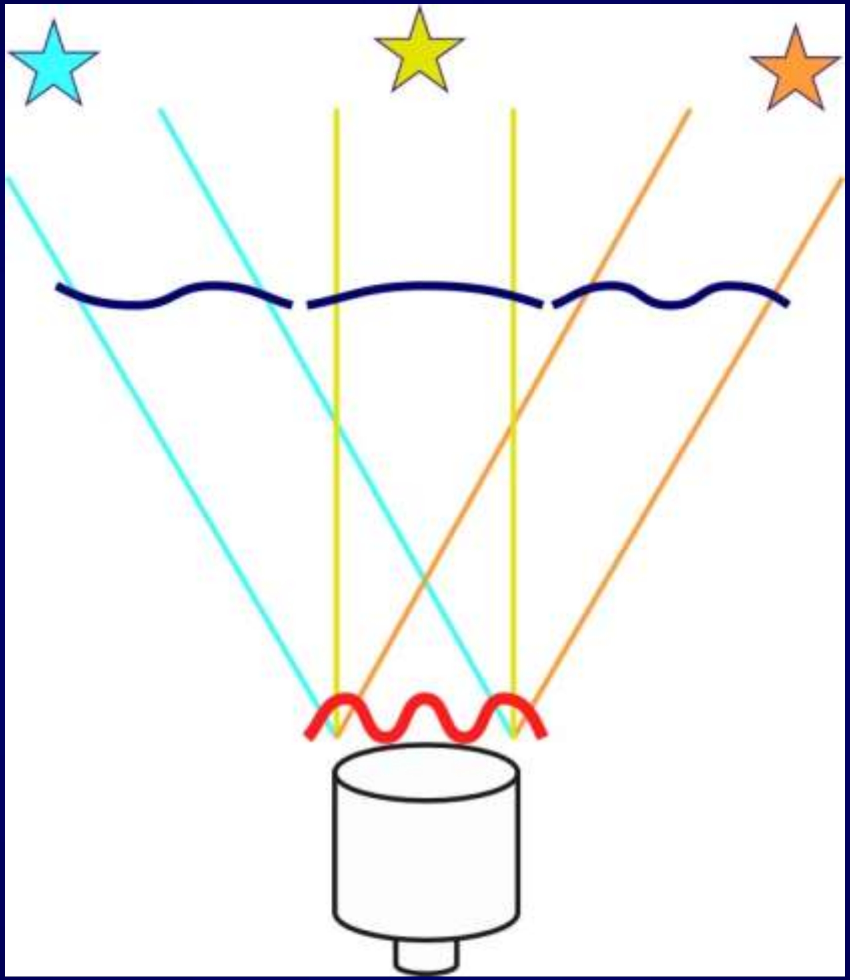
Future Adaptive Optics for Subaru



2011/4/28 @ Hilo, Hawaii

Shin Oya（Subaru Telescope)

Background

Subaru Telescope

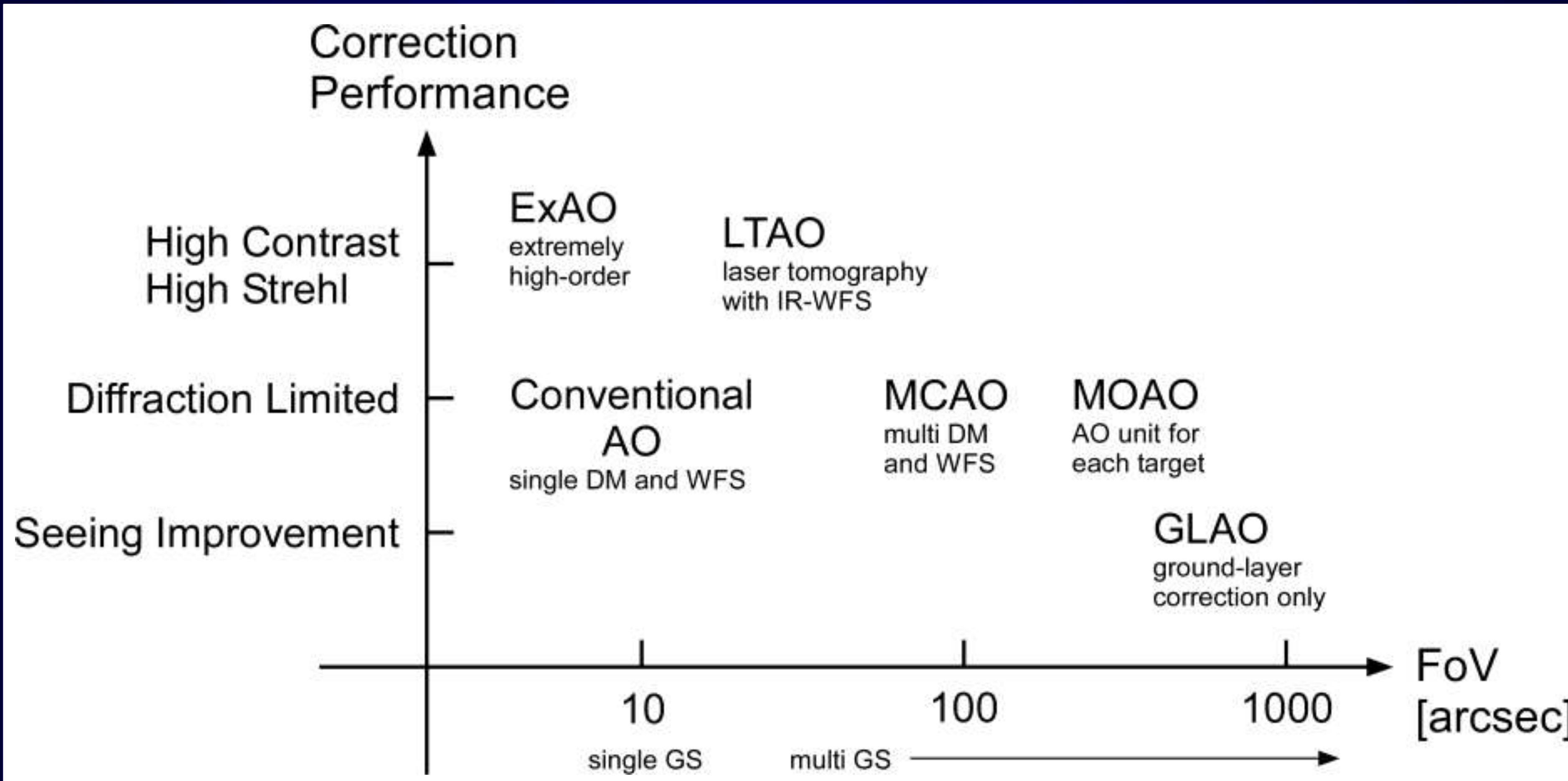
- LGSAO188: commissioning phase
- optical instruments (dark nights)

  huge projects for prime focus
  - HSC: Hyper Suprime Cam   on-going
  - PFS: Prime Focus Spectrograph   partial budget approved
- next Cs Infrared instruments (bright nights) w/ AO
  - discussing by internal committee

