E-ELT Programme

MCAO for Beginners : Principles and Limitations

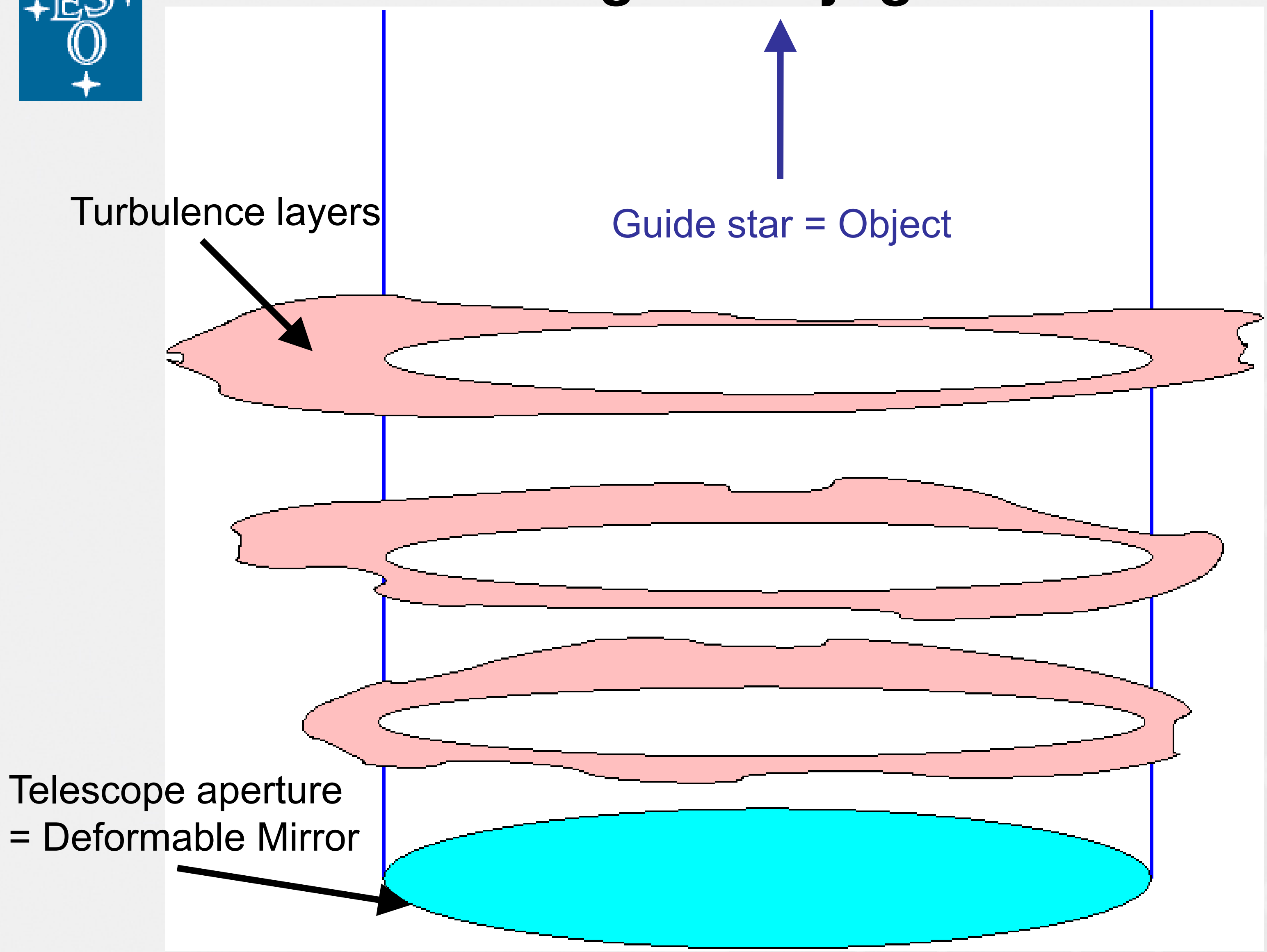
M. Le Louarn

ESO - AOD

Introduction

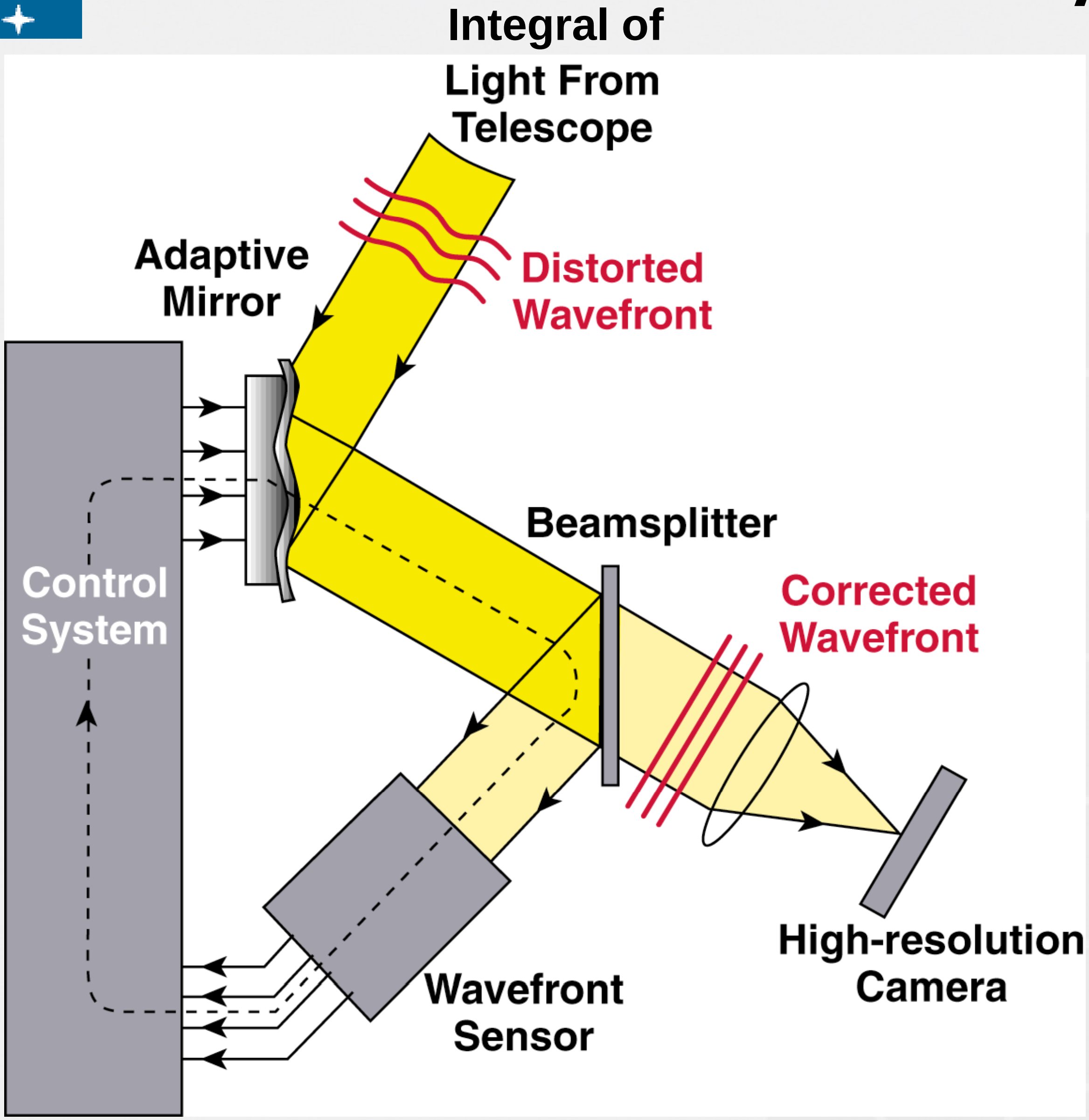
- What is SCAO ?
- Limitations of AO
  - Wavefront measurement
  - Wavefront correction
- Multi-conjugate AO
  - Star Oriented
  - Layer Oriented
  - Particular case: LGSs on ELTs
- Limits of MCAO

