Atmospheric constraints for AO/MCAO

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ESO

AO simulations @ ESO

- For the VLT
  - MAD: MCAO system, 2 DMs
    Star / Layer oriented WFSs (3-8NGSs)
  - MUSE: Ground layer correction in the visible for deep field spectroscopy.
- For OWL
  - "NAOS"-like: medium Strehl at K
  - Planet finder: High Strehl at (K,L,M ?)
  - "MAD"-like: larger diffraction limited FOV
  - Ground-layer: low correction over large FOV

AO/MCAO

- Atmospheric data is required for
  - Simulations & design:
    - need to accurately model system performance
    - Need good statistics to find representative & optimal parameters (DM conjugation height,...)
    - Anisoplanatism/MCAO: Cn2 profile (7-10 layers) are required
    - Temporal sampling: wind profile in 7-10 layers
    - System size: r0, tau0, theta0
  - Reconstructors:
    - a priori knowledge of the atmosphere to regularize inverse problem
    - Typically a "few" points of the Cn2

Regularization example

- Can use SVD or modal control (Zernikes)
- Some methods do not take account of Noise or Kolmogorov phase fluctations.
- Maximum a posteriori (MAP) information (e.g. Roggemann et al., Fusco et al. 2000):

$$\vec{c} = (M^t C_n^{-1} M + C_{kol}^{-1})^{-1} M^t C_n^{-1} \cdot \vec{b}$$

C_n : noise covariance matrix (photon noise + RON)

C_{kol}: Kolmogorov phase covariance matrix for N_DMs

- This scheme requires N_DMs r0 estimates Other schemes require more precise Cn2

Examples

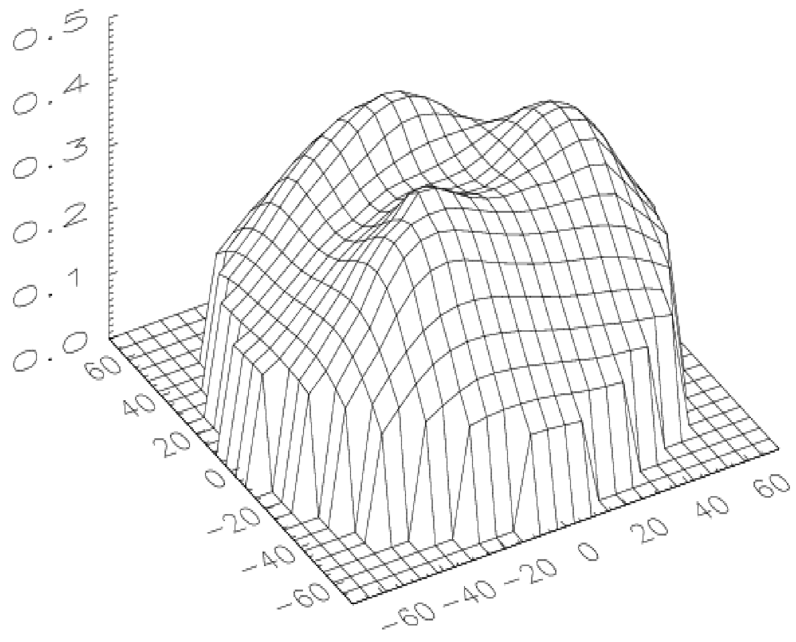
- Here are some examples on which atmospheric parameters have an impact
- Simulations have heavily relied on available data.
  - MCAO
  - MUSE
  - OWL

