The next generation of Wide Field Adaptive Optics

or: How I Learned to Stop Worrying and Love Anisoplanatism

Jeff Stoesz
HIA/UVic

National Research Council Canada | Conseil national de recherches Canada

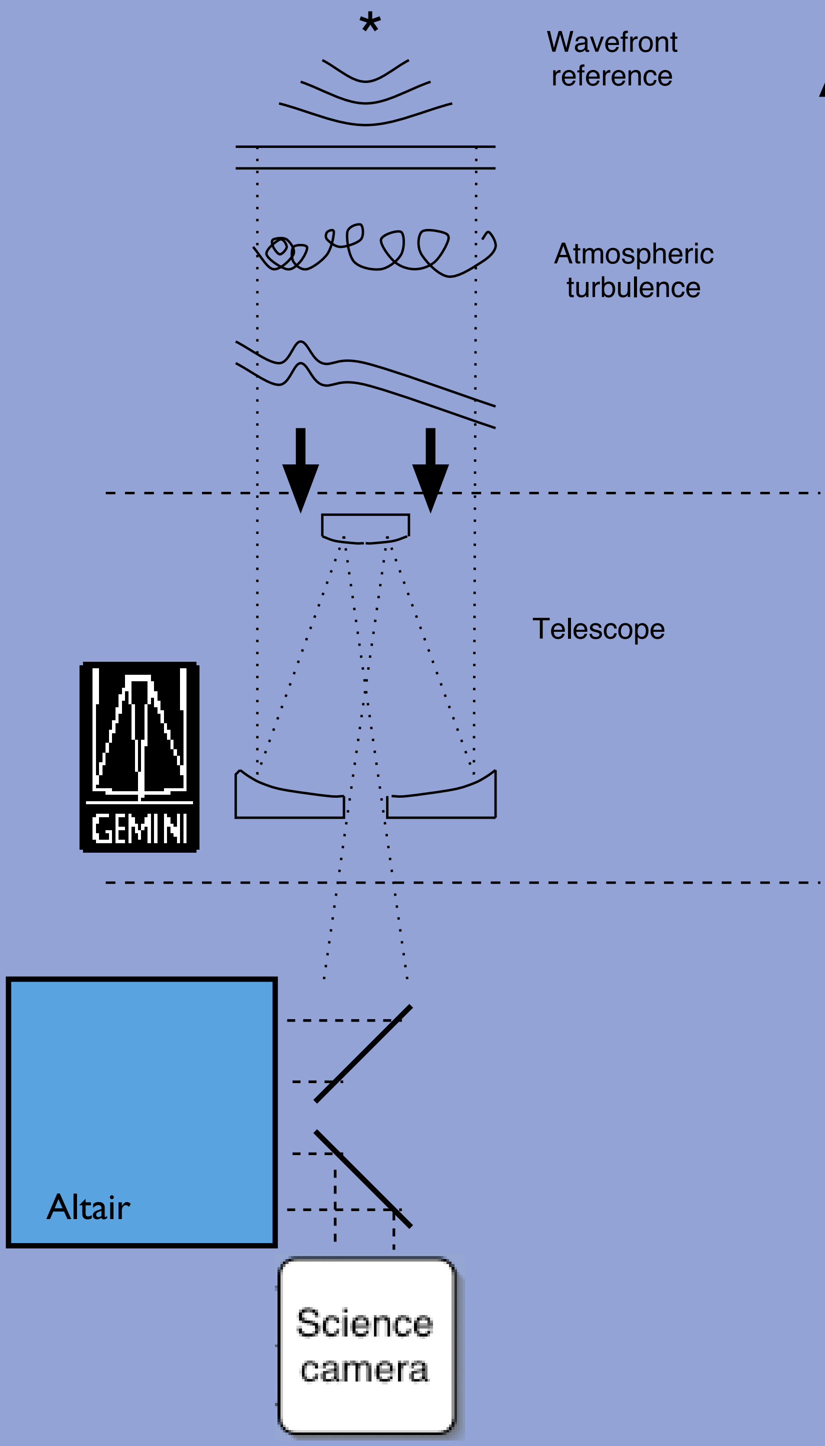
University of Victoria

Jean-Pierre Véran, David Andersen, Tim Davidge, Jennifer Dunn, Danielle Frenette, Glen Herriot, Laurent Jolissaint, Francois Rigaut, Scott Roberts, Malcolm Smith

Outline

- Altair: the first Wide Field Adaptive Optics instrument
- Ground Layer Adaptive Optics
  - Modeling goals
    1. Routinely model performance
    2. Constrain the basic design parameters
    3. Identify and address design issues
       - Gemini GLAO
       - TMT GLAO for the Wide Field Optical Spectrograph

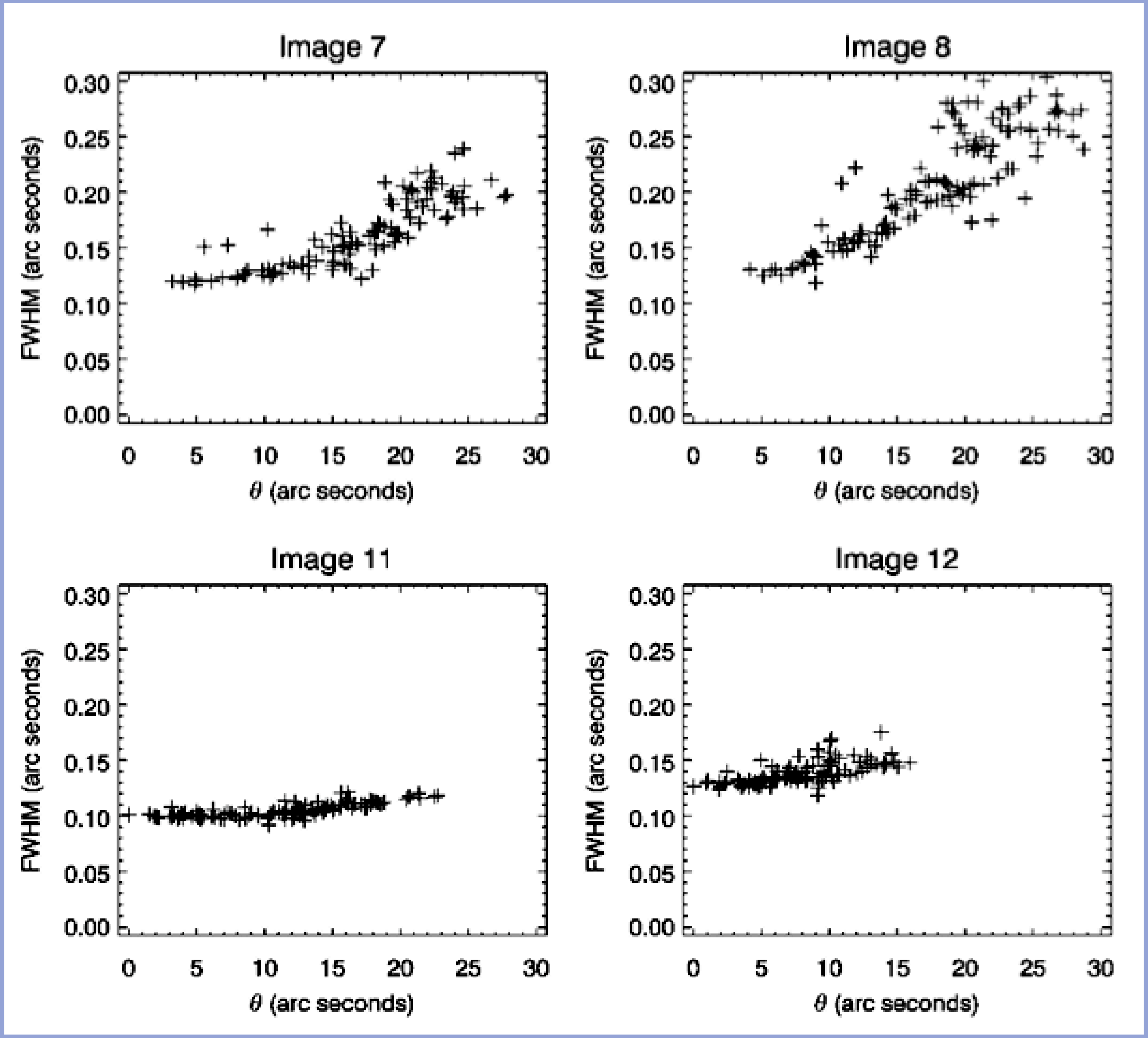
Altair: altitude conjugated WFAO



- Facility AO system for Gemini North, integrated in to the observatory system and not the science instrument.

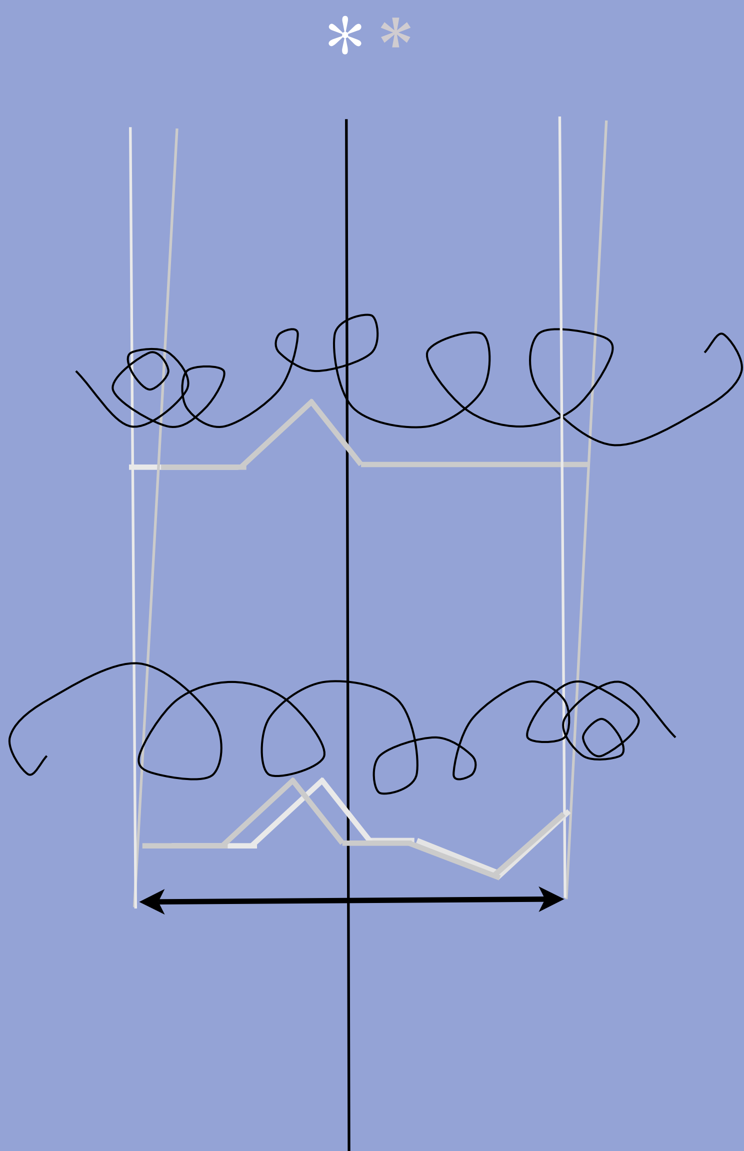
- Altair can be activated by the flip of a mirror, to feed NIRI or NIFS.

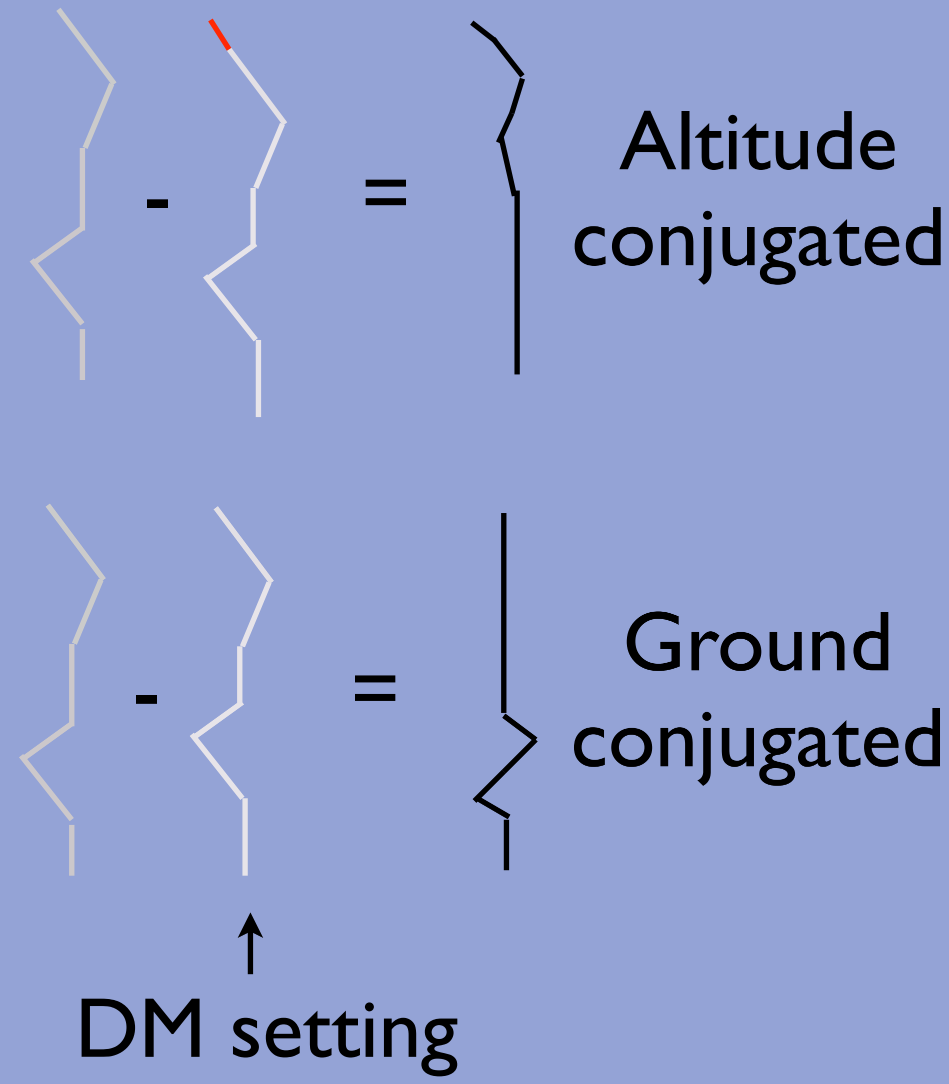
Anisoplanatism



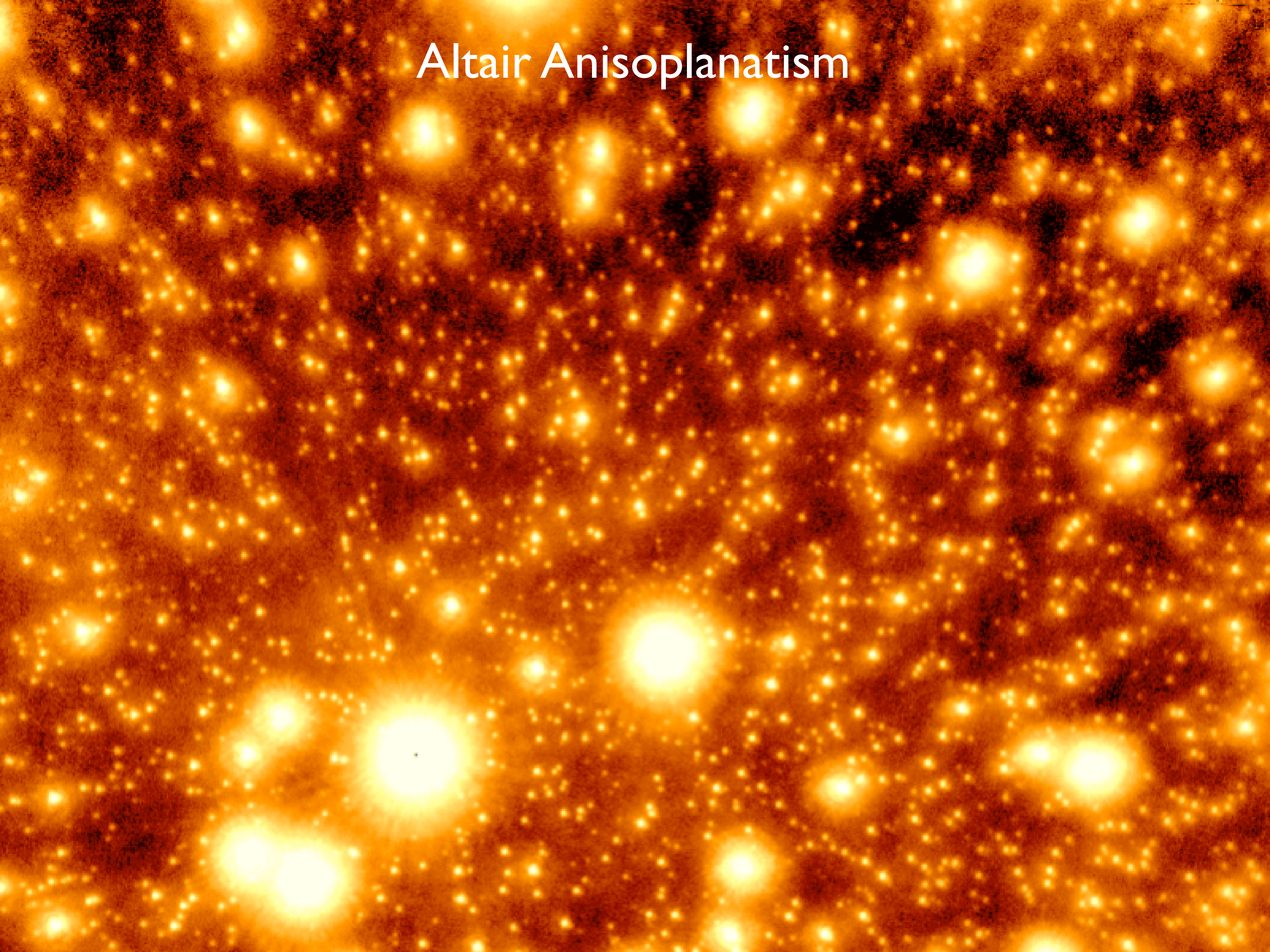
Flicker and Rigaut (2002)

