DRM meeting
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AO PSF simulations for the E-ELT

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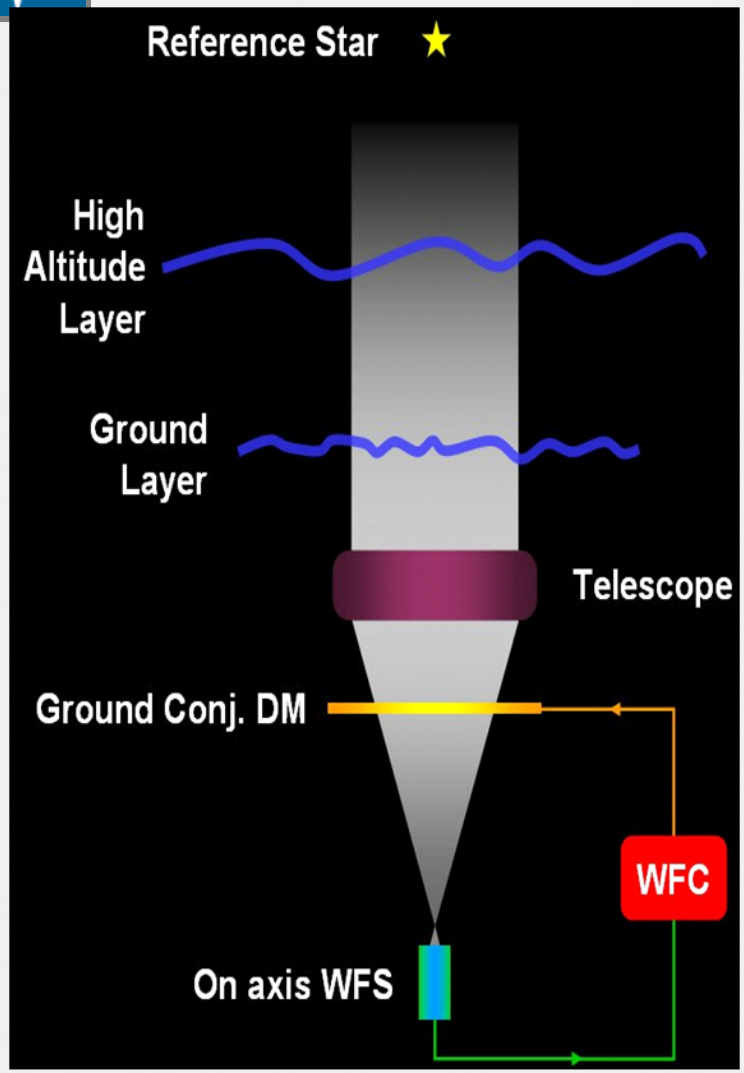
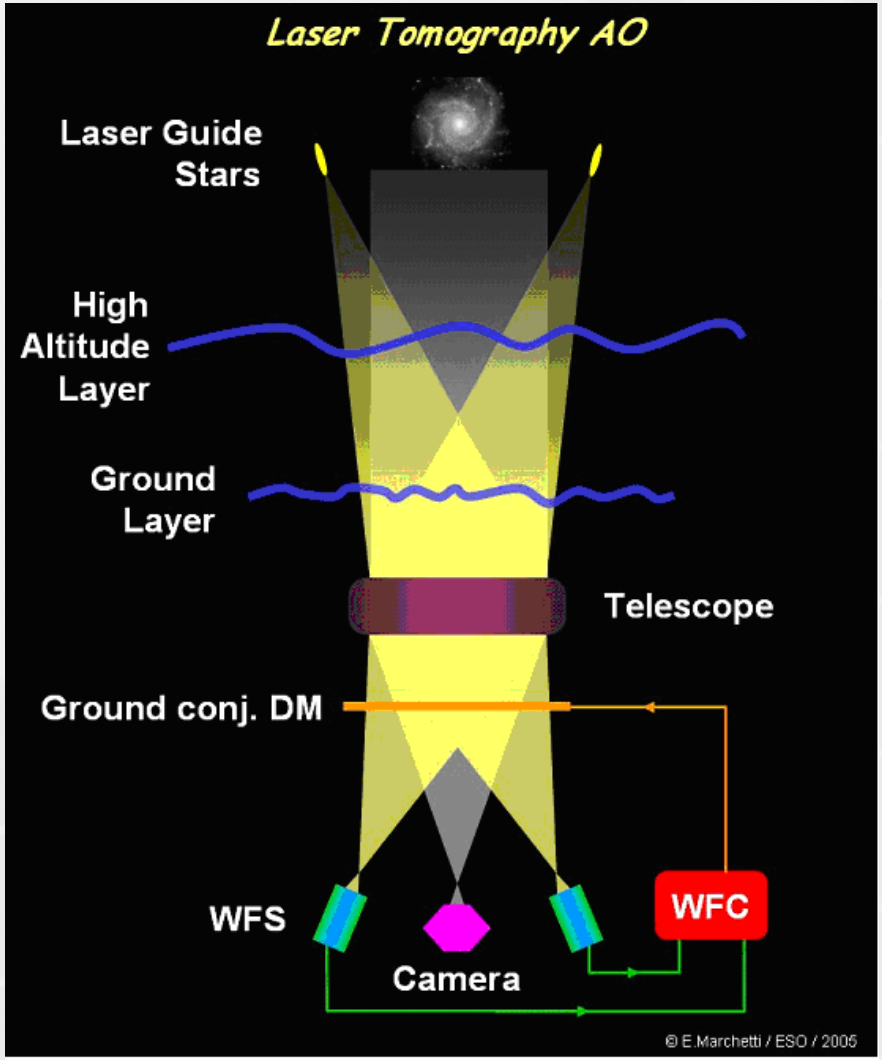
E-ELT AO modes

- Many AO modes will be used on the E-ELT
  - SCAO (commissioning)
  - GLAO (telescope mode) → order of magnitude PSFs available
  - LTAO (instrument) → order of magnitude PSFs available
  - MCAO (instrument)
  - LTAO (instrument)
  - MOAO (instrument)
- Each mode has its own limitations (FOV vs performance trade-off)
- Performance needs to be estimated for each mode
- From the astronomer's point of view, performance = final PSF

