Simulations for future AO instruments – MCAO (/ MOAO)

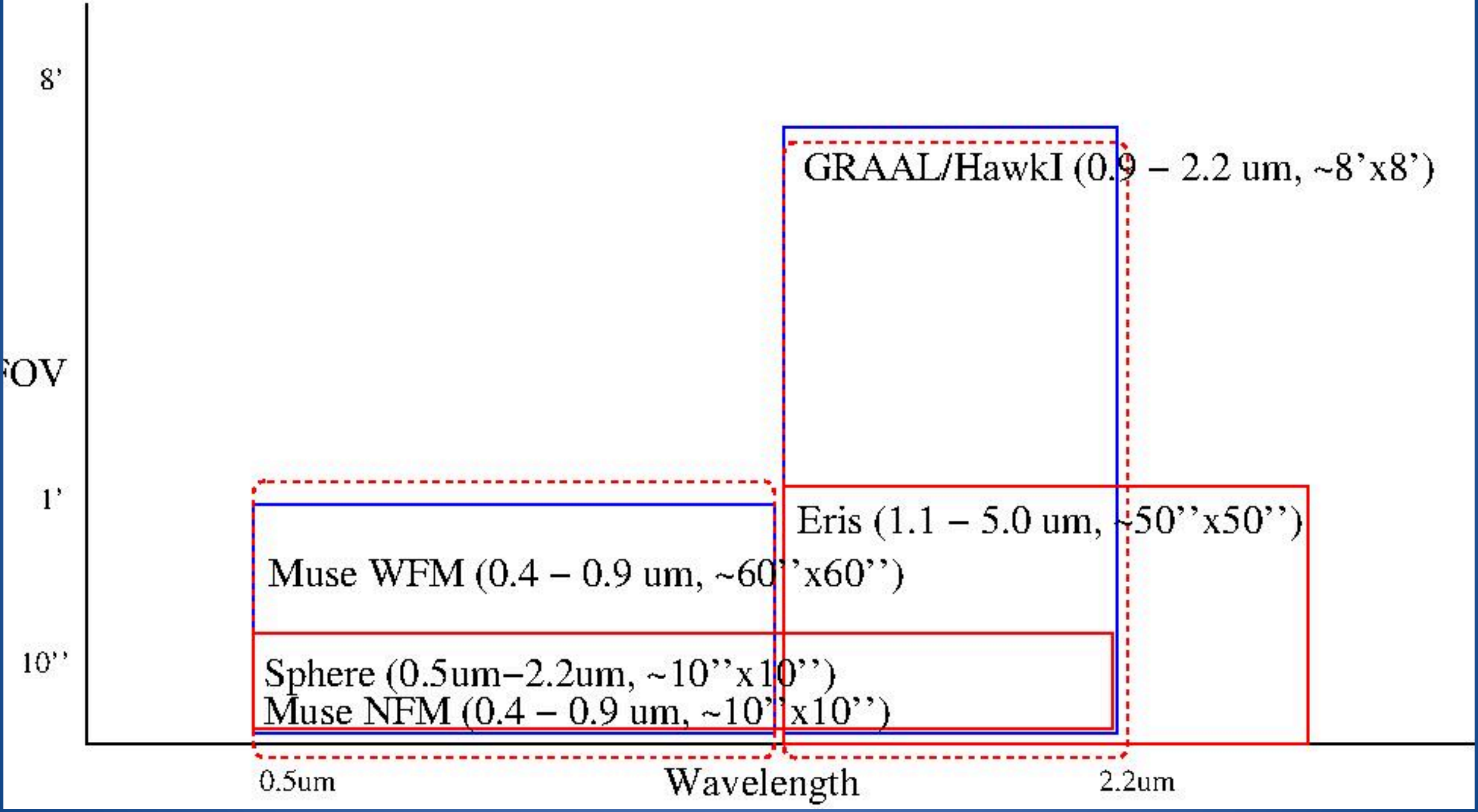
M. Le Louarn

ESO

"Current" status

- New VLT AO instruments go into visible
  - Sphere (Zimpol) provides good correction in the visible
    - Fairly bright NGS (close to) on-axis
  - AOF provides:
    - Wide FOV (1') seeing improvement in visible (for Muse)
    - Diffraction limited correction in visible (10''), with lasers (Muse NFM)
    - Wide field of view (8') for Near-IR seeing improvement (GRAAL / Hawk-I)
  - Eris will provide Median field (~1') diffraction limited spectro-imaging in near-IR
- → Visible AO systems are possible today