Anisoplanatism

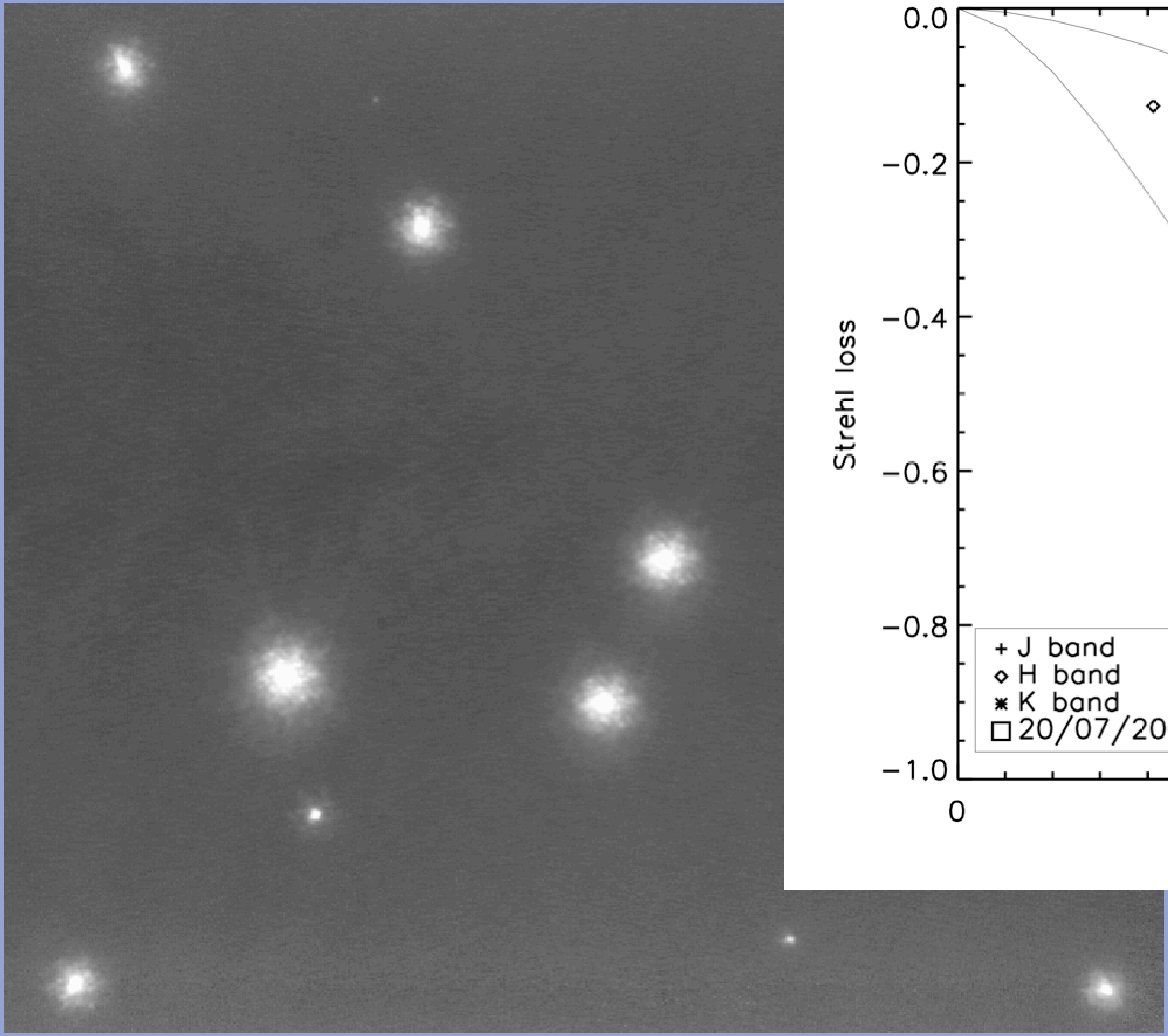


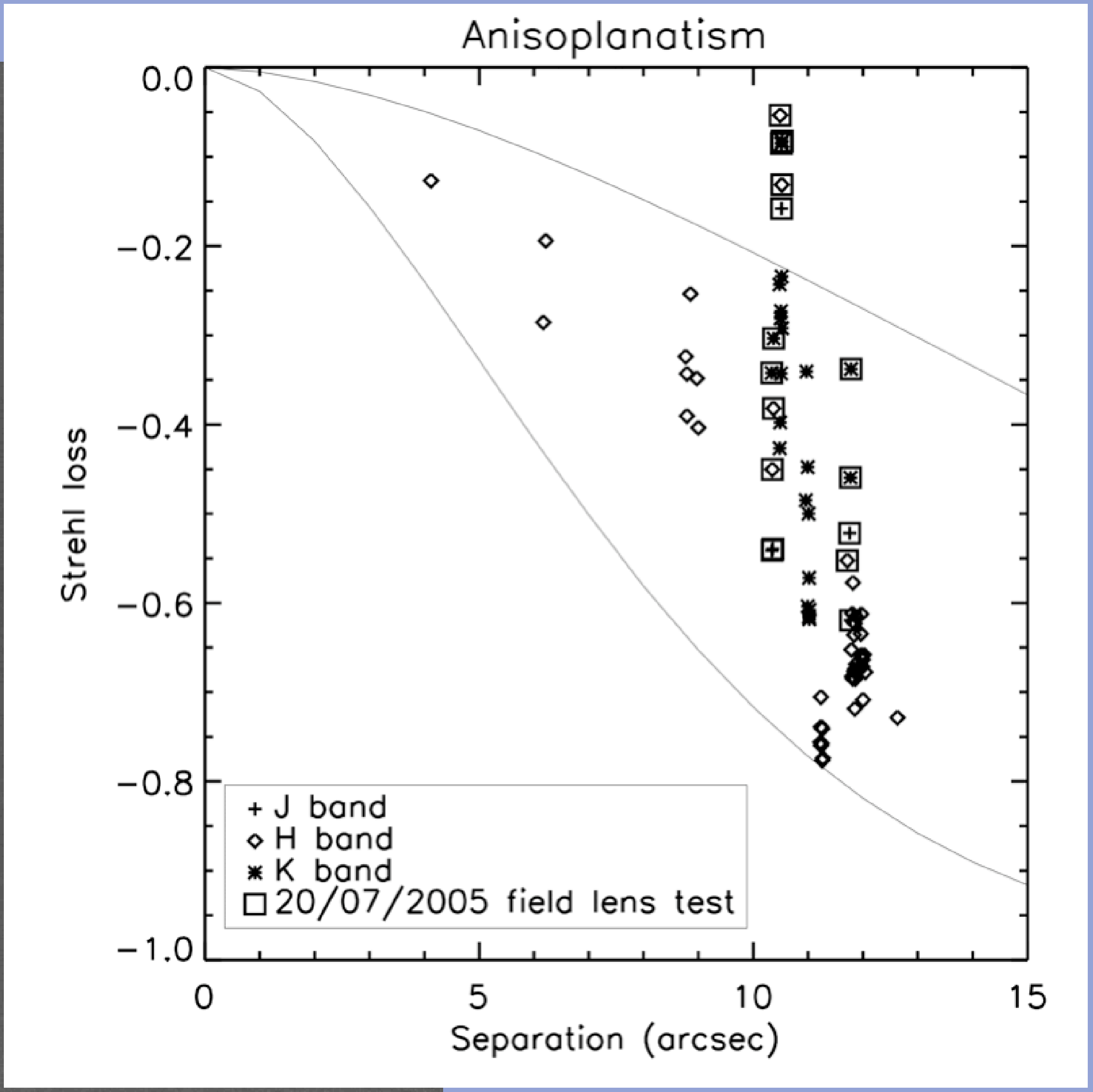


Altair Anisoplanatism

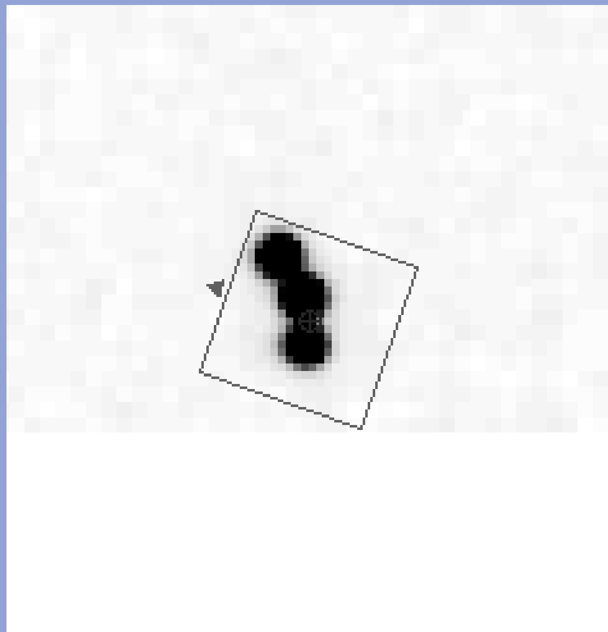


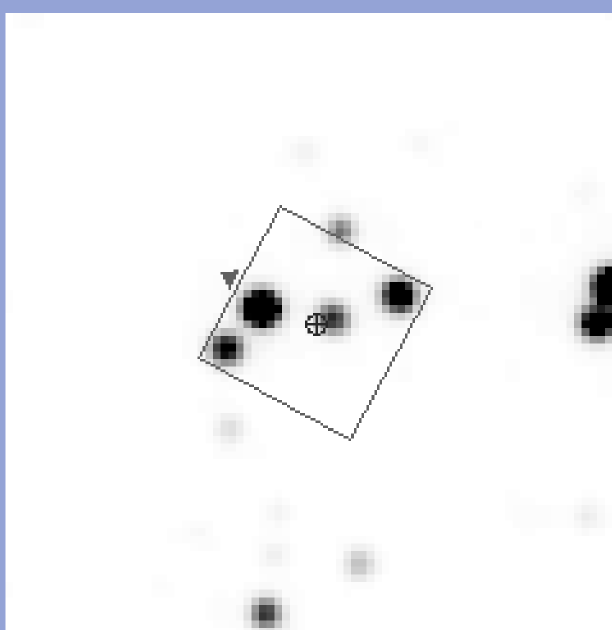
Sparse Fields

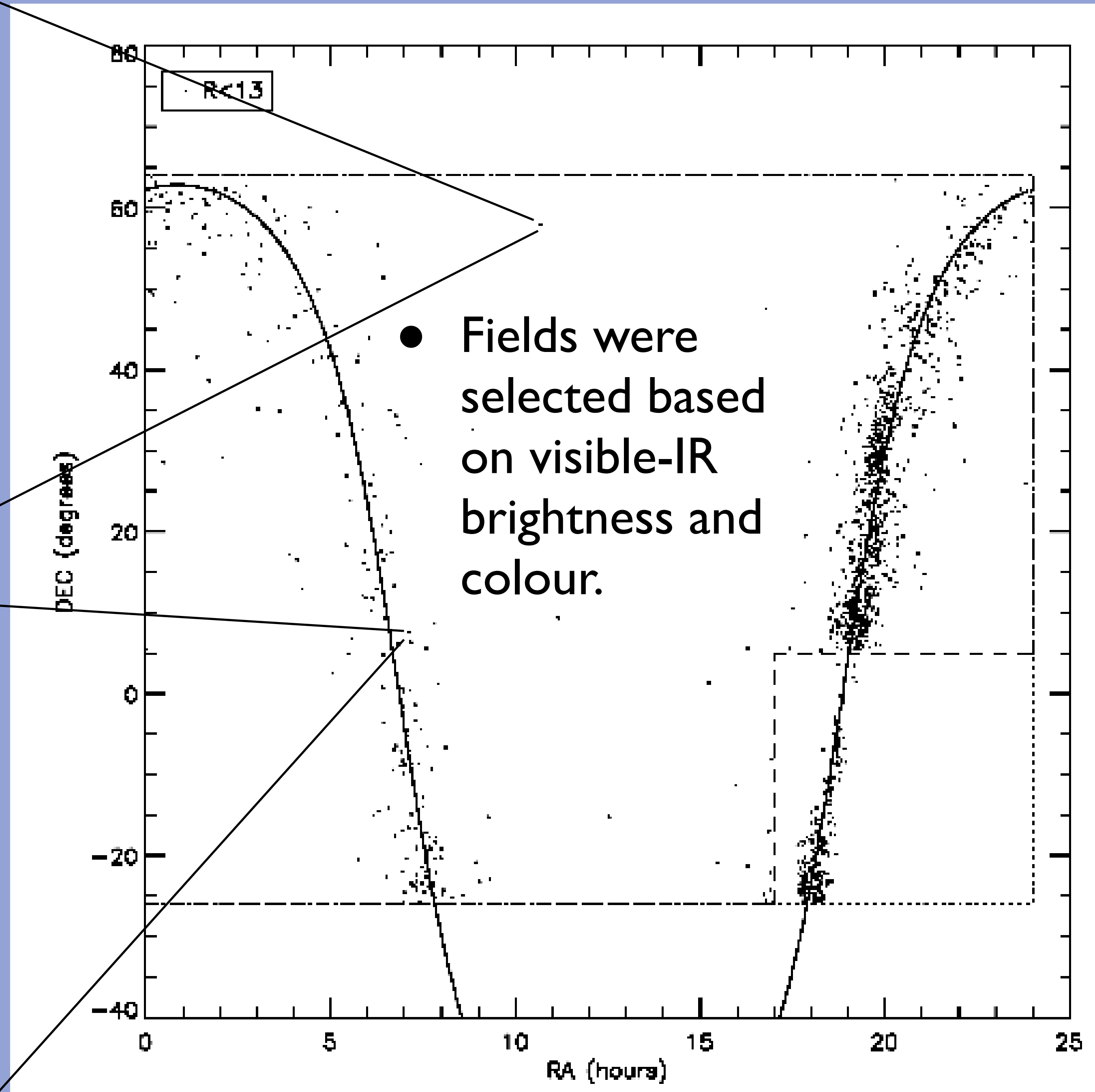




Sparse Fields



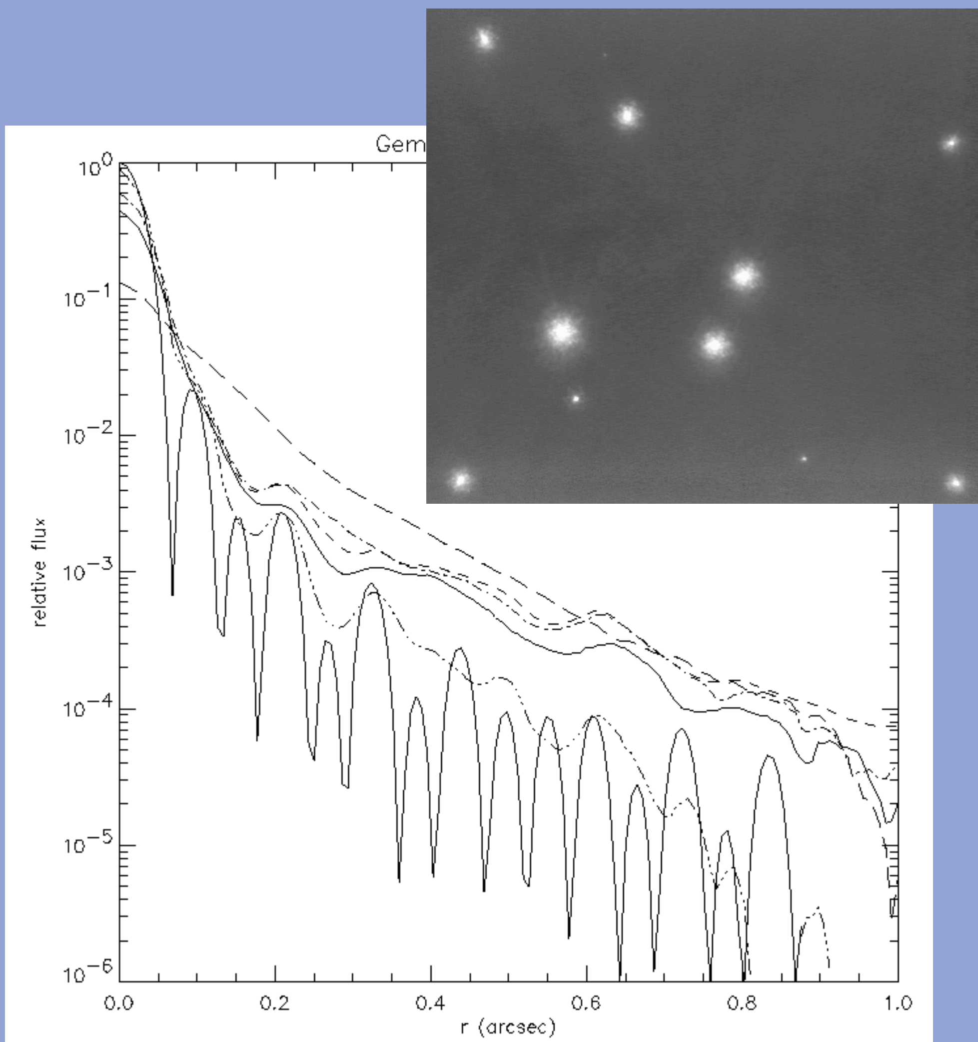


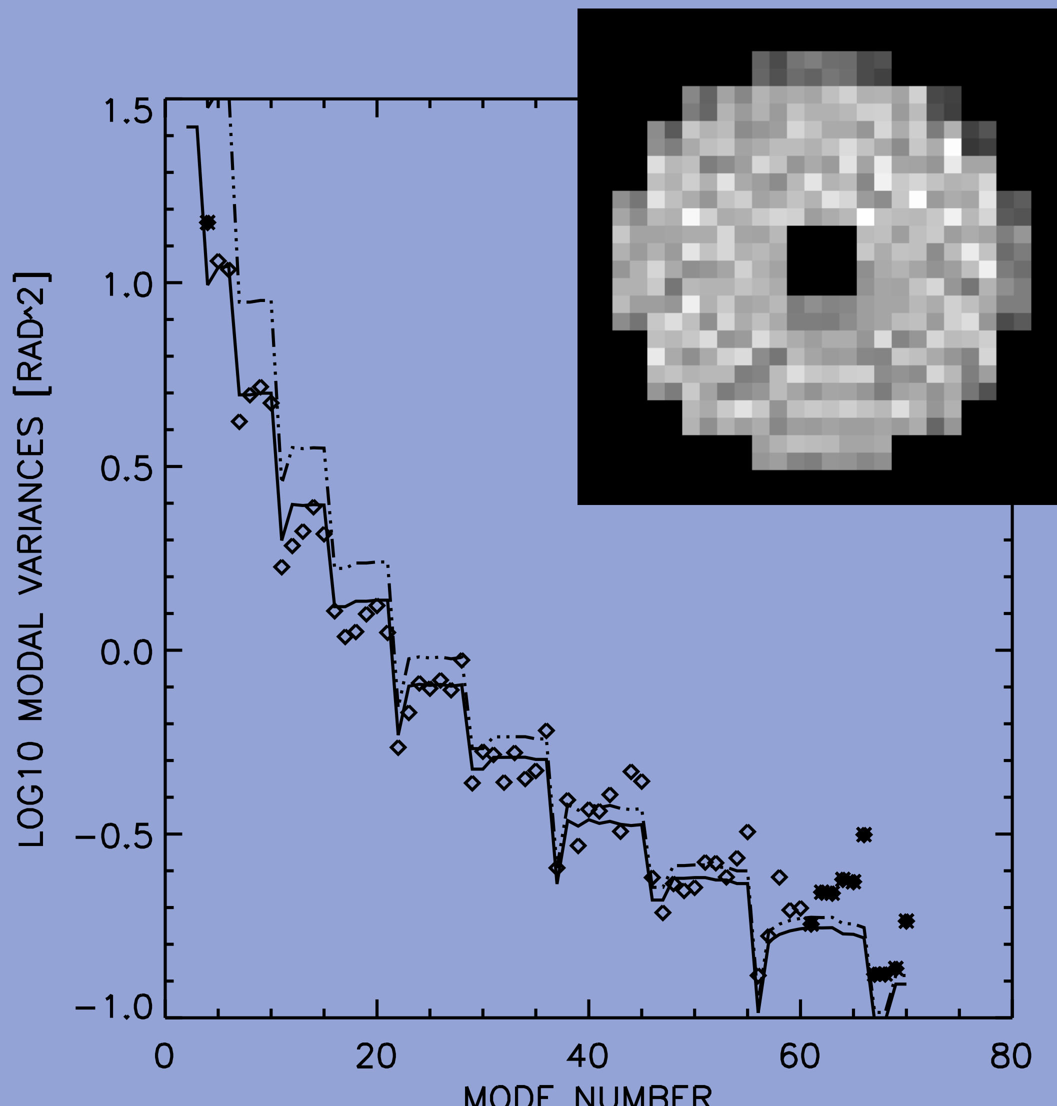


- Fields were selected based on visible-IR brightness and colour.

Focal plane and Pupil plane data

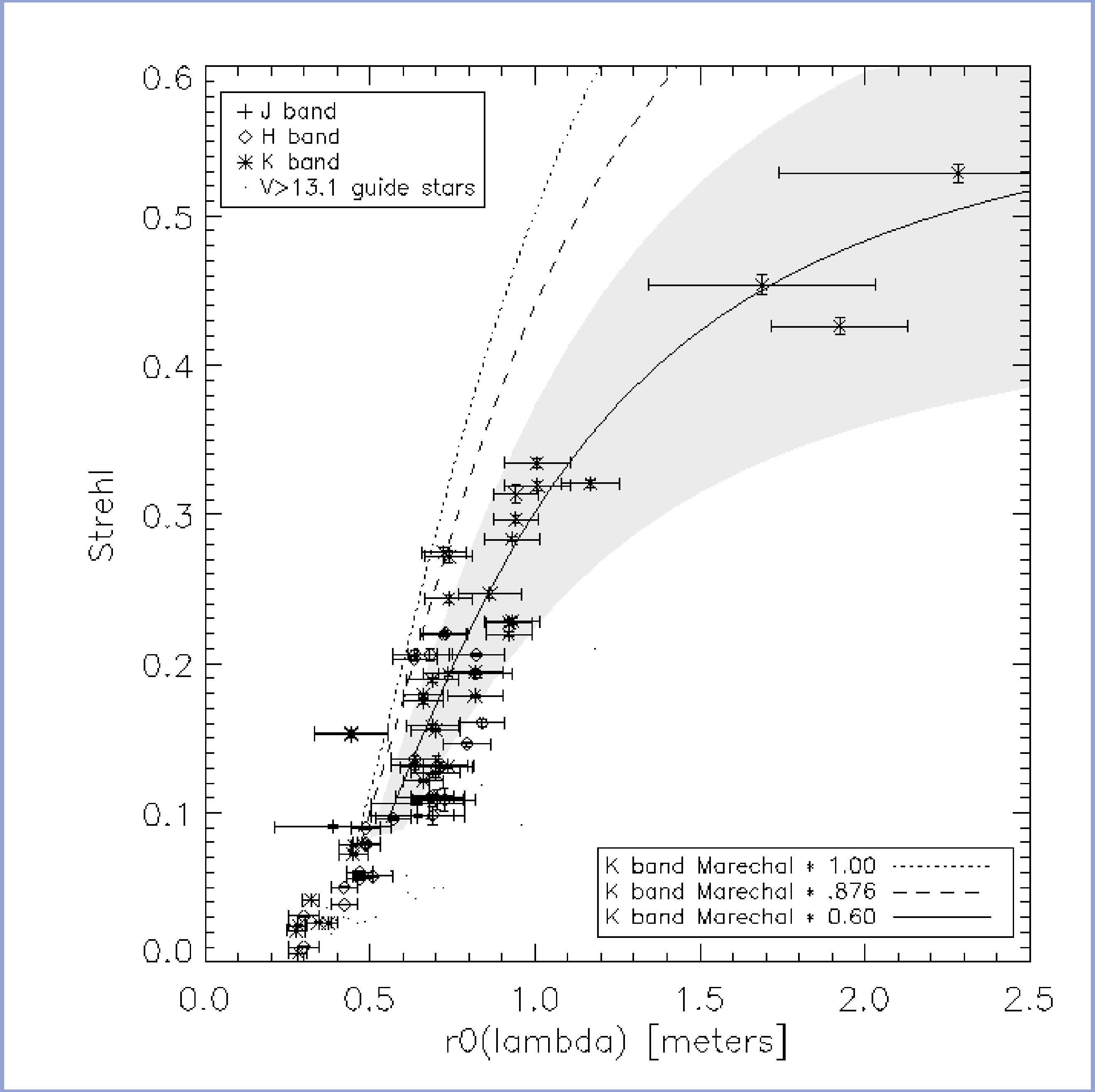
Altair measures seeing,
and outer scale!!





Modeling Altair image quality

- Modeled SR(r_o) with the Maréchal approximation. Important to planning observations with Altair.
