Maunakea & GLAO Performance Limits

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14 September 2014

Outline

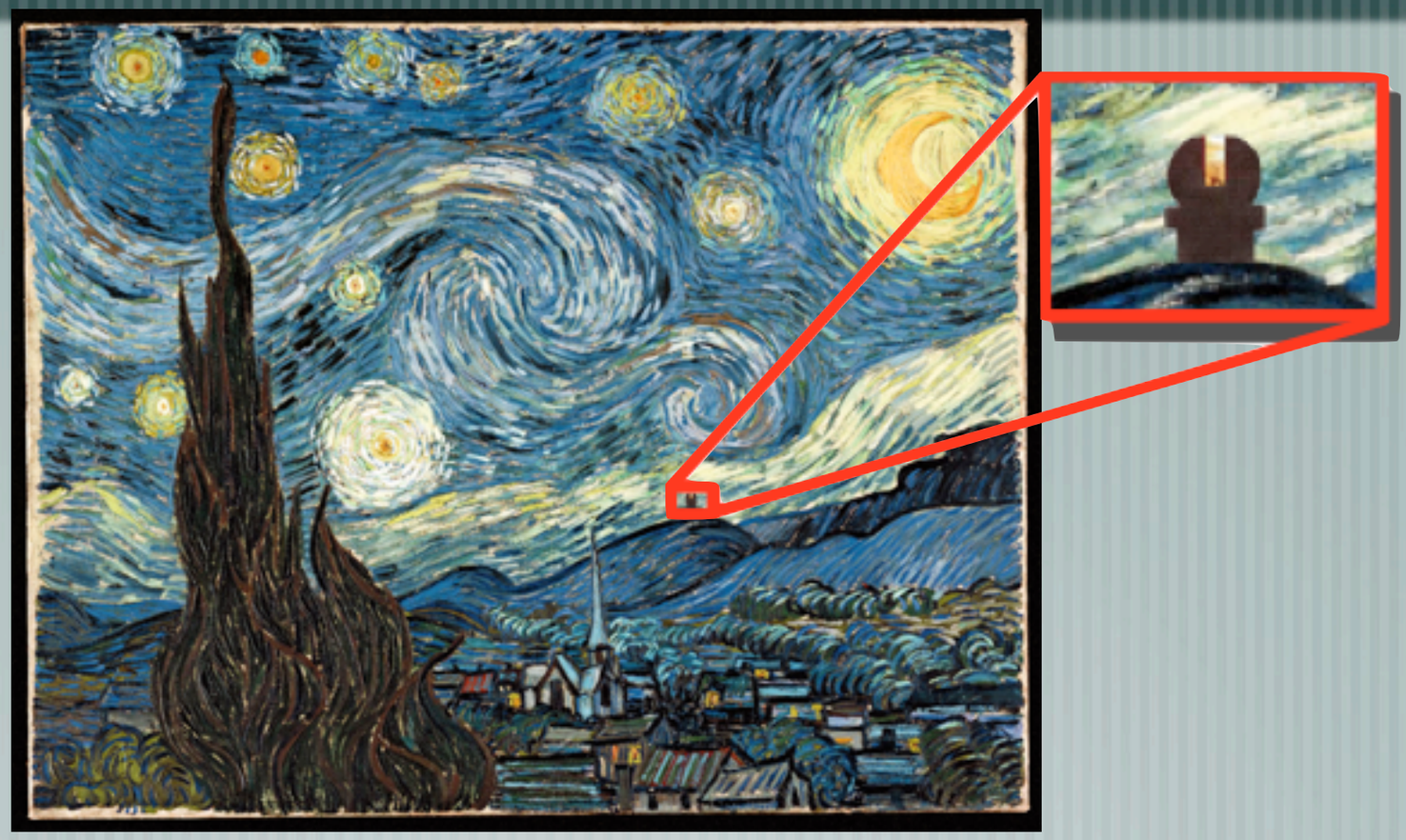
- Statistics - a quick summary
  - what measurements have been made & results
  - what we don't know
- GLAO Performance Limits
  - A tour of the major error terms and some implementation notes

Optical turbulence in the atmosphere

free-atmosphere

ground-layer

surface-layer



in dome

Consider: in dome, surface layer, ground-layer, & free-atmosphere

What we need:
strength, distribution along line of sight, spatio-temporal spectrum

Some Surveys on Maunakea

1980s NOAO Gemini Site Selection		GL	FA
1989/2002/2005 SCIDAR/G-SCIDAR	Dome	GL	FA
2007-2008 Gemini MKGL study with SLODAR & LOLAS Chun et al 2009 MNRAS		GL	FA
2008-2009 TMT 13N with MASS, DIMM, SODAR Schoeck et al 2009 PASP		GL	FA
2009+ MKAM TMT MASS & DIMM		GL	FA
2009+ CFHT OTP	Dome		
2009+ CFHT Dome DIMM	Dome		
2010 PTP (LunarShabar)	Dome	GL	
2012 UH88/CFHT (multiple WFS experiment)	Dome	GL	FA

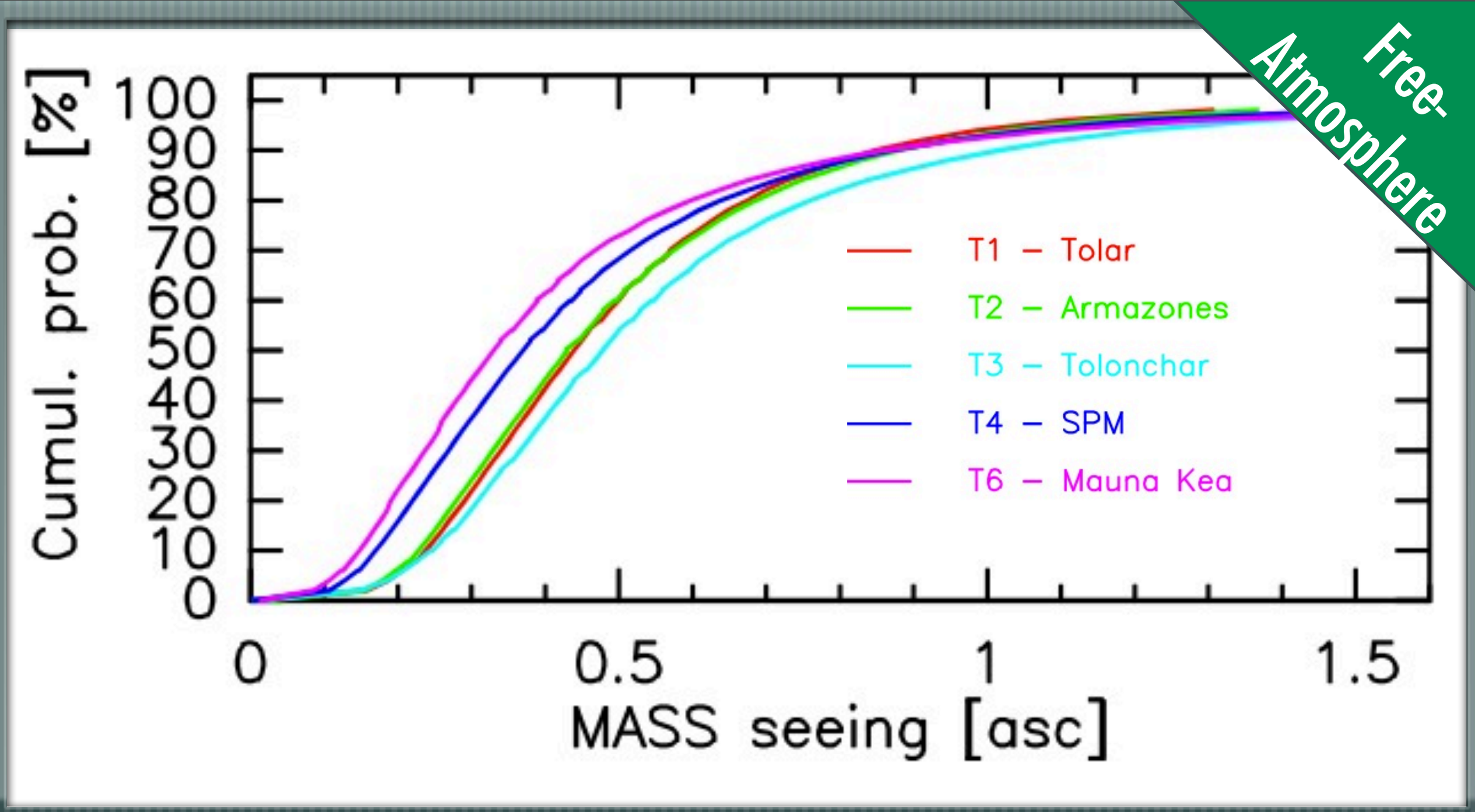
The Site

Free-Atmosphere

- Integrated Strength in layers above h>500m

GSCIDAR at UH88	Gemini MKGL Study	TMT 13N Site Testing	MKAM (TMT MASS)
0.42″	0.4″	0.33″	0.3″

- Layers at:
  - 1km : transitioning from E to W winds
  - 8-12km following the upper winds speed profile

