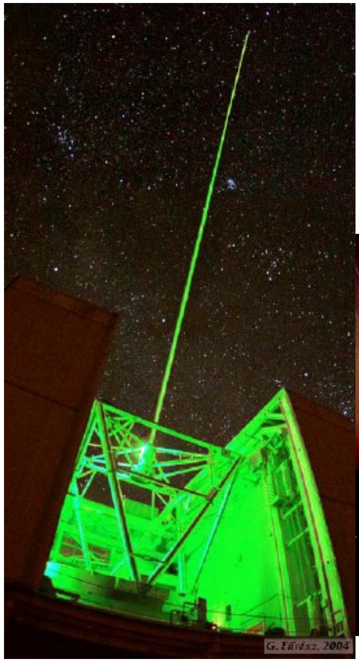
A Laser Guide Star Facility for LBT

L. Busoni



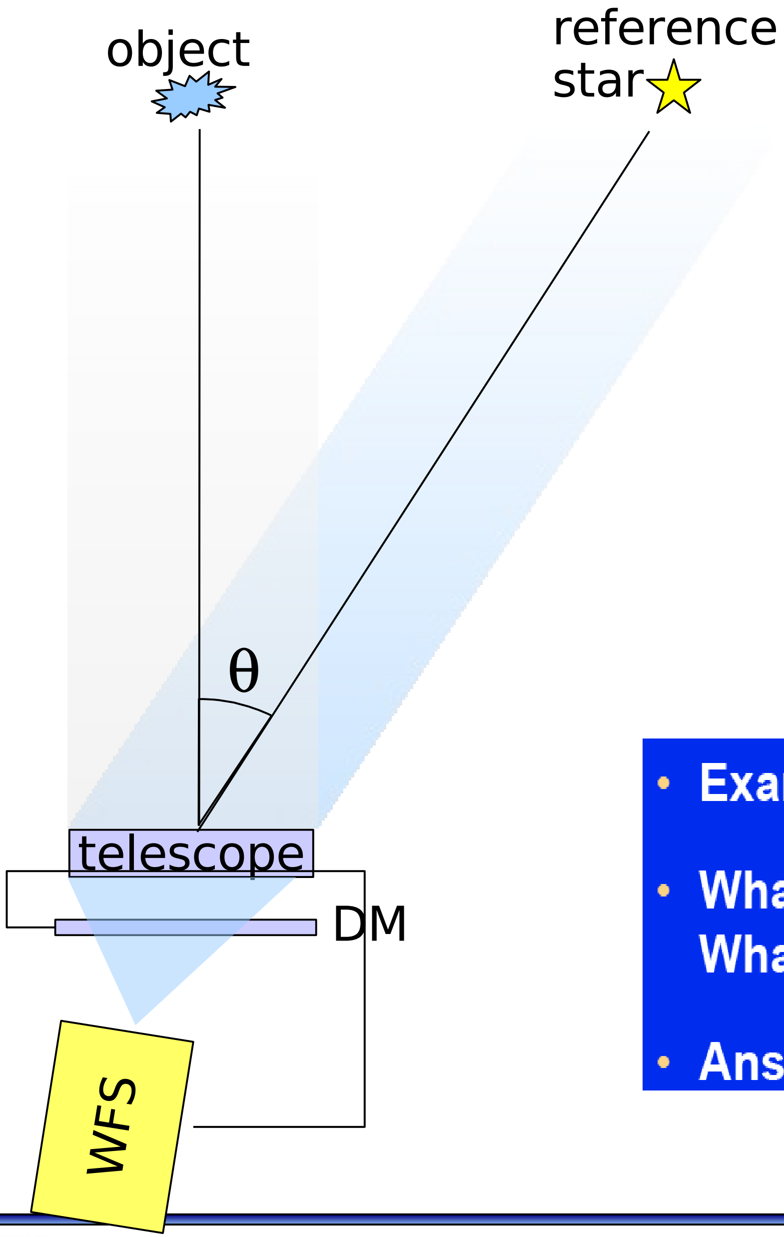
MPE

CAAO Center for Astronomical Adaptive Optics

AIP

LARGE BINOCULAR TELESCOPE

Why are LGS needed?



Anisoplanatism error

$$\sigma_\phi^2 = \left(\frac{\theta}{\theta_0}\right)^{5/3} \qquad \theta_0 \cong 0.314\left(\frac{r_0}{\bar{h}}\right)$$

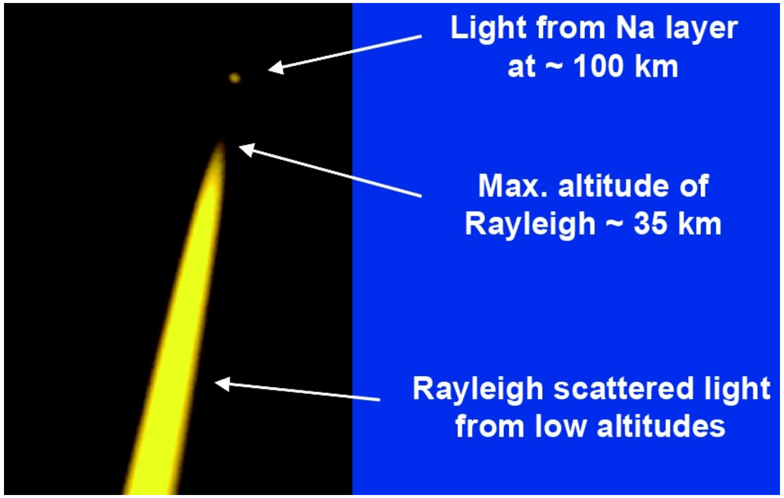
$$\bar{h} \equiv \left(\frac{\int z^{5/3} dz\, C_N^2(z)}{\int dz\, C_N^2(z)}\right)^{3/5}$$

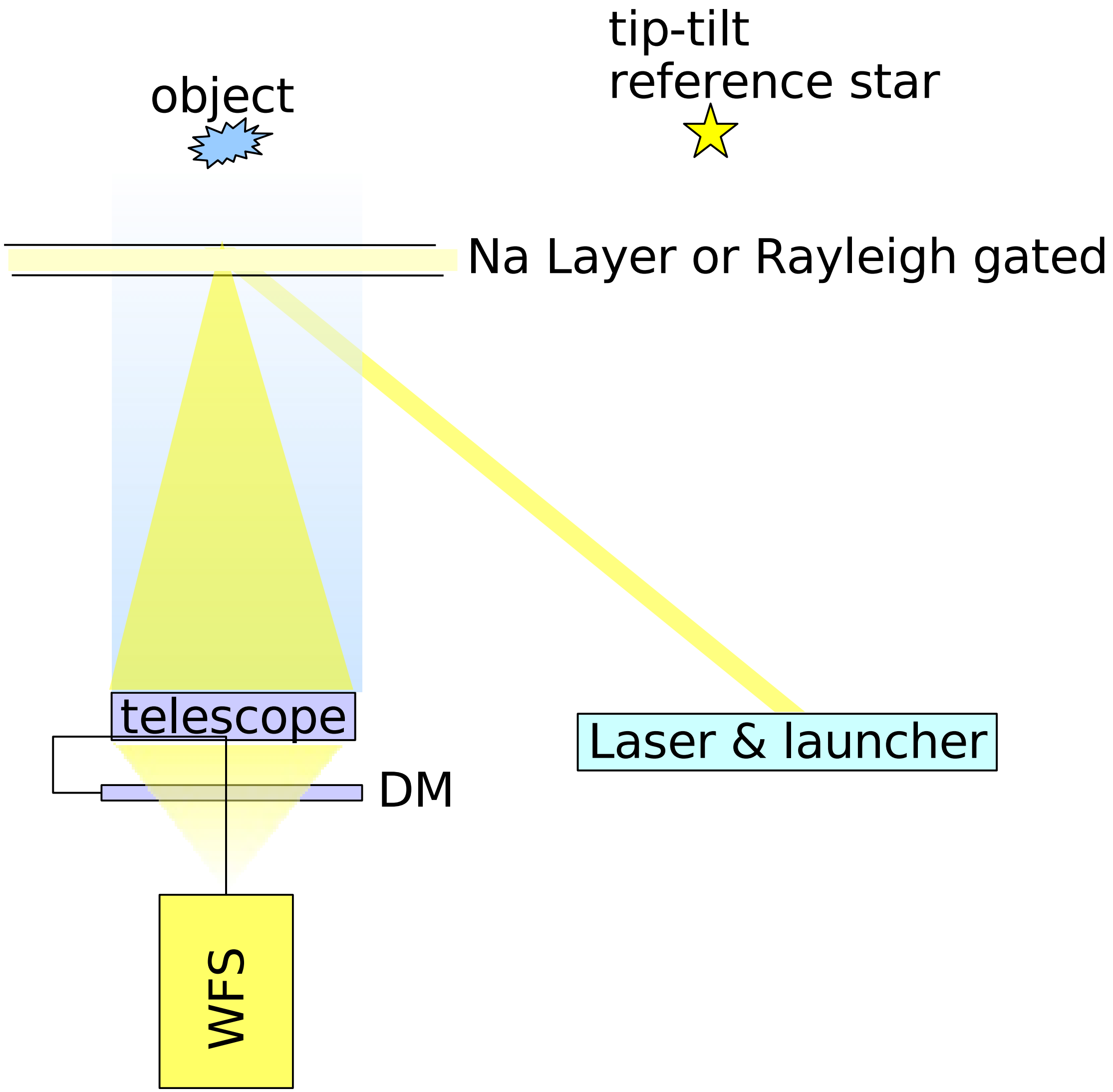
- **Example: At Keck θ_0 ~ 10 arc sec x (λ / 0.5 micron)$^{6/5}$**
- **What is σ_ϕ^2 for θ = 40 arc sec at λ = 1 micron?**
  What is Strehl due to anisoplanatism?
- **Answers: σ_ϕ^2 = 2.52 rad^2, Strehl = 0.08 x Strehl at $\theta = 0$**

A Laser Guide Star Facility

1) Laser and launcher optics

2) Wave Front Sensor and DM





Rayleigh vs Sodium

Sodium laser: resonance scattering of the sodium laser at 90km.