- Quantified wavefront error from vibration and M2 print through.



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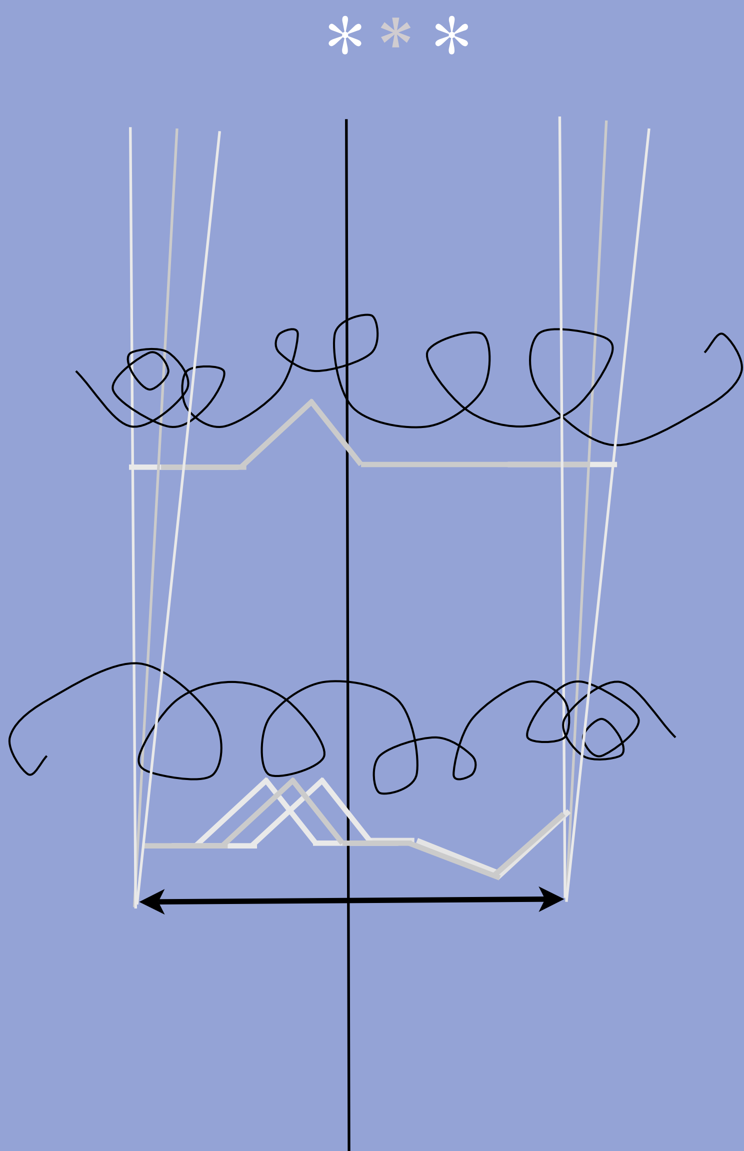
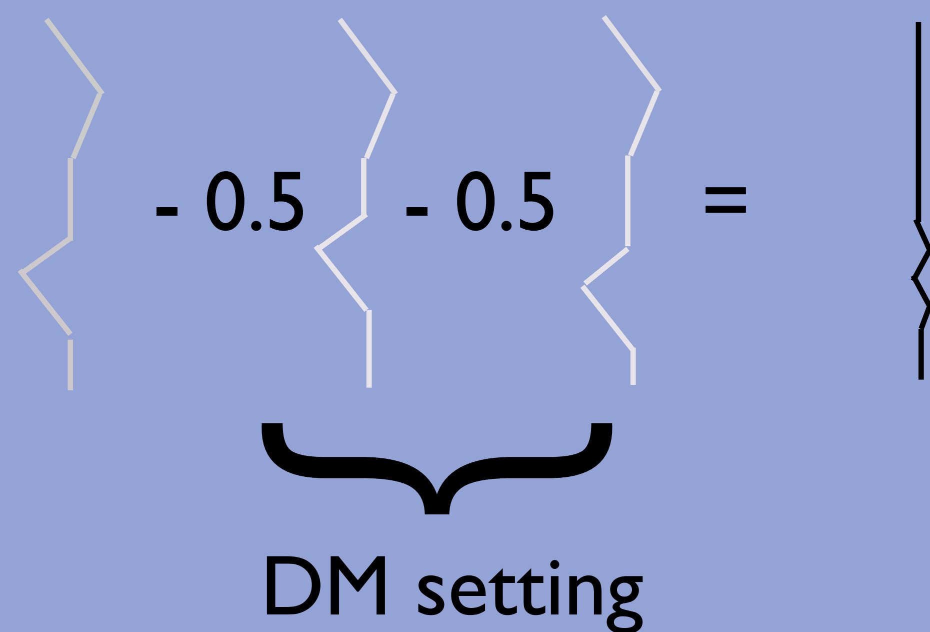
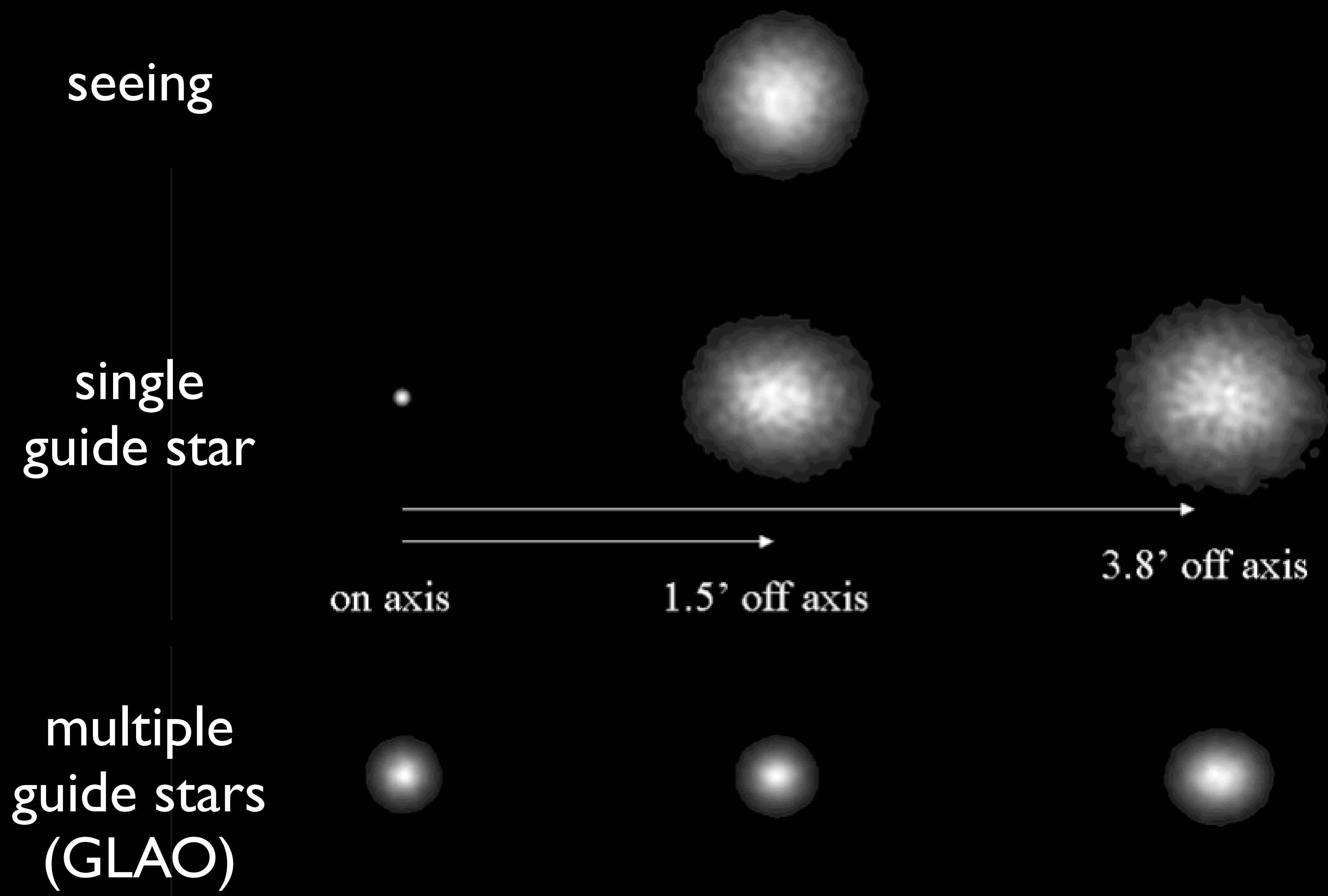
Anisoplanatism in GLAO

Rigaut (2001)






seeing
single guide star
multiple guide stars (GLAO)
on axis
1.5’ off axis
3.8’ off axis

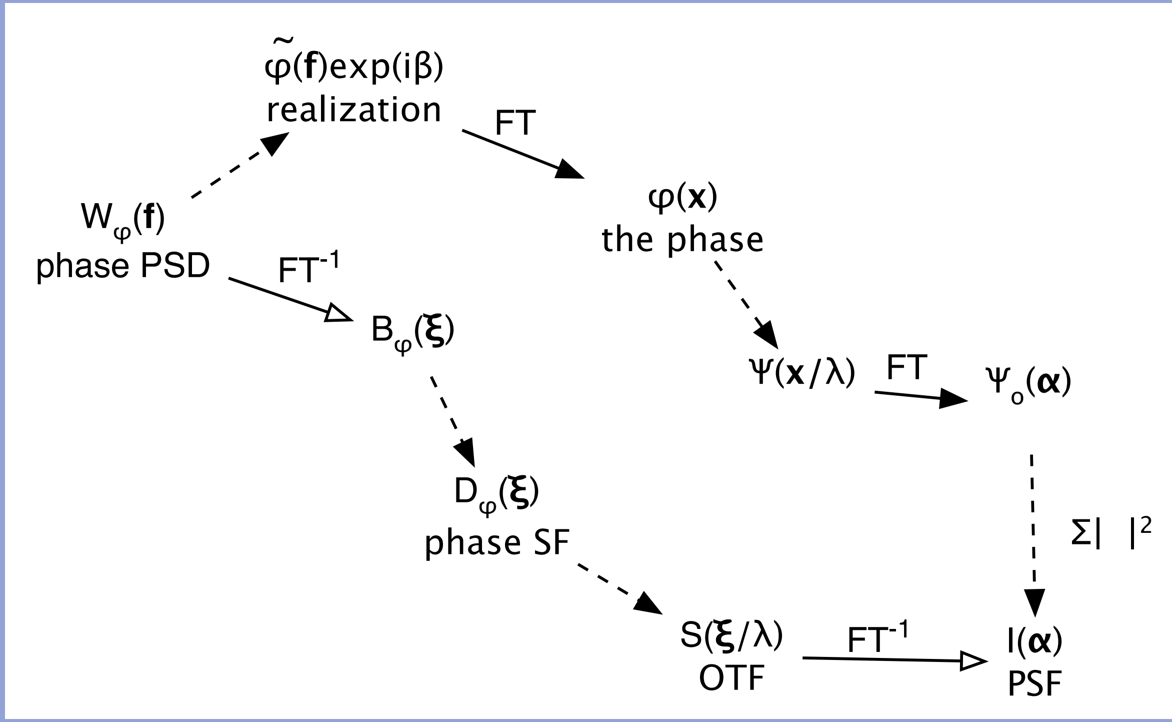
GLAO Modeling Goals

1. Routinely model performance over the relevant parameter space with suitable optical turbulence profile statistics.

2. Constrain the basic design parameters such as guide star asterism, actuator density, and most importantly requirements on frame rate.