Narrow field modes

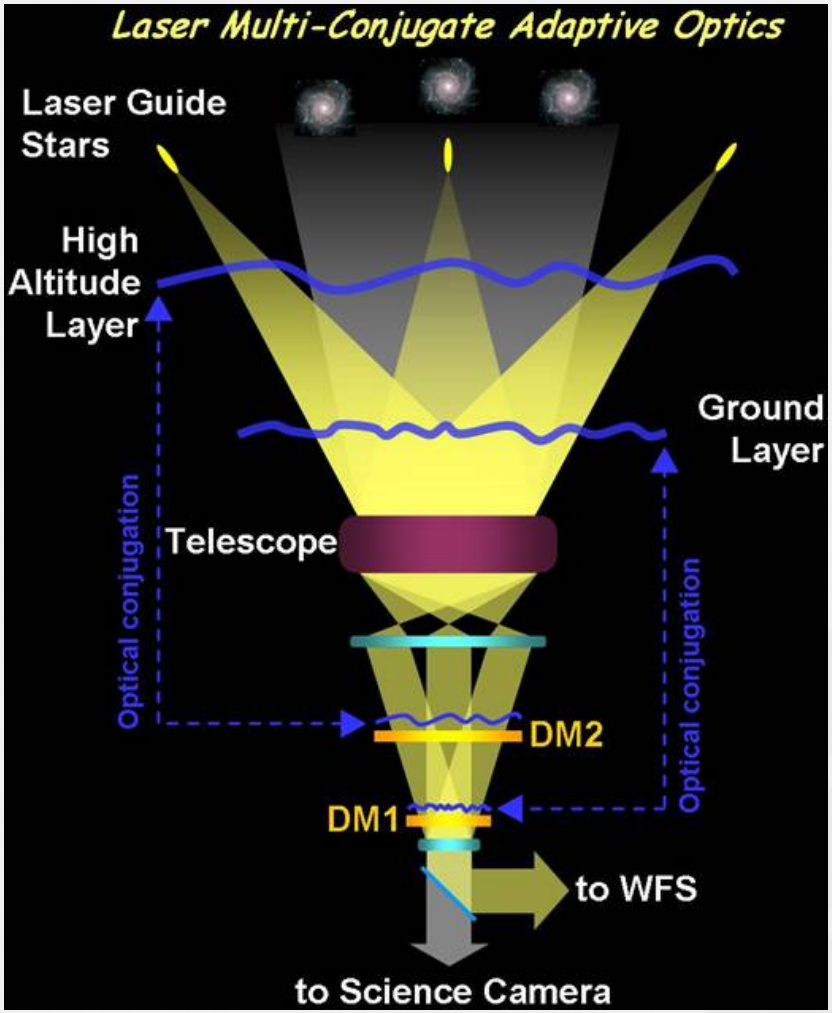


SCAO

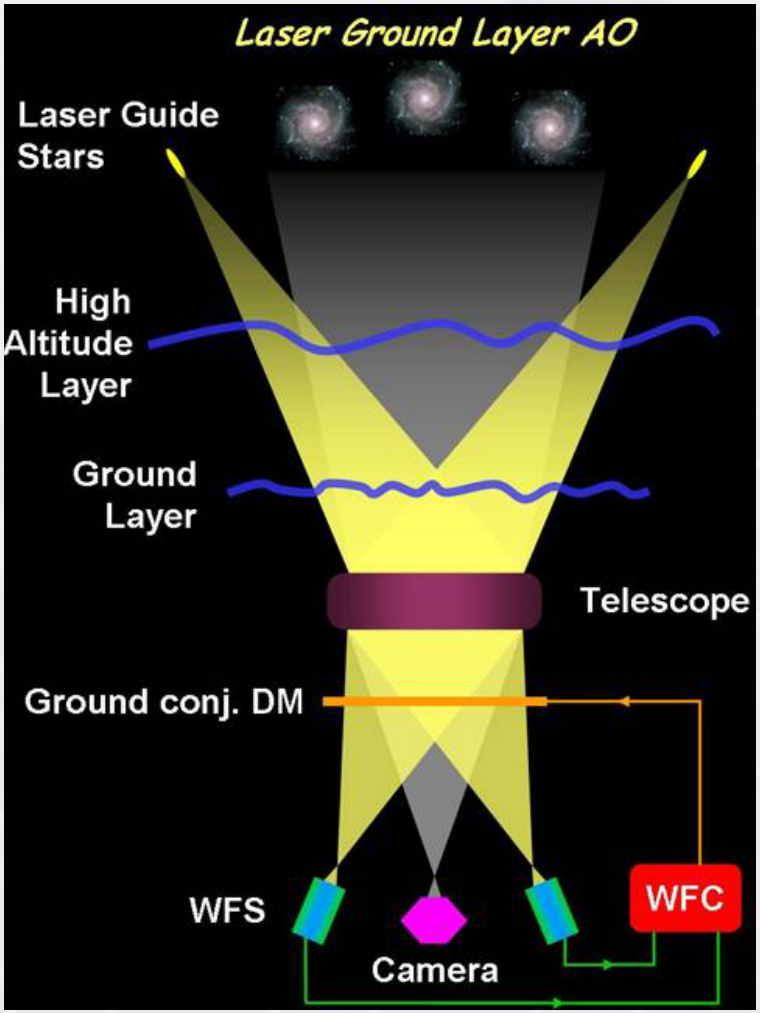


LTAO

Wide field modes



MCAO



GLAO

End to end AO models

- Usually, analytical AO models (a la PAOLA) used for rough system dimensioning
  - Currently, these models are being developed for all the previously mentioned modes
  - Works currently well for SCAO, GLAO (NGS)
  - LGS work is tricky but good progress (PAOLA, ONERA for MCAO)
- For now, we use and end-to-end AO model because it allows all modes to be simulated.
  - Very accurate, many things can be simulated
- BUT very heavy numerically
  - Simulate each AO frame (500Hz – 1kHz frame-rate)
  - “Long” exposures are short (2-4s of real time)
  - Takes a long time to run (~1 day for those 2 seconds)
  - Optimization of system is tedious (because slow & complex)
- Allows study of spatial & wavelength variability
  - But some statistical noise still present

