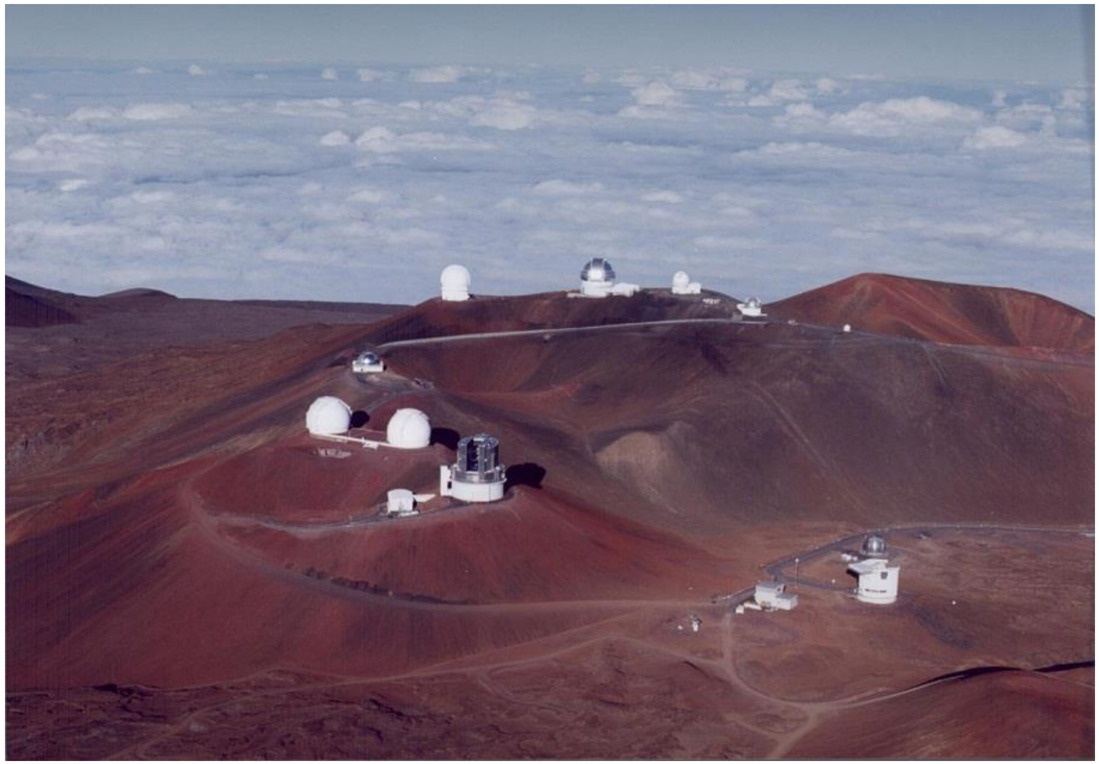
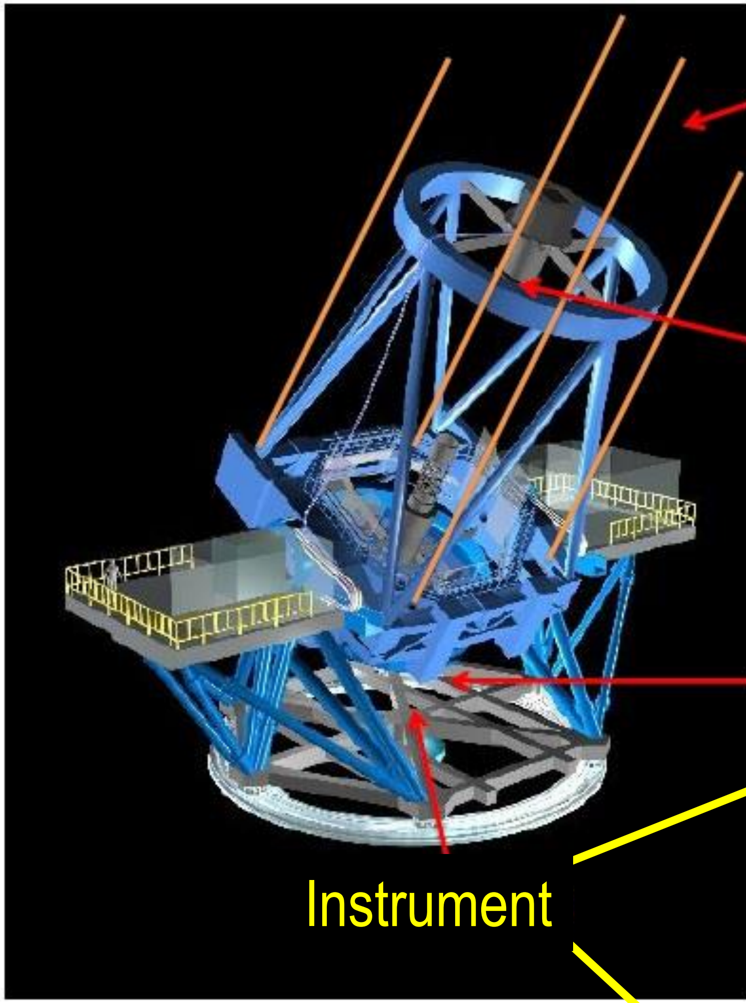
Subaru Next Generation Wide Field AO: Ground Layer AO Simulation



Shin Oya (Subaru Telescope)
Subaru Next Generation AO Working Group

2013/5/9 @ Victoria

Subaru Next Generation Wide-Field AO



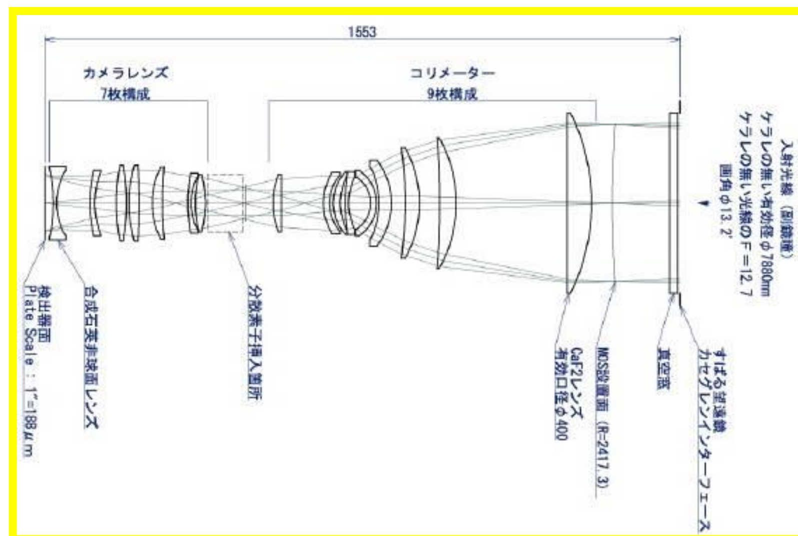
multi-laser

ASM

multi-WFS

Schedule

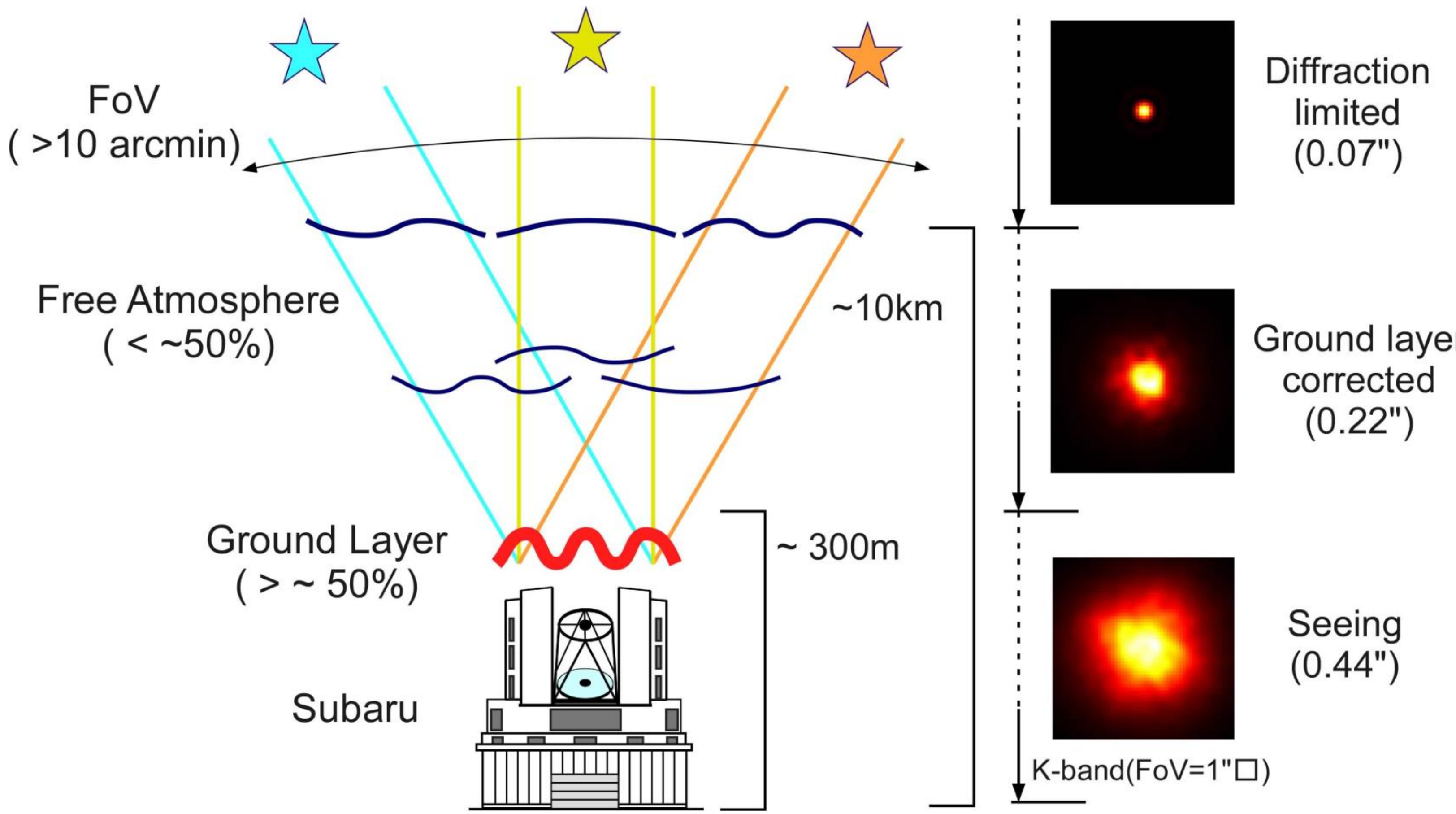
2013: CoDR
2014: PDR
2016: FDR
2017: Integration / test
2019: First Light
2020: Science Observation



What is GLAO?

- Corrects only turbulence close to the ground
- Improves seeing over wide-filed of view

GLAO correction (simulation)