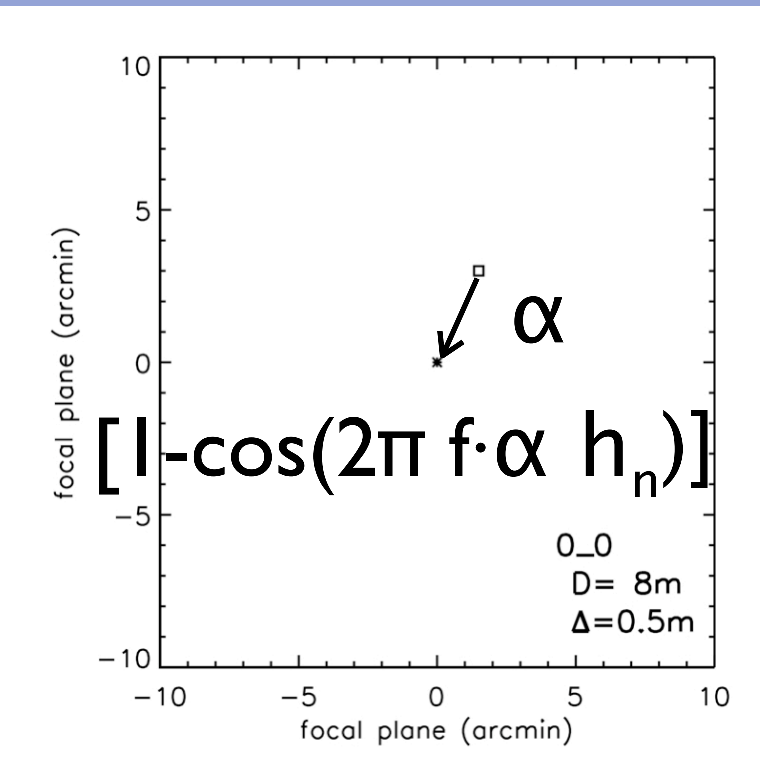
3. Identify and address design issues such as wavefront sensing with LGS, optimal and practical conjugation, PSF morphology and stability, operational concept...

1. Routinely model performance

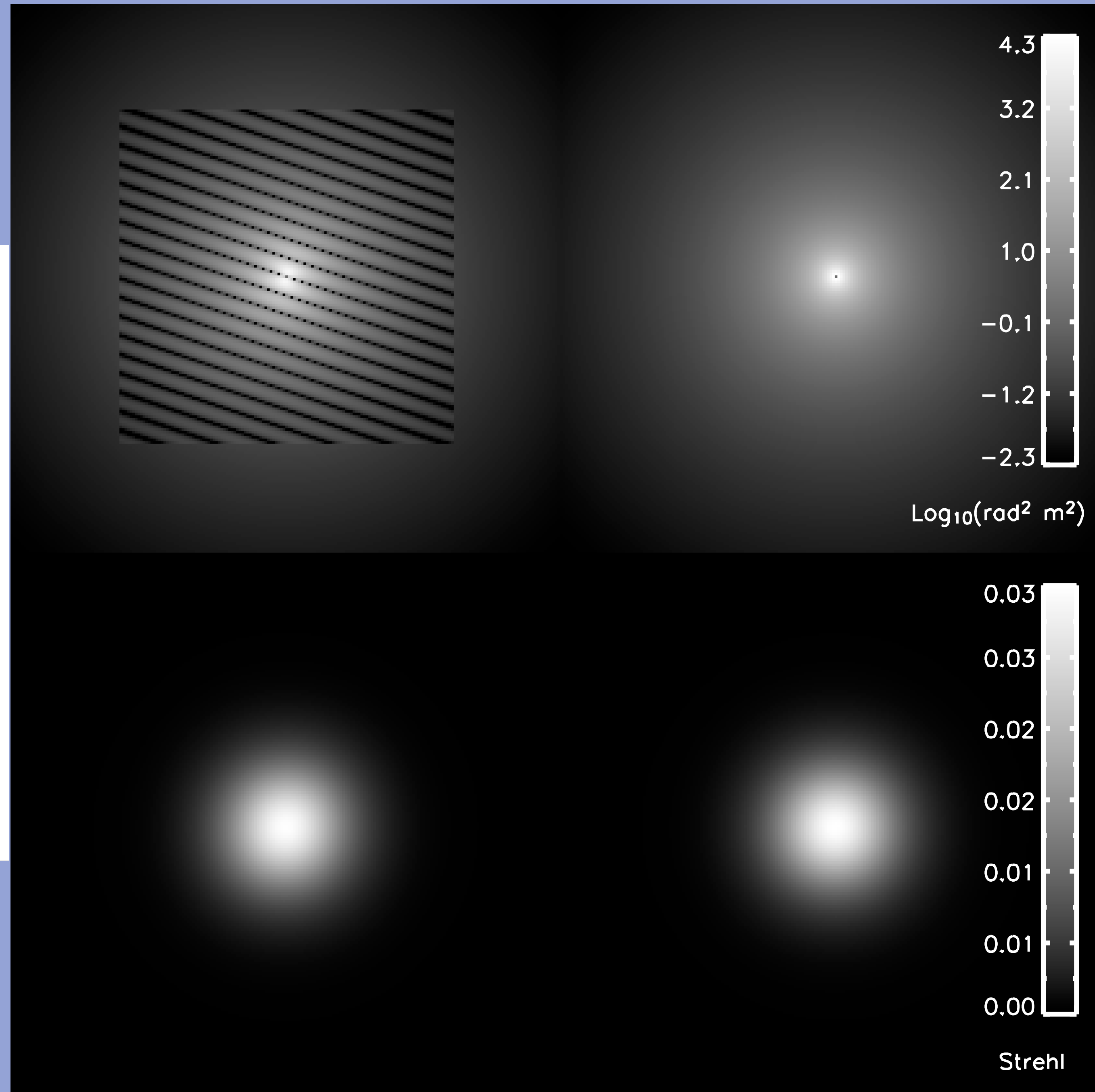


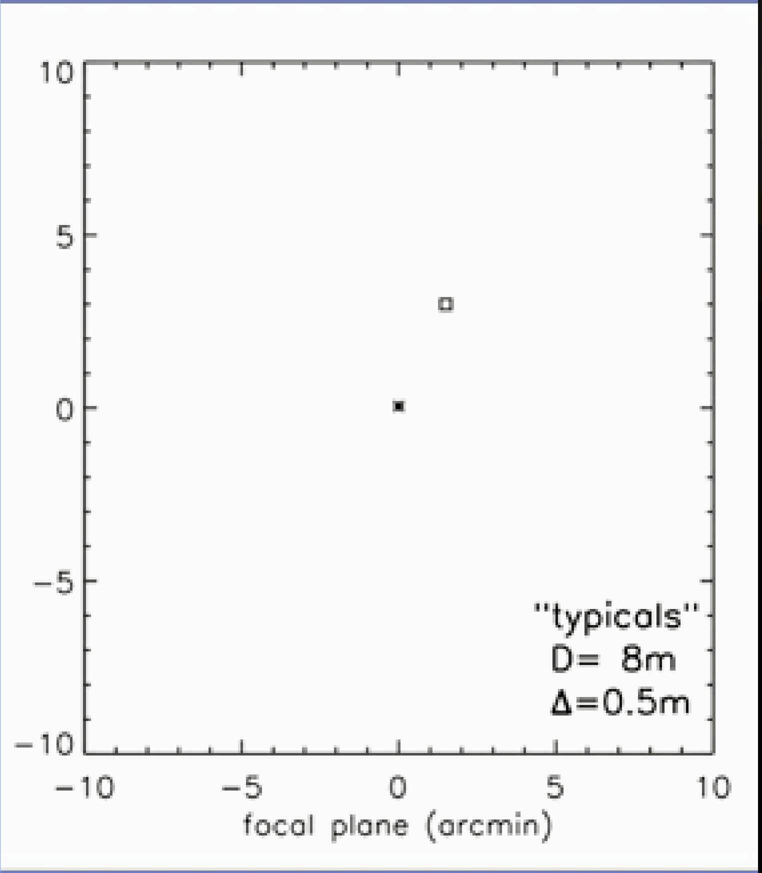
- Point Spread Function (PSF) from analytic Power Spectral Density (PSD) of the AO corrected phase.
  - Pioneering work: Rigaut et al. (1998), Tokovinin et al. (2000), and rigorous development by Jolissaint et al.(2006), Van Dam (2006)
  - Development of anisoplanatism for GLAO: Jolissaint et al. (2004), Stoesz et al. (2004), Tokovinin (2004)
  - GLiFFT: accurately solves GLAO figure(s) of merit for the fundamental parameters, especially in the Very Wide GLAO regime.