Pros: less cone effect, whole atmosphere sampled

Cons: need a 589nm laser, technology not proved and/or expensive

Rayleigh: elastic scattering from atoms and molecules in the atmosphere

Pros: technology available

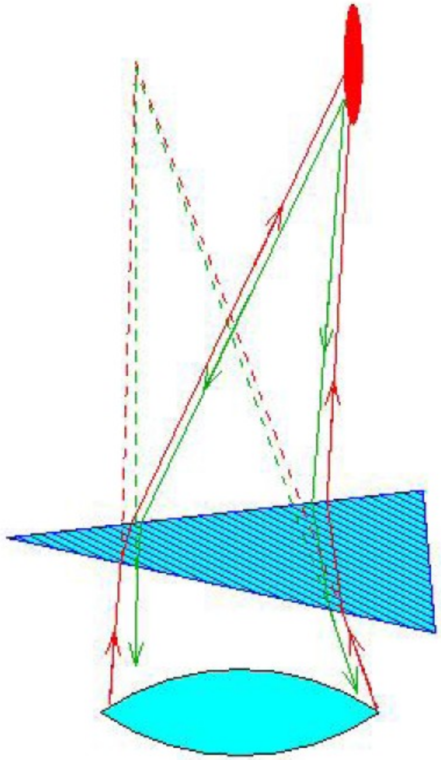
Cons: <12Km. gating required, optics more challenging

New: follow an upgoing rayleigh beacon by dynamical refocusing (MMT)

3 bad news

1) Tip-Tilt indetermination

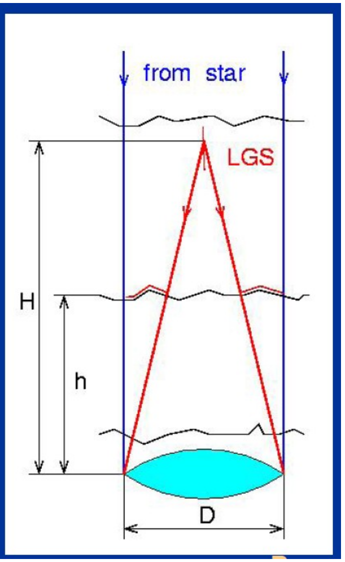
Sky coverage < 100%



$$\sigma_{tilt}^2 = (\theta / \theta_{tilt})^{5/3}$$

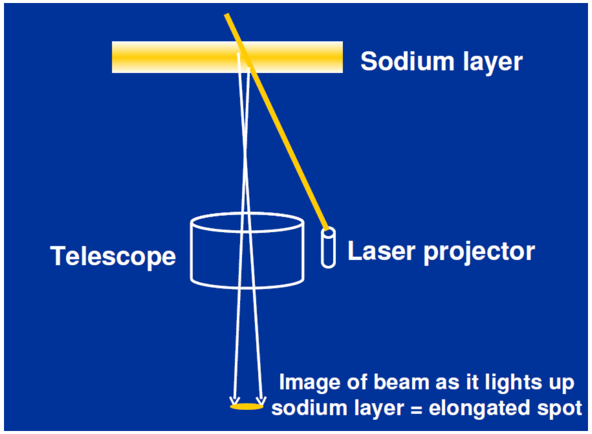
2) Cone effect

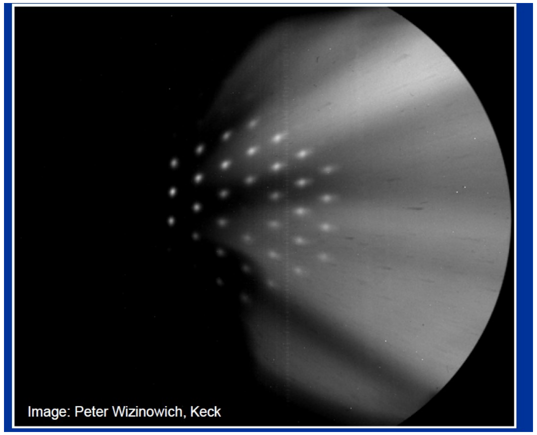
- Two contributions:
  - Unsensed turbulence above height of guide star
  - Geometrical effect of unsampled turbulence at edge of pupil



$$\sigma_{FA}^2 = (D / d_0)^{5/3}$$

3) Spot elongation





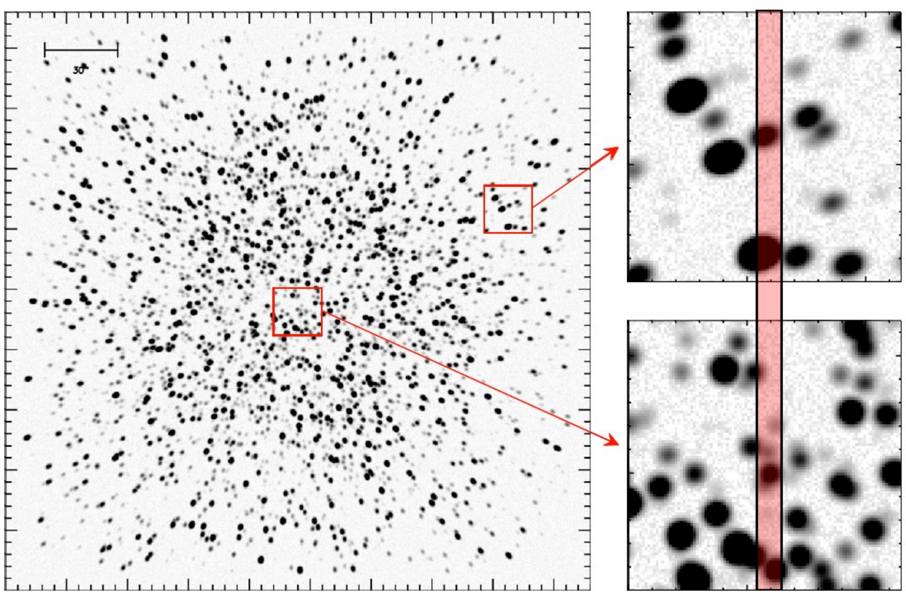
$$\sigma_{meas}^2 \sim (\theta_b / SNR)^2$$

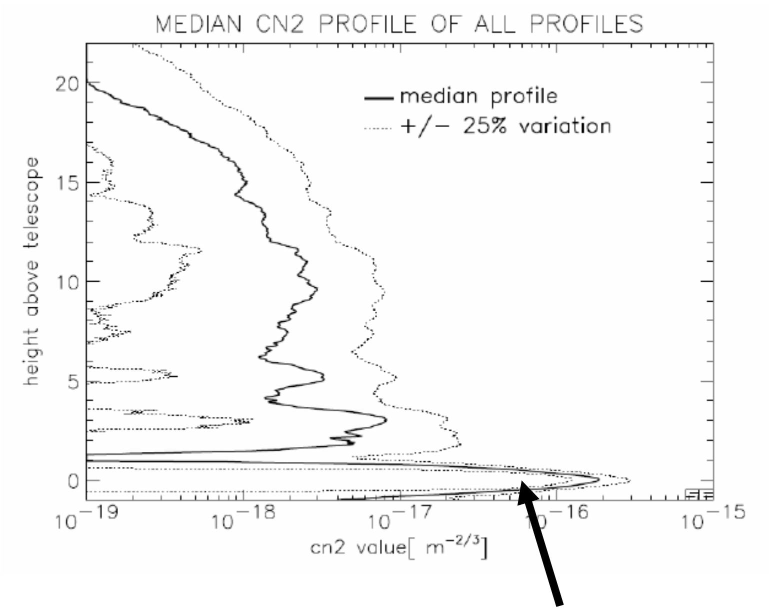
Who really needs to be diffraction limited?

Sometimes the uniformity of PSF over the FoV is more important than high SR.

Ground Layer AO provides low correction, uniformity over the FoV and stability over seeing variations.