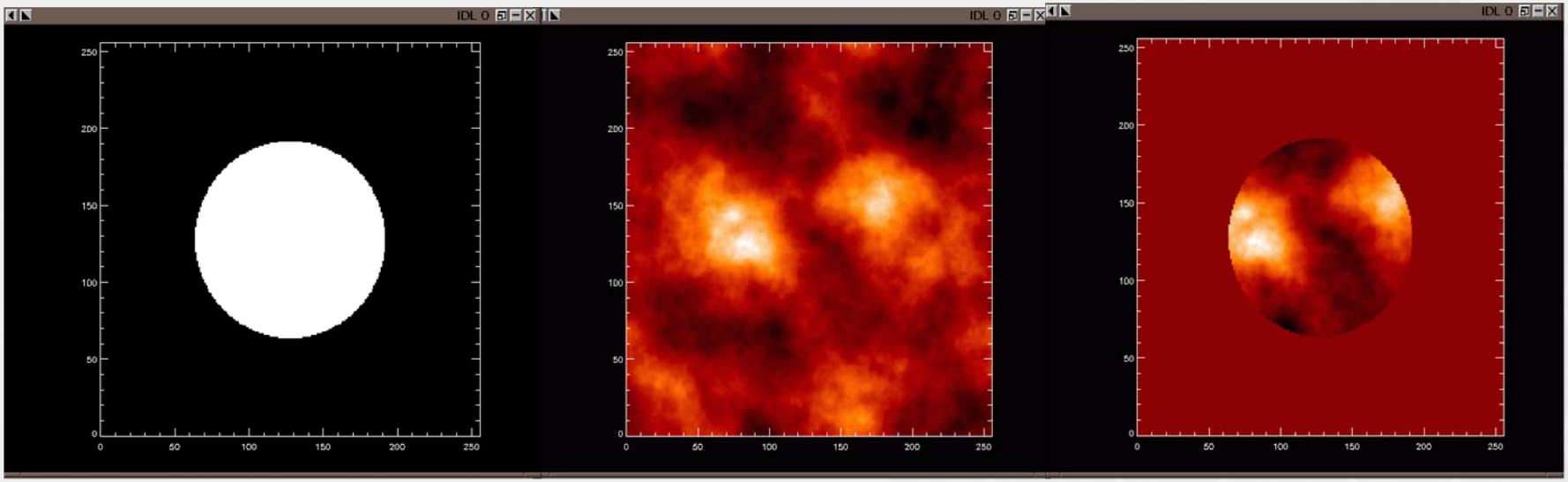
Atmospheric model for current ETC PSFs

Seeing: 0.8'' @ 0.5 um, L0=25m

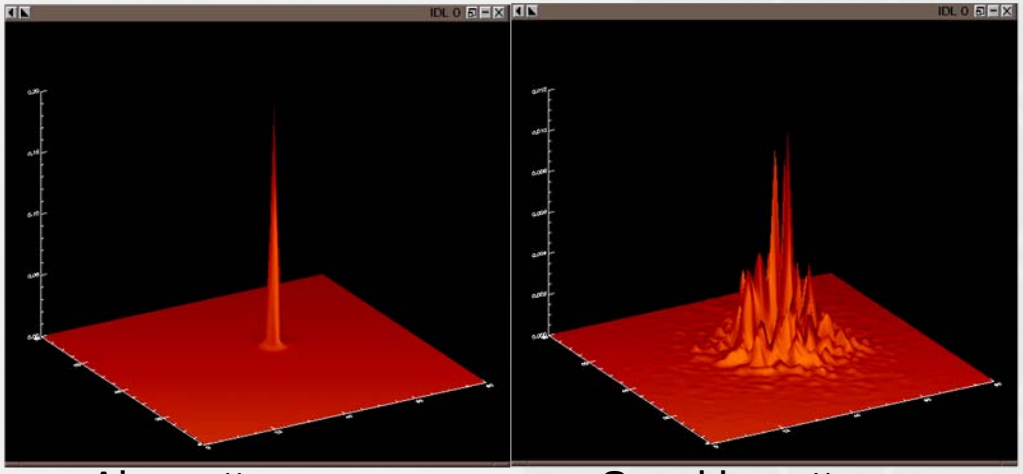
Height [m]	Fraction of Cn2	Wind speed
0	0.335	12.1
600	0.223	8.6
1200	0.112	18.6
2500	0.090	12.4
5000	0.080	8.0
9000	0.052	33.7
11500	0.045	23.2
12800	0.034	22.2
14500	0.019	8.0
18500	0.011	10.0

Note: Ground layer structure not very well known (even in Paranal !)
→ changes likely (GLAO performance most affected)

Simulating a PSF



FFT

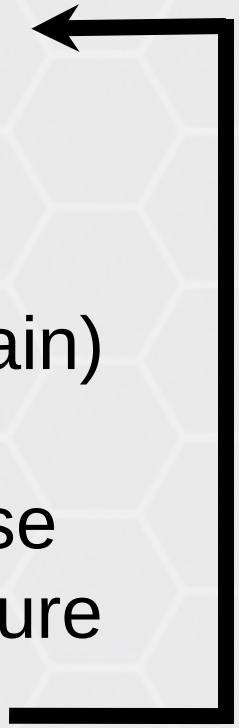


Airy pattern
(no phase screen)

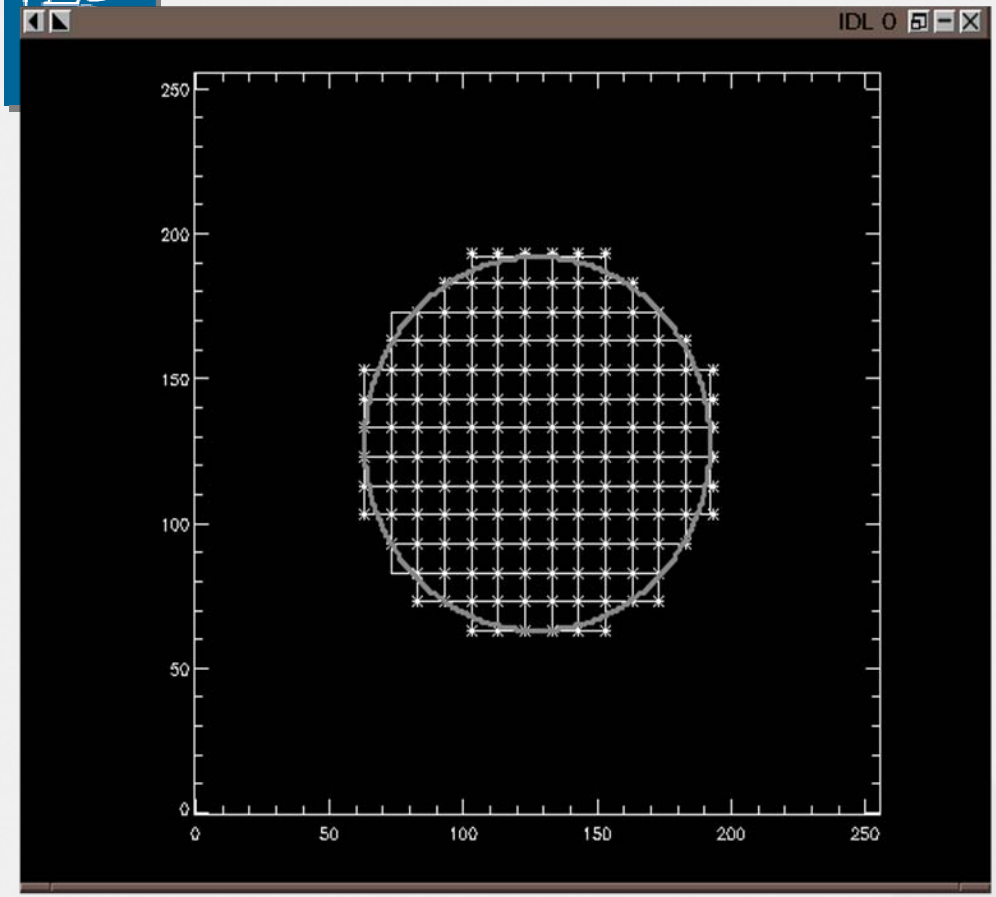
Speckle pattern
(with phase screen)

