AO tomography simulations at ESO

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ESO AO tomography activities

- AOF: Muse NFM
- E-ELT
  - Specifications & Study & Follow up of various tomography modes
    - LTAO, MCAO, MOAO
    - Additional simulations to consortia’s ones to cross check and define studies & constrain telescope
  - Specification of environmental conditions
  - Site testing for r0, Cn2 profiles,…
- Algorithms
  - Testing of new algorithms on Octopus
  - Collaboration with CRAL & Linz

Octopus simulations: System desciption

- 37m full aperture (IR field stop)
- 50cm sub-apertures
- Frim3D reconstructor (Fast, elongation&truncation aware)
- 6 LGS, 4 laser launch stations (LLS), TT stars close to center of FOV (unless otherwise noted), at 0.85' unless otherwise noted
- 500Hz, 500 iterations, 2 frames delay
- Seeing 0.8'', L0=25m, tau0~3ms
- High LGS flux (but same results with 500ph / subap)
- Rudimentary error budget (no telescope, jitter,spiders, segmentations…)

- MCAO: 3 DMs @ 0, 4.5, 12km, LGS position @0.85' (unless otherwise noted)

Cn2 profiles for tomography

- 2 aspects:
  - How to simulate “realistically” atmosphere ?
    → Goal is to get performance estimate close to what we will have @ telescope
  - Definition and test of ESO 35-layer Cn2 profile
  - How many layers the tomography algorithm must estimate ?
    → Complexity & speed of simulations
    → Complexity of the RTC

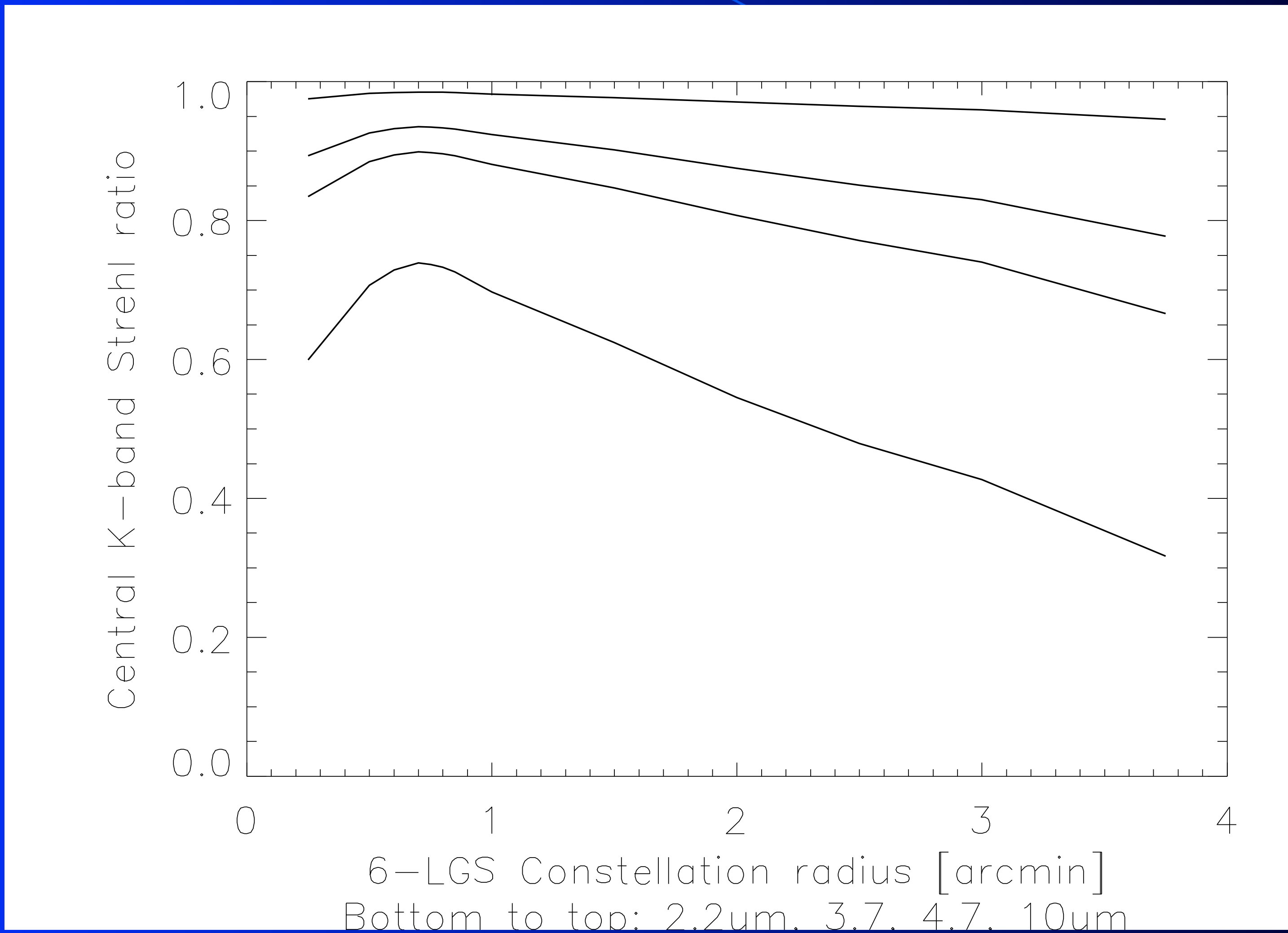
Why is Cn2 important ?