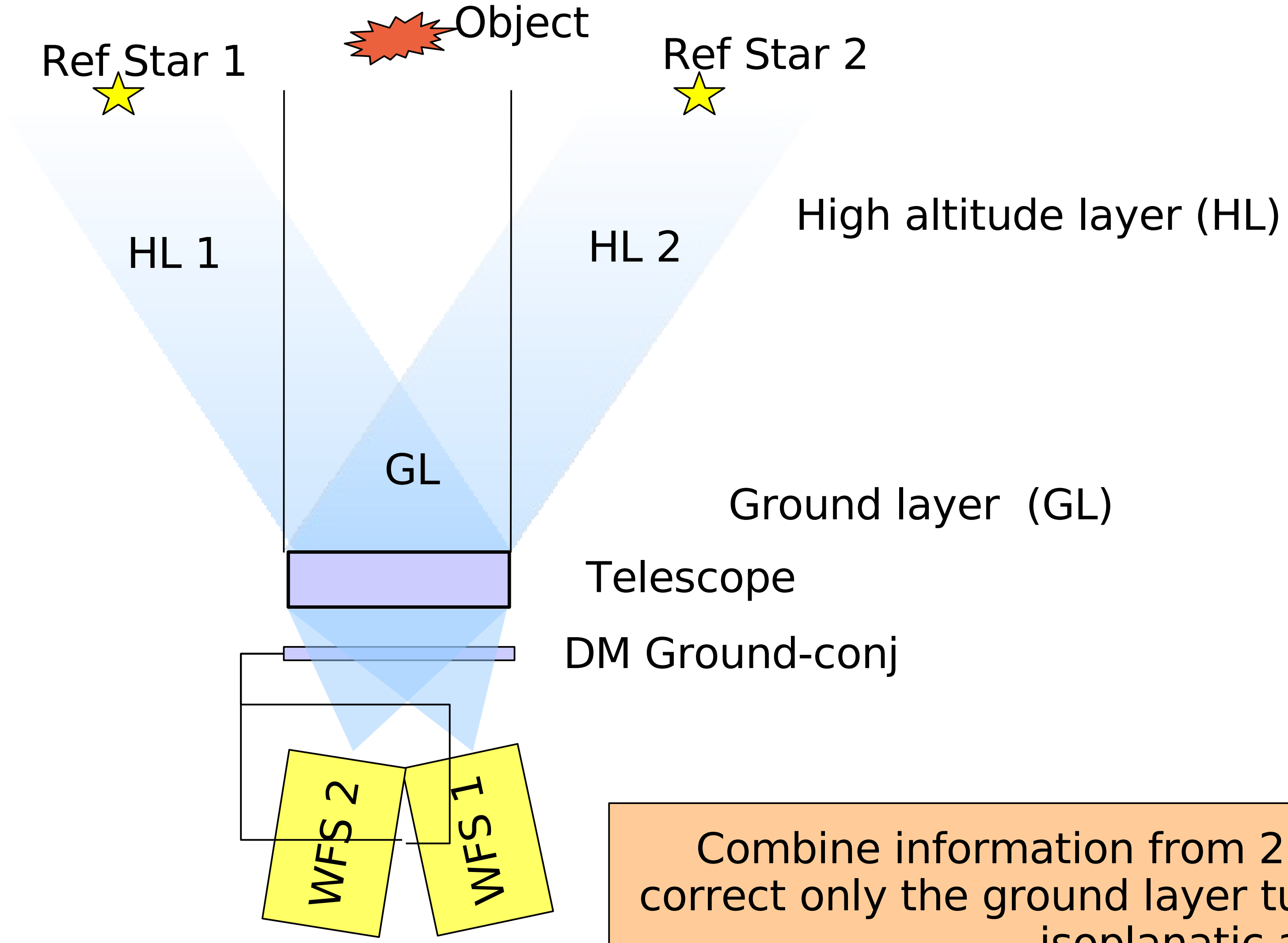
GLAO exploit the strong turbolent ground layer to reduce anisoplanatism





Strong GL often seen

Ground Layer AO



WFS1 = GL + HL1

WFS2 = GL + HL2

$\langle HL1 + HL2 \rangle = 0$

WFS1+WFS2 = GL

Combine information from 2 or more directions to correct only the ground layer turbolence increasing the isoplanatic angle

LBT LGS Phase A study

Unanimous consensus on program goals amongst LBT partners:

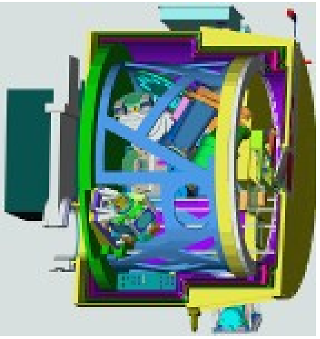
- exploit the scientific competitive edge of LUCIFER MOS and widefield imaging
- need reliable, low maintenance system with low risks, minimize changes to existing telescope systems
- **promptly** realize ground-layer system (GLAO): ~4'FOV, factor ≥2 improvement in FWHM and ≥3 in concentration, operability significantly above median seeing
- identify upgrade path to on-axis diffraction limited performance (=SCAO)
- identify upgrade path to wide-field, modest Strehl, diffraction limited operation (=MCAO)

WFS should not require immediate re-design of AGW units

6 months phase A study started september 2007

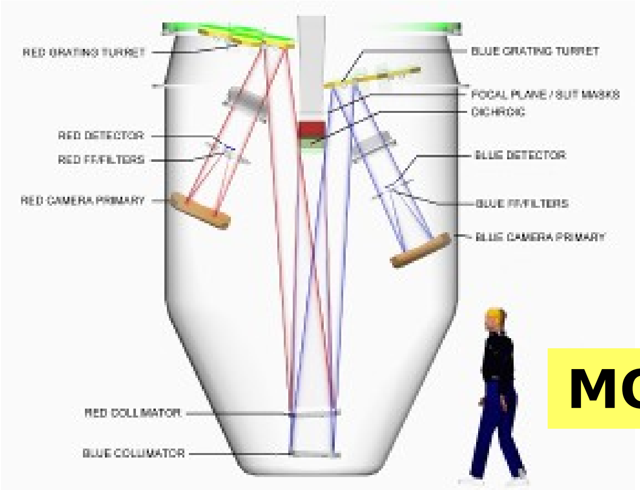
LBT instruments

LUCIFER



Mode	Seeing Limited		Diffraction Limited
Camera	N3.75	N1.8	N30
FOV	4 x 4 arcmin	4 x 4 arcmin	0.5 x 0.5 arcmin
f_{Coll}	1500 mm	1500 mm	1500 mm
f_{Cam}	375 mm	180 mm	3000 mm
N_{Cam}	3.75	1.80	30
f_{eff}	30940 mm	14850 mm	247540 mm
Scale	0.12 arcsec/pixel	0.25 arcsec/pixel	0.015 arcsec/pixel
Beam diameter	102 mm	102 mm	102 mm
Slit length	up to 4 arcmin	up to 4 arcmin	$\leq$ 0.5 arcmin
R_{lim}	10000 (0.24 arcsec slit)	5000 (0.50 arcsec slit)	
FSR (K band)	0.22 μ	0.46 μ	
R_{lim} (K)			20600 (0.137 arcsec slit)
R_{lim} (H)			28200 (0.100 arcsec slit)
R_{lim} (J)			37100 (0.076 arcsec slit)

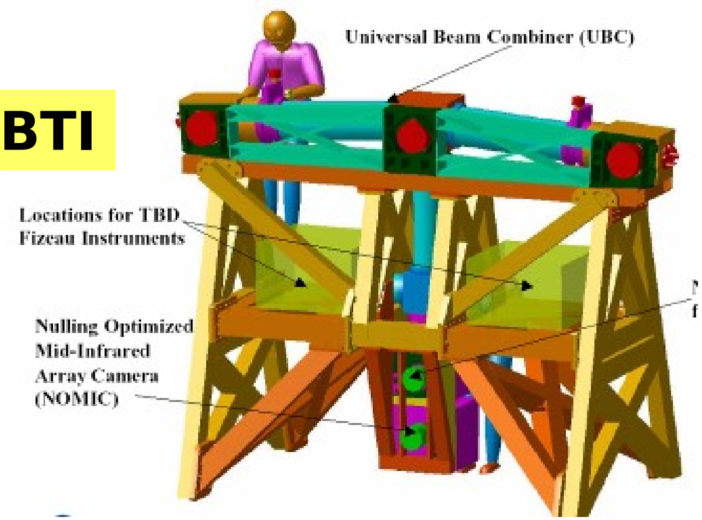
Table 2: Basic data for the instrument in seeing and diffraction limited mode.



MODS

- **Imaging across the 330-1100nm band, 6'x 6', 0.15 arcsec/pix**
- **MOS mode: 25-position mask cassette, slitlets over ~ 4'x 4'**

LBTI

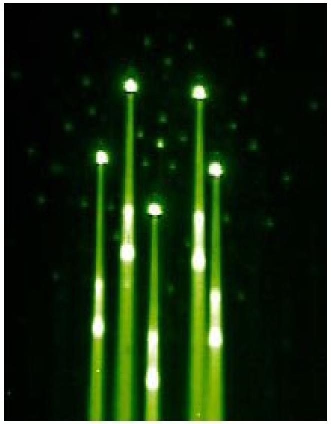


Phase A study: content

- Science case study
- LBT site characterization
- Simulation of LGS-AO performance *
- Laser system identification
- GLAO Wavefront sensor *
- Impact on telescope and LBT requirements
- Management items
- Identification of upgrade path to DL and MCAO *

* Arcetri work packages

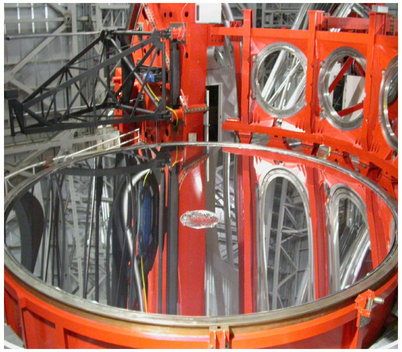
System possibilities under discussion

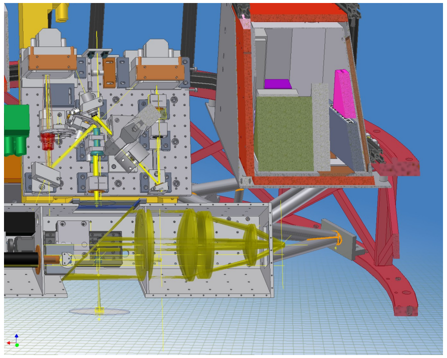



	SR-LGS	MR-LGS	S-LGS	MS-LGS
	Single Rayleigh LGS: gated at low altitude	Multiple Rayleigh stars, low or high altitude	Single Sodium	Multiple Sodium
On-axis performance	Medium	Medium	High	High
Homogenity	Medium	High	Low	High
Tech. Risk	Optics/ Detectors	Optics/ Detectors	Laser	Laser