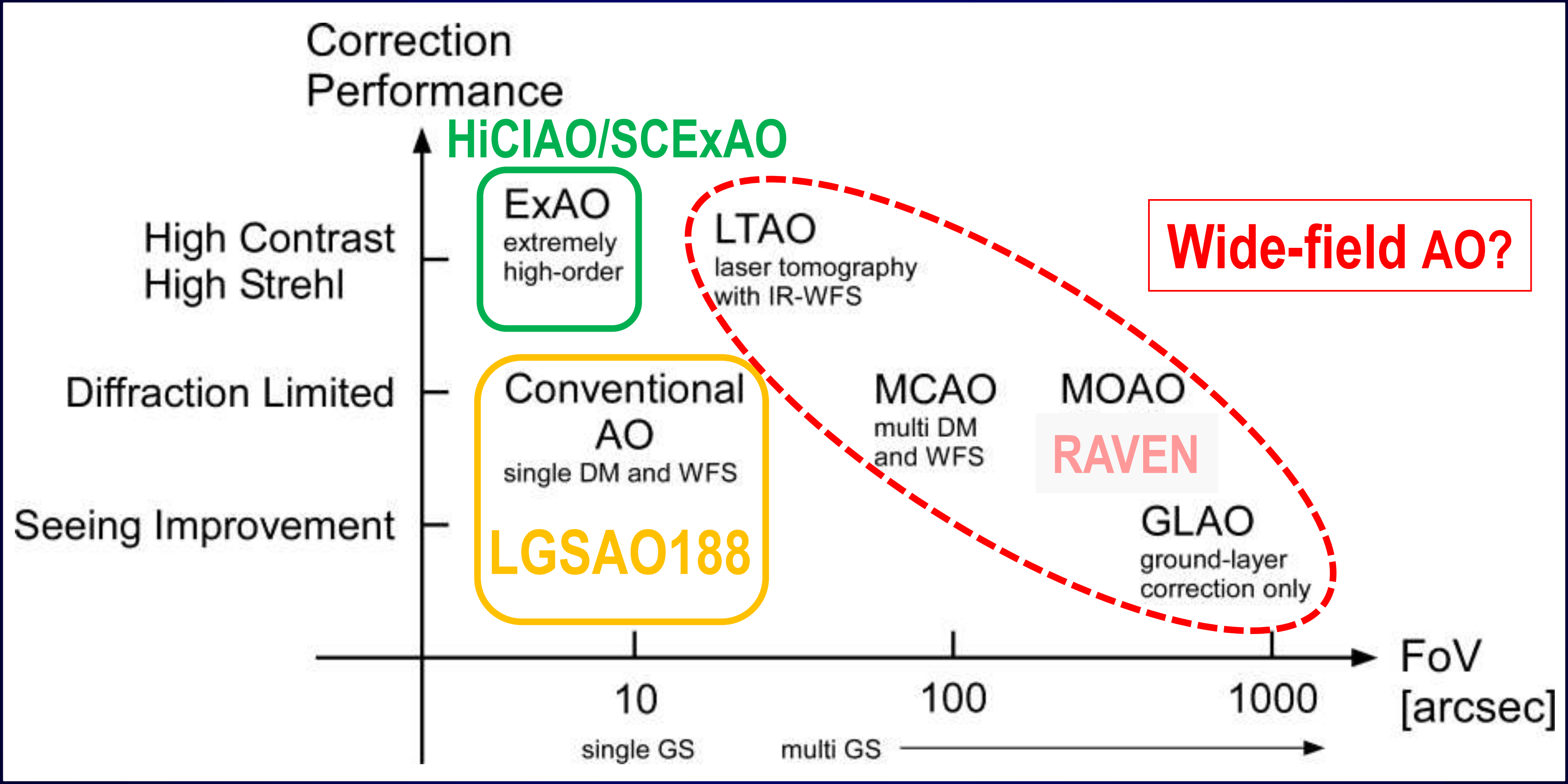
TMT

- contribution to the development: not only the telescope, but also the instruments incl. AO

Variety of AO type



Subaru AO line-up



Why Wide-Field AO?

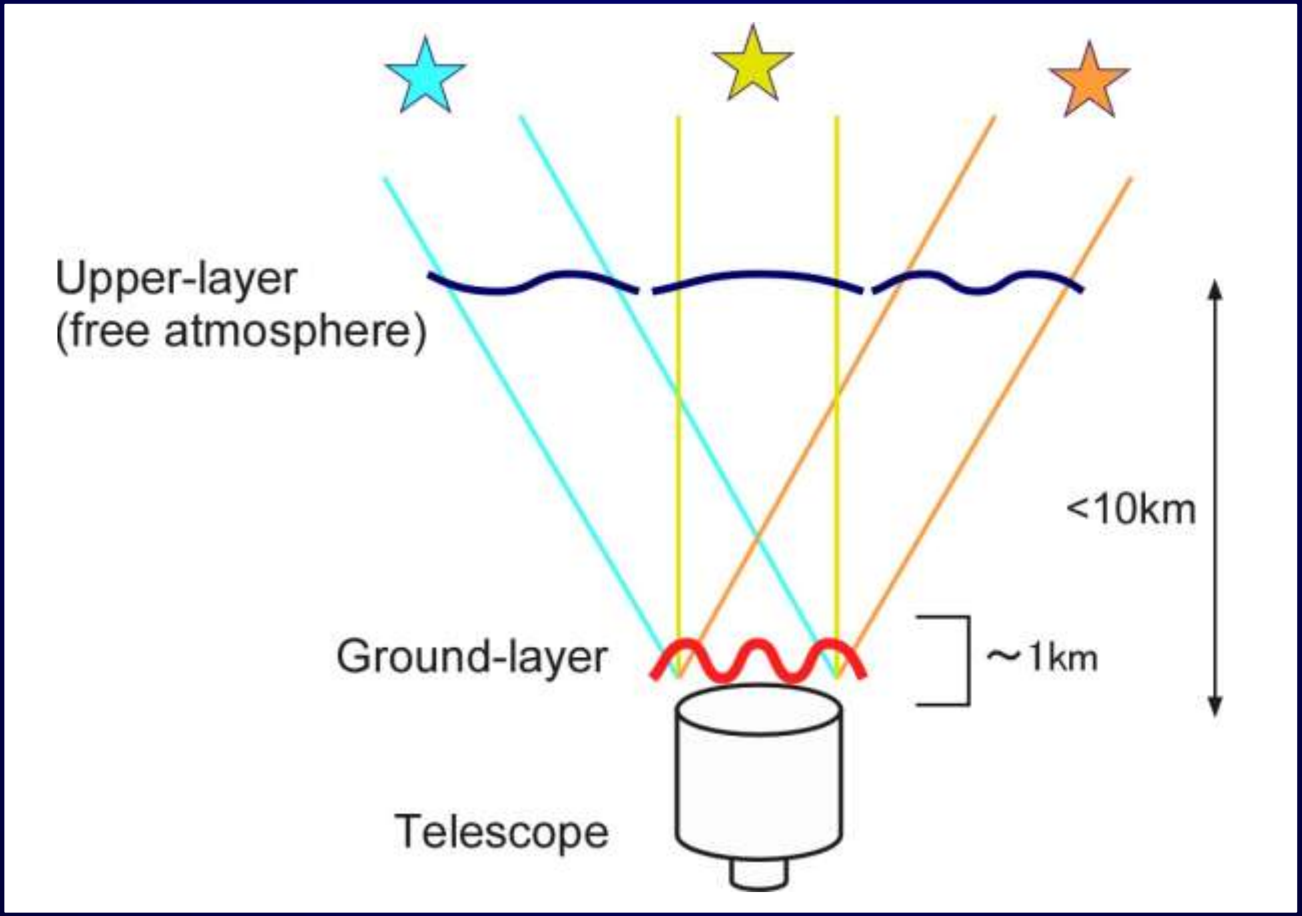
- Subaru has seeing-limited wide-field instruments
  - synergy: data / science
  - rigid structure: prime focus / exchangeable 2ndry

- Relation to other telescopes
  - 8m-class telescopes have a wide-field AO plan
  - complementarity with 30m-class telescopes

    (light-collecting power and angular resolution of 8m-class will be not attractive any more)

What is necessary for WF AO?

- Considering 3D structure of atmospheric turbulence
- Multiple guide stars



Which type of WF AO?

- GLAO: Ground-Layer AO
  - FoV: 10 arcmin, fwhm: < 0.4 [arcsec]
  - survey observation is possible
  - Low thermal background in the case of ASM
  - seeing-limited science: MOIRCS,FMOS,SuprimeCam

⇒ discussion w/ community: science case

- MOAO: Multi-Object AO
  - FoR: 3 arcmin, FoV :a few arcsec, diffraction-limited
  - targeted observation only
  - RAVEN (experimental) / MOIRCS upgrade (optional)
  - Field-of-Regard expands w/ Telescope aperture

⇒ a candidate of TMT 2nd gen. instrument

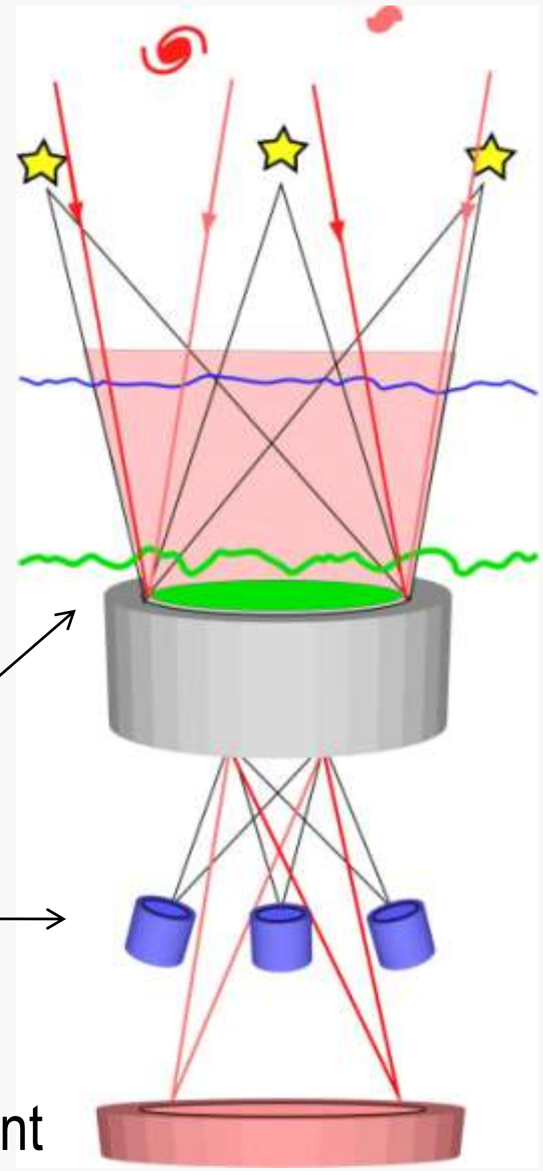
MCAO: lower SR

LTAO: Keck; complicated system (especially LGS)