Parameter space



Increase resolution compared to GLAO, either in

- visible (30'' – 1-4'),
- or IR (2' – 4' ?), perhaps with MOAO

Red: Diff lim
Blue: Seeing improvement

Scaling

- Corrected FOV (isoplanatic angle), Coherence time and r0 (DM pitch) are all proportional to $\lambda^{(6/5)}$
- → Everything is harder in the visible
    - Factor of ~3 between 1.6um and 0.6um…
- BUT the key technology is available TODAY:
    - MCAO & MOAO are well proven technologies that allow increasing the corrected field of view (MAD, Raven, Canary, GeMs,…)
    - DSM & post-focal DMs can now provide enough actuators for visible correction (AOF, Sphere,…)
    - Lasers are now powerful enough to provide visible correction (AOF)
    - WFS detectors have low noise & enough pixels for visible correction (AOF & Sphere)

My "Super"-MCAO Assumptions

- Use the DSM (~20cm pitch)
- Use the 4 LGSF + upgraded laser behind secondary (→ this is a significant upgrade)→ 5 LGSs spots total (LLT exists, Laser light not)
- 2 post-focal DMs in addition of DSM (it's probably the max "reasonable" number)
- → This is the "best" one can hope short of very big project
  - Next steps above this:
    - even more LGSs
    - More DMs
- No opto-mechanics, so could be (too) BIG
- Smaller field (15'' -30'') would make the system MUCH simpler (→ Simone)