Single Conjugate / Conventional AO



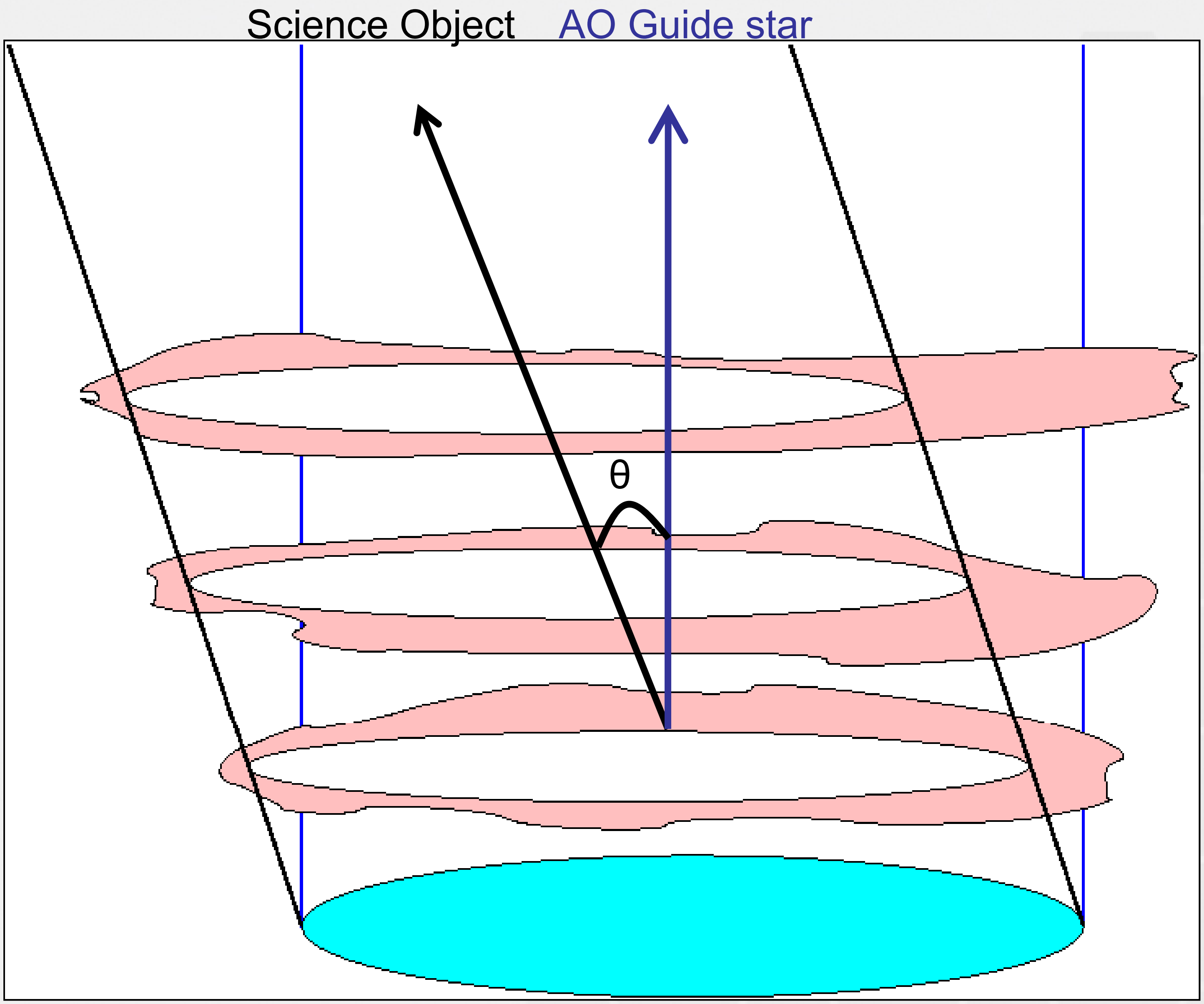
Single conjugate ("conventional") AO sees / corrects the **integral** of the turbulence along its line of sight

AO Closed loop



Iterative process
→Need to be faster than turbulence Evolution ("coherence time", θ_0)

Anisoplanatism



In a direction different from GS, measurement / correction is not valid

E-ELT Programme

Seeing limited 0.5'', J band

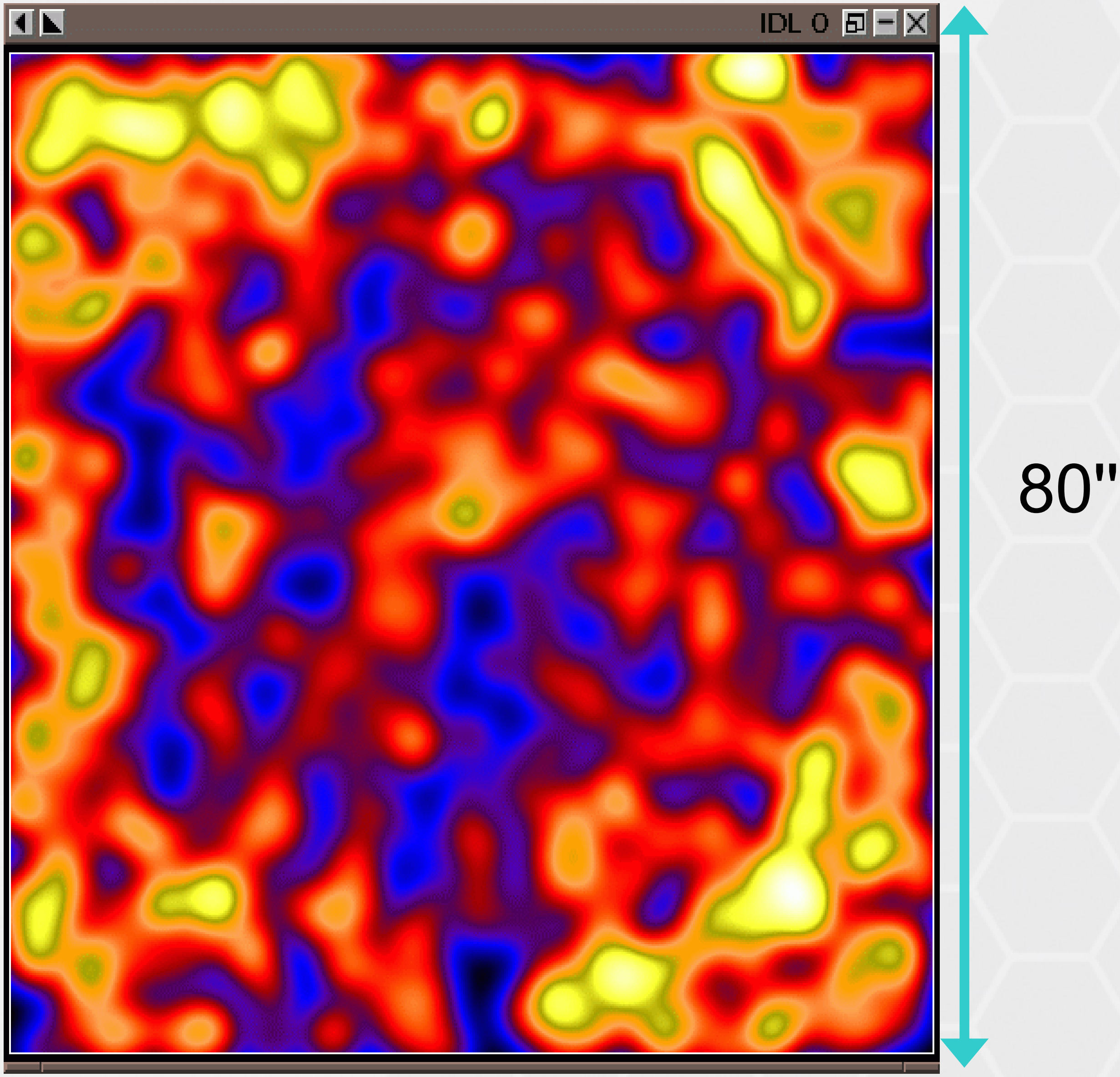
ø 80''

J band

1000 stars

FWHM

~ 0.4''



NGS-AO, J band

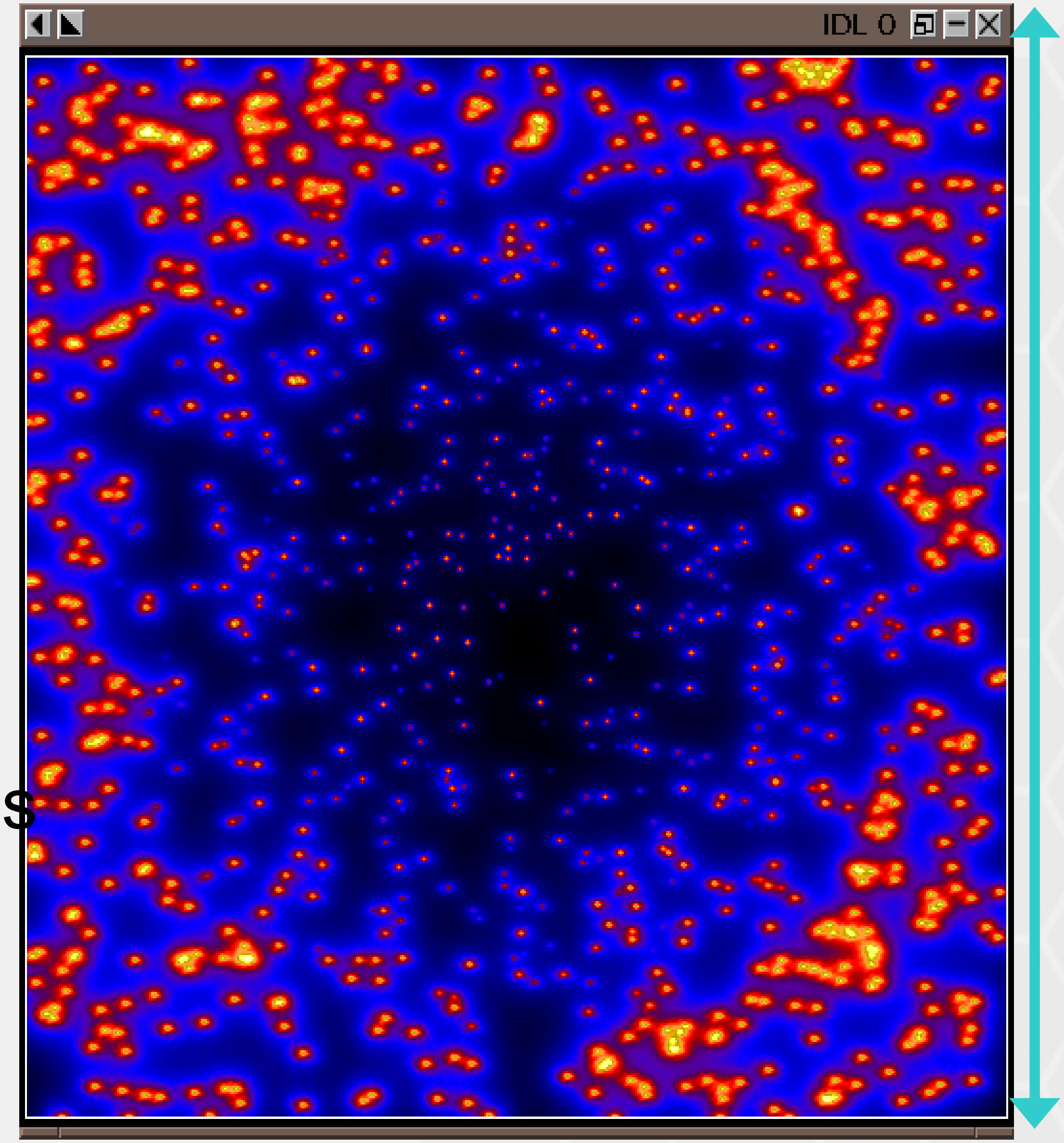
ø 80"