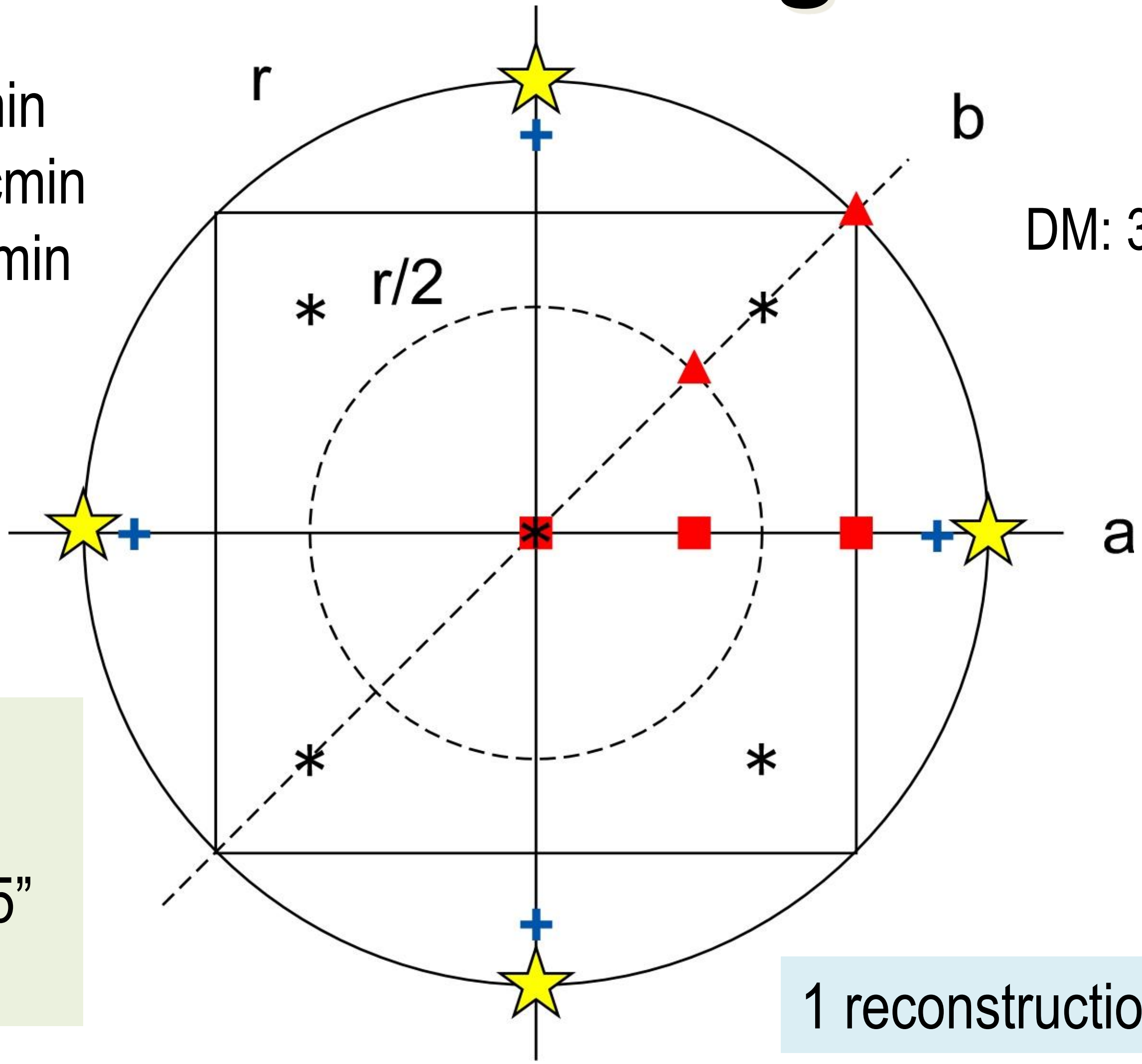


Multiple guide stars are required to determine the ground layer strength

Early Results before 2013

Subaru GLAO configuration

r = 5 arcmin
7.5 arcmin
10 arcmin



DM: 32 act. Across
@ -80m

RAVEN seeing:
- good: 0.52”
- moderate: 0.65”
- bad: 0.84”

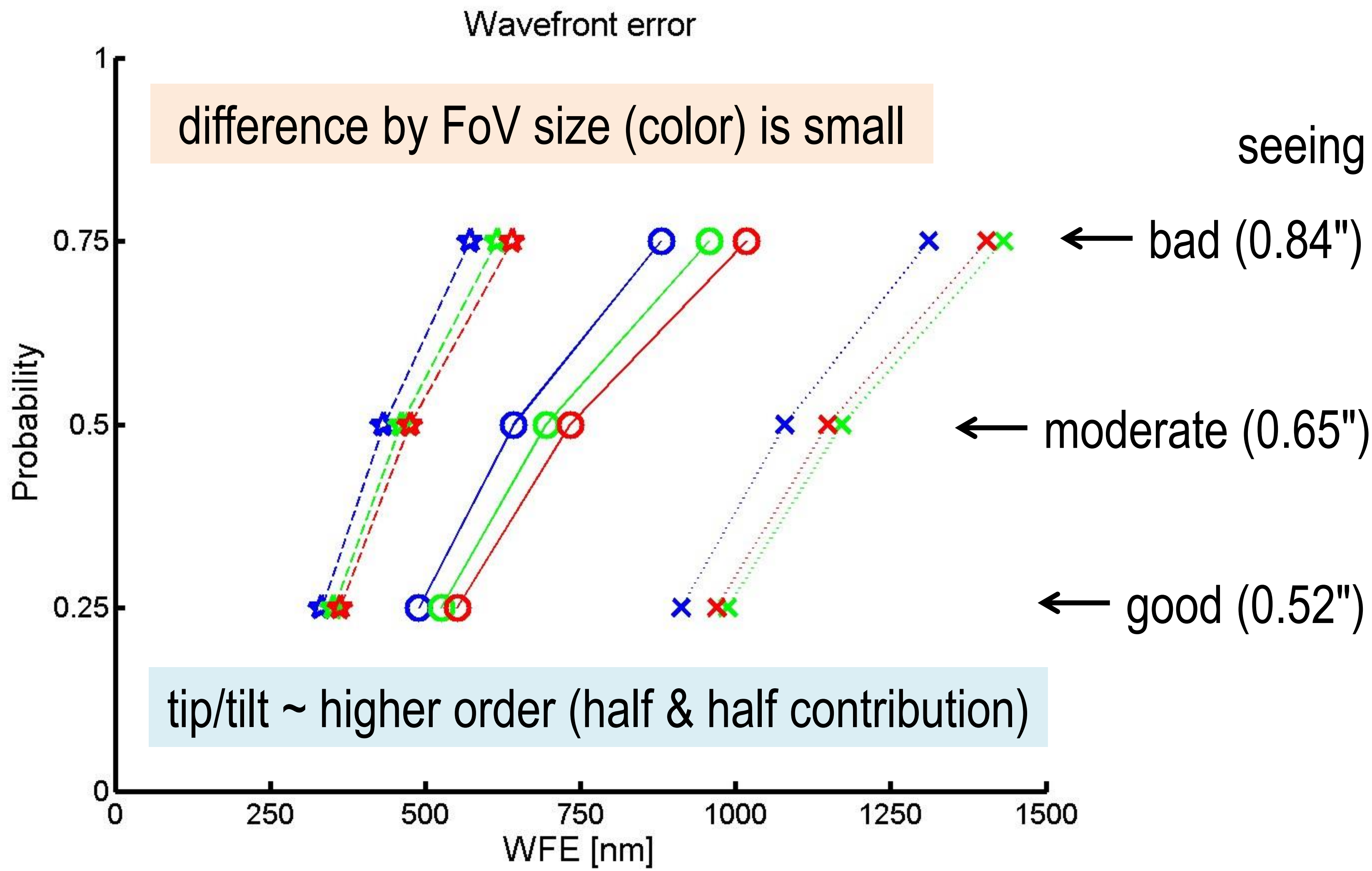
1 reconstruction layer (0m)

★: HoGS +: TTF-GS (50" inside of LGS)

■: PSF eval.(toward GS) ▲: (between GS)

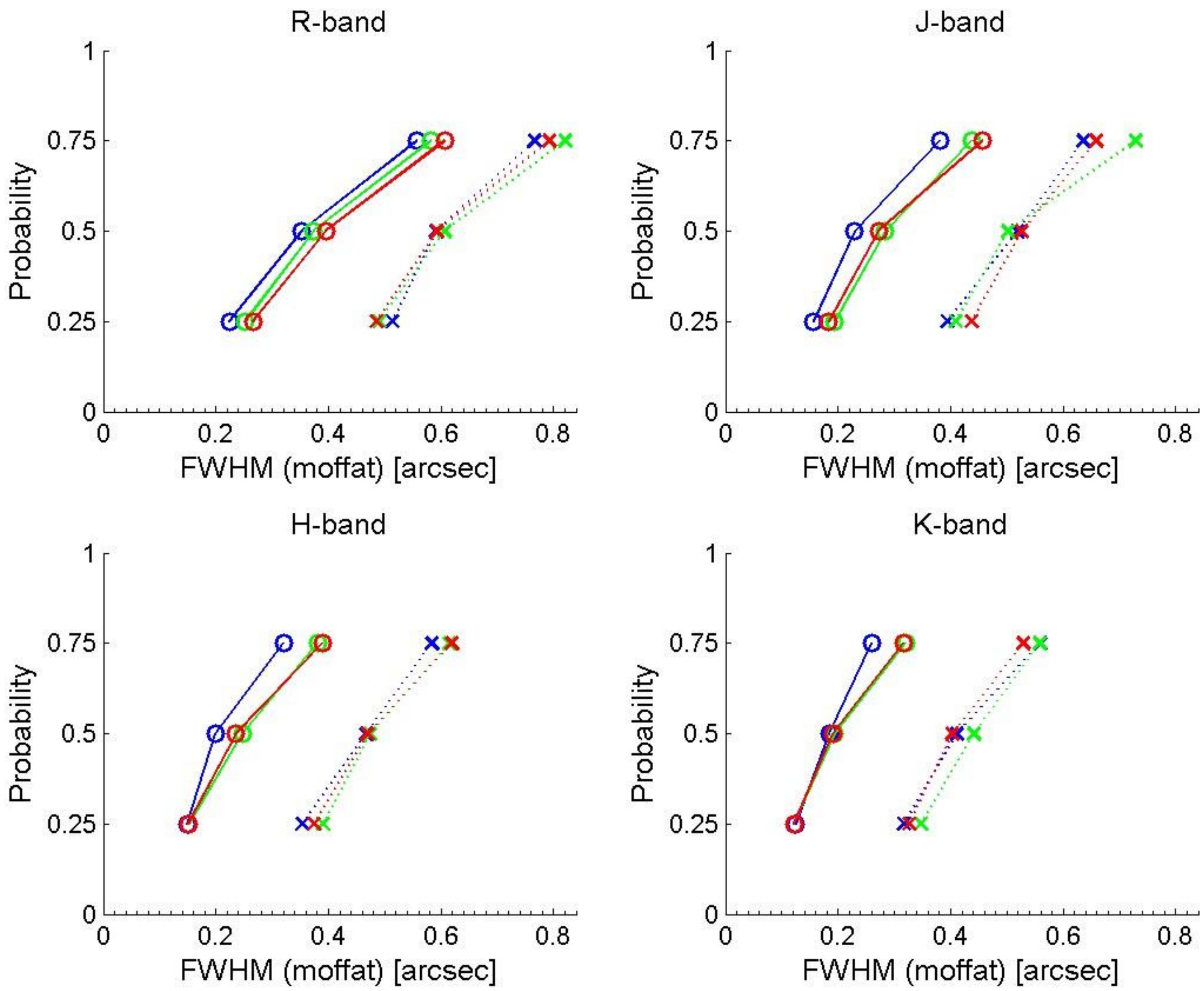
∗ : DM fitting

Seeing dependence of WFE



FOV: blue:φ =10arcmin、green: φ =15arcmin、red:φ =20arcmin
WFE order: ○: all order、☆: tip/tilt removed = higher order
Seeing: ×

Seeing dependence of FWHM

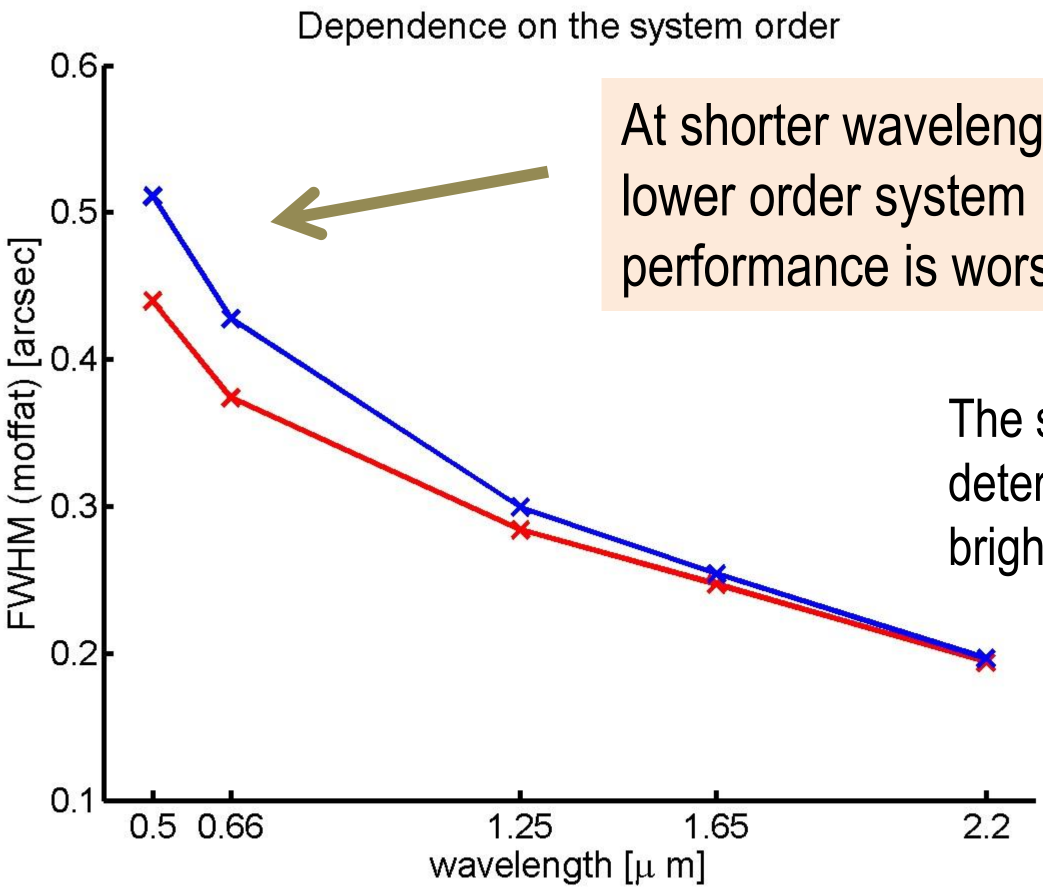


FOV: blue:φ =10arcmin、green:φ =15arcmin、red:φ =20arcmin
GLAO: ○、Seeing: ×

Dependence on the system order

FoV:15' ϕ
moderate
seeing

NGS
simulation



At shorter wavelength, lower order system performance is worse.

