Mixed LGS/NGS tomographic real-time control using CANARY

AKA Tomography: Not just simulation/modelling

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Contents

- CANARY tomography
- WFS timeline
- RTCS solutions
- Telemetry
- Modelling

CANARY RTCS & Tomography

- DARC RTCS (free, open source)
- Single control matrix from Slopes vector to MOAO DM commands
  - Usually produced by L&A
  - Simulation version also used
  - And LQG (~6 matrices), Neural networks
- Complexities arise from multiple WFS
  - Hardware interfacing, synchronisation, etc
  - An issue for tomographic AO systems
    - Particularly with mixed LGS/NGS

CANARY WFS timeline

- 2010: 4 NGS
- 2011: 1 LGS
- 2012: 4 NGS+1 LGS
- 2013: 4 NGS+4 LGS
- 2014: 4 NGS+4 LGS+2 Figure Sensors
- 2015: 4 NGS+4 HOLGS+2 Figure Sensors
- 2015: 4 NGS+4 LGS+2 FS+1 NaLGS
- 2016: + 1 HONGS + CAWS

WFS interfacing

- 4 NGS
  - ESO SPARTA-Lite system (customised)
  - sFPDP (customised Andor iXon)
  - Processing of pixels→DM upon arrival
    - Rather than waiting for full frame to begin processing
  - Issues with infrequent dropped frames
    - Either incomplete, or shifted
    - Detectable at the end of frame/beginning of next
      - By which time, most processing has been done!

Dropped frame handling

- Upon detection, error message passed along processing pipeline
  - DM is frozen
  - States (integrators, etc) are reset to previous state
  - Certain glitches cause 2 frames of error
- WFSs synchronised by always using most recent frame
  - Complete missing frames also detected

LGS commissioning

- sCMOS camera
  - cameraLink
- Lincoln Labs gated CCD/Scimeasure controller
  - sFPDP
- Andor iXon

4 NGS + 1 LGS

- All Andors, sFPDP
  - No additional complications

4 NGS + 4 LGS

- 4x Andor
- 1x Scimeasure (4 LGS imaged onto same detector)
  - Electronically gated for Rayleigh range gate
- All sFPDP (custom electronics)
- Trigger timings adjusted such that last pixels for each camera arrive at the RTCS at same time
  - DM is updated using latest information available
  - Removes different camera electronics effects

