MORE CANARY

Tomography workshop

Edinburgh, 25-26 March 2014

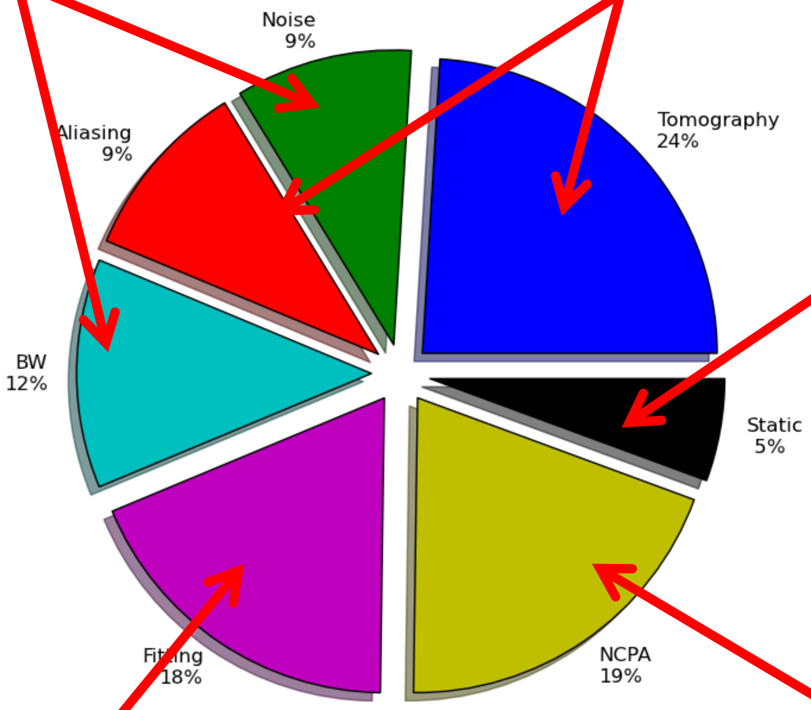
Overview

- System tomographic performance has been covered
- We'd still like to try to reduce overall system errors further
- New upgrades for Phase C (LTAO & MOAO) are being installed now
  - How will these affect the system?
- What can we learn for future systems?

CANARY

Reasonably well balanced

Changes with asterism, WFS, and atmosphere



Annoying…but we'll come to this…

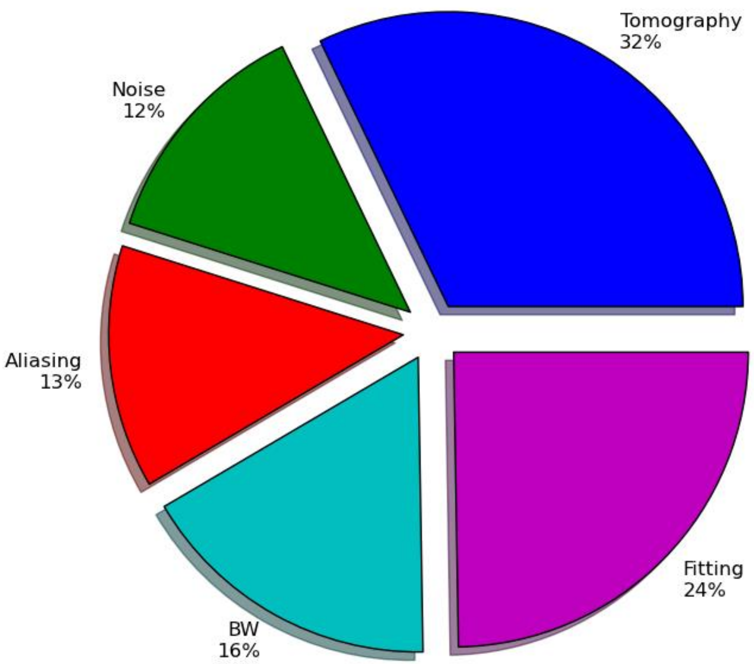
Can only vary by changing the DM or the atmosphere

Mainly due to high-frequency errors on the DM

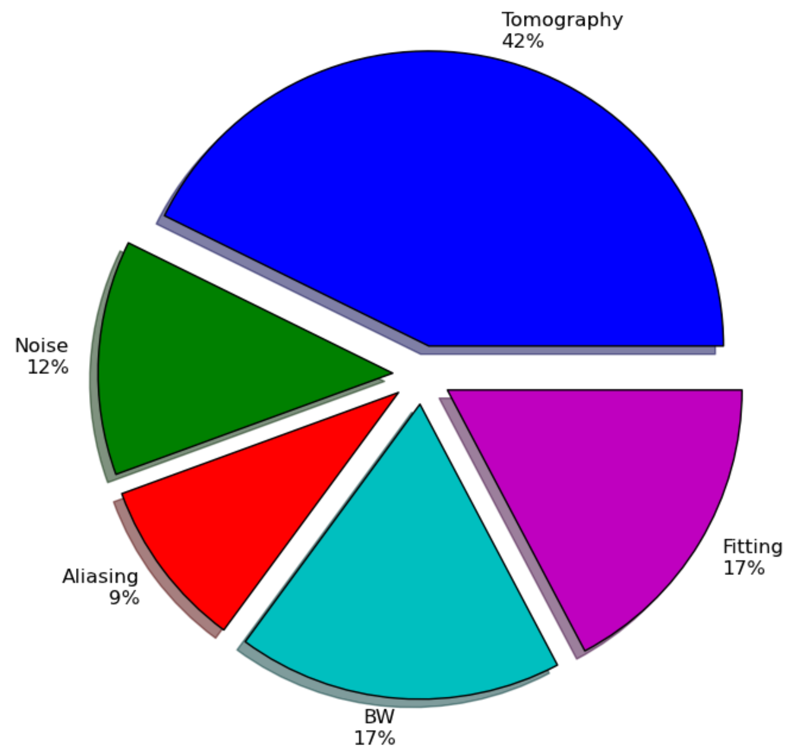
2013-09-19_01h59m01s
4 LGS + 3 NGS

Mixed and NGS-only tomography

4 LGS + 3 NGS



3 NGS only



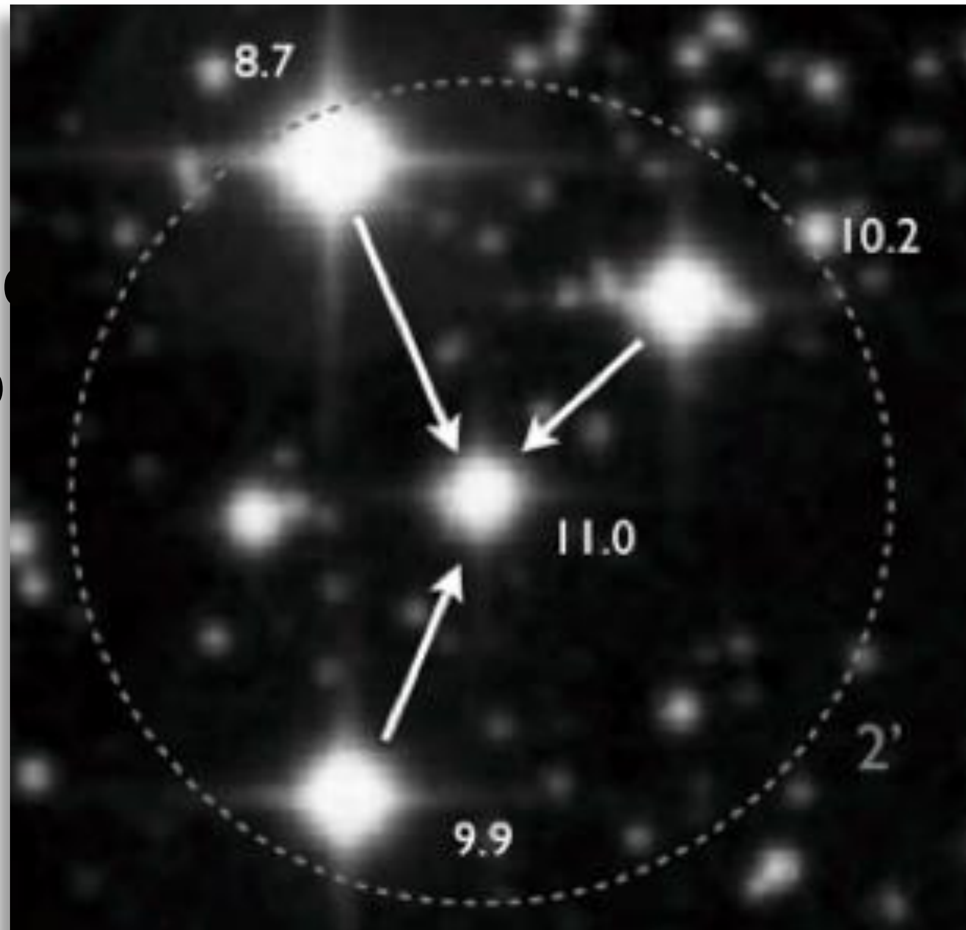
Tomographic error is largest but doesn't dominate

Tomography on a 4m telescope

- Tomography requires nearly overlapping pupils
  - Adjacent non-overlapping pupils still correlate
- Following example shows pupil overlap at altitude for one CANARY asterism

Tomography on a 4m telescope

- Tomography requires nearly overlapping pupils
  - Adjacent ... elate
- Following ... at altitude fo...