MAD / MCAO

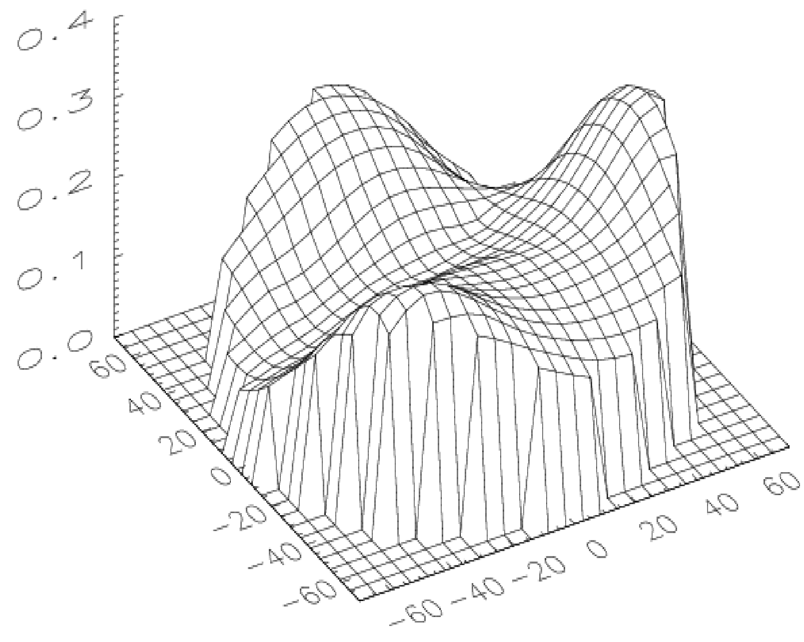
- Defined an atmospheric model by fitting balloon data with a 7 layer model
- BUT: Paranal has changed:
  - Scale a few layers contribution to get currently measured r0, theta0
- Generate phase screens with this 7 layer model
- Why 7 layers ?
  - Because 7 >> 2-3 DMs !

MAD simulation results

1' GS constellation



2' GS constellation



"Hole" in the middle is mostly due to the turbulent layers between deformable mirrors

→ Cn2 info is needed to model MCAO system !

Top level requirements for MUSE AO

- 1st generation Muse AO
  Very deep fields of extra-galactic objects
  - Provide x2 Encircled Energy increase at 750 nm in a 0.2" square pixel including losses due to possible additional AO mirrors...
  - 1'x1' corrected FOV
  - NO light pollution by NGS in the corrected FOV, LGS ok (monochromatic pollution) if off-axis
  - Work ~70 % of time (v. long exposure times, 1-2h / frame, total of 80h / field), 30° off-zenith
    $\rightarrow$ operating seeing of 1.1" (at 0.5 µm) (NAOS is about 0.65"-0.9")

- 2nd generation Muse AO
  galactic nuclei at high spatial resolution:
  - Provide Strehl of 10 % at 650 nm, within a goal of 10"x 10" FOV
  - Less stringent light pollution constrains
  - Median seeing ok (shorter exposures)

Atm. Statistics @ Paranal (zenith)

Percentile (%)	Seeing ('')	Tau0 (ms)	Theta0 ('')
10	0.51	6.54	3.69
20	0.60	4.96	3.20
30	0.67	4.14	2.89
40	0.74	3.54	2.64
50	0.81	3.04	2.42
60	0.90	2.59	2.22
70	1.00	2.19	2.01
80	1.14	1.81	1.78
90	1.40	1.42	1.51

MUSE TLR specifies median seeing, but very long exposures require to use worse atmospheric values.