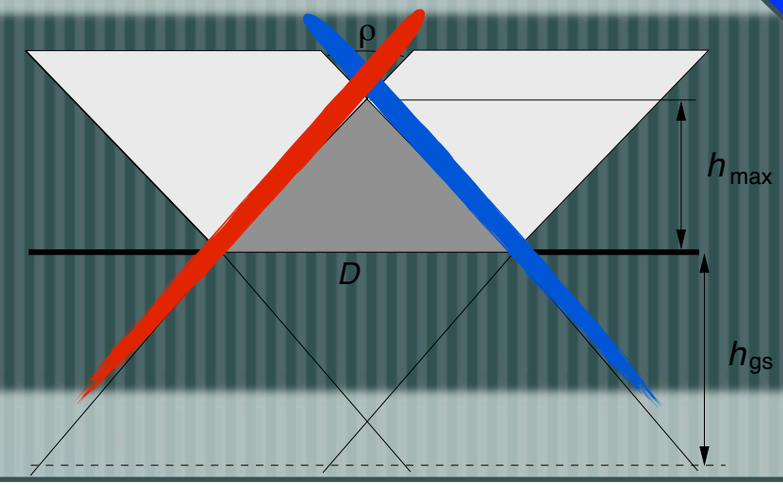


MK compared to others

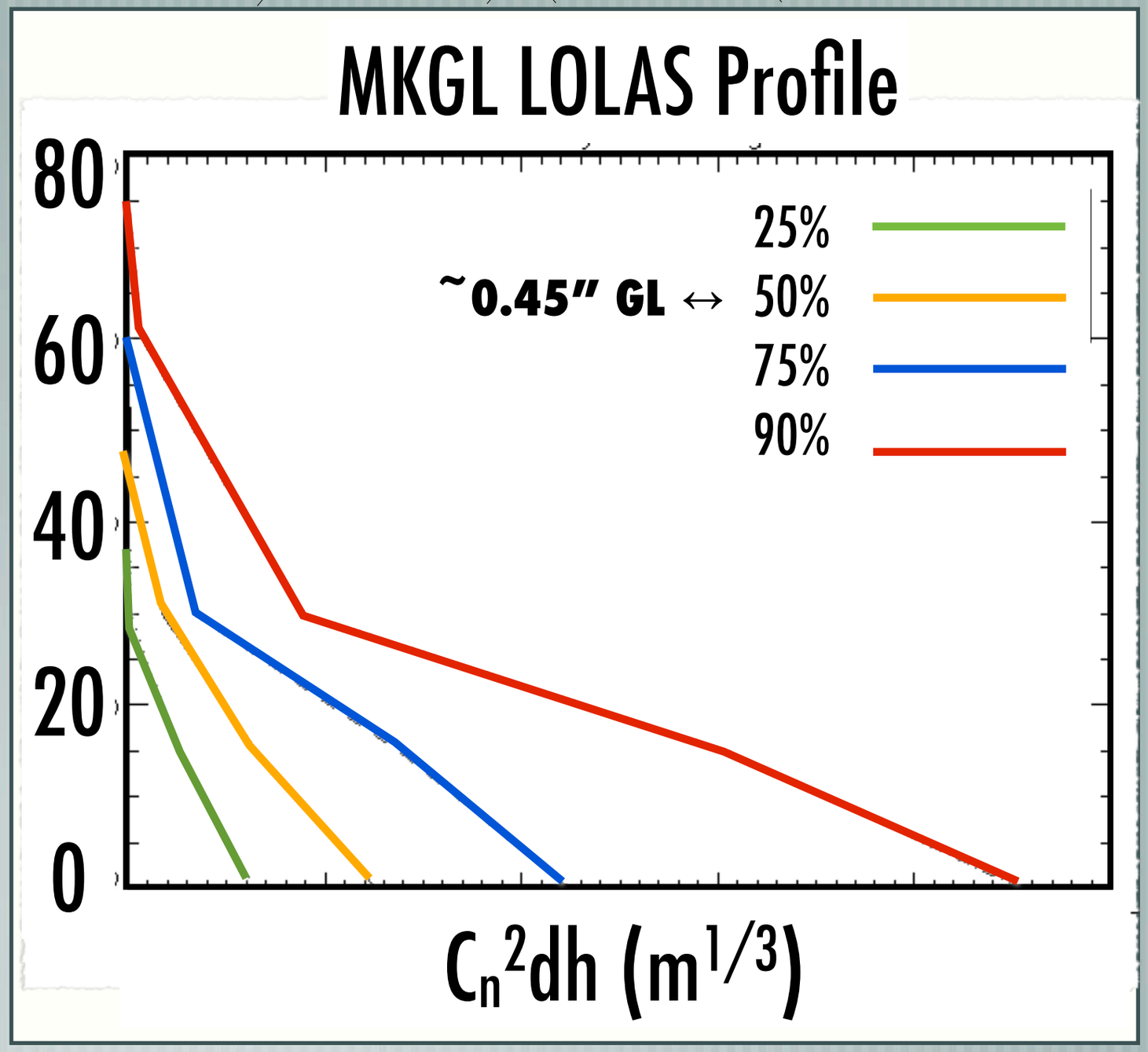
Schoeck et al. 2009 PASP

The Site

Ground-Layer



- Gemini MKGL Study
- Pfrommer (UBC) LunarSHABAR
- mWFS Experiment



Chun et al. 2009 MNRAS

The Site

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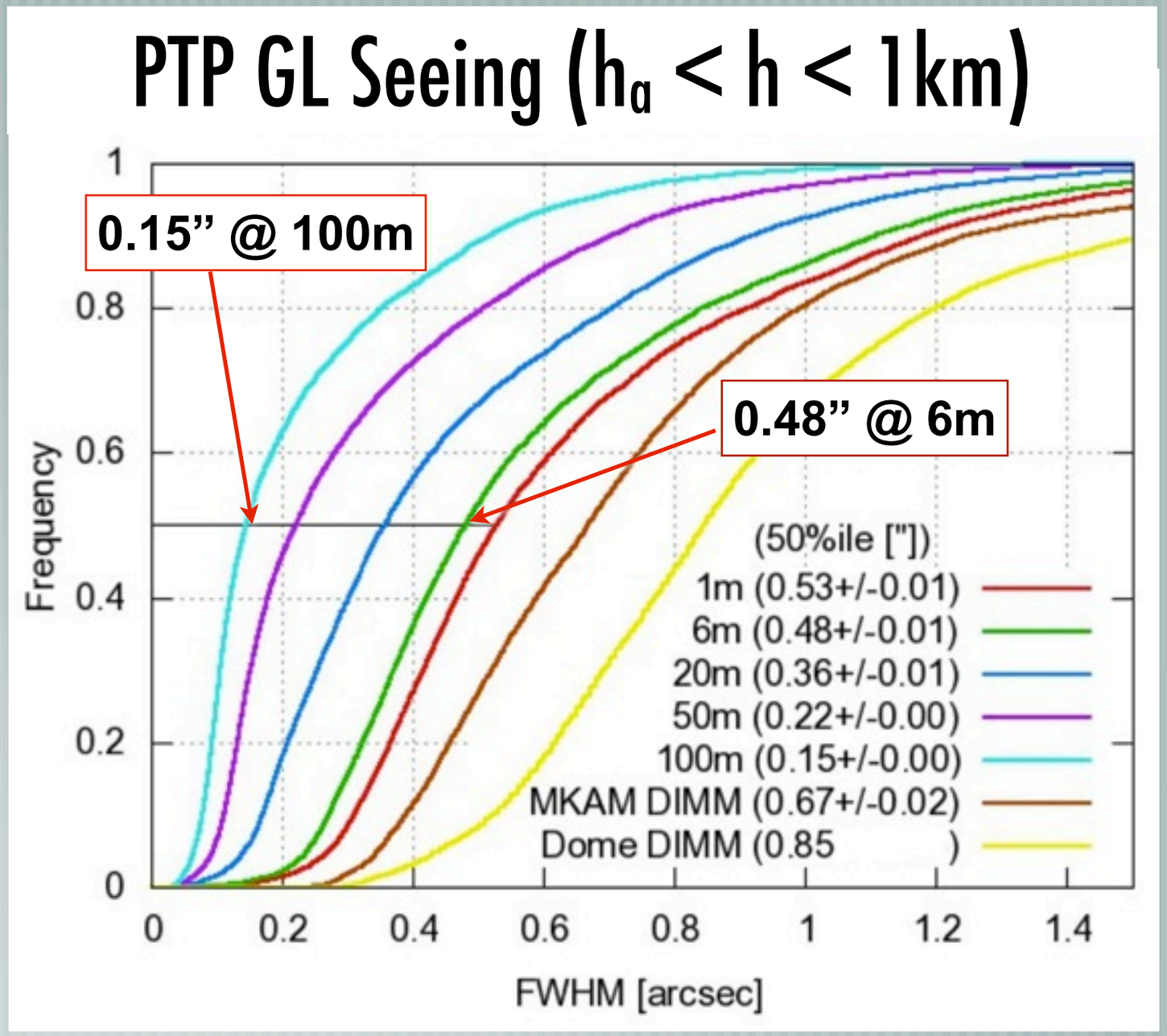


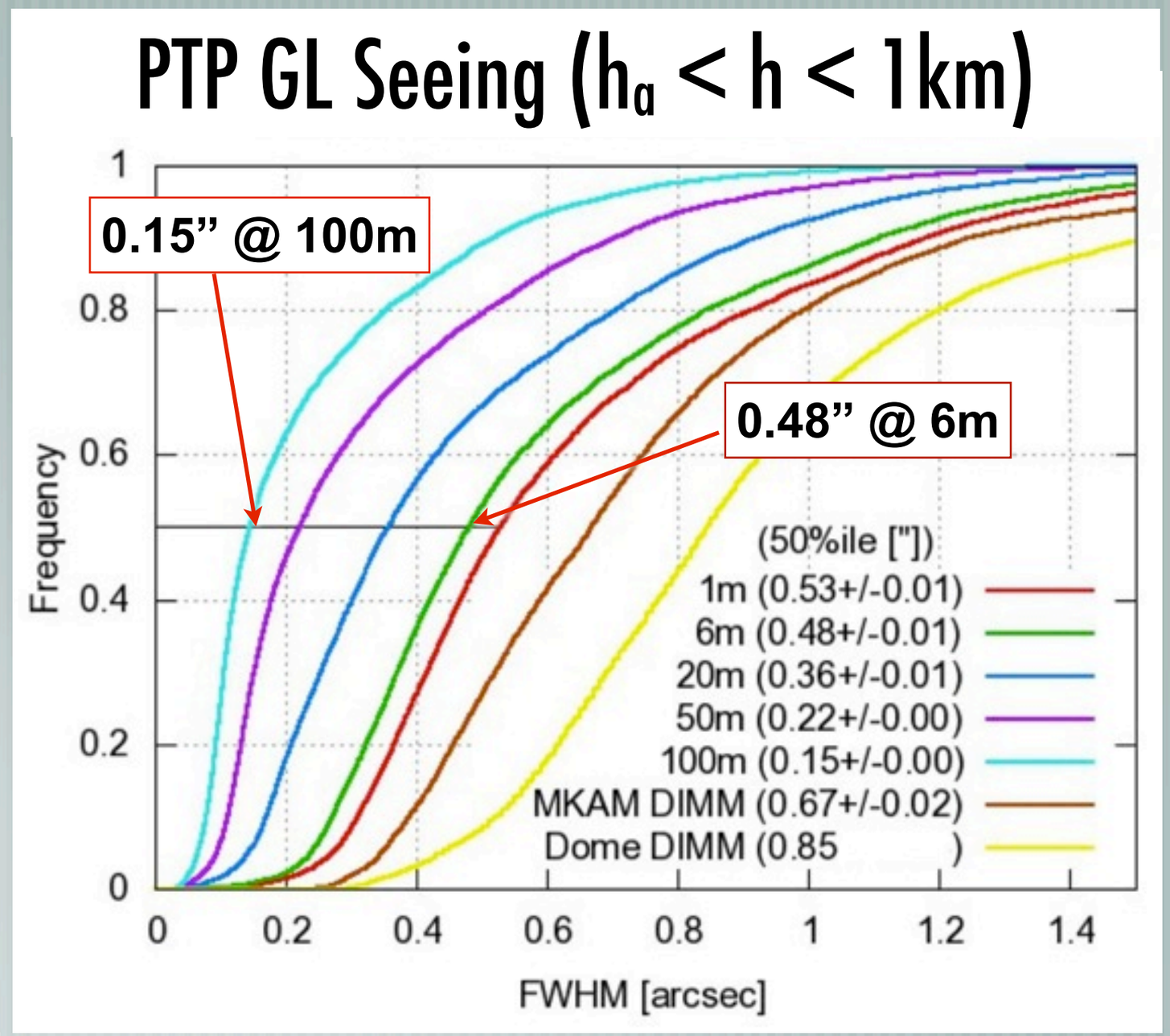
Pfrommer 2010 UBC PhD. Thesis

The Site

The GL is mostly a surface layer+dome and not much else...

Ground-Layer

- Gemini MKGL Study
- Pfrommer (UBC) LunarSHABAR
- mWFS Experiment



Pfrommer 2010 UBC PhD. Thesis

Rene Racine's CFHT UM2013 Presentation Slide 4

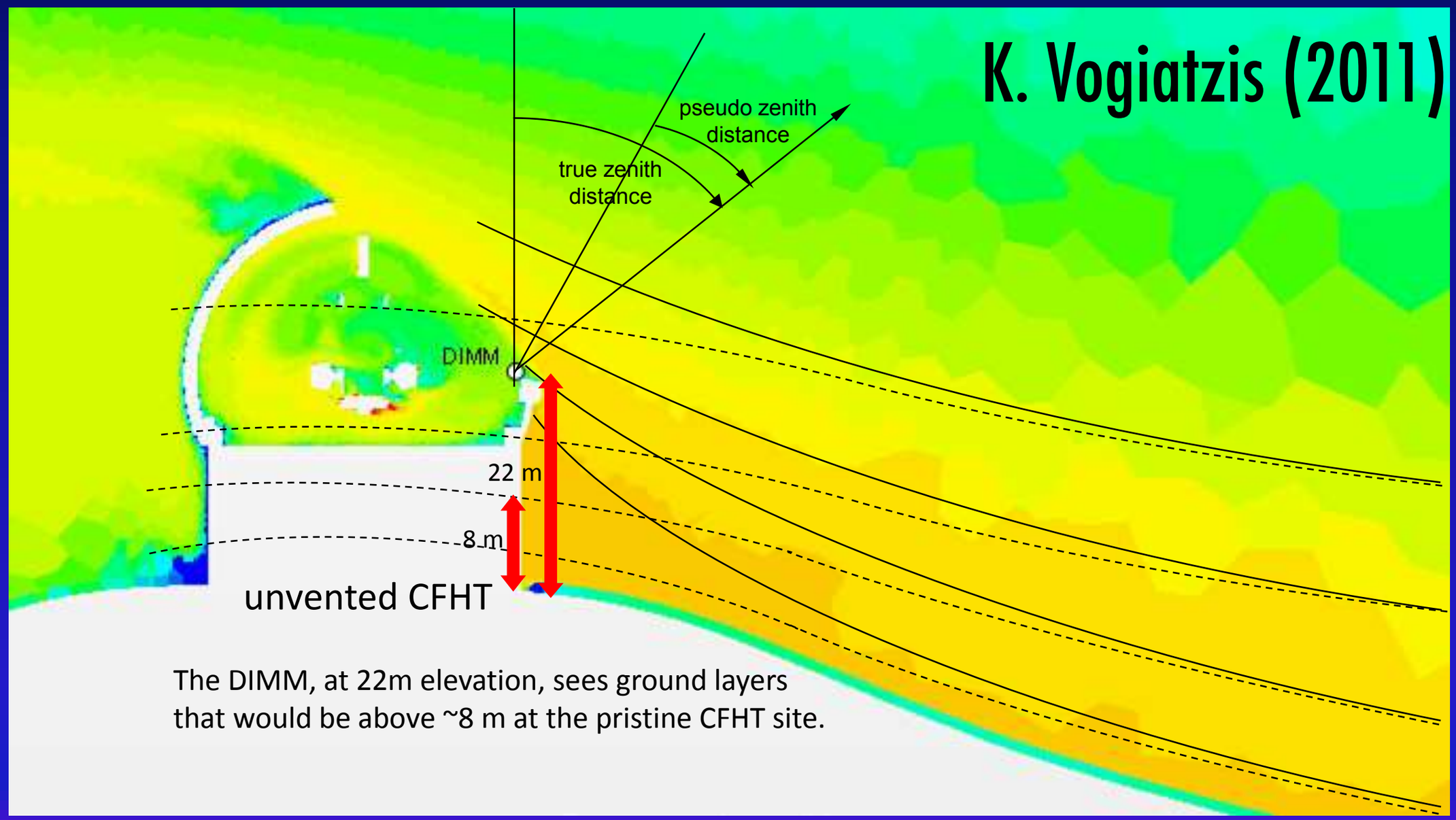
UM 2013

Upwind, the GL is TILTED and UPLIFTED by the building.

1- GL uplift brings lower elevation, stronger optical turbulence in the line of sight.

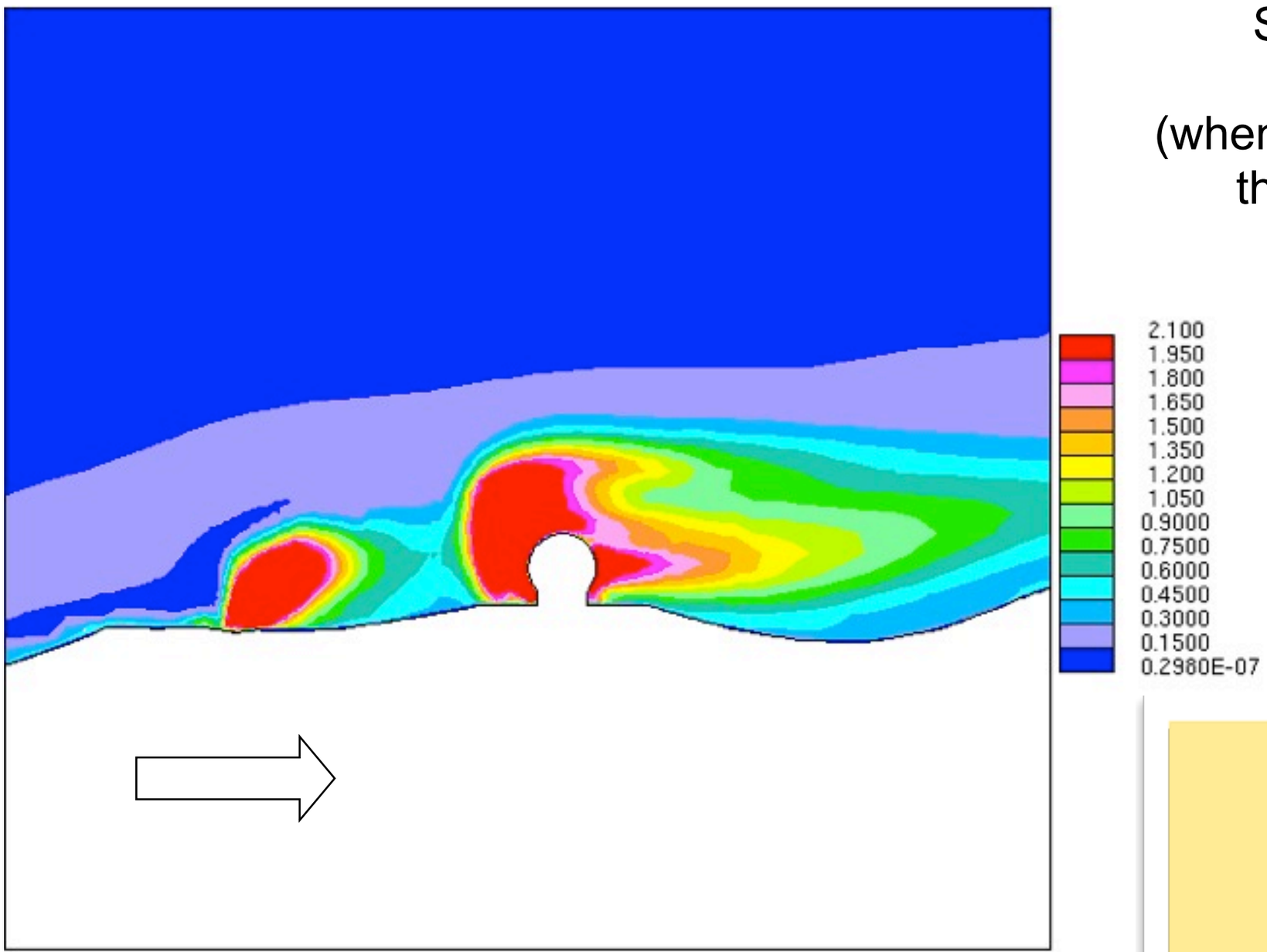
2- GL effective or "pseudo" zenith distance < true zenith distance *z* at large *z*.