How to fit the LGSF into LBT

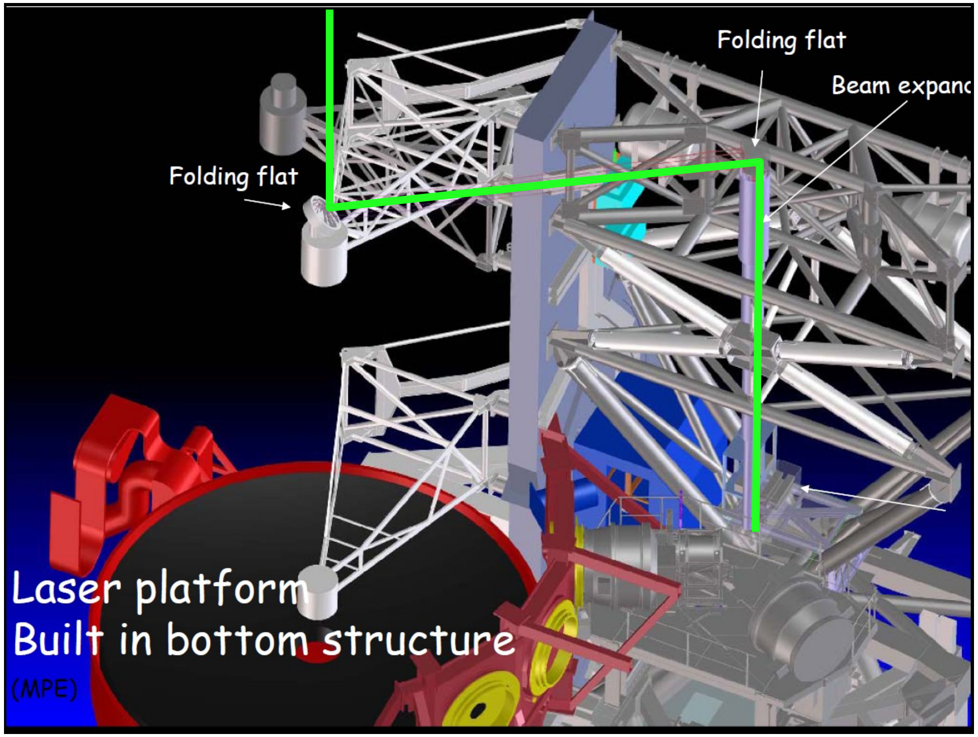
2 proposed solutions for
the LGS WFS



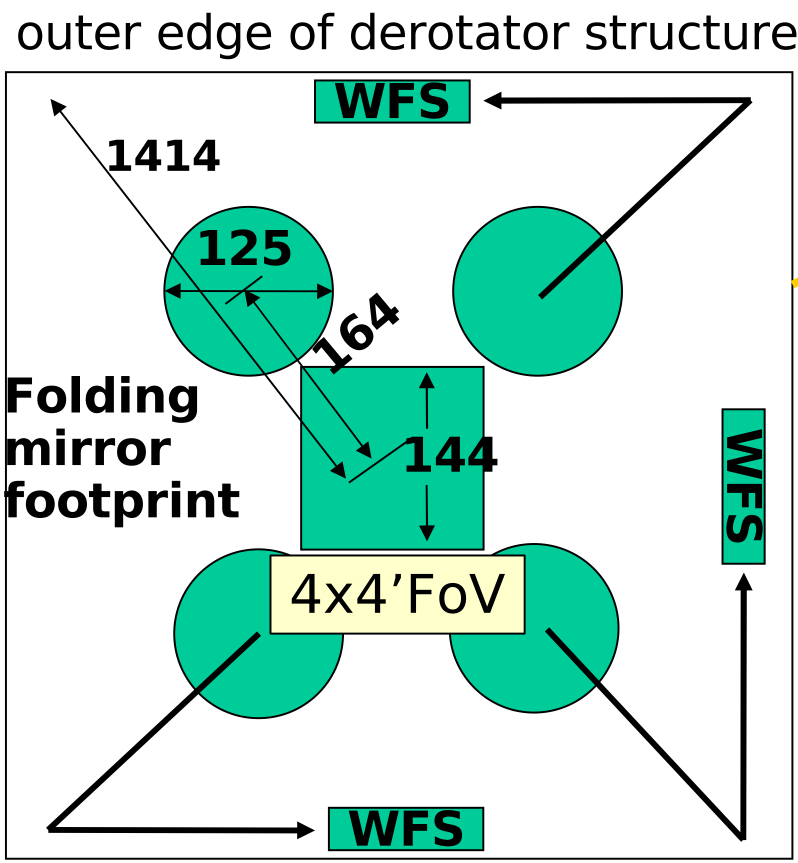


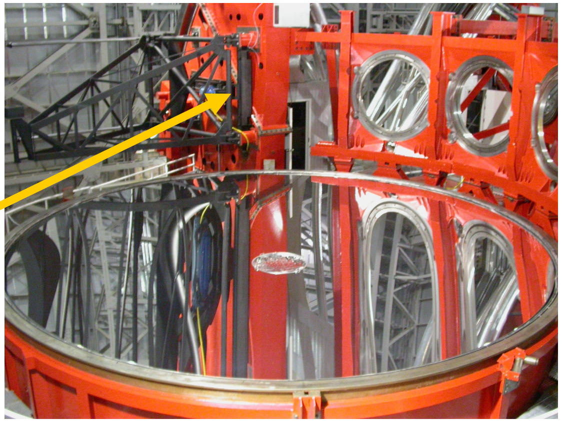
Na-WFS can be placed in the existing AGW

No problem for the launchers

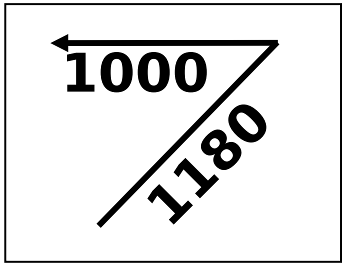


Rayleigh WFS arrangement



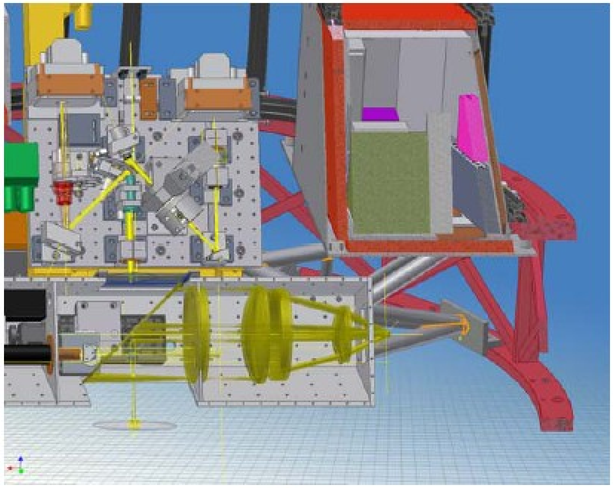


Mirrors at 4'.5 from center. Some vignetting close to the FMs of the 4x4 arcmin FoV. NGS beam width is 39mm.

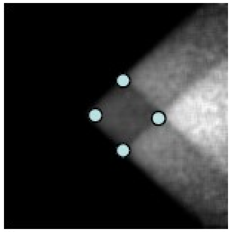


Total track for RB 2006mm F/16.6
Total track for SB 758mm F/15.2
Total track for NGS 585mm F/15

Sodium WFS fits in the AGW

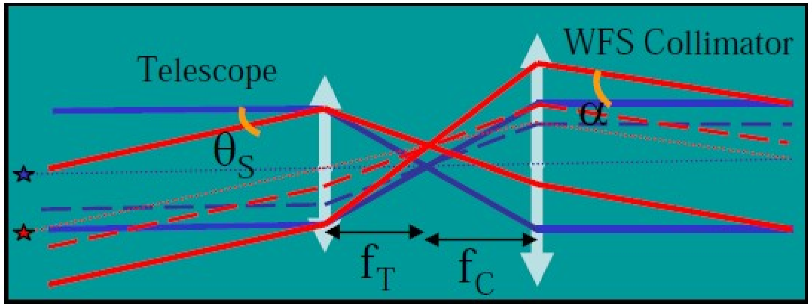


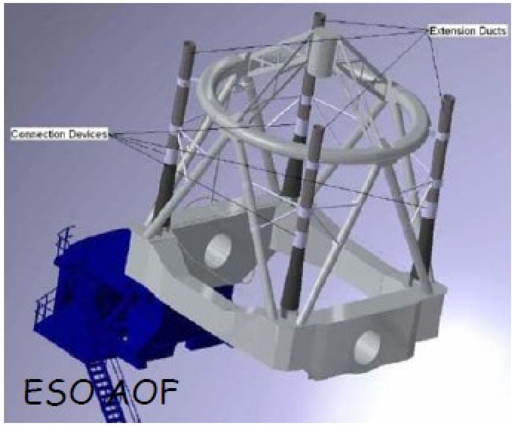
Layer oriented Shack Hartmann could fit in AGW unit



Fracticide of four off-axis sodium stars

- Requires high power 589nm laser
- Off axis launch facility needed
- Layer oriented, or tomographic sensing possible





Aim of the simulations

Comparison of some possible **configurations** of a GLAO system for LBT using the existing AGW unit

Parameters:

- Asterism (# of LGS, angular separation, gating)
- Laser source (Rayleigh vs Sodium, power)
- Launchers (geometry, fratricide effect, spot elongation)
- WFS (# subapertures, FoV)
- Atmospheric profiles