+2 Figure Sensors

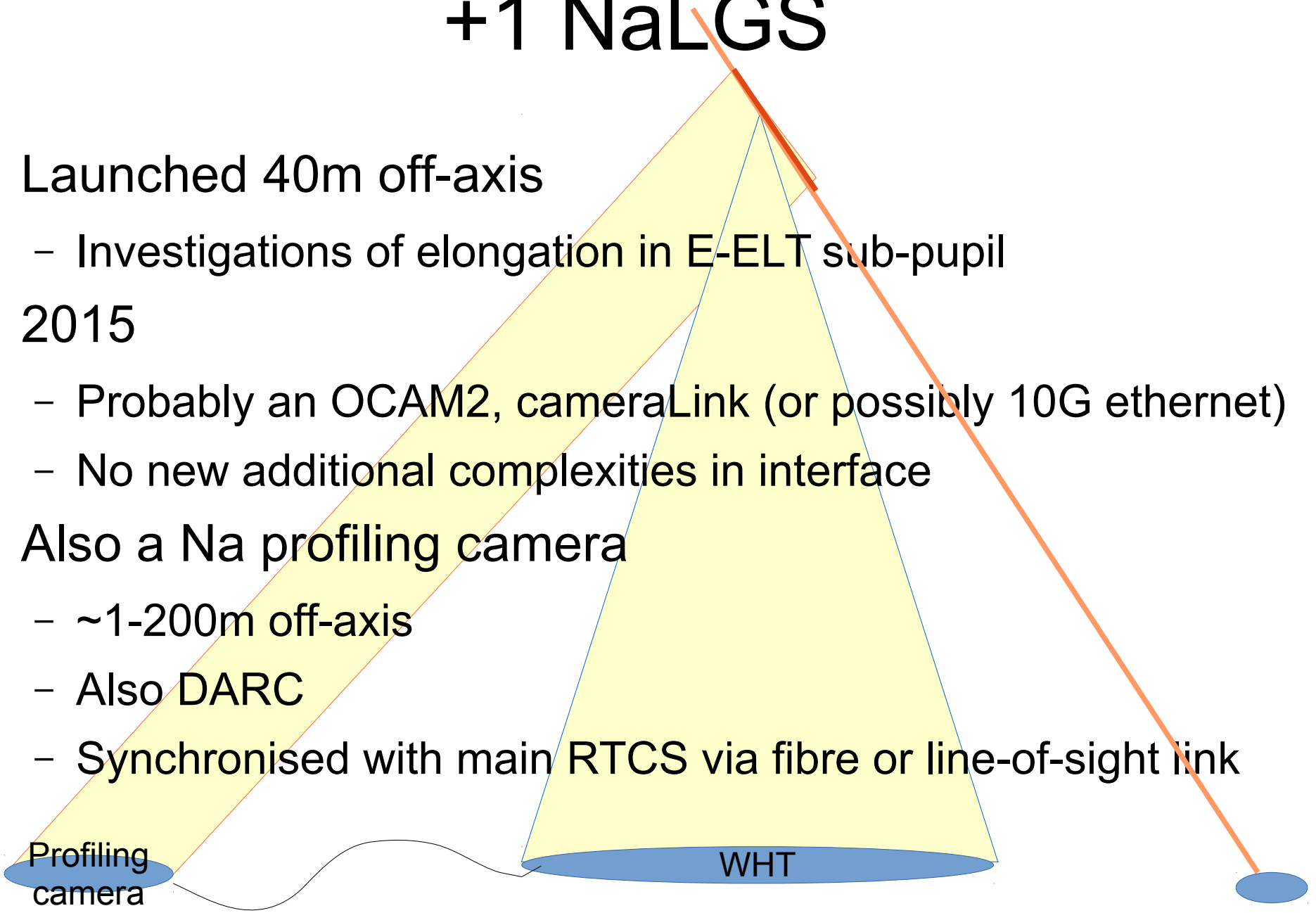
- For pseudo-open-loop calculations
  - Measure the DM surfaces
- And non-linear DM calibrations
- Input into RTCS, at same frame rate
- Gig-E vision – a frame-driven protocol
  - Reverse engineered to give pixel stream access
  - Allowing processing of sub-apertures as soon as they have arrived
- To be interfaced alongside the 5 sFPDP cameras
- Trigger pulses (start of frame) to be adjusted such that last pixel into RTC arrives at same time for each camera
- Dropped packets sometimes seen
  - As before, error flag propagated down pipeline and state frozen

LGS → HOLGS

- Using OCAM2
  - 240x240 pixels
  - Time-gated
  - EMCCD
  - CameraLink
  - Full frame access already tested with DARC
  - Access to pixel stream possible by modification of camera waveforms (extra V-Sync)
  - Integration with sFPDP and GigE cameras required
  - 3 different types of WFS cameras

+1 NaLGS

- Launched 40m off-axis
  - Investigations of elongation in E-ELT sub-pupil
- 2015
  - Probably an OCAM2, cameraLink (or possibly 10G ethernet)
  - No new additional complexities in interface
- Also a Na profiling camera
  - ~1-200m off-axis
  - Also DARC
  - Synchronised with main RTCS via fibre or line-of-sight link



CHOUGH

- +1 HOWFS +1 CAWS
- But not tomographic...

