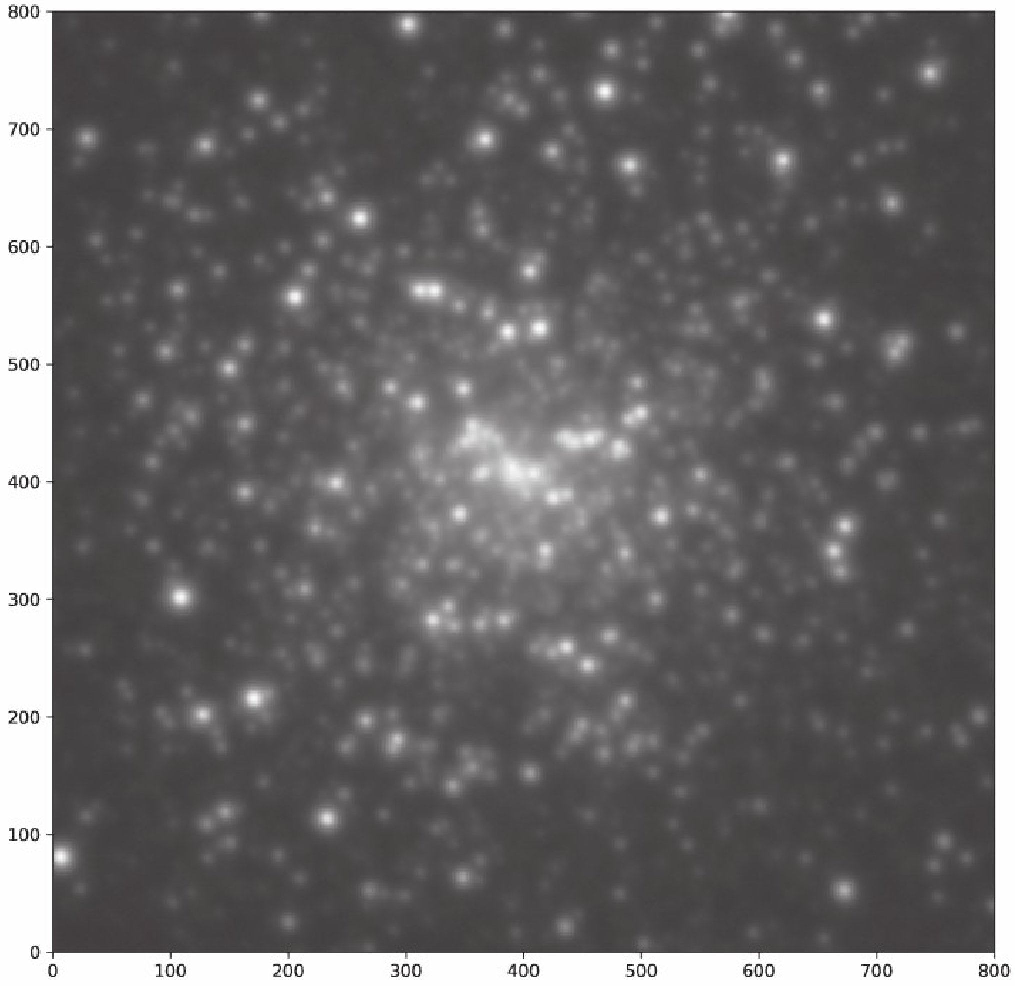
(d) Long-exposure image.