A $\sec(z)^{0.6}$ correction increasingly underestimates the GL strength at large *z*.



The DIMM, at 22m elevation, sees ground layers that would be above ~8 m at the pristine CFHT site.

Structure interactions, W wind, velocity rms (m/s)



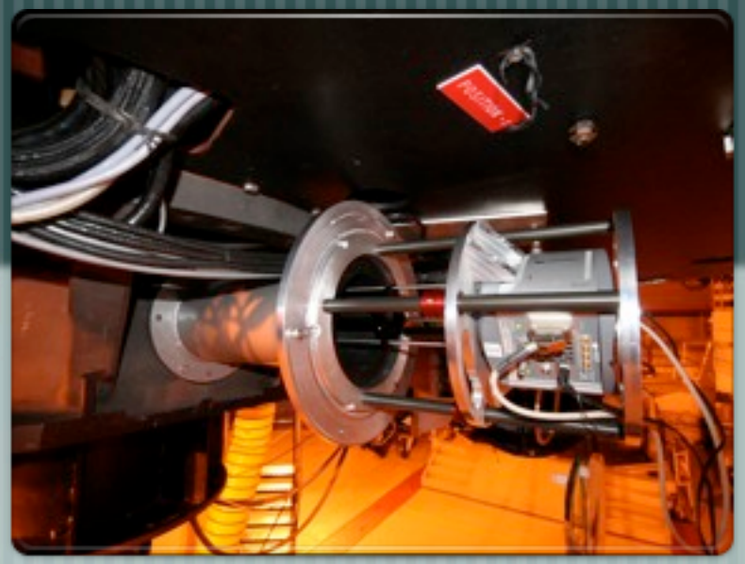
Subaru to Keck wake

(when the wind is from east it's the other way round…)

Konstantinos Vogiatzis
Thirty Meter Telescope

March 14, 2007
San Pedro Mártir, Baja, Mexico

The Site



Dome Seeing

- mWFS
- CFHT IQ Study
  Salmon et al 2009 and
  Racine 1984, 1989, 1991
- CFHT OTP

The Site

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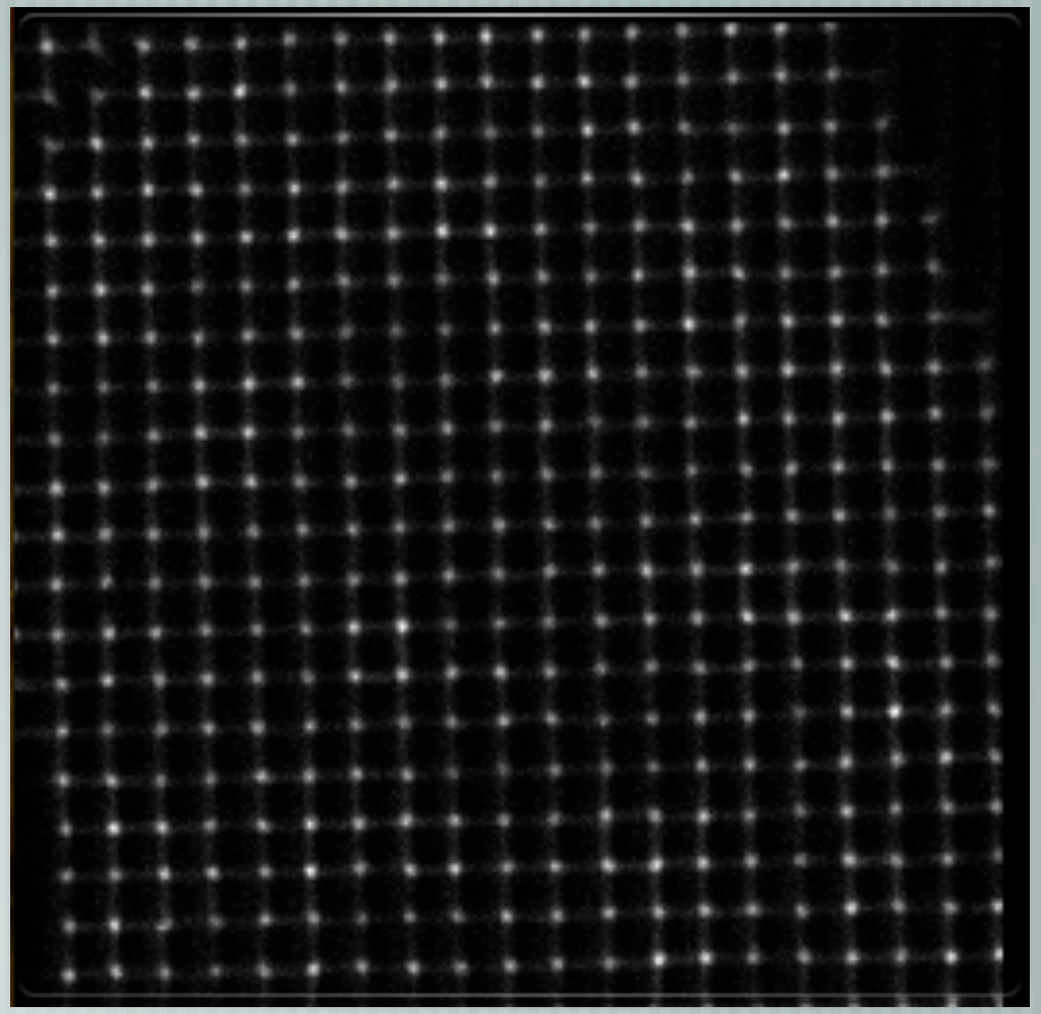


Dome Seeing

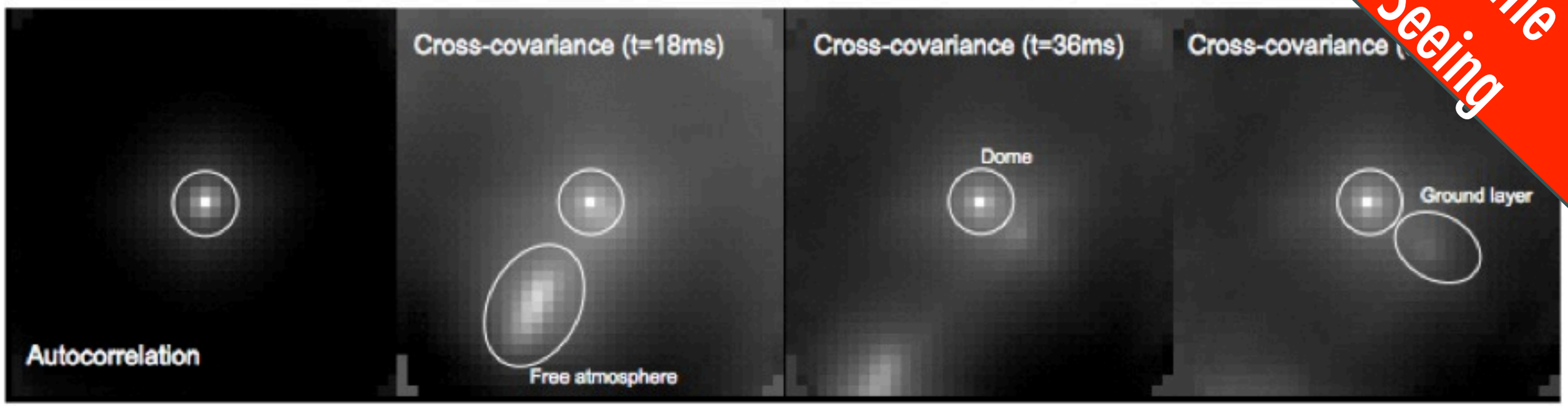
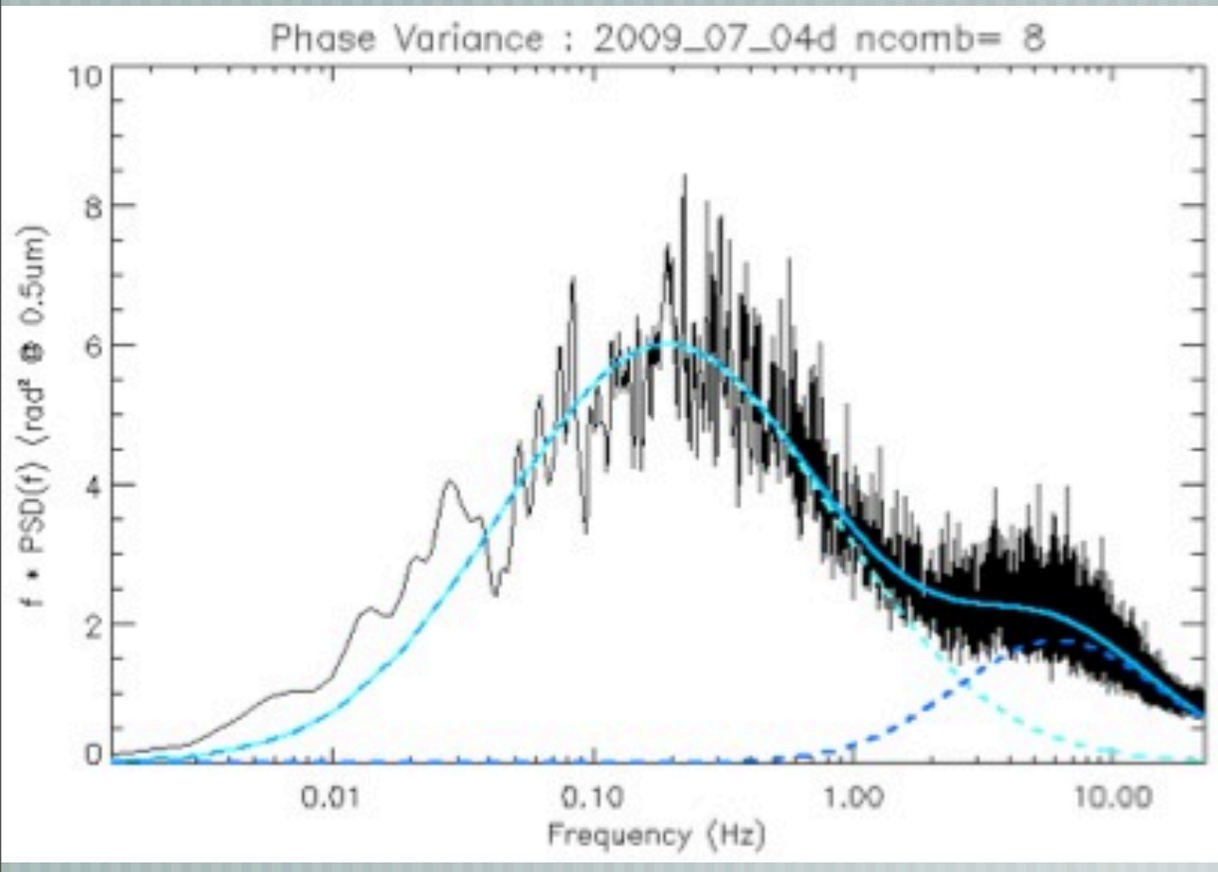
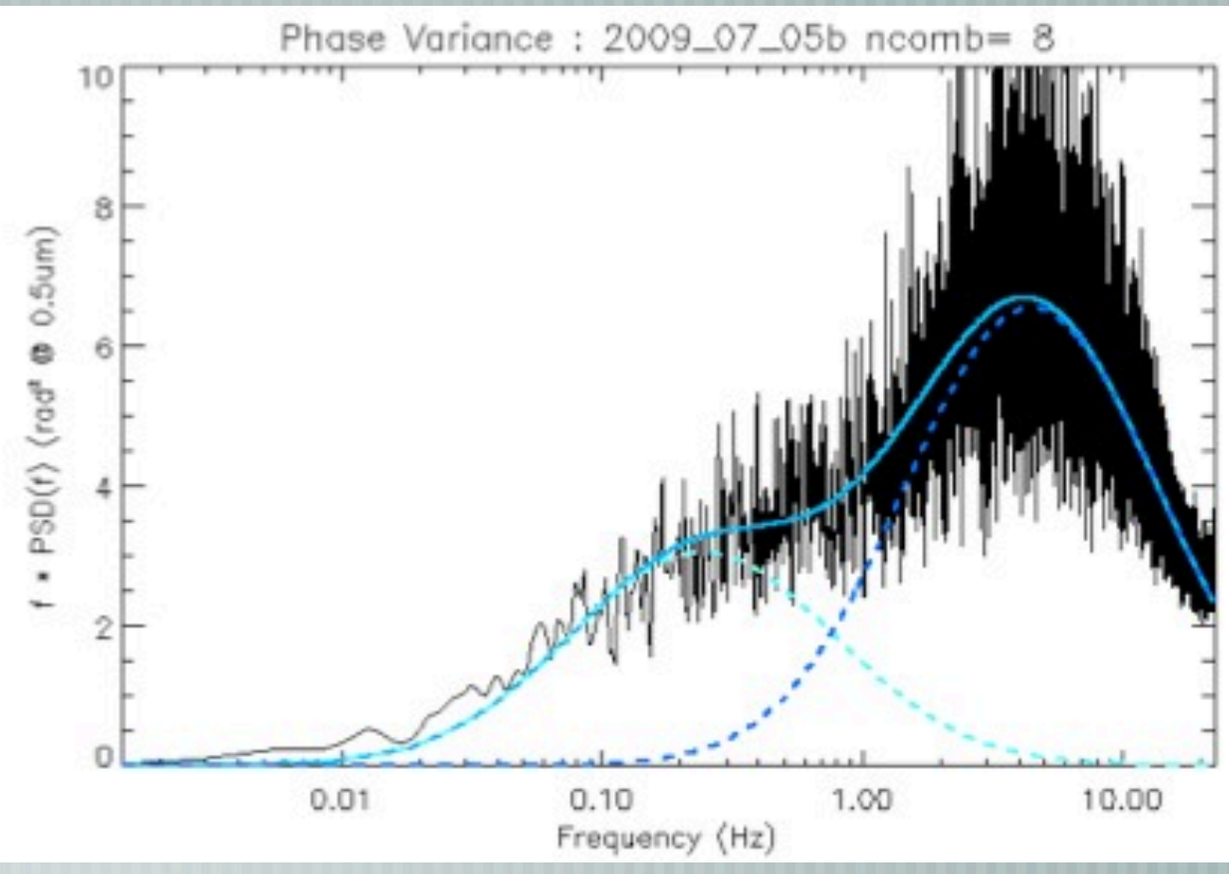