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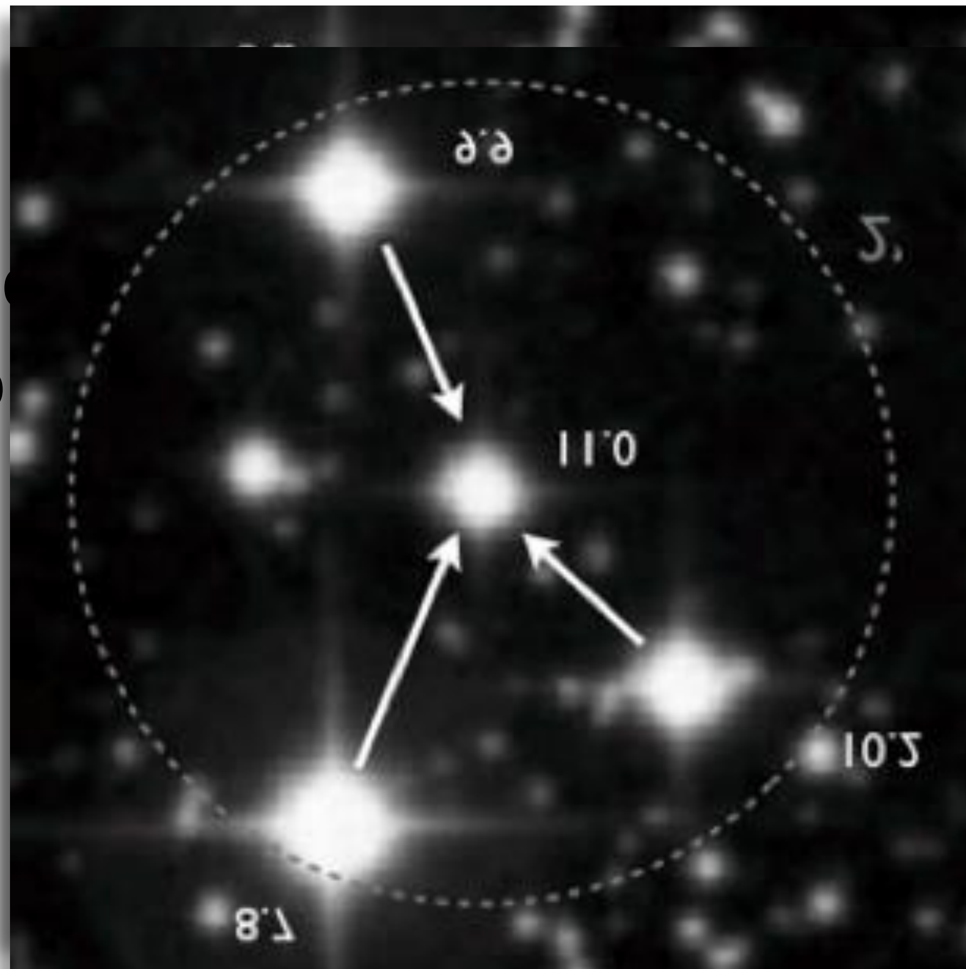
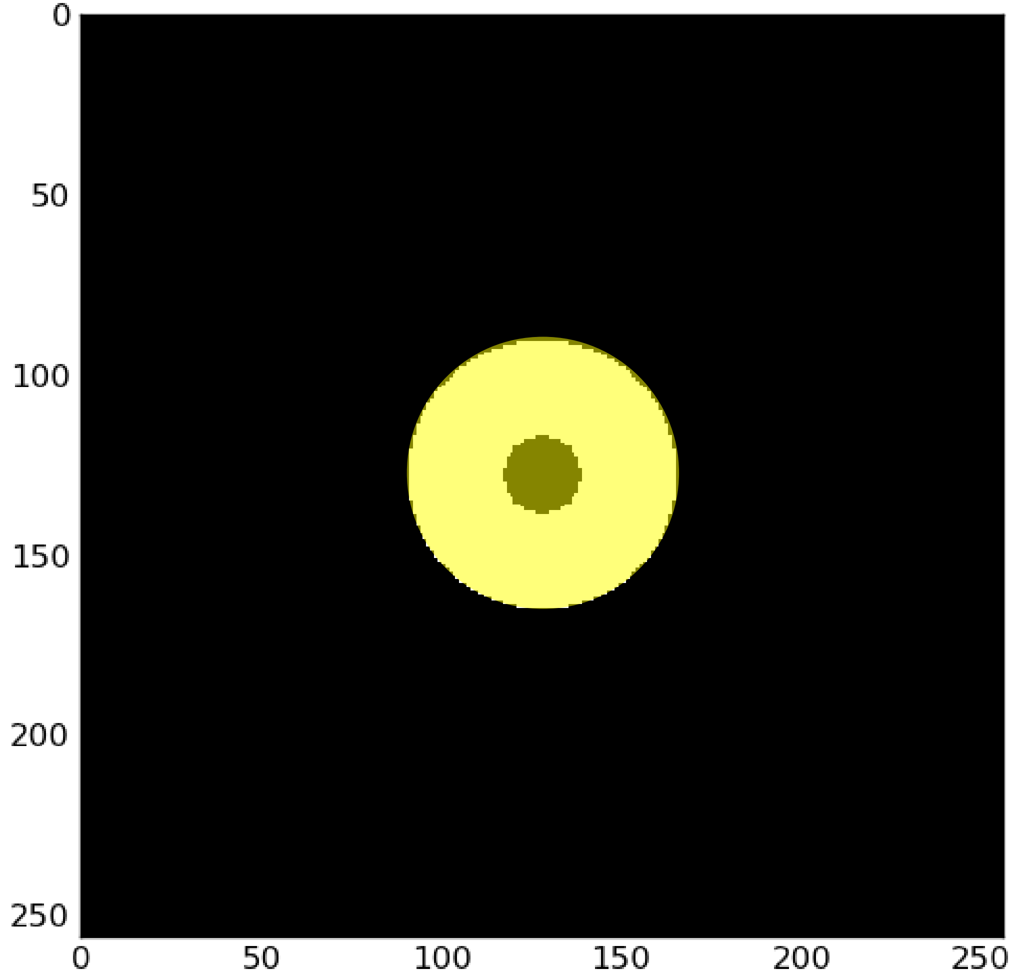
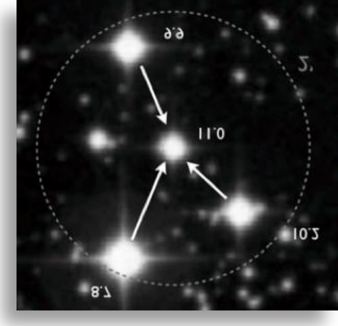
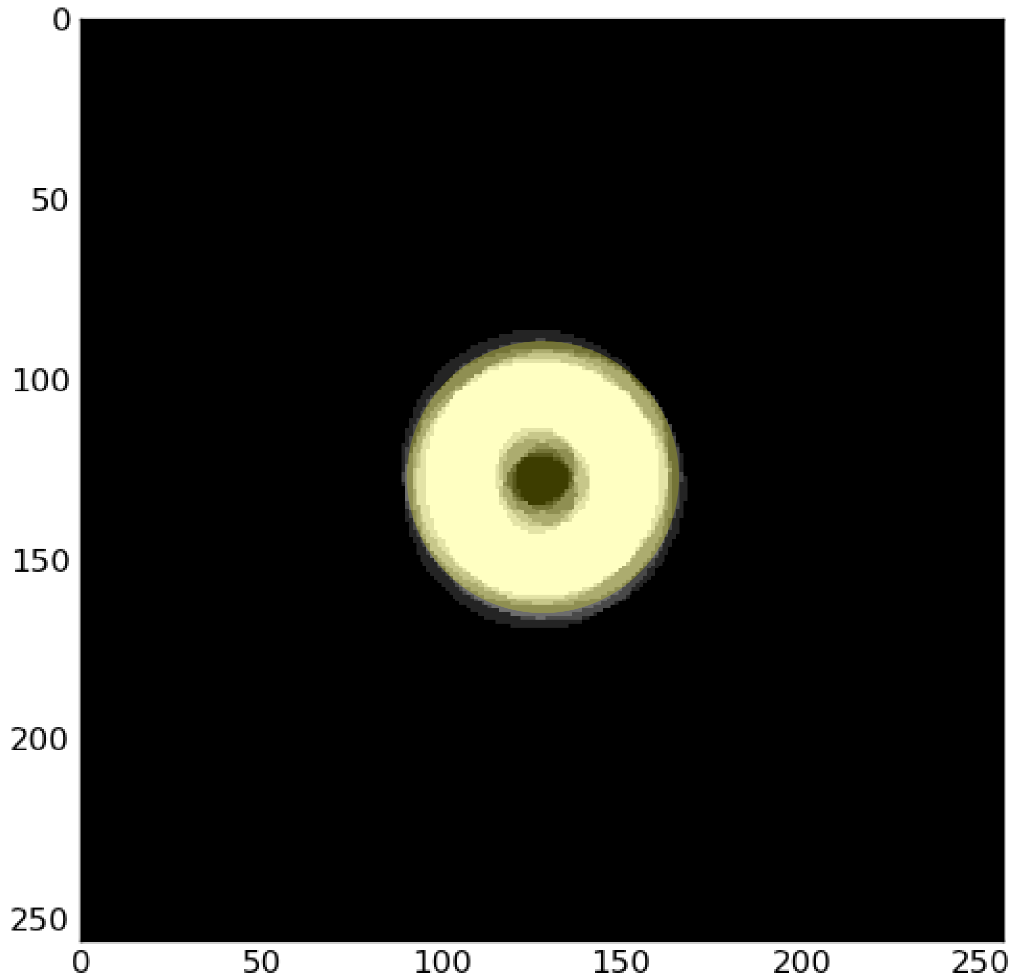