r0 = 1.1' ' at 30 degrees off-zenith

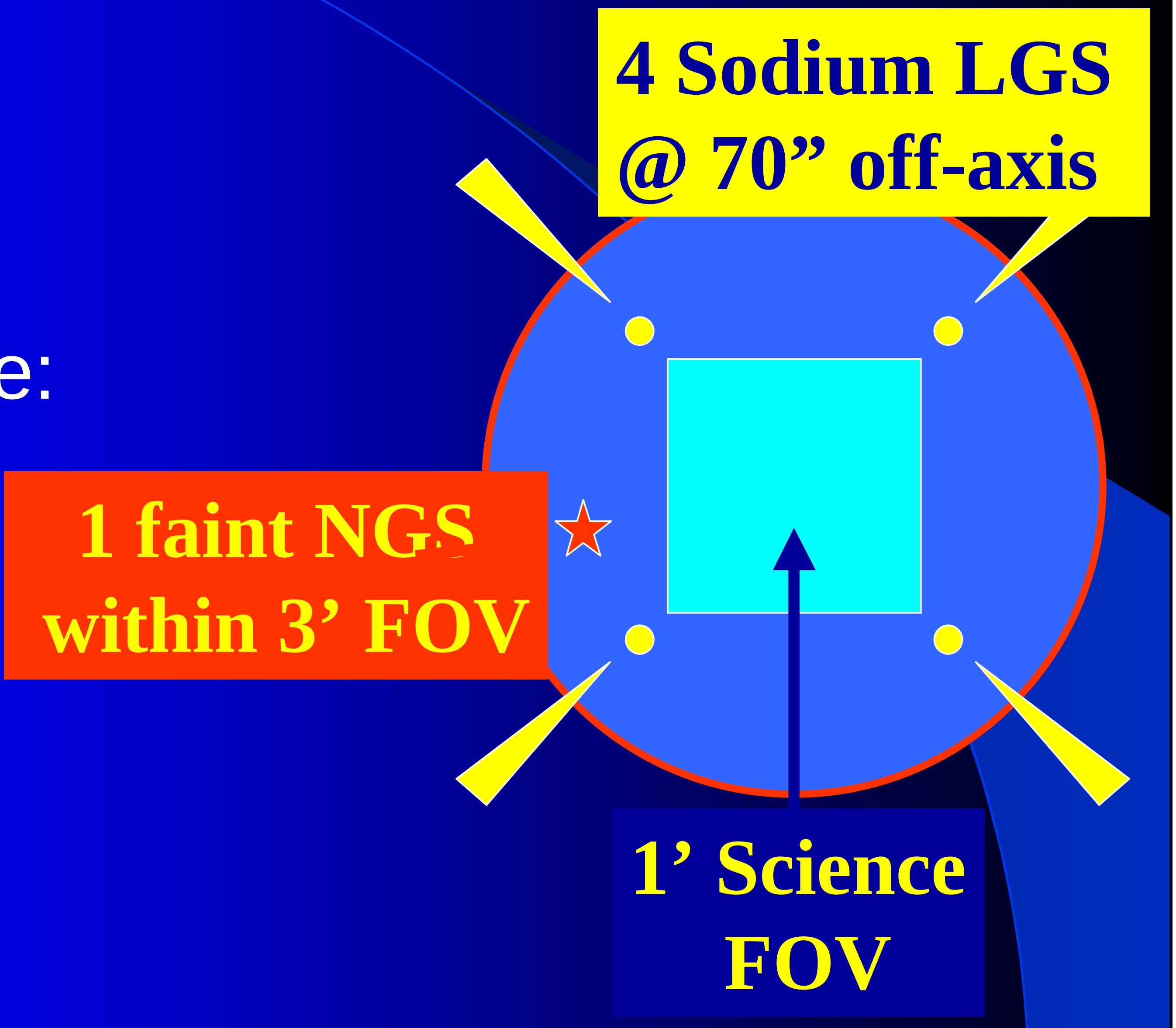
Tau0 seasonal variations

Photometric Nighttime (23h-10hUT)	median (ms)	tau0 > 3ms (%)
January	4.6	78
February	4.8	83
March	4.1	76
April	3.5	61
May	2.6	41
June	2.2	27
July	2.4	37
August	2.9	47
September	2.4	35
October	3.2	55
November	3.0	50
December	3.5	64
Year	3.1	53