Simulation code

Full-wave propagation MonteCarlo code

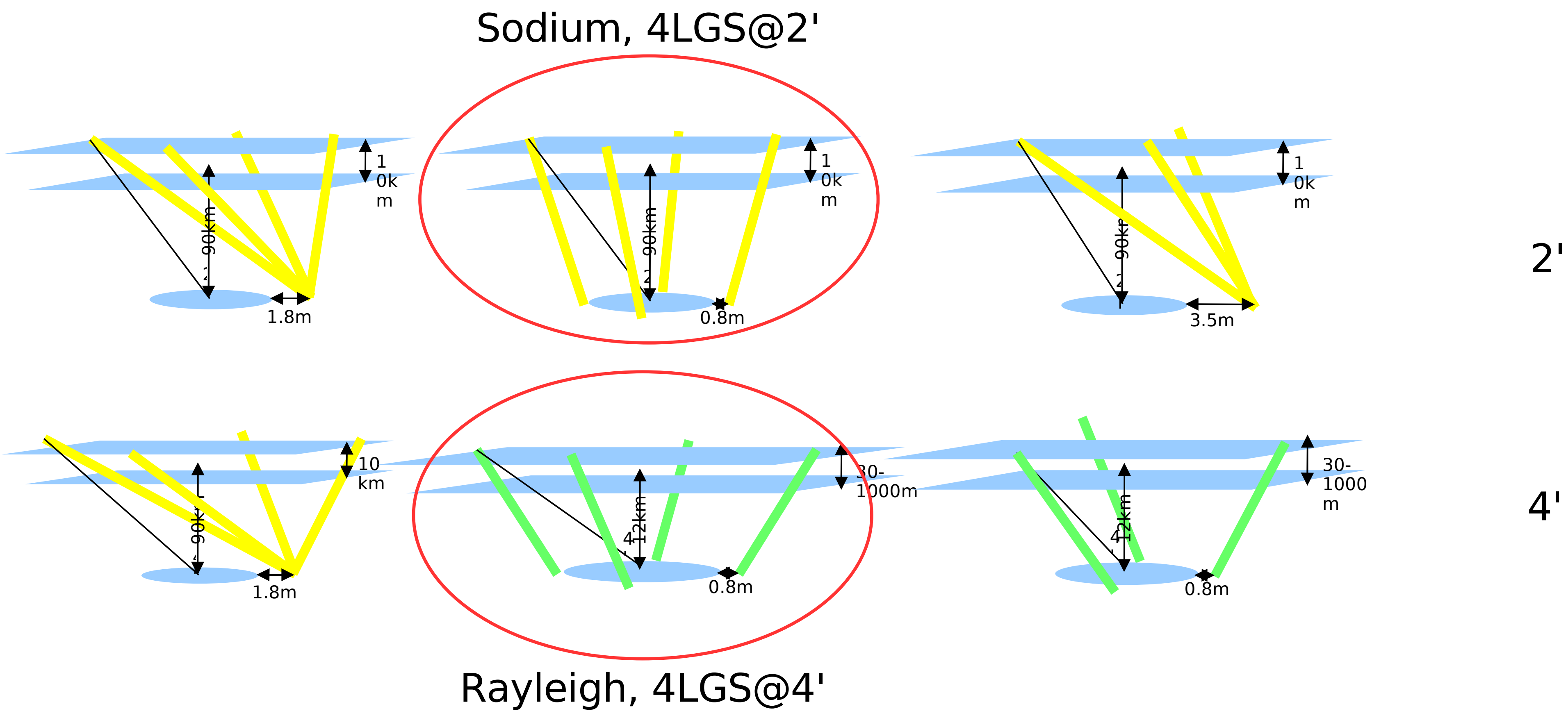
Taken into account:

- cone effect
- GLAO SH optical recombination of the beams on a single detector
- Diffraction theory simulation for SH sensor
- photon noise
- fratricide effect
- spot elongation on each subaperture

Other simulation characteristic:

- Open loop
- Tip-tilt measured on LGS
- Perfect mirror (but 672 actuators and 150 modes)

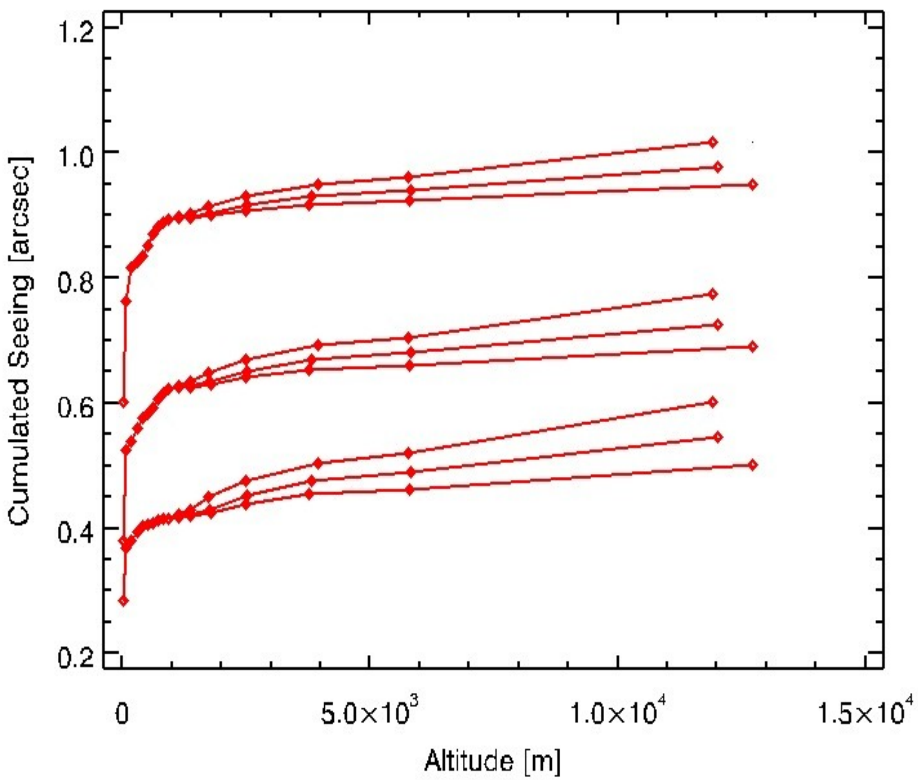
Simulated Configurations



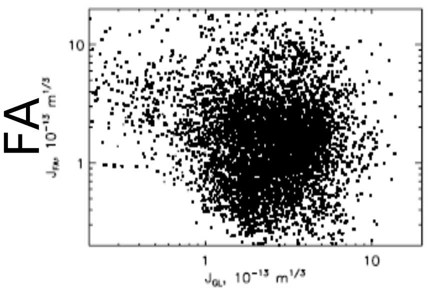
Atmospheric profiles

height [m]	r0 [m]		
	25%	50%	75%
10	0.17	0.27	0.35
78	0.26	0.33	0.52
184.5	0.48	1.24	1.47
291	1.27	0.99	1.47
397	1.30	1.04	1.82
503	0.92	2.11	4.79
609.5	0.86	1.47	3.34
716	1.18	1.24	2.86
822	1.63	1.37	3.97
928	1.62	1.78	4.79
1125	2.35	3.16	4.54
1375	1.93	3.82	5.80
1786	1.10	1.93	2.31
2496	0.89	0.99	1.35
3767	0.85	0.97	1.30
5783	1.14	1.30	1.75
12728	0.42	0.55	0.69