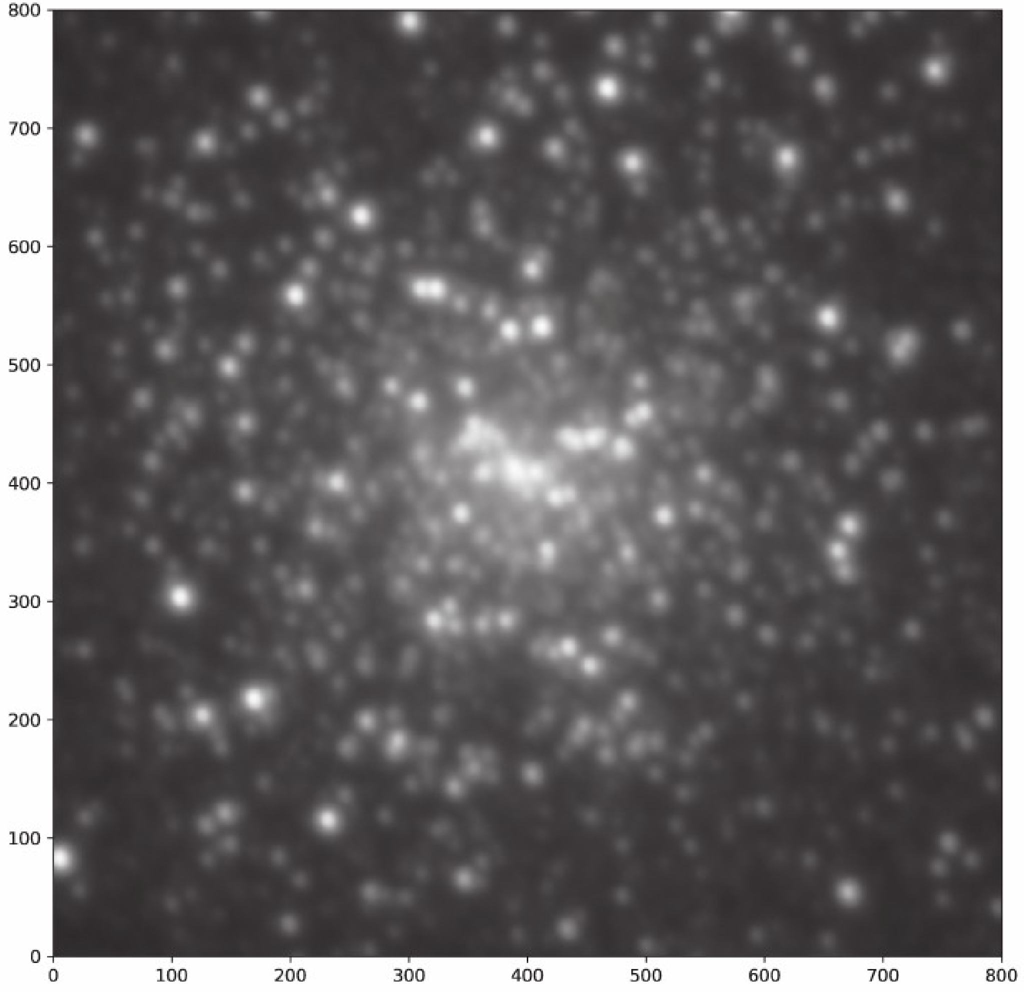
(b) Best 10% selection.



(d) Long-exposure image.