The system order will be determined by LGS brightness and WFS noise.

red: 32 act. across DM (& WFS)、blue: 10 act. across DM (& WFS)

Note that the result for the combination of high-order DM (32 act. across) and low-order WFS (10 act. across) is the same as 10 act. across DM (&WFS).

The early results says

- Expected performance is 0.2" in the K-band under moderate seeing condition.

- The performance little changes by FoV between 10 arcmin and 20 arcmin; i.e., hardware (telescope of instrument) limits the available FoV

- The system order as low as 10x10 results same performance at NIR wavelengths. The number of ASM actuator is determined by possible mechanical spacing range. S/N in a sub-aperture determines the number of WFS sub-aperture.

- No slide here, but see Oya+12,SPIE,8447,3V

TTFGS < R=18, Frame rate of LGS WFS > 100Hz

Recent Results

Seeing Model

Raven Model (Andersen+12,PASP124,469) has been used

- free atmosphere: TMT site test (13N) (Els+09,PASP,121,527)
- ground layer: difference between Subaru IQ and 13N

Subaru Model

percentile seeing	25%-ile (good)	50%-ile (moderate)	75%-ile (bad)
height	fractional contribution		
0 km	0.4777	0.5507	0.5000
0.06 km	0.2055	0.1957	0.1872
0.5 km	0.0394	0.0605	0.0860
1 km	0.0137	0.0204	0.0359
2 km	0.1107	0.0234	0.0400
4 km	0.0488	0.0546	0.0518
8 km	0.0313	0.0429	0.0556
16 km	0.0731	0.0518	0.0435
$\int C_N^2 \times 10^{-13} \mathrm{m}^{1/3}$	3.5749	5.2736	8.1315
$r_0(0.5\mu\mathrm{m})$	14.9cm	11.8cm	9.1cm
fwhm(0.5μm)	0.56"	0.73"	0.97"
fwhm(AG)	0.49"	0.64"	0.84"

Added t o meet Subaru IQ (0 km row)

TMT site test (0.06 km – 16 km rows)

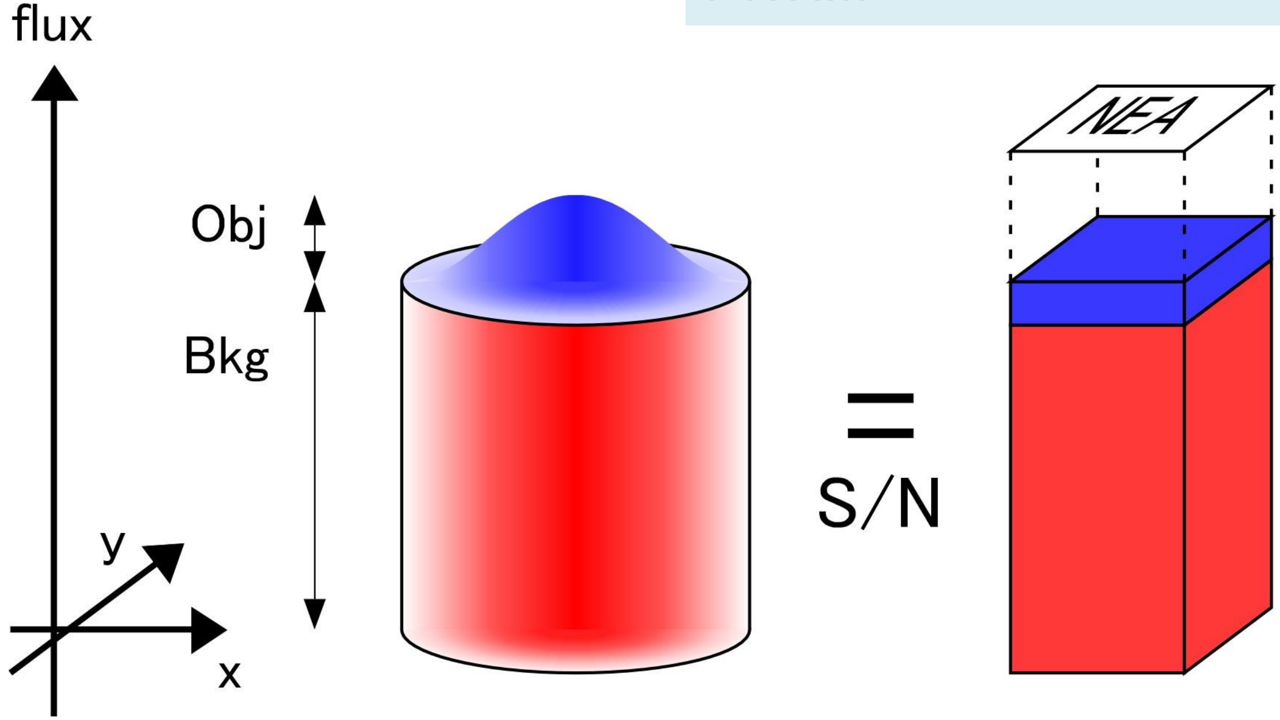
AG wavelength (0.73um) & <u>outer scale</u> corrected

NEA as a performance measure

Noise Equivalent Area = $1/\int \mathrm{PSF}^2$

King+83,PASP,95,163

No need to assume profile, FWHM

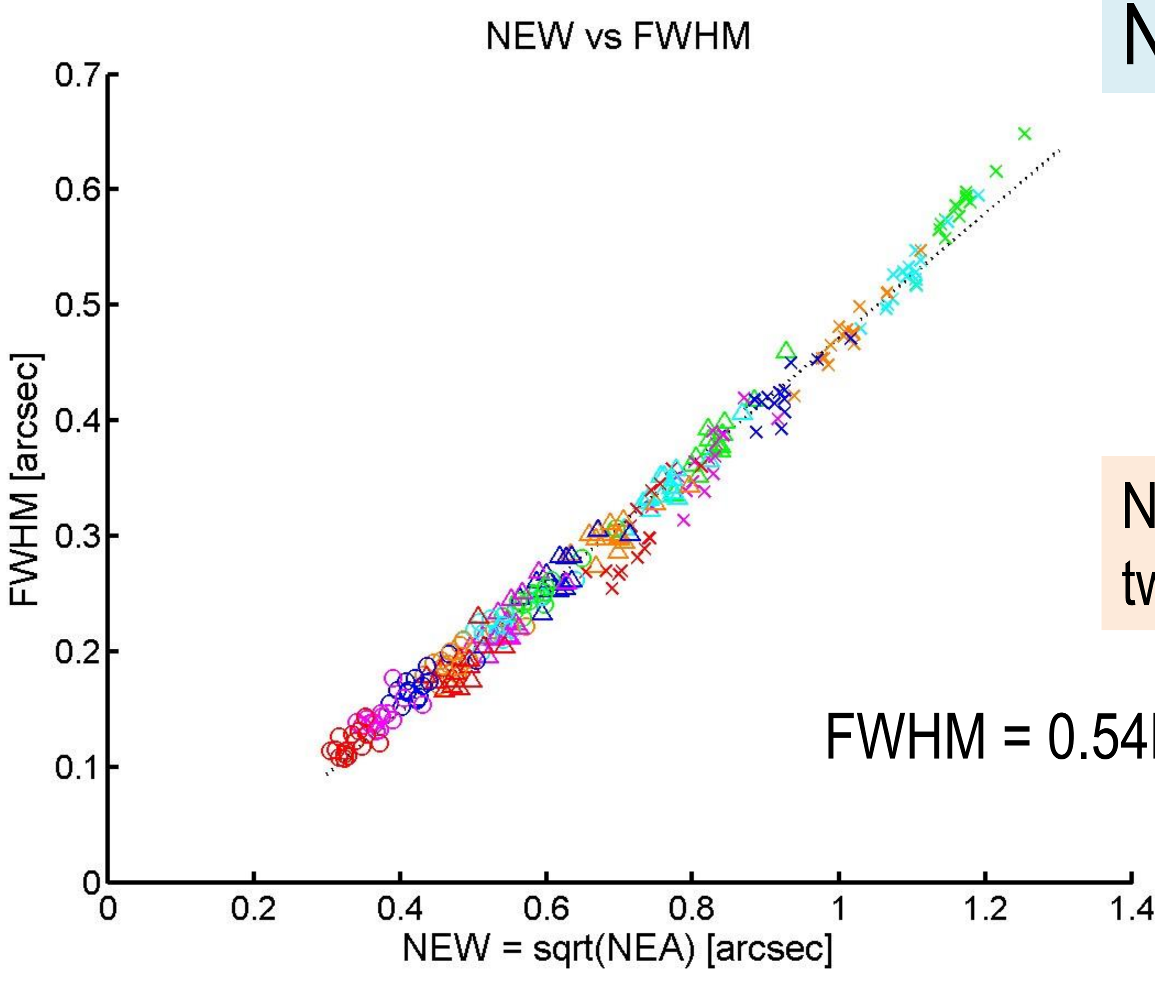


- limiting flux ∝ √NEA
- astrometry ∝ NEA

In the case of Subaru GLAO
FWHM ~ 0.54√NEA

Relation between NEW and FWHM

NEW≡√NEA



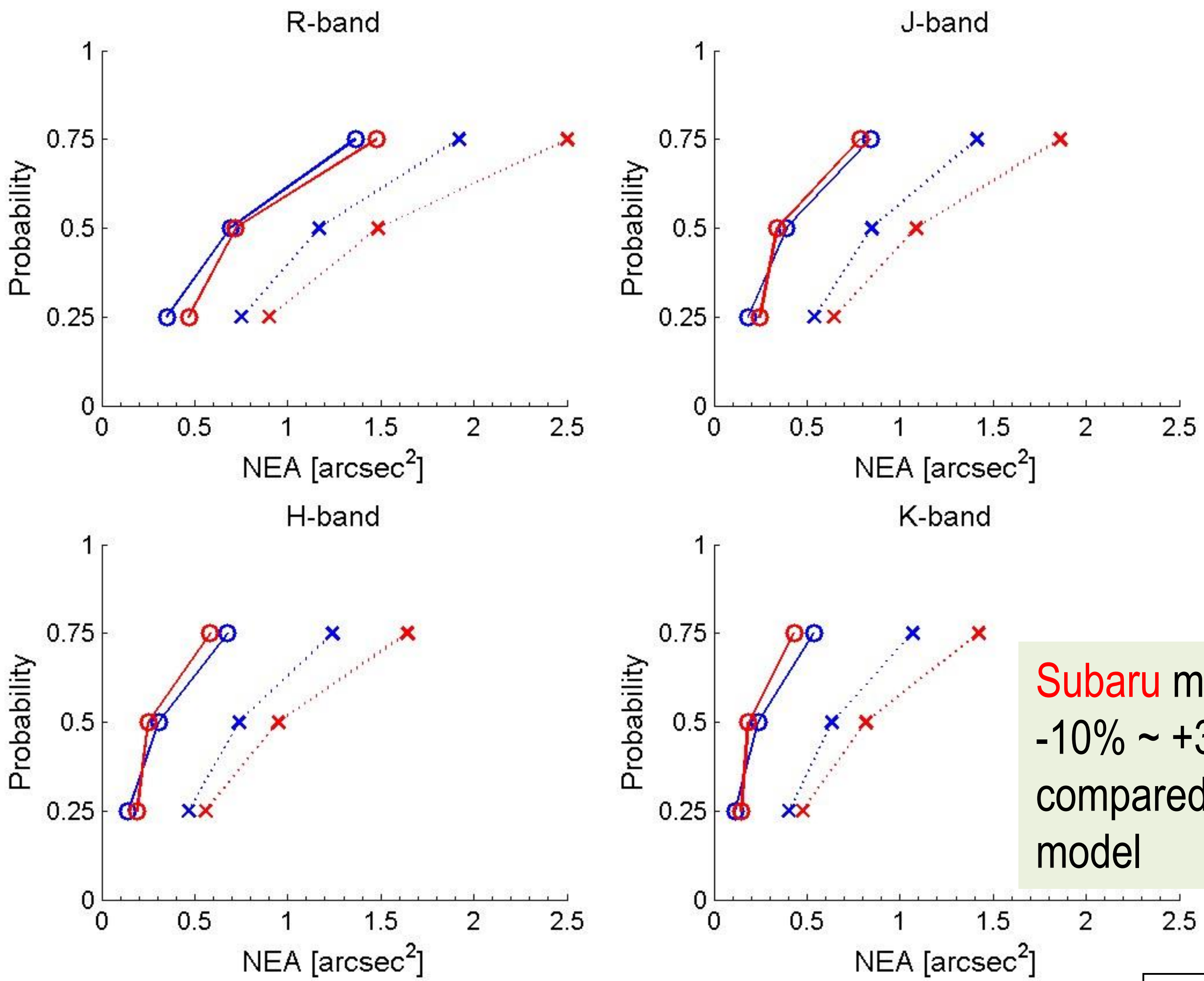
NEW is roughly twice of FWHM

FWHM = 0.54NEW - 0.07

band: R、I、z、J、H、K

seeing: good: ○、moderate: △、bad: ×

Seeing model dependency



Subaru model results -10% ~ +30% NEA compared with RAVEN model

Seeing model: Blue: RAVEN、Red: Subaru
GLAO: ○ & solid、Seeing: × & dotted

NGS
φ =15arcmin

Difference by ground layer

Subaru Model

- GL height of TMT site test (13N) is set to 60m
- The difference of Subaru IQ is set to 0m

if any change by some tweaks:

- raising the height of 60m to 100m
- combining 60m strength to 0m
- dividing 0m strength and put the half at 30m

The difference of results in

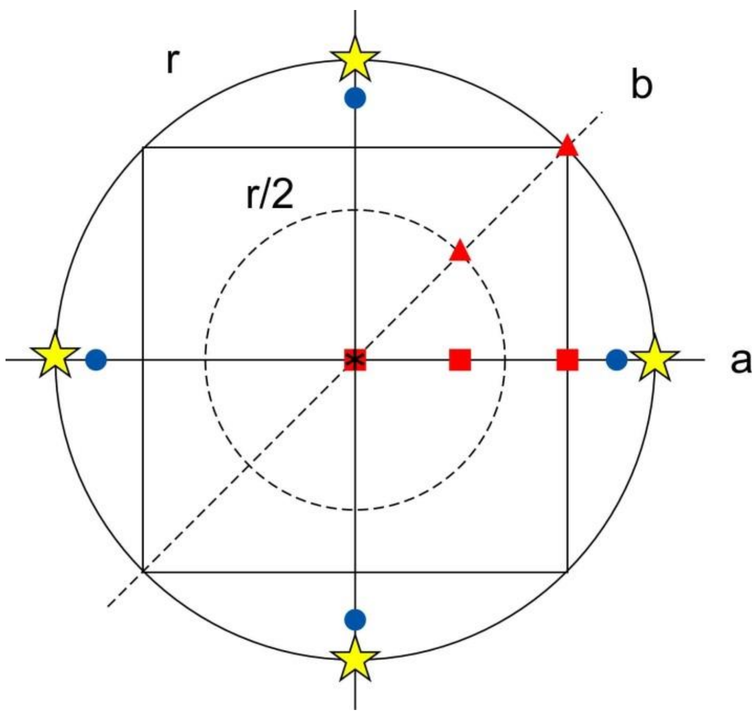
WFE < ~10%, NEA < ~20% (not so large),

GL turbulence evaluation needed to be more precise

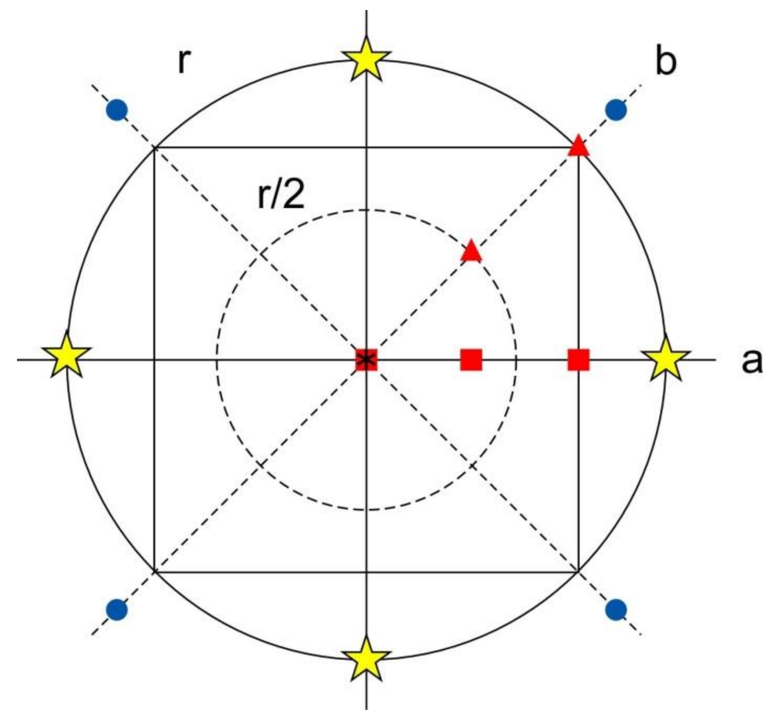
Tip/Tilt/Focus GS config dependency

★ : LGS (10mag)、●TTFGS (18mag)

A-conf: TTGS adjacent to LGS

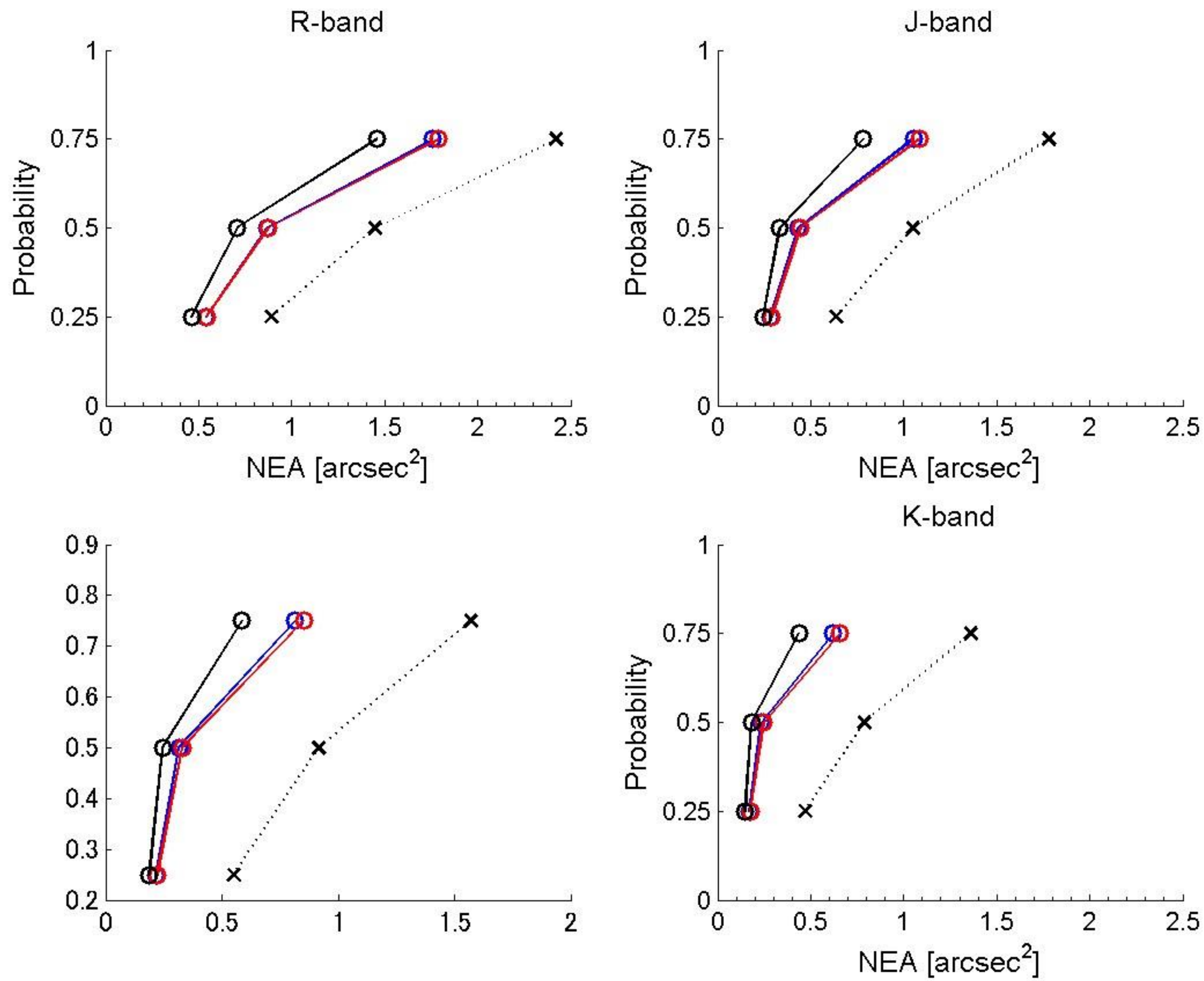


B-conf: TTGS between LGSs



B-conf results worse (WFE: ~10%、NEA: ~ 5%) than A-conf.
Adopt B-conf for further simulation for worse case estimation.

Guide Stars Configuration Dependency

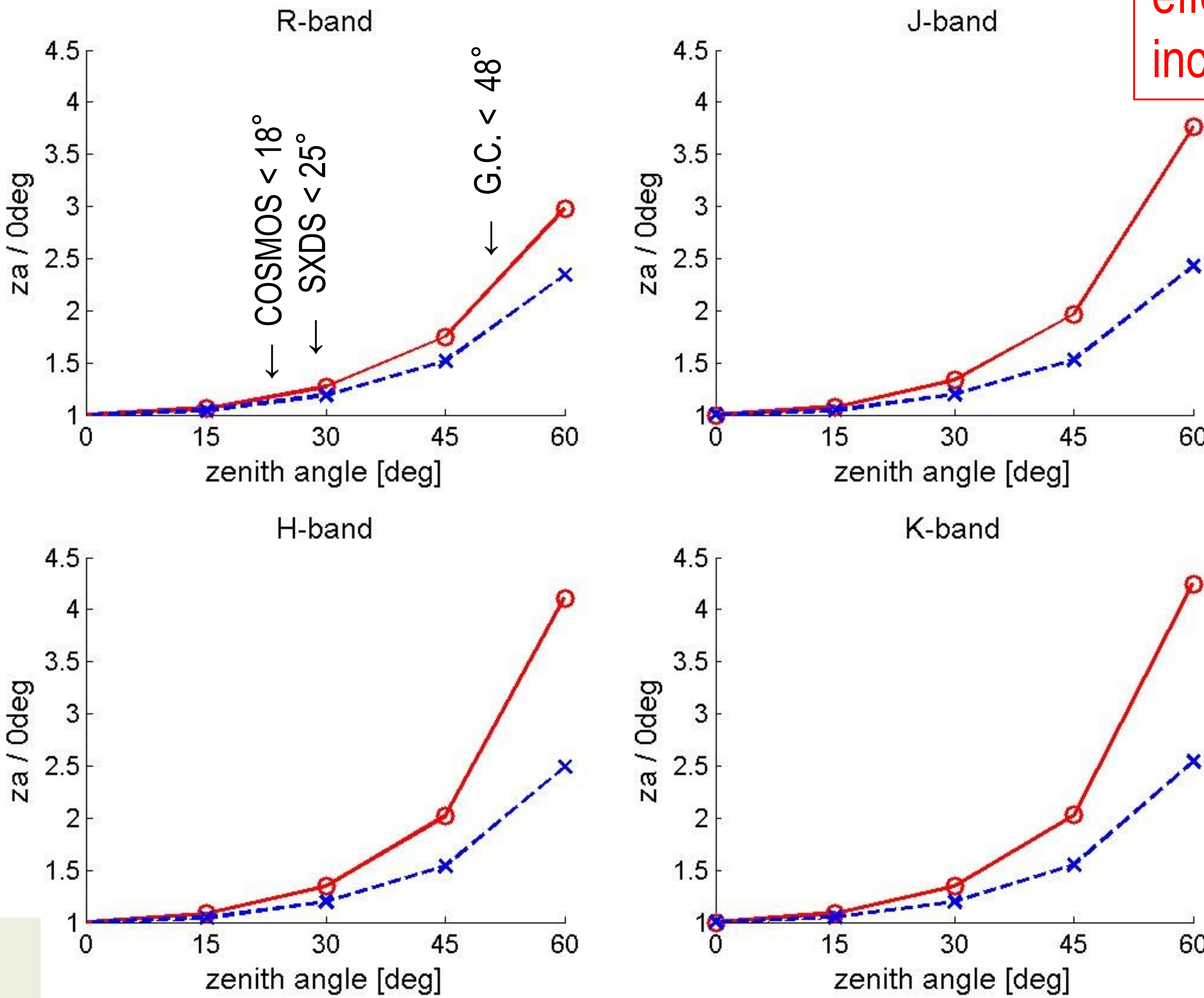


Configuration: black NGS、blue: LGS-A、red: LGS-B
GLAO: ○、Seeing: ×　　(φ =15arcmin)

