A User's Guide to Lucky Imaging

(With a focus on mosaic cameras)

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OUTLINE

Outline

Why mosaic?

Spatial sampling

- High spatial resolution surveys require many pixels on sky.
- At the frame rates lucky imaging requires, it becomes difficult to run a 1Kx1K CCD without getting swamped by readout noise.
- Unfortunately, current generation of EMCCDs cannot be abutted (though this is changing).

Why mosaic?

Dynamic range

- Independent gain control is a bonus.
- Dynamic range on a single EMCCD is limited to about 10 magnitudes by electron well depth in multiplication register. *(Disclaimer: back of envelope calculation.)*
- Can't guide well on a saturated star.
- Ok if GS is $Mag \approx 16$. Potentially problematic if GS is $Mag \approx 10$.

Why mosaic?

But...

- Significant hardware challenge – alignment, synchronisation, multiple control systems...
- High data rates.
- More calibration.

(See below...)

Outline

Why mosaic?

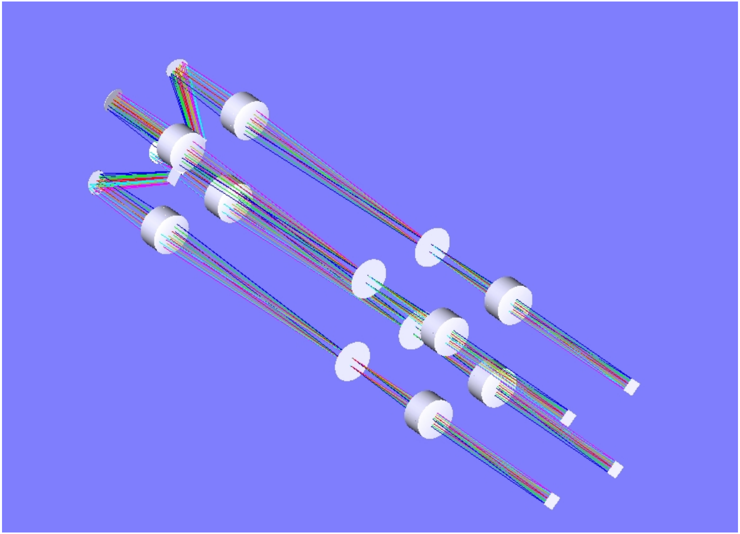
LuckyCam 2009 & the NOT

Reduction

Performance

Tradeoffs, Recommendations

A HARDWARE IMPLEMENTATION



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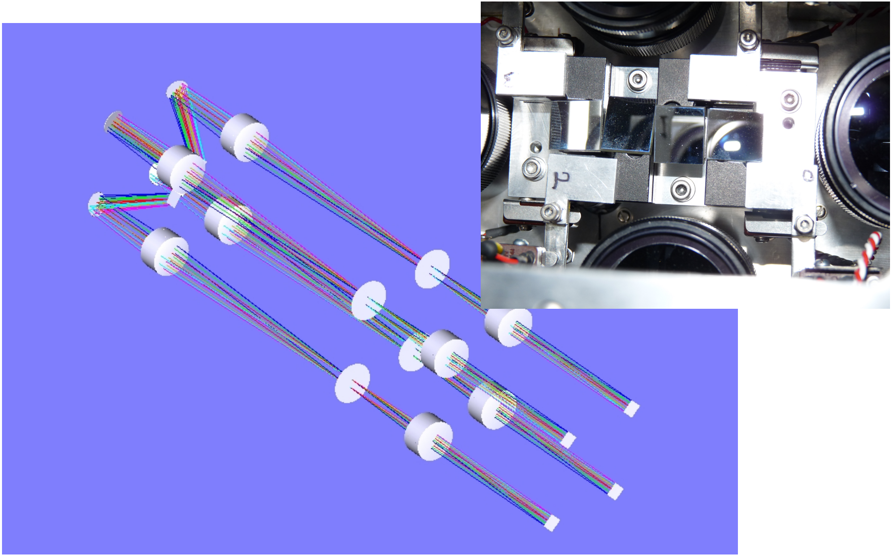
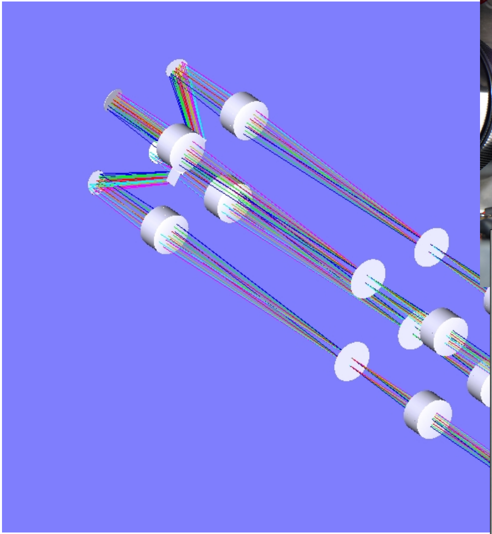
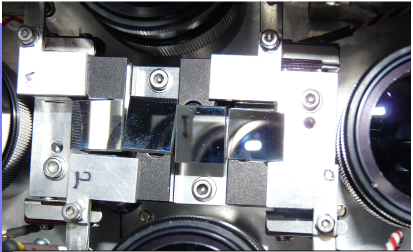
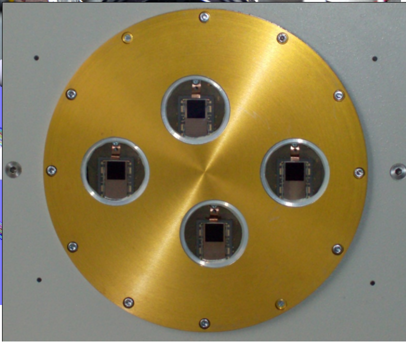


A hardware implementation







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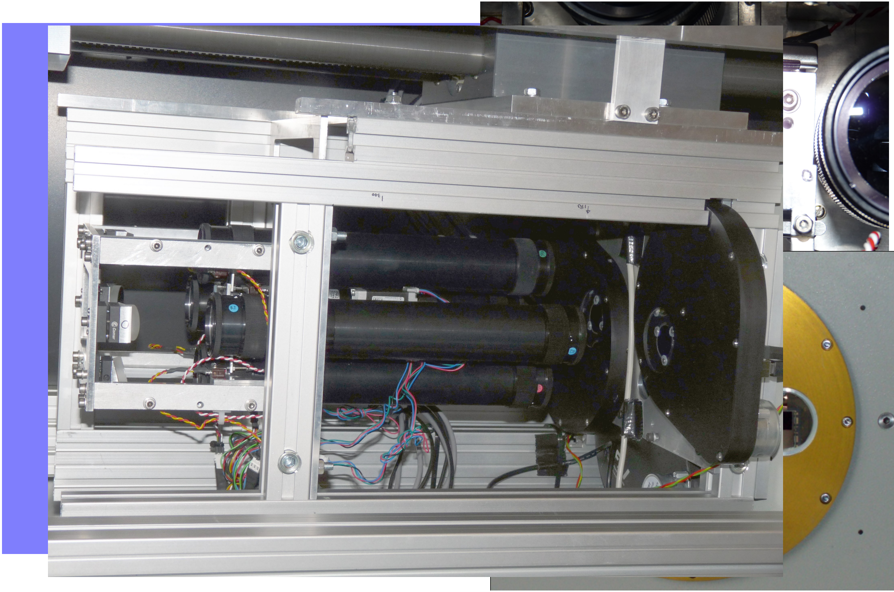
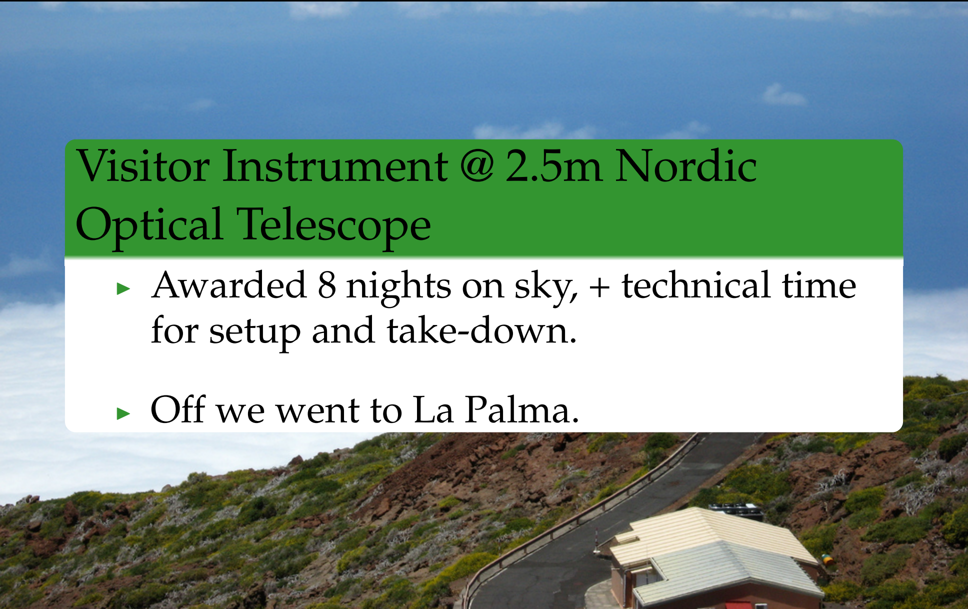