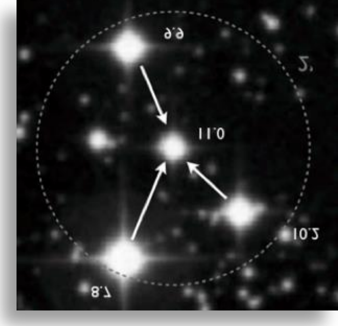
0km



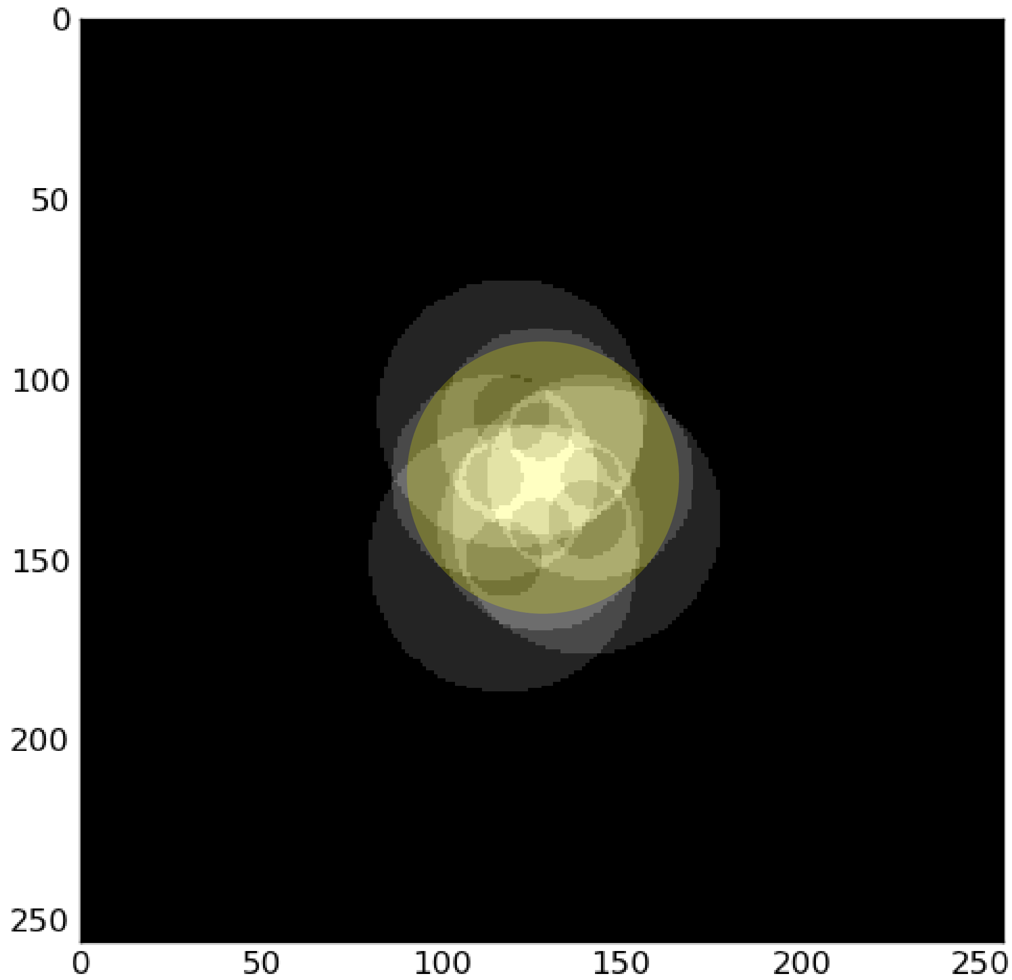


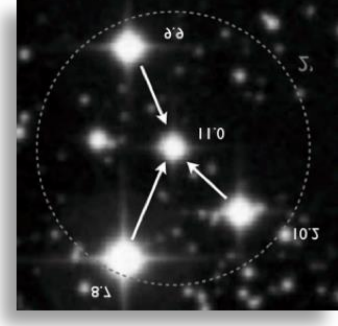
1km



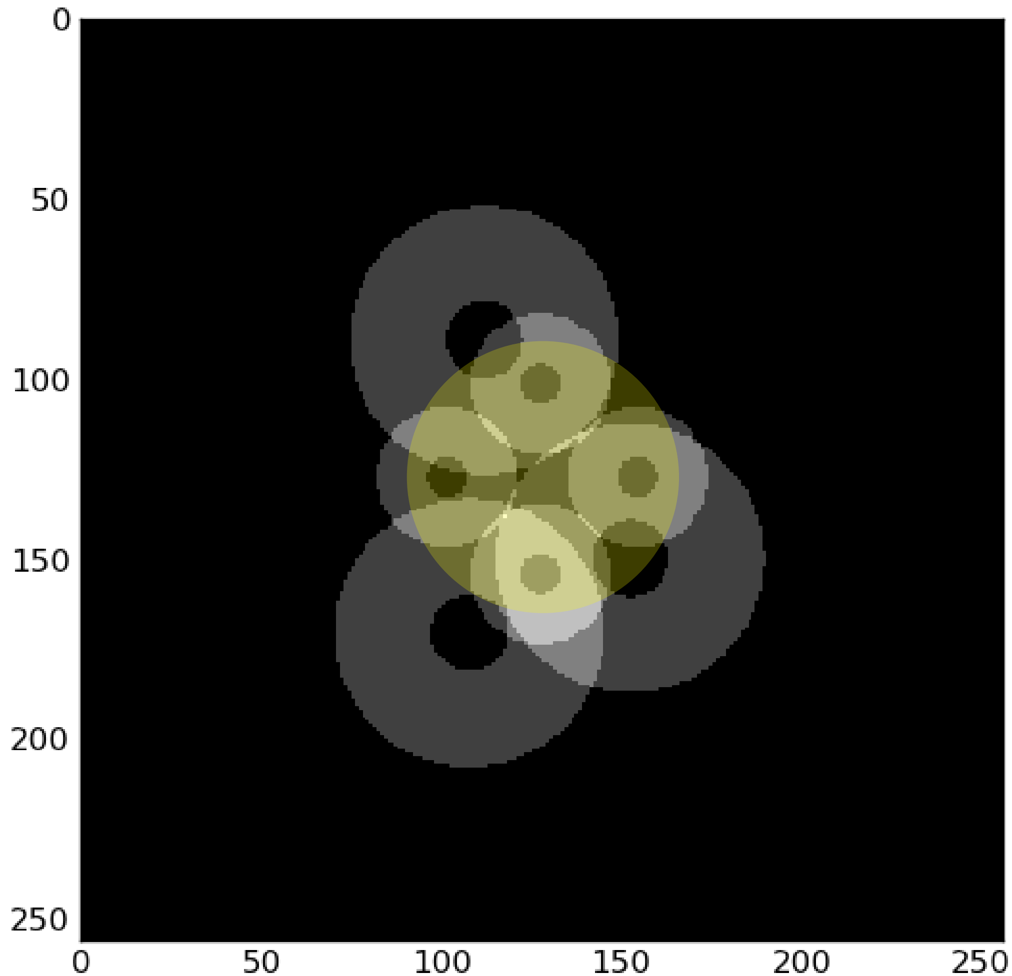


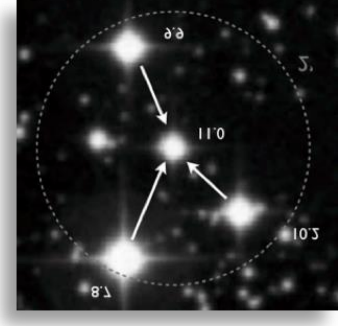
5km



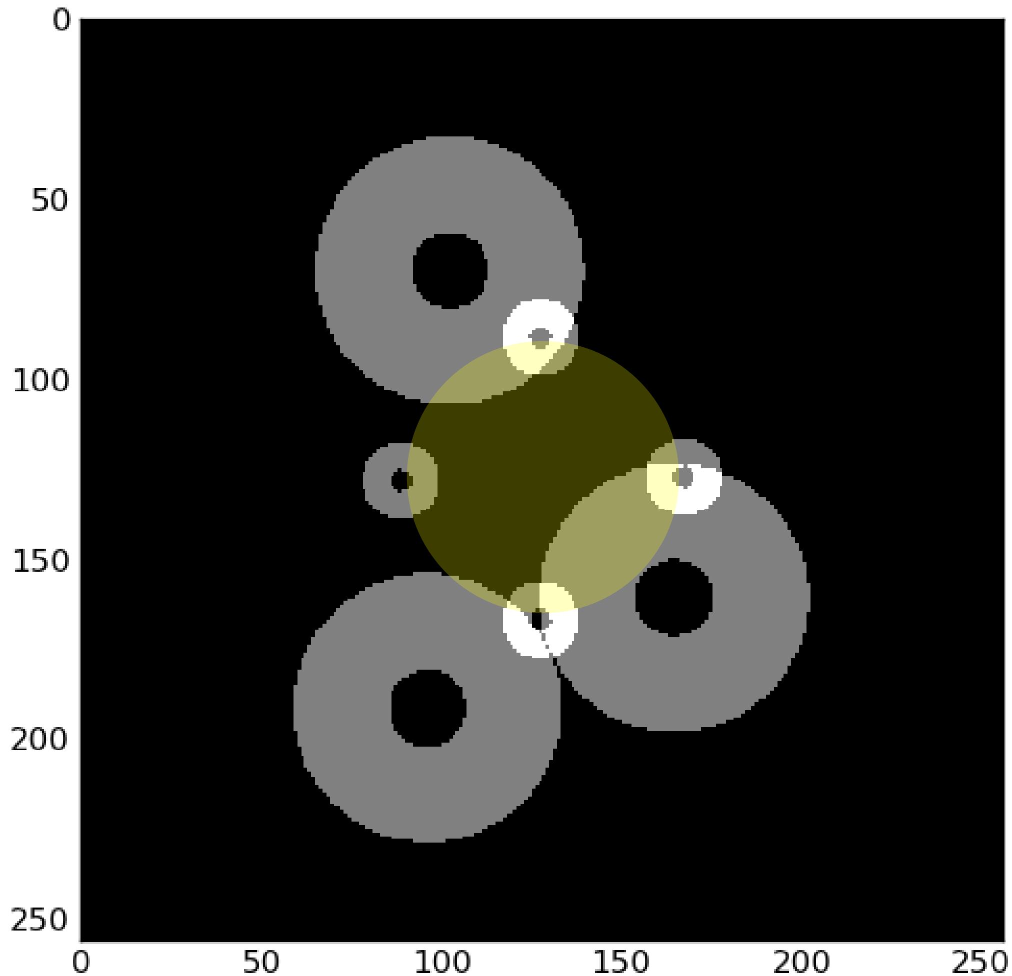


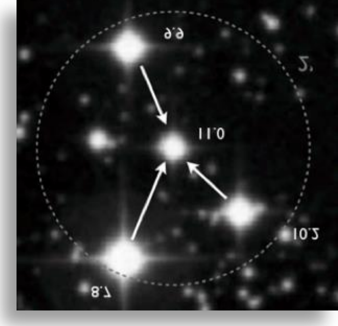
10km



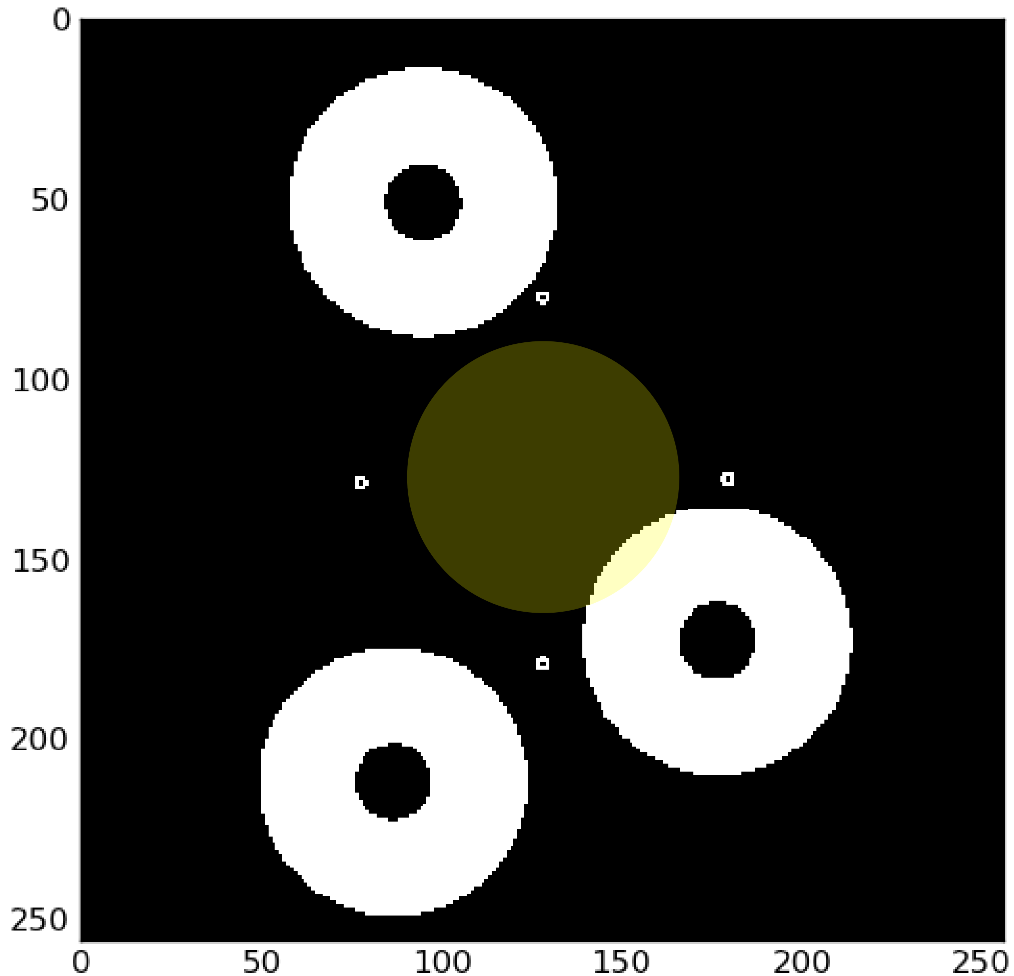


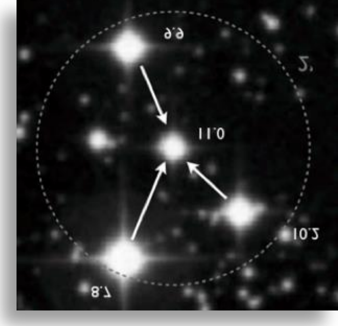
15km



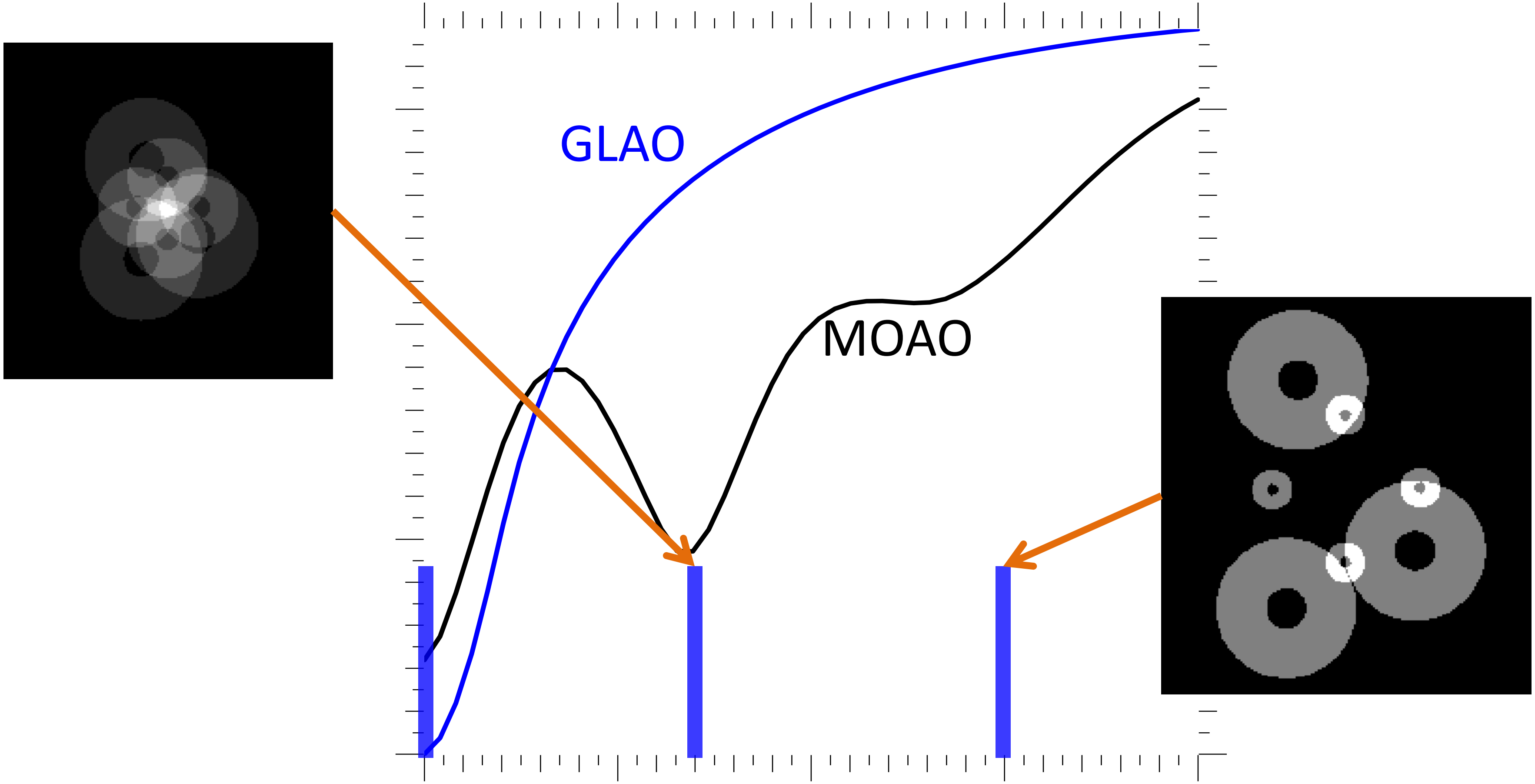


20km



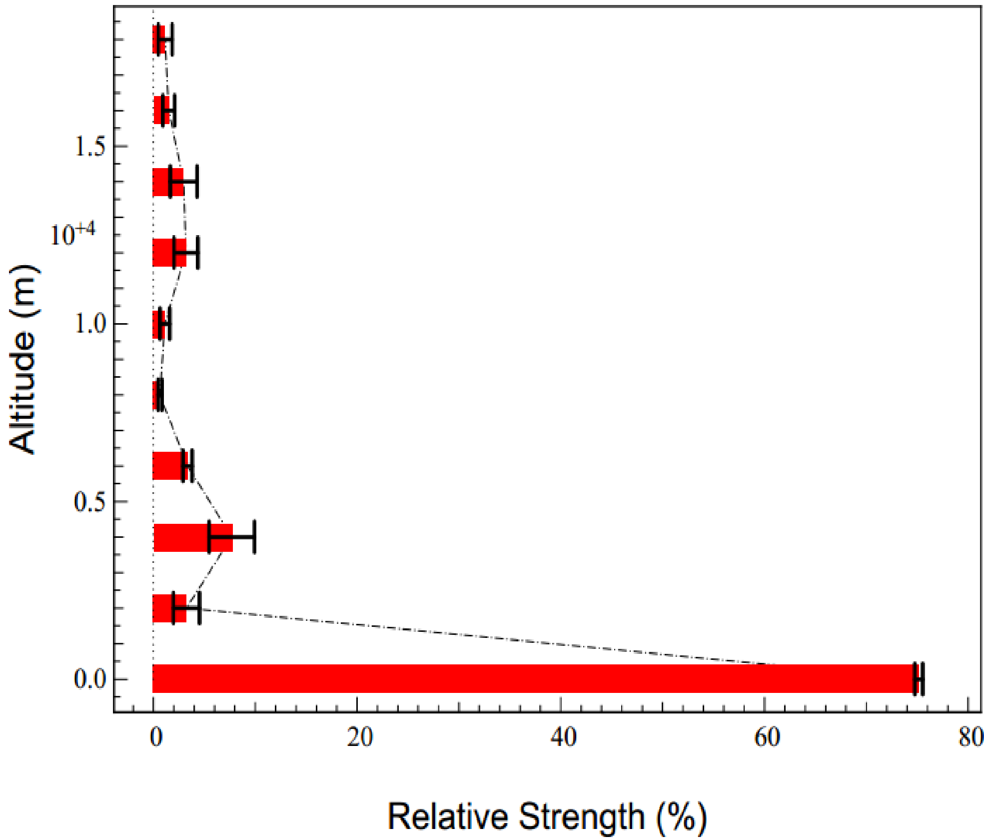


Shamelessly stealing from Eric…



Increasing performance

- CANARY performance is highly dependent upon turbulence strength >10km distance
  - Distance not altitude
- Pupils separated by ~10km for most asterisms
  - 4m diameter at the limit for non-Na LGS tomography

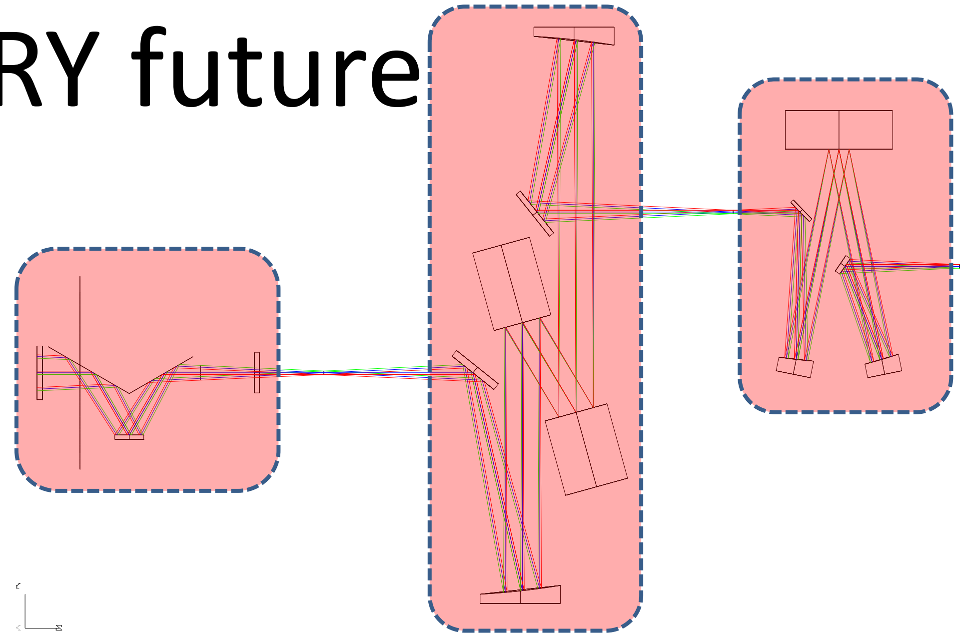


Mean atmospheric profile during CANARY runs
Mostly summer (2010-2013)