GLAO

FoV: 10 arcmin
fwhm: < 0.4 [arcsec]
survey possible

ground-layer correction only

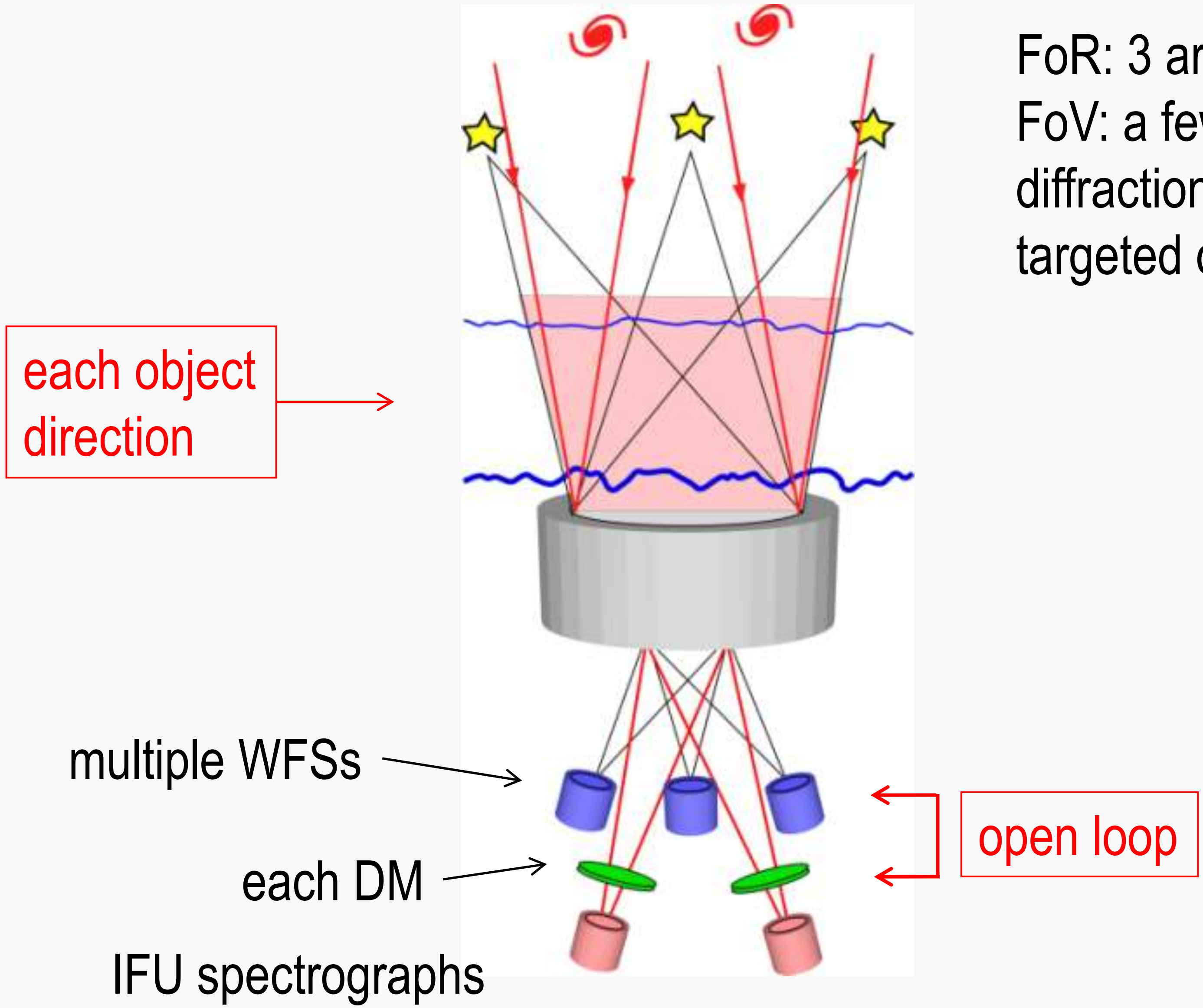


single corrector
(deformable 2ndry)

WFS(s)

wide-field instrument

MOAO



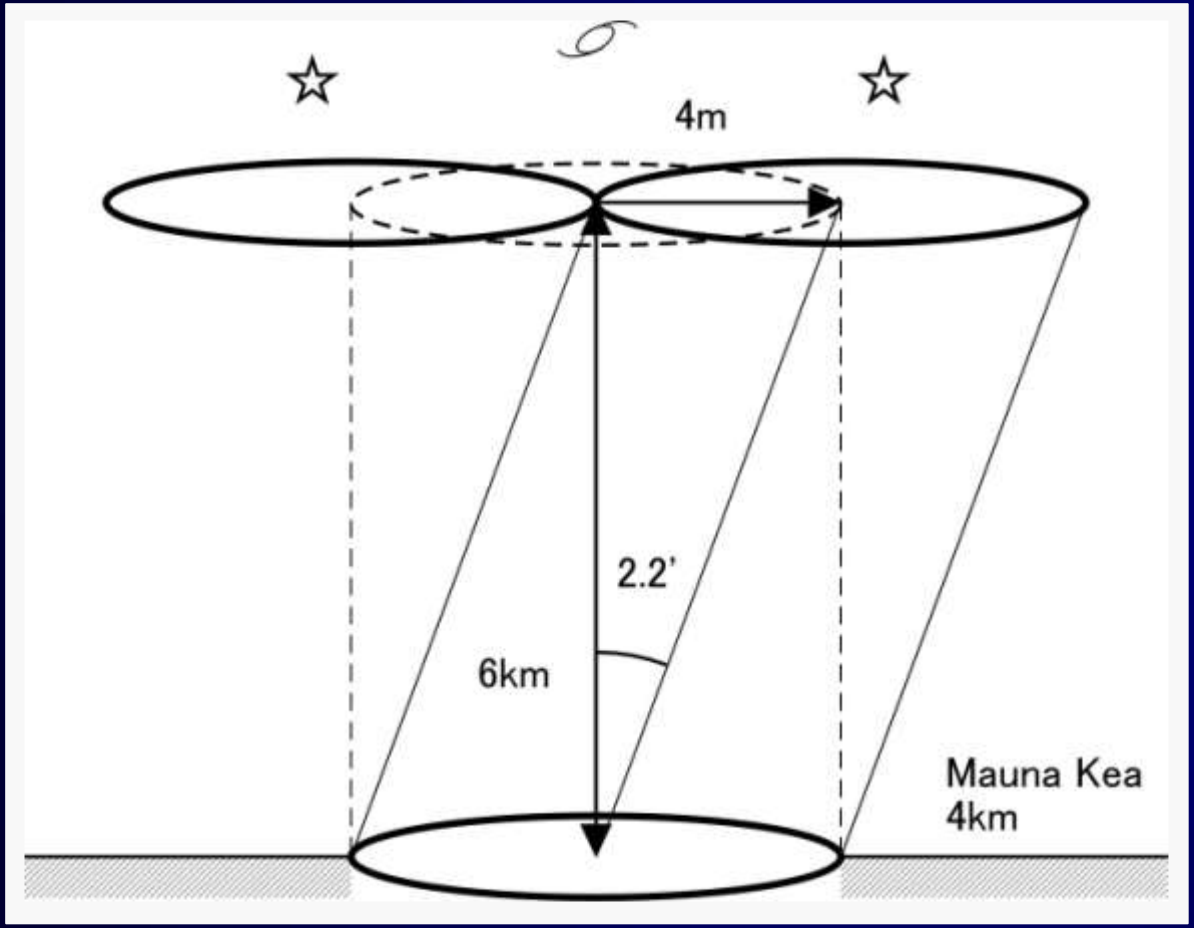
FoR: 3 arcmin
FoV: a few arcsec
diffraction-limited
targeted only

GLAO or MOAO ?

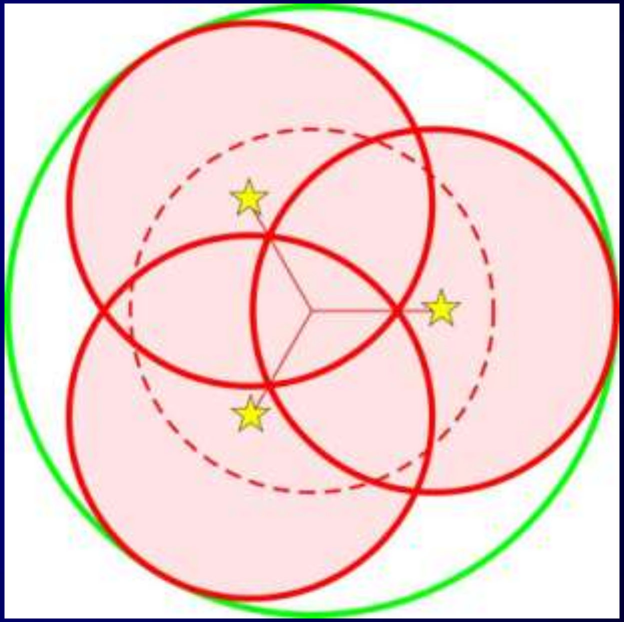
– proposed for Subaru or interested developers at Subaru
– possible contribution to TMT future instrument

	GLAO	MOAO
FoV	10 arcmin	3 arcmin
correction	seeing improvement (< 0.4”)	diffraction-limited
survey	Yes	No
port	Cs/Ns (w/WFS)	One port
budget	>$20M?	<$10M?