Zenith angle dependency

effective height increases

NEA



GLAO gain over seeing decreases by
10% at 45°
20% at 60°

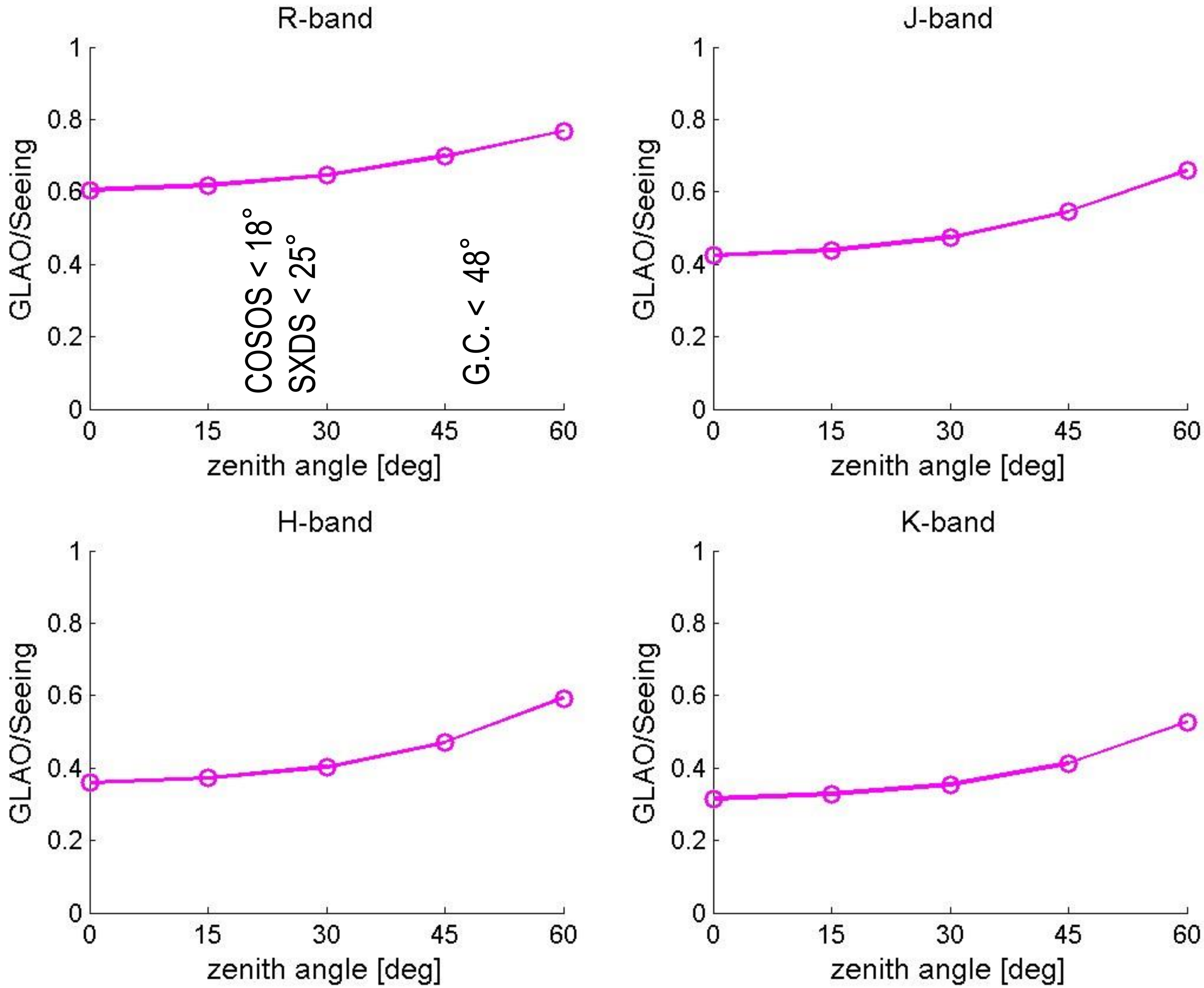
Subaru moderate seeing
FoV: 15' ϕ

Seeing changes as Kolmogorov

NEA: red (solid): GLAO, blue (dashed): seeing

Zenith angle dependency: GLAO / Seeing

NEA



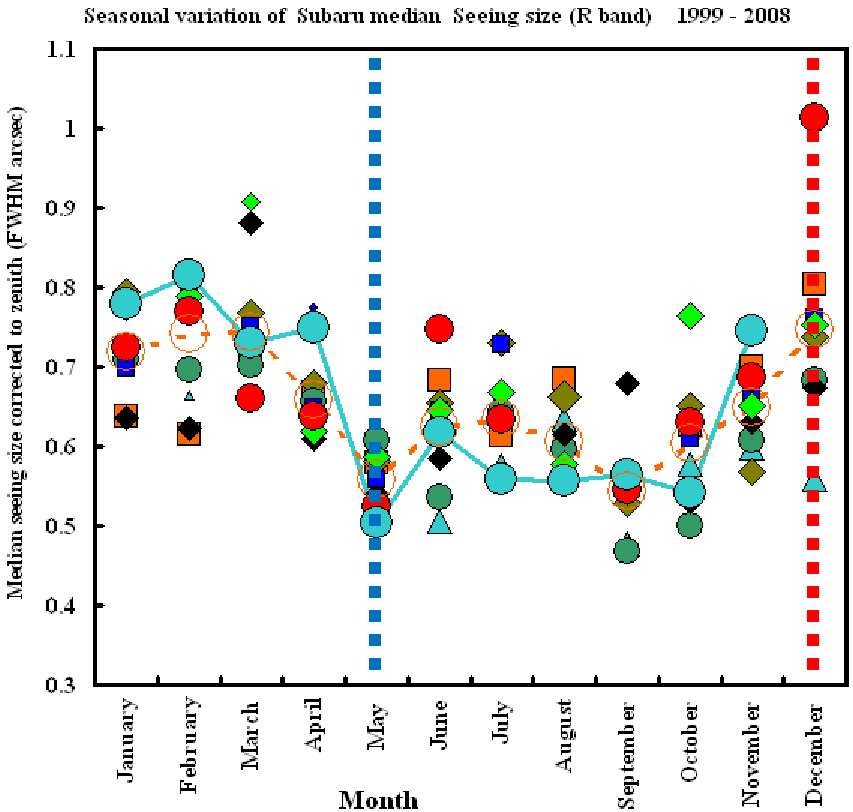
loss by 10% at 45° and by 20% at 60°

Subaru moderate seeing FoV: 15' ϕ

Seasonal Variance of Seeing

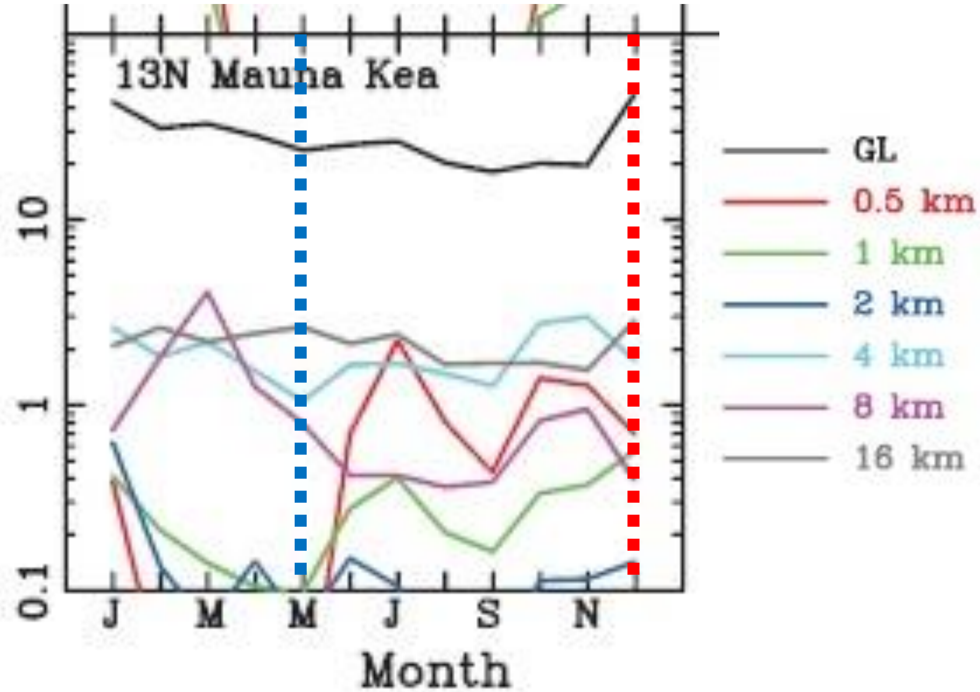
Subaru IQ

http://www.subaru.nao.ac.jp/Observing/Telescope/ImageQuality/Seeing/



13N site, profile

Els+09,PASP,121,527(Fig.5)

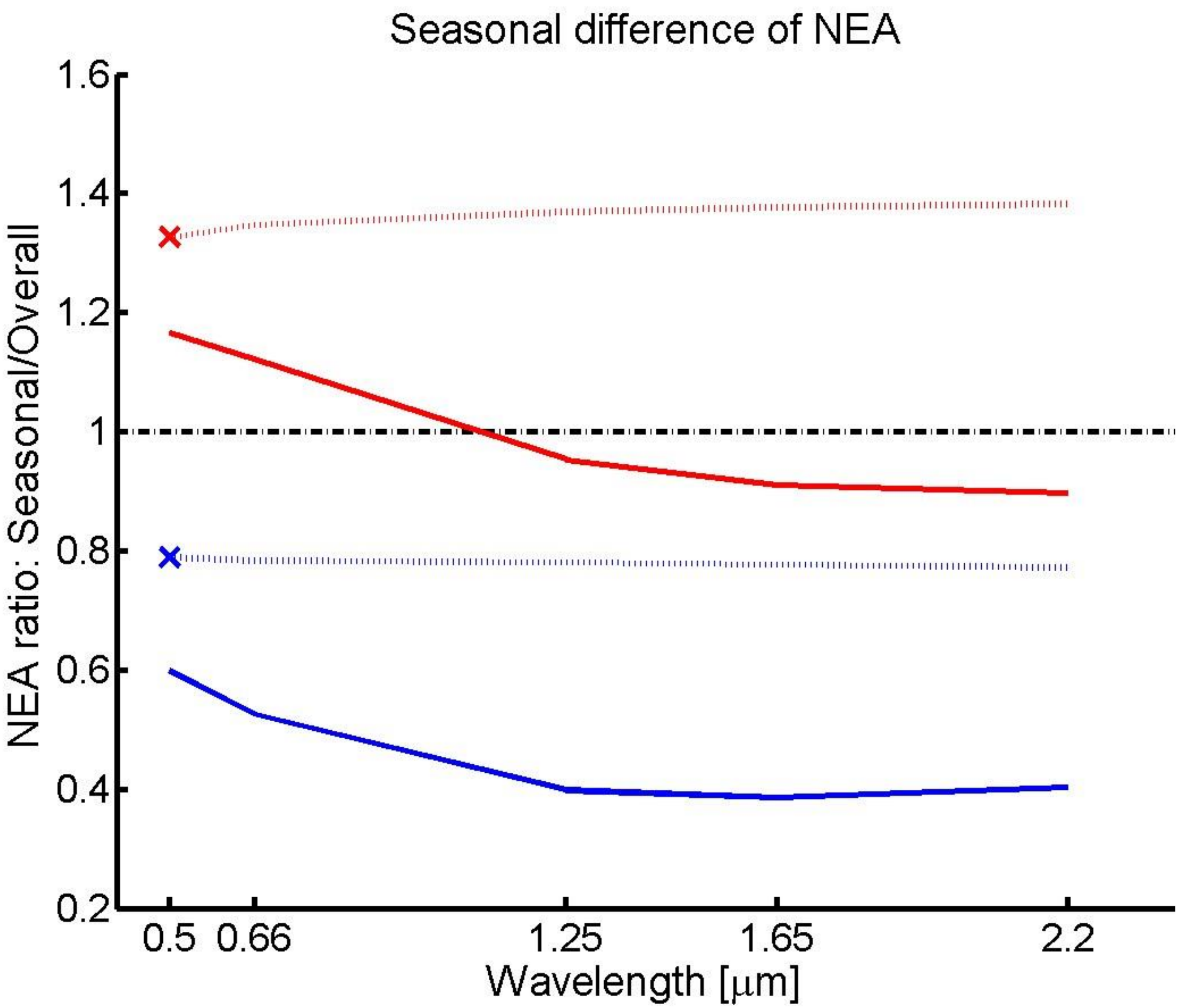


Simulation of characteristic months May (good) & Dec (bad).

Subaru AG

25%-ile	May (50%-ile)	50%-ile	Dec (50%-ile)	75%-ile
0.49"	0.56"	0.64"	0.75"	0.84"

Seasonal variation / all year



Seeing is bad in Dec, but GLAO correction is not bad.

Probably, the bad seeing in Dec is dominated by GL turbulence.