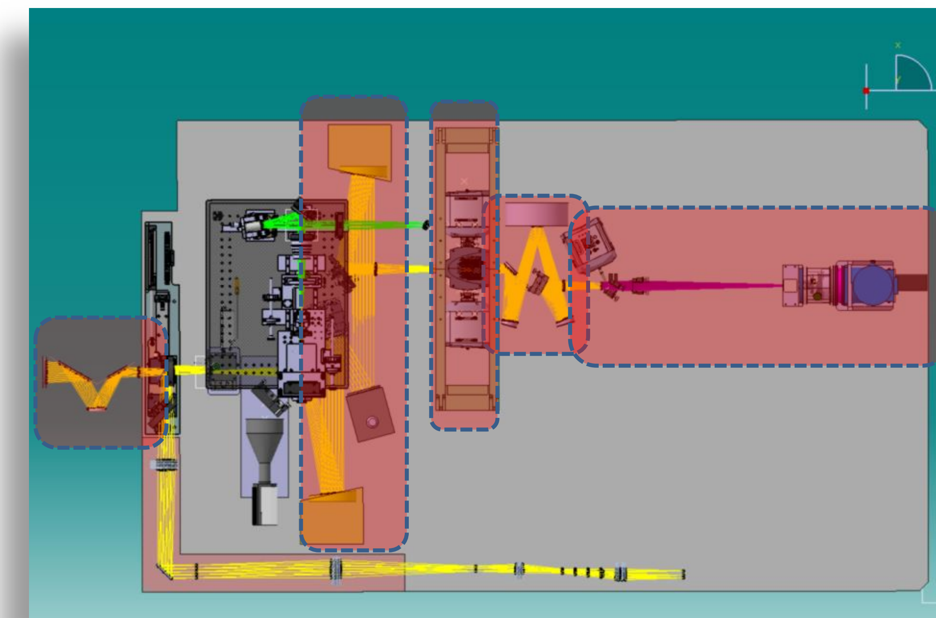
Increasing performance

- Errors scale with telescope diameter
- 8m CANARY can use the same asterism and get the same tomographic sampling up to 20km
- 40m telescope
  - Same asterism at a zenith angle of 60 degrees to 50km
  - So can get double pickoff field to 6’ diameter
- 4m CANARY however will always be limited to lower-altitude turbulence
  - We’re left with the smaller error terms…

CANARY future



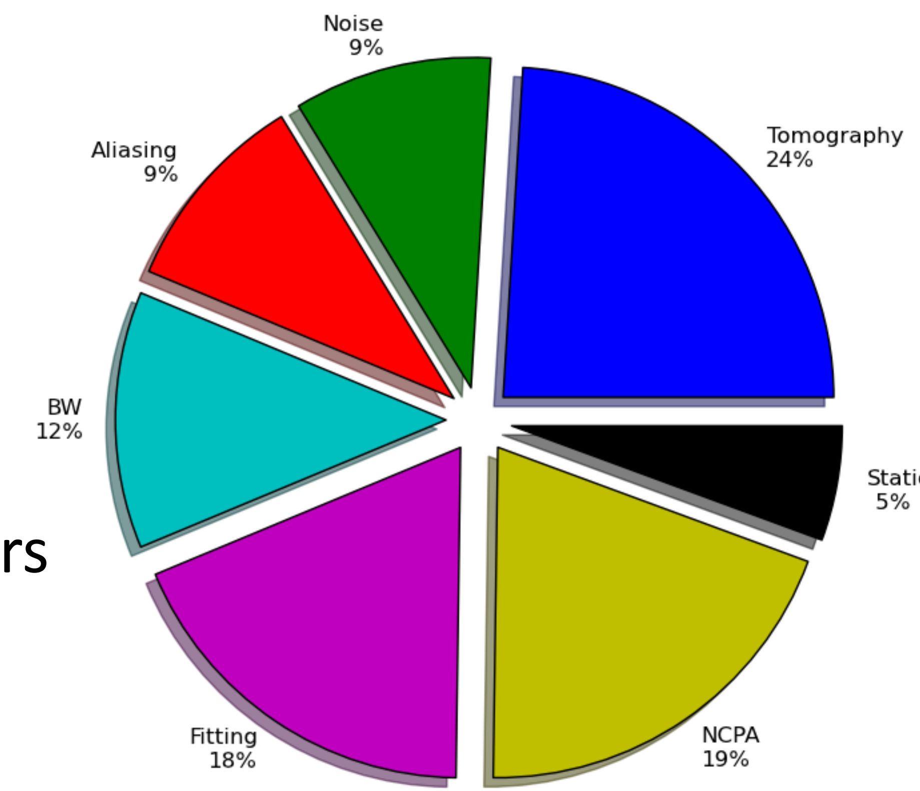
- Phase C1: LTAO (on-sky June 2014)
  - Design review next week
  - Reorganisation of the bench to place WFSs behind DM
  - Additional figure sensor for pseudo open-loop operation
- Phase C2: E-ELT configuration MOAO (on-sky 2015)
  - Closed-loop GLAO DM (existing low-order DM)
  - Open-loop MOAO DM (high-order DM)
  - High order figure sensor
  - High order LGS WFSs