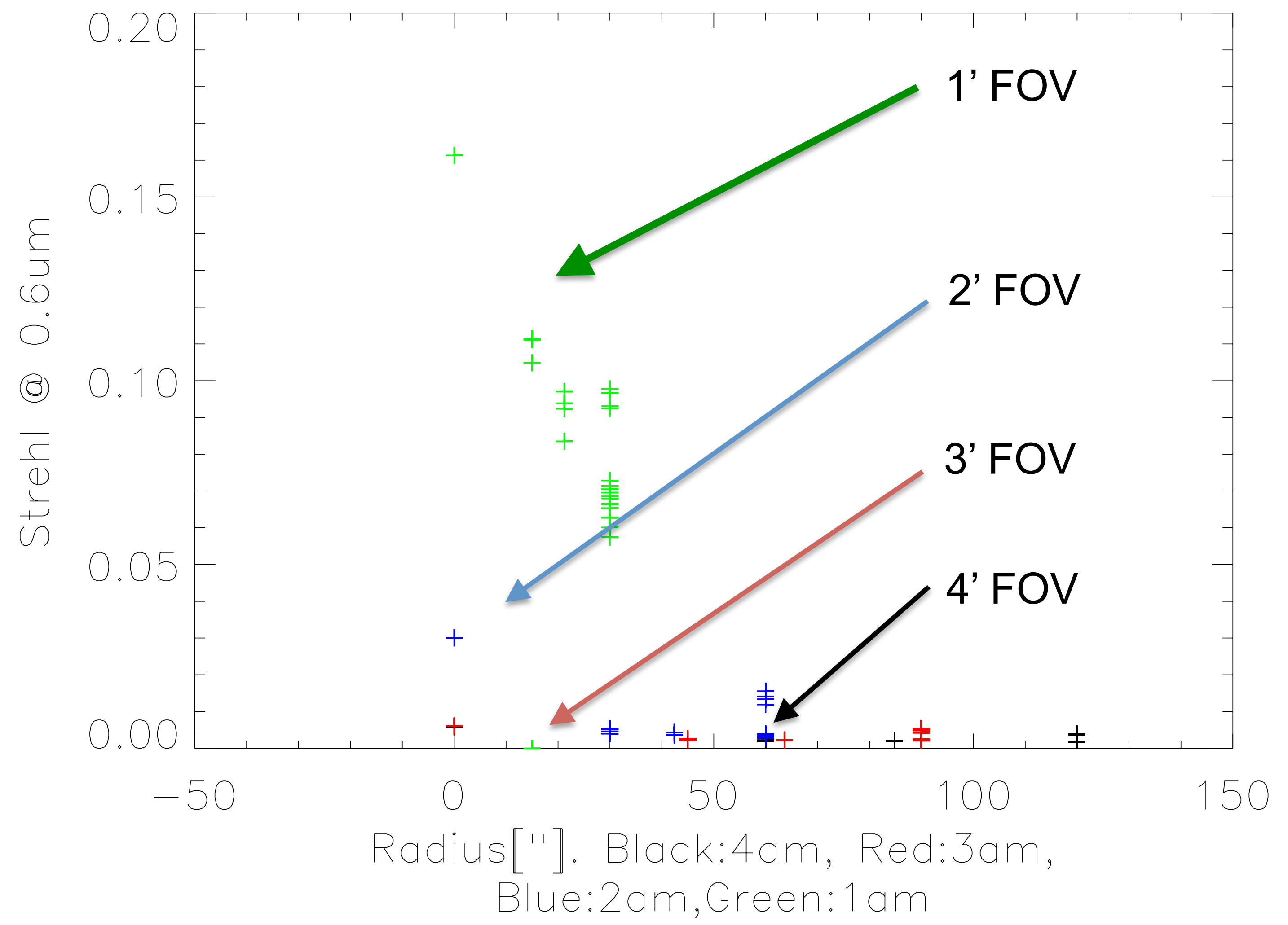
MCAO Simulation conditions

- r0 = 0.118m alos (~0.8'' @ zenith)
- Cn2 profile: 10 layers AOF profile @ Zenith
- High flux for LGSs (should not limit)
- 1kHz, 1s (only) of total simulated time
- 25 PSFs distributed in the corrected FOV (1,2,3,4' diameter)
- 4+1 LGS config (→ implies one extra LGS compared to AOF)
- 3 DMs (total), 0.2m pitch, at 0km, 4km, 12km
- 3 (bright) NGS at the edge of corrected FOV

On the importance of metrics

- There are so many free parameters in (MC)AO, that having the right metric to optimize is key.
- Possible metrics:
  - Strehl: the classic, if you want diff lim
  - FWHM (yuk !): tricky, because depends on PSF shape (→ error prone), and not necessarily very sensitive (i.e Strehl of 5% yields already diff lim FWHM, but tiny peak having 5% of energy)
  - EE in a given pixel size (ex. 0.2'' or 0.1'' for GRAAL, GALACSI) at given wavelength
  - How to quantify homogeneity of PSF in field ? PSFs will NOT be 100% stable, whatever you do (unless turn AO off !)
    - Suggestion: EE in 50mas (?) shall not change more than X over FOV.