Season: Blue: May、Red: Dec
Solid: GLAO, Dotted: Seeing

Subaru
moderate
φ =15arcmin

Updates by recent results

- Seeing model revised, taking into account
  - Subaru Auto Guider wavelength (0.73um)
  - outer scale (30m)

- Introducing NEA: Noise Equivalent Area as performance measure
  - GLAO improves seeing by 20% ~ 70% in NEA basis

- Evaluating dependency on observation conditions
  - zenith angle: gain decreases by 10 % at 45°
  - seasonal variation: influence is small, if GL causes bad seeing

    should be checked for all months?

Comparison

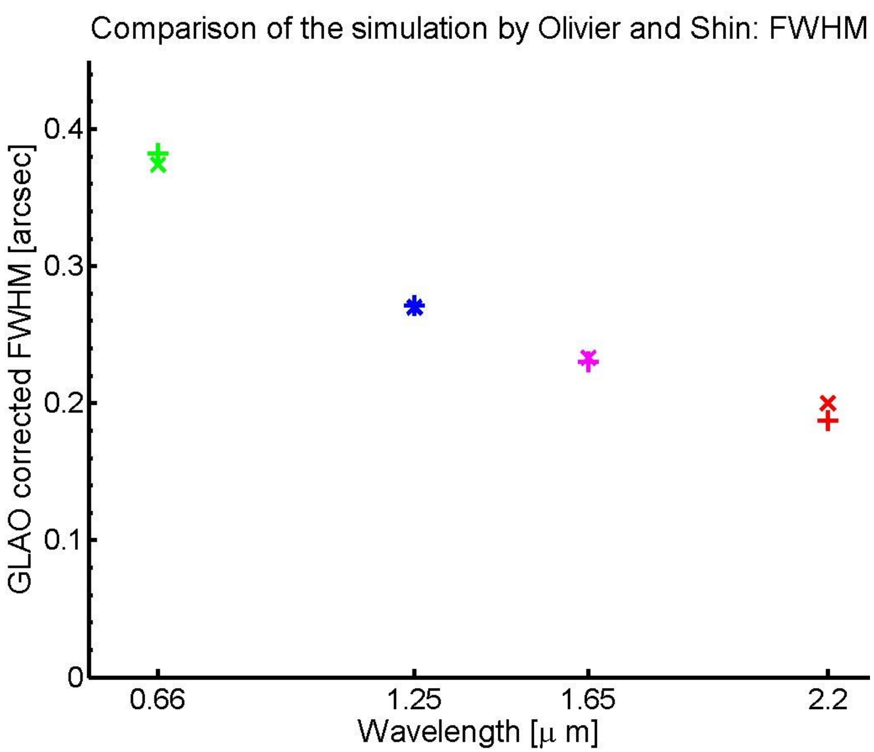
Simulation Conditions

	instatn_GLAO	MAOS
Telescope diameter	7.92m	
Central obstruction	1.265m	
GS extent	15' diameter	
GS number	6 hexagon	4 square
WFS	30x30 SH	32x32 SH
DM	31x31 SAM	33x33 ASM
Conjugation	-80m	
Seeing	0.65"	
L0	30m	
Turbulence layer#	7	
Turbulence height	0 ~ 1500m	0 ~ 16000m

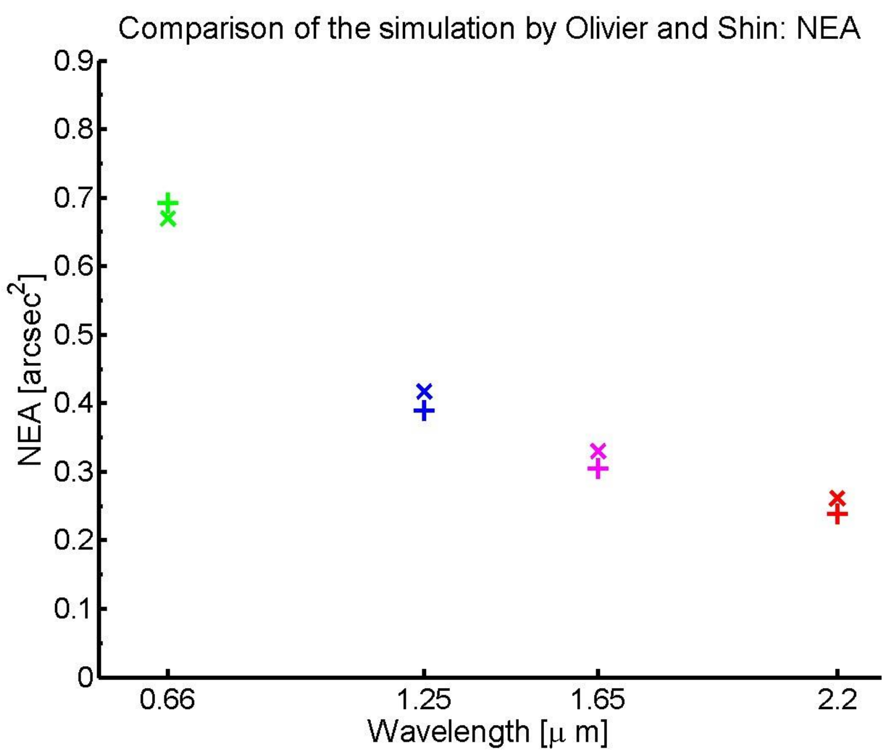
No telescope aberration; No dome seeing (included in 0m in MAOS)

Comparison of Results

FWHM



NEA



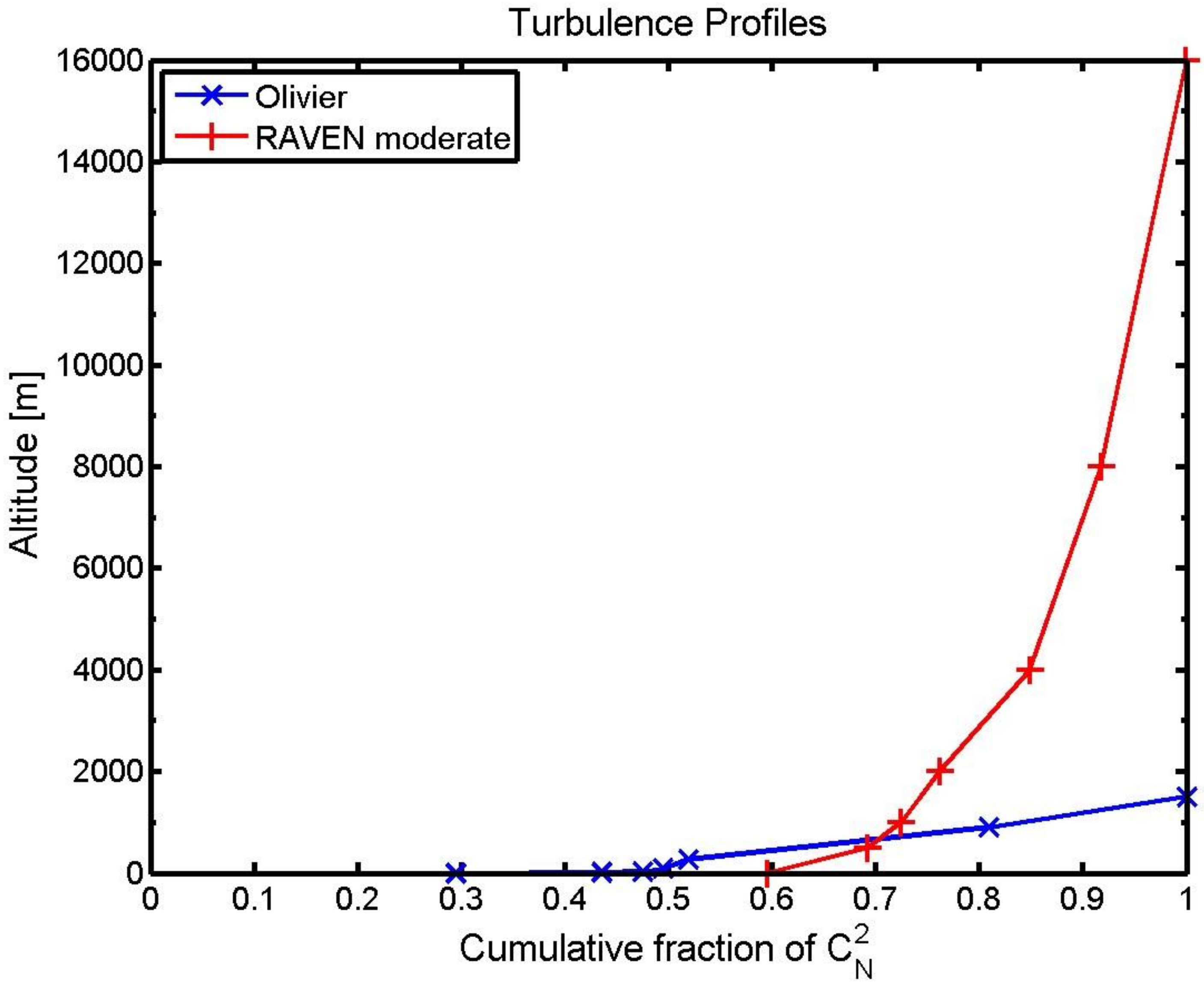
typically ~0.2" @ K

Band: R, J, H, K

X: instant_GLAO, +: MAOS

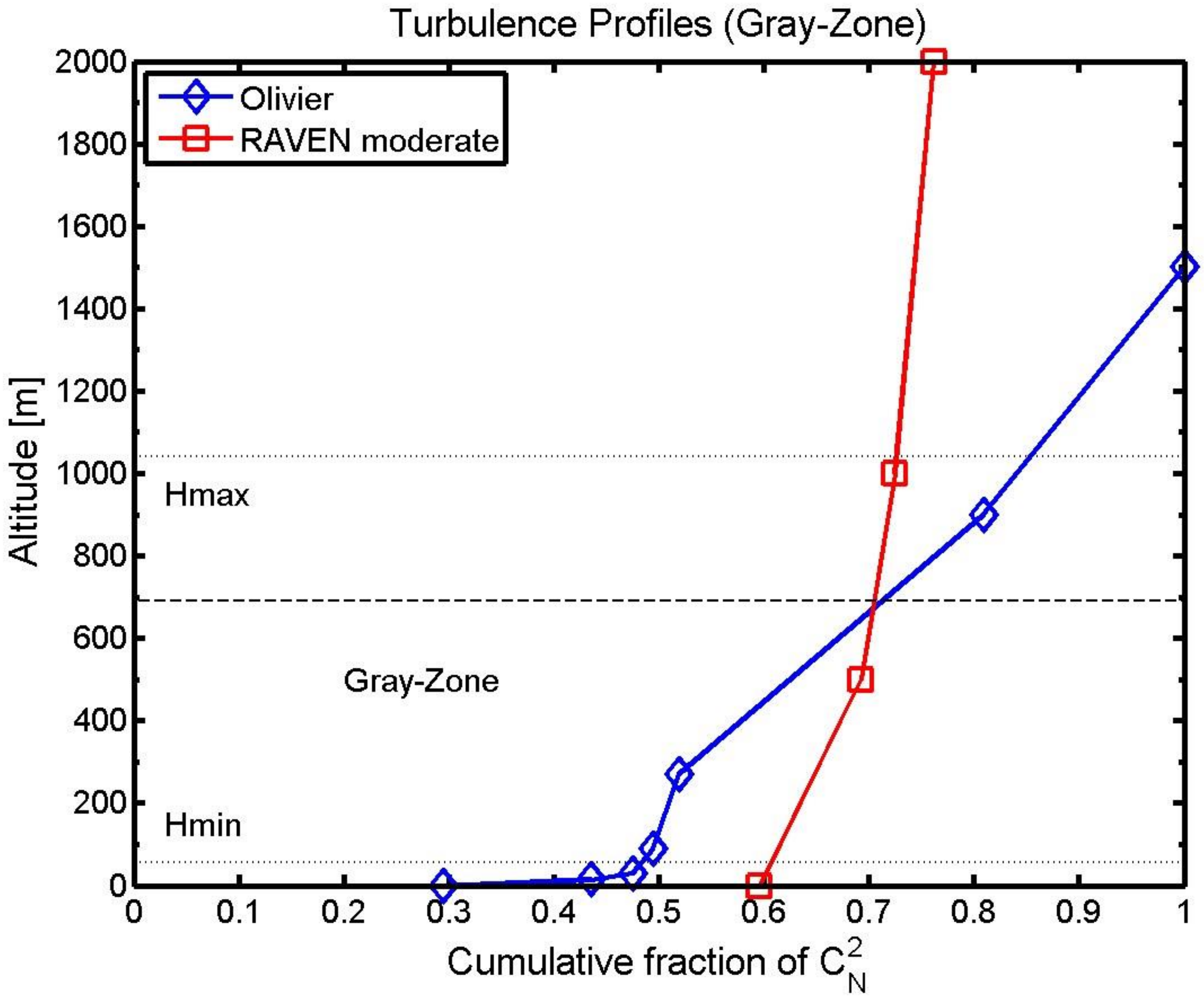
Surprisingly, both results agree quite well even with different turbulence profiles

Turbulence profile



Contribution from the high layer is different though the fraction is small.