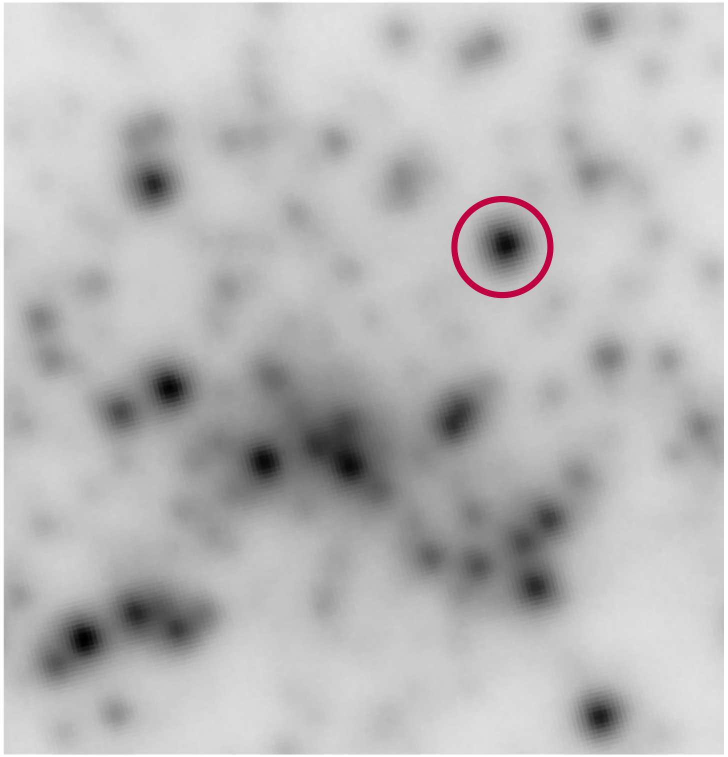


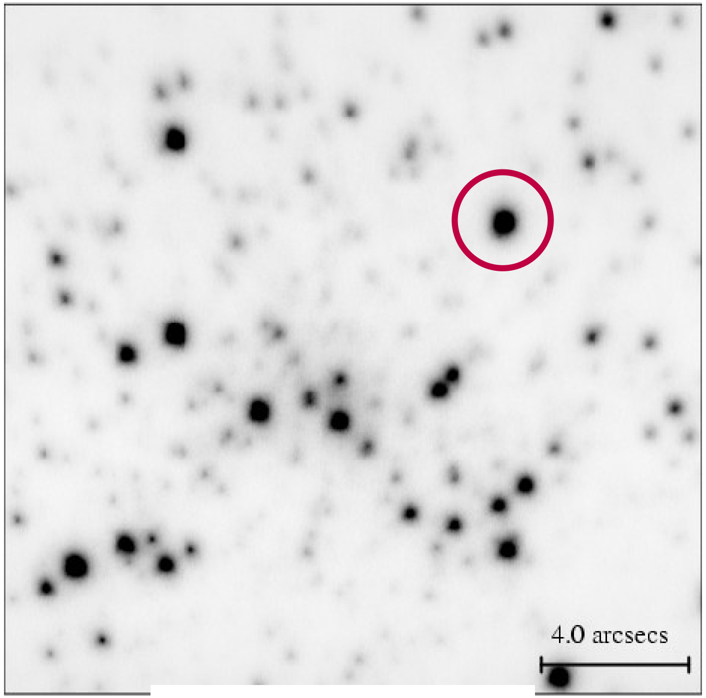
(c) 100% selection.



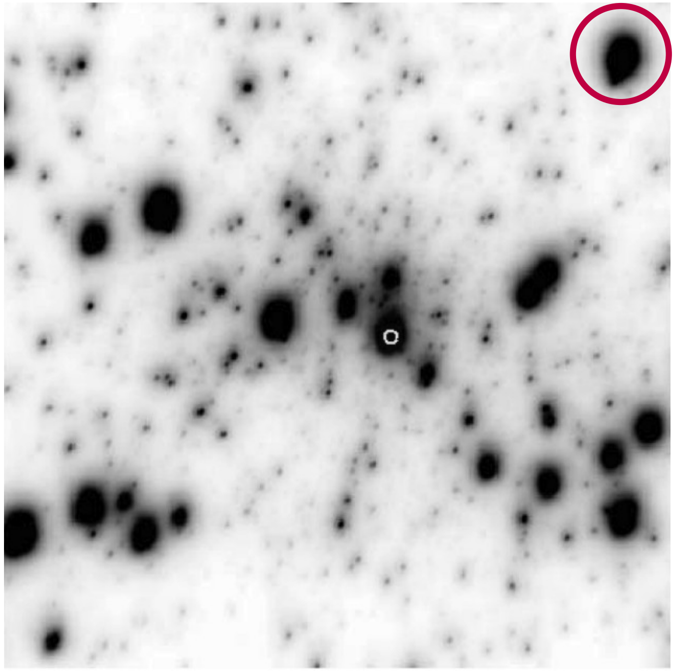
(d) Long-exposure image.

Compared to Previous Work





Law et al. (2006a)