Strehl @ 0.6um

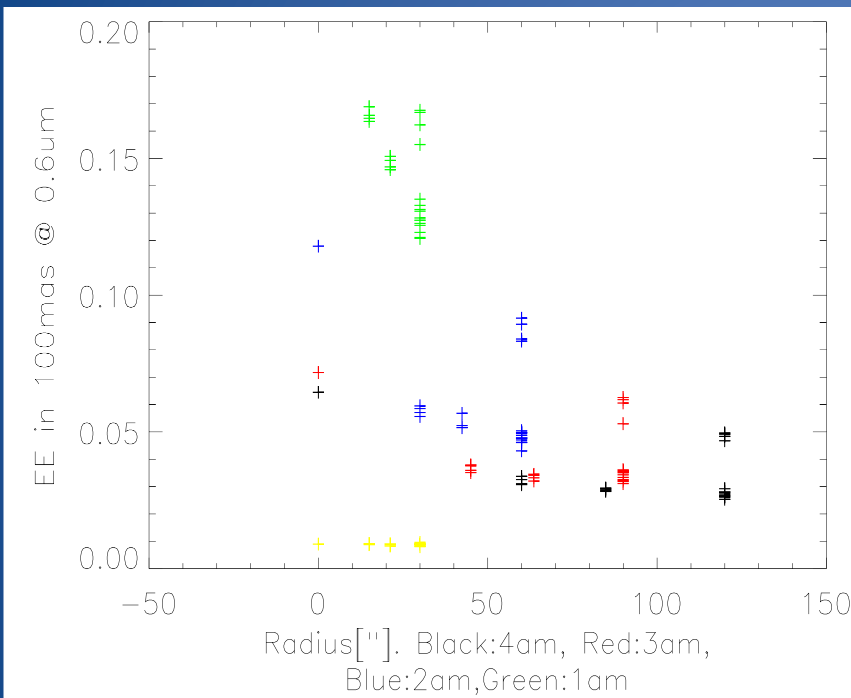


For Strehl, 1' seems the maximum FOV with this amount of LGS/ DMs in visible

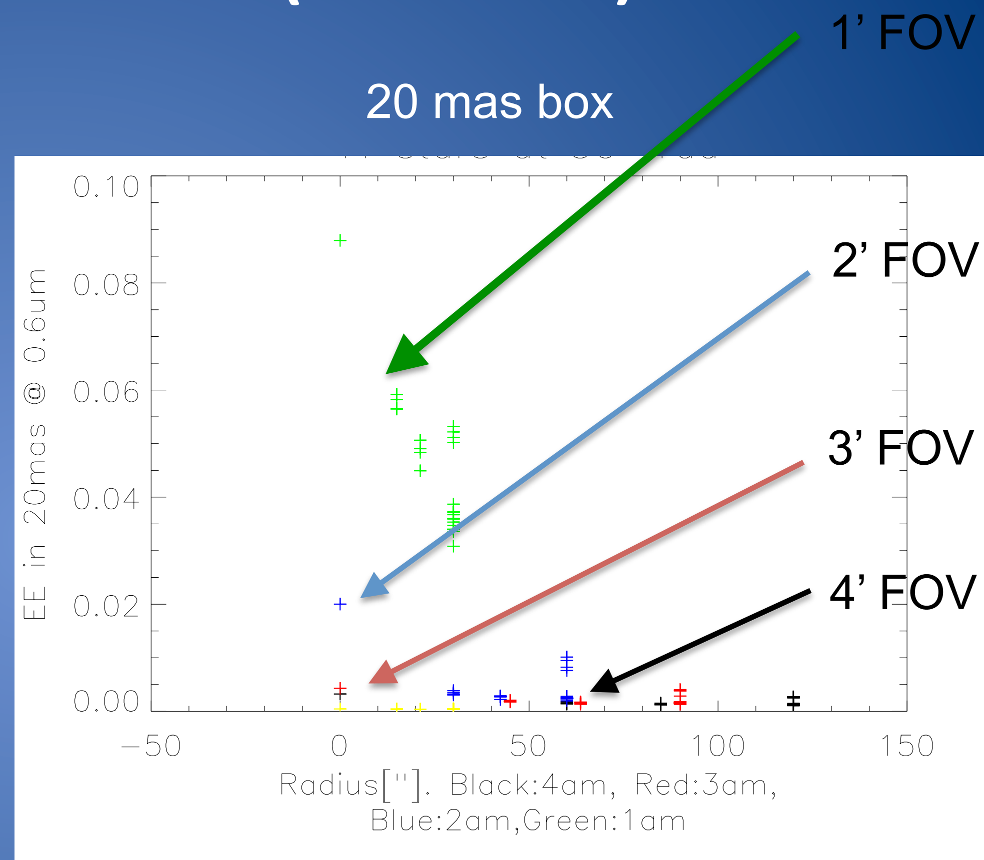
Up to 1'→ ~ Diff lim, after that partial correction

EE Visible MCAO (0.6um)