J band

1000 stars

FWHM

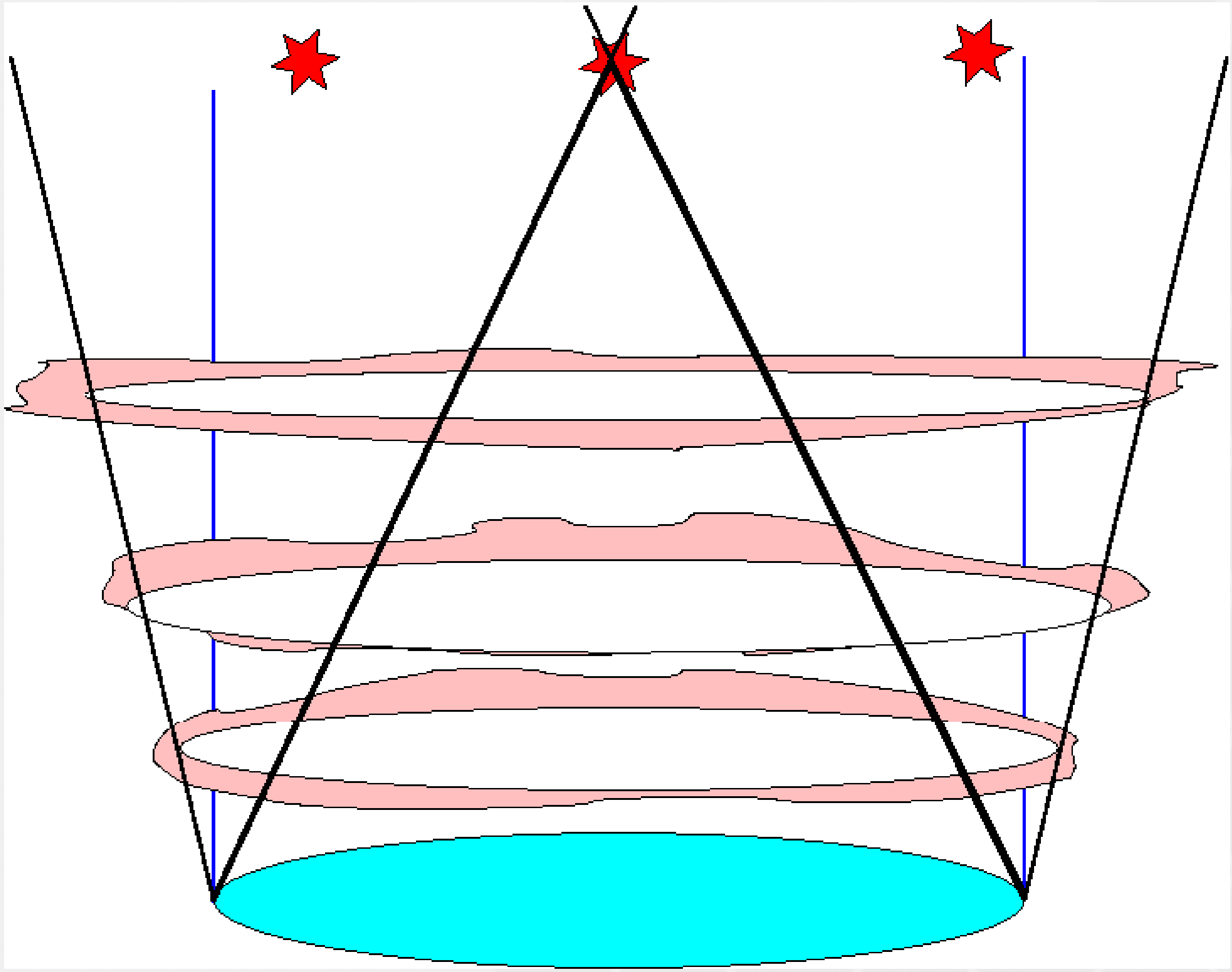
34 → 70 mas



Single Conjugate AO summary

- AO system measures and corrects integral of turbulence
- FOV limited by anisoplanatism
  - Due to vertical distribution of turbulence
  - Different measurement / correction needed for different directions
- Want more FOV ?

Wide FOV AO: Measuring

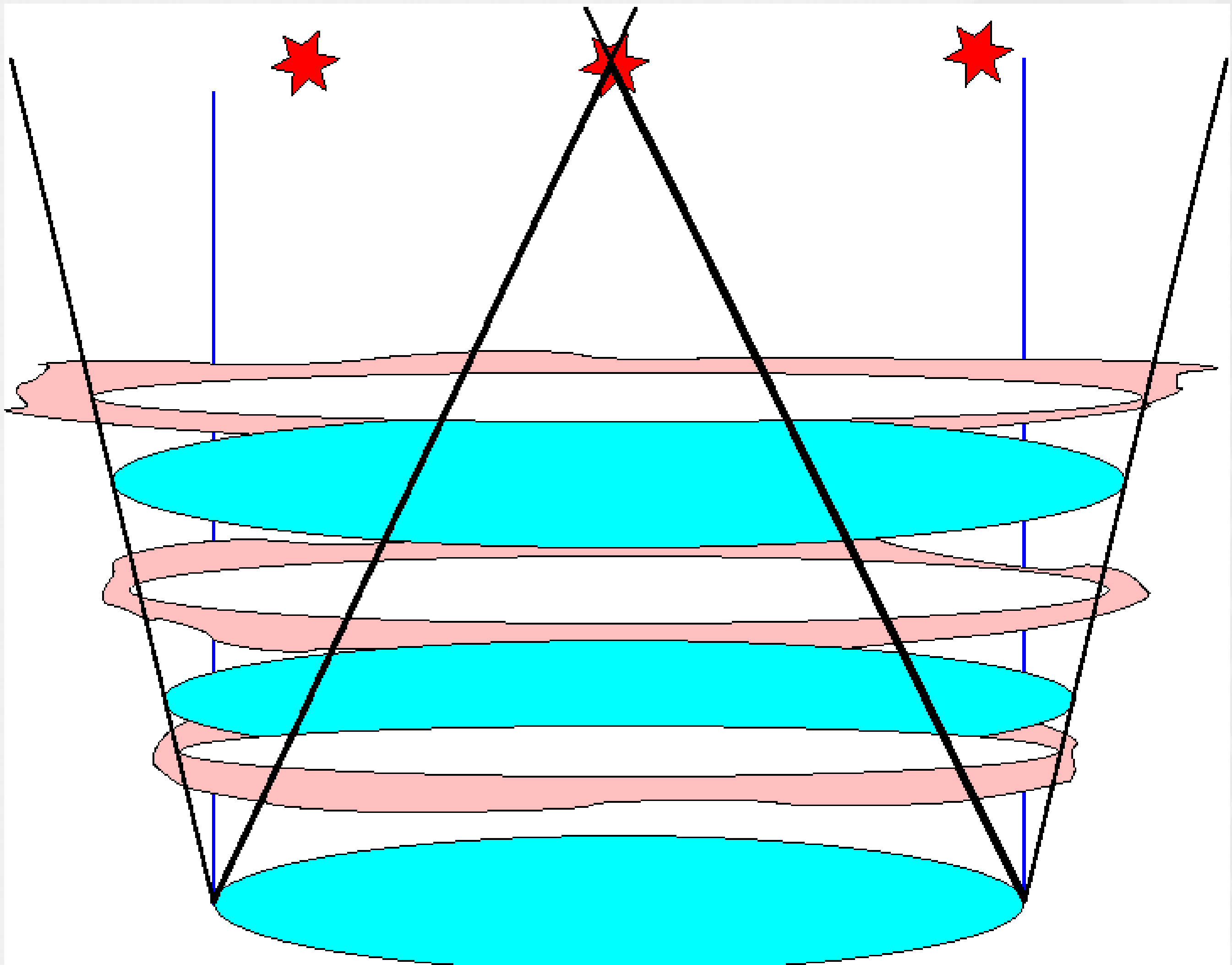


Multiple Guide stars allow to **measure** turbulence over a wider field

MCAO: Correcting

DM conjugated
to turbulence height

DM conjugated
to turbulence height



Multiple DMs allow to **correct** turbulence over a wider field

Multi-conjugate AO

- Multiple guide stars allow to measure turbulence volume
  - Different guide stars give different signals
  - Tomography allows to say what turbulence came from what direction / what height
  - The turbulence volume is reconstructed
- Multiple DMs allow to correct turbulence volume
  - DMs must be optically conjugated to strongest layers
  - Anisoplanatism is reduced