Field Test

Field Test

Visitor Instrument @ 2.5m Nordic Optical Telescope

- Awarded 8 nights on sky, + technical time for setup and take-down.
- Off we went to La Palma.



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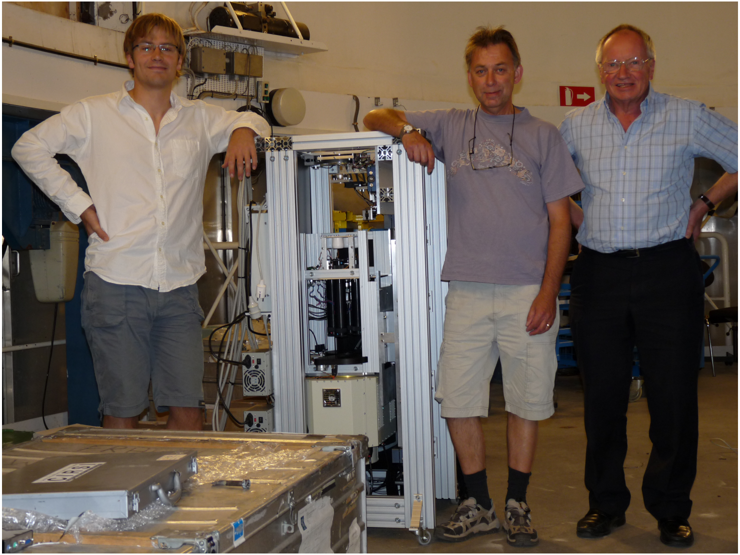