- Input Cn2 profile can have a significant impact on system performance
- The wider the FOV, the more sensitive the performance to the Cn2 profile
- The LGSs have a "natural" optimal position. The wider the LGS constellation, the more sensitive the system is to Cn2 (→ compensate "wrong" LGS position with Cn2 knowledge / sensitivity to Cn2).
  - LTAO: LGSs optimum (~1.7' diameter)

History

- Studies started with ESO "standard" 9 layer model
  - Did not realize then that Cn2 was so critical (it's less critical for VLT cases studied so far)
- Phase A studies made with 9 layers + sensitivity analysis (see e.g. Costille & Fusco)
- → Studies Identified need to increase Cn2 resolution
- 30-40 layers seemed ok for LTAO & MCAO (2'-4' LGS constellations – diameter)
  → ONERA 40 layer model used for some simuls
- Some simulations still made with 9 layers to maintain consistency

Position of the LGS for LTAO



9 layers simulated / 9 layers estimated

→ Large LGS radii are ~ ok for 4-10 um science

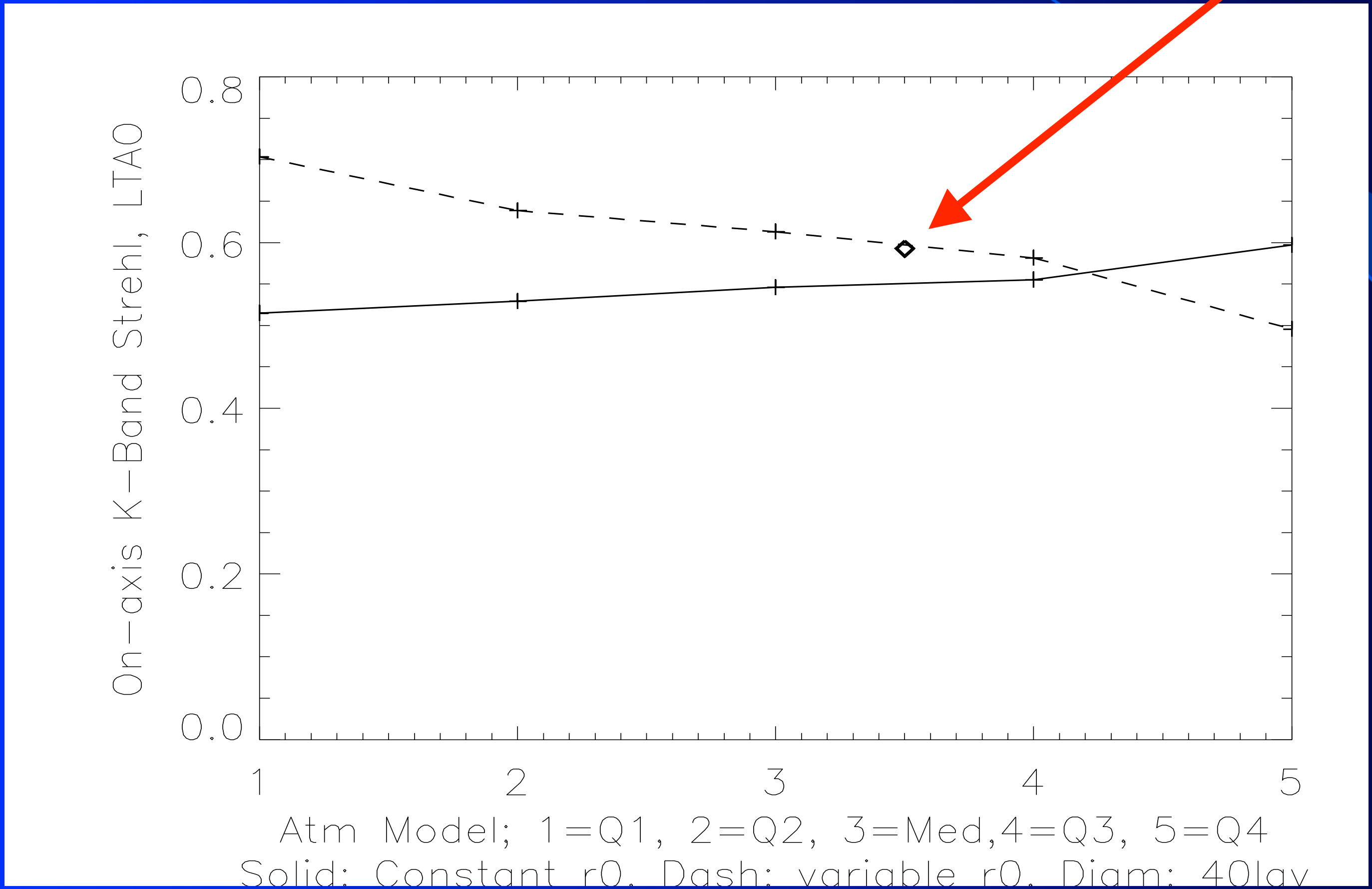
35 layers vs 40 layers

- 9 layers is not enough → what to use ?
- ONERA (Th. Fusco et al.) defined a 40 layer model for simulations
  - Using balloon data
  - Subsampled to 40 layers
  - See Costille & Fusco 2012
- M. Sarazin defined an “official” ESO 35 layer model, based on:
  - Merging of several sources @ Paranal + Armazones
  - See Sarazin & al. AO4ELT III
  - Provides correlations r0 & Cn2, statistics