E-ELT Programme

Seeing of 0.5'', J band

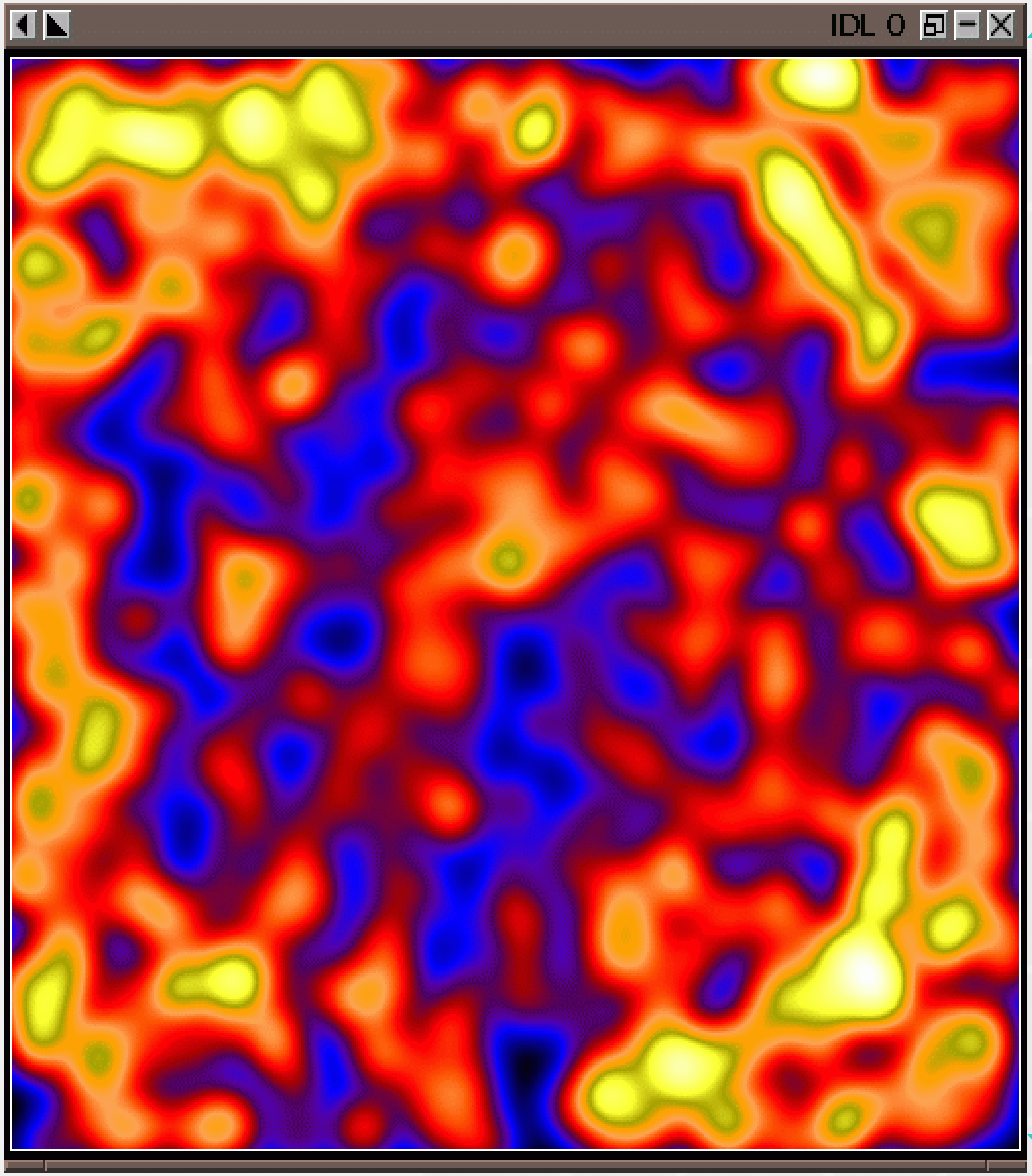
ø 80''

J band

1000 stars

FWHM

~ 0.4''



80''

NGS-AO, J band

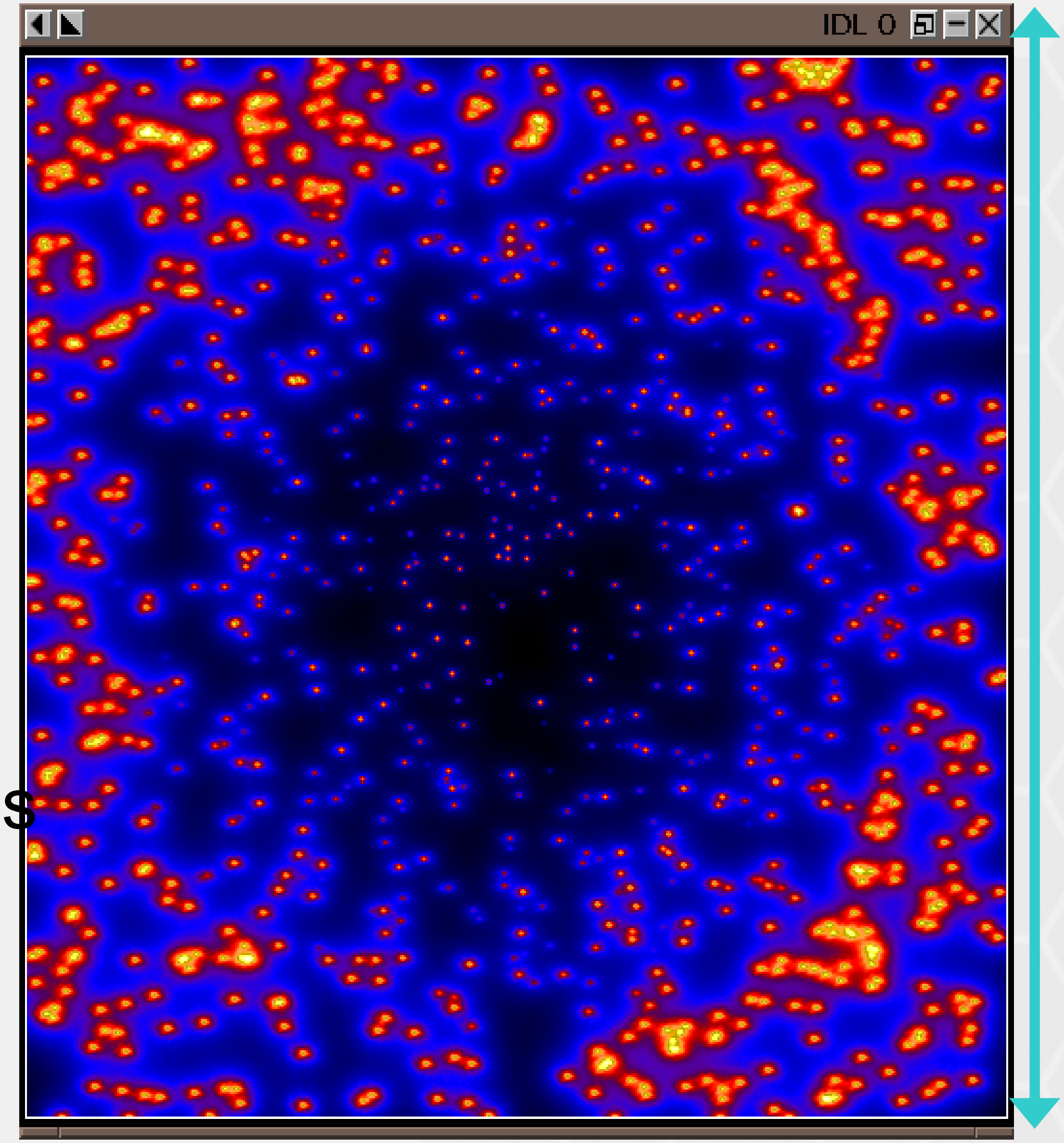
ø 80"

J band

1000 stars

FWHM

34 → 70 mas



MCAO, J band

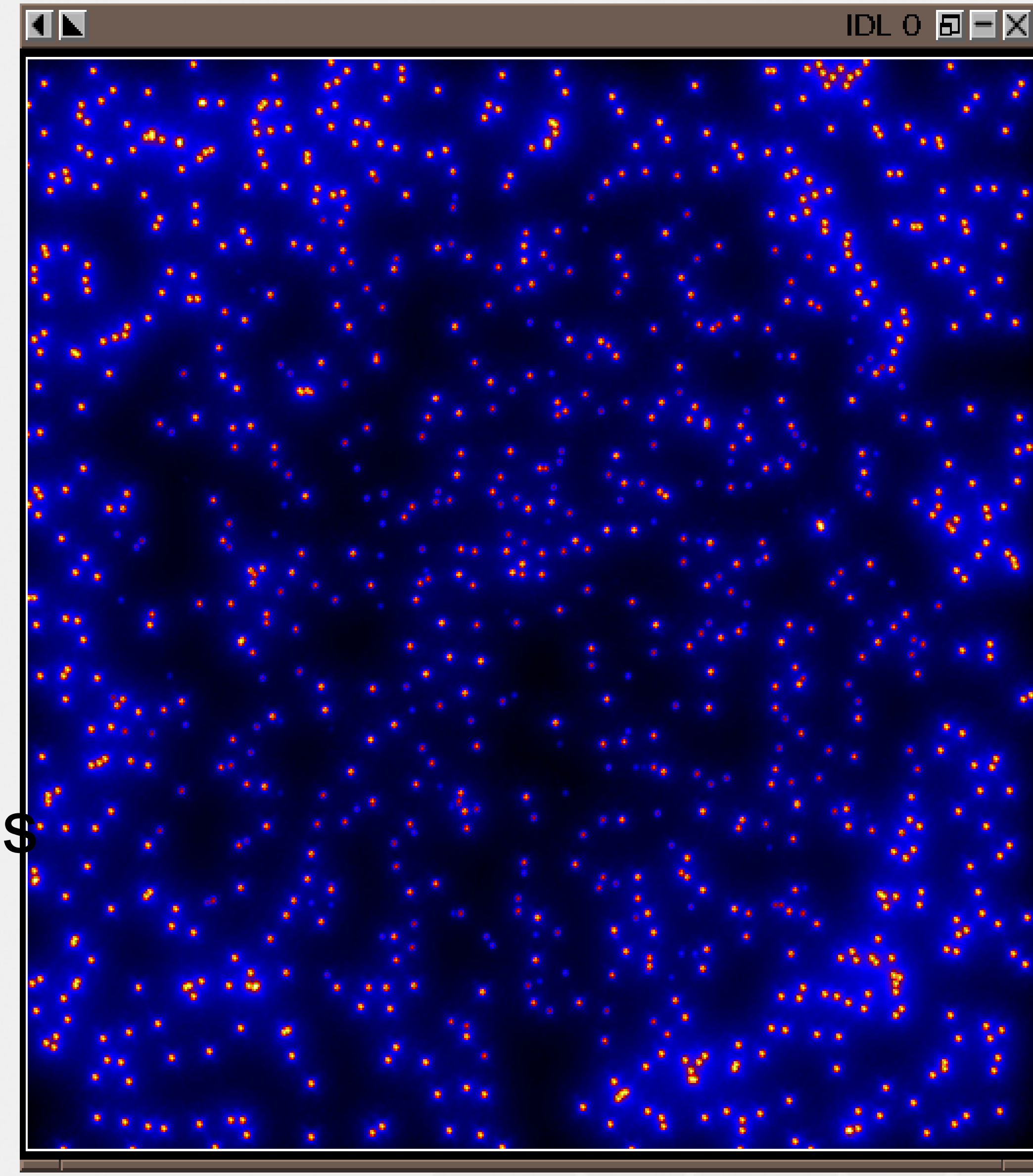
ø 80"