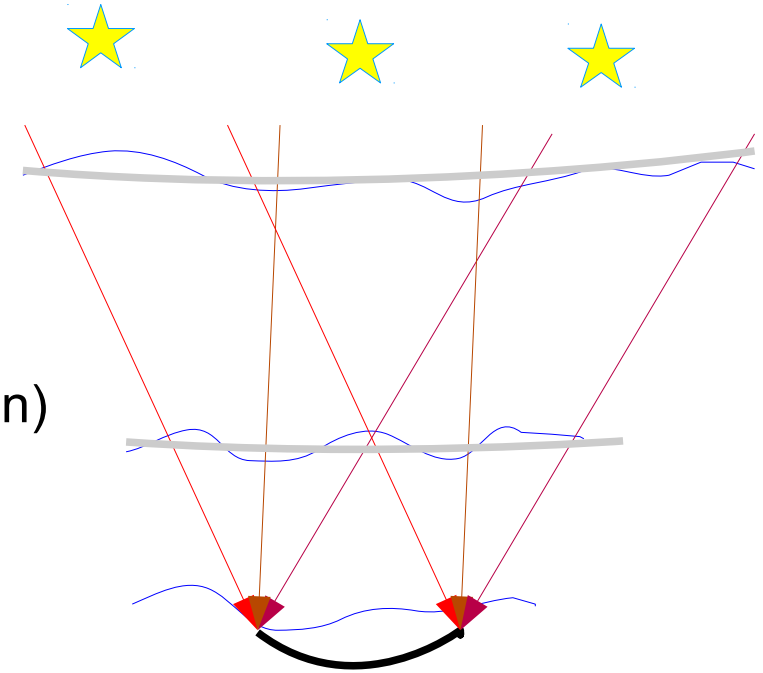
DRAGON

- Wide-field AO real-time test-bench
  - 4 NGS, 4 LGS
  - 4x GigE Vision Bobcat cameras (NGS)
  - 1x 10GigE Vision EVT camera (LGS)
  - Low number of packet drops
    - Until some critical frame rate
    - Under investigation
  - Reverse engineered pixel stream access

RTCS telemetry

- Live access to RTCS pipeline data
  - Every frame of:
    - Pixels, ***slopes***, phase, DM demands
      - (and others such as internal state, sub-ap positions, correlations, etc)
    - Linked to parameter state of RTCS