LTAO performance – 35 layers & 40 layers

6 LGS, in 1.7 (diameter) ring

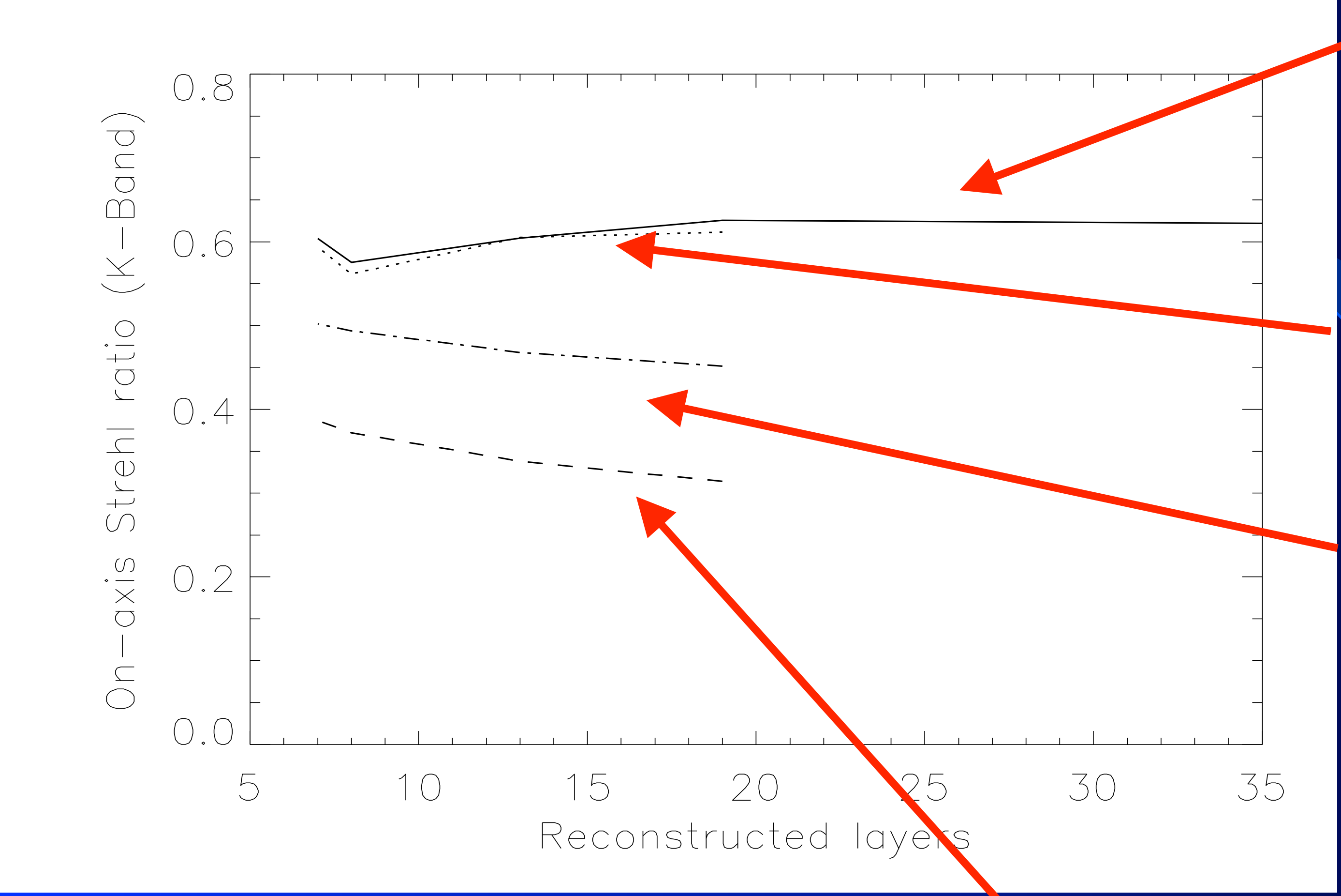
ONERA 40 layers



All layers reconstructed

Cn2 correlated with r0: here wanted to disentangle both effects ("good" r0 vs "good" Cn2 profile) → Maintain r0 constant