J band

1000 stars

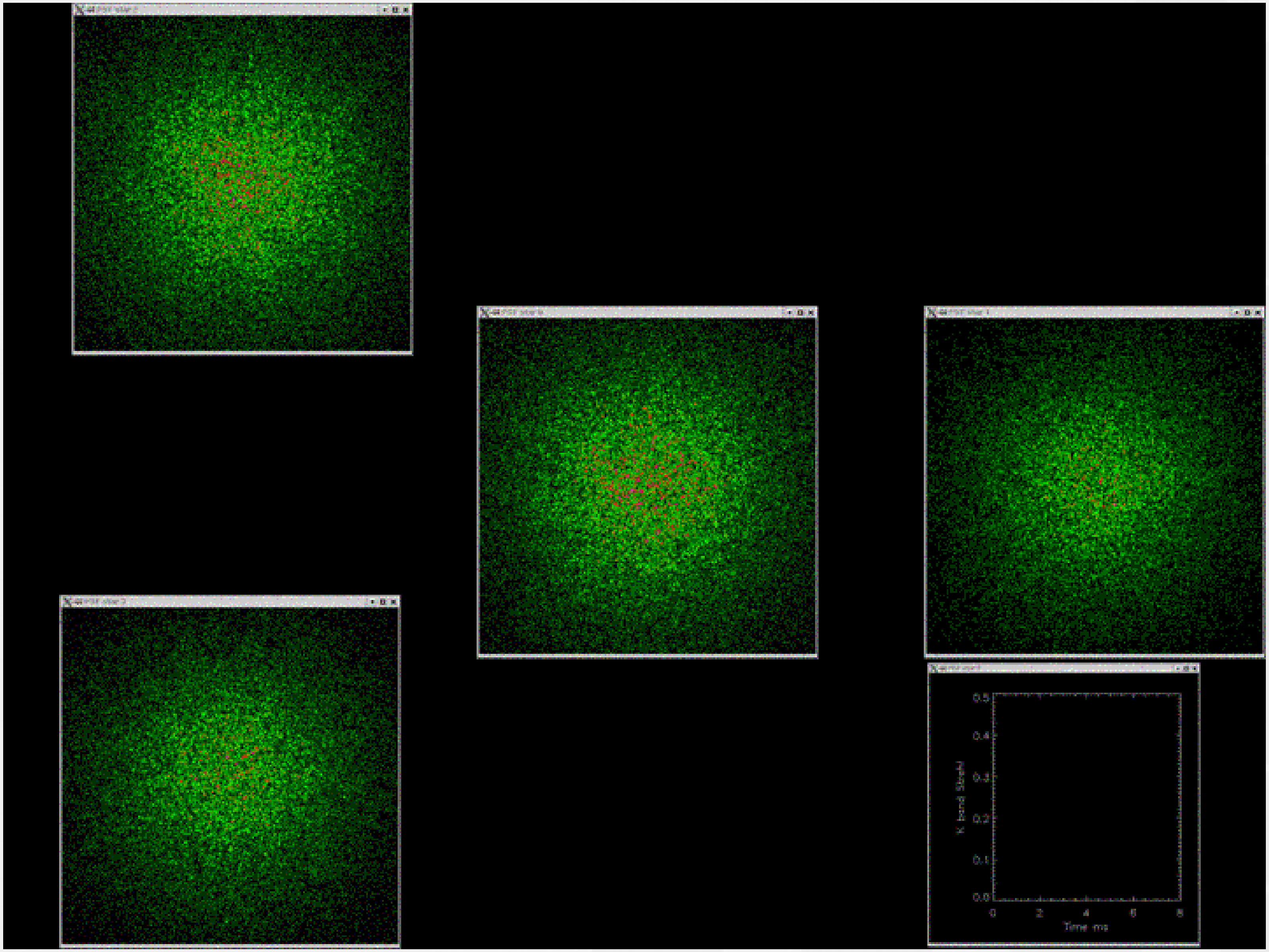
FWHM

37 → 39 mas

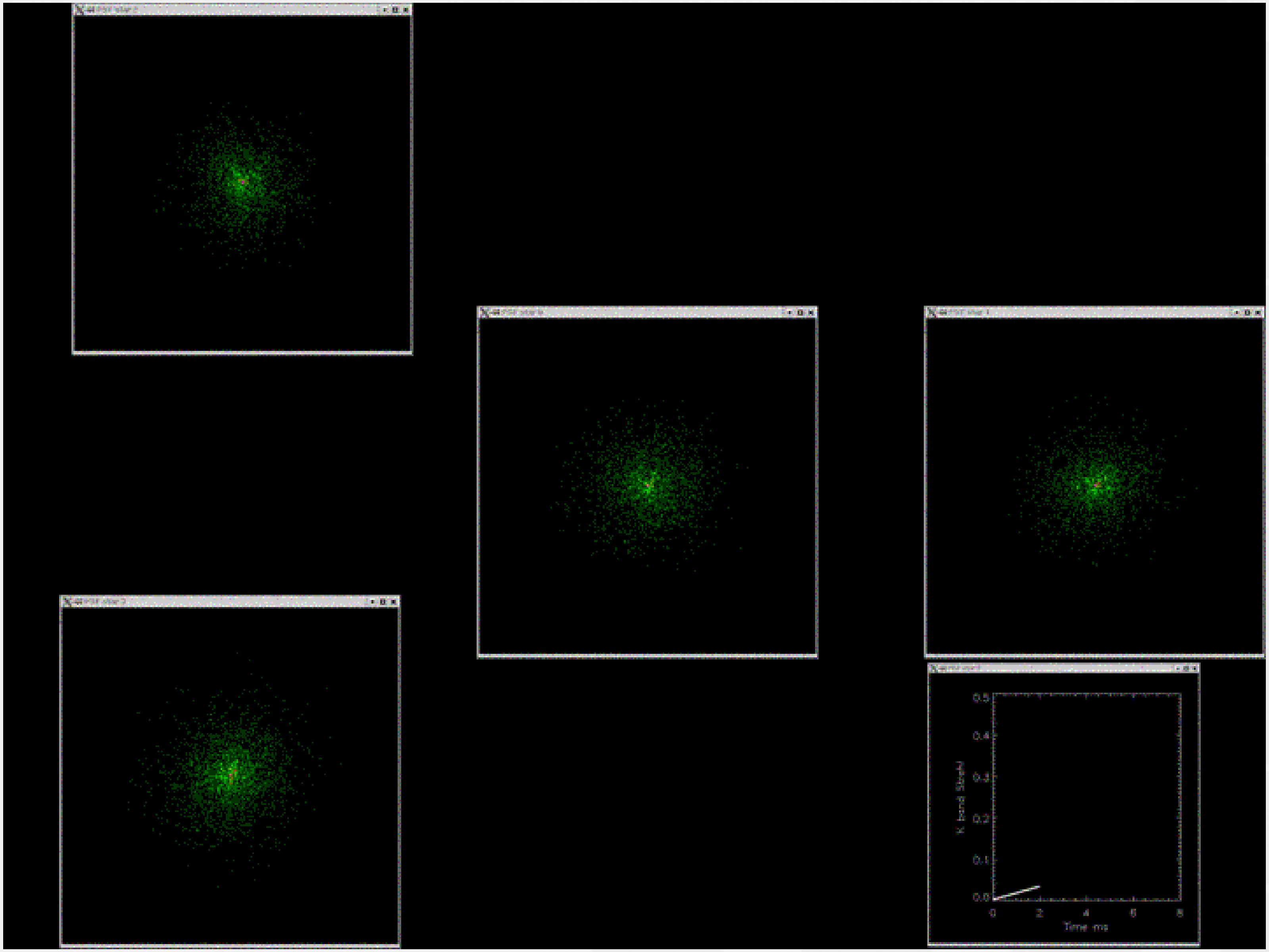


80"