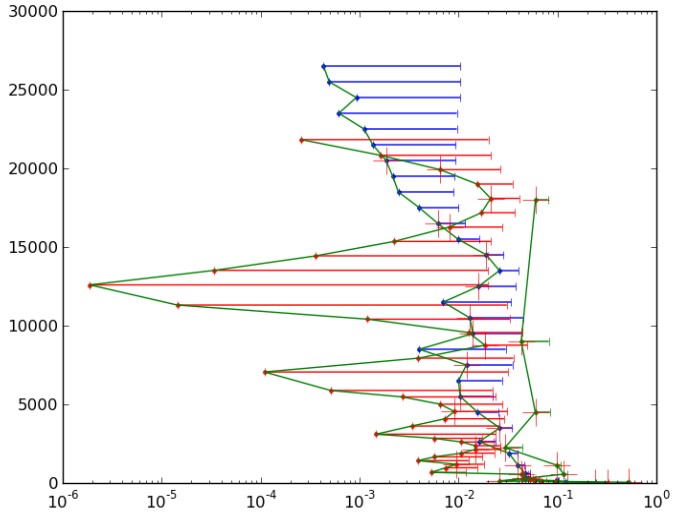
Tomographic simulation

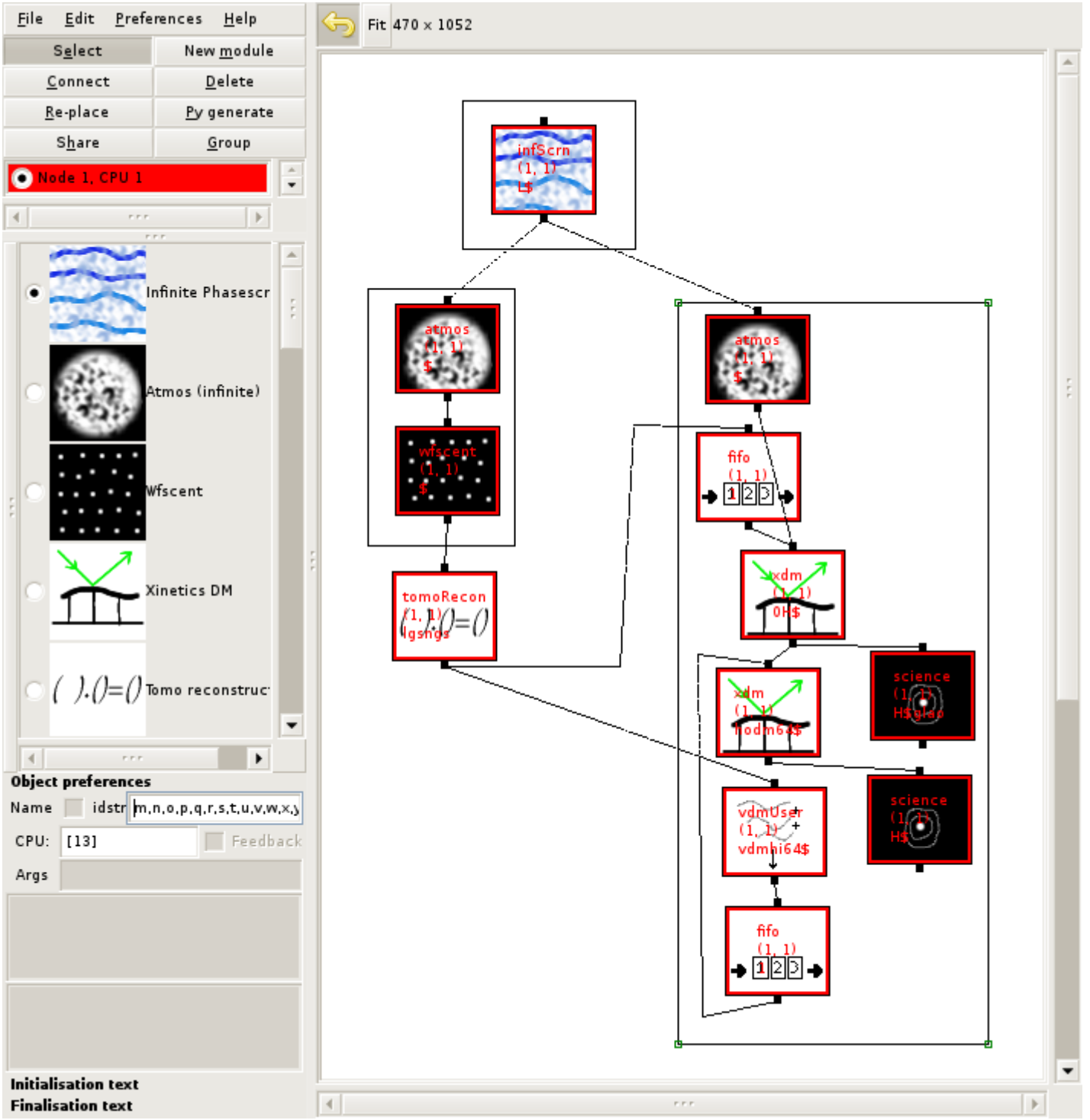


- Durham AO Simulation Platform (DASP)
- Monte-Carlo end-to-end tool
- Tomography via virtual DMs
  - Produce interaction matrices (response function)
  - Inversion (MAP/LSQ)
  - Approximations for phase/noise covariances
- For CANARY:
  - Virtual DMs placed at heights corresponding to measured CN2 profile
  - Theoretical NGS/LGS positions used
  - Theoretical reconstructor gives slightly worse performance than L&A
    - But only a very quick testing carried out