and only change Cn2 to see profile's effect – solid. Combined effects – dash.

LTAO: 35 reconstructed layers



Input profile

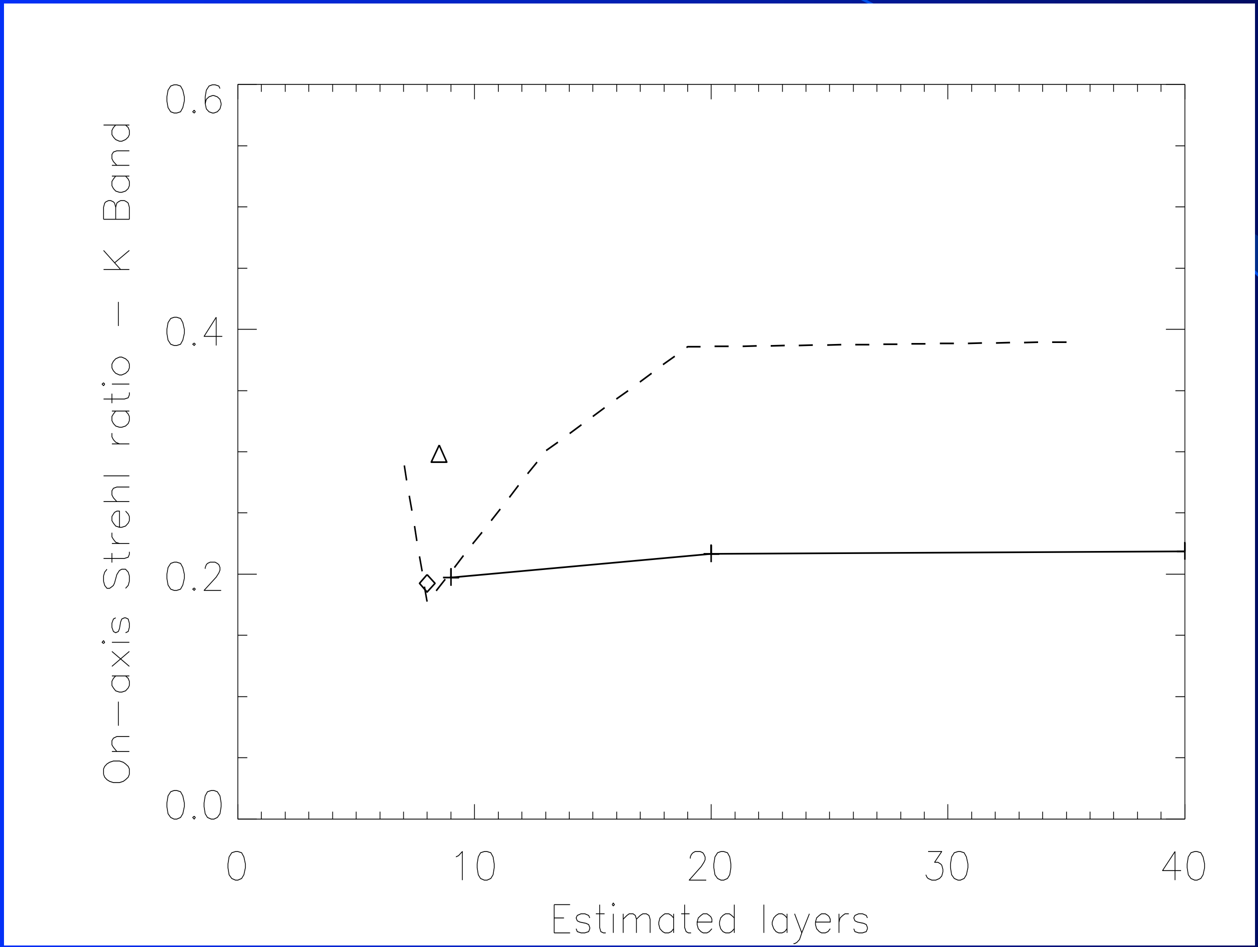
Measured heights, but flat Cn2 profile

Equi-distributed heights with a max height at 24km, flat Cn2 profile.