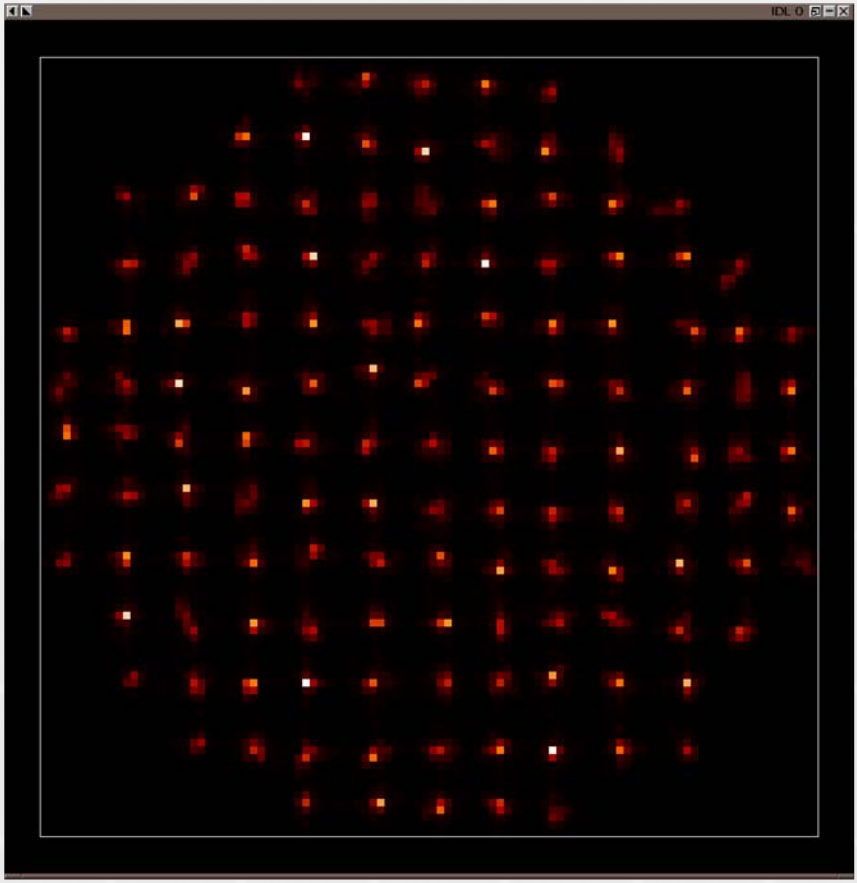
Closed loop / temporal evolution

- Temporal behavior:
- Shift phase screens
- Propagate screens
- New WFS measurement
- IM # measurements → c
- New DM commands: $c_n = c_{n-1} + g\ c$ (g:gain)
- New DM shape
- Atm. phase - DM shape = Residual phase
- Long exposure PSF = Sum(Short exposure corrected PSF)



Wavefront sensor



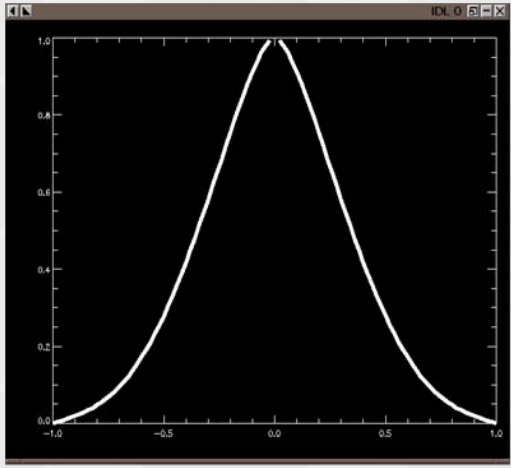


- Cut phase screen into sub-apertures
- FFT -> SH PSF = SH speckles are taken into account

- Add noise (photon, RON, sky, dark...)
- Threshold
- Compute centroids
- Output measurement vector

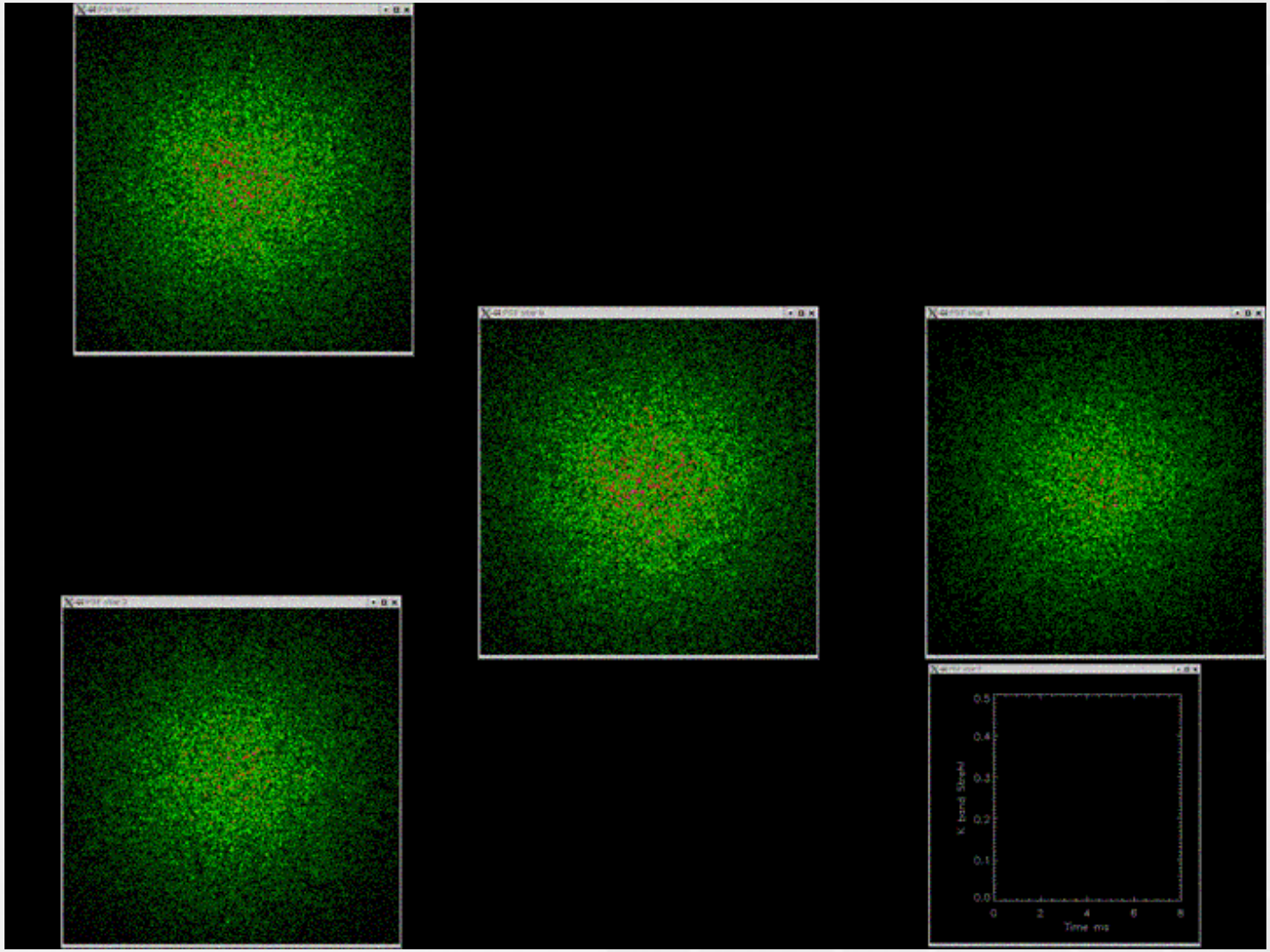
Deformable mirror

- Place actuators in phase-screen-pixel space. Any geometry is possible:
- Square pattern (Piezo DM)
- Hexagonal (Piezo DM)
- Circular (Bimorph, Adapt. Sec.)