Gray-Zone



Contribution from the gray-zone can be said similar?.

Seeing

Seeing at Mauna Kea

Suitable for GLAO

- Ground layer turbulence is stronger than that of free atmosphere
  - Els+09,PASP,121,527
- Concentrate < 100m
  - Chun+09,MNRAS,394,1121

- However, no GL turbulence data at Subaru

  modify TMT(13N) site test data to match Subaru IQ

  - Andersen+12, PASP,124,469

  Simulation results depend much on the seeing condition.

  We are preparing seeing profilers

Local ground-layer at Subaru?

- 70m below and leeward of the ridge (laminar flow?)
- fine resolution data for more detailed simulation

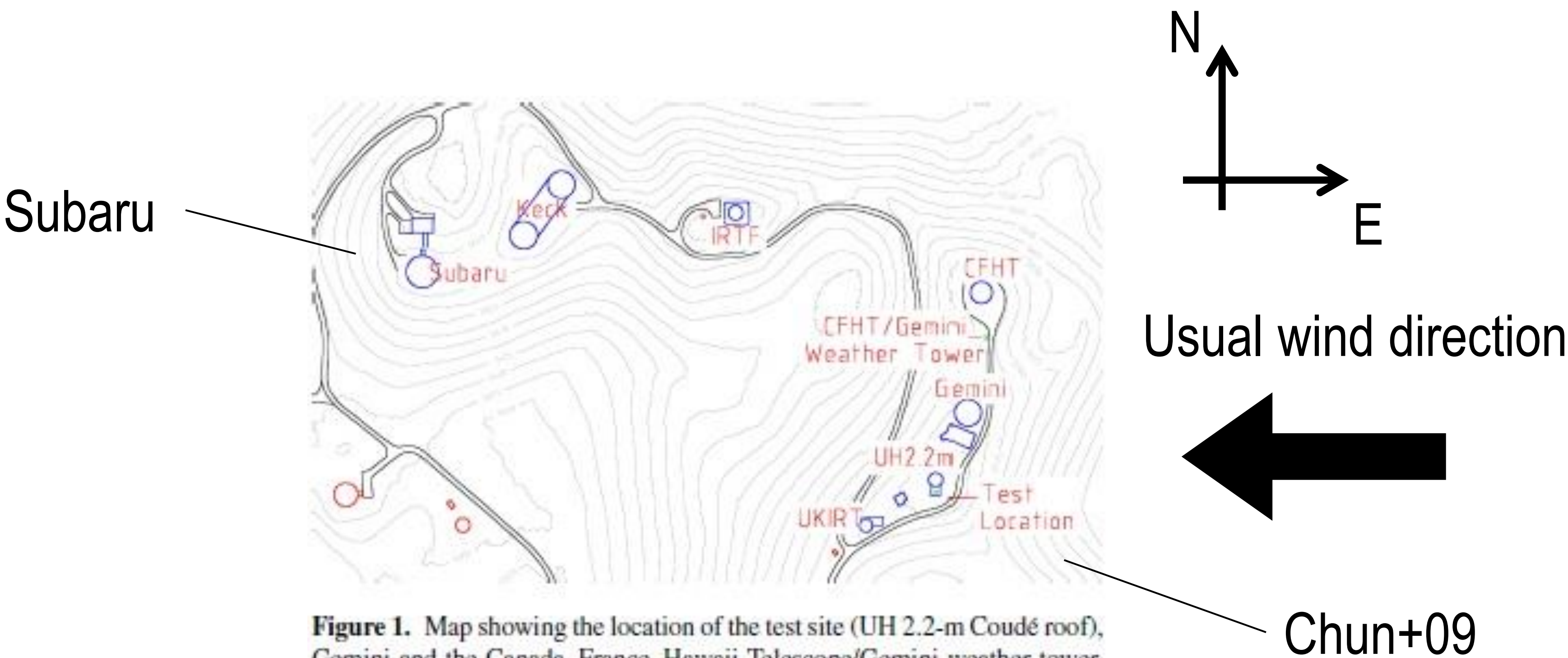
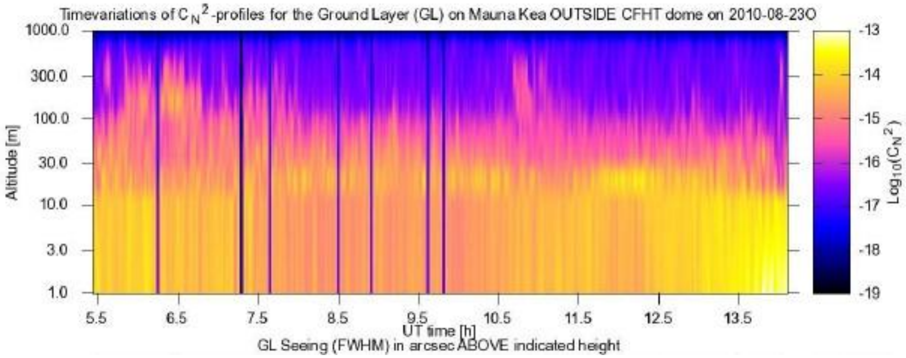
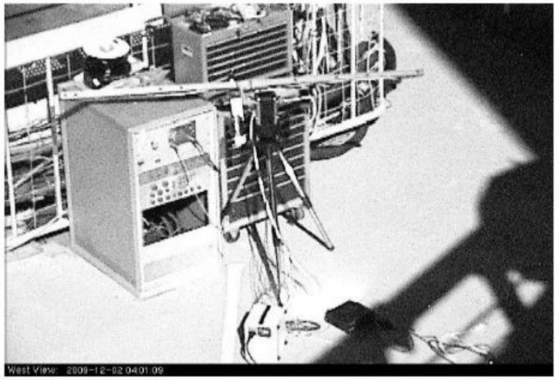


Figure 1. Map showing the location of the test site (UH 2.2-m Coudé roof), Gemini and the Canada–France–Hawaii Telescope/Gemini weather tower. North is up and east is to the left-hand side in the figure. For scale, the distance between the centres of the Gemini and UH 2.2-m domes is about 80 m and the full extent of the map in the north and south direction is about 525 m. Topographic contours are shown every 25 feet (7.6 m).

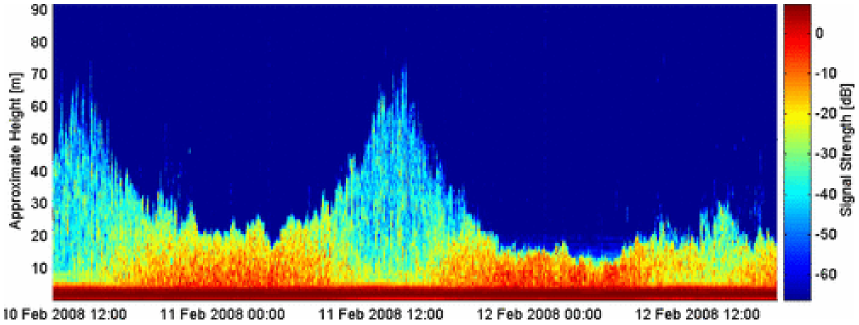
Seeing measurement plan at Subaru

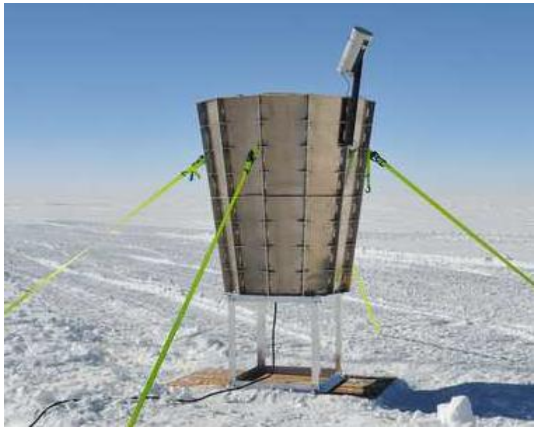
Luna Shabar (PTP) by Univ.BC
optical: 1 ~ 1000m





SNODAR by Univ. NSW
acoustic: 10 ~ 100m





Two important parameters for GLAO

In addition to the ground-layer turbulence strength, there are two important parameters for performance estimation of GLAO.

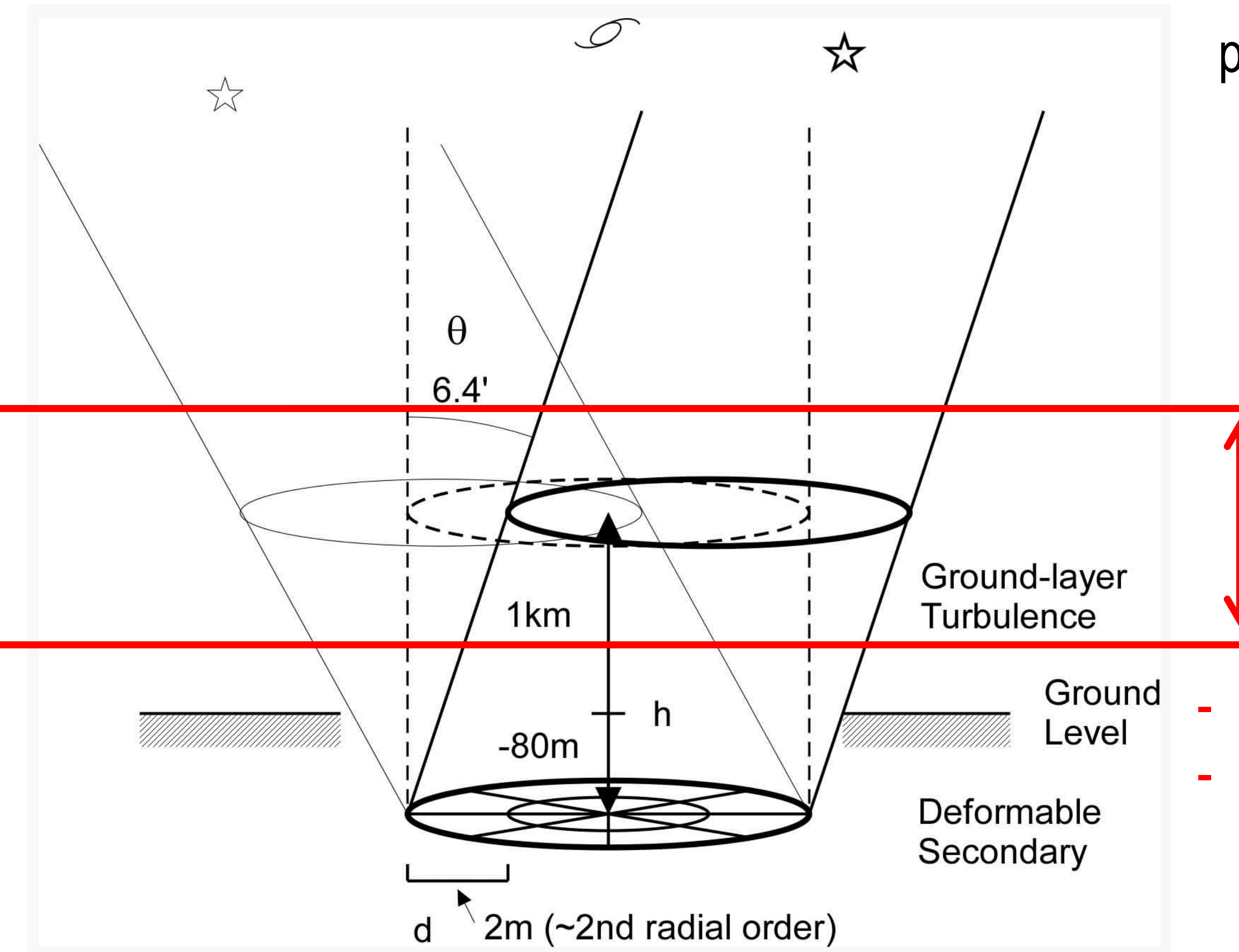
- Gray-zone

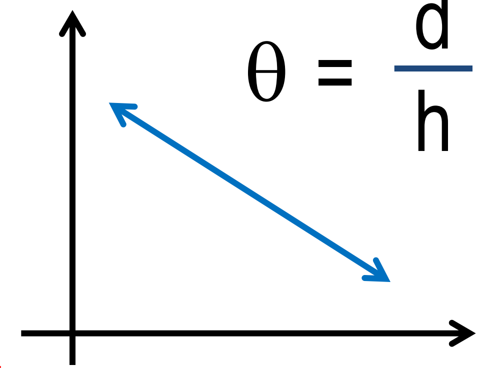
  Even with the same total turbulence strength, performance changes if the height and strength of 'gray-zone' changes.

- Outer Scale

  The wavelength dependency of natural seeing size changes by 'outer scale'. To estimate the gain of GLAO, not only GLAO corrected image size but also seeing image size is required. (GLAO performance little changes by outer scale, but seeing size does.)