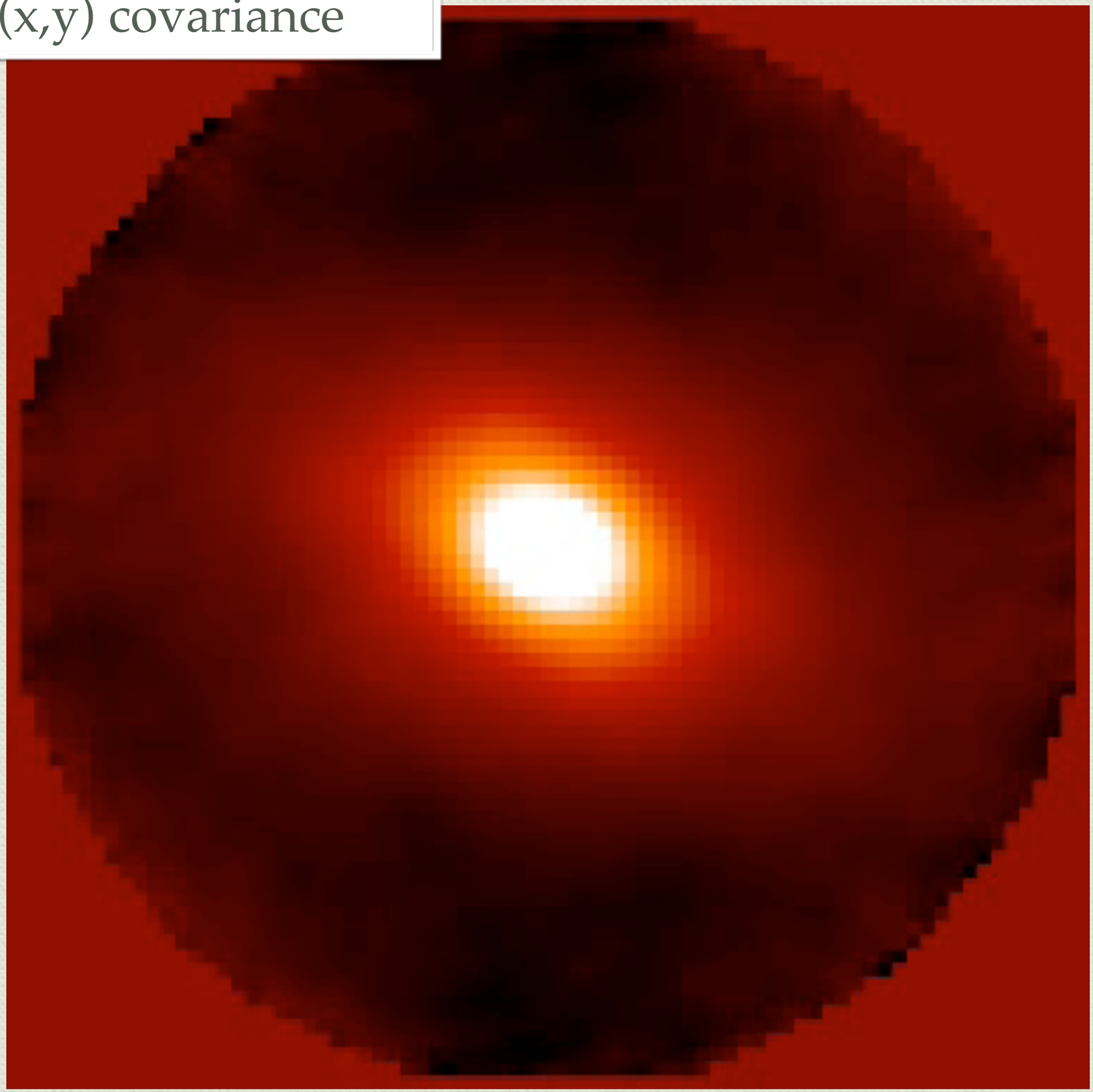
Figure 5: OTP slope covariance maps





Slope (x,y) covariance

mWFS on CFHT



Other stuff...

Dome Seeing

- For older telescopes many terms in the IQ budget...

TABLE 4 (Salmon et al 2009) CONTRIBUTIONS TO MEDIAN IQ

(FWHM [″], 500 NM, ZENITH)

Individual Components and Values		Total (arcsec)
Atmosphere	General (0.49″) Ground layer (0.20″)	0.55″
Local seeing	Primary mirror (0.09″) Caisson (0.11″) Tube (0.15″) Cage (0.08″) Slit (0.10″) Wind (0.08″) Other (dome wake?) (0.25″)	0.43″
Optics	Primary mirror (0.24″) MegaCam (0.08″) Other optics, etc. (0.18″)	0.33″
TOTAL		0.89″

Salmon et al. 2009 PASP

Atmosphere summary

- Seeing in GL is 0.4-0.5″ and all within the first 10s of meters
- Seeing in FA is 0.3-0.4″ and distributed throughout (layers at 1-2km, then very weak higher up)
- “in-dome” seeing/IQ degradation at the older telescopes can be as large but is static or moves very slow.
- Worries: MASS FA seeing and the outerscale in GL and dome

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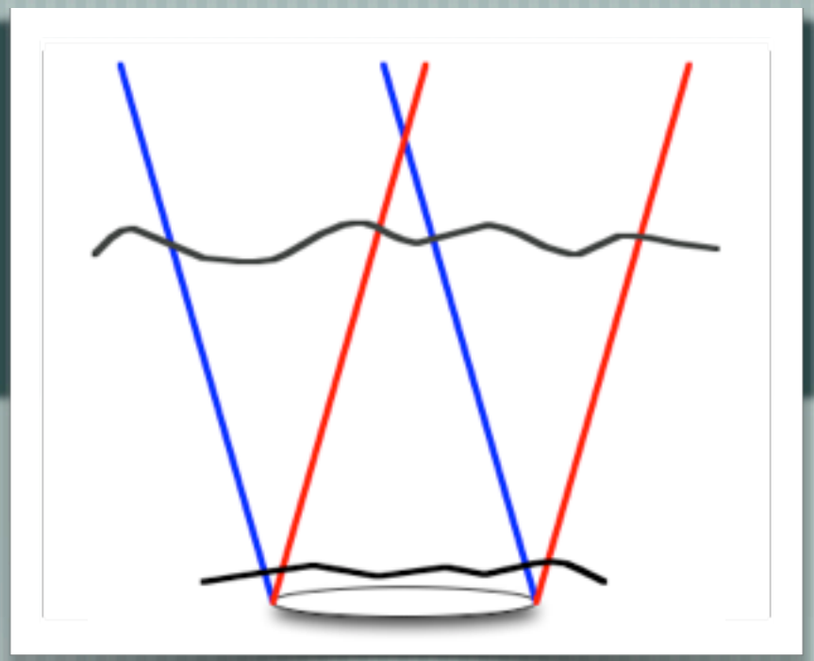
Gray-zone



Tokovinin 2004 PASP

- "full" correction of low-alt layers depends on the field angle and $r_{0,GL}$ or the shear of actuators over field
- "partial" correction up a shear of at order a pupil.

imaka88 (12′ FOV)

"full"
h<100m

"partial"
100m<h<600m

For MK no turbulence in gray zone ⇒ go wide!

Key GLAO IQ error terms

Error Term	imaka88	Comment
Uncorrected high-alt residual	400 nm rms	$(D/r_{0,FA})^{5/3}$
Tomographic Error	150 nm rms	averaging goes as $(D/r_{0,FA})^{5/3}/N_{GS}$
Pupil Distortion	90 nm rms	from simulations
Fitting Error	60 nm rms	wavefront outerscale is important
Static NCP Aberrations	50 nm rms	Most design/figure errors are NCP
Small terms	measurement error, bandwidth error, potentially atmos dispersion (NIR)	

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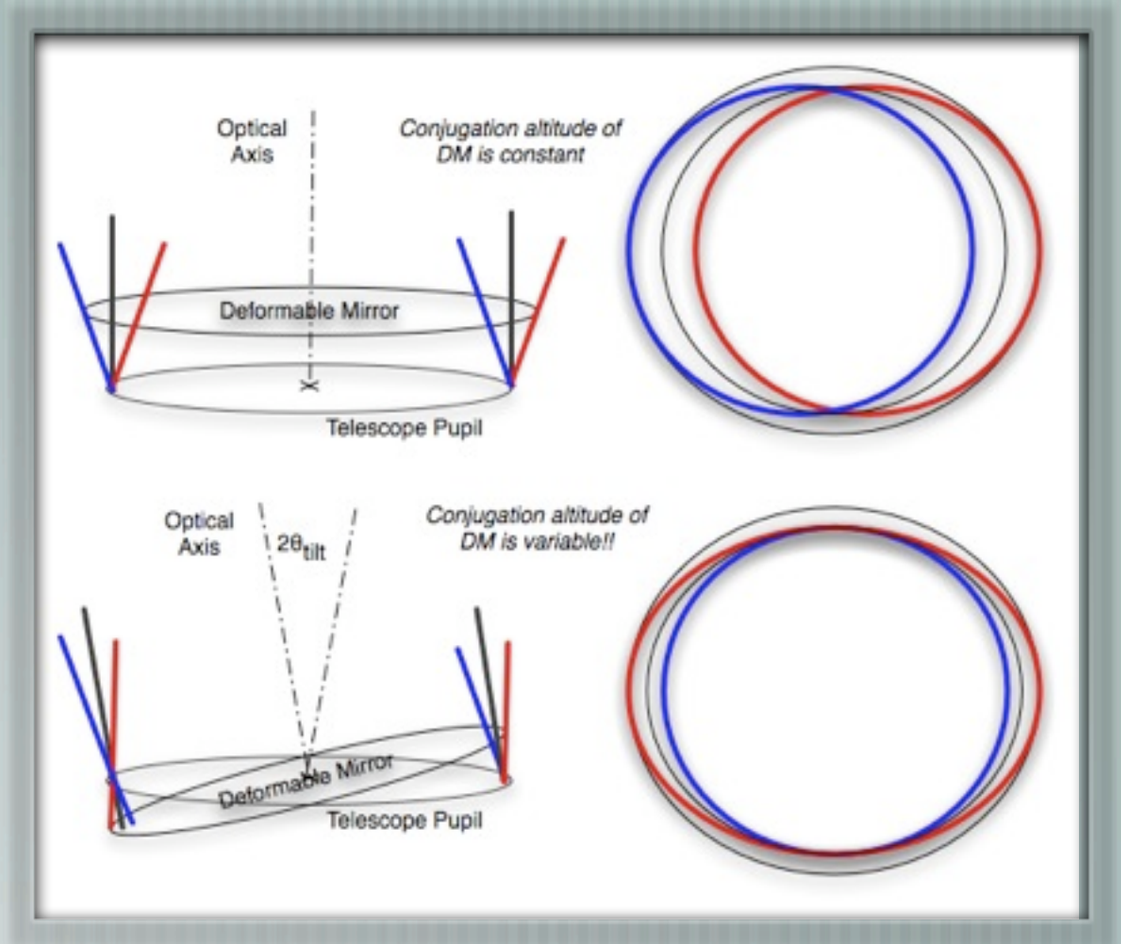
Astrometric error budget is even more challenging!

DM Misconjugation

side note

- Misconjugation due to conjugation altitude of mirror (say an AM2)
- Misconjugation due to the tilt of the DM wrt the desired conjugate plane