Equi-distributed heights with a max height at 18km, flat Cn2 profile

35 layers simulated
35 layers reconstructed

GMCAO –NGS MCAO



Q: Which layers to estimate ?

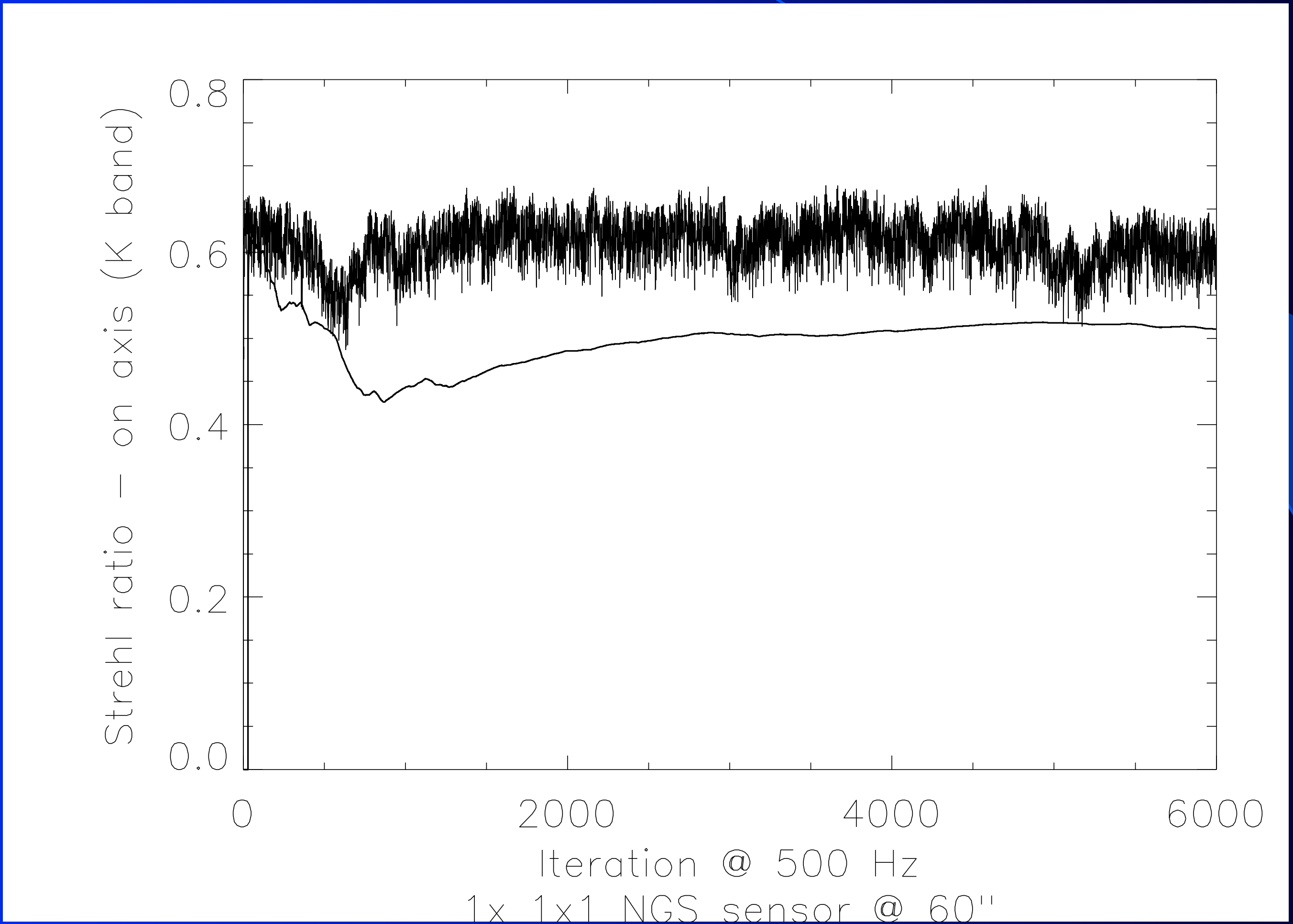
4’ diameter 6 NGS constellation, 3 DMs @ 0, 4.5, 12km

On-axis performance in the earlier 40-layer model (full line) and the present 35-layer model (dashed line). Triangle: “improved” 10 layer estimation.