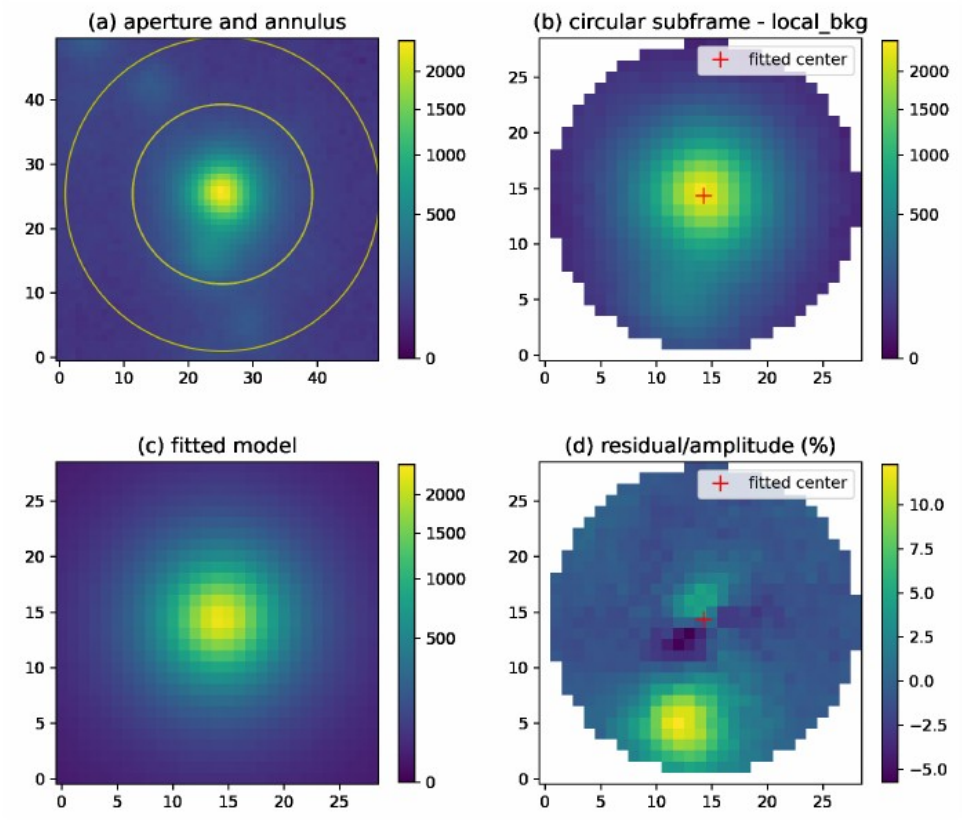


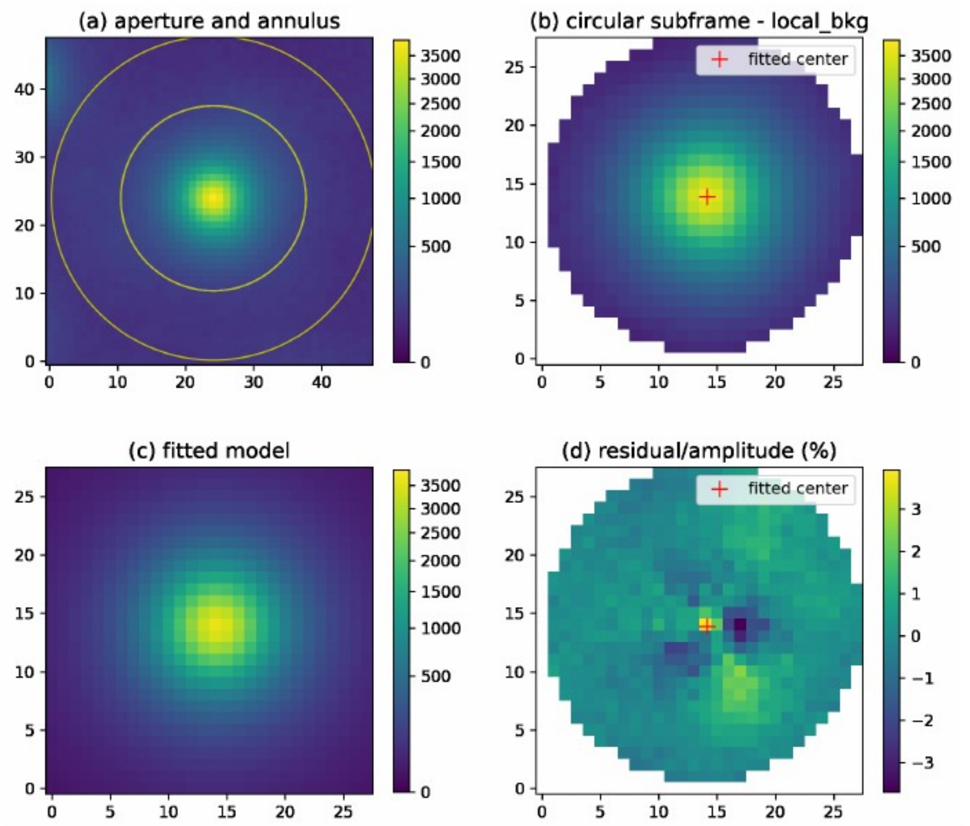
Díaz-Sánchez et al. (2012)