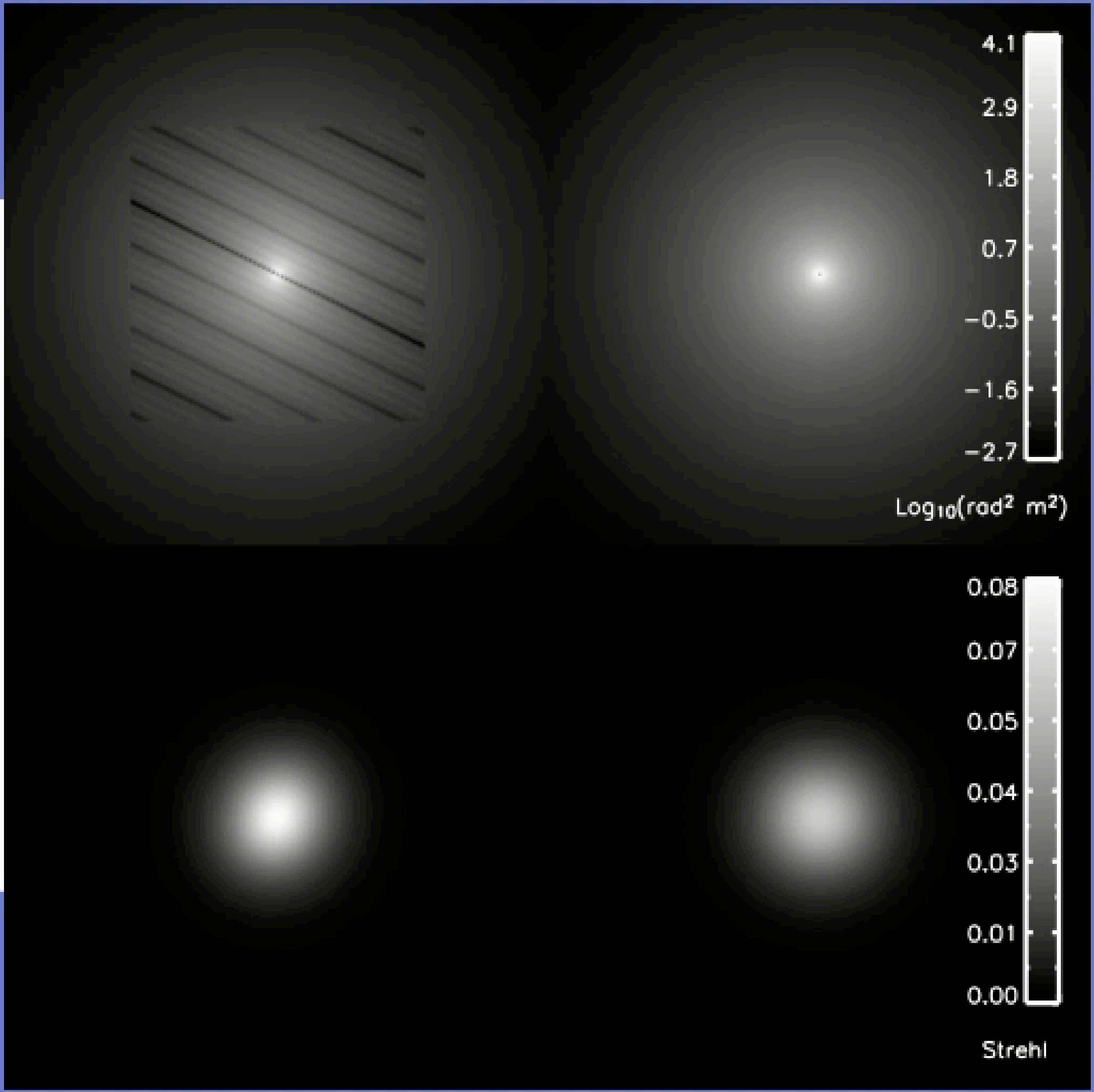
GLAO Seeing

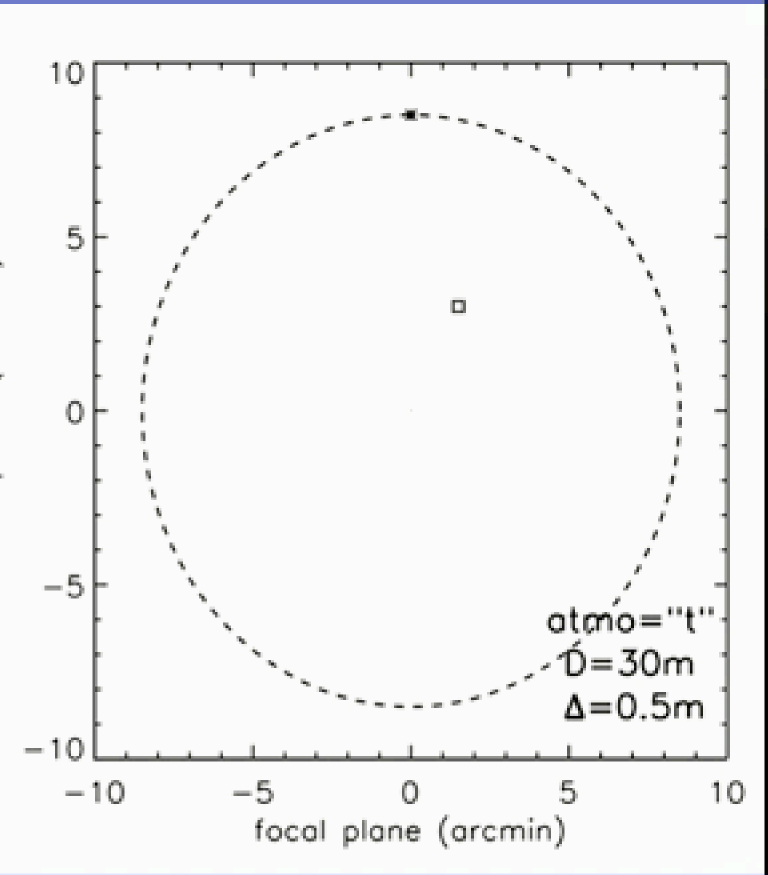


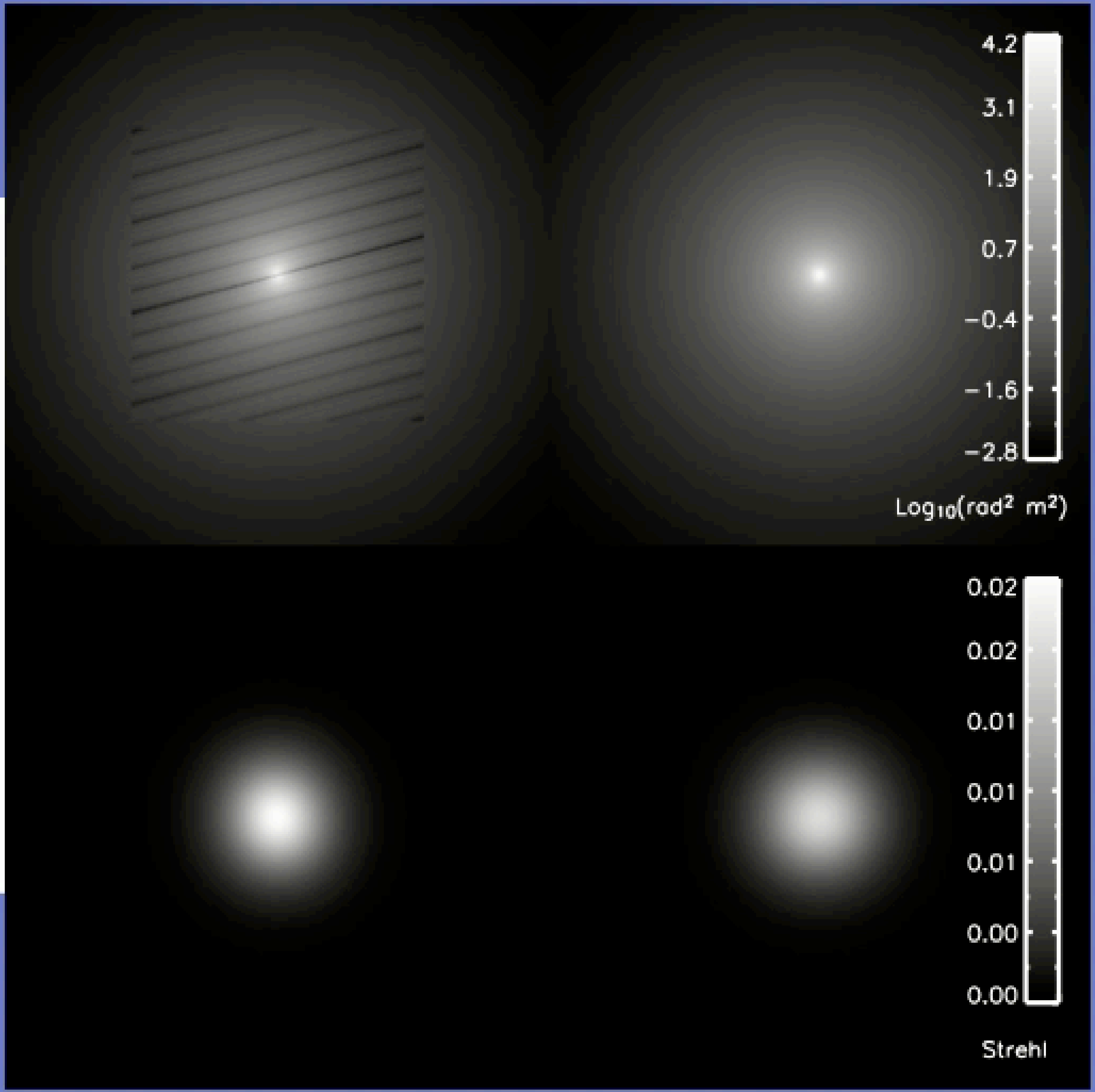
$$[1 - \cos(2\pi f \cdot \alpha h_n)]$$

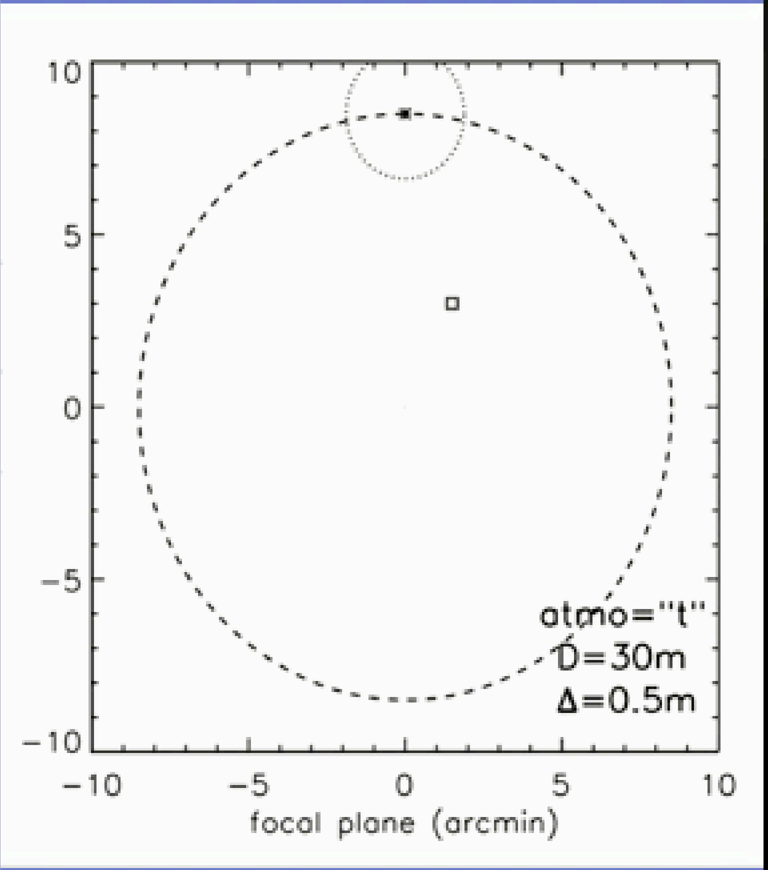



10
5
0
−5
−10
−10
−5
0
5
10
focal plane (arcmin)
"typicals"
D= 8m
Δ=0.5m


4.1
2.9
1.8
0.7
−0.5
−1.6
−2.7
Log10(rad² m²)
0.08
0.07
0.05
0.04
0.03
0.01
0.00
Strehl


10
5
0
−5
−10
−10
−5
0
5
10
focal plane (arcmin)
atmo="t"
D=30m
Δ=0.5m


4.2
3.1
1.9
0.7
−0.4
−1.6
−2.8
Log10(rad2 m2)
0.02
0.02
0.01
0.01
0.01
0.00
0.00
Strehl



10
5
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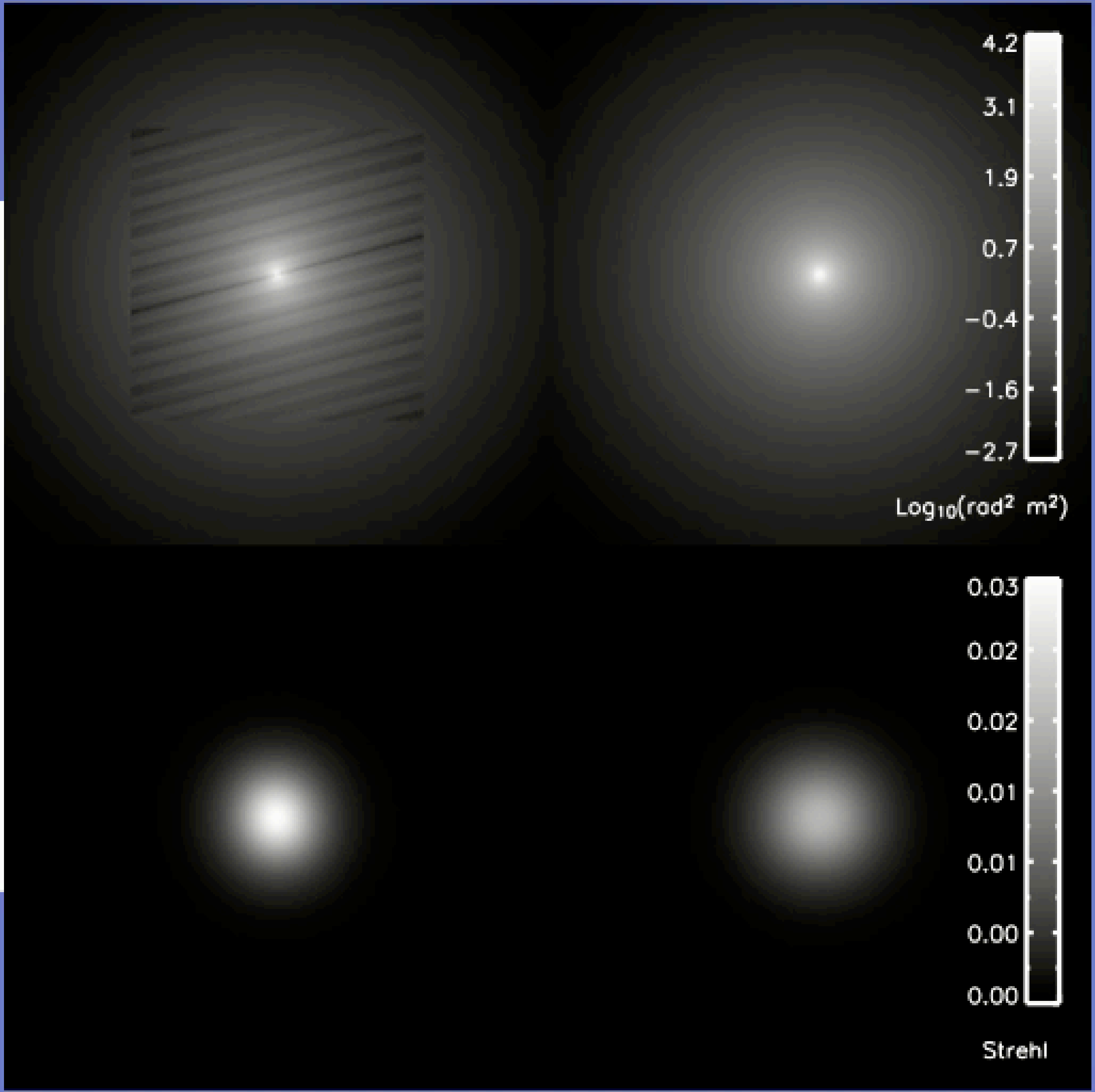
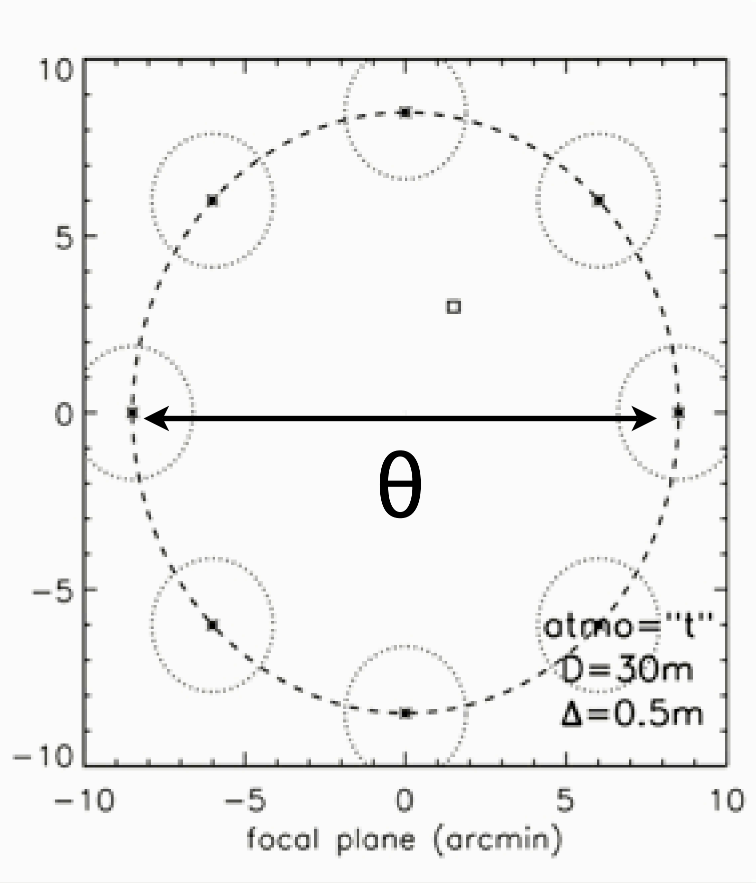
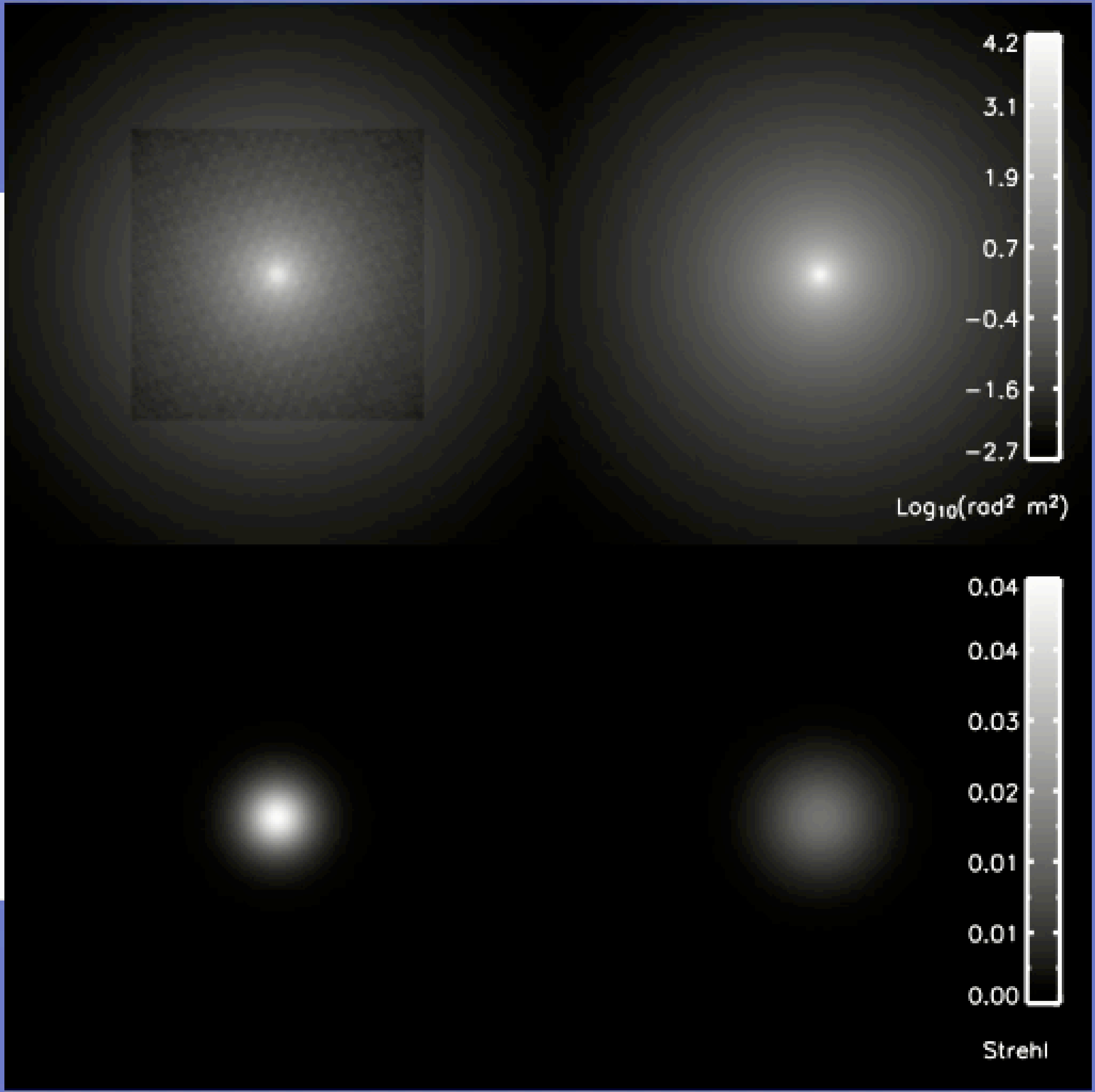
10
focal plane (arcmin)
atmo="t"
D=30m
Δ=0.5m

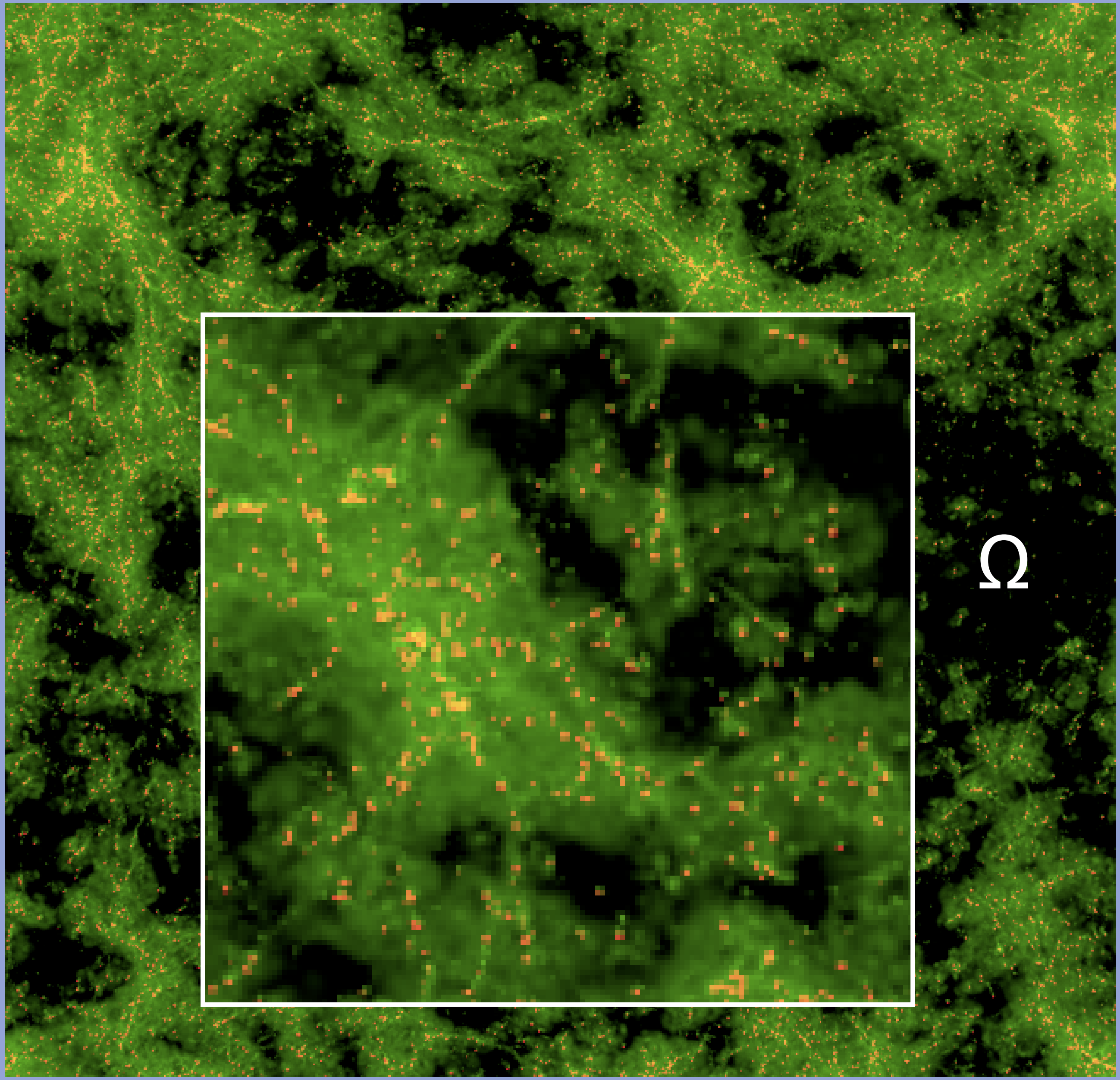


4.2
3.1
1.9
0.7
−0.4
−1.6
−2.7
Log10(rad2 m2)
0.03
0.02
0.02
0.01
0.01
0.00
0.00
Strehl