100 mas box



20 mas box

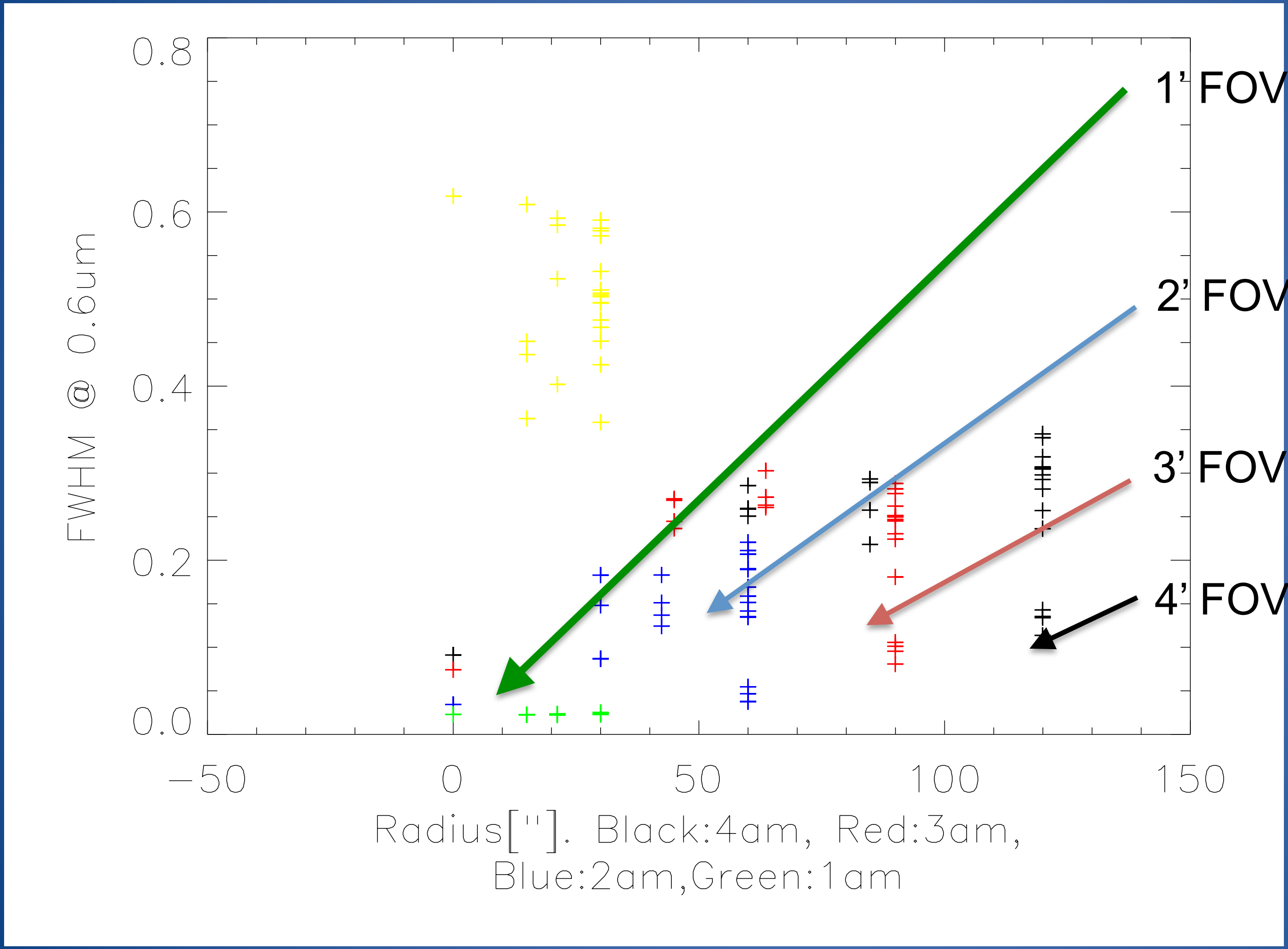


20 mas → Diffraction limit tracer
100mas → Seeing improver regime

Yellow: seeing

→ If EE in 100 mas is “interesting” larger FOVs could work