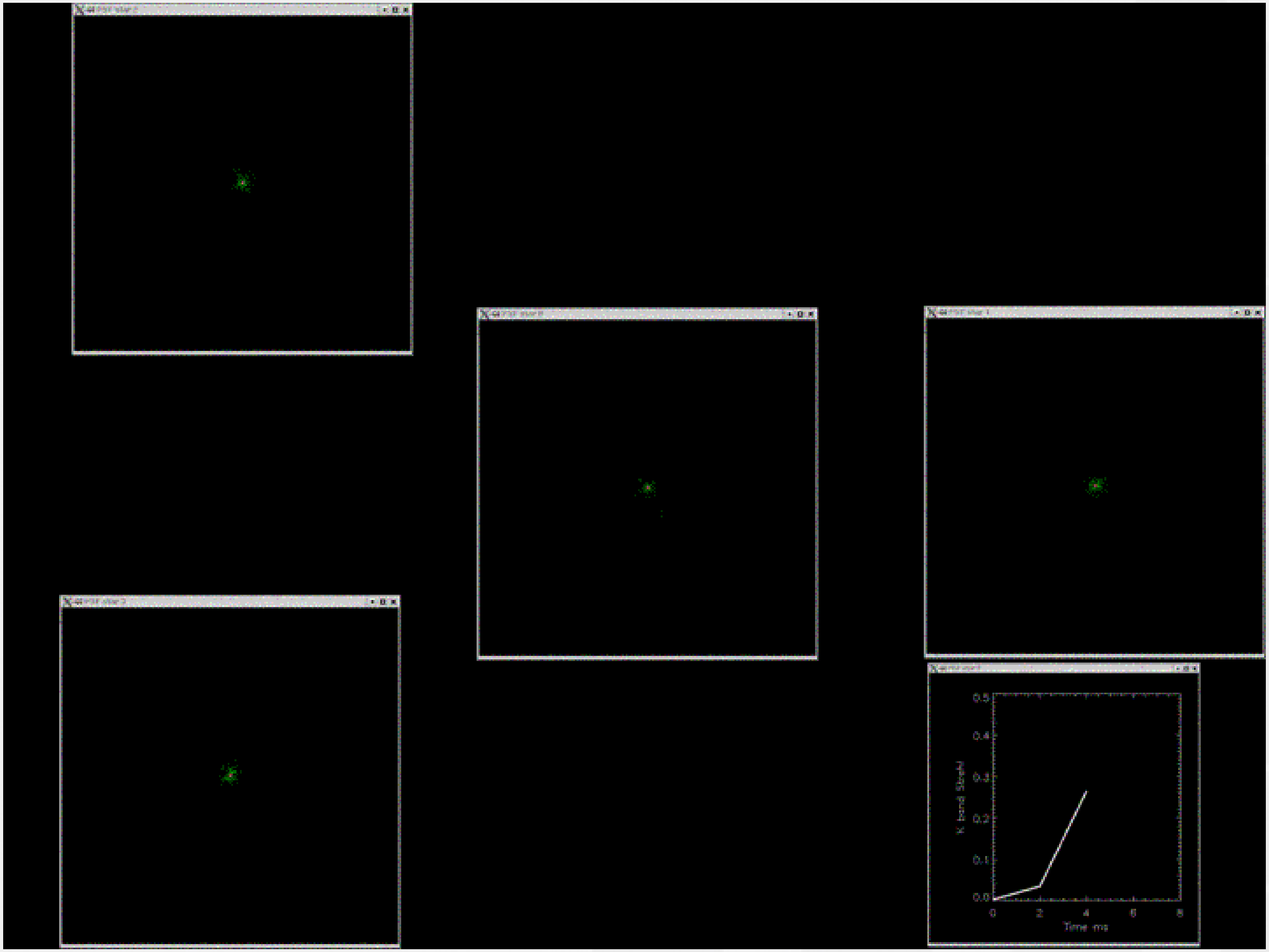
MCAO on E-ELT example



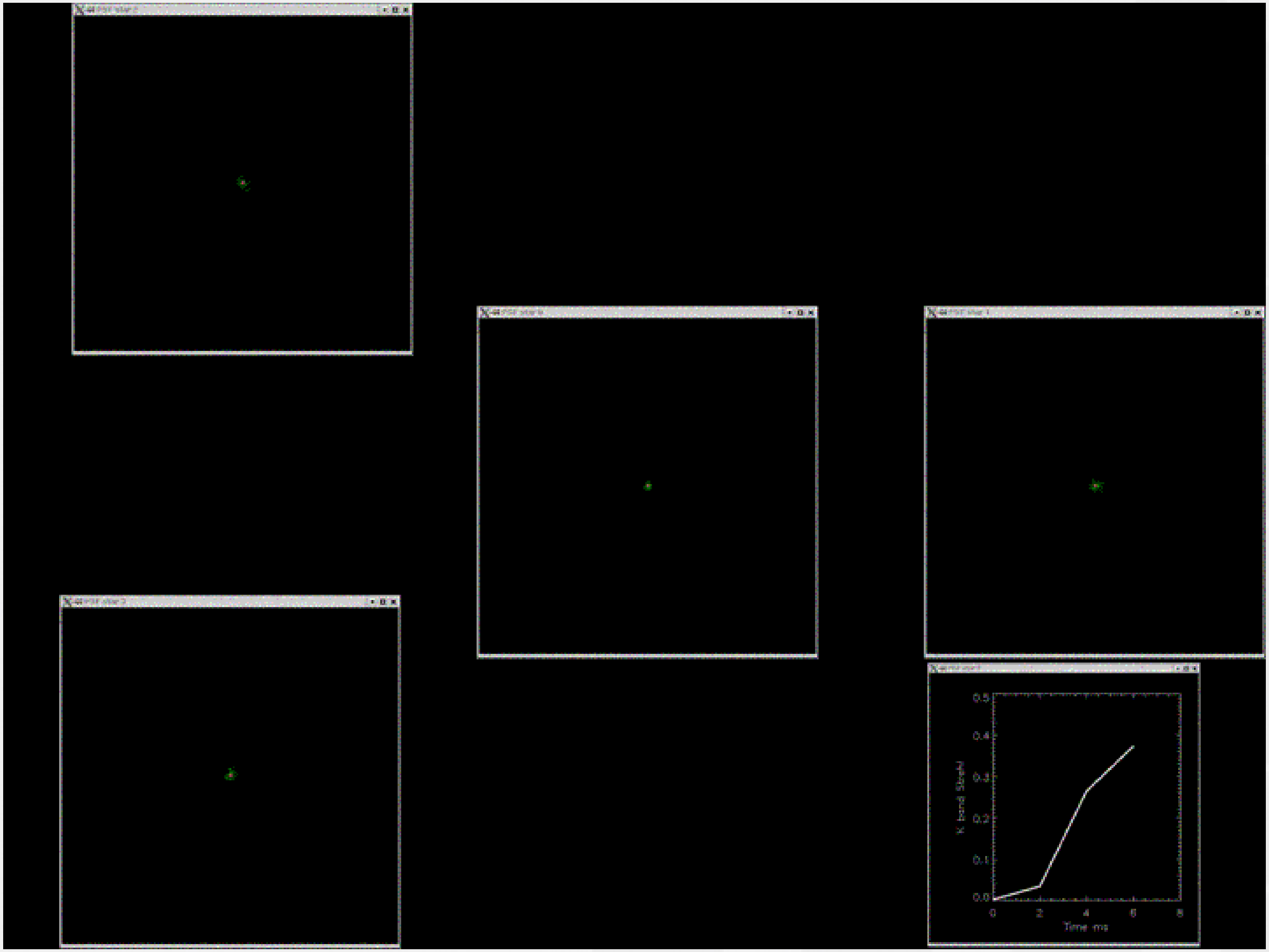
MCAO on E-ELT example



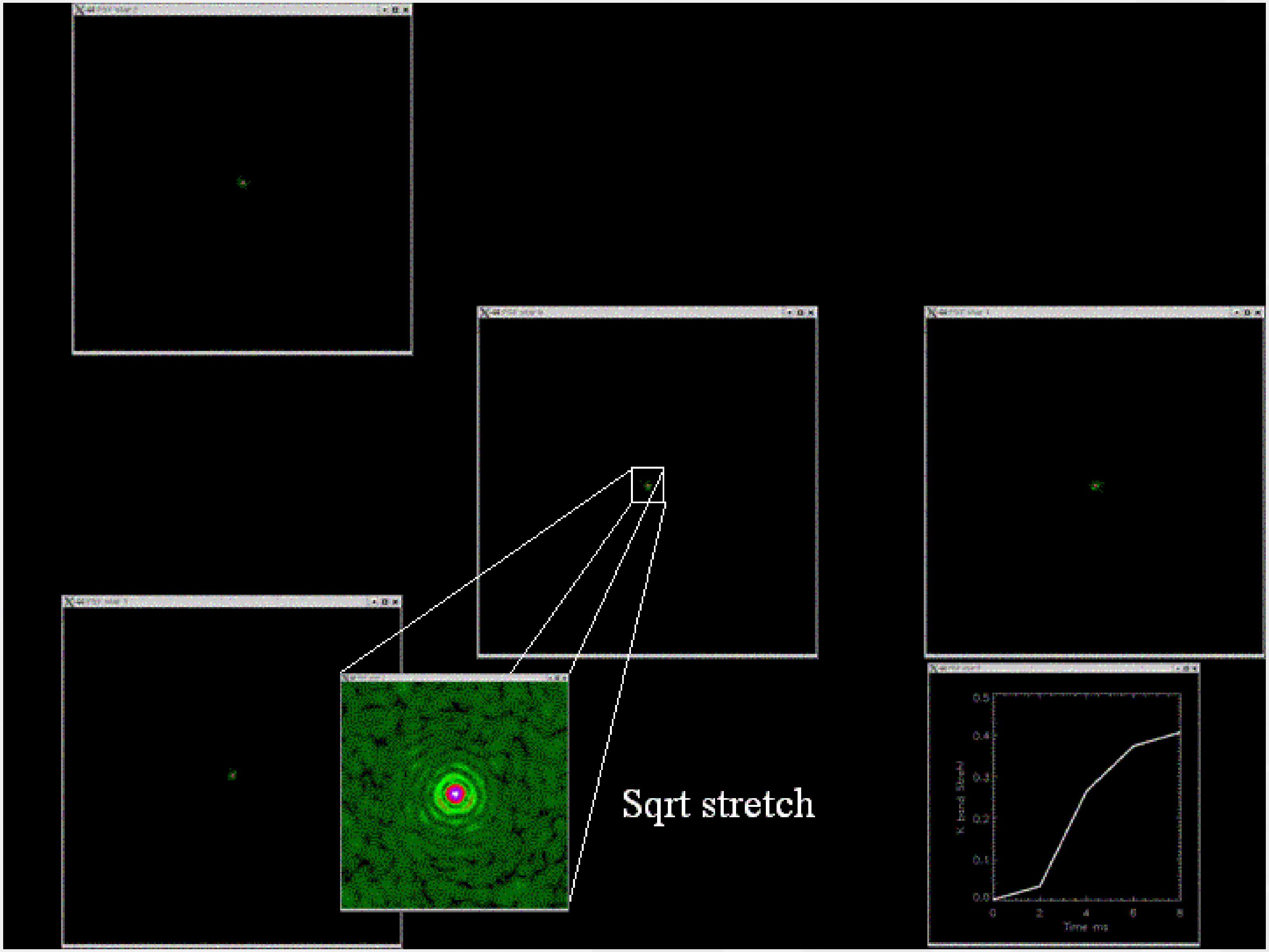
MCAO on E-ELT example



MCAO on E-ELT example



MCAO on E-ELT example

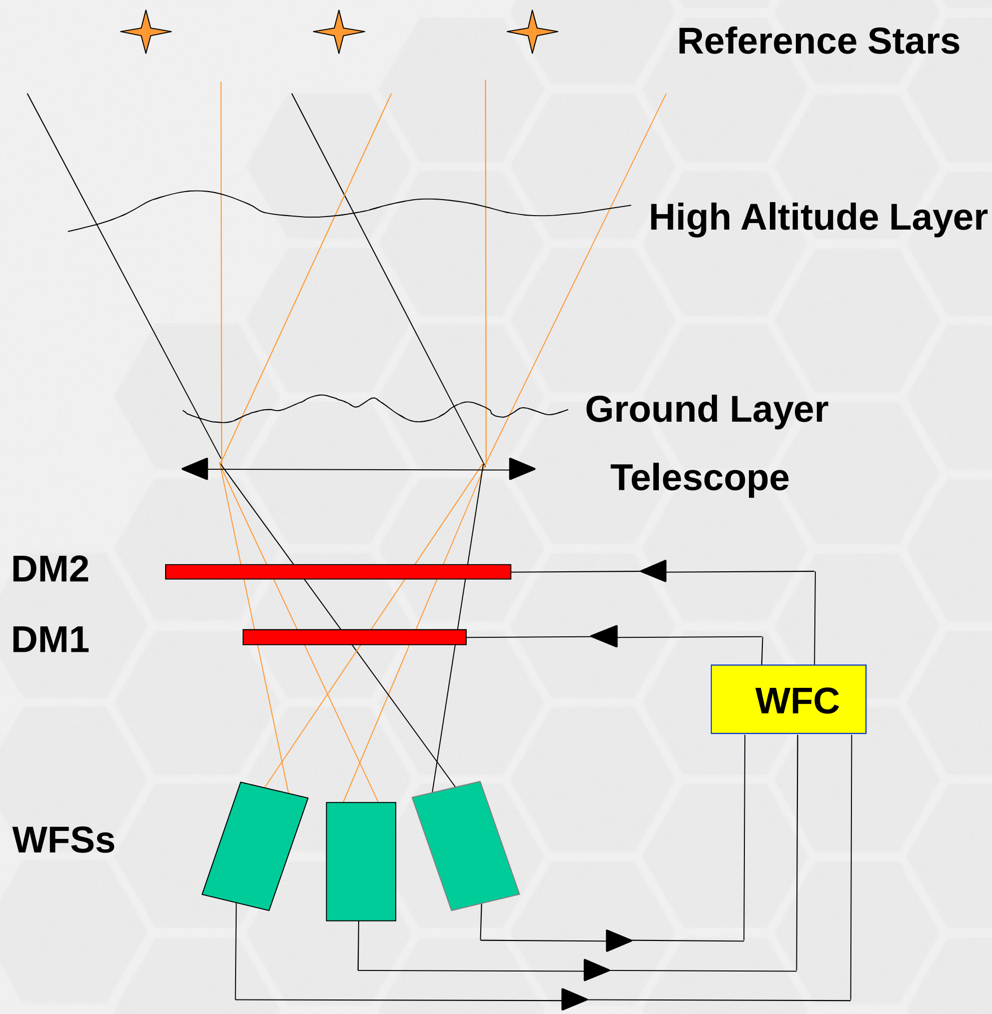


Concepts investigated with MAD

Star Oriented MCAO

- Single Star WFS architecture
- Global Reconstruction
- *n* GS, *n* WFS, *m* DM, 1 RTC

The correction applied at each DM is computed using all the input data. The correction across the FoV can be optimised for specified directions.



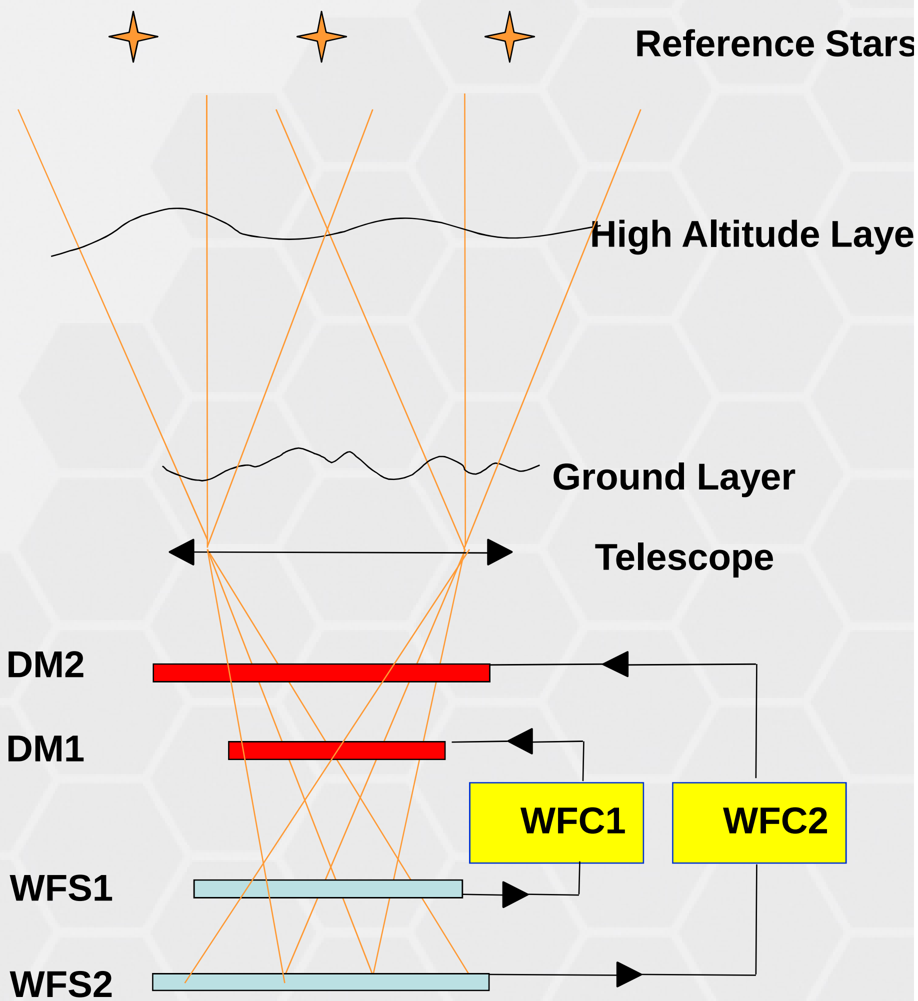
E.Marchetti et al.

Concepts investigated with MAD

Layer Oriented MCAO

- Layer Oriented WFS architecture