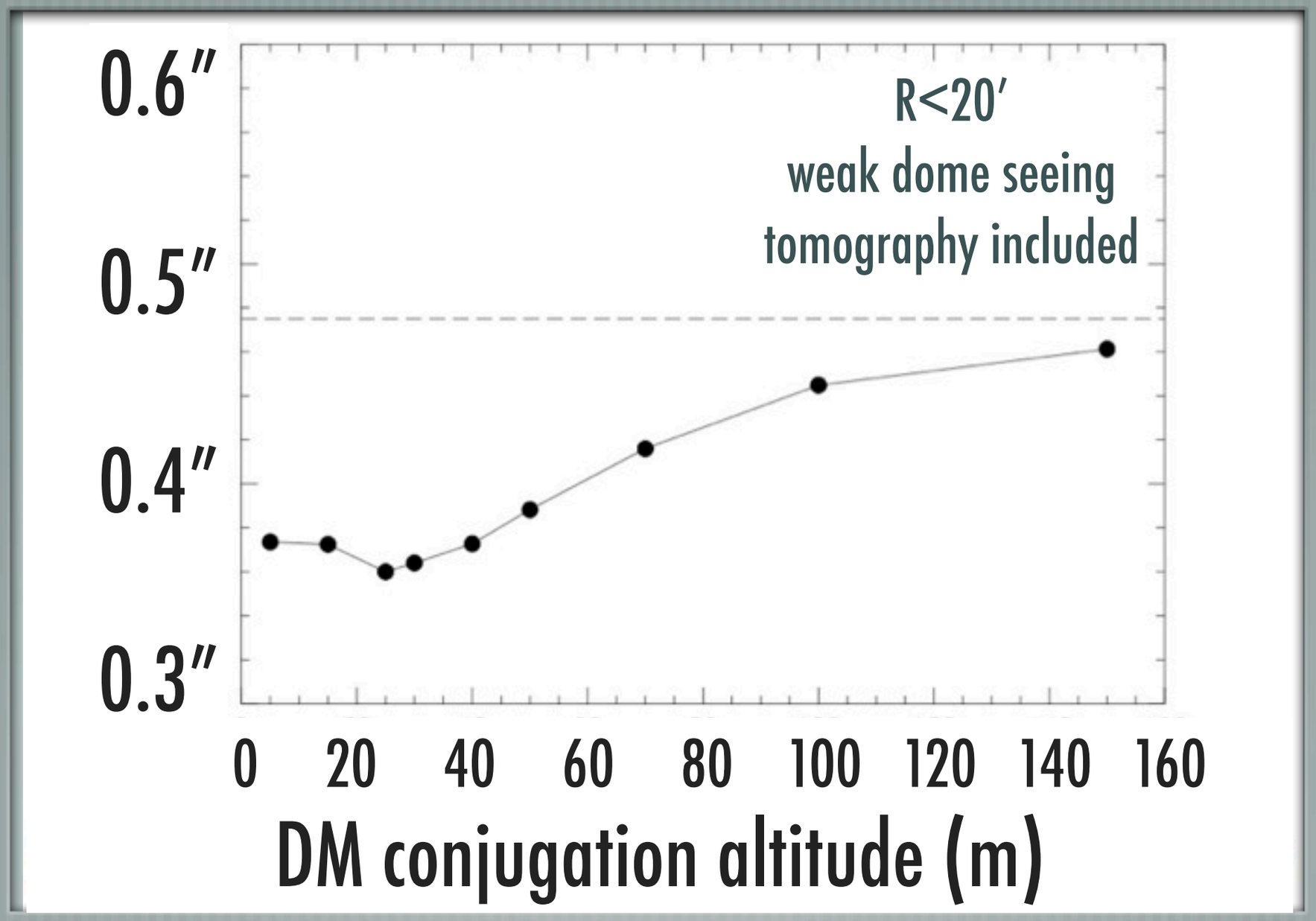


DM Misconjugation

side note

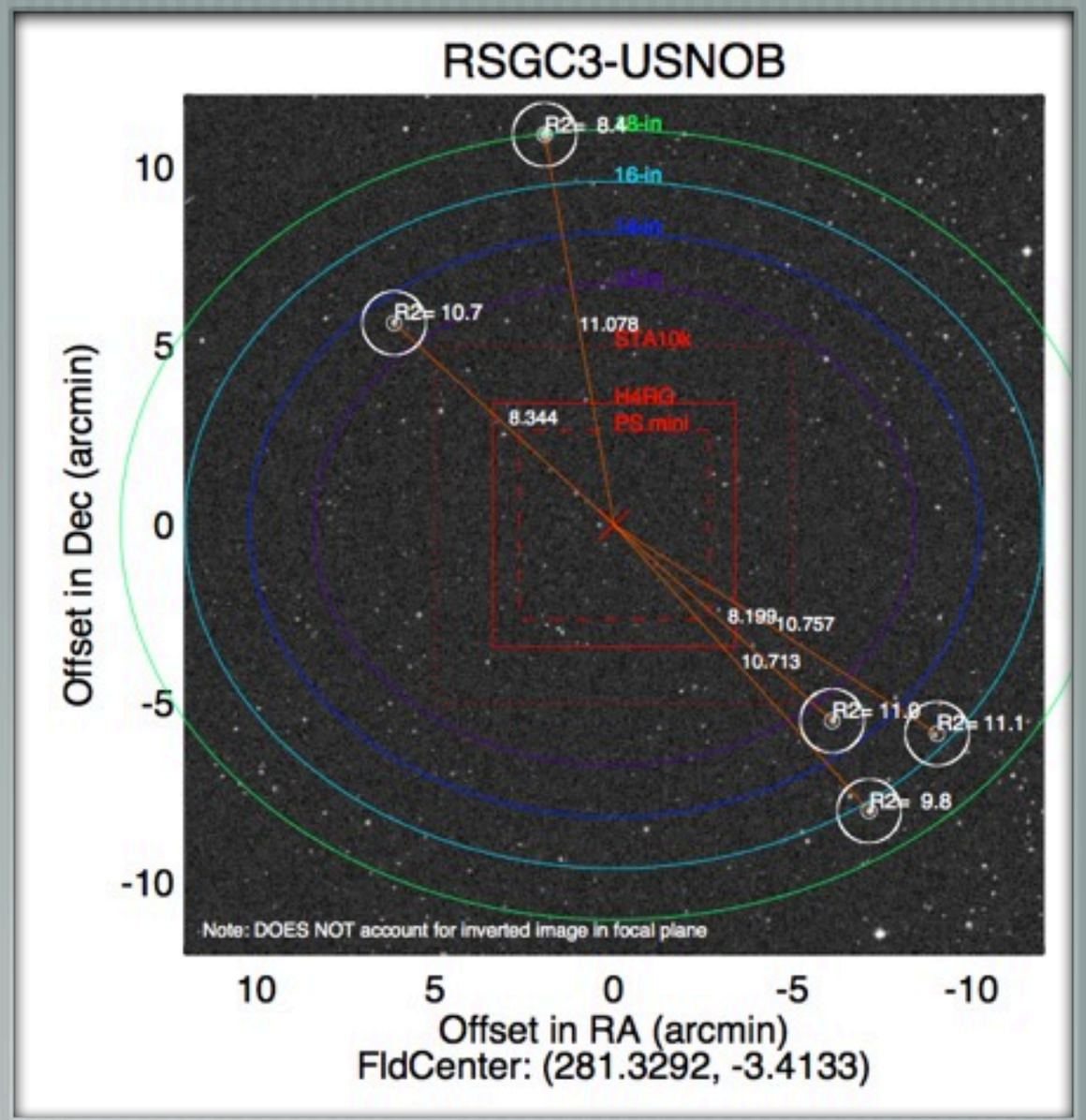
Important when we go to the largest fields of view

D. Andersen (2009) using LAOS

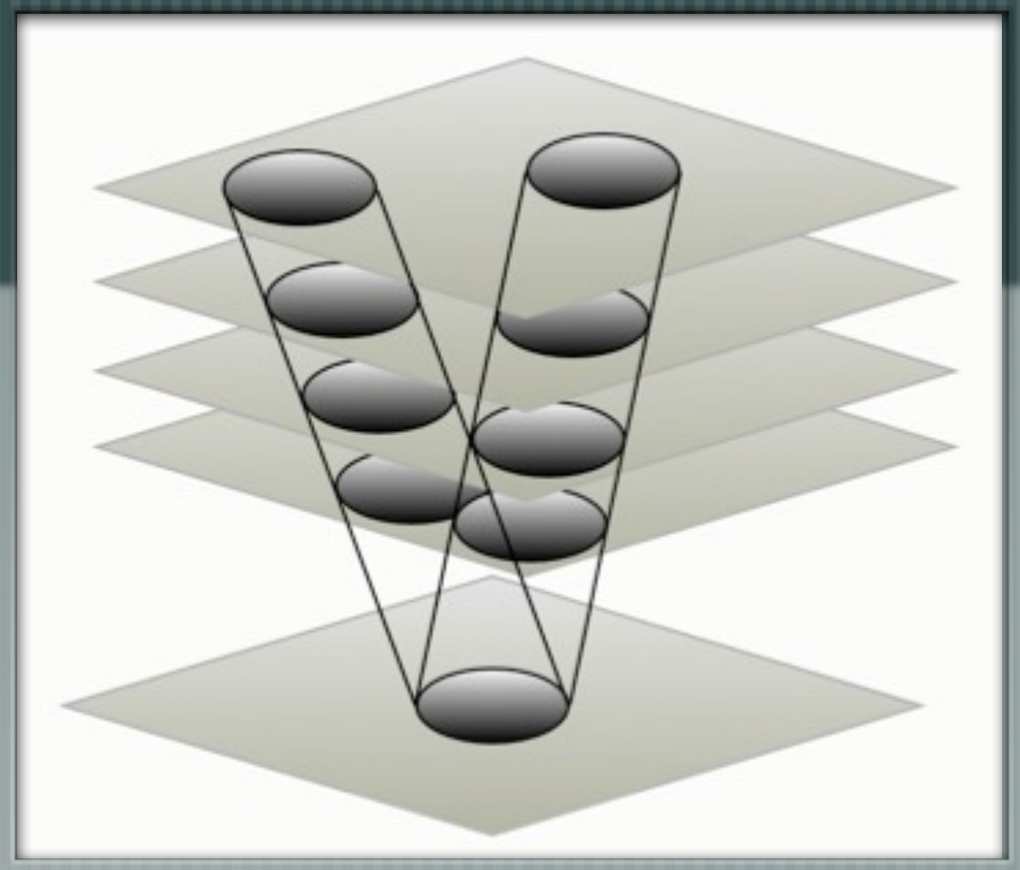


Natural Guide Stars v. rLGS

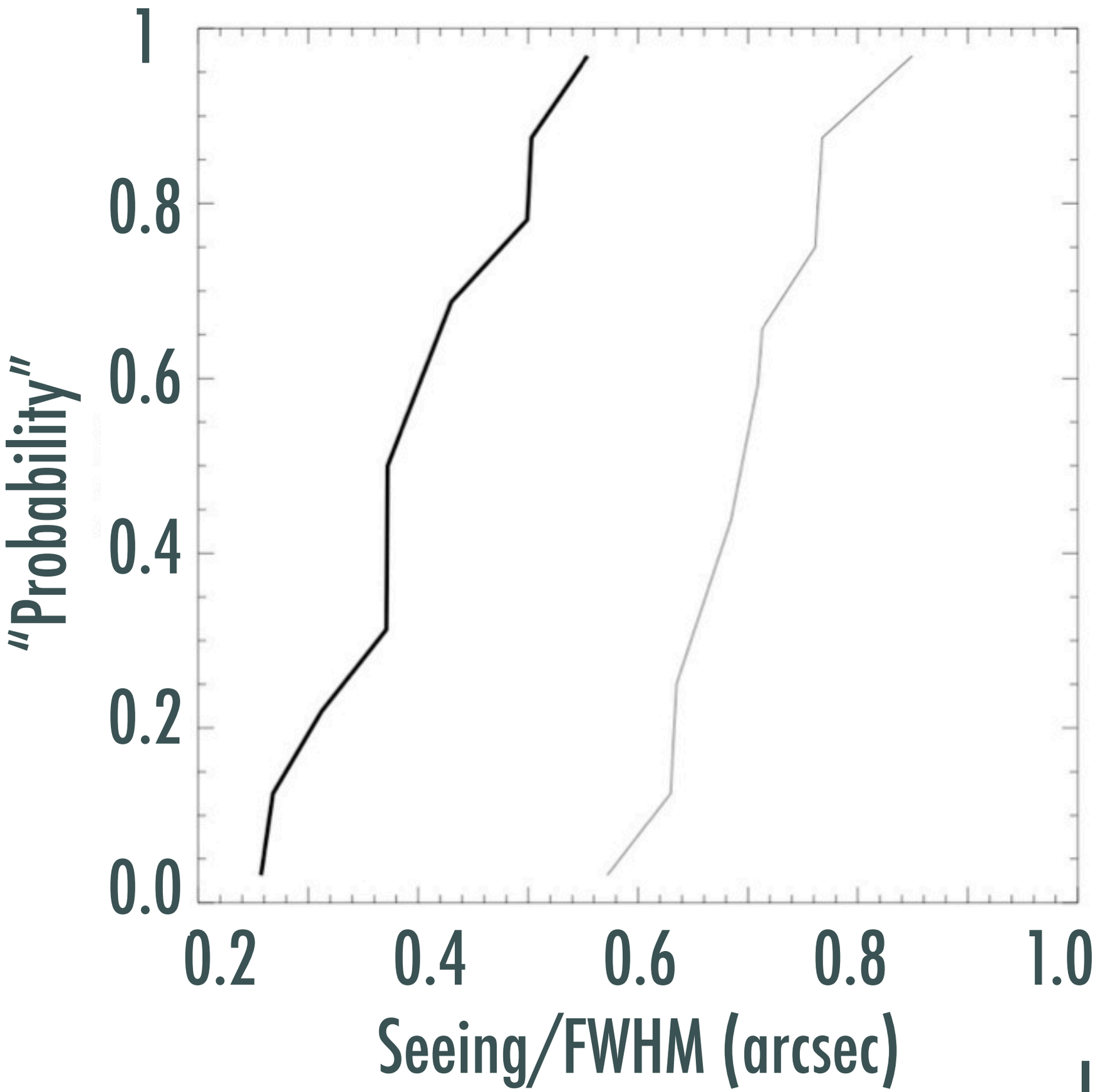
- distribution of the GSs matters
  - 3 stars rarely make an equilateral triangle!
  - tomography helps some but does not "buy back" many fields.
- RLGS ideal - less upper atm measured and no gray zone (no cone effect).



Simulations



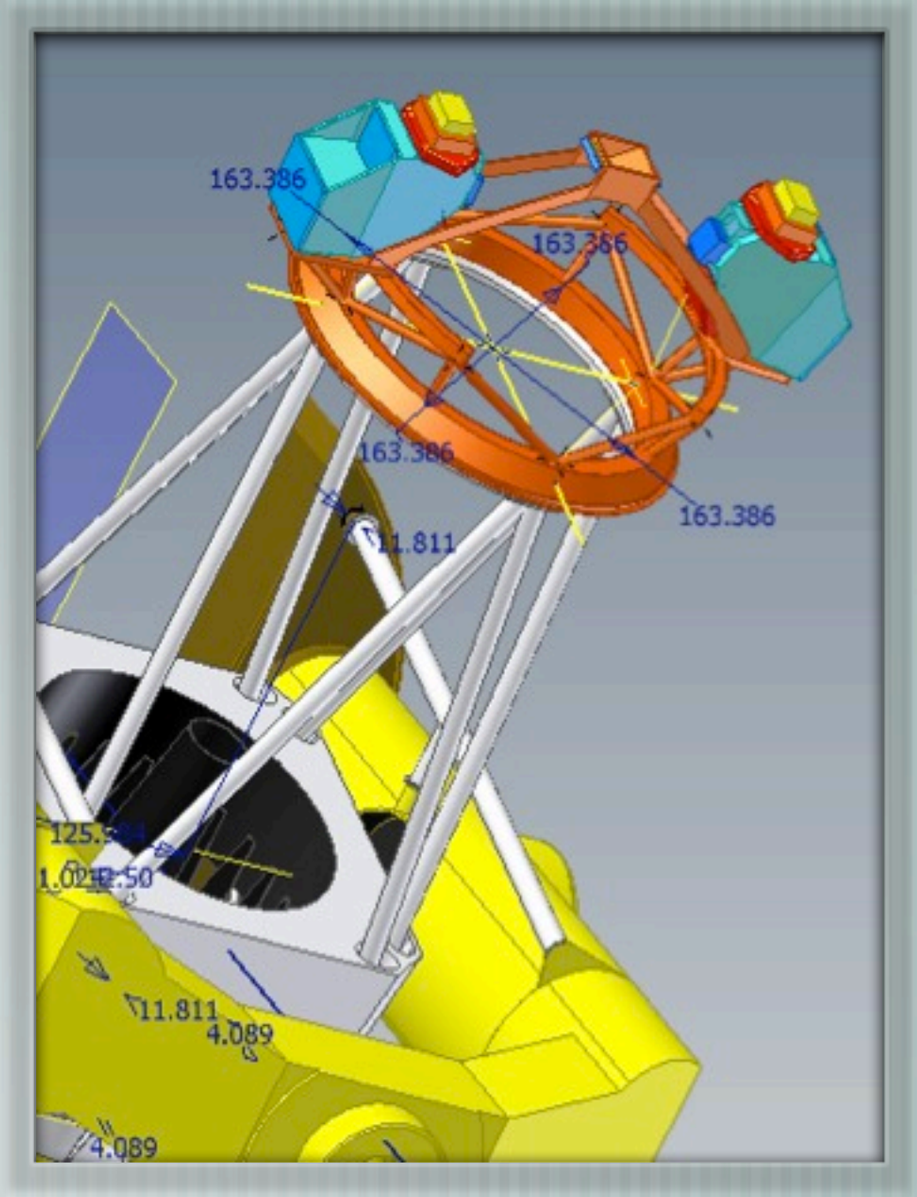
- Simulations need resolution in the GL...
- Maunakea (imaka sims)
  - 8 layers in first 1000m
  - 3 layers distributed out to 20km (RLGS sims)
- imaka sims (O. Lai) include all the major terms - though pupil distortion is only the elongation/misconjugation of the DM
- PSF variations may be limited by tip/tilt corrections.