ELT-scale modelling

- Large number of slopes (~100k, ~11 WFS)
- Large number of virtual phase reconstruction points
  - Selectively choose which atmospheric layers to reconstruct
  - Reduce phase pitch depending on Cn2
- Then becomes manageable to compute reconstruction matrix
- For MOAO:
  - Reconstruction + projection
  - Reconstruction and projection

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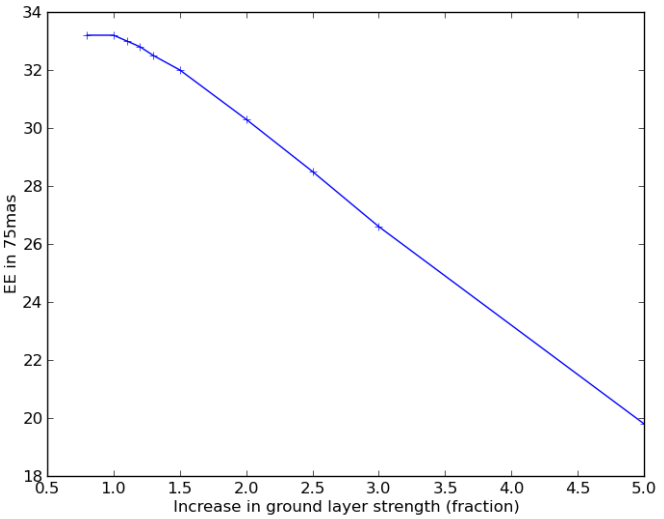
Mixed LGS+NGS

- Compute reconstruction of LGS+NGS with mean slopes removed
  - Removing mean slopes is a matrix operation
- Compute reconstruction of NGS with mean slopes
  - Averaging mean slopes is a matrix operation
- Add together to get final reconstructor