data from S.Egner, Jeff Stoesz. G-Scidar @ VATT

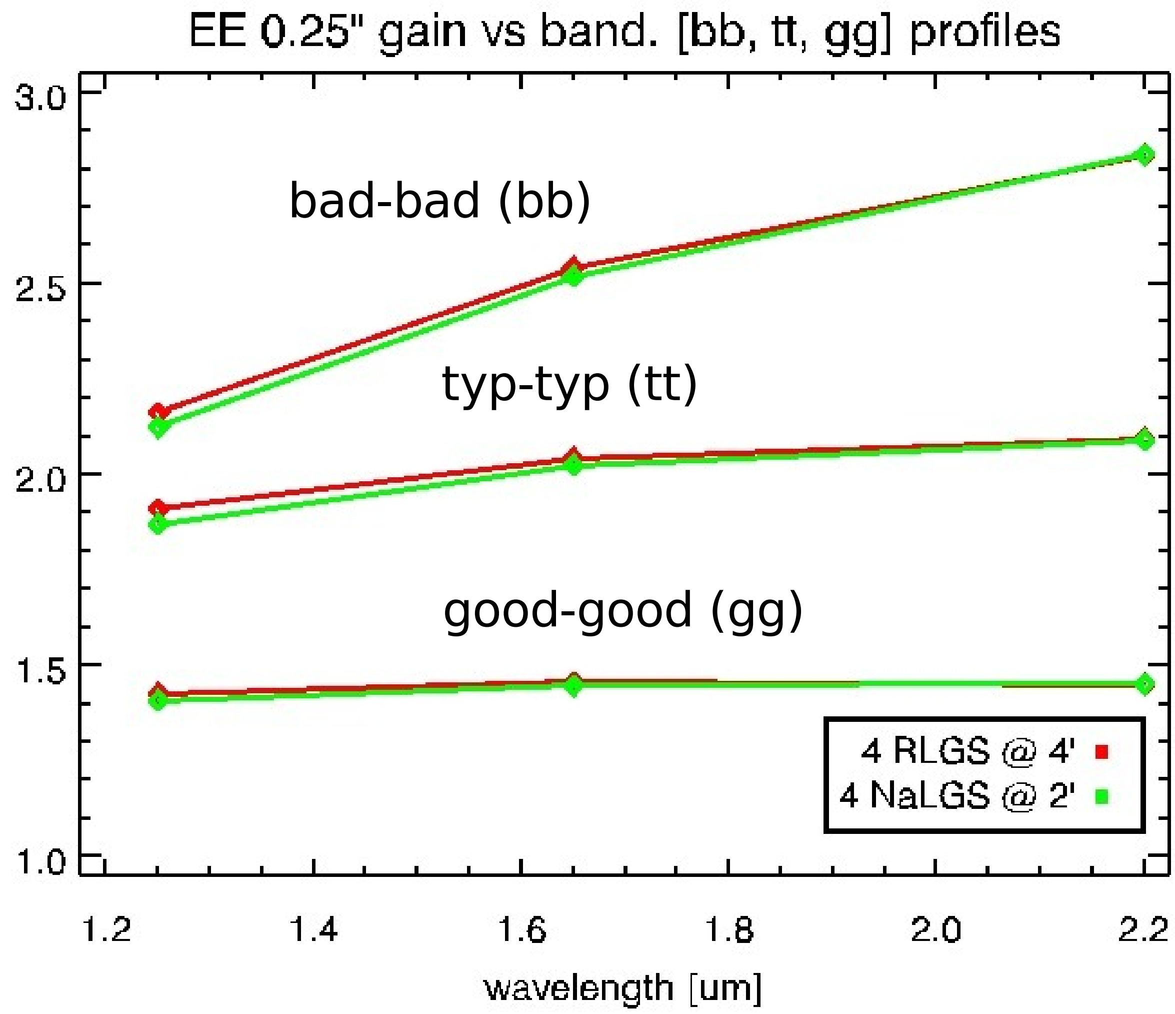


FA

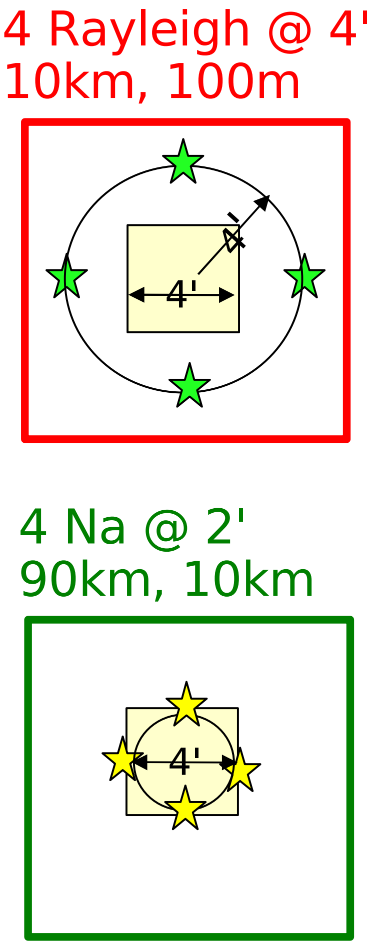


GL

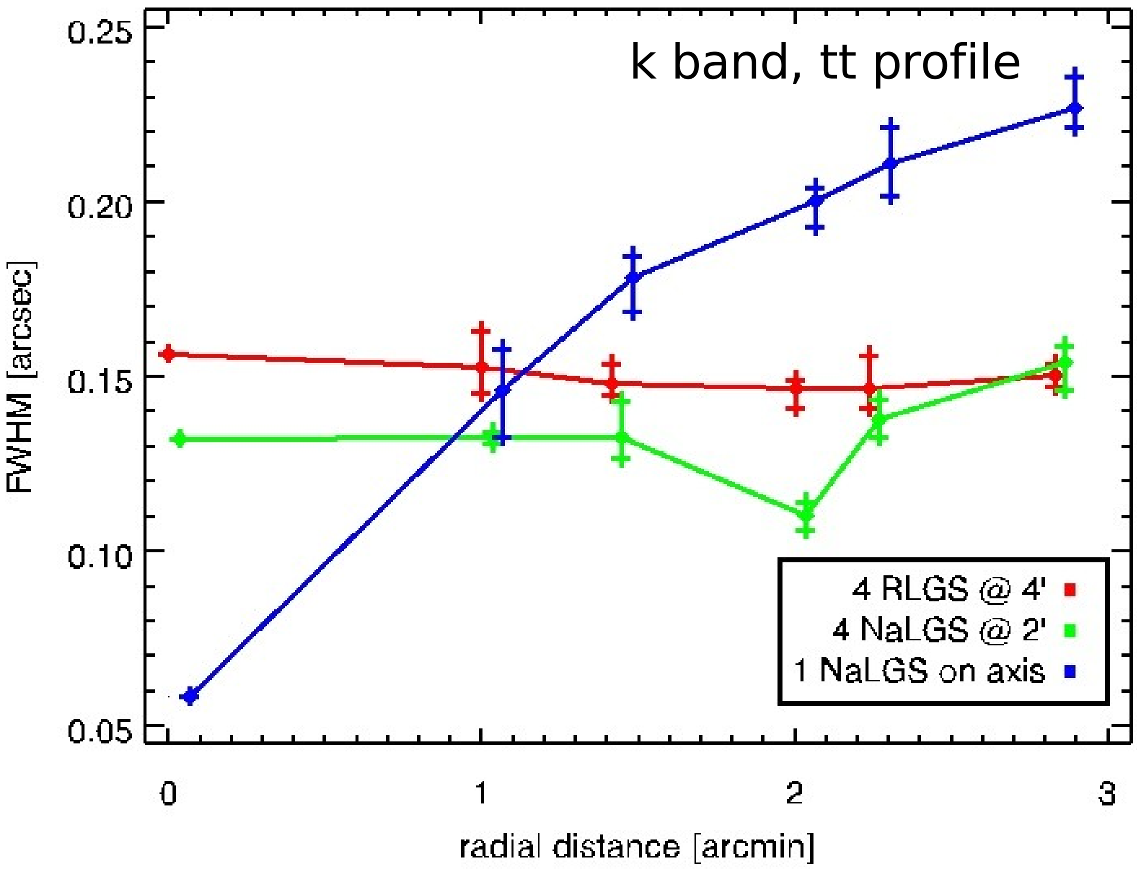
GLAO performance: EE

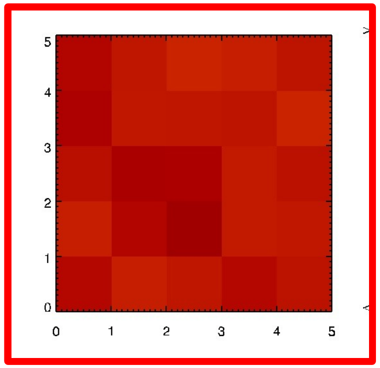


EE gain ~ observing efficiency

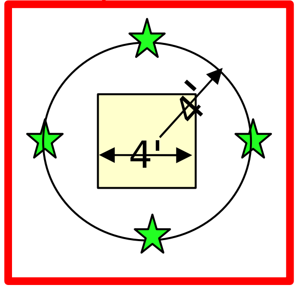


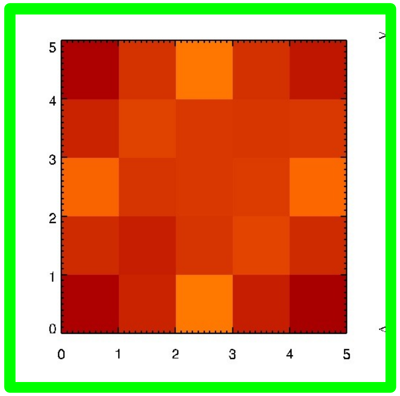
PSF uniformity



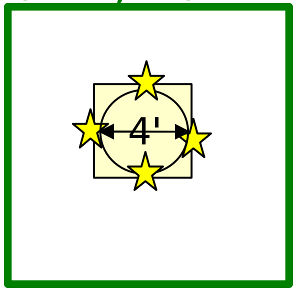