IMAKA 2009

AM2 v Relay

- IQ Requirement is <u>somewhat</u> relaxed over classical AO but note NCP errors
- Pupil Quality Requirement is unchanged and <u>harder</u> to achieve. Pupil at DM over entire science field
- Std OAP relay falls apart at a few arcminutes.
- pupil requirements ⇒ larger DMs

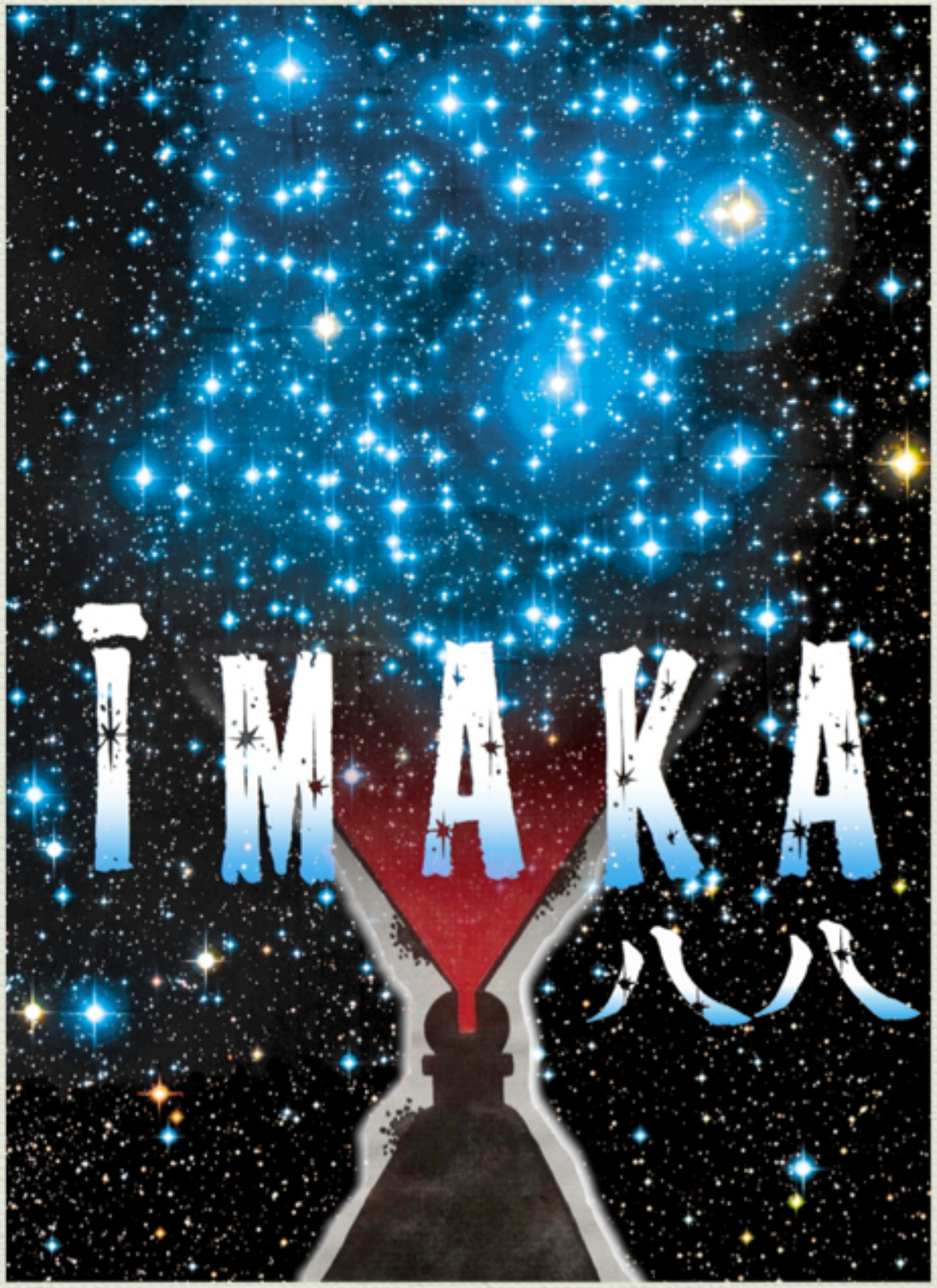


AM2 v Relay

- An AM2 works for all but the largest fields of view...
- Feeds existing instrumentation, maximizes thruput,
- hits the large controllable error terms fitting, pupil dist, NCP errors)
- Very large fields ⇒ an AM1?

GLAO errors

- Need to be smart about upper atm: tomography RLGS.
- AM2
  - ✔ reduces the large "controllable" error terms, helps existing instrumentation, other AO modes
  - ✘ brings "issues"



a pathfinder for wide-field GLAO for the UH2.2m on Maunakea

Mark Chun

2014 Sept 15

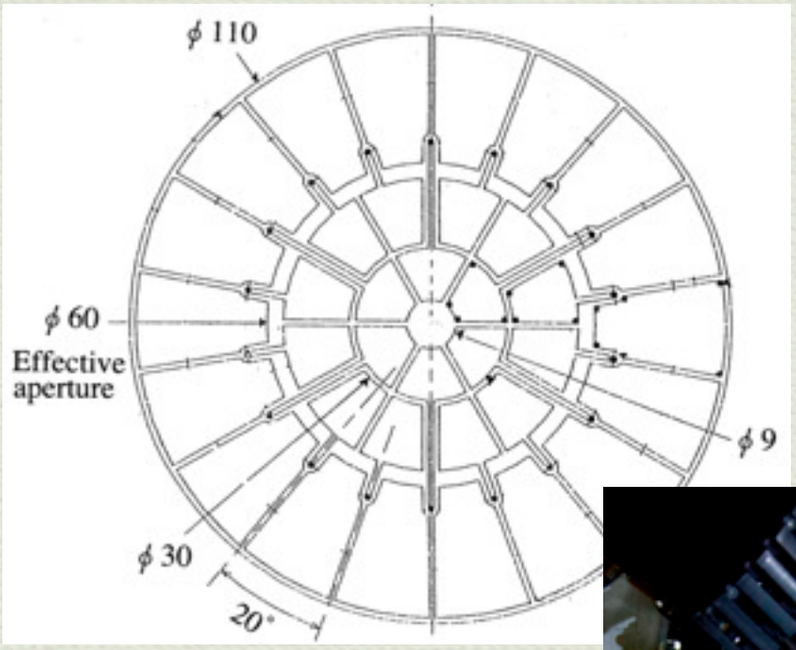
CalTech GLAO Workshop

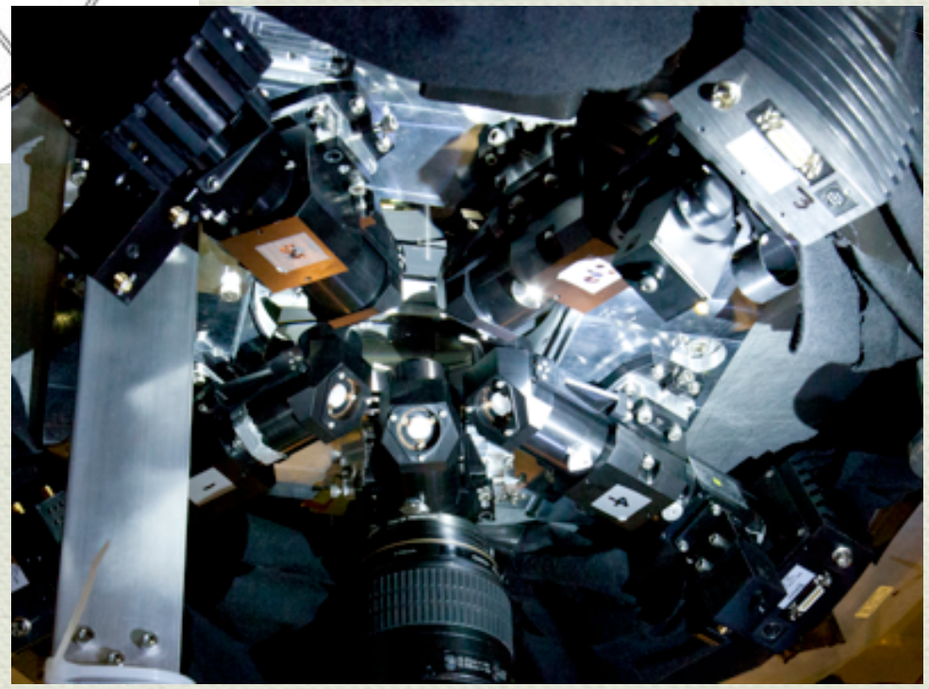
`imaka project

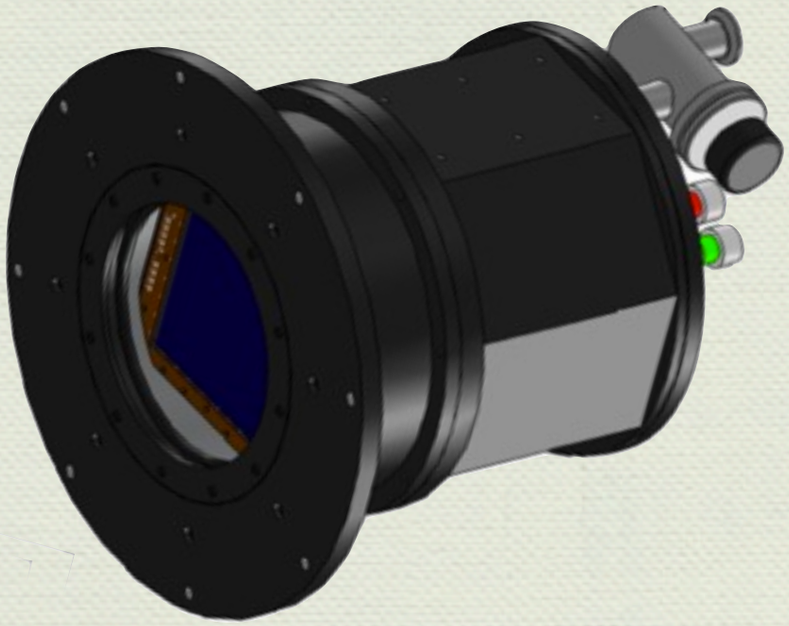
- An NSF-funded testbed for wide-field GLAO on MK to develop on-sky astronomical/AO expertise in prep for GLAO on larger telescopes.
  - reuses hardware/software/expertise from around the MK AO community including UH, Subaru, Gemini, CFHT.
  - limit ourselves to natural GSs and design to do science and technical demonstrations on a limited set of “design targets”
  - Reconfigurable final focal plane and entrance FP (cal unit)
- Lab integration next year...