MOAO: limitation of FoR



beam overlap (meta pupil)
at 6km (top view)

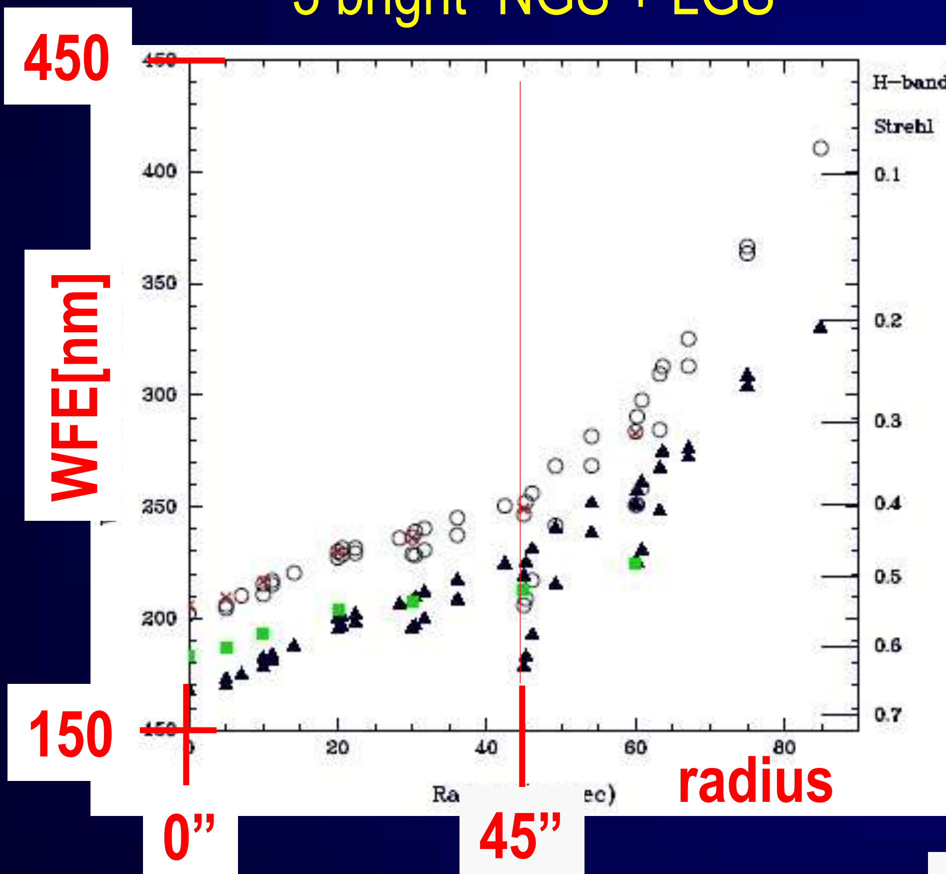


8m aperture
3arcmin FoR
3GS

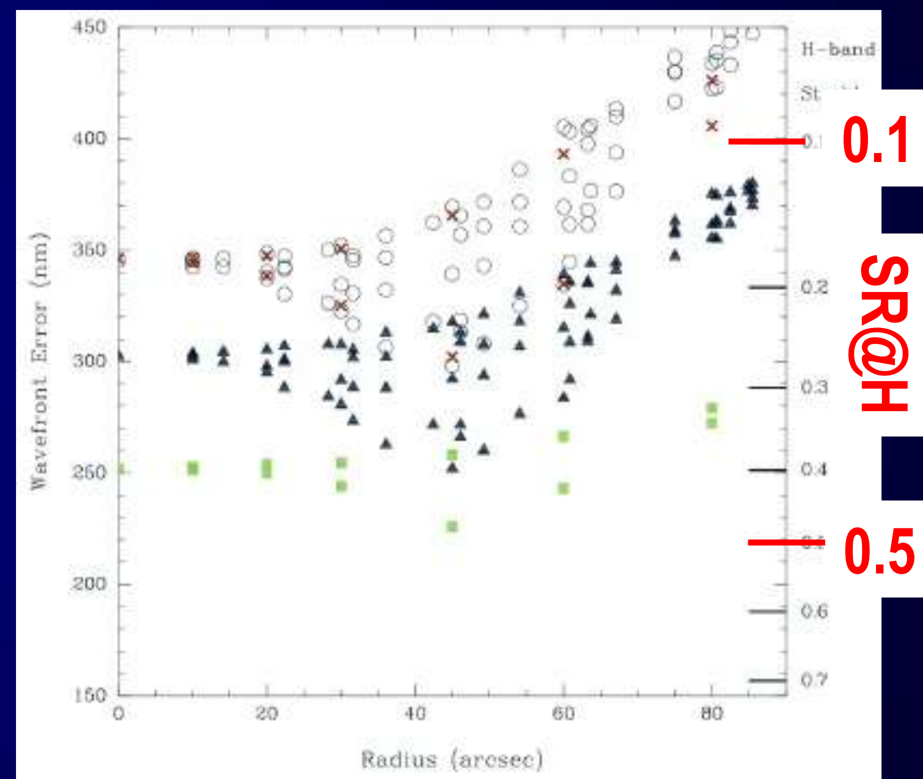
MOAO: RAVEN simulation

- 2’～3’ FoR, 3 NGS (r=45”) + LGS (center)
- element # :10x10 (WFS: 10x10 SH, DM: 11x11)

3 bright NGS + LGS



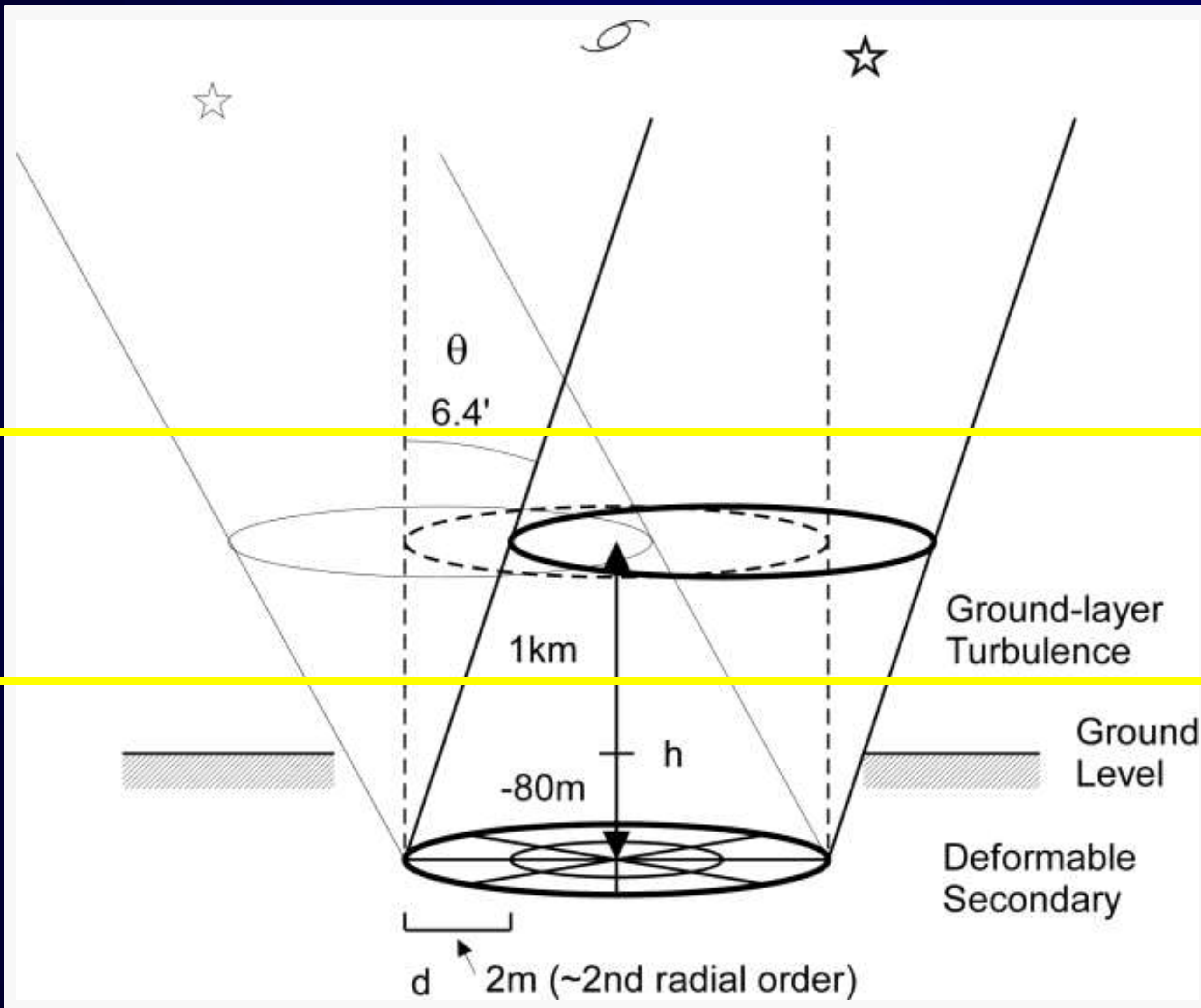
3 faint (R=14.5) NGS

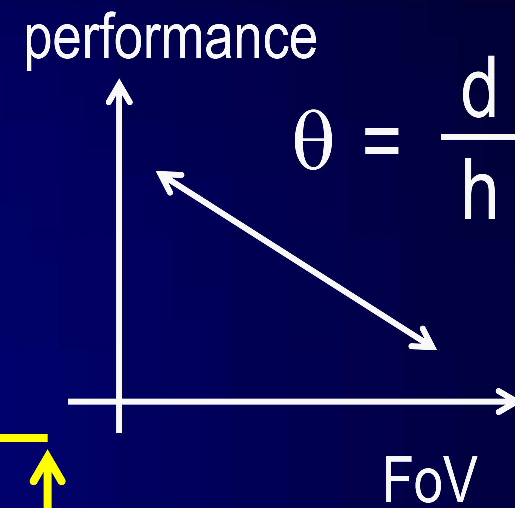


X-axis: separation form the center of FOV in arcsec
Y-axis left: WFE in nm: ○ all modes; ▲ TT removed
right: SR ×; ■ EE

taken from RAVEN CoDR document

GLAO: limitation of FoV





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

gray zone
500m ~ 1500m

- lower: well corrected
- higher: uncorrected

GLAO: seeing data

Important for accurate simulation

- Cerro Pachon (Gemini –S,1998,4 seasons)
- Balloon data (43 launches)
- resolution:6m, altitude:<5km