10
5
0
−5
−10
−10
−5
0
5
10
focal plane (arcmin)
θ
atmo="t"
D=30m
Δ=0.5m


4.2
3.1
1.9
0.7
−0.4
−1.6
−2.7
Log10(rad² m²)
0.04
0.04
0.03
0.02
0.01
0.01
0.00
Strehl

GLAO figure of merit

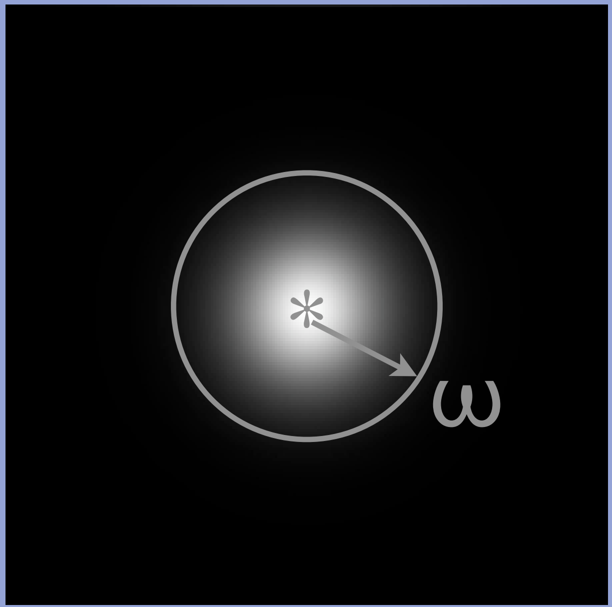


Springel & Hernquist

- For evaluating feasibility and the significance of various trade studies.

$$\frac{area\ surveyed}{unit\ time} = \frac{\Omega}{\Gamma\ SNR^2}$$

GLAO figure of merit



- Reduced the PSF to the optimal background-noise-limited aperture and its fraction of encircled energy.
- Take the ratio with respect to seeing, which is important to gauge the significance of each trade study.

$$\Gamma'/\Gamma = \text{Integration Time Ratio} = \left(\frac{\bar{\omega}'}{\bar{\omega}}\right)^2 \left(\frac{EE_{circ}(\bar{\omega})}{EE'_{circ}(\bar{\omega}')}\right)^2$$

"ITR"

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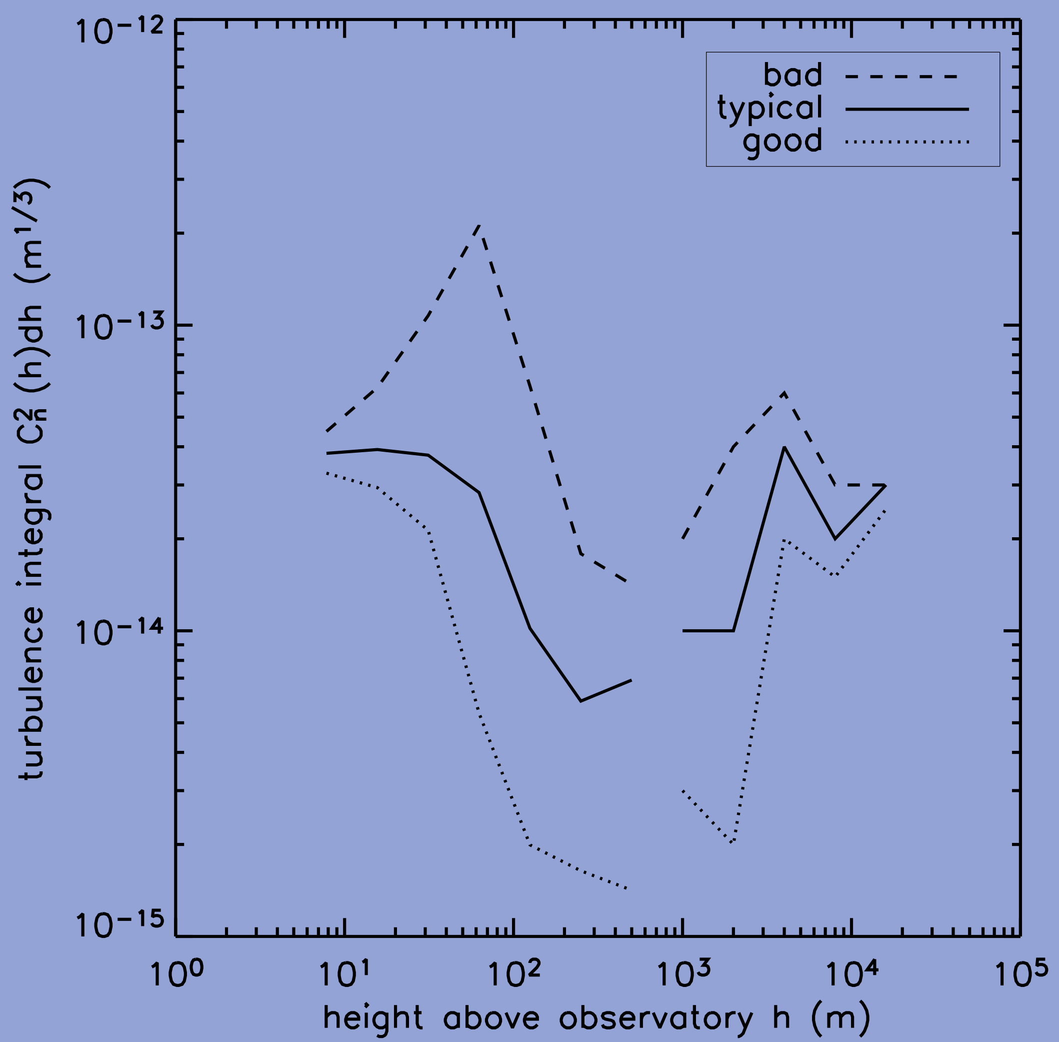
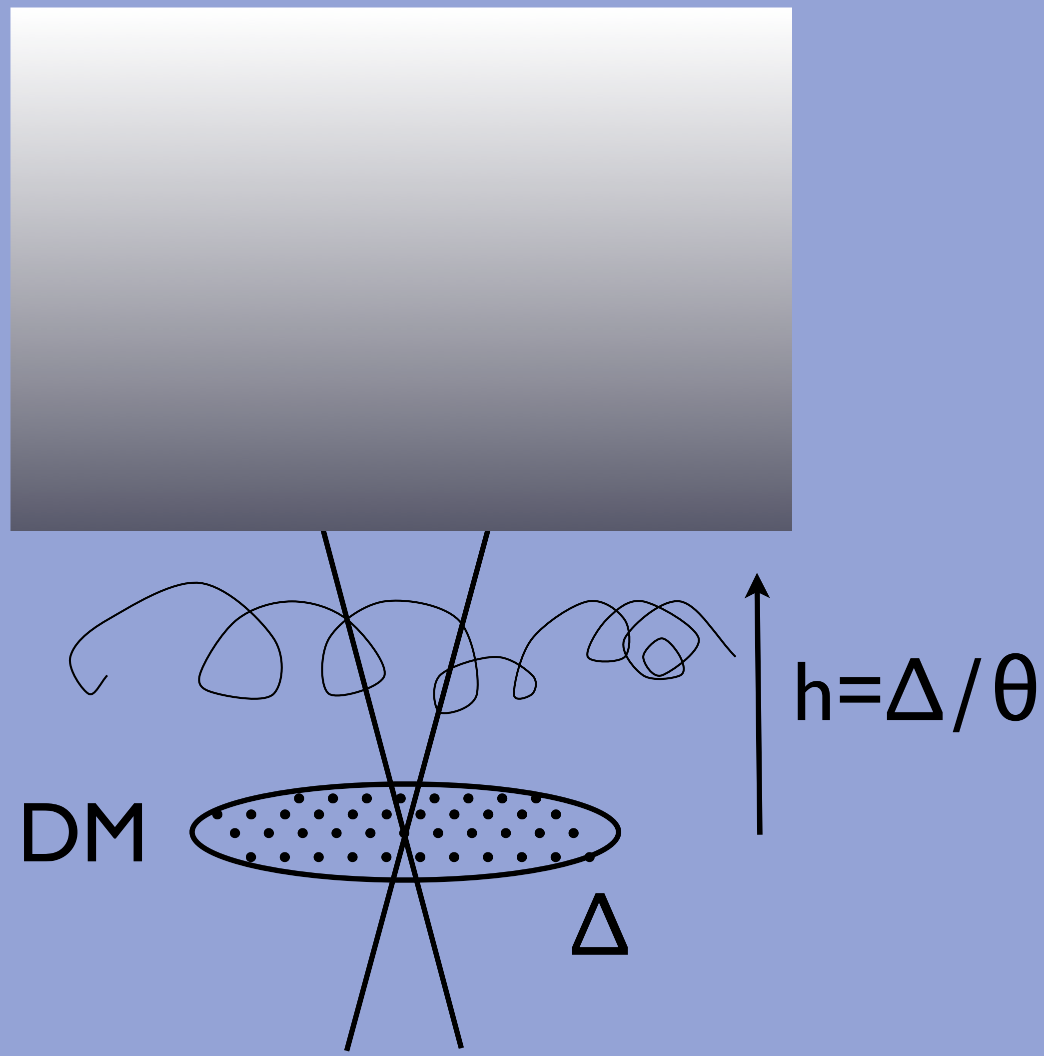
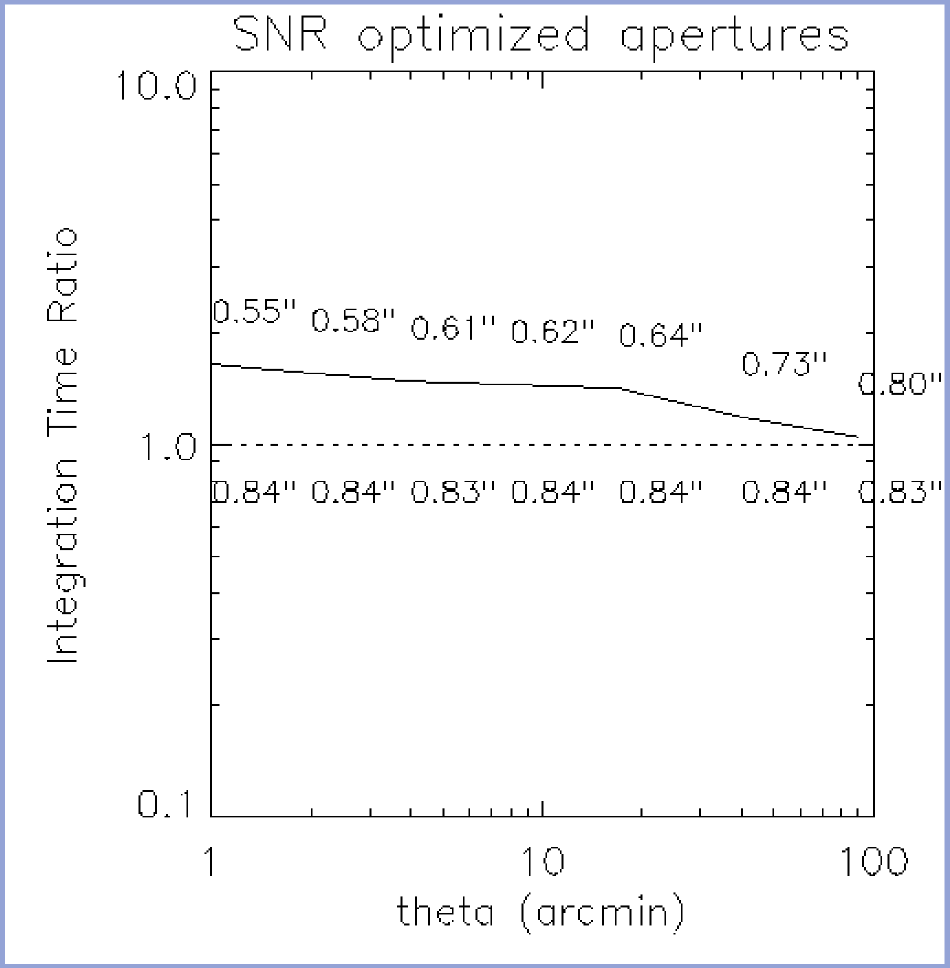
Realistic turbulence distributions



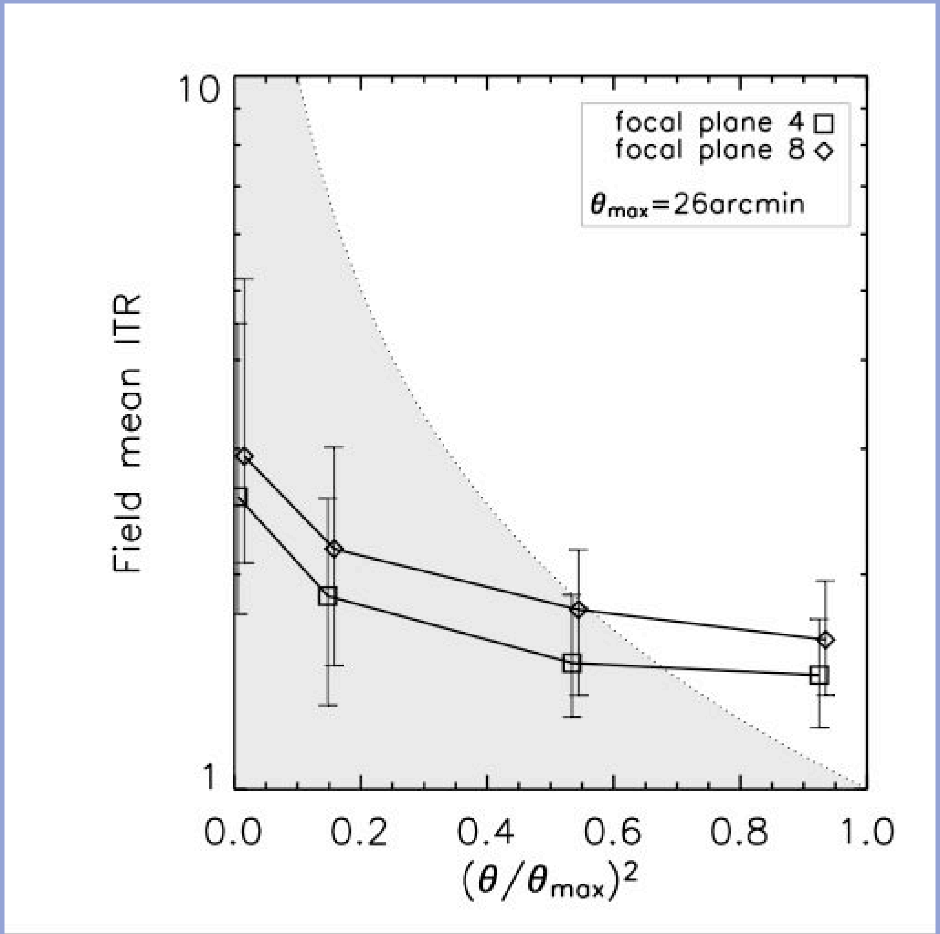
The gray zone and the Very Wide Field





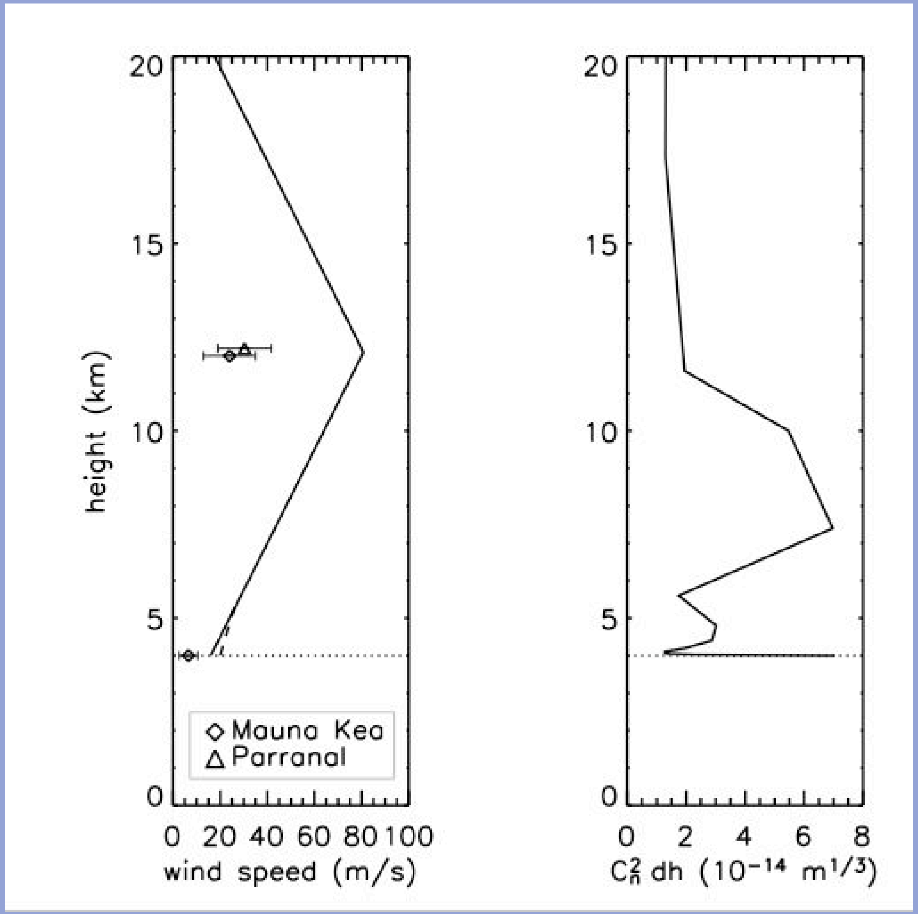
The lack of turbulence leads to a shallow ITR(θ) curve for roughly 2'<θ<20'.