CANARY

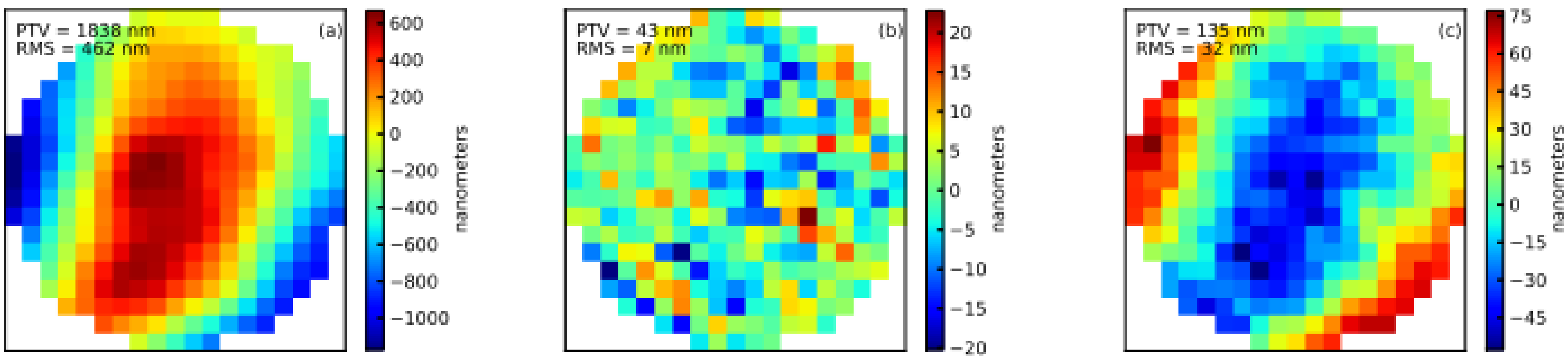
CANARY Phase C

- Adding a 241-actuator second DM in open loop in should reduce fitting and NCPA errors
- Reduced WFS subaperture size required for control
  - Increases noise
  - Decreases tomographic errors for *sensed* turbulence
- ALPAO DM itself is highly linear, however has one problem…



ALPAO DM

- Surface exhibits creep over a timescale of several hours
  - Speak to Urban to learn more



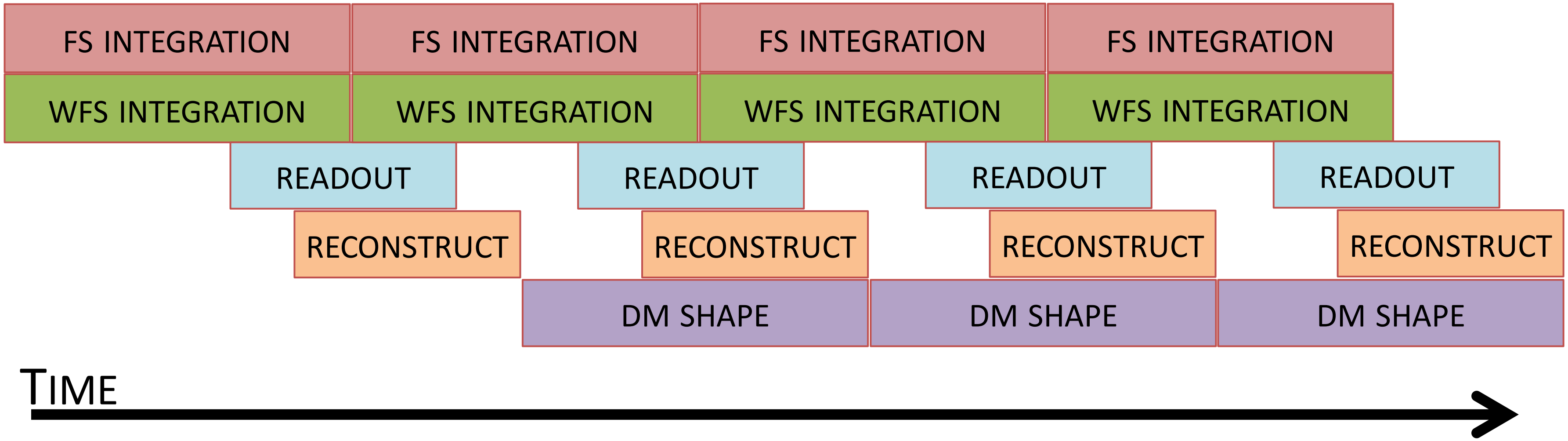
- Not great for an open-loop DM
- Fortunately seems to be repeatable
- Demonstrated <10nm RMS error over course of several hours

Controlling the DM

- CANARY includes both open and closed loop DMs
  - ADONIS 52-actuator (8x8): closed loop
  - ALPAO 241-actuator (15x15): open loop
- Tomography requires open-loop slopes
  - Wavefront statistics are contaminated
- Open-loop AO requires an open-loop capable DM
- Both issues can be addressed using a dedicated DM figure sensor
  - Observes at off-axis point source in focal plane
  - ALPAO FS could also be used to compensate for creep
- Figure sensors synchronised to NGS and LGS WFSs
  - Appear to AO control system as two additional WFSs
  - Synchronisation scheme depends on control method

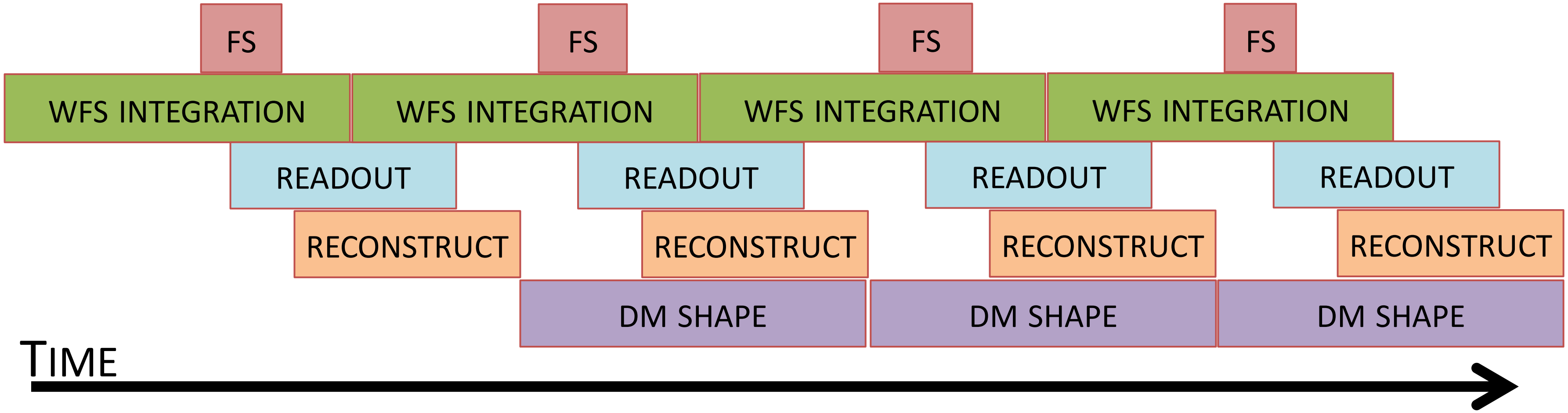
Pseudo-open-loop control

- ADONIS DM runs in closed loop on NGS and LGS WFS signals
- POLC control requires knowledge of the DM surface during the entire WFS exposure
  - Dependent on overall system latency
- Synchronising FS to WFSs allows for POLC to be implemented through a simple modification of the control matrix to subtract DM slopes from closed-loop slopes

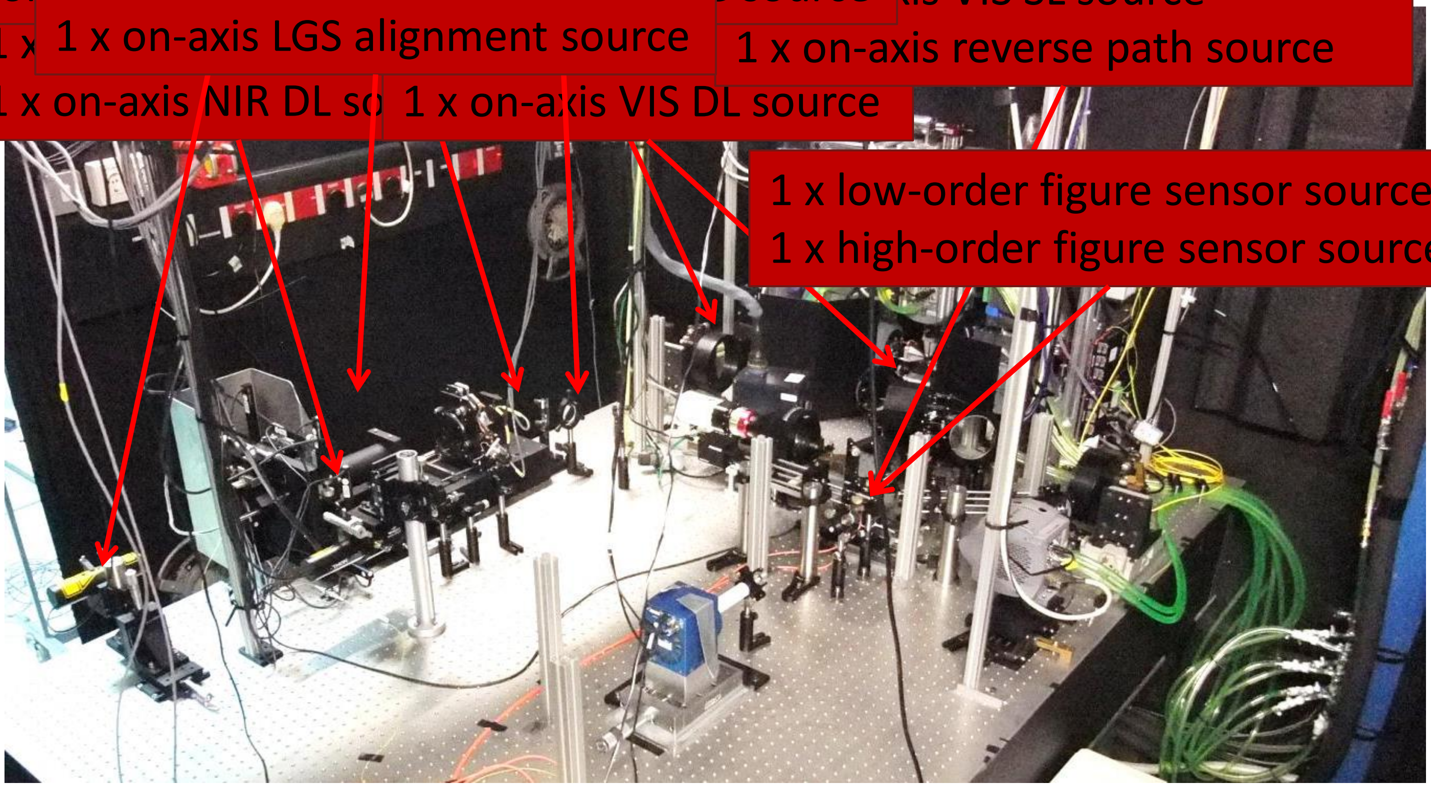


Temporal filtering

- LQG control uses knowledge of past WFS data for additional temporal fitting of wavefronts
  - Very good for removing vibrations
  - Very good with high wind speed layers
- Wants a frozen snapshot of the DM surface shape during each iteration
  - Mathematically accounts for latency
- Different triggering scheme
  - Pixels must still arrive in time to not affect reconstruction latency