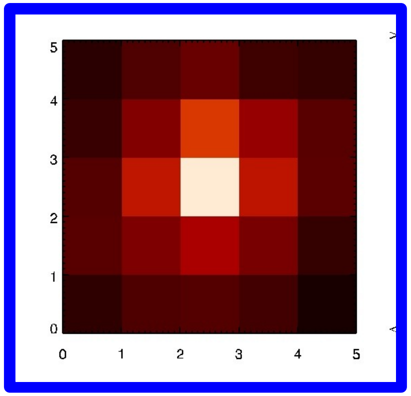
4 Rayleigh @ 4'
10km, 100m



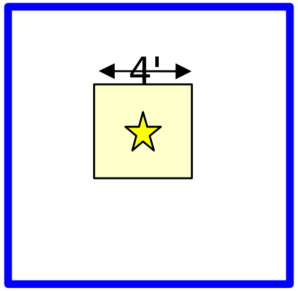


4 Na @ 2'
90km, 10km



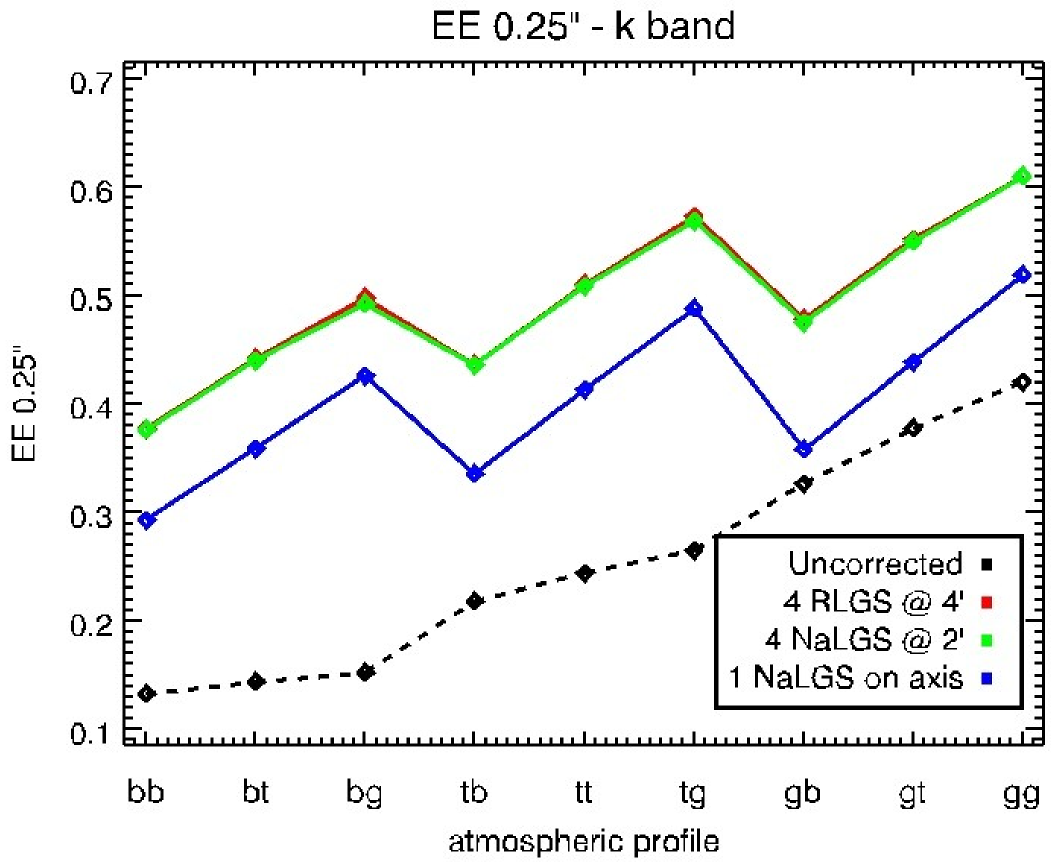


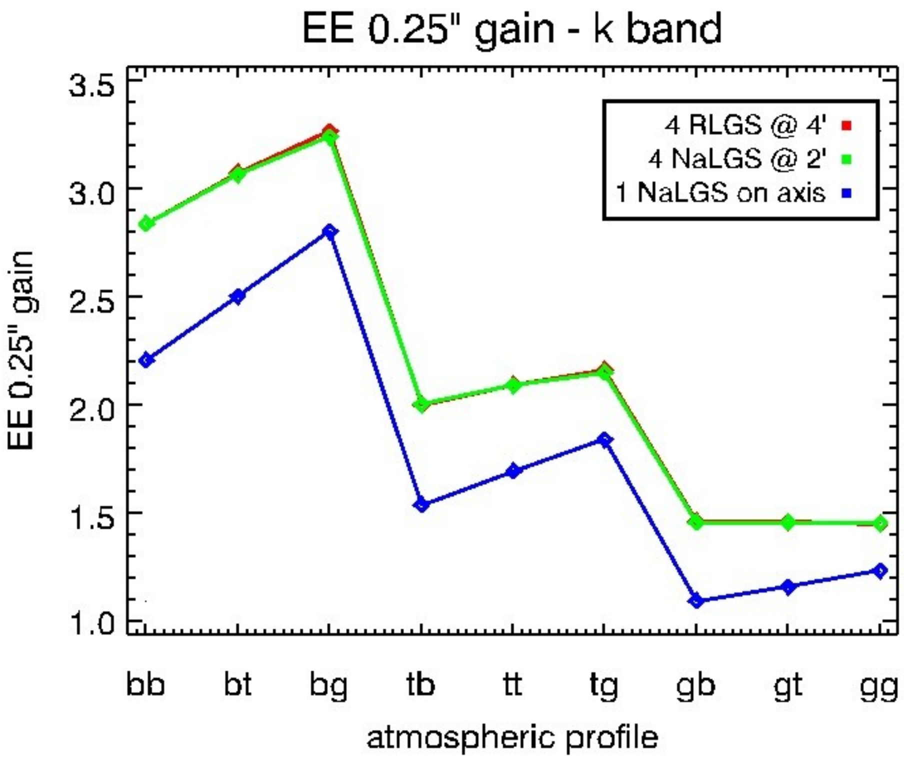
1 Na on axis'



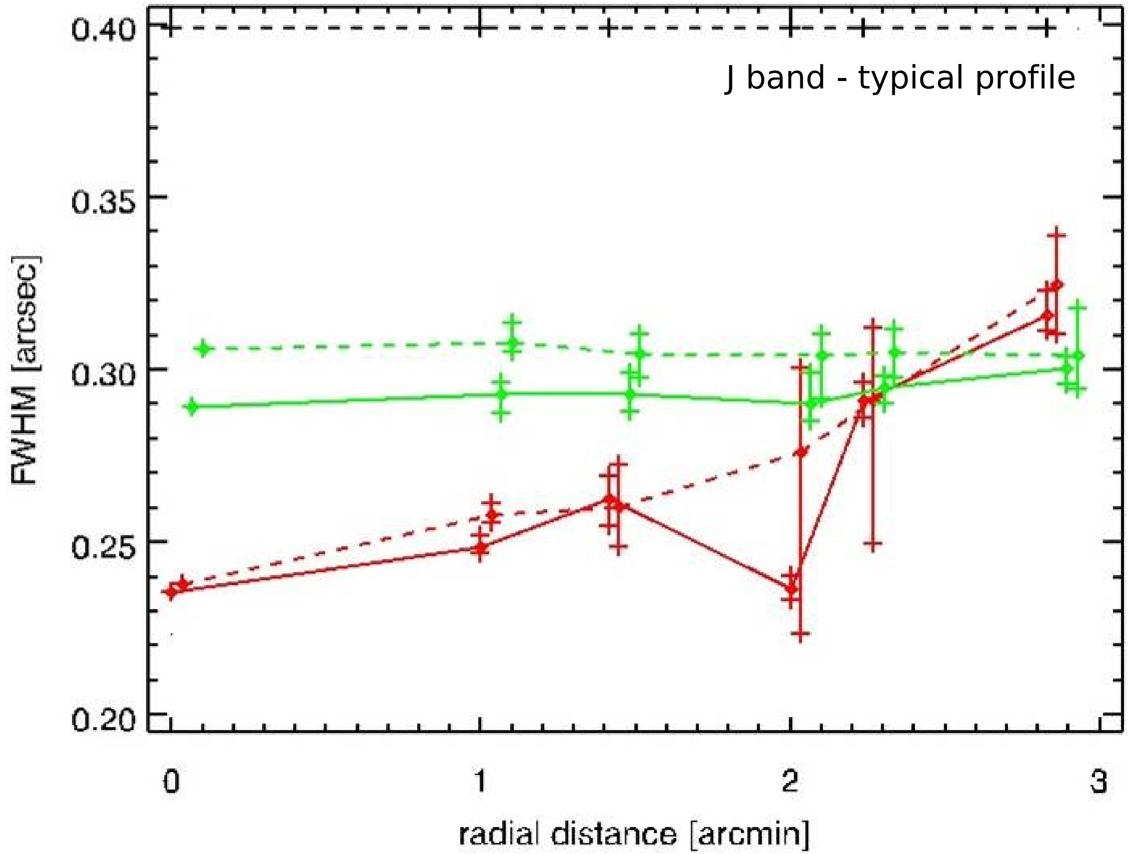
PSF Stability

GLAO acts as a “stabilizer” wrt to seeing varibility

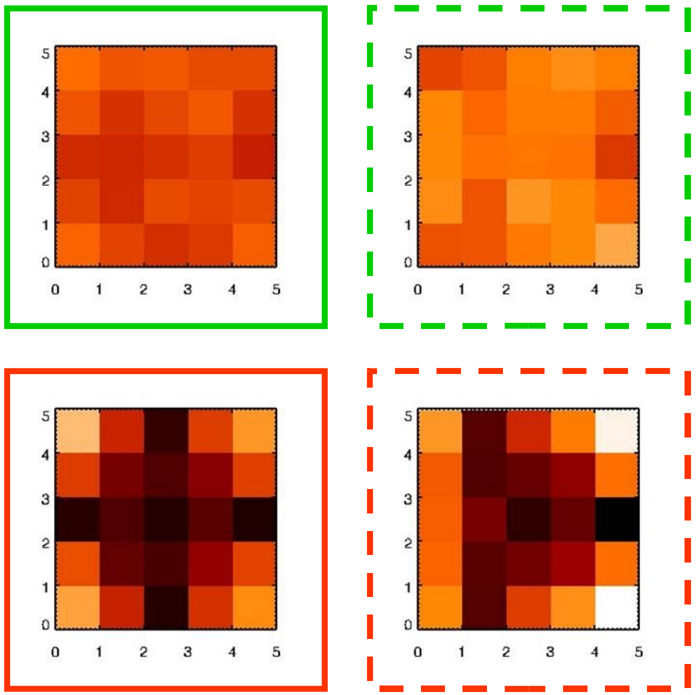


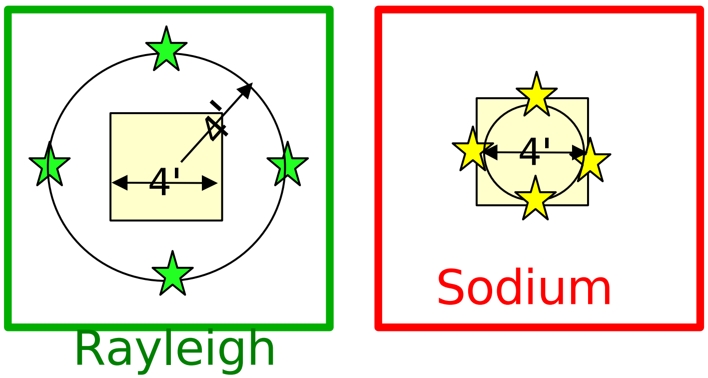


How many LGS for GLAO?