- Select influence function:
  - Several types are available, depends on DM
- When an actuator is pushed, the DM shape is given by the IF
- Sum of IFs gives total DM shape
- DM shape is a “special” phase screen (with ~ - atmosphere)

MCAO on E-ELT example



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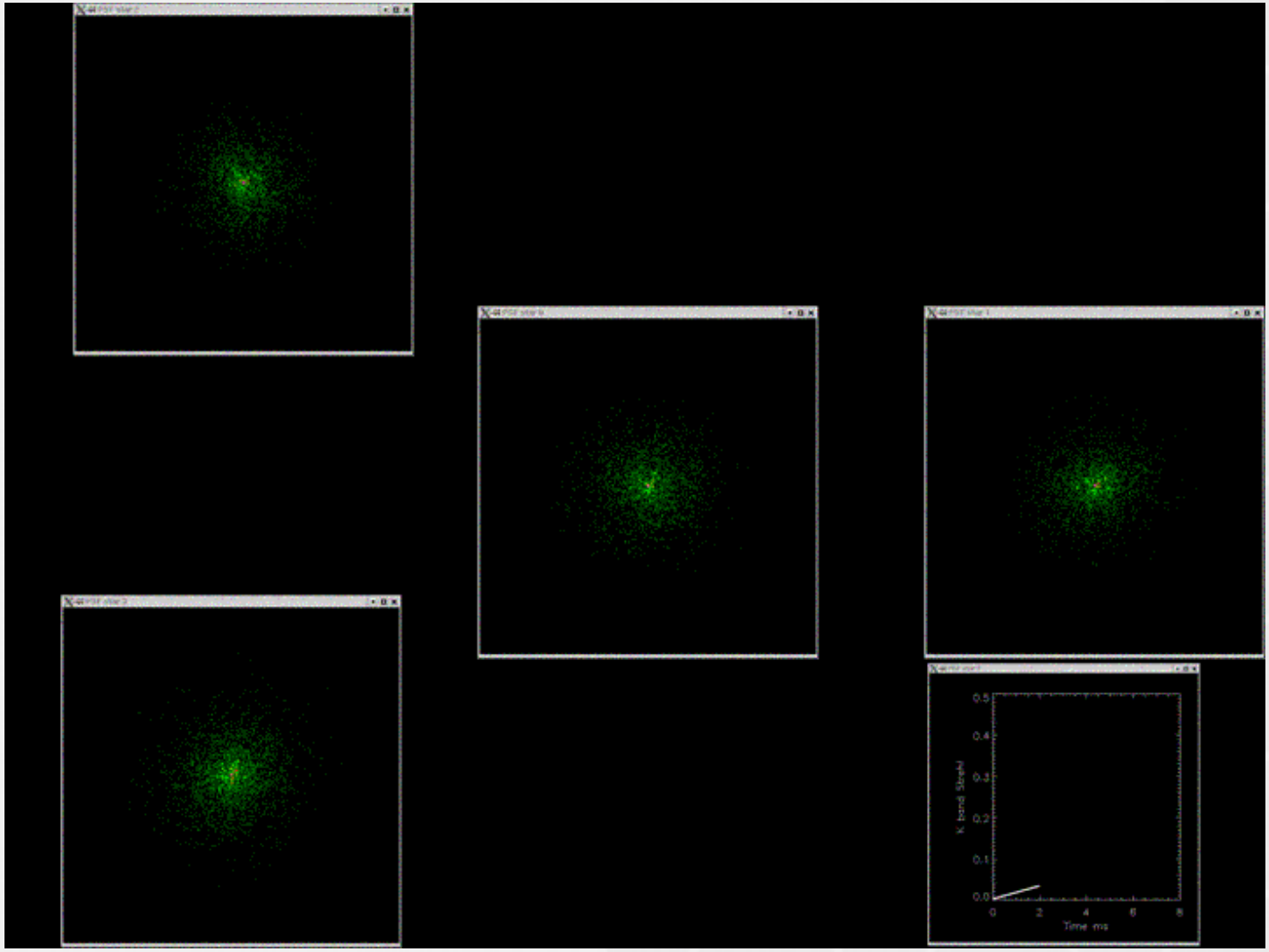
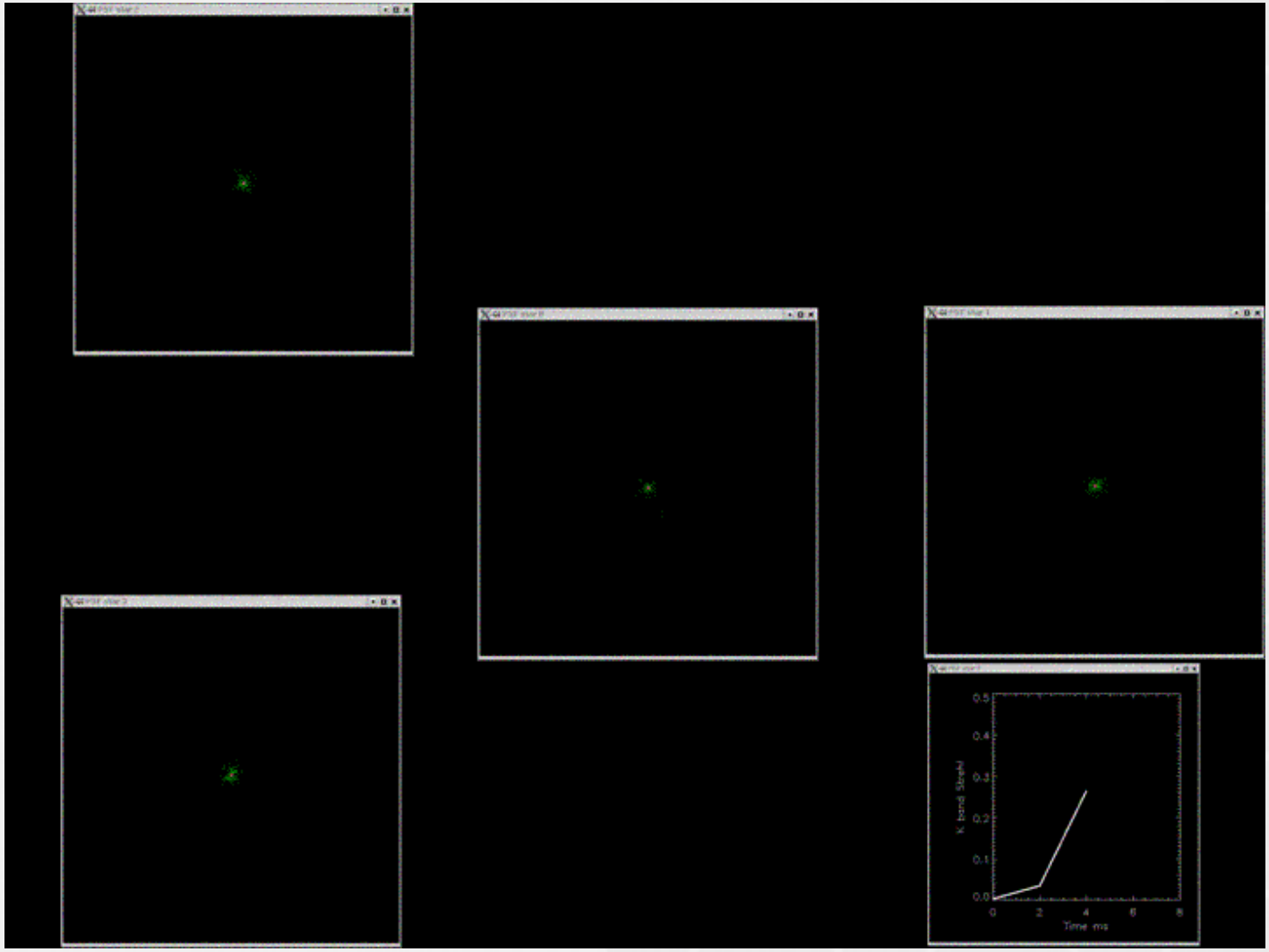