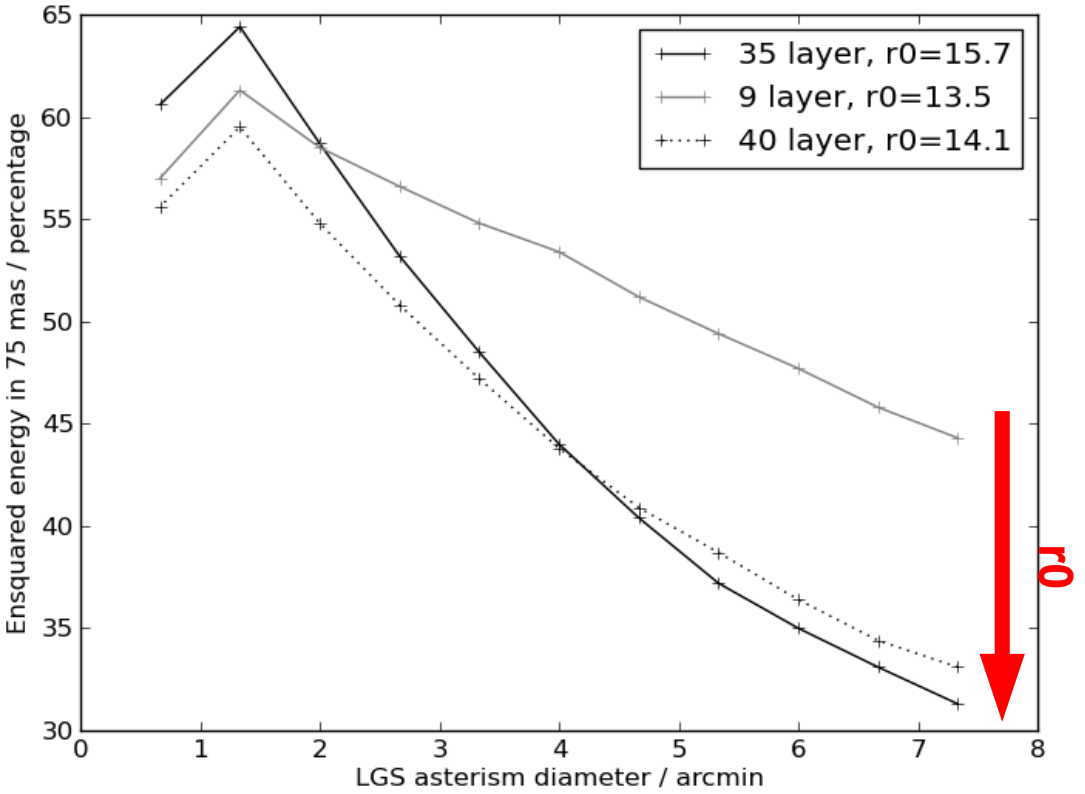
Some EAGLE/MOSAIC results

- Studies of DMs
  - DM order, faulty actuators, mis-alignments
- Optimal LGS asterism diameters
- NGS asterisms and photon fluxes, SNR
- Ground layer strength
  - Unknown for ELT!



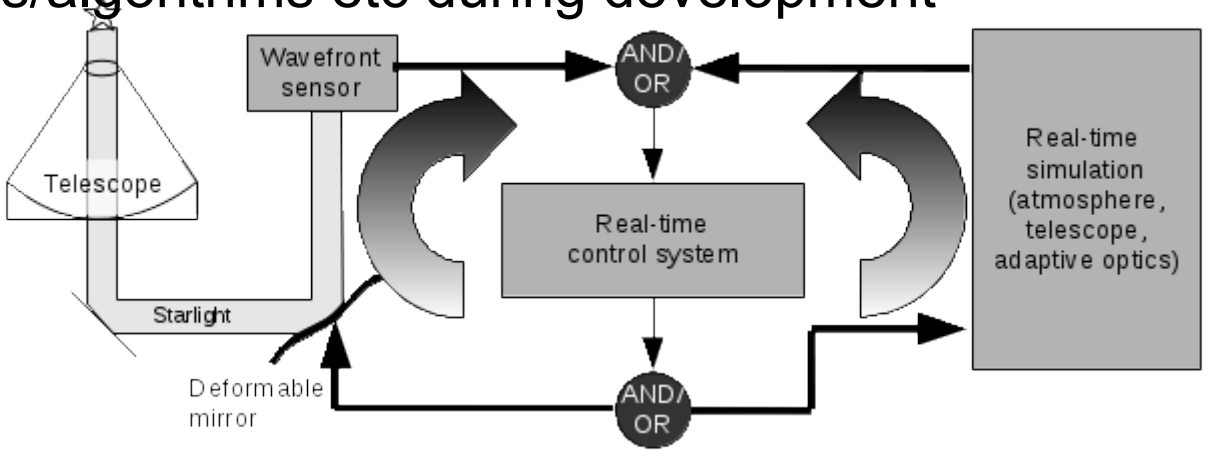
Performance v Atmospheres

- Performance v. dependent on Cn2 profile
  - Not just r0/L0
  - Not just number of layers
  - Increased dependence for wider fields