The basic parameters: Δ,θ,Δt



- Solve for optimal Δ.
- The θ of the VWGLAO regime: useful gains demand the full seeing limited field of view.

Δt: GLAO does not make new demands on WFS



- The VWGLAO regime:
  - The shortest upper bound on Δt demanded to eliminate lag still provides enough WFS flux => noise and lag for these cases is negligible. => no new demands on WFS

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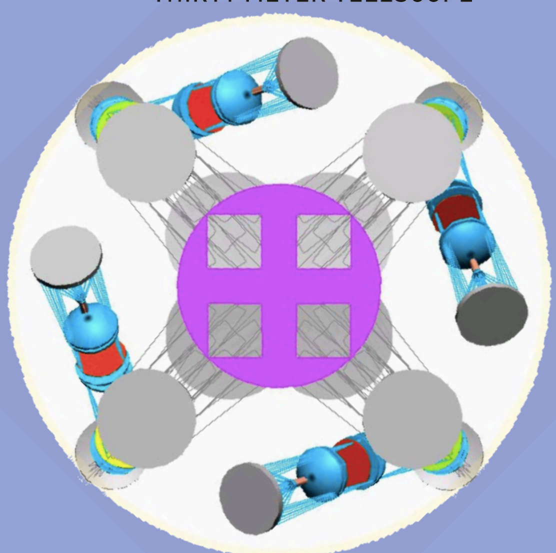
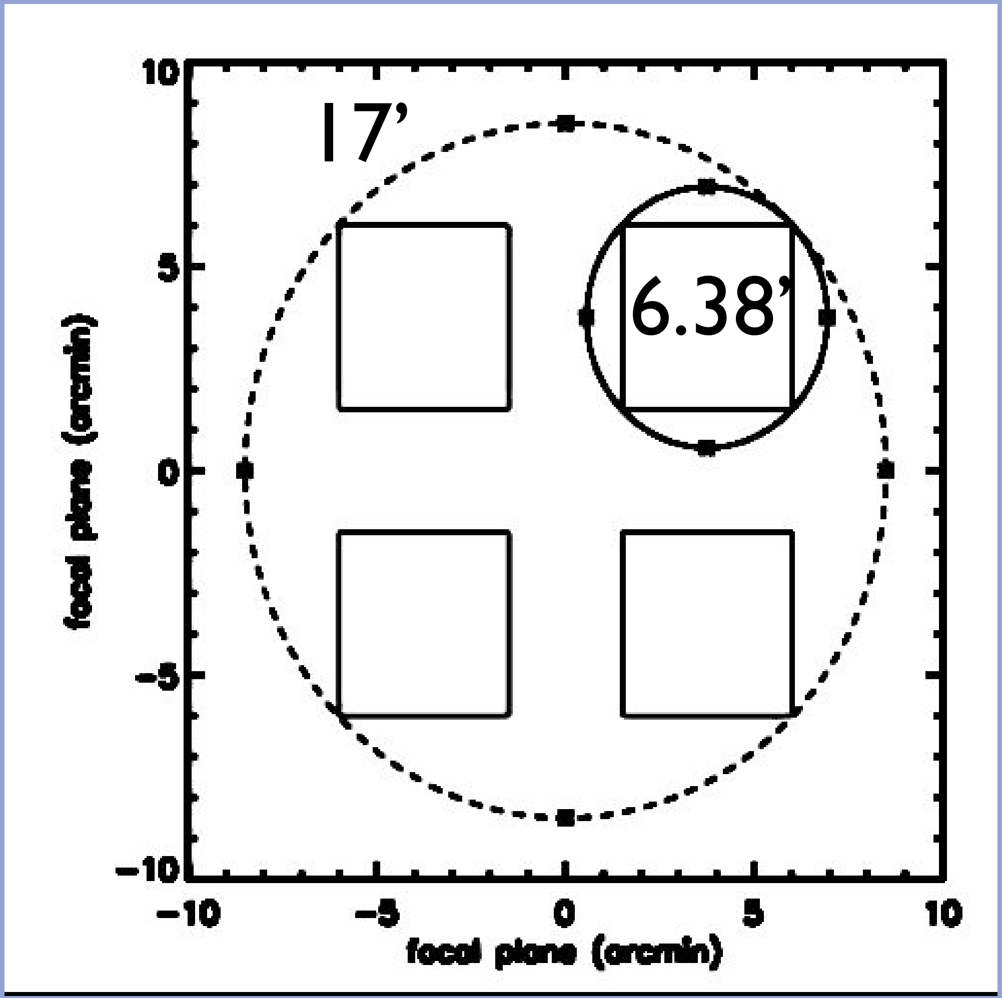
3. Identify and address design issues

- Gemini GLAO feasibility study:
  - θ set to the maximum for the telescope (10').
  - 4 laser guide stars (plus 3 tip-tilt NGS) is better than numerous natural guide stars.
  - GLAO considered a motivator for an Adaptive Secondary (AM2).

- TMT Wide Field Optical Spectrograph GLAO feasibility study:
  - AM2 is motivated by other AO instruments - GLAO for WFOS co-opts.
    - AM2 pitch and bandwidth requirements.
  - θ set to enclose required 81 square arcminute WFOS FoV (17').
  - 4 laser guide star wavefront sensors have special design issues.
    - LGS WFS NCPA correction: by electronics and optics.
    - LGS WFS and NGS WFS requirements.
    - LGS requirements.
  - WFOS-GLAO operational concept.
    - Global efficiency predictions.



Global Efficiency Predictions

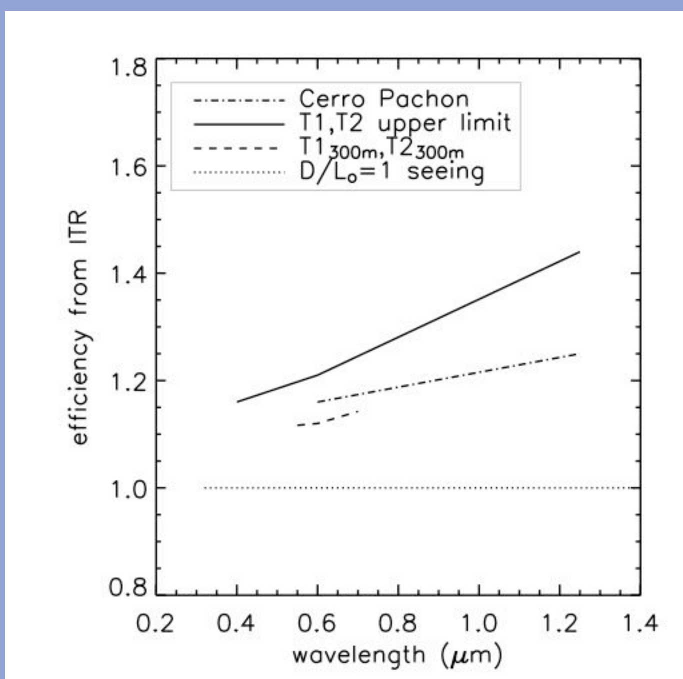


- θ=6.38' Arm-GLAO (>$12.6M, potential 27% time savings)
- θ=17' AM2-GLAO ($2.2M, potential 17% time savings)

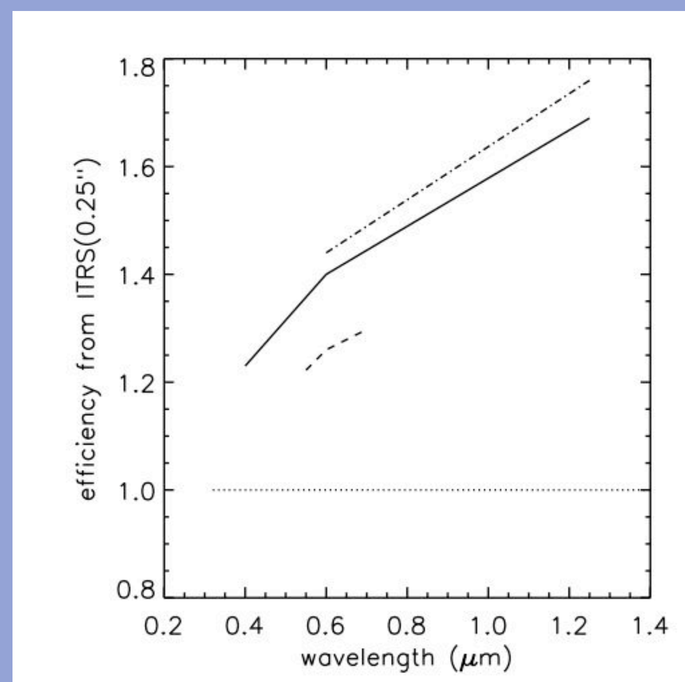
Global Efficiency Predictions

- Accounting for LGS downtime.
- Zenith angle effects are subtle for $\zeta<45$ degrees.