MCAO on E-ELT example



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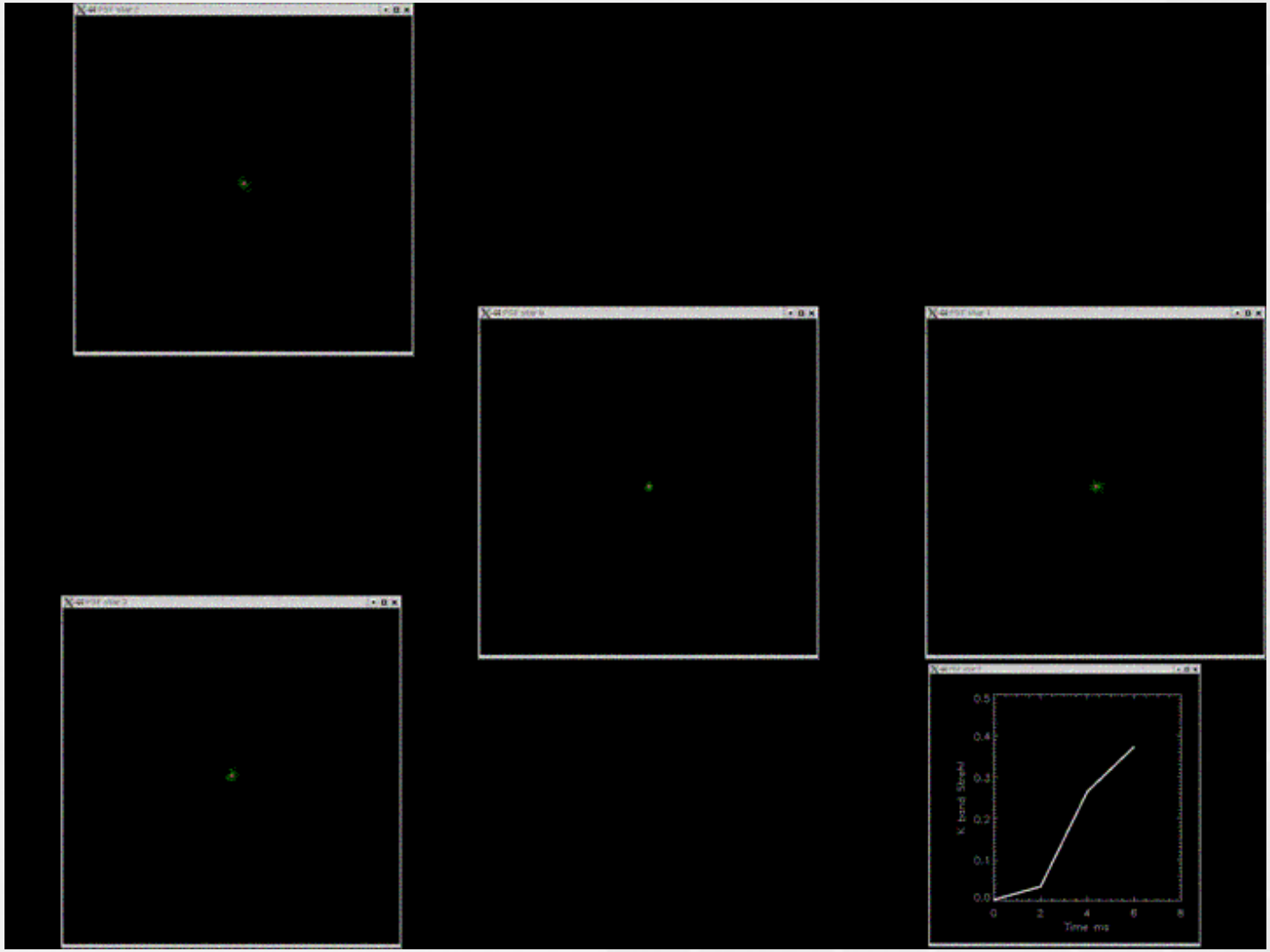