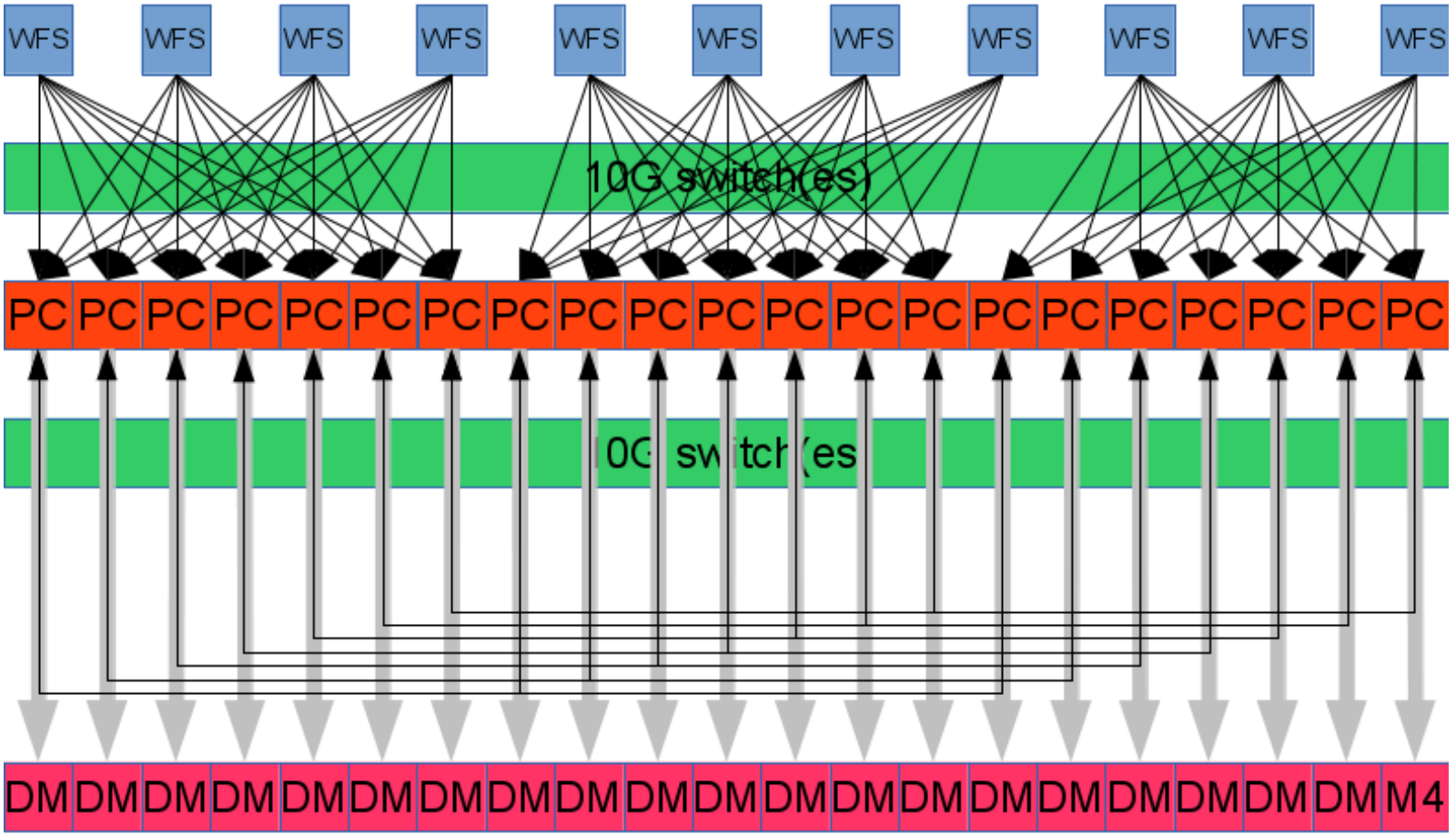
Real-time simulation

- Merging of simulation and RTC
  - Simulation of selected physical components
    - e.g. missing DMs or WFSs
    - Or the entire system
  - Allows RTCS to operate off-sky/off-bench
  - Ideal for pre-commissioning, integration etc
- Basic implementation for CANARY
  - More work to follow
  - To allow full testing of tools/algorithms etc during development



Tomographic ELT RTCS designs

- For EAGLE/MOSAIC:



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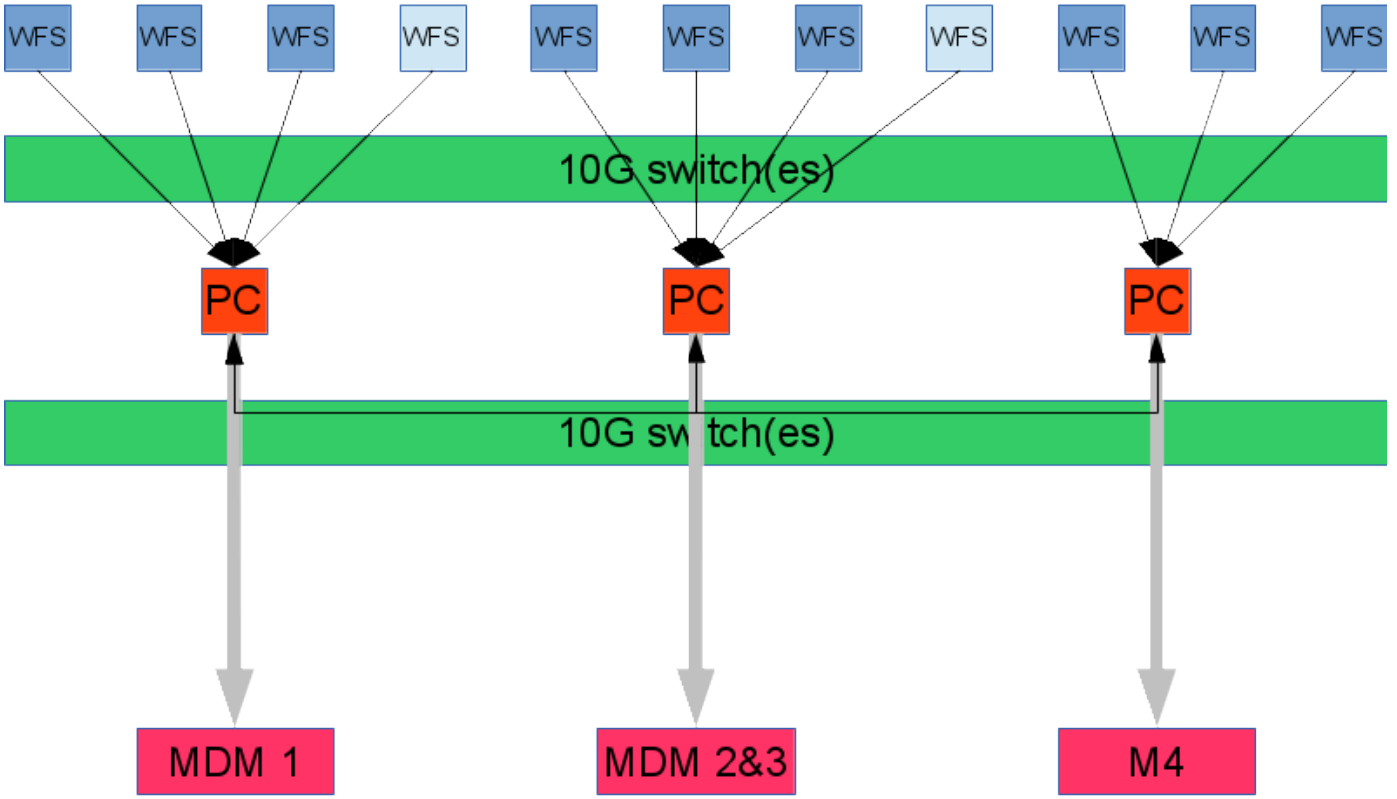
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10G switch(es)
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PC
10G switch(es)
MDM 1
MDM 2&3
M4

Conclusions

- Thought required when mixing WFSs
- For ELT, performance of wide-field AO will vary significantly depending on atmospheric conditions
  - Simple seeing monitors no longer sufficient
  - Wide range of conditions must be modelled
  - Ground layer is somewhat unknown