Andersen et al.(2006),PASP,118,1574

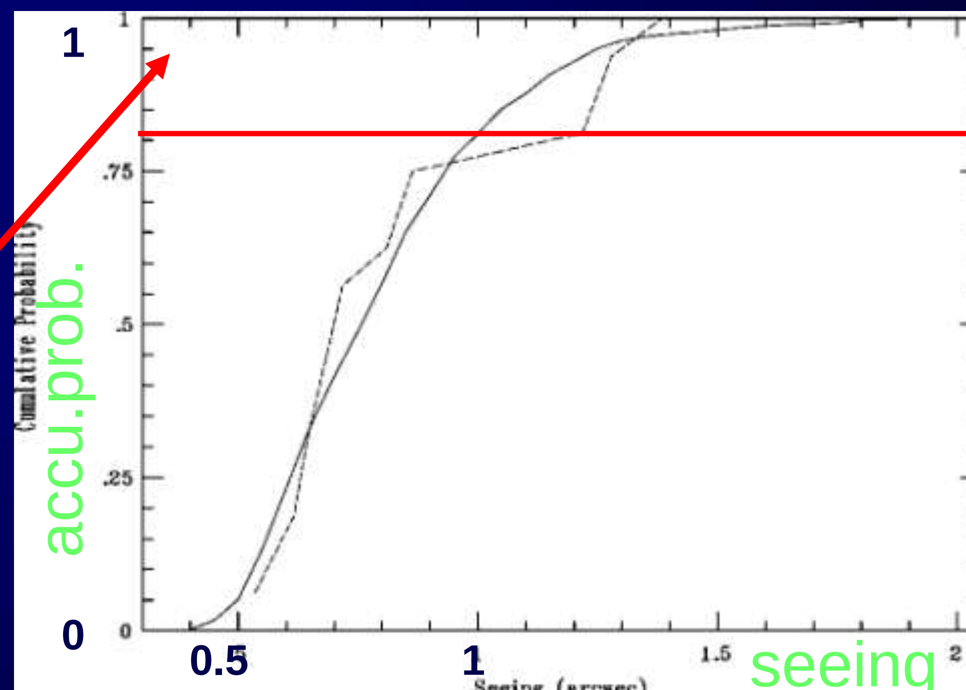
INTEGRATED TURBULENCE $J = \int C_n^2\, dh$ FOR "GOOD," "TYPICAL," AND "BAD" GROUND AND FREE ATMOSPHERES

Altitude (m) (1)	Good J (10^{-14} m$^{1/3}$) (2)	Typical J (10^{-14} m$^{1/3}$) (3)	Bad J (10^{-14} m$^{1/3}$) (4)
0	9.26	7.04	13.8
25	1.83	2.25	10.8
50	0.574	1.35	15.3
100	0.362	1.24	15.8
200	0.614	1.99	10.3
400	0.960	2.87	6.46
800	1.18	3.02	7.29
1600	0.913	1.75	6.77
3600	...	...	32.0
5500	...	17.0	...
8400	9.00	...	...

NOTE.—Altitudes >3 km are considered "free."

25% 50% 75%

gray zone

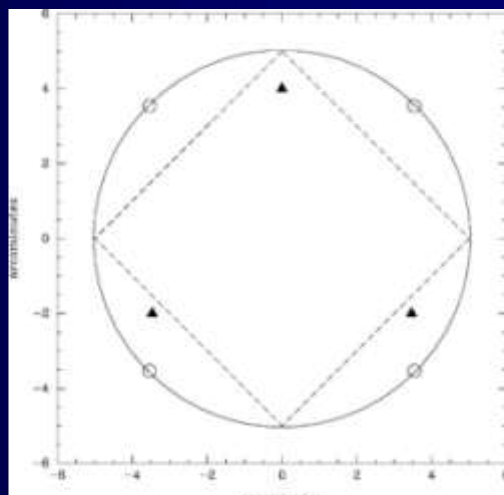


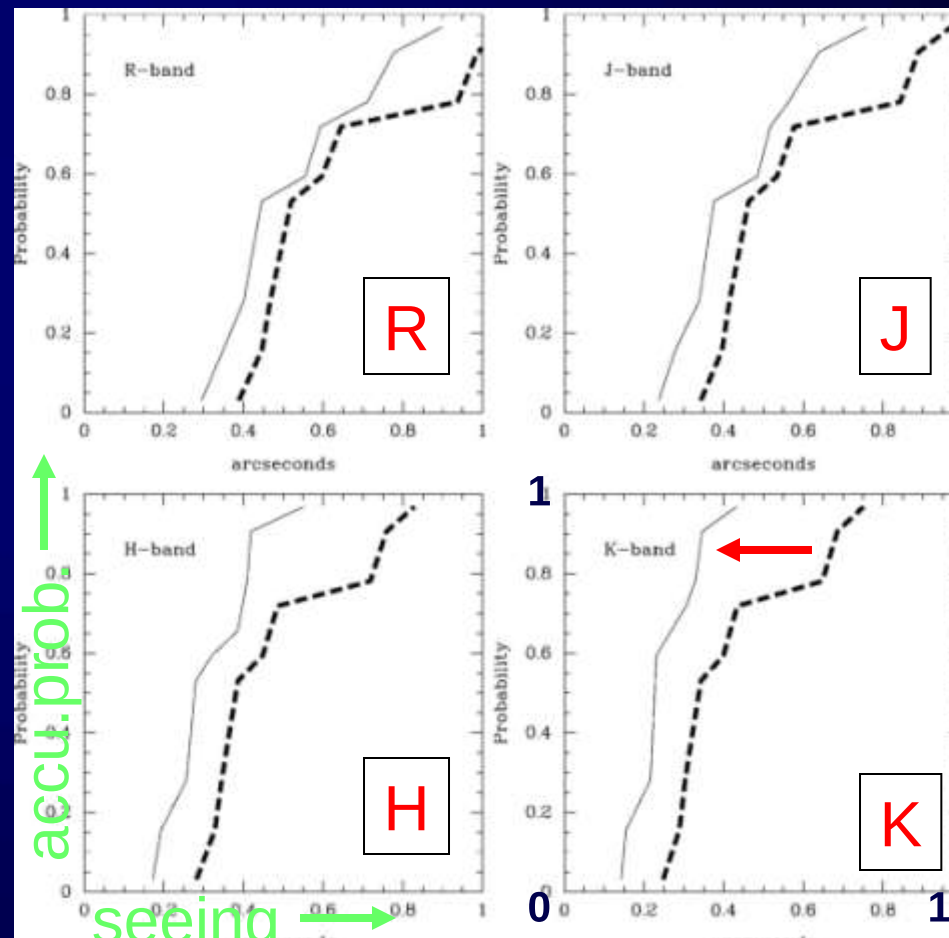
GLAO: Gemini-S simulation

An example of 8m-class telescope

- 7’ X 7’ FOV, 4LGS(V～13)+3TT-NGS(V<15)
- WFS: 10x10 SH, SO
- DM: 77DOF

white ○: LGS
black ▲: NGS
circle: 10’ φ
squre: FOV





- effective under bad seeing (depends on seeing statistics)
- slight improvement even at visible

Andersen+06,PASP,118,1574

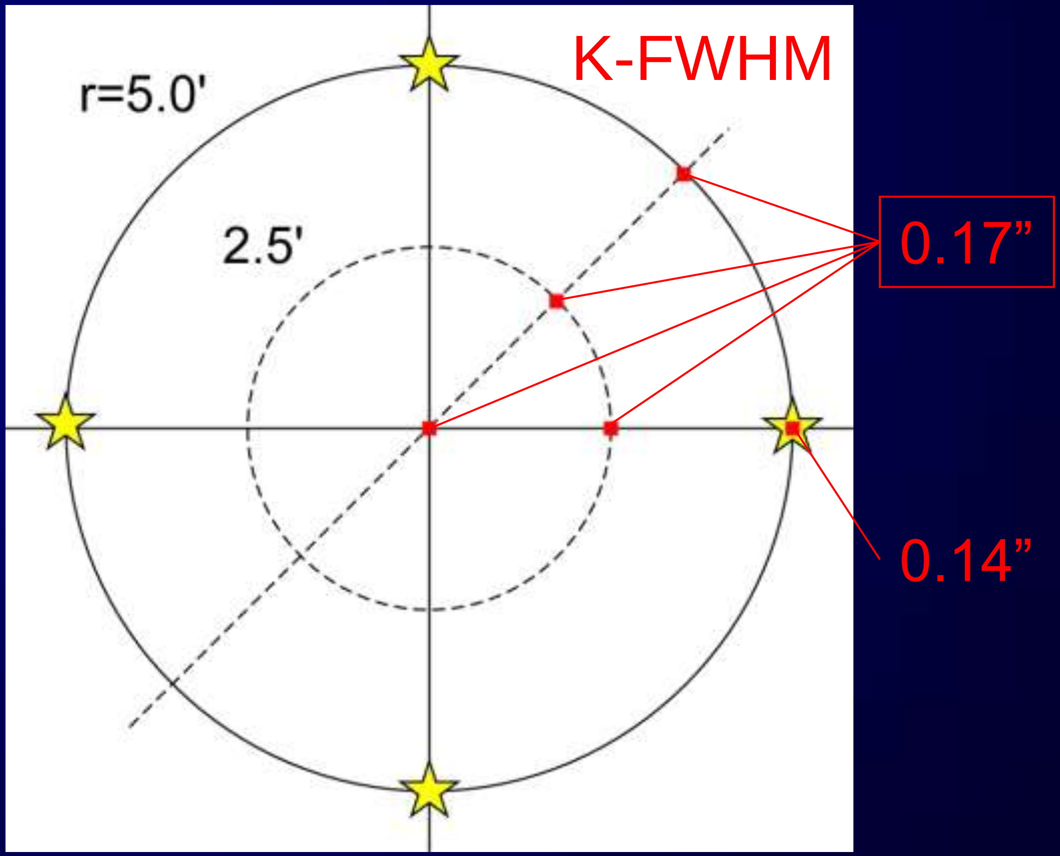
GLAO: Subaru simulation

– 10’Φ FOV, 4NGS (bright enough than noise leve)
– element #: 32 x 32
– equivalent seeing condition to RAVEN simulation