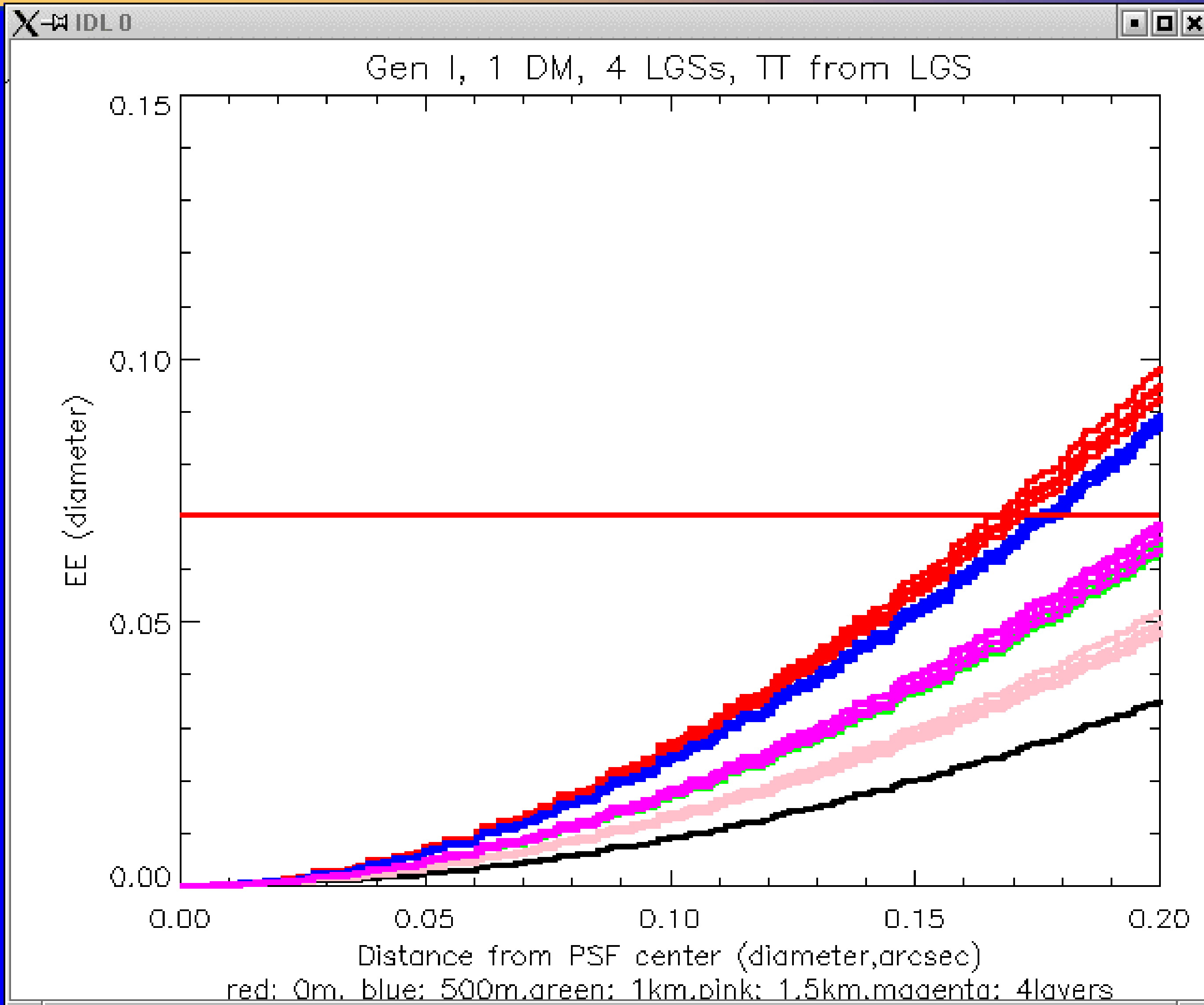
Simulations used tau0 of 2.45 ms (no observations in June, July !)

System geometry

- 1 DM conjugated to pupil
- Sky coverage: 60% @ poles
- NGS tilt star mv>17.5
- ~32x32 sub-aperture WFS