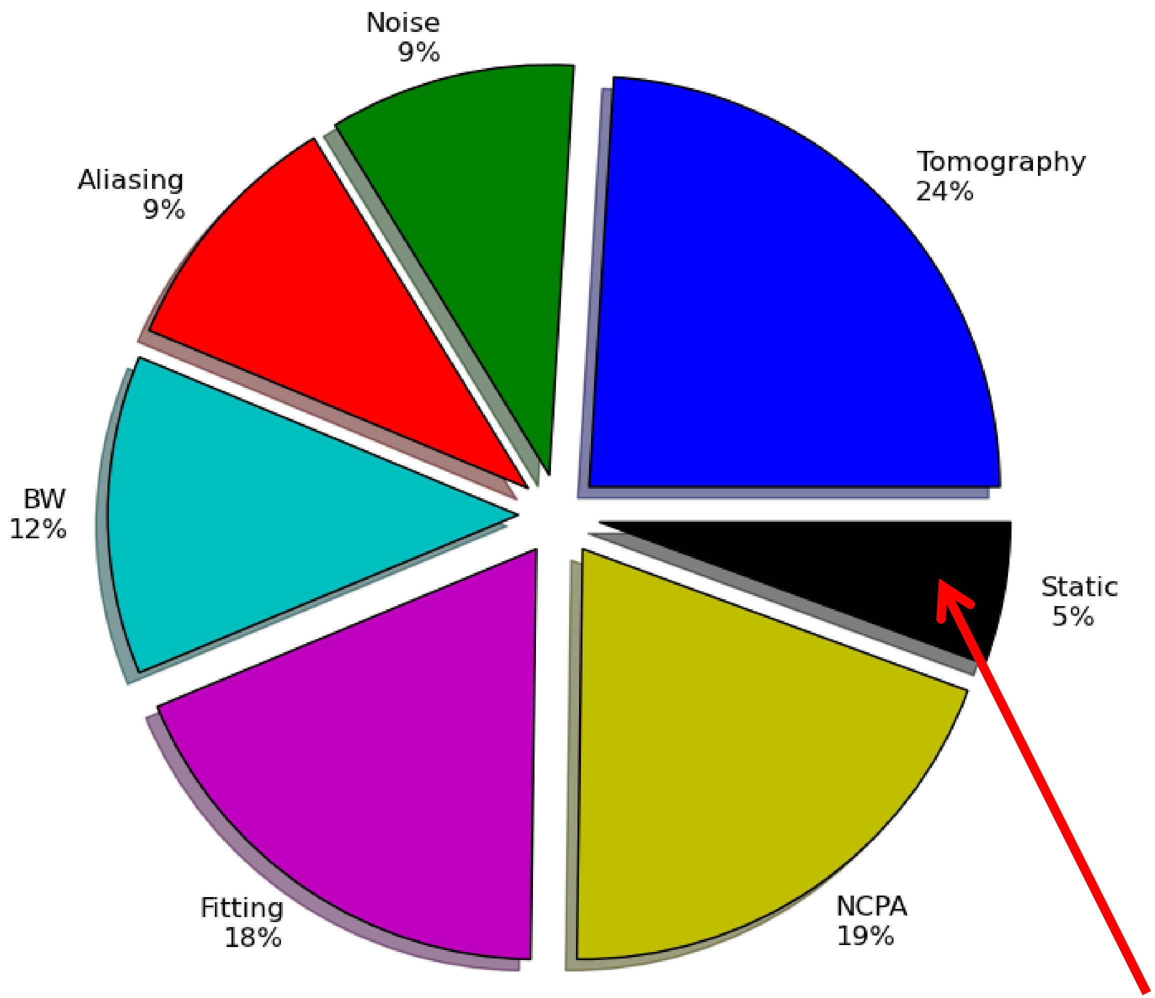
Phase C calibration sources



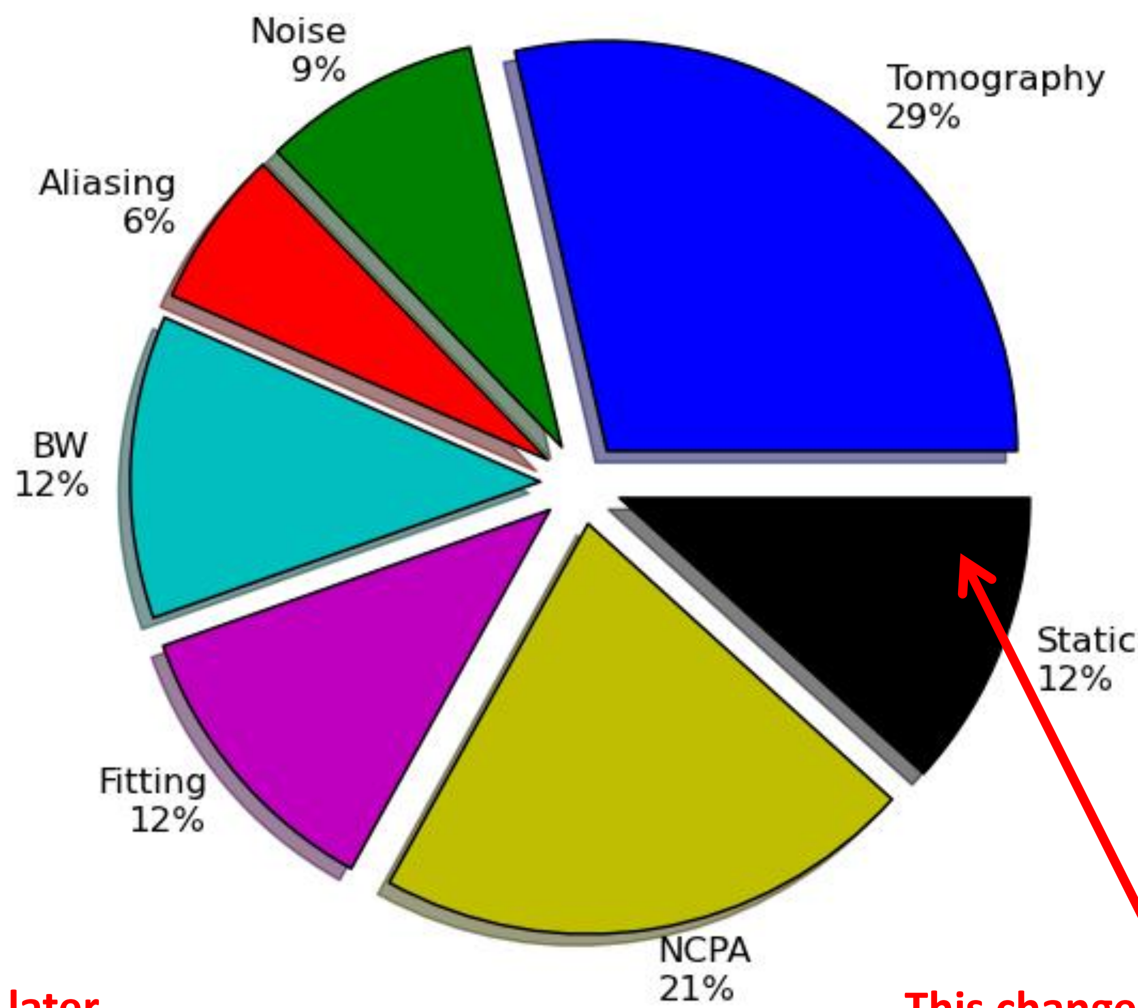
- The majority of system calibration is done using bench sources
  - NCPA (phase diversity)
  - WFS calibrations (alignment, sensitivity, scaling, pickoff location…)
  - Closed-loop control matrices
- Not all would be required in a facility system…but many would be useful…

On-sky calibrations

- Things we can't measure on the bench:
  - Atmospheric parameters (profile, strength, windspeed, etc.)
  - Static off-axis wavefront errors of telescope
- Static terms are measured through integration of the on- and off-axis WFS slopes
  - Typically a few thousand frames – takes on-sky time!
  - Sum of many possible errors…
- These are the terms that would be offloaded to the active optics system in the E-ELT



This changes quickly on the timescale of minutes (70 nm RMS to begin)



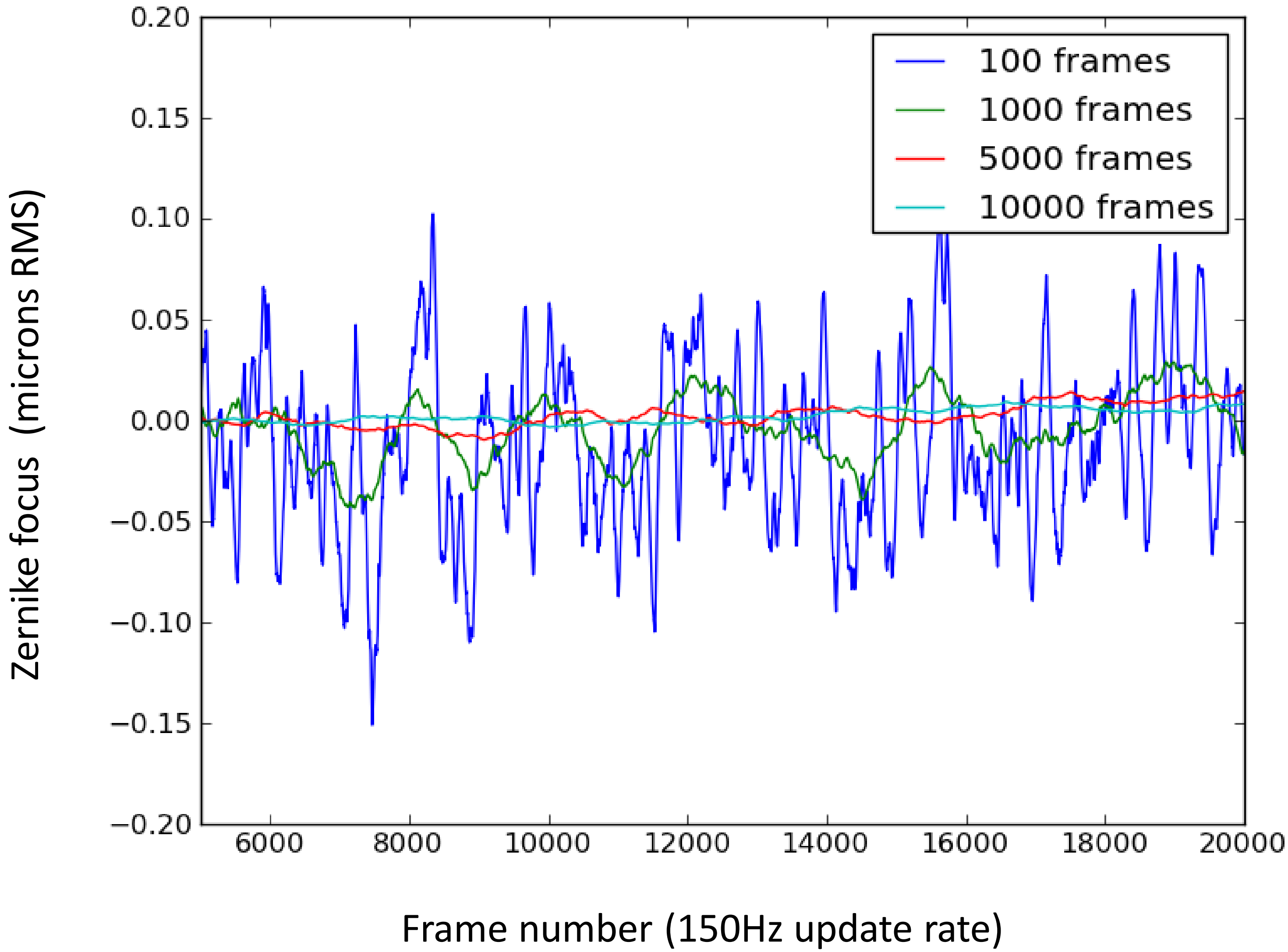
Thirty seconds later…
70nm RMS -> 110nm RMS

This changes quickly on the timescale of minutes (70 nm RMS to begin)

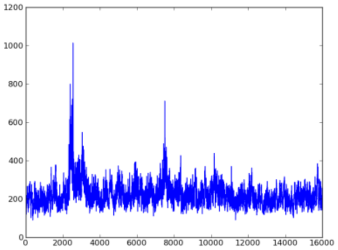
How long should we calibrate for?