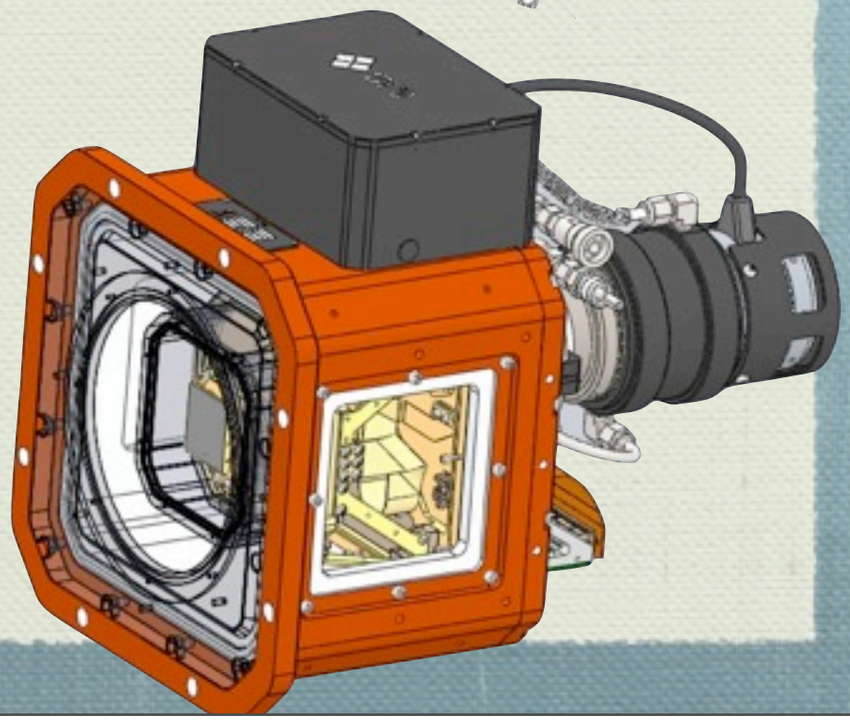
a wide-field GLAO pathfinder

Major Components from other projects



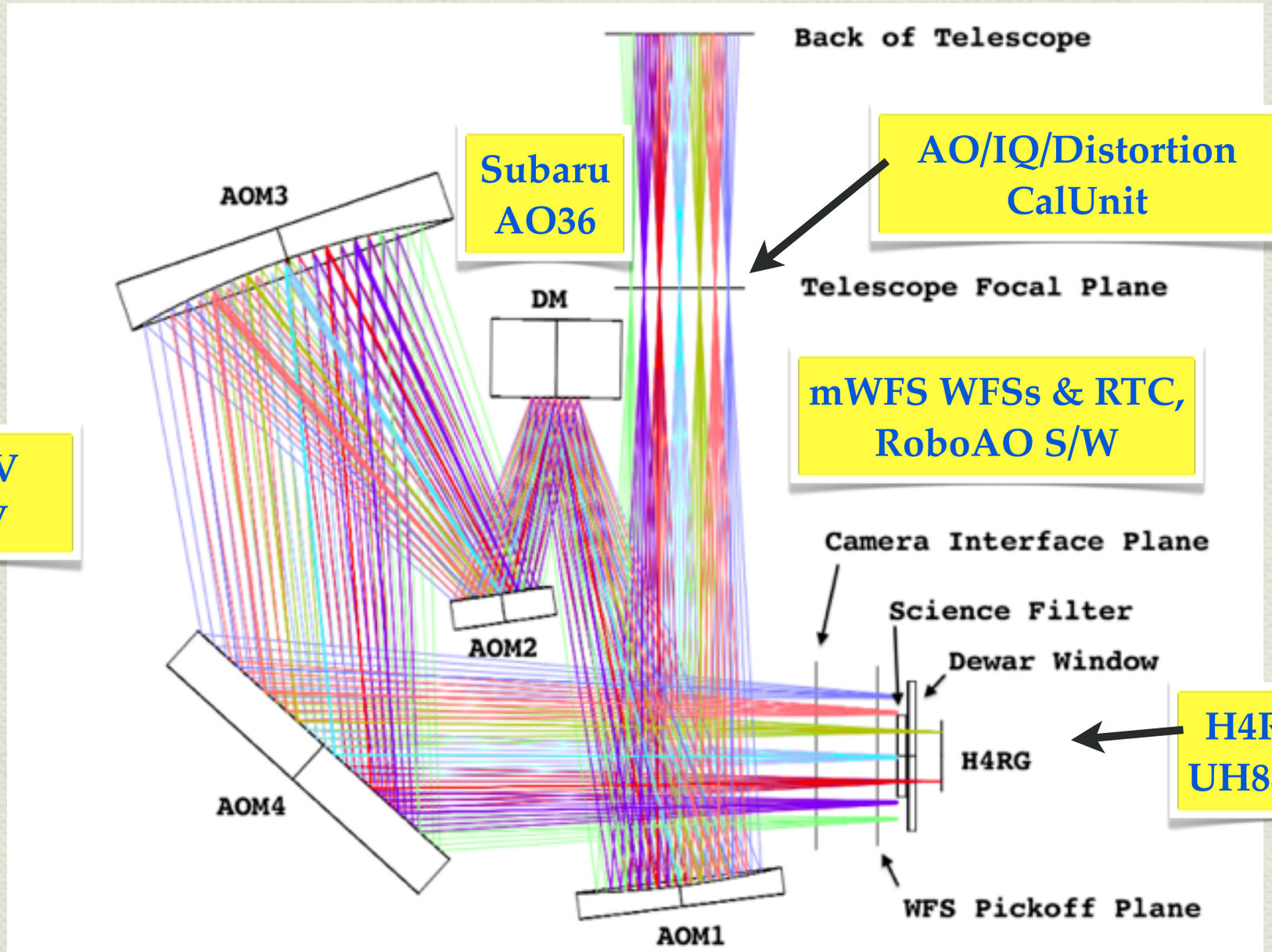






a wide-field GLAO pathfinder

Layout



0.4x0.3 deg FOV
12'x12' SciFOV

a wide-field GLAO pathfinder

Mechanical Design

- Stability and thermal changes in the alignment (IQ and distortion stability) are drivers given the overall size
- We also have a mass limitation at the back of the telescope (500# total)
- Working concept is a carbon-fiber box structure with light-weighted mirrors

a wide-field GLAO pathfinder

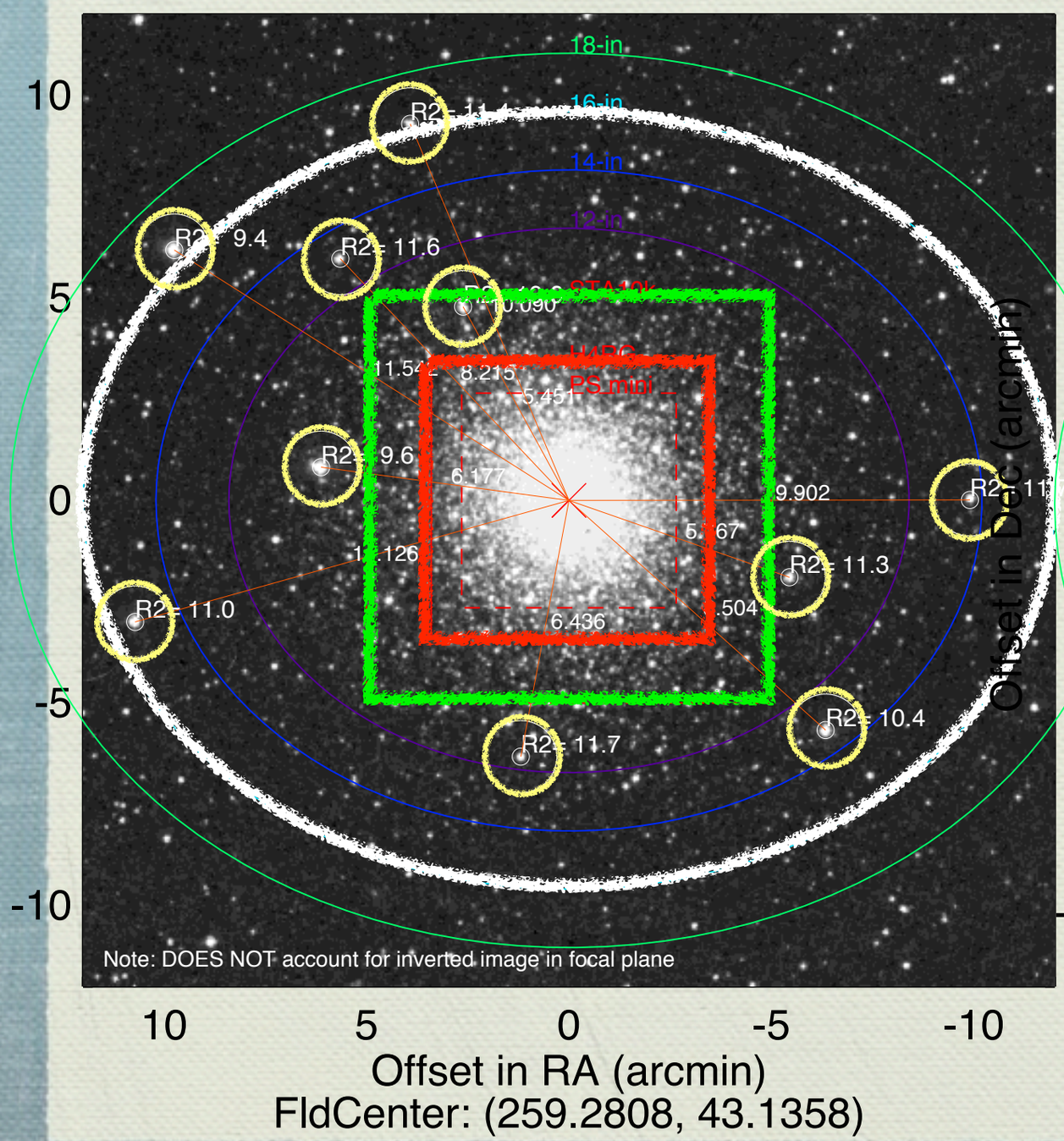
Basic System Specs

AO Relay	0.4 x 0.3 deg acquisition for GS 12'x12' "Science FOV"
DM	CILAS curvature bimorph from Subaru AO36
WFSs	3-5 SHWFSs with 8x8 subap, 10 pixels/subap, 0.4"/pixel, Pupil Imaging mode
RTC	COTS PC and RoboAO s/w, 200Hz sampling
Science Cameras	STA10k H4RG-15

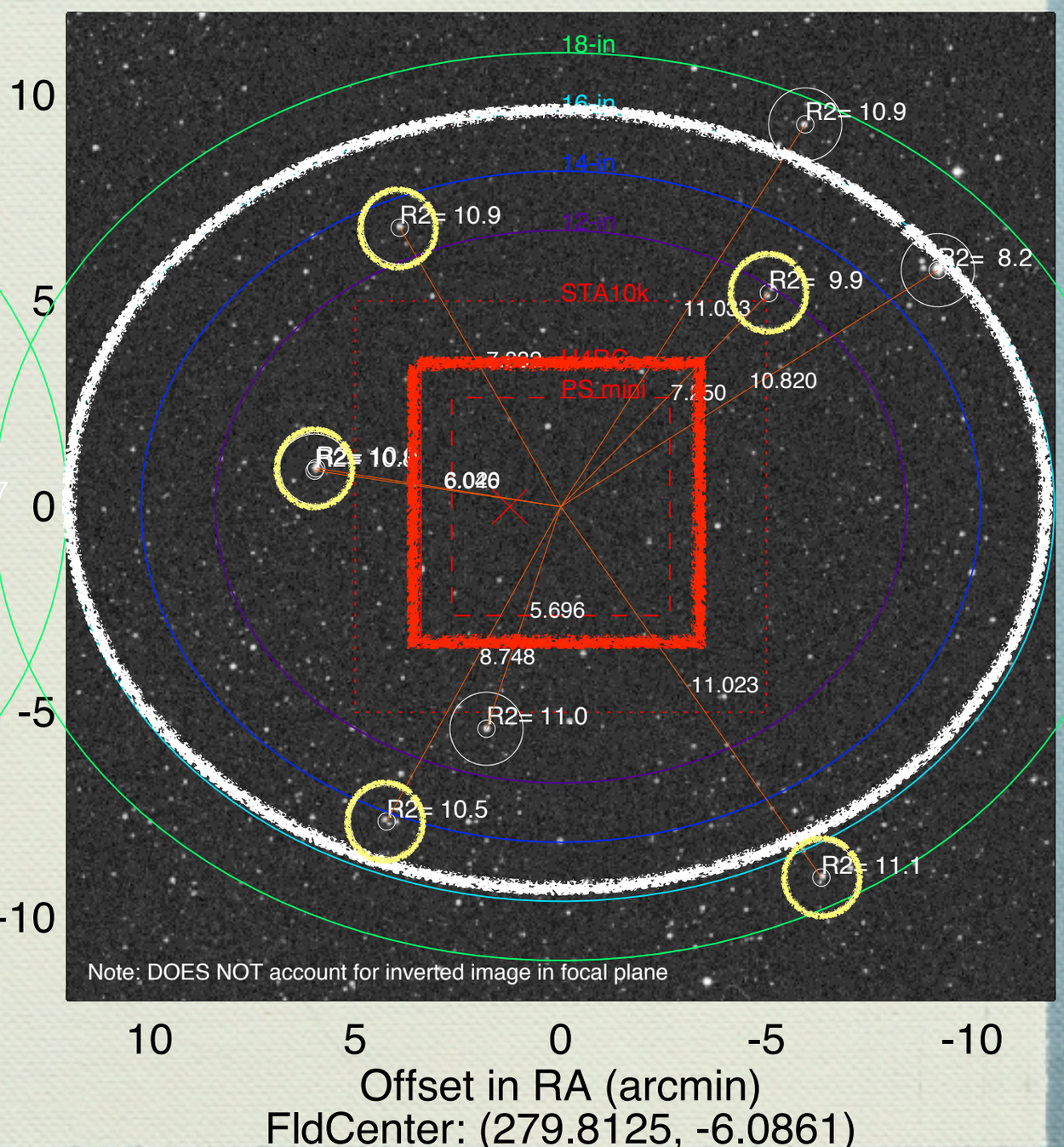
a wide-field GLAO pathfinder

Example Fields

M92-USNOB



RSGC2-USNOB



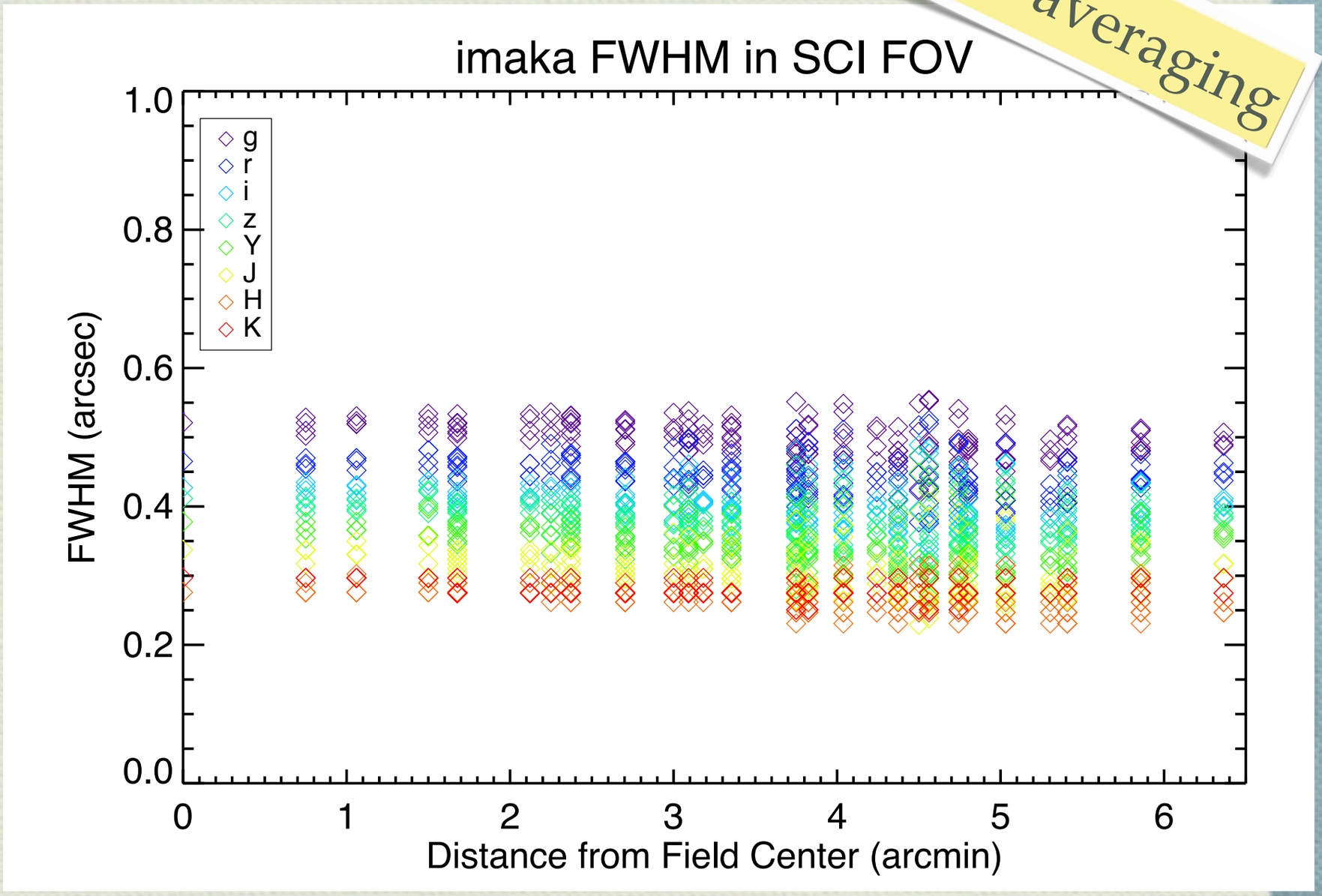
a wide-field GLAO pathfinder

Performance Estimates

N.B.