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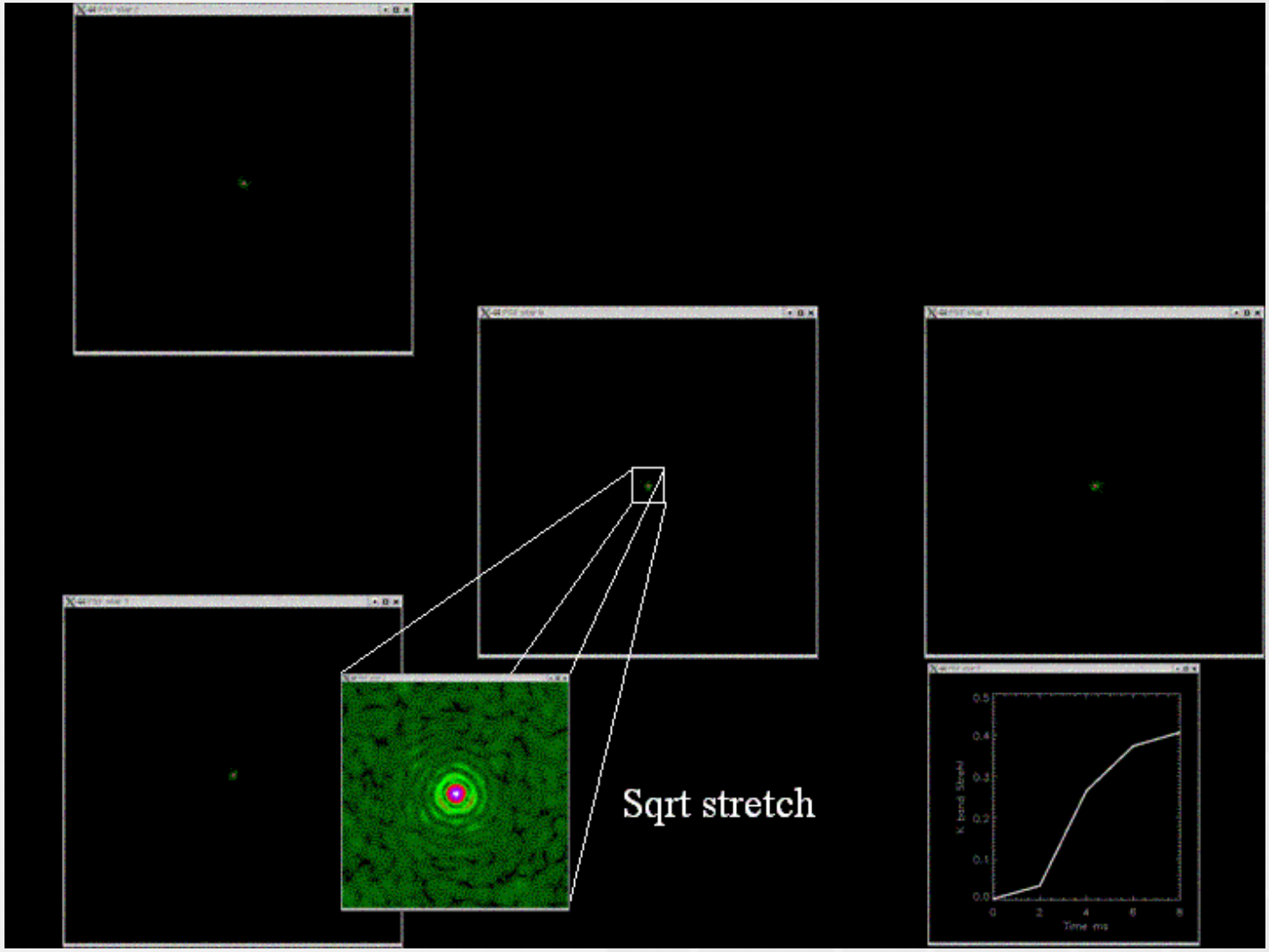
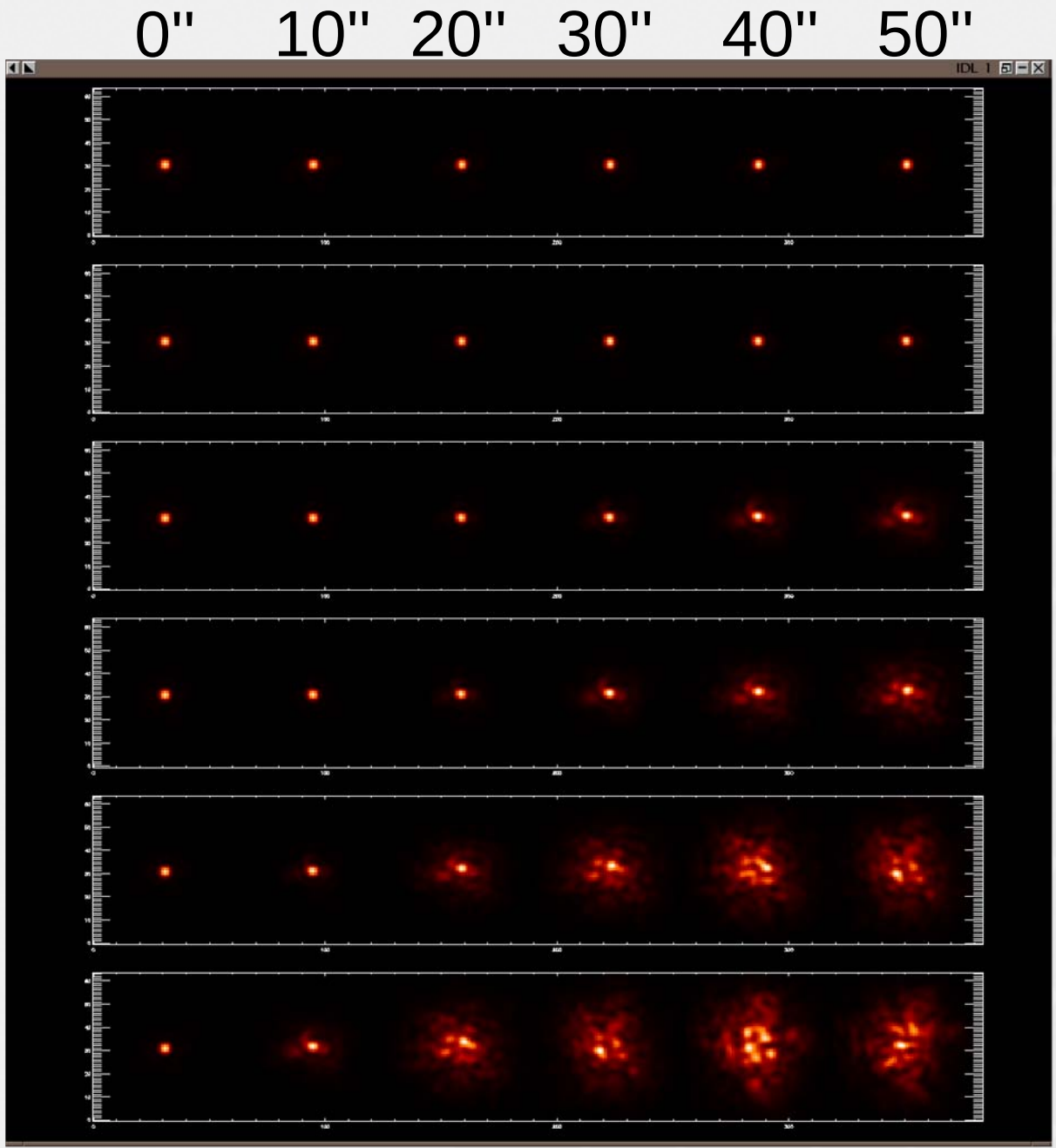