Simulation code: MAOS
(common with RAVEN)

- seeing ~ 0.66” at 0.5um
- corrected FWHM @ center
  - R: 0.40”
  - J: 0.20”
  - K: 0.17”

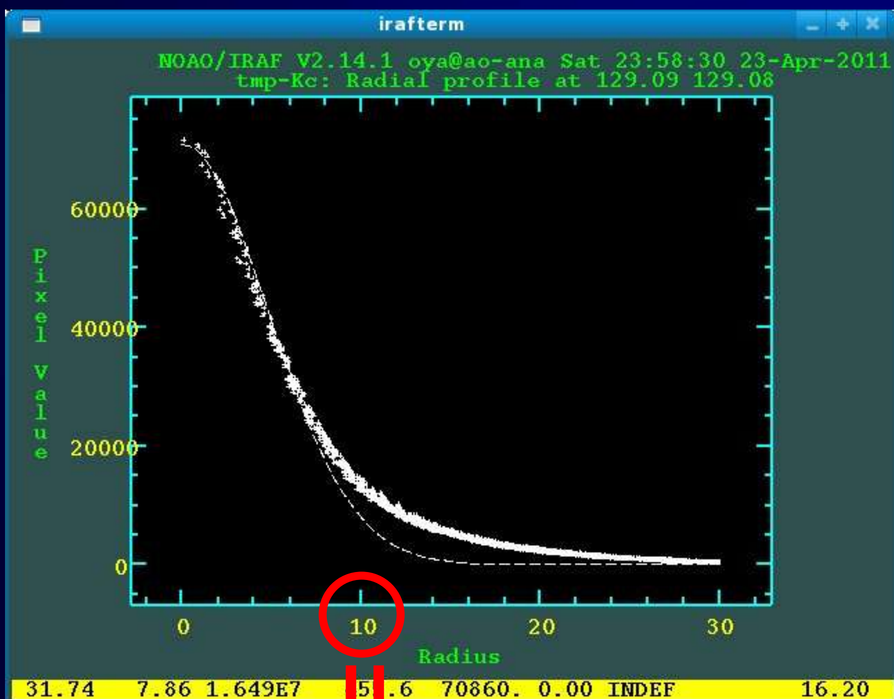
the results are preliminary



GLAO: radial plot

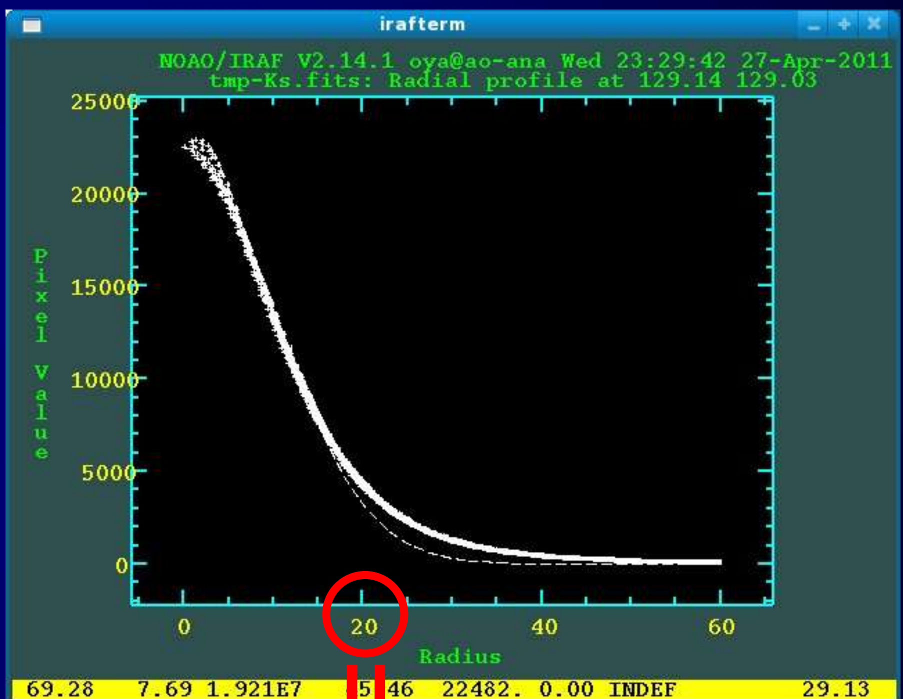
Subaru simulation: K-band

GLAO center



0.15”

Natural seeing



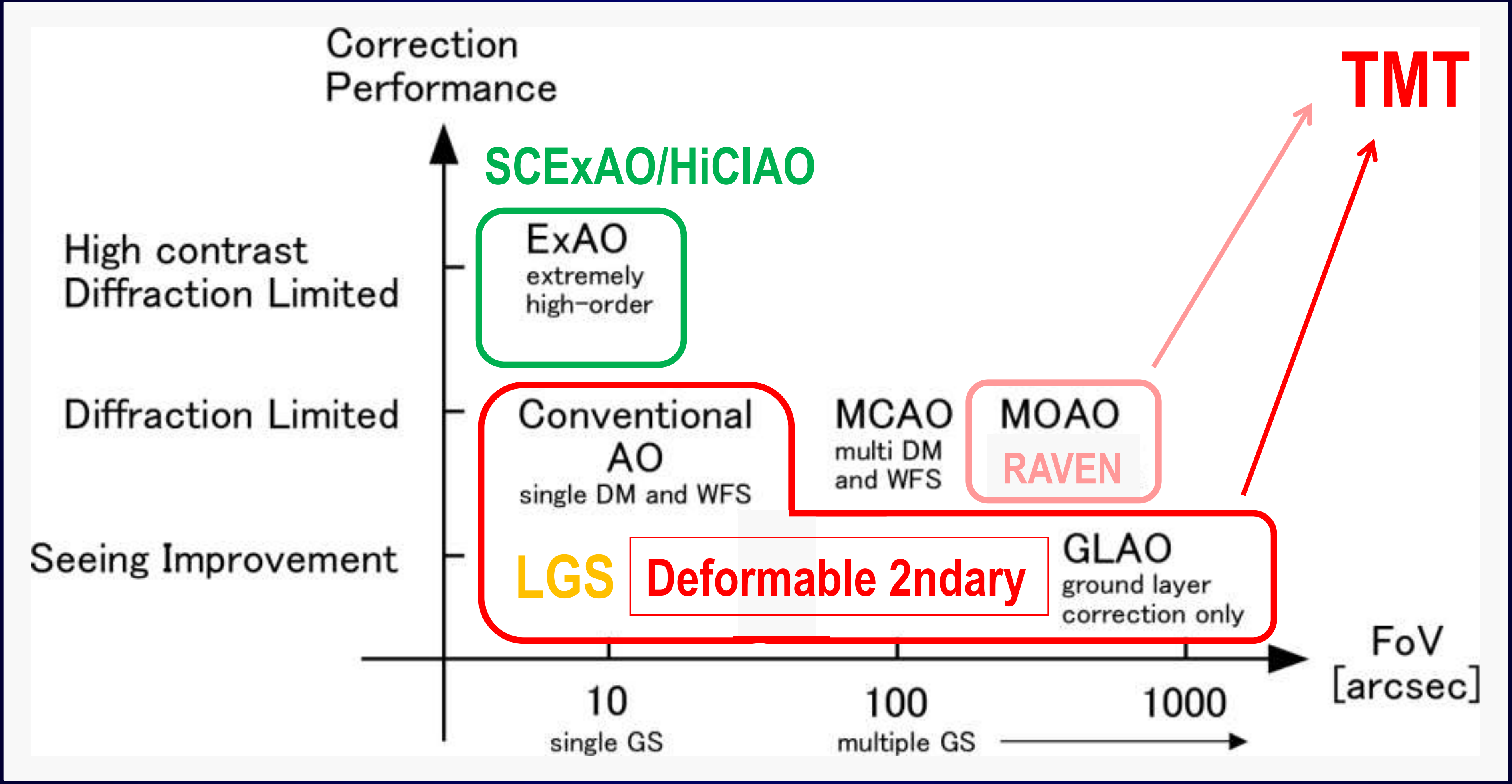
0.30”

Current view

- GLAO with MOIRCS like instruments
  - meeting focused on Science Case
  - September 8 & 9, 2011 at Osaka, Japan

- MOAO experience of RAVEN
  - on-sky tomography (basis of wide-field AO)
  - expand the experience to TMT IRMOS (2^{nd} gen.)