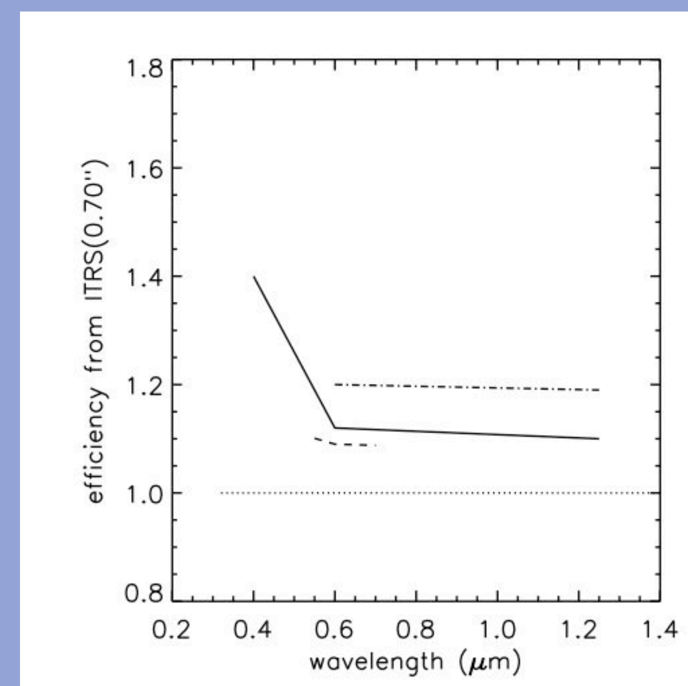
ITR $\overline{\omega}$



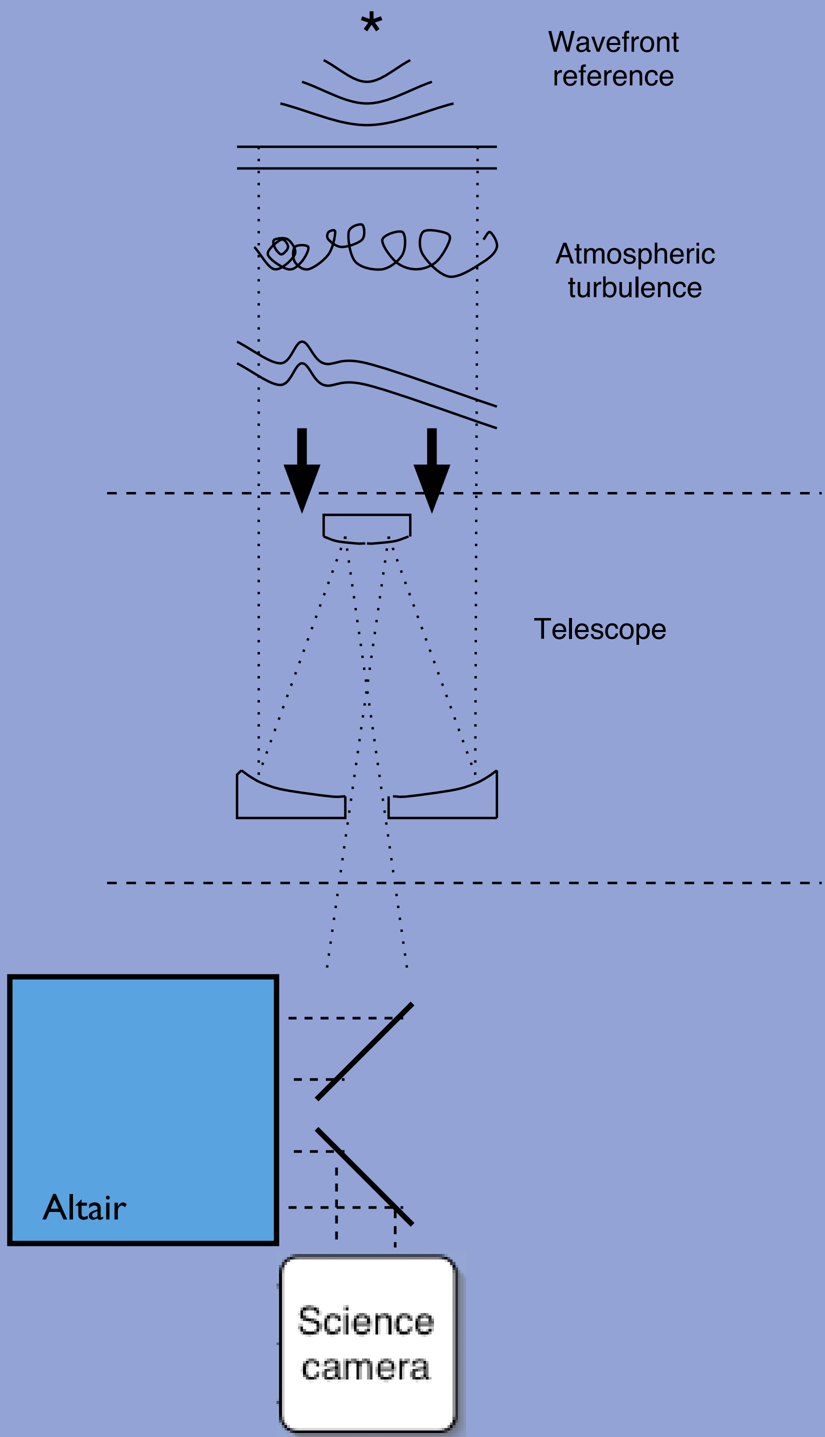
ITRS(0.25") ω

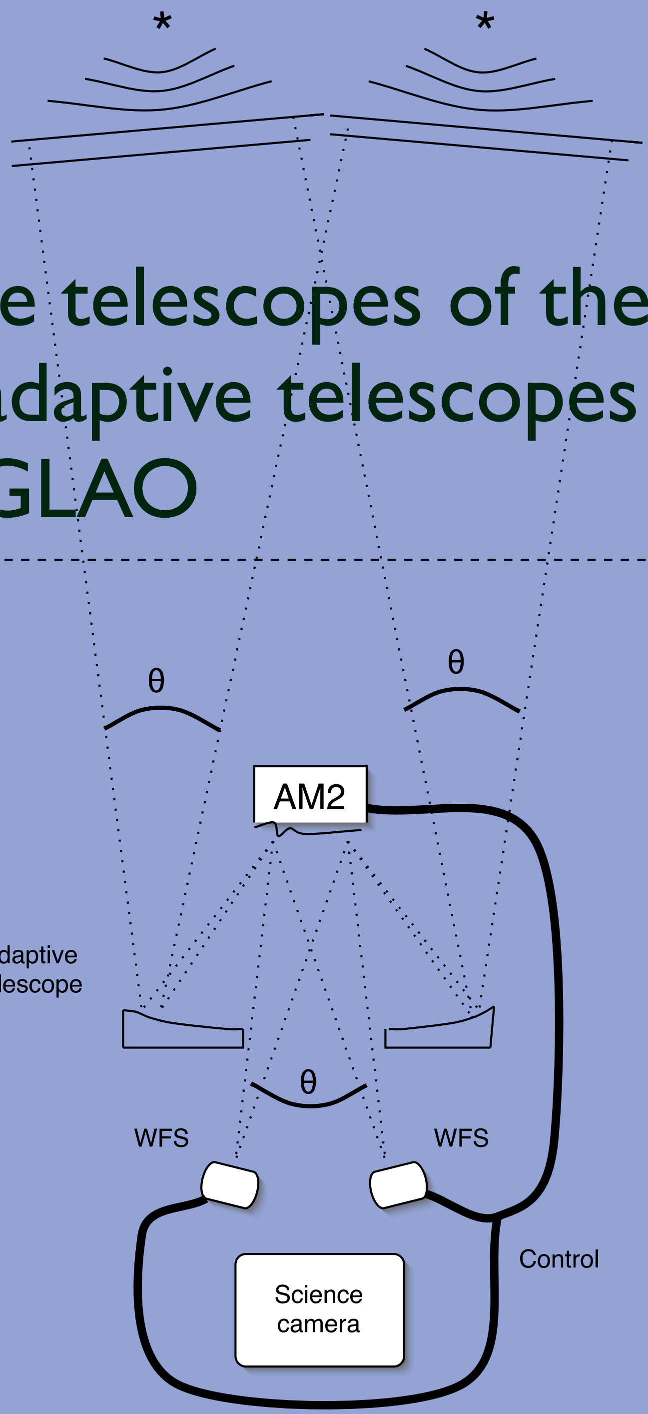


ITRS(0.70") ω

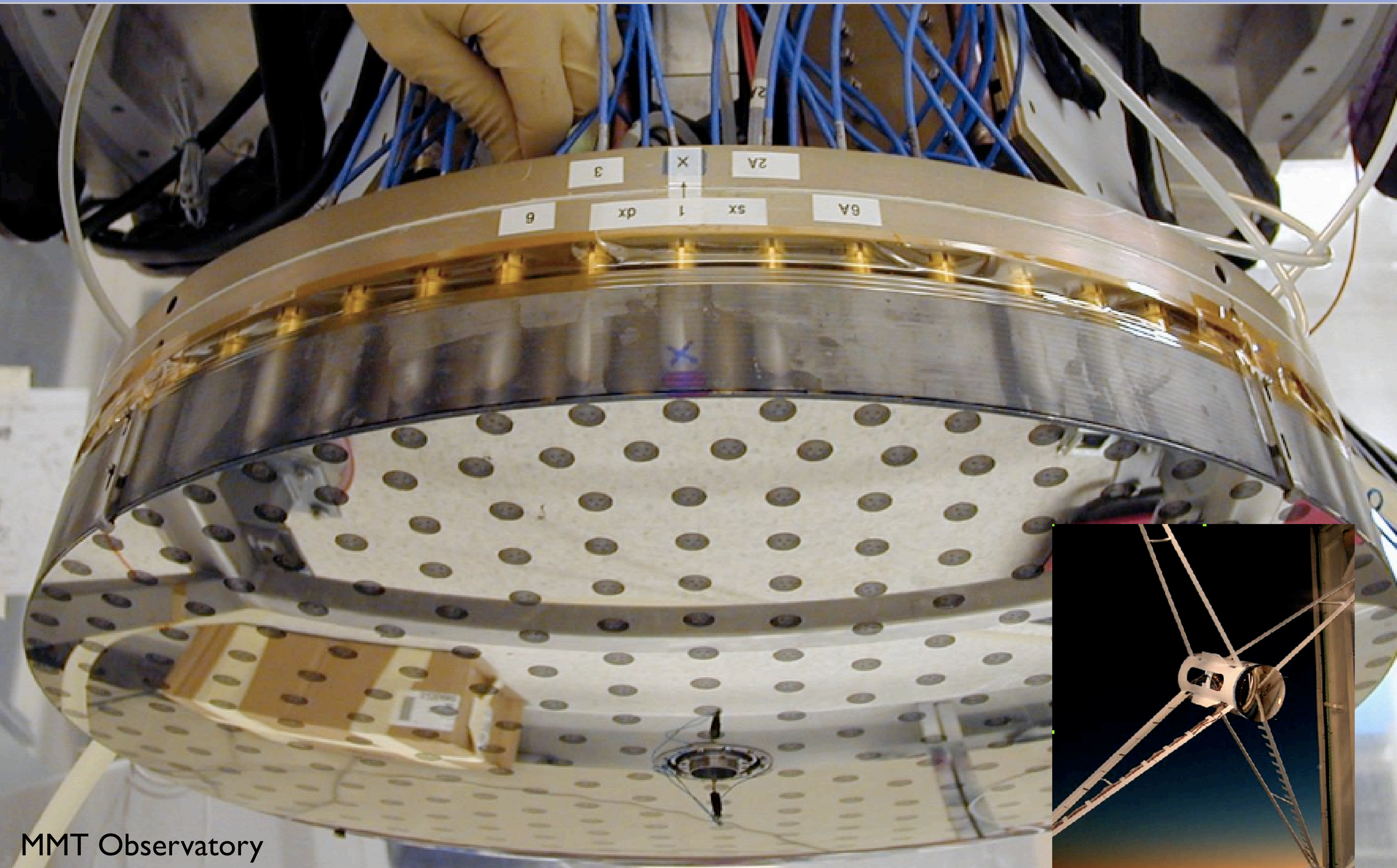


Large telescopes of the future
=> adaptive telescopes
=> GLAO





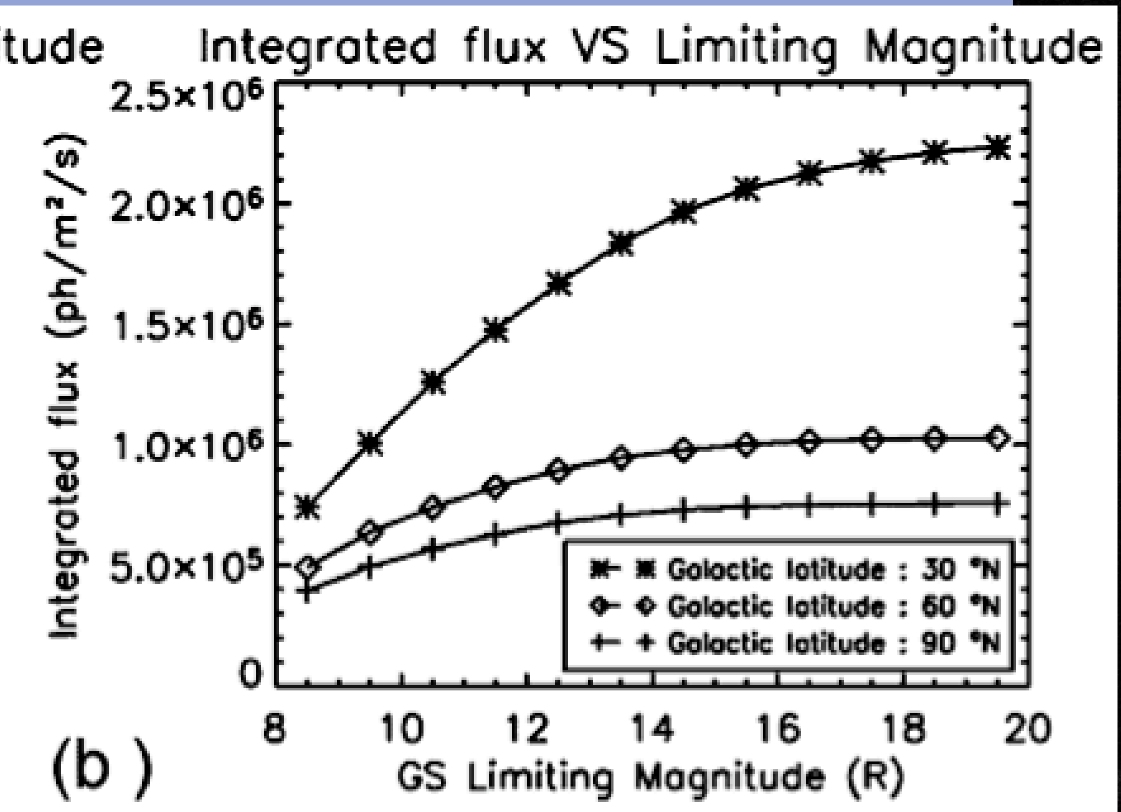
Adaptive Secondary (AM2)



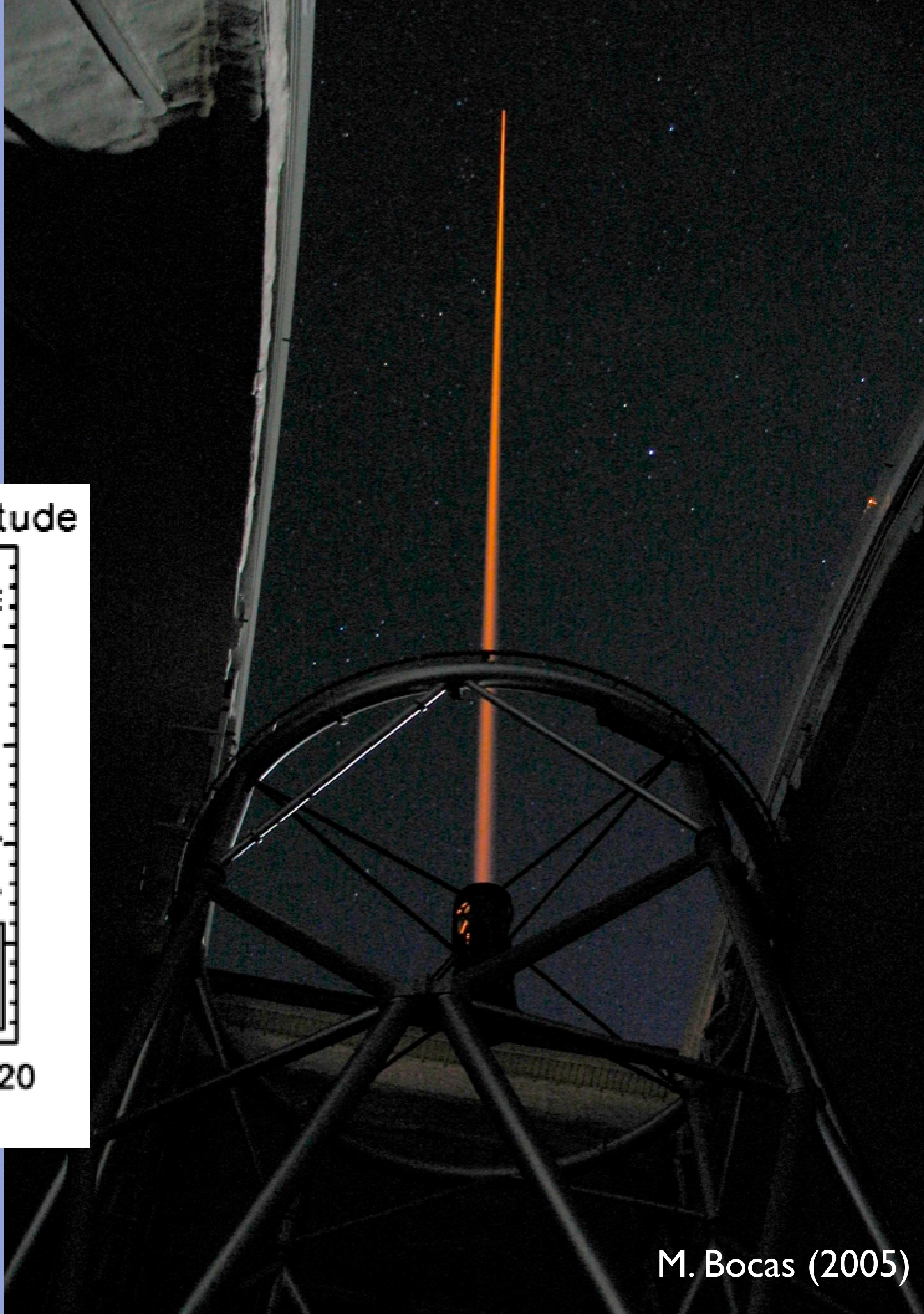
MMT Observatory

Guide Star facilities

- + Sodium LGS facilities maturing and can provide over 4×10^6 photons/m^2/s/beacon



Nicolle et al. (2006)

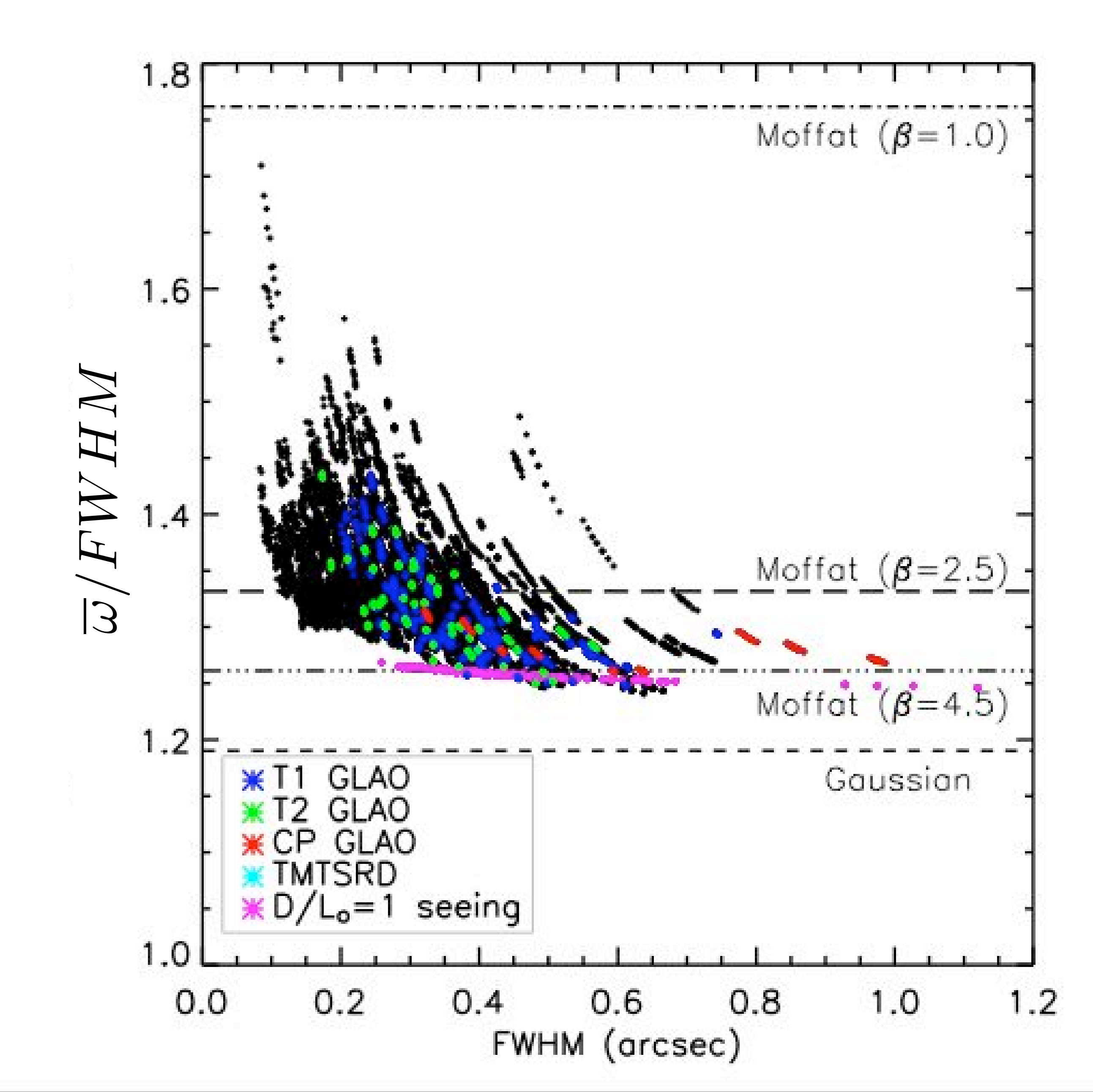


M. Bocas (2005)

Future GLAO Modeling Development

- Use atmospheric models as input to the PSD: outer scale and other non-Kolmogorov effects, Cn2 profile statistics near the ground (SODAR, G-SCIDAR, SHABAR).
- Enhance the semi-analytic PSF models to account for: aberrations affecting blue and UV performance, real actuator geometries, lag optimization, large telescope wind shake, etc..
- Not only for feasibility and trade studies. Eventually....

GLAO PSF morphology

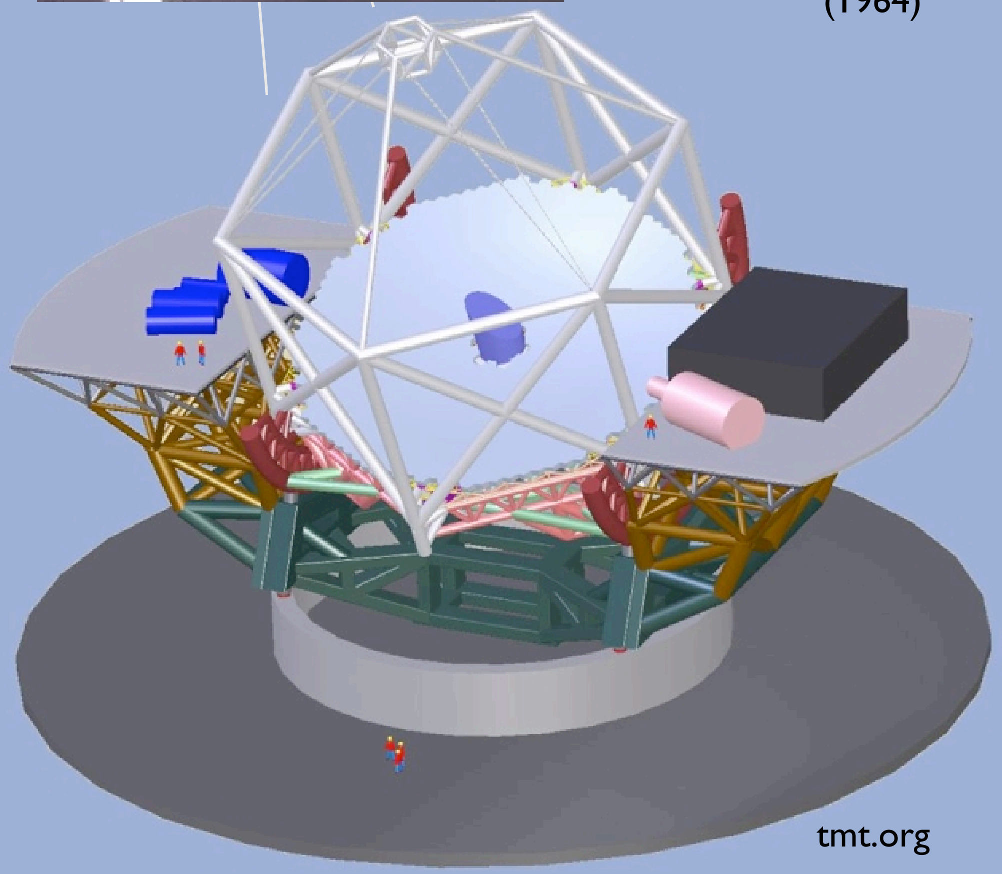


Future GLAO PSF Modeling

- Large adaptive telescopes will have a GLAO mode rather than the seeing-limited mode as we know it now.
- Data from adaptive telescopes of the future will include measurement of atmospheric parameters.
- GLAO PSF models will be used in data reduction from the next generation of Wide Field instruments.

http://grus.berkeley.edu/~jrg/SEEING/node3.html

Dr. Strangelove, Kubrick (1964)



tmt.org