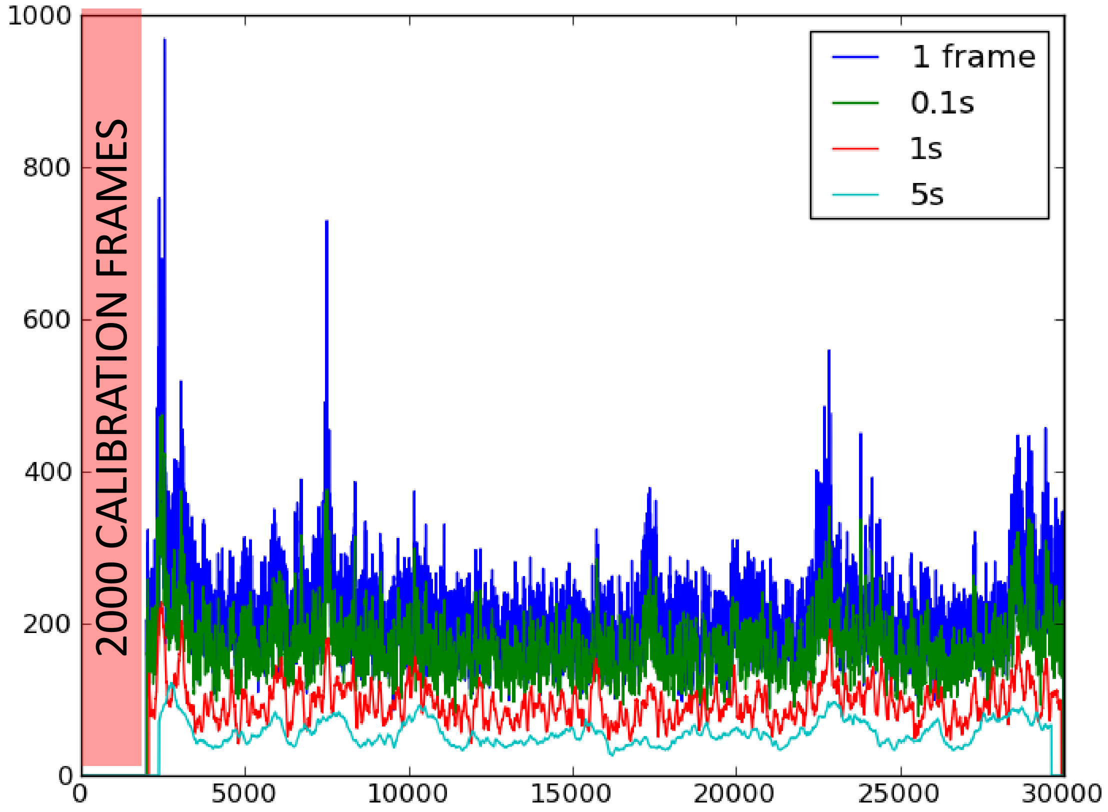
- All results taken on a 3-star asterism within 15 minutes
  - Only using on-axis truth sensor data here though
- Completely open-loop slopes
  - Only telescope autoguiding enabled
- Reconstructed 35 zernike terms
- 30000 slope dataset @150Hz (3min20s)
- A few plots…
  - Indications of problems only
  - Much more analysis to be done

Temporal averaging



Typical CANARY dataset





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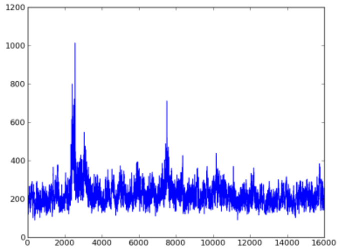
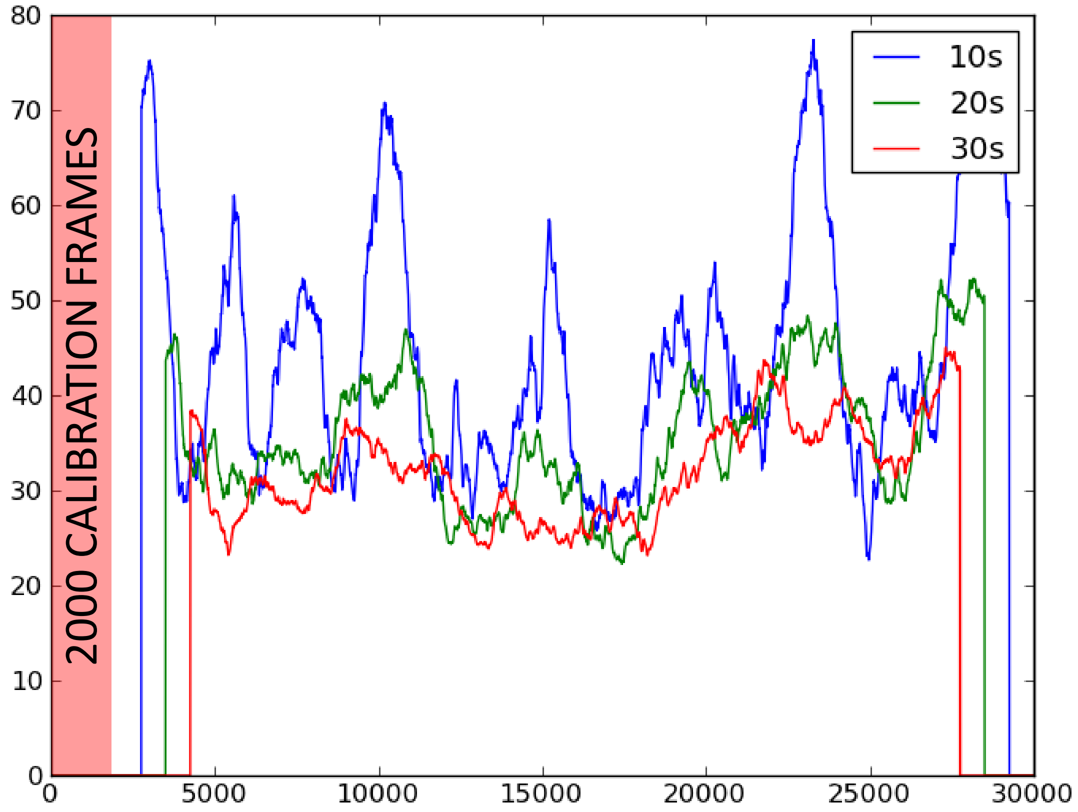
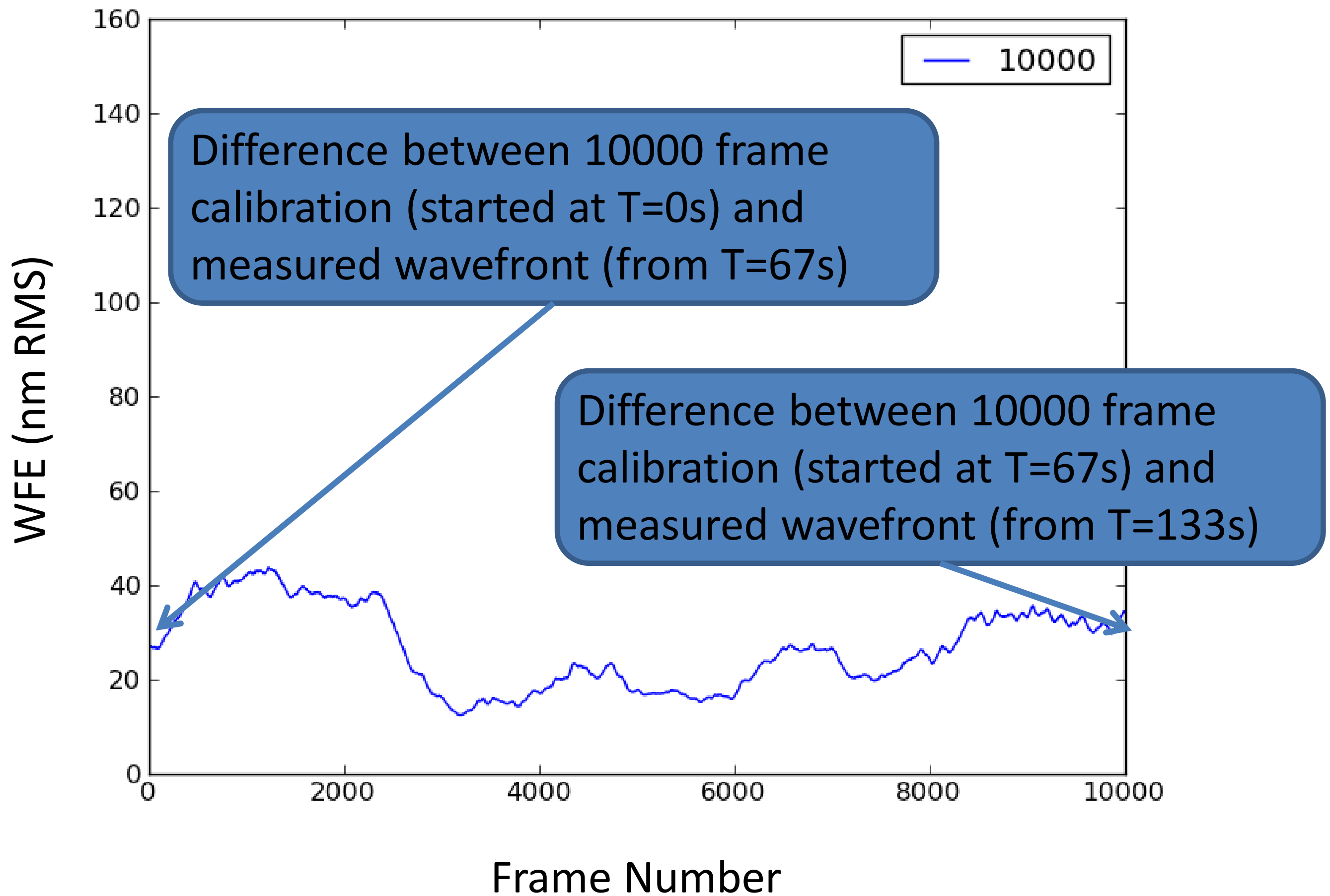