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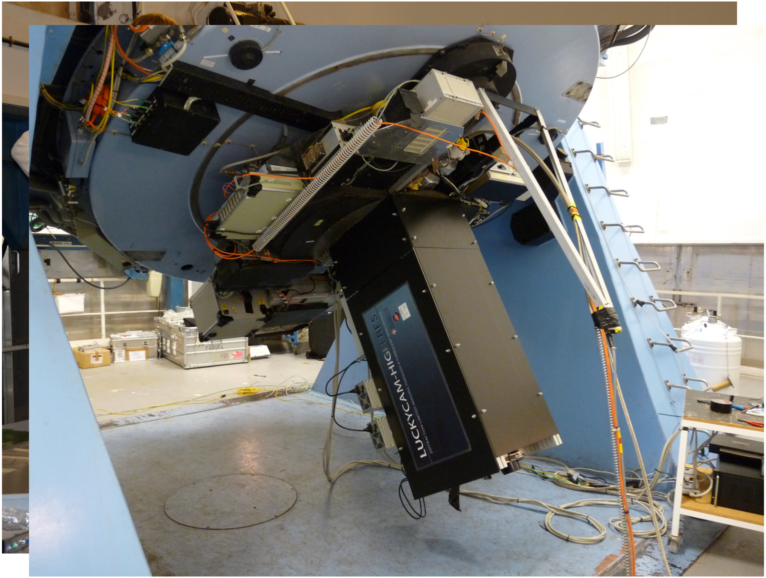
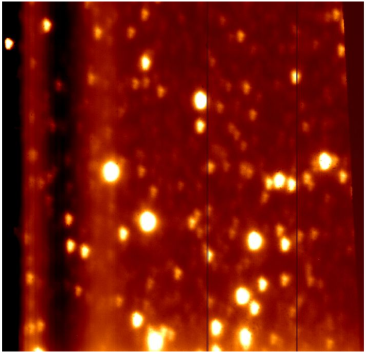


Results?



- Minor software glitches slowed progress for first couple of days.
- Overall, system performed very well.
- Some good weather.
- Now, we hads lots of data to reduce ($\sim$ 8TB).

Outline

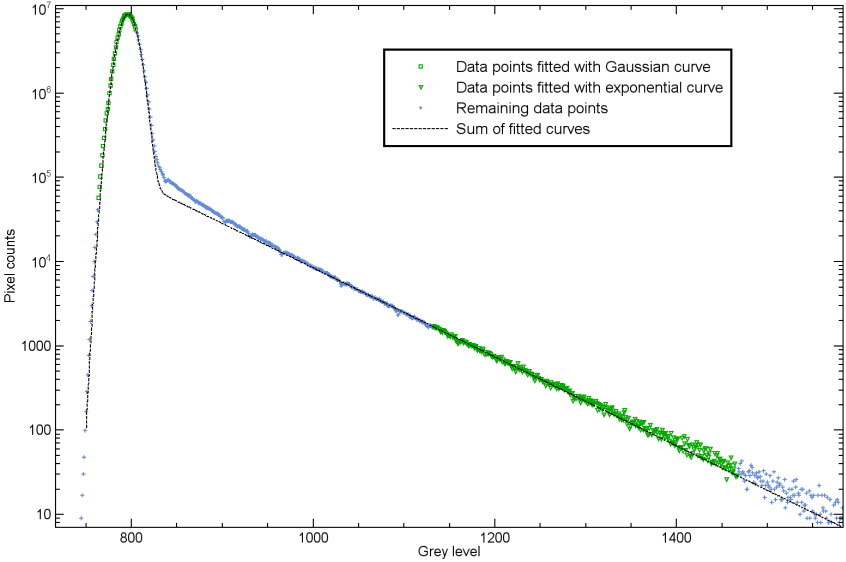
- Why mosaic?
- LuckyCam 2009 & the NOT
- **Reduction**
- Performance
- Tradeoffs, Recommendations

PHOTOMETRIC CALIBRATION

Specific to EMCCDs:

- Accurate on-sky gain calibration via pixel histograms is desirable (CCDs independently adjustable).
- Histogram based bias map estimation is the most robust way to separate bias pedestal and internally generated signal (i.e. dark current + clock induced charge).

Photometric calibration



PIPELINE OVERVIEW

- Custom pipeline written in C++.
- A 2 stage process, comprising **evaluation** and **reduction**. Almost always I/O limited (∼60–80MB/sec).
- Make use of thread-friendly STL based containers and Intel Thread Building Blocks library to implement a 'pipeline of filters' pattern.