Gray-zone turbulence for GLAO





$$\theta = \frac{d}{h}$$

gray zone
500m ~ 1500m

- lower: well corrected
- higher: uncorrected

Gray-zone impact on the performance

A test case in "Gemini GLAO feasibility study report "(Apdx.F1)

MAOS calc.

- The same total seeing strength

  r0=17cm(0.6") @ 0.5 um, L0=30m and 8m aperture

- But 3 different gray-zone cases of height & relative strength

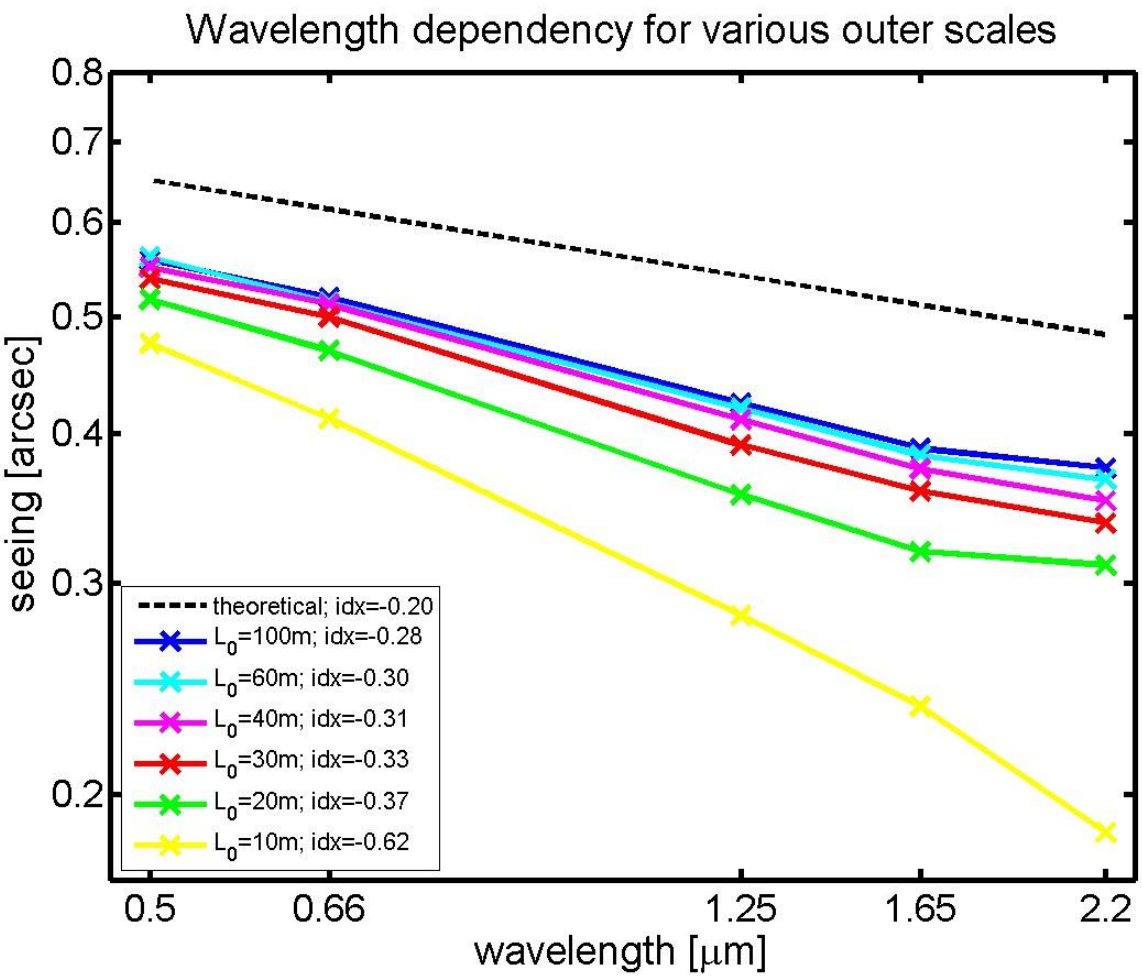
Altitude [m]	low & week	medium	high & strong
10000	0.33	0.33	0.33
2000	0.07	0.07	0.07
900	-----	-----	0.40
500	-----	0.30	-----
300	0.15	-----	-----
0	0.45	0.30	0.20
J-band FWHM GLAO :	0.230"	0.250"	0.330"

Range of Luna SHABAR. (900 m – 0 m)

seeing 0.344"

GLAO performance changes even with the same total strength of seeing!!

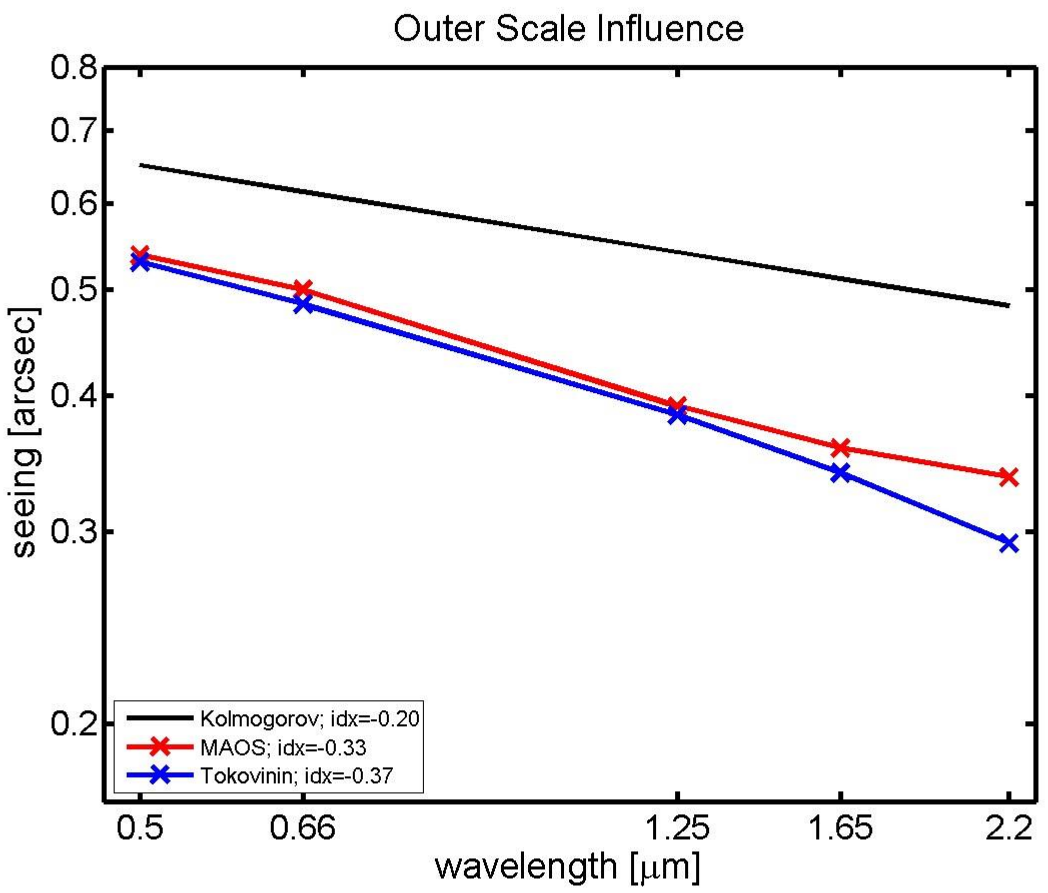
Wavelength dependency of seeing



Wavelength dependency: Seeing ∝ λ^-0.2; fitting: -0.28 ～ -0.62
Seeing is better at longer wavelength for smaller outer scale (L0).

Comparison of outer scale correction

Tokovinin02,PASP,114,1156 vs MAOS

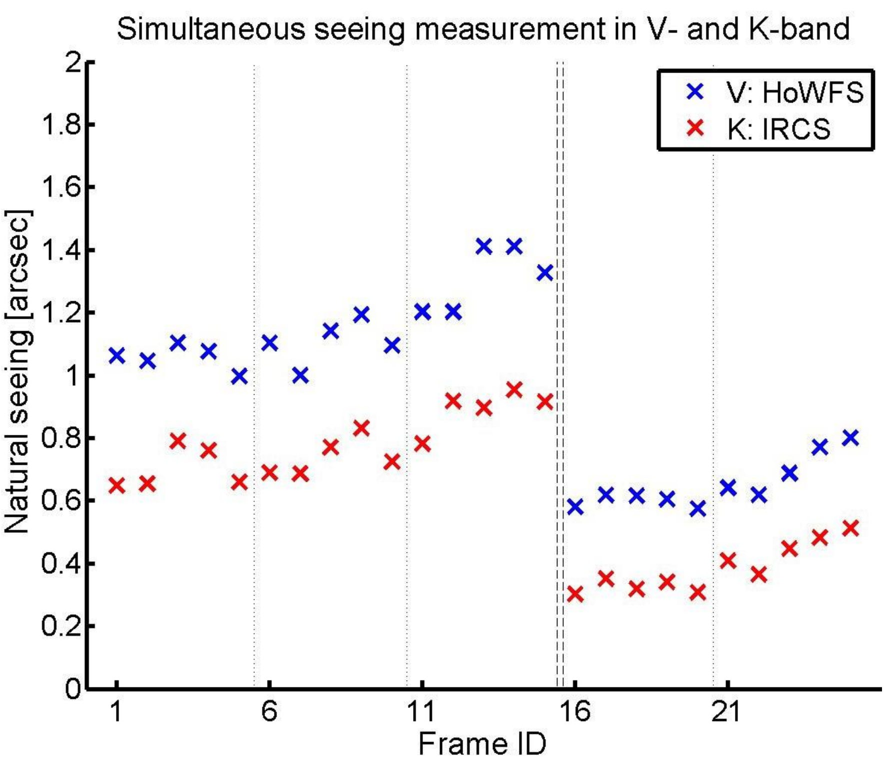


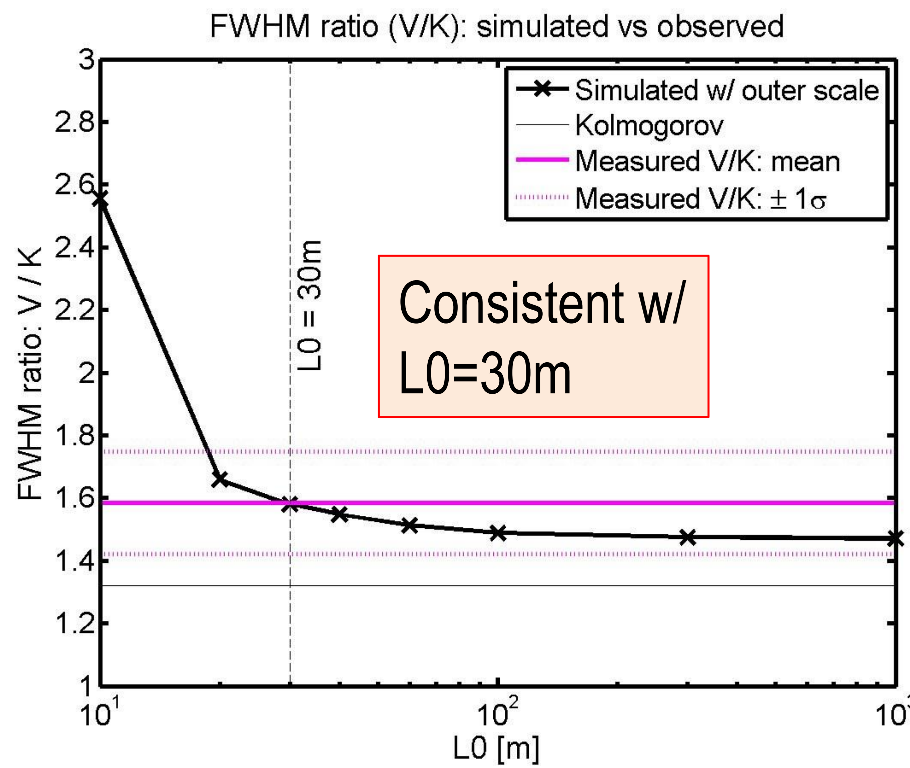
A little difference at longer wavelength, but over all agreement is good.

Observational evaluation of outer scale

- General method is to evaluate tip/tilt correlation between two points with different baseline (e.g., Ziad+04,Appl.Opt.,43,2316)
- For GLAO, the ratio of image size between optical and infrared is important (even not caused by outer scale).

Simultaneous FWHM measurement in V (AO188 HoWFS) & K (IRCS)





Seeing

- Mauna Kea is know to be a suitable site for GLAO

  should be checked Subaru site is the same as ridge or TMT site

- Subaru is preparing two profilers:
  - Lunar SHABAR: 1 ~ 1000m (gray-zone), optical
  - SNODAR: 10 ~ 100m

- Two important parameter on GLAO
  - gray-zone: height & strength
  - outer scale: uncorrected NIR image size under certain optical seeing

    quick results by simultaneous FWHM measurement at VIS and NIR.