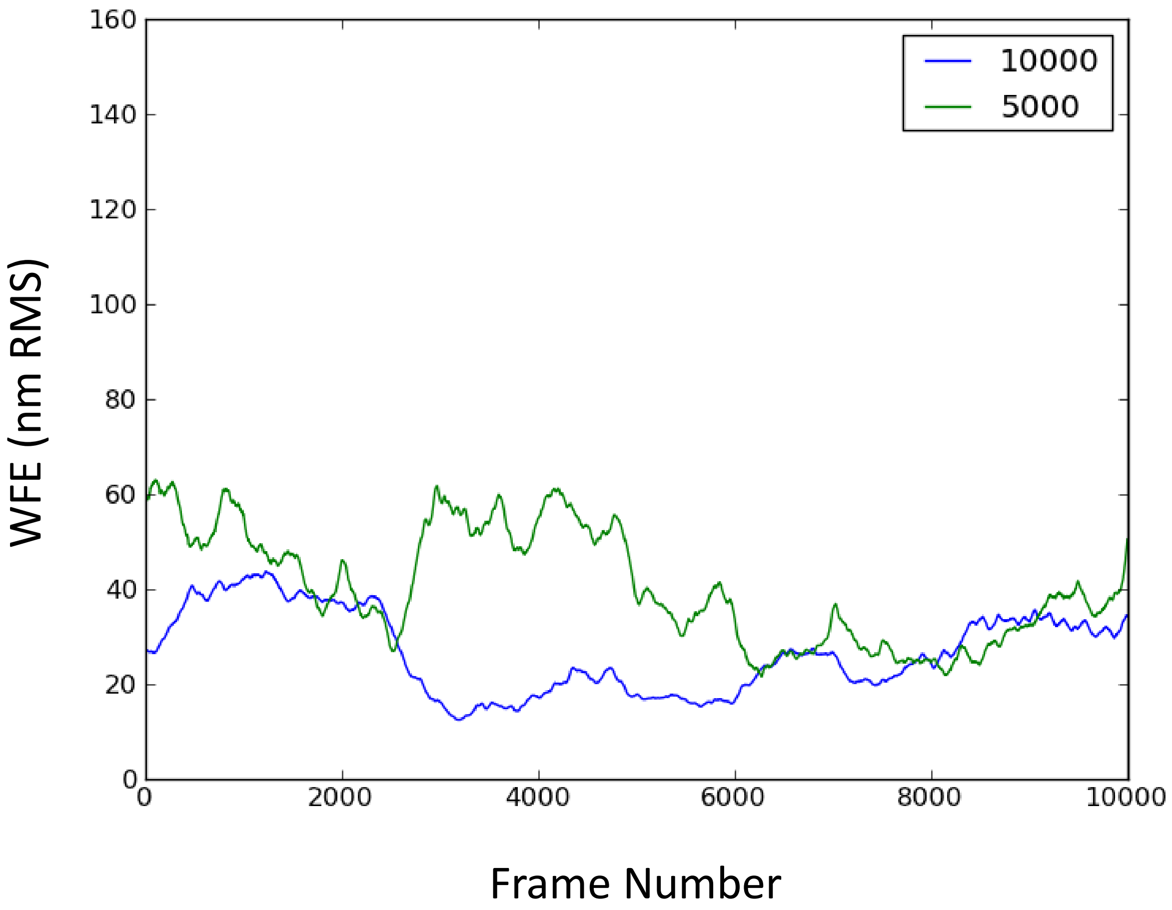
On-sky calibration

- How quickly can these average slopes vary?
  - Or, how long is a calibration valid for?
- In longer datasets we can look at how different averaging periods end up changing the observed static aberrations
- Simple method:
  - Take a rolling average of N frames of WFS data
  - Compare to later averages (i.e. the static aberration term we'd measure in the error budget)
  - Reconstruct (up to Z35 here)

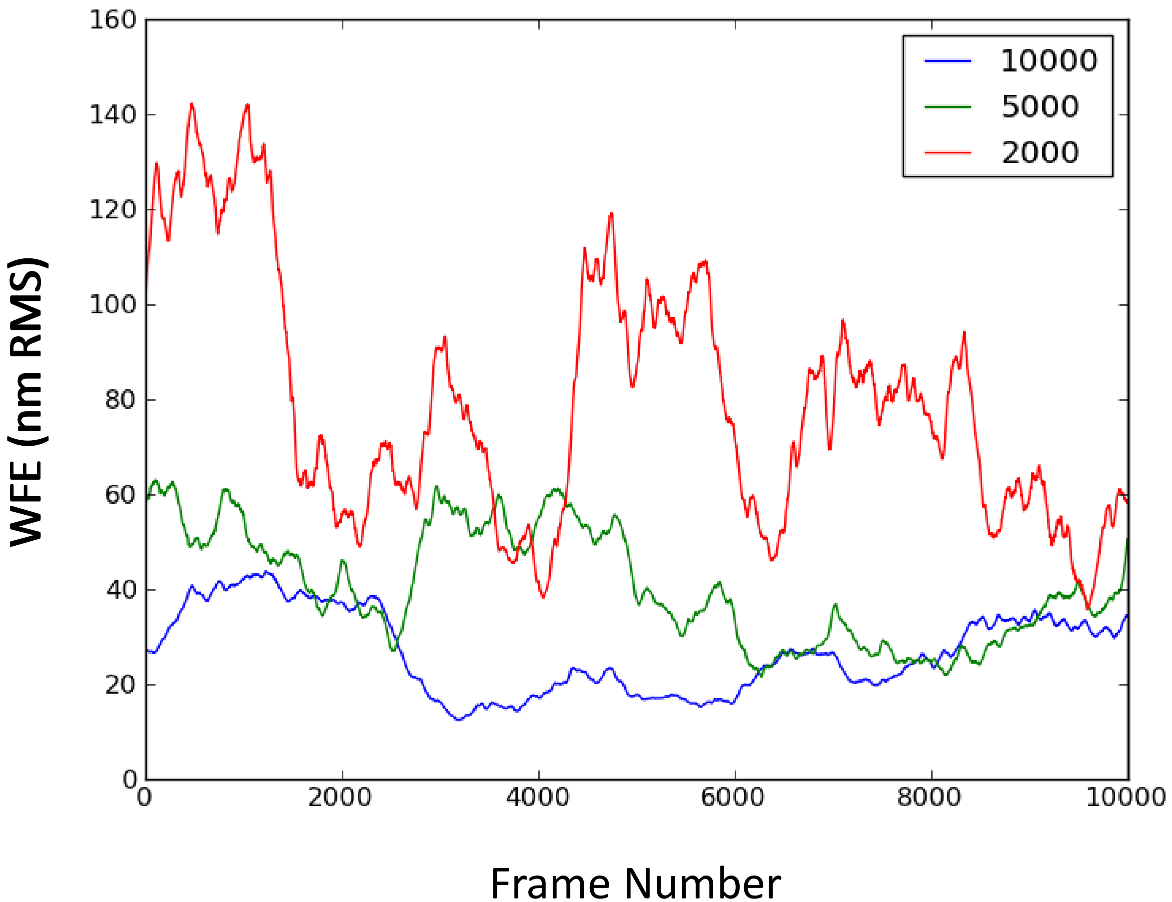
10000 frame averaging (67 seconds)



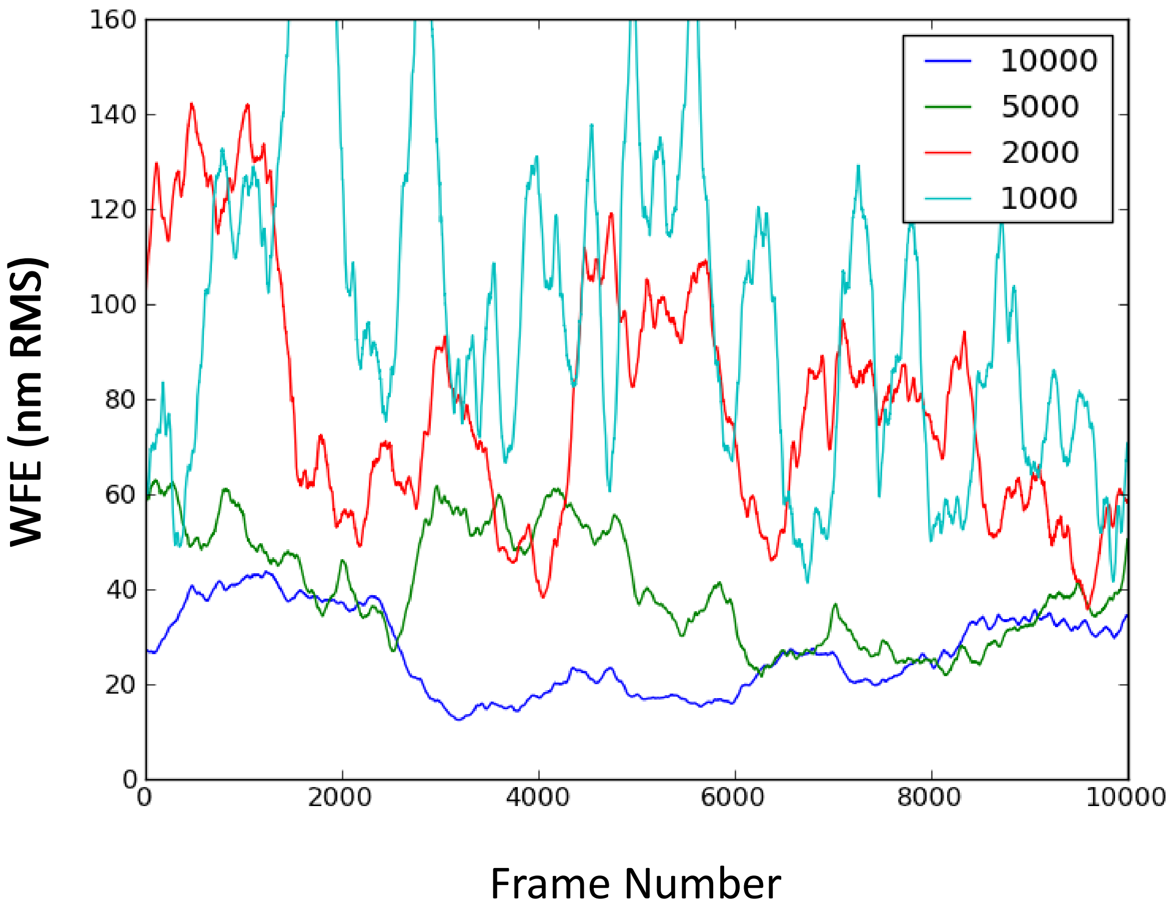
5000 frame averaging (33 seconds)



2000 frame averaging (13 seconds)



1000 frame averaging (6.7 seconds)



Averaging

- For *these* atmospheric conditions:
  - Needed a >5000 frame average to keep errors below 50nm RMS (CANARY initial goal)
  - There's a lot more data to analysis (e.g. off-axis WFSs)
- Need to monitor shorter term variability during calibrations
  - We don't get these using our on-bench telescope simulator
- Rolling averages – continual static monitoring – could reduce the error
- Places additional requirements on the system:
  - Dedicated truth sensor (long exposure)
  - Pseudo open-loop control for a closed-loop system

Conclusions

- Tomographic AO on a 4m telescope isn't ideal
- Not the case for larger telescopes
  - More challenging tomographic reconstruction, but smaller error terms should become more apparent
- Scaling errors to higher actuator densities will be tested at CANARY Phase C
  - Validation of scaling laws in a telescope environment
- **Some** on-sky calibrations procedures aren't stable unless sufficient time is taken for averaging
  - Still need to characterise over observation-length timescales