Future of Subaru AO



Summary

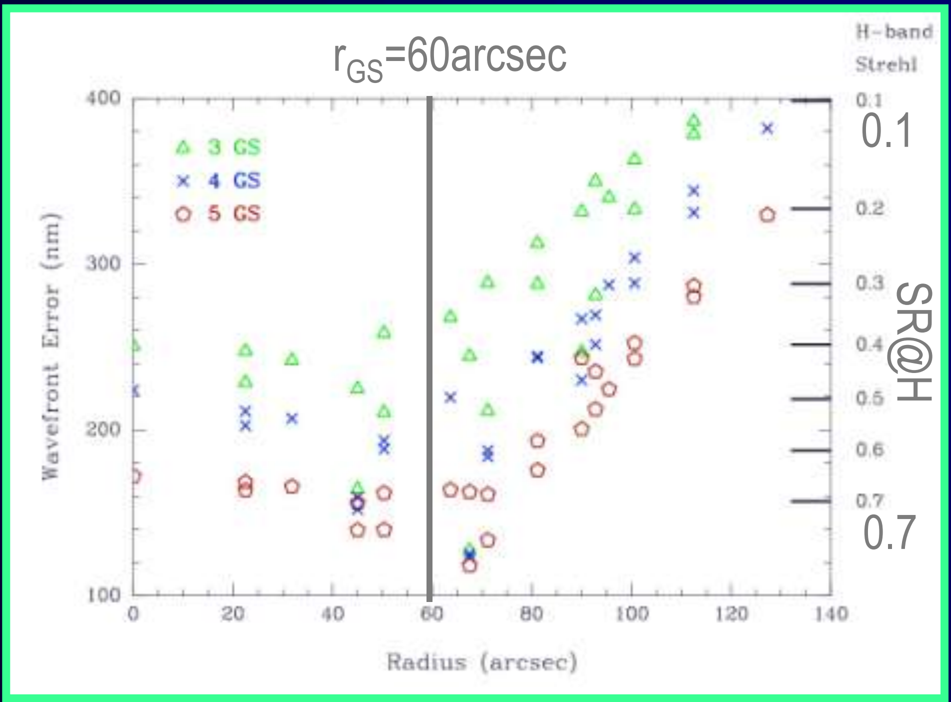
- Wide field AO is suitable for Subaru future plan
  - synergy with prime focus instrument
  - competitiveness among 8m-class telescope
  - complementarity with 30m-class telescope
- GLAO by deformable 2ndry is 1st candidate
  - 10-15 arcmin FoV; 1 mag gain; 1000act ASM
  - deformable 2ndry: on-source high order / low emissivity
  - MOIRCS like wide-field IR instrument at Cassegrain
- Study is needed
  - performance: simulation / seeing data
  - science case, technical feasibility, time-line, budget plan

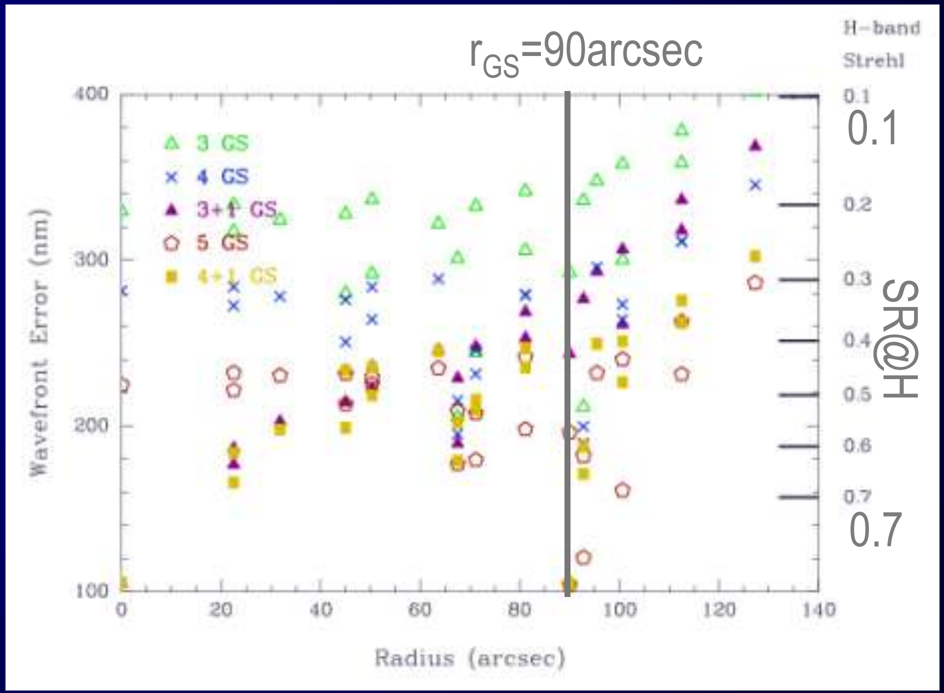
Appendix

MOAO: expected performance

Raven case

- 2'～3' FoR, 3～5 NGS (bright enough; V～10)
- WFS: 15x15 SH (?)
- DM: 16x16





Simulation by Andersen (2010)

GLAO: FoV & Performance

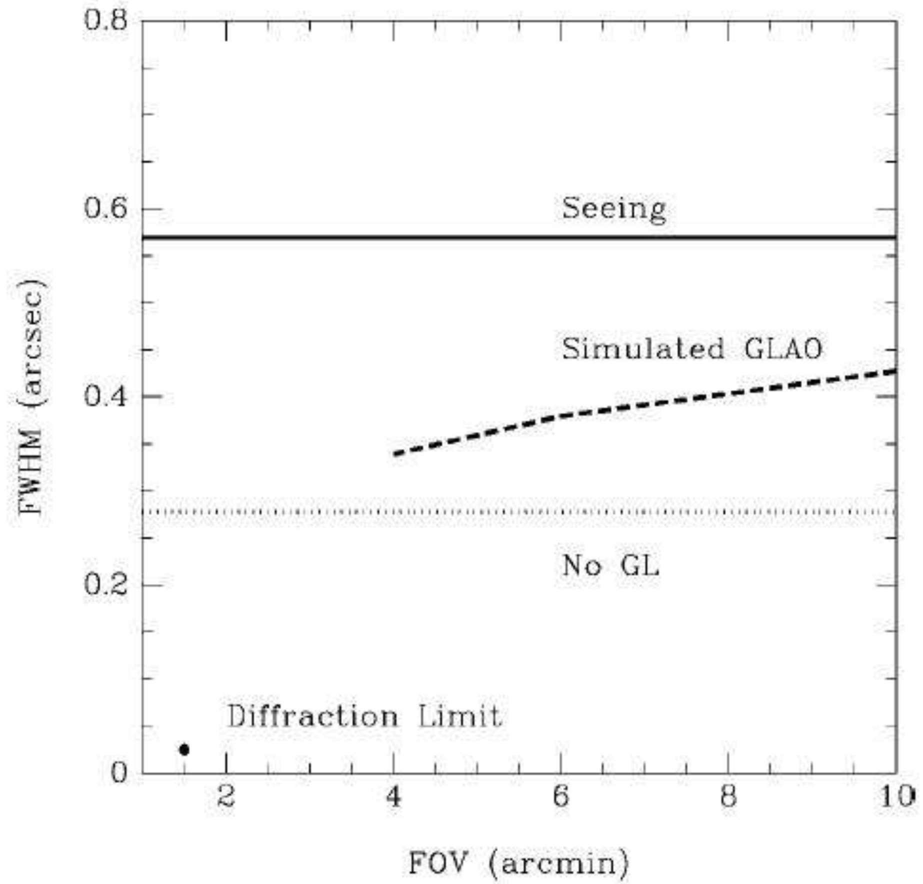


FIG. 15.—FWHM as measured at 1 μm as a function of the FOV, using the typical : typical turbulence profile. While the GLAO performance improves as field size shrinks, the gains are small; reducing the area of the FOV by a factor of 6.25 only improves the FWHM by 18%.