Pipeline Overview

First, **frame evaluation**:

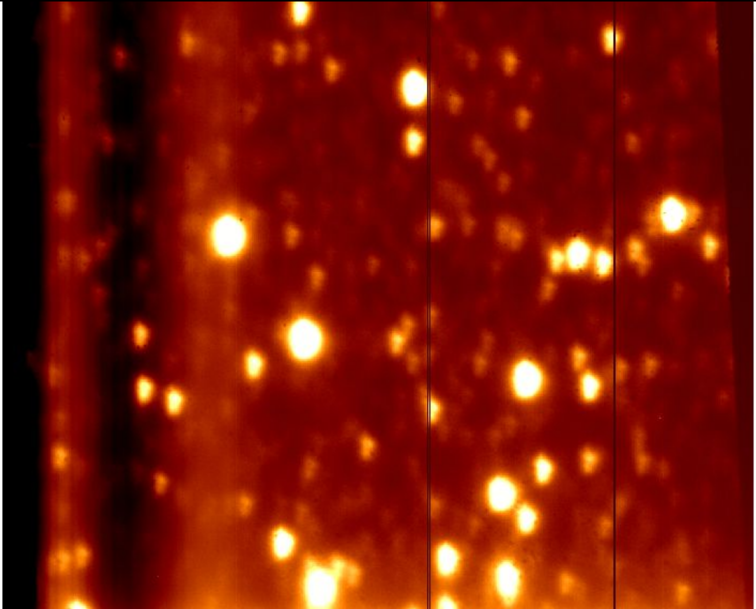
- Load frame, debias, gain normalize, subtract internally generated signal (DC + CIC).
- Interpolate GS region, cross-correlate with Airy core to estimate tip-tilt and (relative) Strehl.
- Save position and quality estimates to file.

PIPELINE OVERVIEW

Second, **selection and recombination**:

- Sort frames by estimated quality, selecting according to user-criteria.
- Load and calibrate, optionally applying thresholding to a copy.
- Drizzle to create final image, writing to file whenever a user-selection criteria is met.

Pipeline Overview



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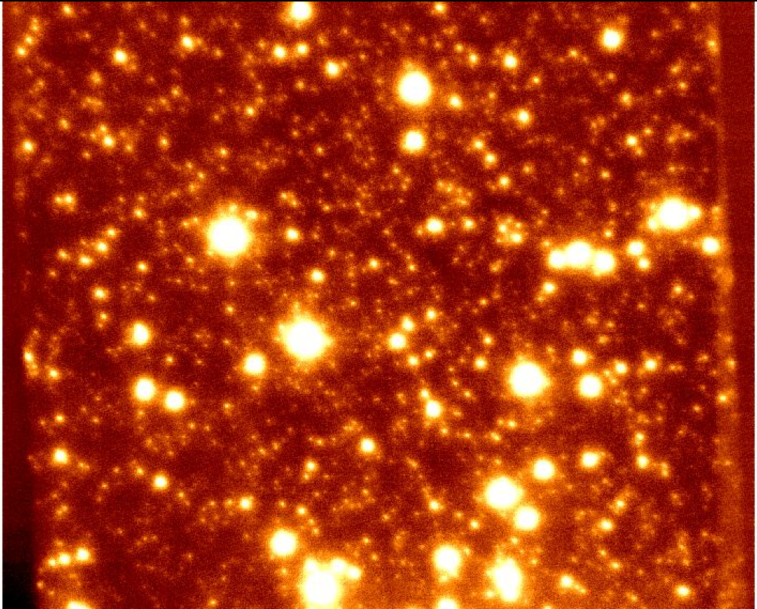

Astrometric calibration

How do you calibrate a high-resolution mosaic detector?