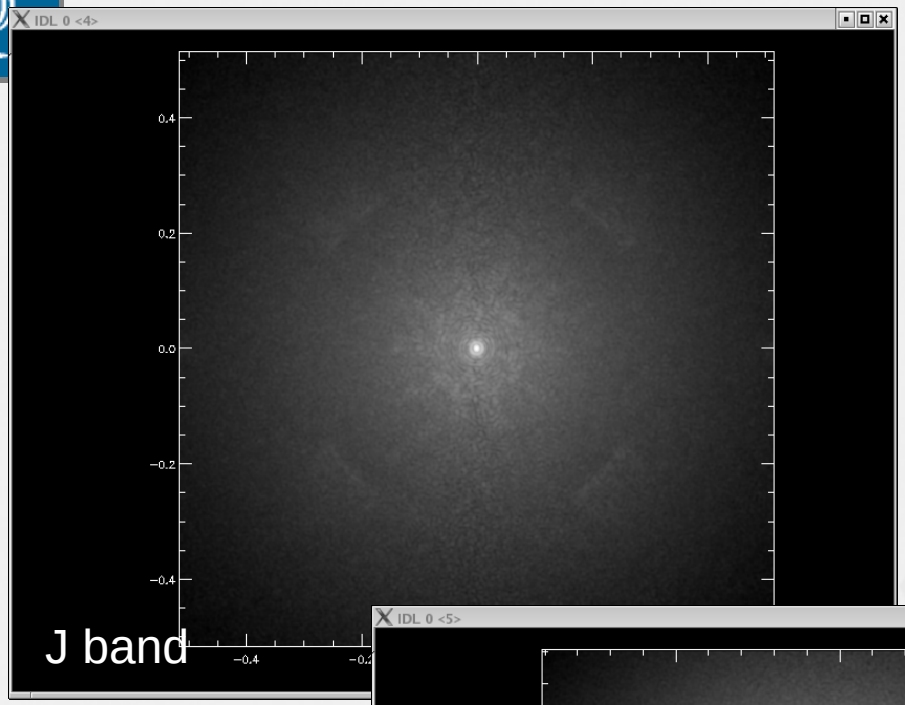
Anisoplanatism @ 1.25 um

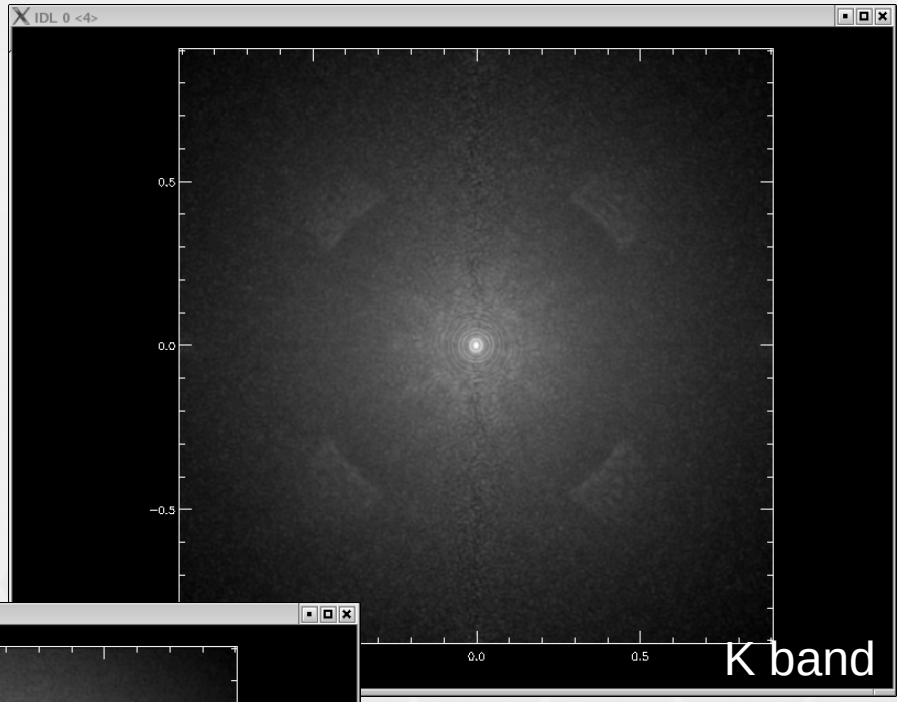


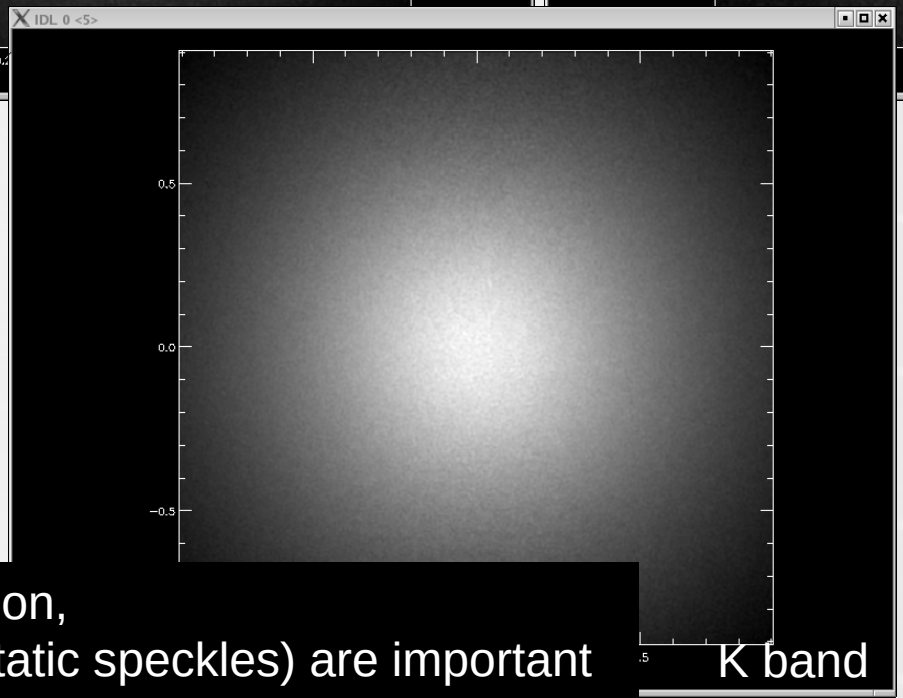
1 layers moving in height

AO PSF properties

Log stretch







Residual speckle structure well visible

The better the correction,
the less the halo (-> static speckles) are important

AO PSF properties

- Simulation “long exposure” is astronomical short exposure
  - 2-4s of real time simulated (a few thousand AO iter.)
  - Residual speckles still present → can bias astronomical simulation
    Speckles are diffraction limited “spots”.
- How to simulate really long exposure PSFs ?
  - Analytical fit (cf. J. Liske).
    Pro: conceptually simple. PSFs become just coefficients of fitting function
    Con: where to stop the fit ?
  - Radial average
    Pro: simple
    Con: lose possible asymmetries
  - Use analytical AO simulation (a la PAOLA), to
    - ⇨ Do the full simulation (if mode supported) OR
    - ⇨ Fit the end-to-end simulation data (will be done for Muse)
    - ⇨ Can scale these results to end-to-end (more accurate) results

Simplifying assumptions

- Telescope not (yet) fully modeled
  - M4 conjugated to ground (should be +~400m) → GLAO affected
  - No segmentation (being studied separately) → Diff lim modes
  - No spiders (being studied separately)→ Diff lim modes
  - No windshake, […]
- Not all AO effects taken into account
  - LGS spot elongation assumed to be perfectly corrected
  - High flux on all stars (NGS / LGS)
  - […]
- In general, error budgets are not yet included (will reduce performance, significantly at least in the visible).
- LTAO studies by consortium
  - ETC PSF are “order of magnitude” simulations
- MCAO, MOAO studies by consortium
  - Simulations will be refined and adapted to instrument
- (SCAO) GLAO study by ESO
  - Parameters will change, due to improved telescope &atmospheric models

Conclusions

- Simulation methods more precisely described in Le Louarn et al. 2005. (see PSF web site)
- AO simulations are all work in progress
  - More effects are being added (until we are on the sky….)
  - Environmental conditions will be refined
  - Performance usually goes down as simul precision goes up
- PSFs giving order of magnitude performance are available for GLAO / LTAO.
- Updated PSFs will be calculated by consortia & ESO
  - These PSFs will eventually replace the first order PSF estimates.
  - For LTAO, MCAO, MOAO, EPICS → Consortia
  - SCAO, GLAO → ESO
- Important to understand how science cases are affected by changes in AO performance (be it because simulations evolve, or environment changes)
  - How much science do you lose, if Strehl is reduced by X ?