- Local Reconstruction
- *x* GS, *n* WFS, *n* DM, *n* RTC

The wavefront is reconstructed at each altitude independently.
Each WFS is optically coupled to all the others.
GS light is co-added for a better SNR.



E.Marchetti et al.

→ More in the talk of R. Ragazzoni

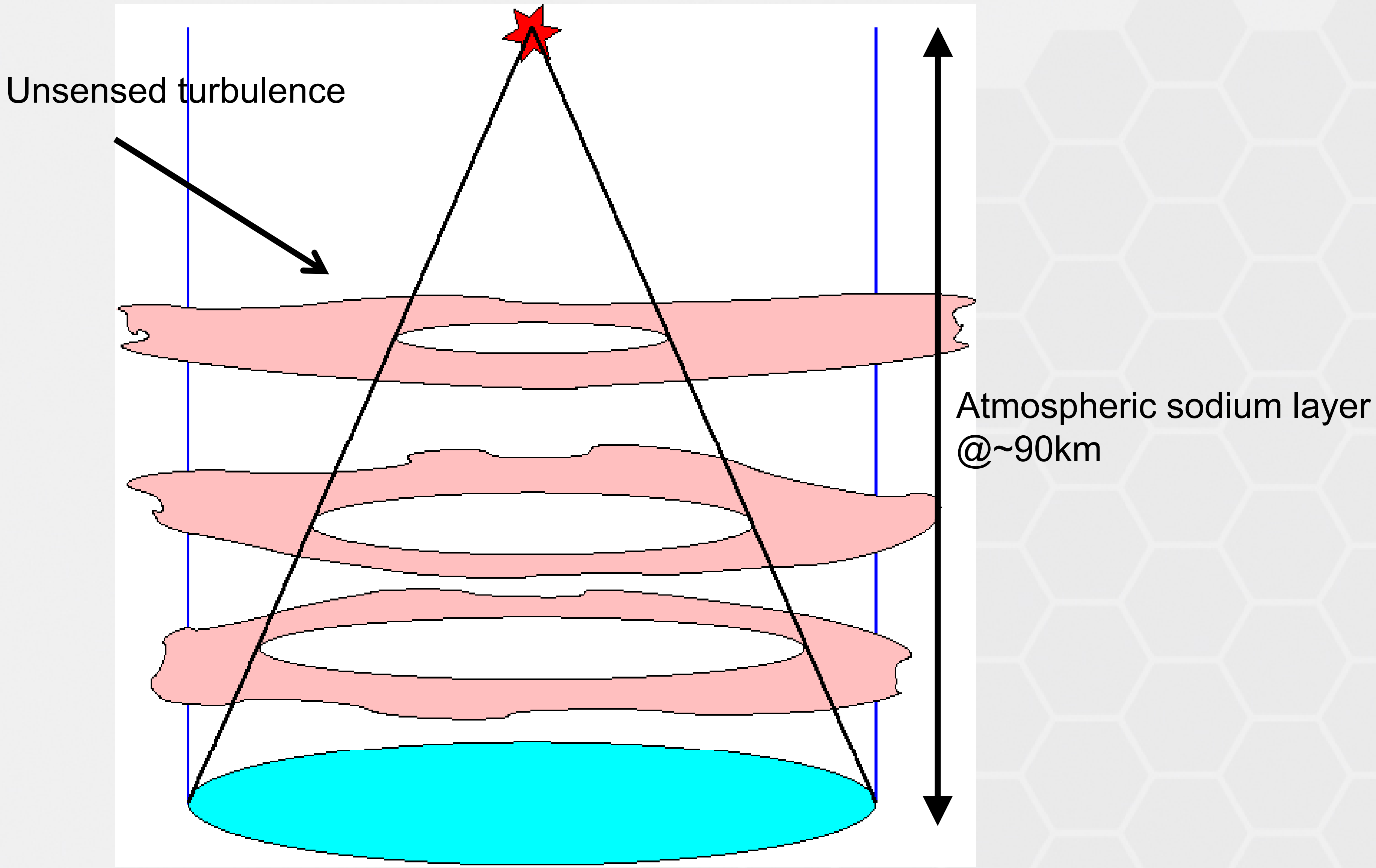
Star Oriented vs. Layer Oriented

- PC vs. Mac discussion ☺
- Star oriented:
  - More easy opto-mechanically
  - Control easier, since signals processed in CPU
  - "Classical" approach, used for E-ELT
- Layer Oriented
  - Better use of NGS photons (optical SO)
  - More stars can be used (8 in MAD vs. 3 in SO)
  - The ultimate sky coverage in NGS/MCAO
- → Results similar on MAD
- → See talk of R. Ragazzoni later