Low order sensing in LTAO / MCAO

- What patrol field for NGS in LTAO ?
- Large patrol field
  - → Large sky coverage
  - BUT tough optics / mechanics
  - Serious constrain to opto-mechanical design
- Want to see if LTAO can use a large patrol field despite only 1 DM
- Compare this to MCAO (additional correction)
- NGS sensing:
  - No extra DM for NGS sharpening
- NO spot elongation & Na layer variations → May require more modes from NGS

Convergence of Low order modes

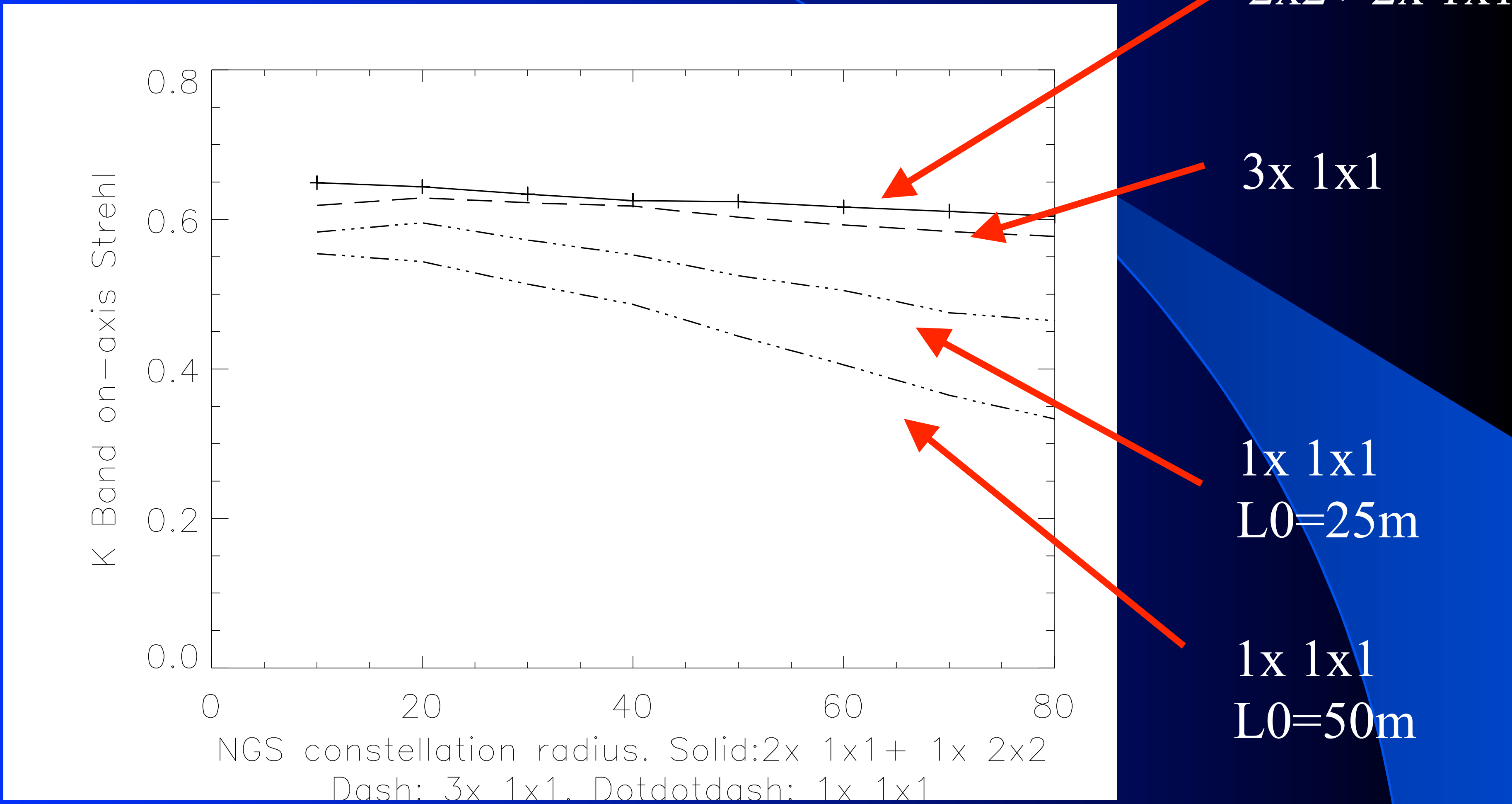


LTAO, L0=25m, single NGS @ 60”