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- Using standard binaries would take at least (2n-1) pointings per focal lens.
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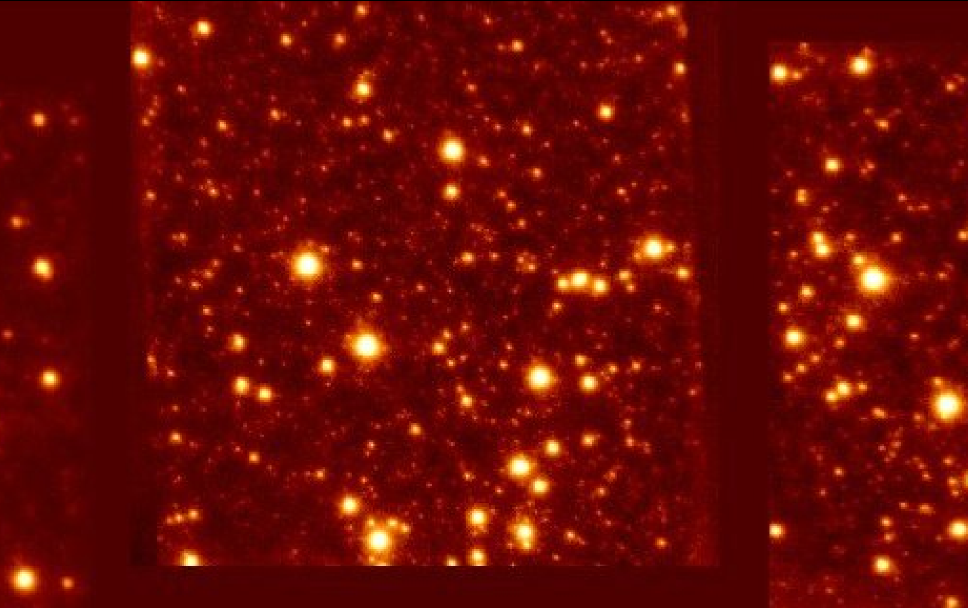
- Using standard binaries would take at least (2n-1) pointings per focal lens.
- So we observe a crowded field.
- But: standard catalogues (2MASS, USNO) do not have the resolution (2MASS pixels are 2 arcseconds width).
- Solution: Create own catalogues from HST/WFPC fields, cross match using custom code.

Astrometric calibration



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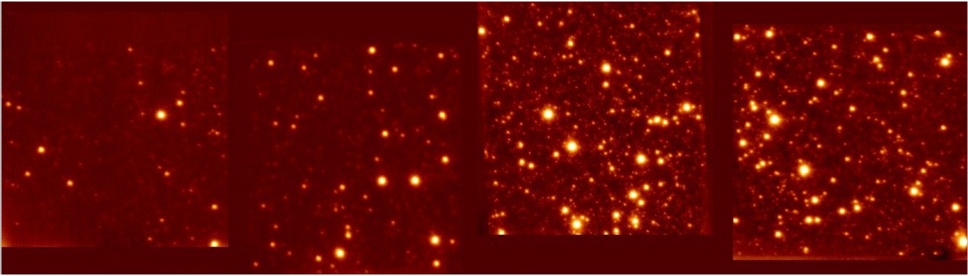


OUTLINE

WHY MOSAIC?