4 LGS, 1 DM, sensitivity to C_n^2



H=0

H=500m

H=1km

H=1.5km

H=0+0.5+1+1.5

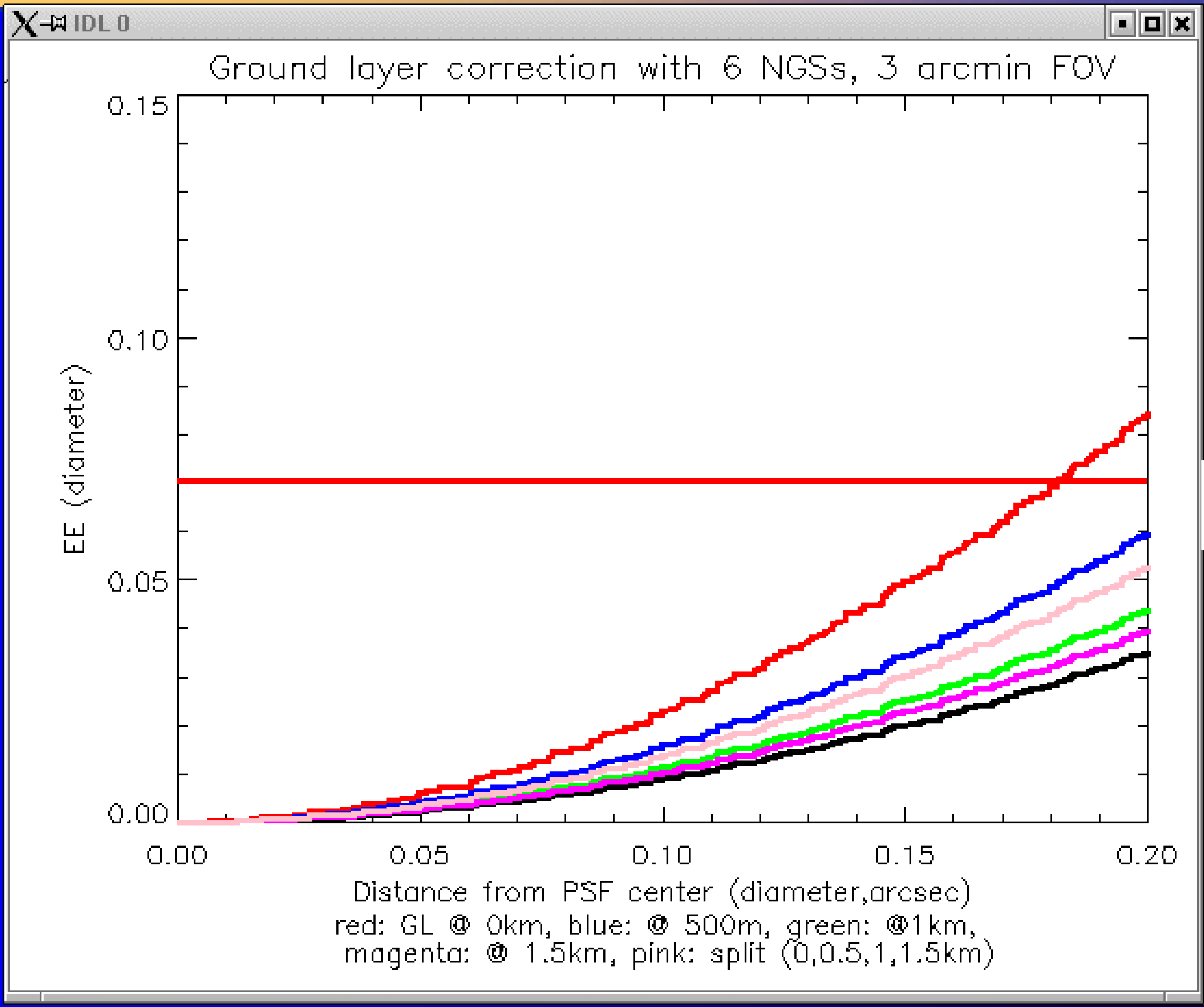
Assumes GL is 60% of Cn2

We need to get C_n^2 measurements at Paranal

BUT: control algorithm needs improvements !