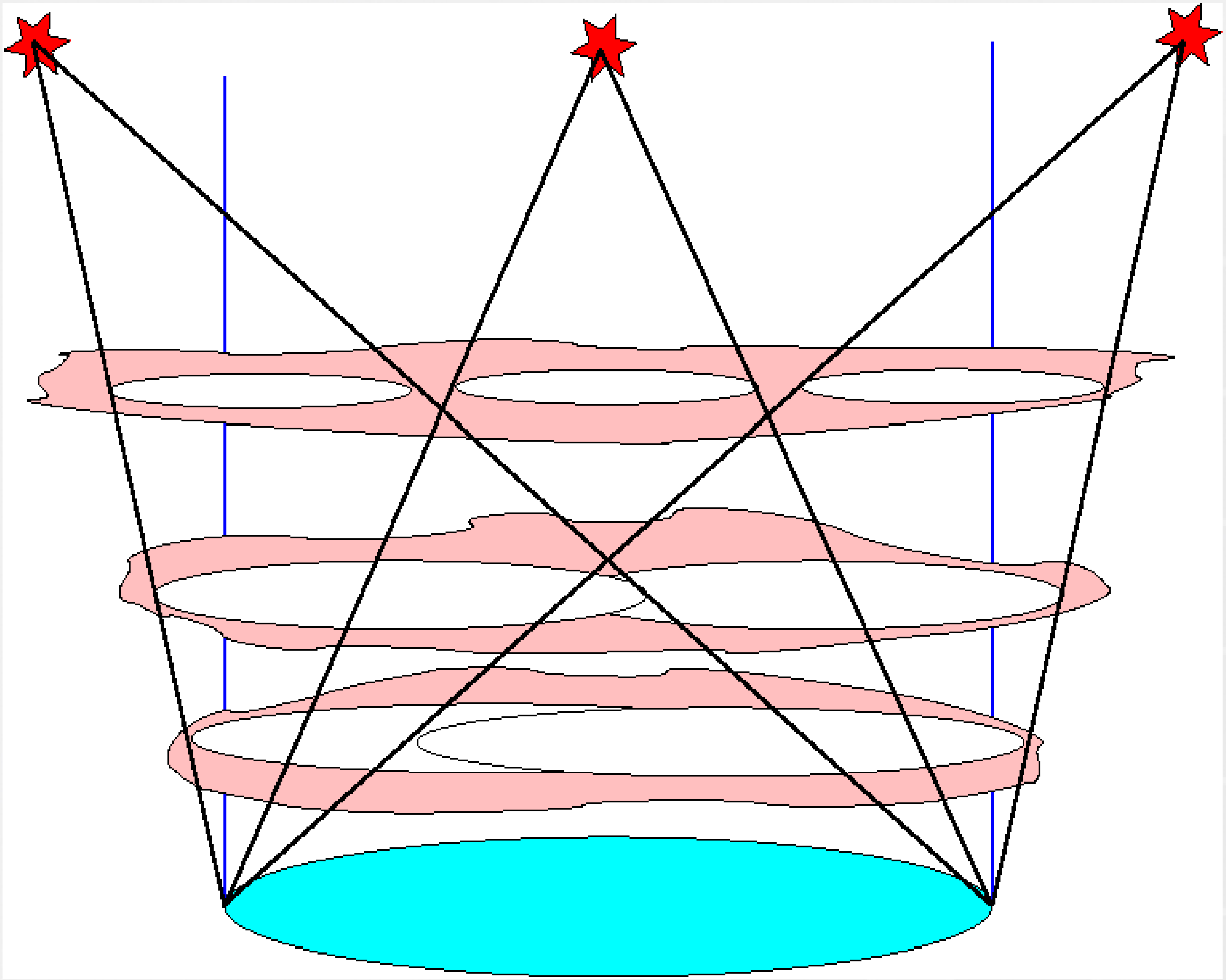
Laser Guide stars

- Provide high sky coverage
  - Guide star is where you want it
- Multiple LGSs are needed
  - Increased FOV
  - Cone effect (see later…)
- Used for AOF, ELT
- “Companions” to any MCAO instrument
  - Only they allow to fully use MCAO potential
- Problems of LGSs
  - TT determination problem
  - Cone effect

AO: cone effect



AO: Increasing the FOV

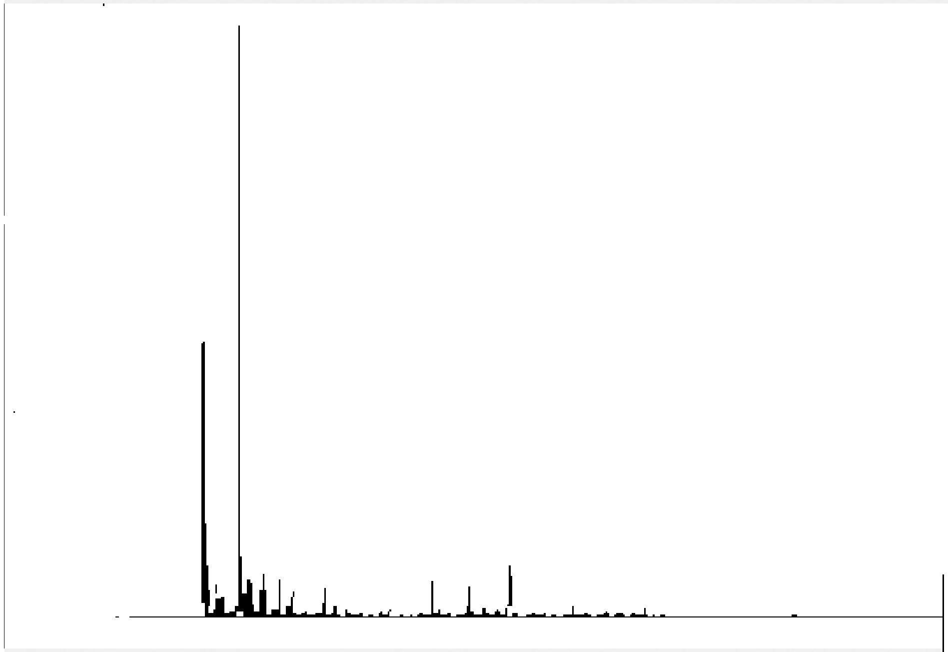


Multi-LGS allows to fight cone effect AND increase FOV

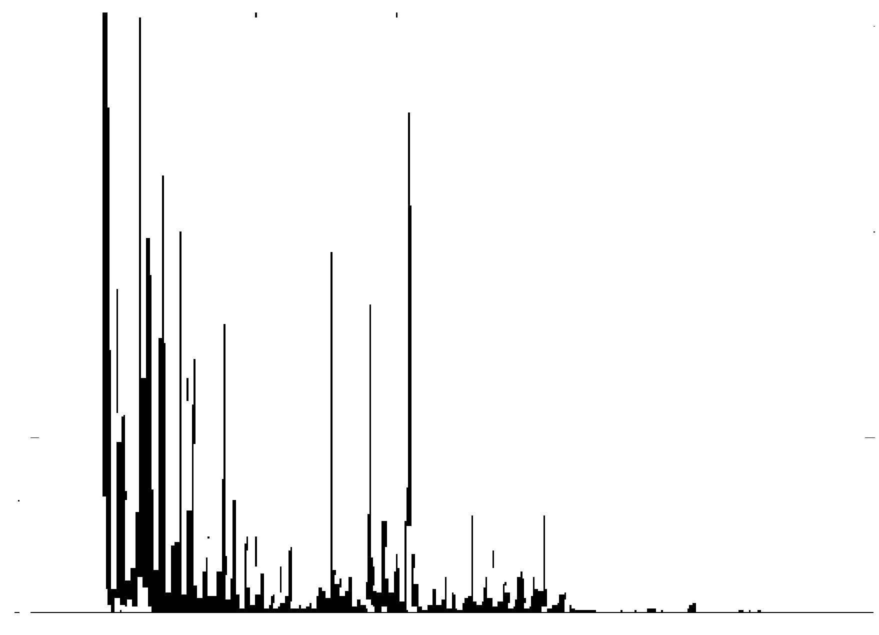
Limitations of MCAO

- Turbulence profile not always “friendly”
  - Introduces residual anisoplanatism & performance variability
- Optomechanical complexity !
  - 2-3 DMs ok (Gemini, ELT)
  - 4-6 LGS ok (VLT, Gemini, ELT)
  - More is probably a stretch at this point
- Number of LGSs
  - Cost & complexity (again !)
- Diminishing return
  - Once main layers are sensed and corrected
- In practice:
  - ~2’ (diameter) maximum in the near IR
  - 0.5 – 1’ (diameter) maximum in visible

C_n^2 profiles



Sometimes a few layers…
Sometimes not !



Conclusions

- MCAO is an AO technique which allows to increase the corrected FOV
  - Multiple guide stars to sense
  - Multiple DMs to correct
- Limits are imposed by:
  - Atmospheric physics (number and strength of layers) → ~2’ Max in IR, less in visible
  - Complexity of the system
    - 4-5 LGSs on VLTs
    - 6-8 LGSs on ELTs
    - 3 DMs