→ 3000 iterations is ok

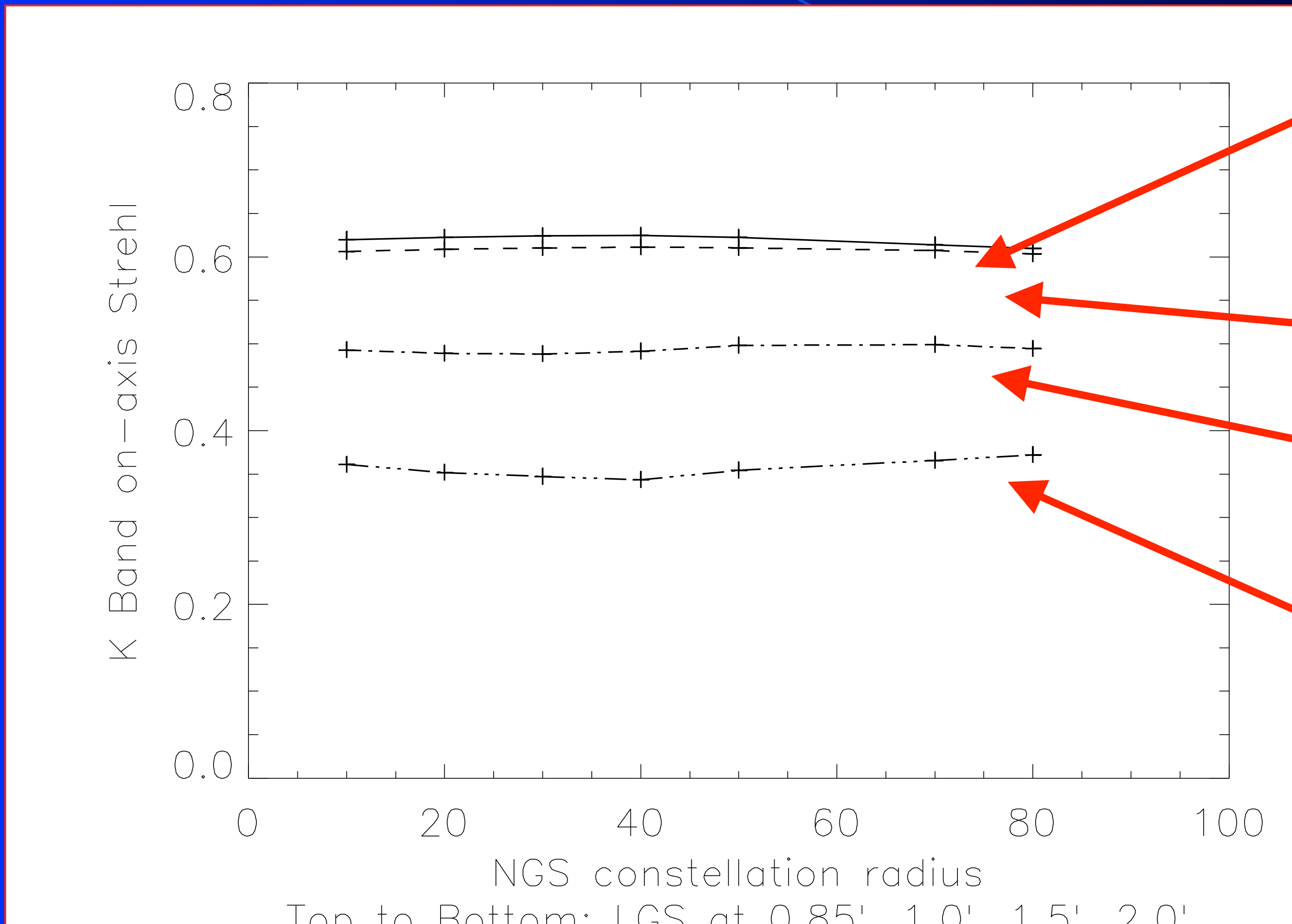
Low order sensing in LTAO

NO SPOT ELONGATION



- → TT tomography helps (3 stars has much less anisoplanatism than 1)
- → Higher order NGS doesn’t help much (But NO spot elong)
- → L0 is quite important at least for the 1x 1x1 case

Low order sensing in MCAO & 3 NGS



Top to Bottom: LGS at 0.85', 1.0', 1.5', 2.0'

LGS @0.85’ (radius)

LGS @1.0’

LGS @1.5’