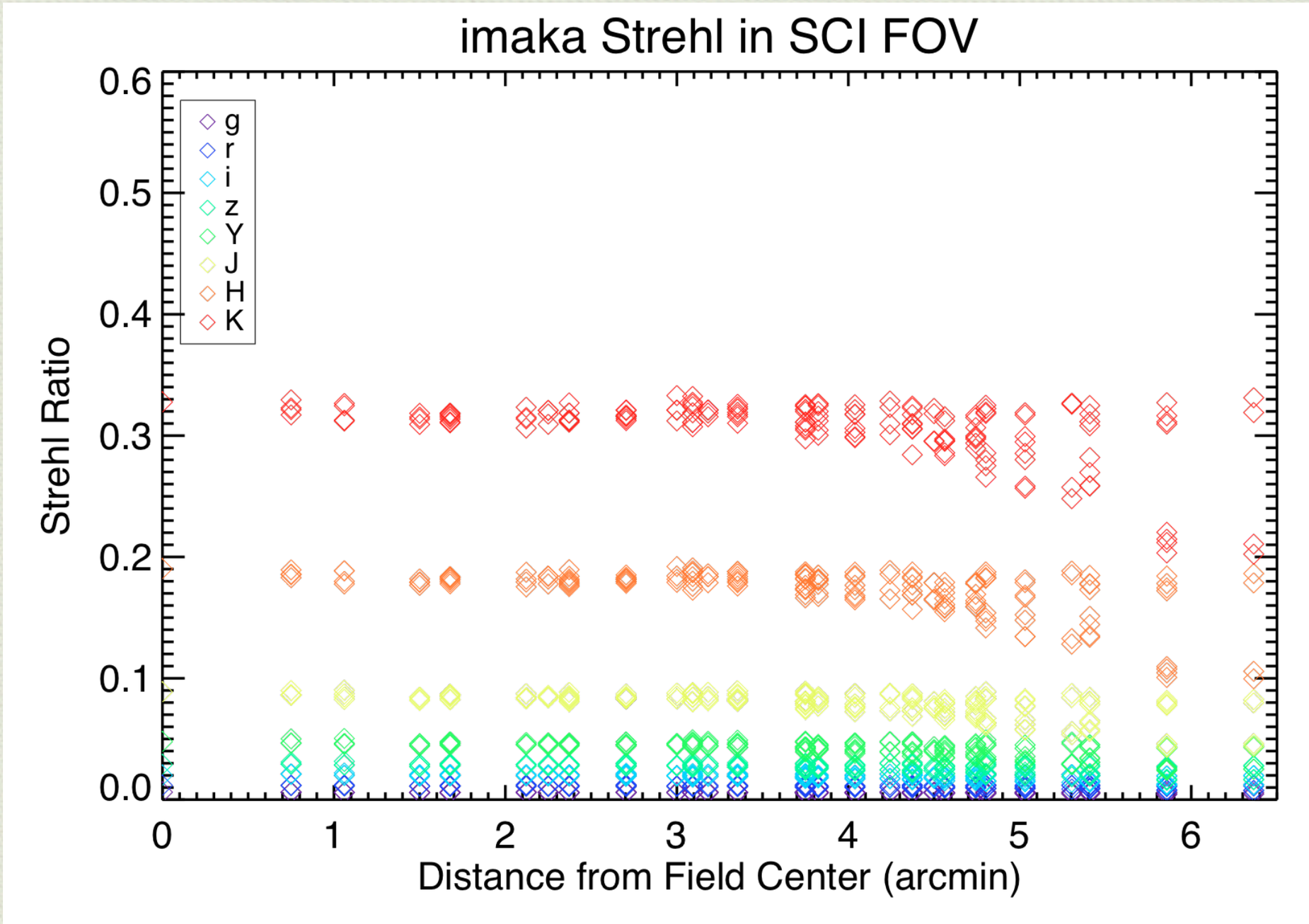
WFS averaging

- Developing error budgets and Monte-Carlo simulations
- Agree in FWHM ~ 10%
- Detailed PSFs from simulations
- NCP errors...



a wide-field GLAO pathfinder

Performance Estimates

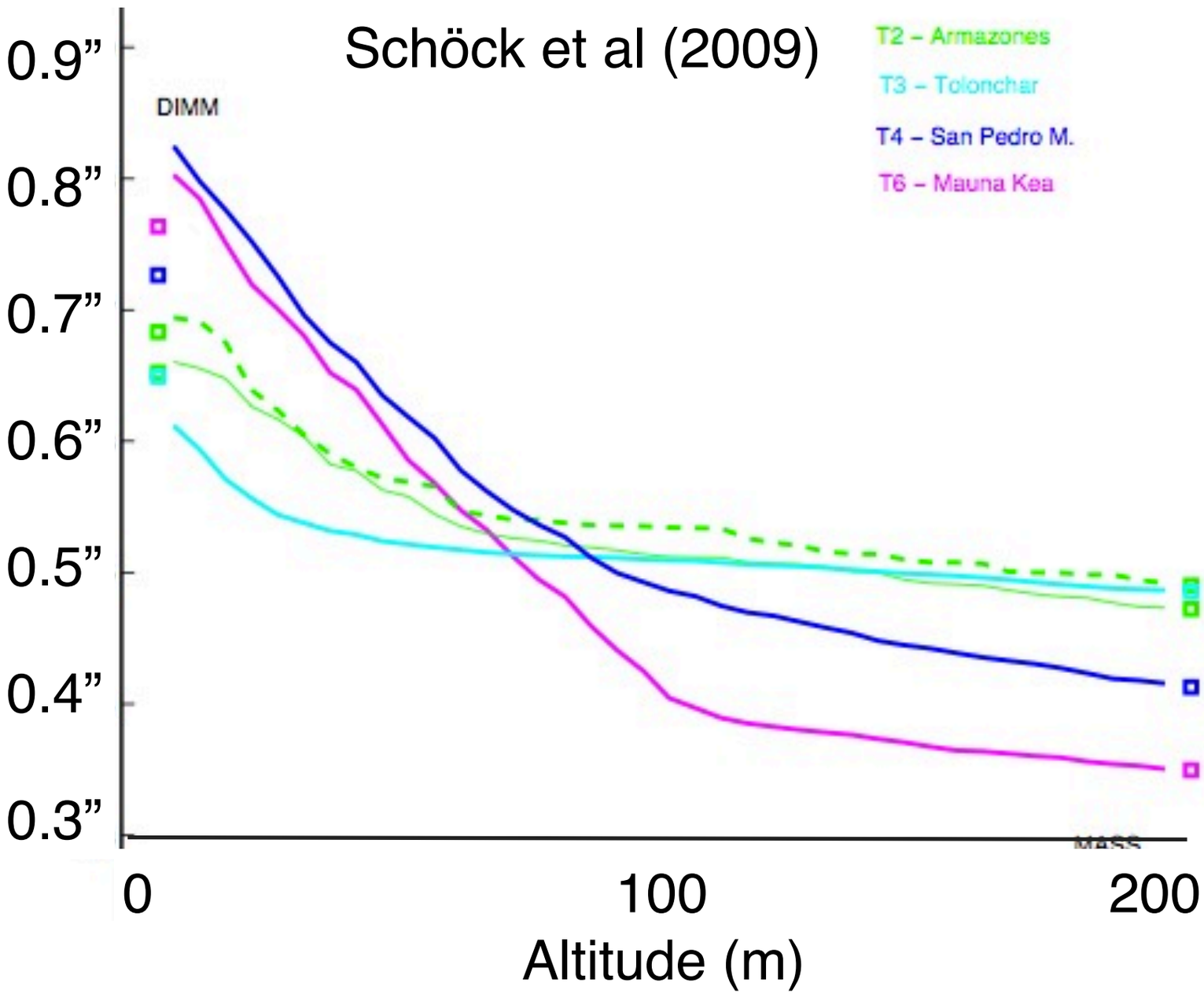


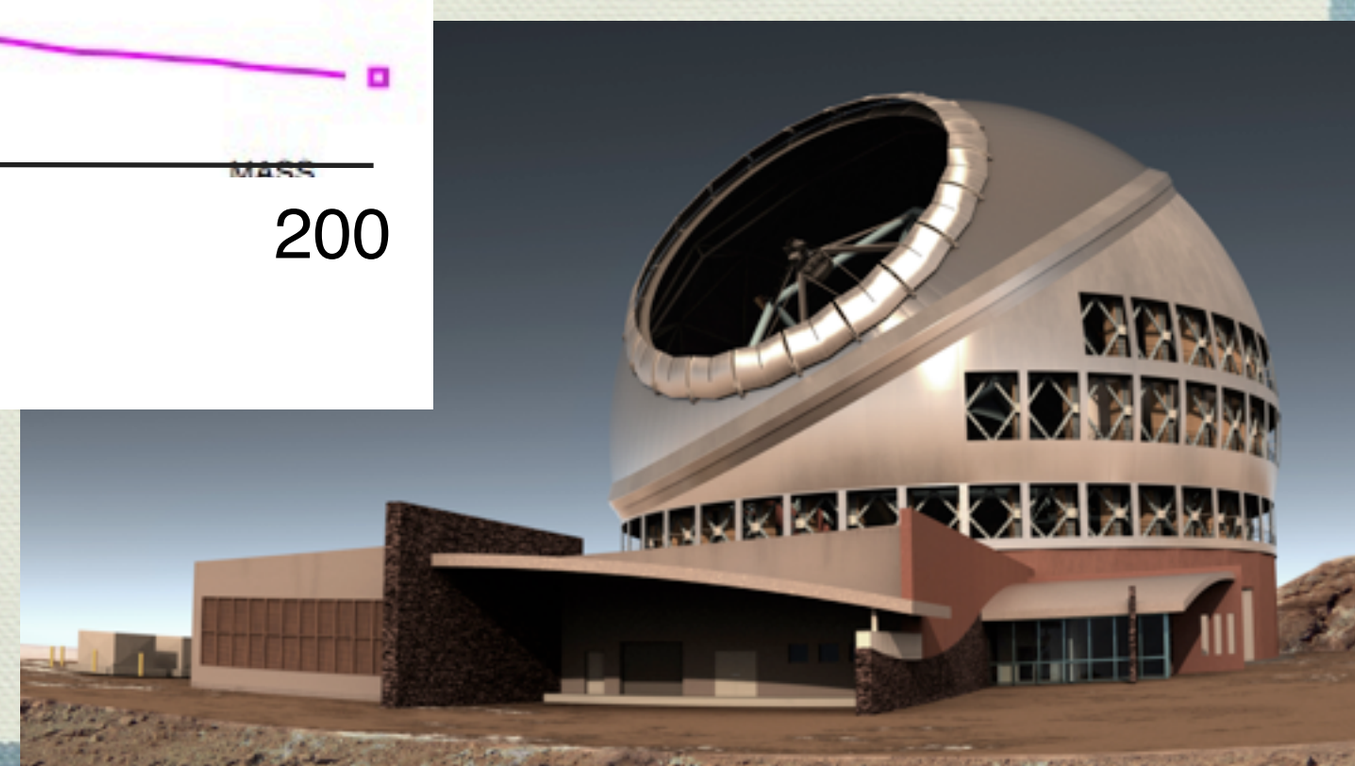
`imaka Team

- Mark Chun, Jessica Lu, Christoph Baranec, Mike Connelley (UH)
- Olivier Lai, Yutaka Hayano, Shin Oya (Subaru/NAOJ)
- Doug Toomey (Mauna Kea Infra-Red)
- Simon Thibault, Denis Brousseau (Laval)

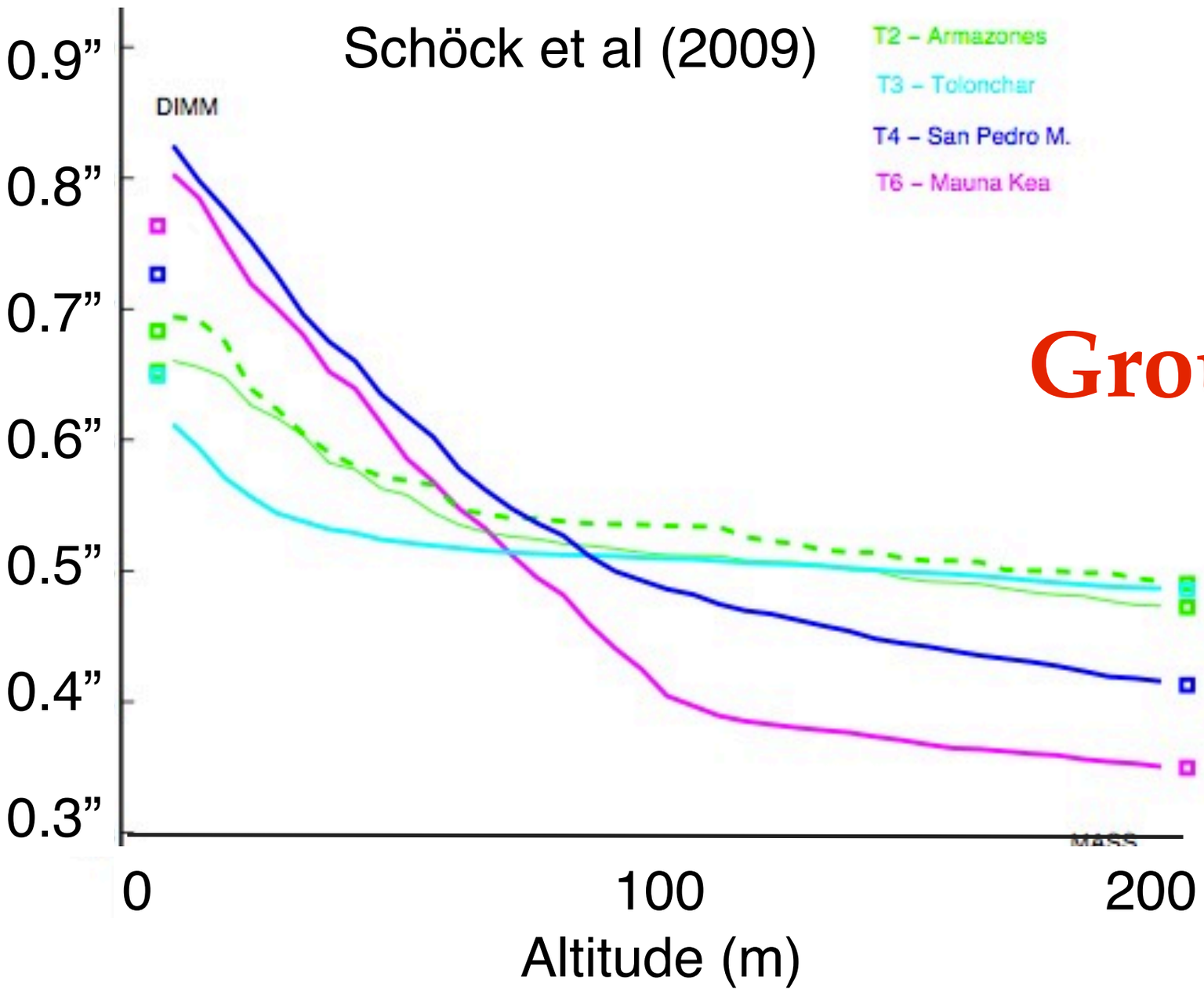
http://www.ifa.hawaii.edu/~mchun/imaka.html

Seeing from above 13N (TMT)





Seeing from above 13N (TMT)



Ground-Layer AO!