LUCKYCAM 2009 & THE NOT

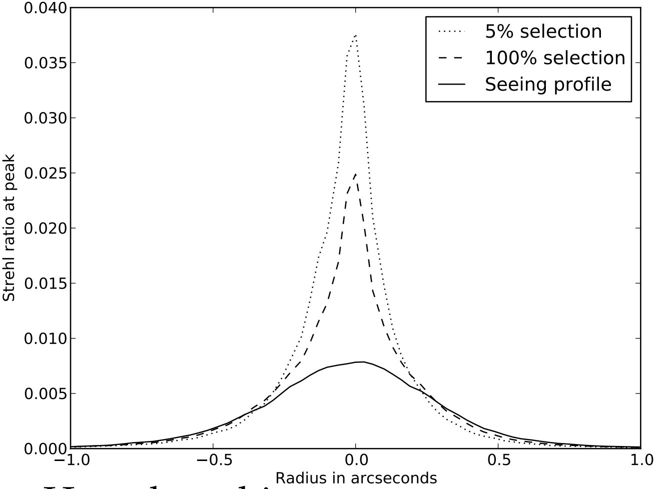
REDUCTION

PERFORMANCE

TRADEOFFS, RECOMMENDATIONS

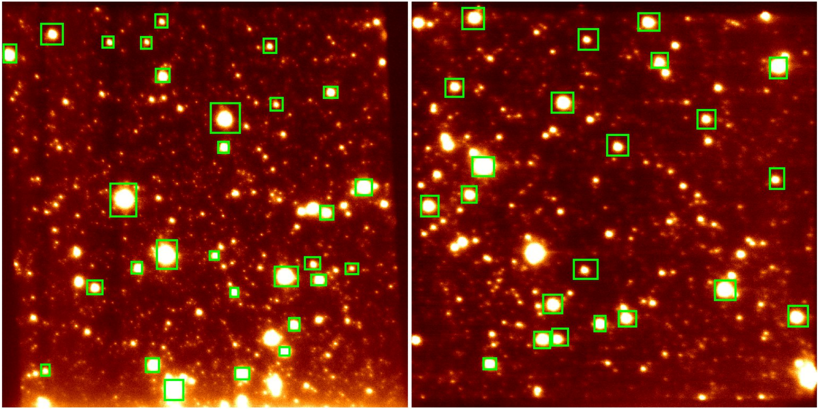
- What resolution improvement do we obtain?

PSF PROFILES

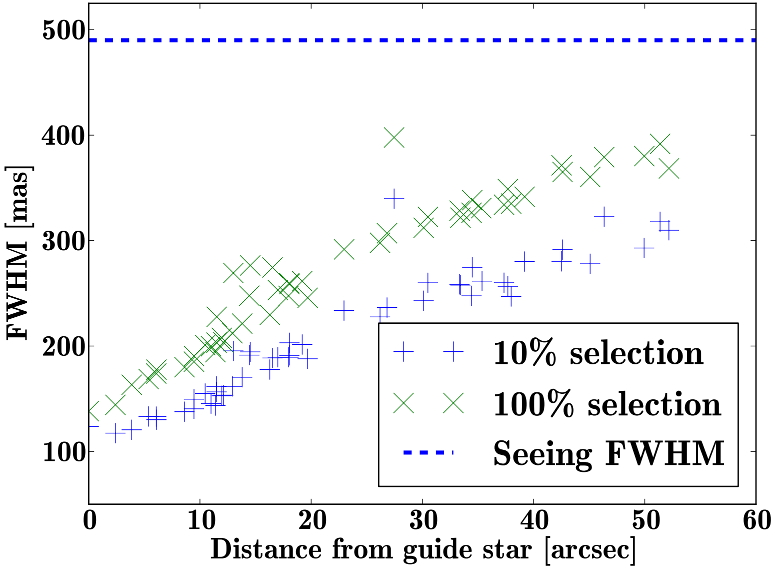


How does this vary as we move away from GS?

FWHM across the field

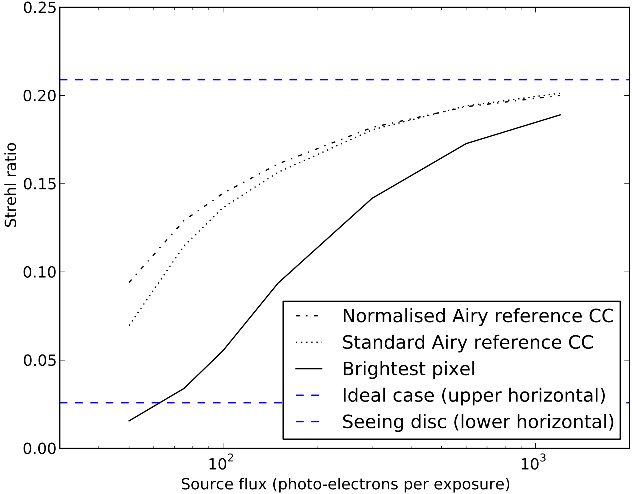


FWHM ACROSS THE FIELD



- How faint can we go?