Andersen et al.(2006),PASP,118,1574

GLAO: EE & SR

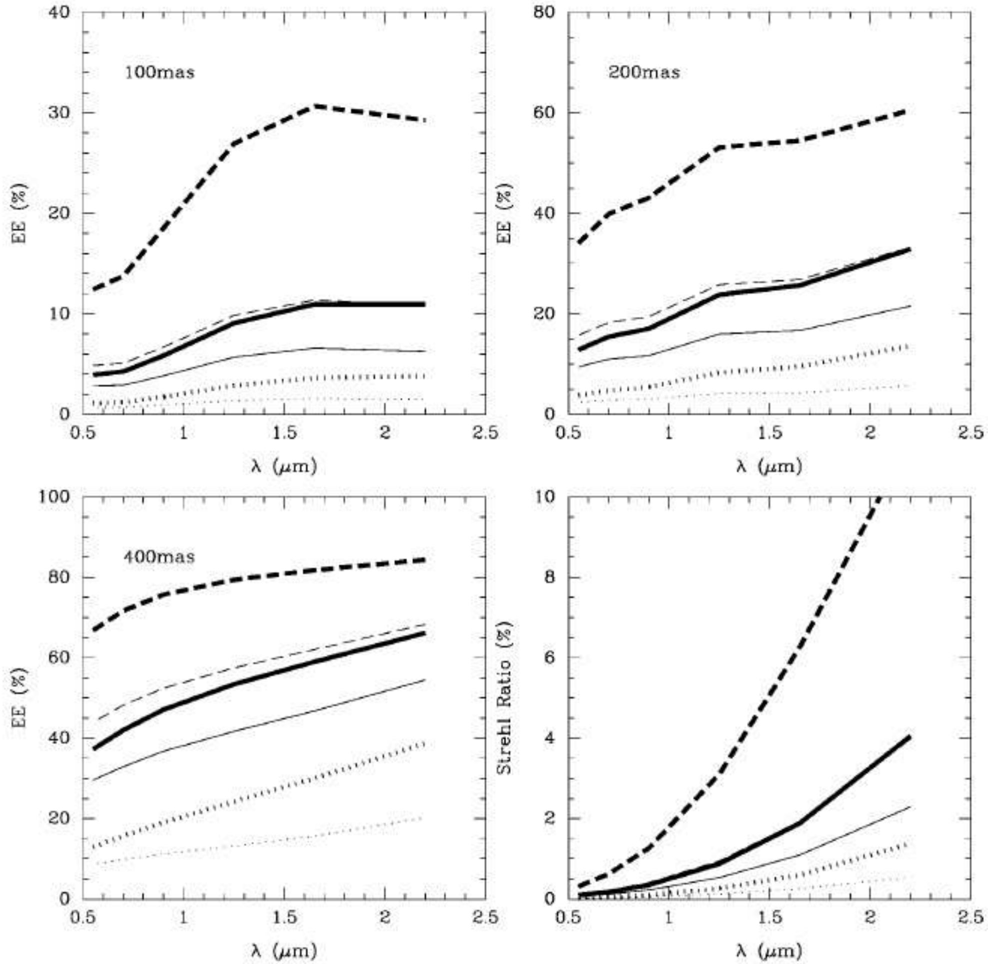


FIG. 5.—EE within 100, 200, and 400 mas, and Strehl ratio vs. wavelength for bad : bad (*dotted lines*), typical : typical (*solid lines*), and good : good (*dashed lines*). Thick lines show the GLAO performance, while thin lines show the seeing-limited measurements. The EE within 100 mas is less than 10% at most wavelengths and for most turbulence profiles. Only 20% of the EE is within 200 mas in most cases. The Strehl ratio is very low for wide-field GLAO observations and is less than 4% in most cases (except for the good : good performance at $\lambda > 1.5\ \mu m$).

Andersen et al.(2006),PASP,118,1574

GLAO plans for other telescopes

e.g., introduction of Baranec et al.(2007),ApJ,661,1332

- VLT: DSM, 4LGS+1NGS
  - GLACSI(MUSE:1’), GLAAL(HAWK-I:7.5')
- LBT: DSM, 16 NGS
  - MCAO NIRVANA (GLAO mode)
- MMT(6.5m): DSM, 5 Rayleigh LGS
  - the first closed loop of GLAO in 2008
- SOAR(4.1m): 1 Rayleigh LGS + multi NGS
  - SAM(3’)
- Gemini North: LGS, DSM ⇒ Subaru?

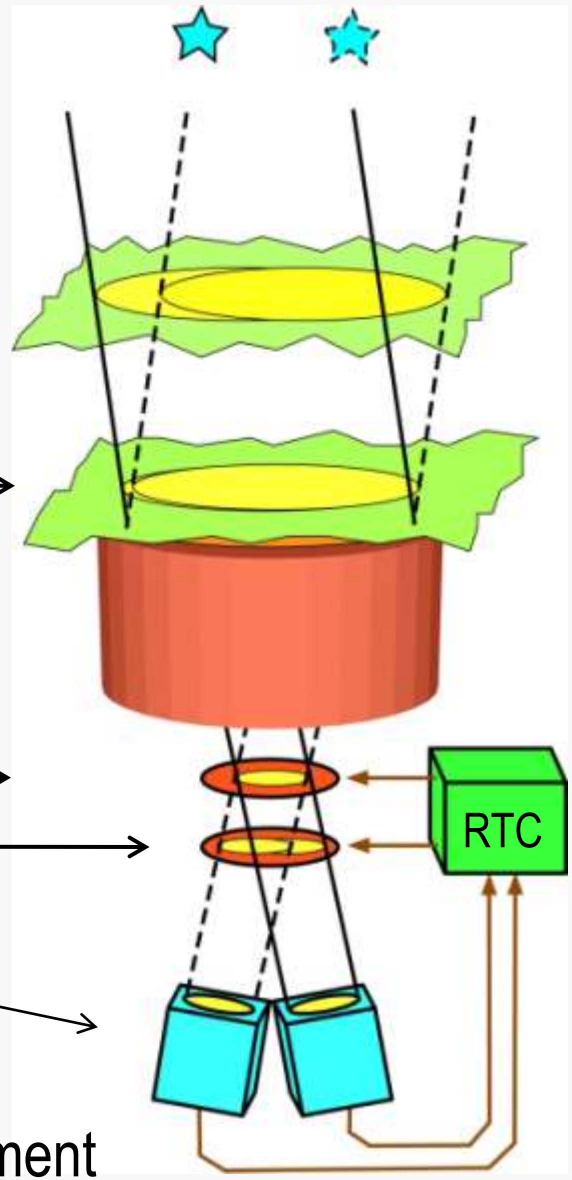
MOAO plans for other telescopes

- ViLLaGEs (Gavel et al.UCSC)

  Open Loop/Closed Loop MEMs DM AO on Lick 1m Nickel telescope.
  - Also works in open loop mode
  - First use of MEMs DMs in on-sky AO system
- Canary (Morris et al. Durham & Paris)

  3 phase MOAO instrument at 4.2m WHT.
  - 1st phase (VOLT-like open loop demonstration) scheduled for this summer.
  - Eventually will be upgraded to full Laser Guide Star MOAO system
  - 1/10th scale of Eagle (minus a real science instrument)
- Condor for VLT / NGAO for Keck

MCAO



FoV: 2 arcmin diffraction-limited survey possible

multiple layers
&
multiple correctors

conjugated

multiple WFSs

wide-field instrument

MCAO: expected performance

MAD case

- 1’ or 2’ FoV; 3 NGS (V=9mag)
- WFS: 8x8 SH
- DM: 60 elem. bimorph x 2

Marchetti et al. (2006)

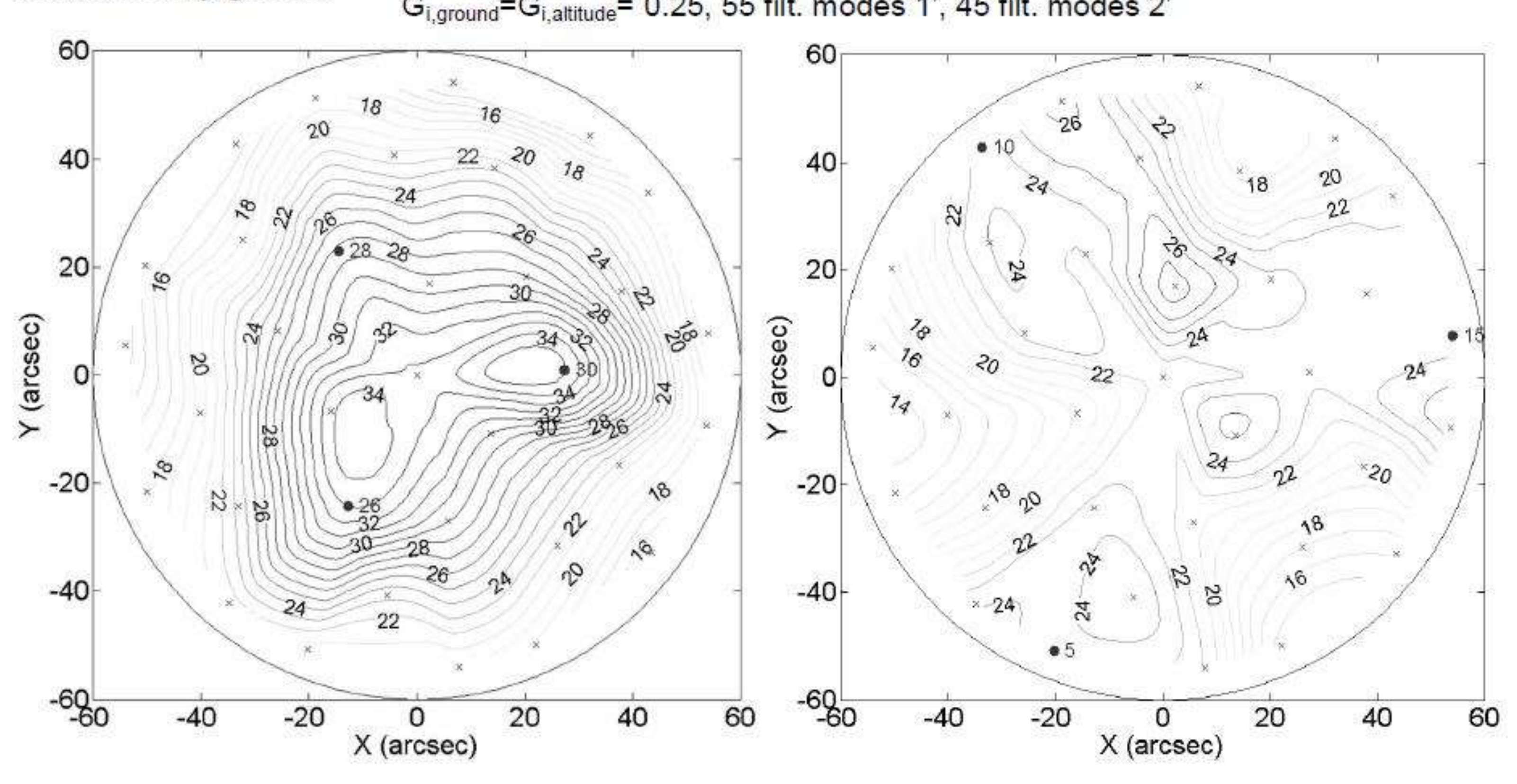


Figure 10 MCAO Strehl performance at 2.2 µm. Left: 1 arcmin FoV configuration. Right: 2 arcmin FoV