6 NGS in 3' - sensitivity to C_n^2

GL: 60% of C_n^2



H=0

H=500m

H=1km

H=1.5km

H=0+0.5+1+1.5

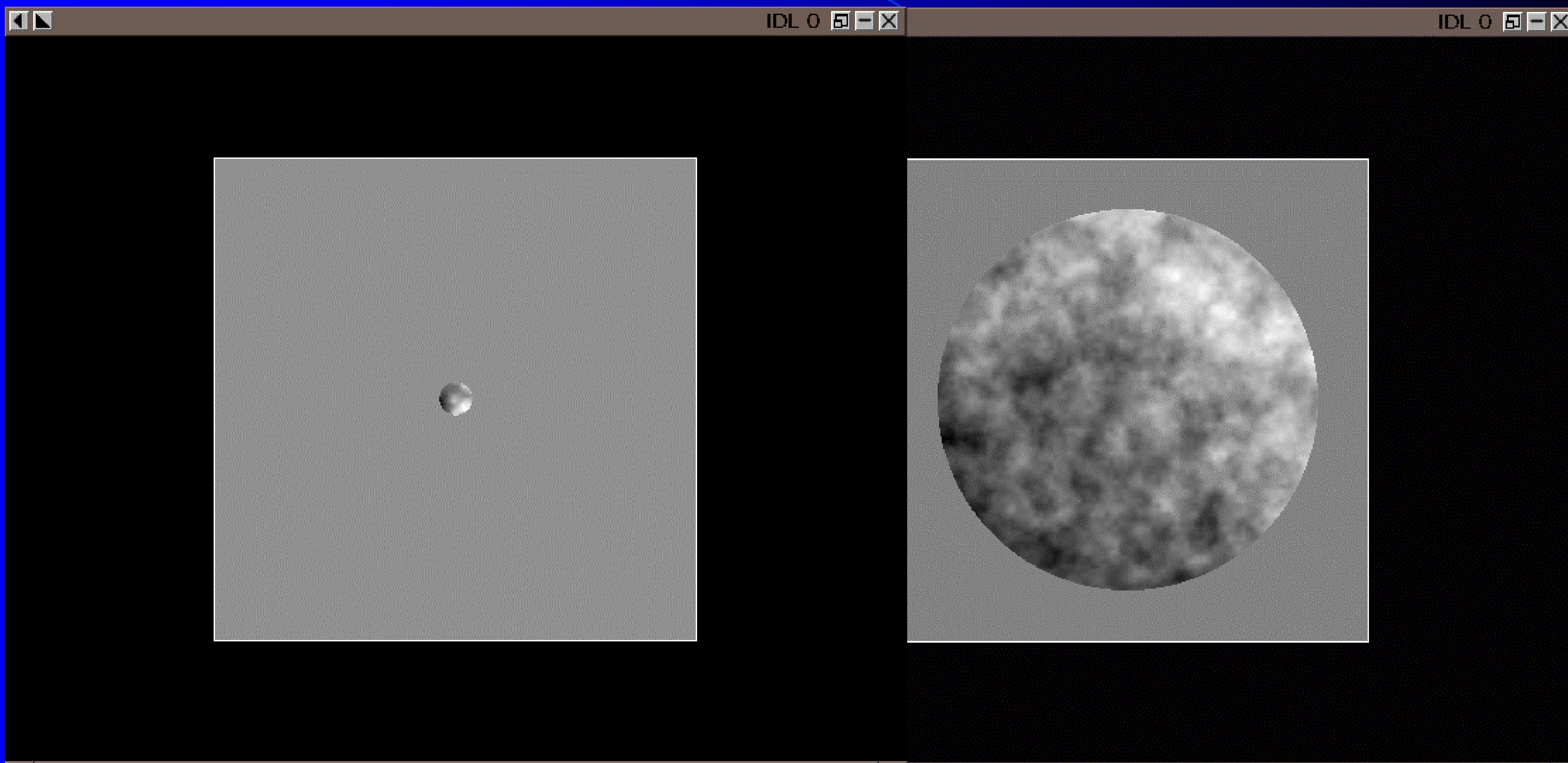
Sensitive to ground layer height because of larger NGS separation

BUT: control algorithm needs improvements !

OWL simulations

- Assume von-Karman type spectrum
- Assume L0 of ~25m
- Do these hold for 100m telescope ?
- Impact of L0 on critical design parameters:
  - DM stroke
  - Number of required actuators
  - Anisoplanatism (?)
- Predictive methods might be used
  - Taylor frozen flow shoud be characterized on these scales.

DM Size of OWL !



8m DM 100m DM

L0 becomes an important parameter !

Do we know enough about it to simulate its effects ?

What is the turbulent power spectrum on these scales ?

Conclusions

- Atmospheric measurements needed for
  - Instrument design
  - Simulations & performance analysis
  - Command of MCAO systems
- Need long-term statistics to chose optimal parameters in design phase
- Data with different resolutions are useful

Conclusion II

- High resolution data:
  - Simulations / design
  - C_n^2, wind profile
  - Ground layer contribution/structure is important for some instruments
- Long measurement periods
  - Cn2 / (wind ?) trends at lower resolution
  - r0, theta0, tau0
- Power spectrum at 100m scales
  - Needs to be measured before final AO design
  - L0 statistics on longer term for DM stroke