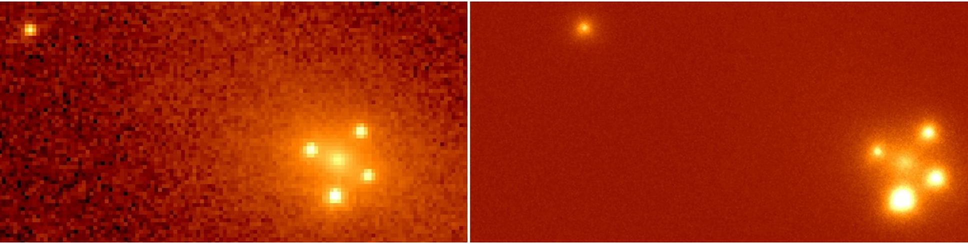
FAINT LIMITS: GUIDE STARS



(Simulated)

FAINT LIMITS: GUIDE STARS

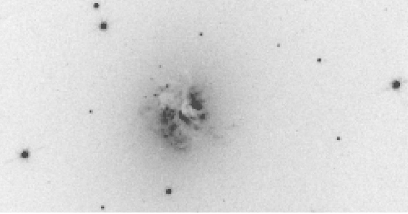
A real world example: the Einstein Cross.

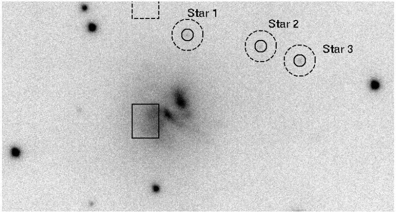


(Left: HST. Right: LI. GS $M_i \approx 17$)

FAINT LIMITS: SCIENCE TARGETS

3C 405 (Cygnus-A)





Left: HST. Right: LI.

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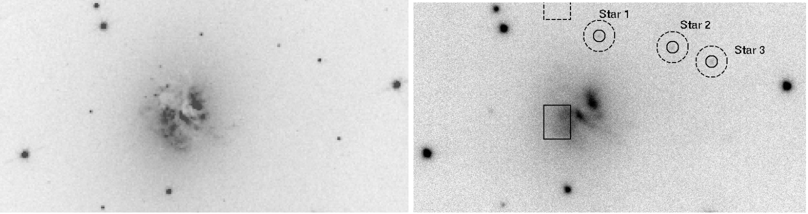

Left: HST. Right: LI.

- One hour observation, 50% selection, ∼0.5″ seeing.
- Galaxy approx 30″ from guide star.
- Weakly detect stars of estimated $M_i \geq 23$.
- Can do better with latest hardware.

OUTLINE

Optimal pixel size and framerate trade-offs

- Spatial sampling vs detector noise.
  (Old issue with a new twist: Drizzle many frames with subpixel offsets.)
- Longer exposures for faint targets vs atmospheric blurring above coherence time.
- Data rates.

OBSERVATION PLANNING

- Will there be a close / bright enough guide star?
- Will de-saturating my guide star ruin my faint limit? (Can I position the mosaic to avoid this?)
- What resolution / magnitude depth do I need to achieve, and what weather conditions / selection criteria does this require?
- (For very bright sources:) Would I be better off turning off the EM amplifier altogether?

Astrometric calibration

- This is non-trivial!
- Worth investigating: `http://www.astromatic.net/software/scamp`
  (Cannot read custom catalogues when I last checked, but this is probably an easy feature to add.)

Open questions / Research problems

- Use of multiple guide stars.
- Crowded field photometry with a slowly varying PSF.