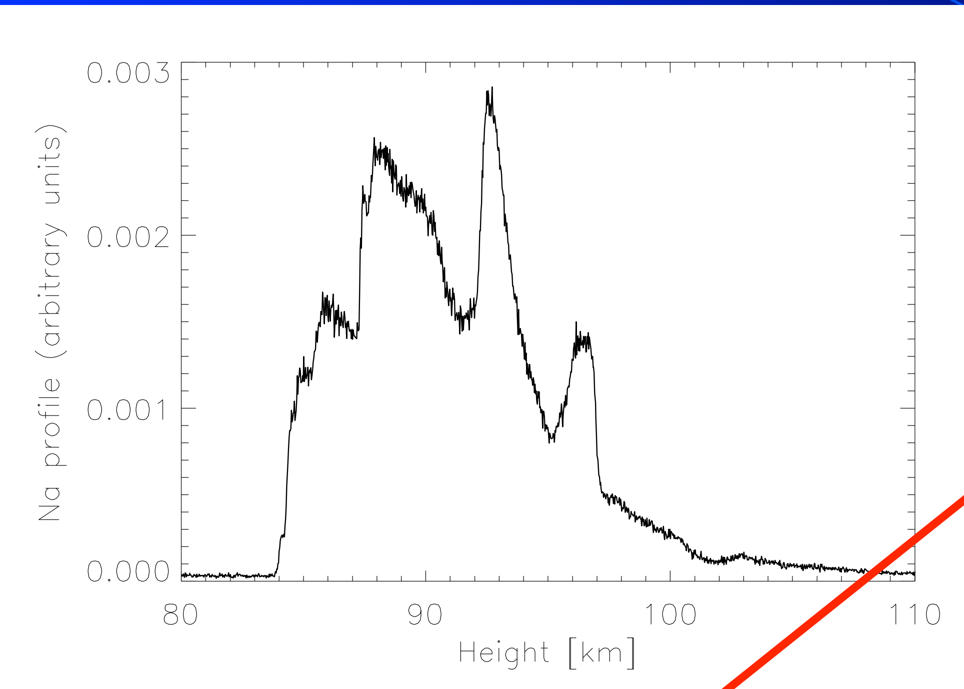
LGS @2.0”

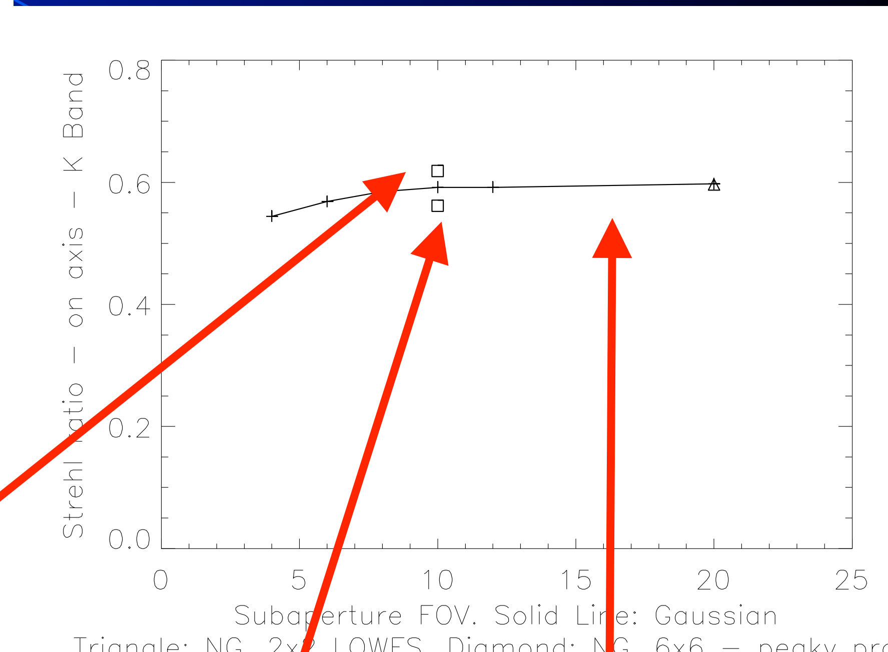
3 NGS= 1x 2x2 + 2x 1x1

How many pixels for WFS CCD ?

- Currently, E2V "demonstration" detector for ELT AO is 800x800 pixels ~ available
- Do we need to develop the full detector ?
  - 1600x1600 pix
  - Very expensive ☺
- With 74x74 subaps (50cm on M1) we would have 10x10 pixels
- Assume ~1'' / pixels → 10'' FOV : this will truncate LGS spot (side launch) by quite a lot on the edges (~20'' for 10km Na FWHM)
- Related to tomography because side launch + truncation doesn't work well in non-tomographic systems (i.e. single LGS).

Spot elongation for MCAO





Non Gaussian, 2x2 NGS

Non Gaussian, 6x6 NGS

Solid: Gaussian Na, 2x2 NGS

→ Truncation seems ok. But we probably need a lab experiment
→ to be 100% sure

Conclusions

- Cn2 needs attention:
  - 35 layers defined by ESO for further instrument simulations
  - Measurements @ Armazones to define better profile for simulations
  - ~30-40 layers
    - → Starts to be challenging for SLODAR (?)
    - SCIDAR needs big telescope
    - Balloons data is not easy to interpret and expensive
  - Statistics
    - Correlations with r0, seasons, jet stream etc
- NGS scheme
  - TT decorrelates slowly → slow simulations…
  - Low order tomography allows to use large patrol field efficiently, even in LTAO (2.5’ diam is ok)
  - L0 needs attention (incl profiles !)
- CCD pixels: seems ok to truncate but lab experiement needed before committing…