4 Ra LGS @ 4'
3 Ra LGS @ 4'
4 Na LGS @ 2'
3 Na LGS @ 2'

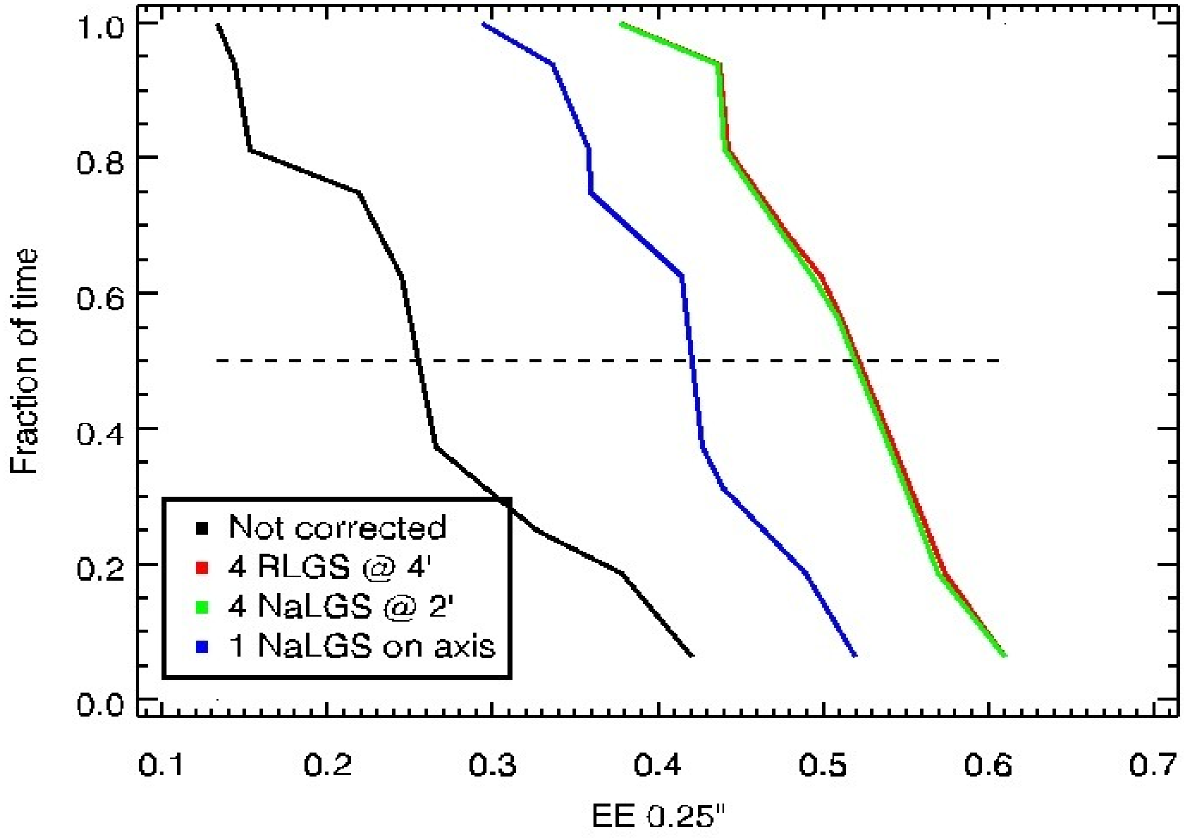




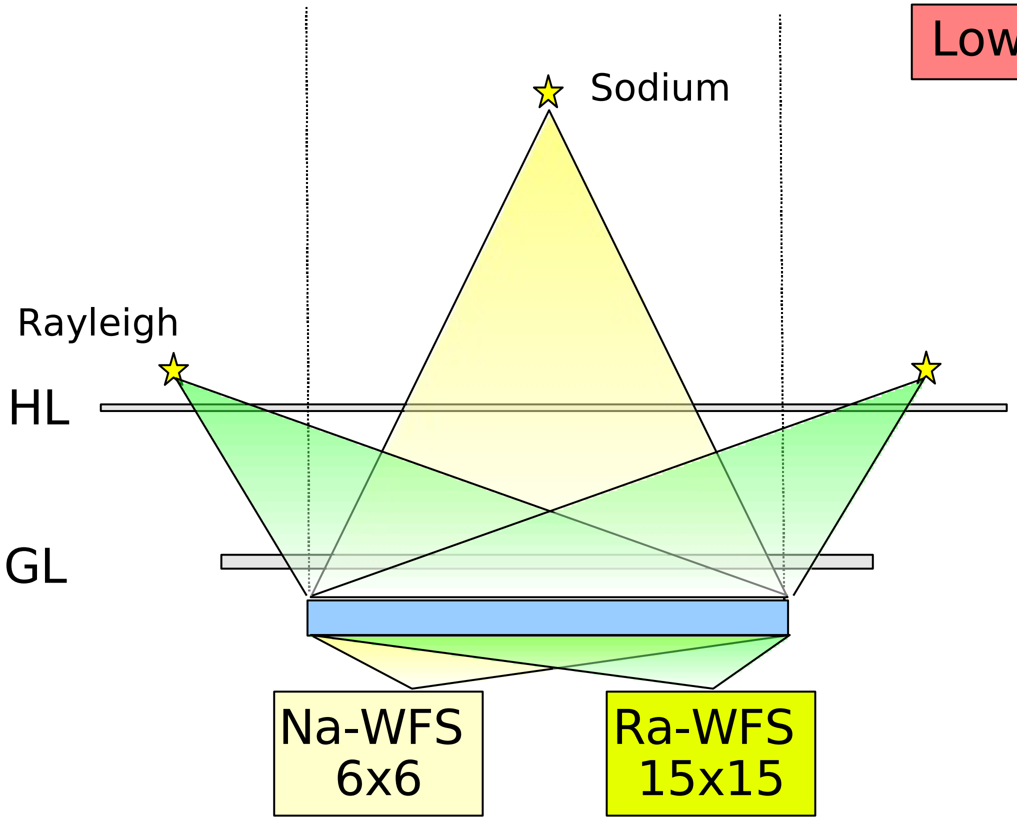
Time is money

a factor 2 of telescope time => a **lot** of money

50 night/year x 10 years x 50K$/night = 25M$



Upgrade: Low-cost tomography



Low power Na Laser are available!

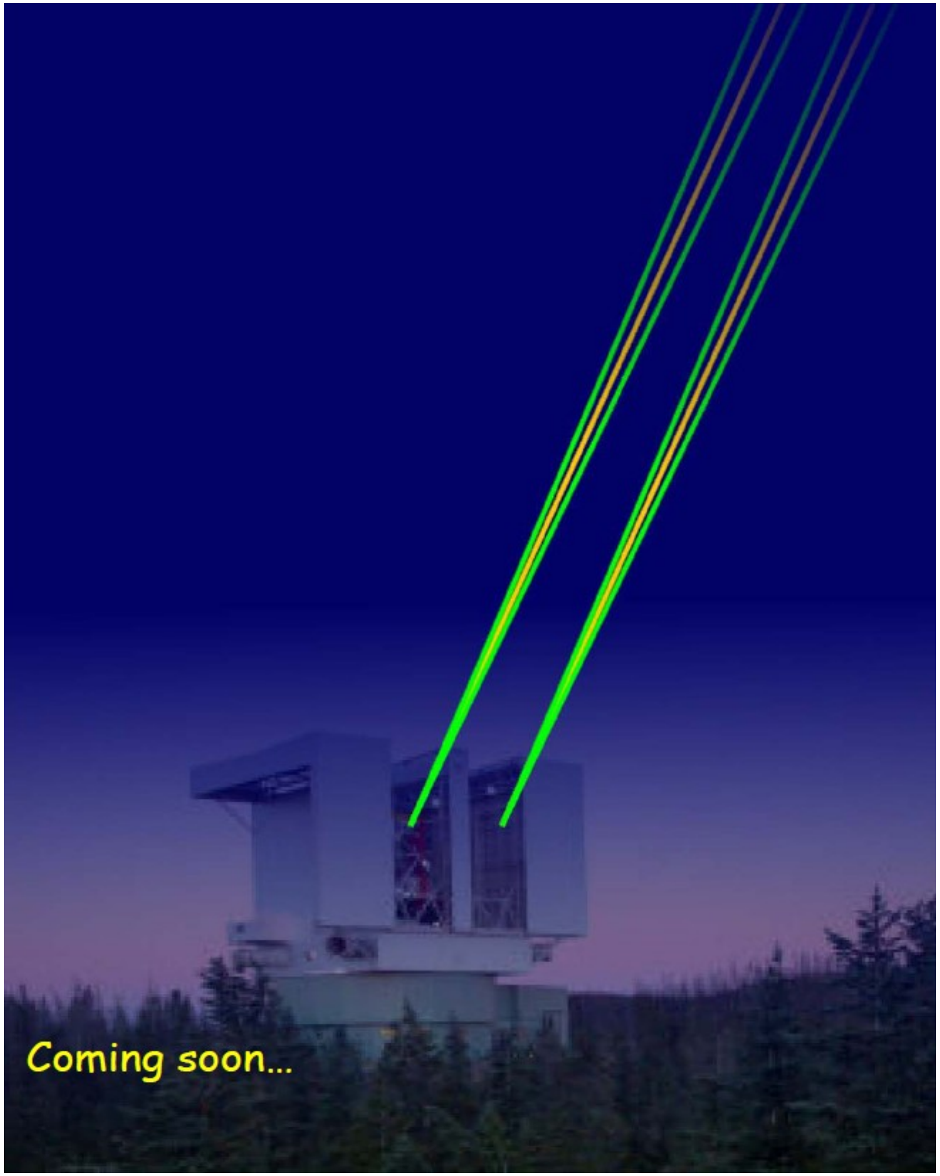
Rayleigh: powerful -> 15x15 subap
Sodium: **low power** -> 6x6 subap

Rayleigh: bad HL sampling
Sodium: good HL sampling

2 measures of the wavefront:
Ra-meas = GL_{150}
Na-meas = GL_{30} + HL_{30}

1) Downgrade Ra-Meas to a 30 modes basis GL_{150} -> Ra-GL_{30}
2) Estimate HL_{30} from Ra-GL_{30} Est-HL_{30} = Na-meas - Ra-GL_{30}
3) Combine to get the best estimate BestEst = Ra meas + Est-HL_{30}

BestEst has the strong GL sampled @ 150 modes by the Ra LGS, and the weak HL sampled @ 30 modes by the Na LGS


Coming soon...