Telescope	1-m LOT	2.56-m NOT	2.56-m NOT
Camera	ASI294MM	LuckyCam	FastCam
Diffraction limit	0.16″	0.08″	0.08″
Pixel scale	0.12″/pixel	0.04″/pixel	0.03″/pixel

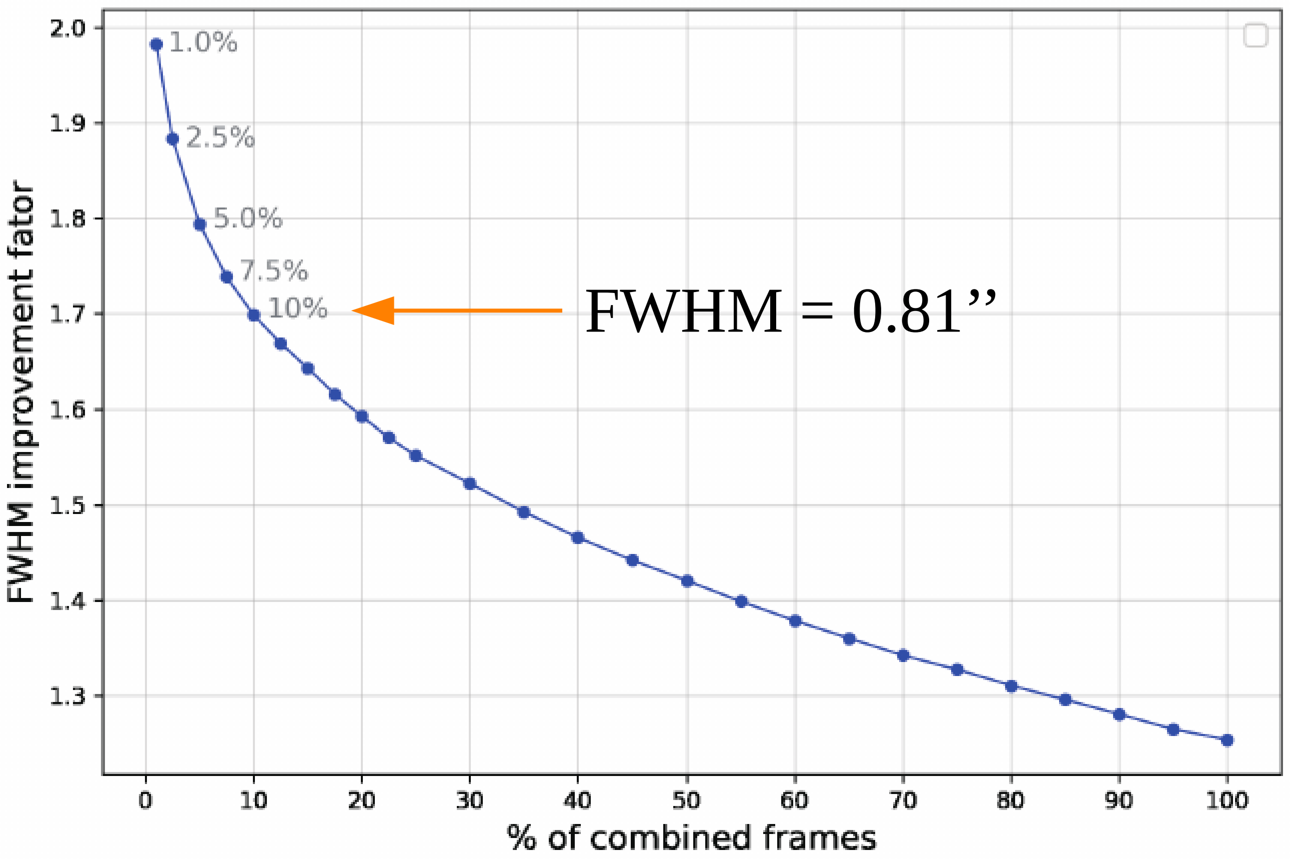
○ = same star

Fitting Moffat PSF on Reference Stars





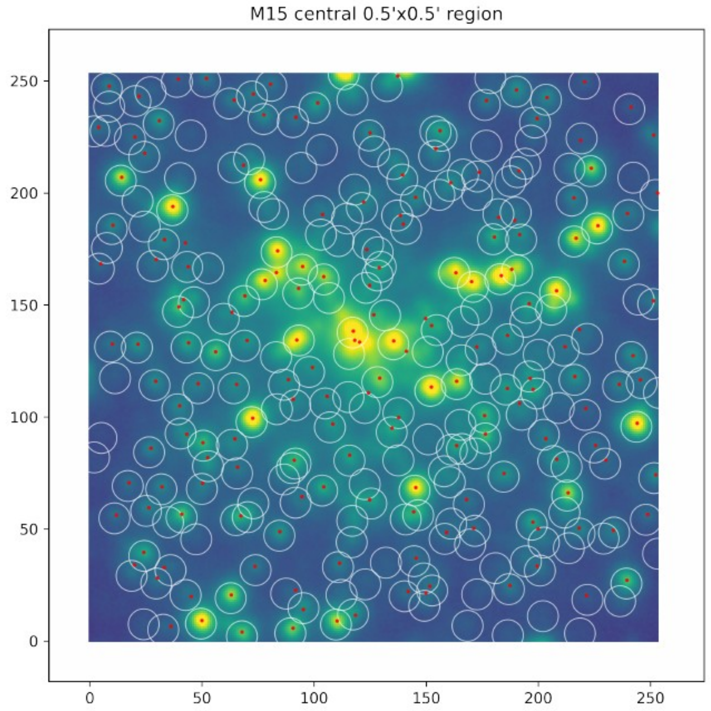
FWHM Improvement vs. Nominal Seeing of 1.38 arcsecond

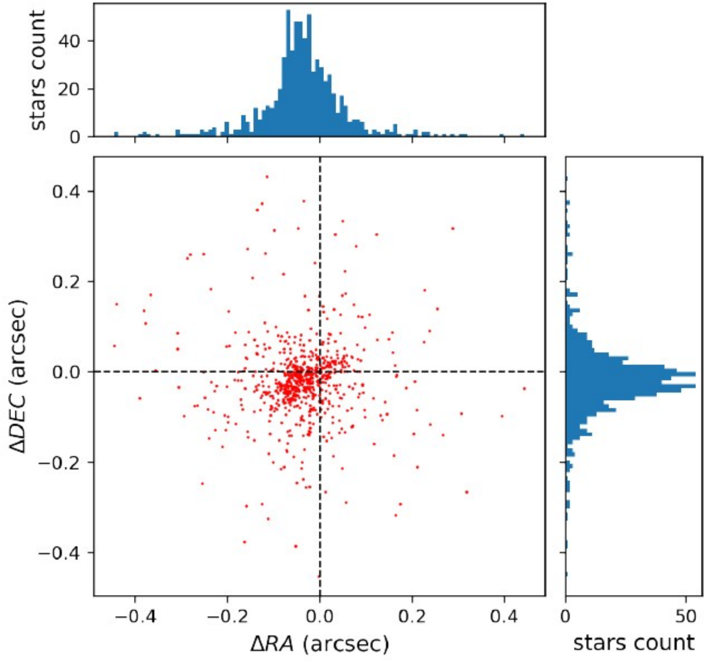


Astrometric Performance

- ~700 detected sources matched to Gaia DR3, achieving

$$\langle \Delta RA \rangle = -0.04 \pm 0.09'' \qquad \langle \Delta DEC \rangle = -0.02 \pm 0.09''$$





== Conclusion ==

- LI technique on LOT with commercial CMOS? YES

- With LI observations on M15 globular cluster, showed:
  - FWHM can be improved by 1.25x to ~2x (for different selection of best images – selected using the I_p algorithm) vs. conventional long exposure
  - Astrometric accuracy can reach to sub-arcsecond level

- Apply to variety of science requiring high-resolution images (binaries, hosts of exoplanets, globular clusters, and more)