FWHM 0.6um



Diff lim for 1', intermediate for larger FOVs

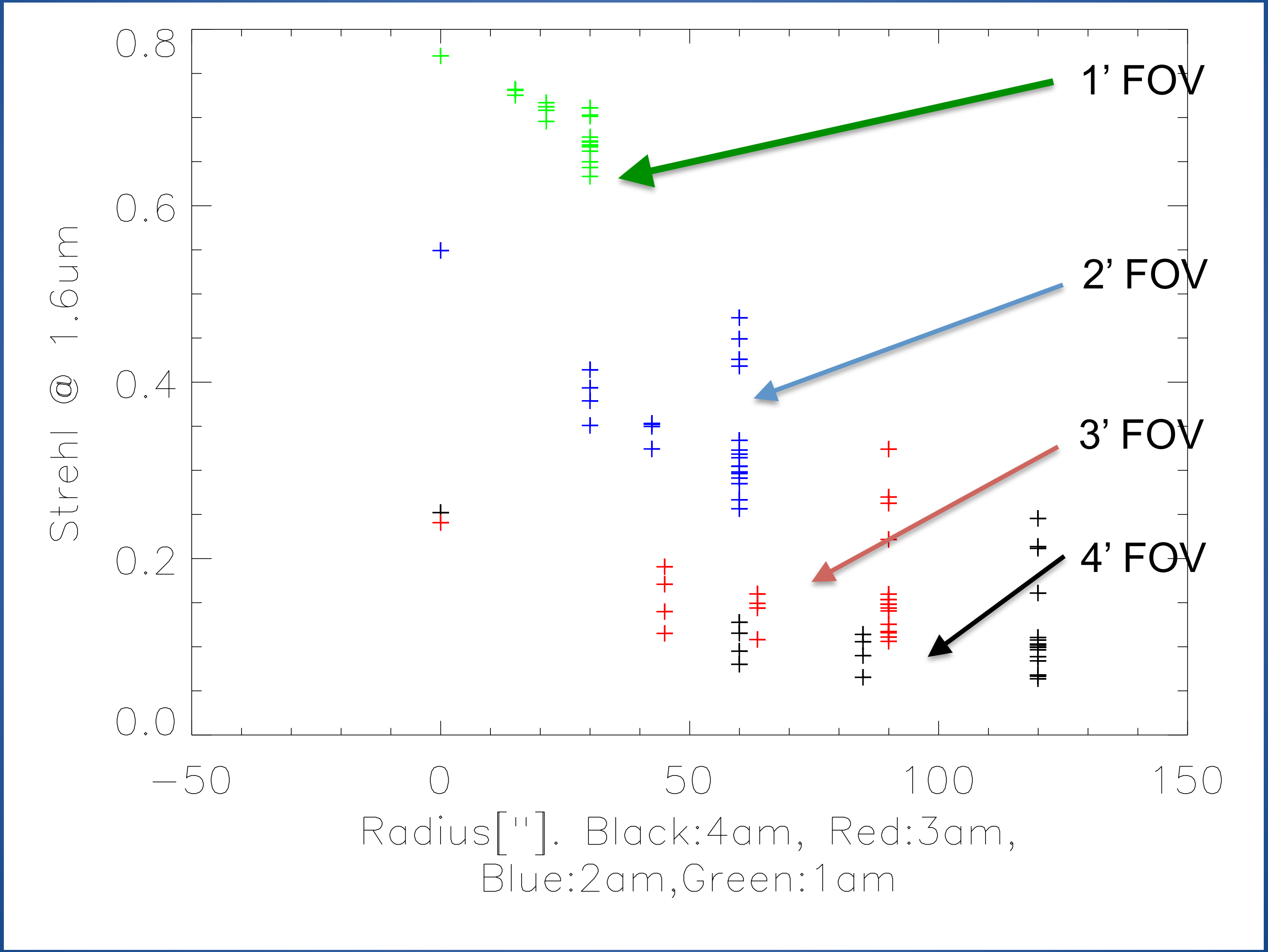
"simulation noise" for seeing limited case, not very robust metric

Yellow: seeing

What about Near-IR ?

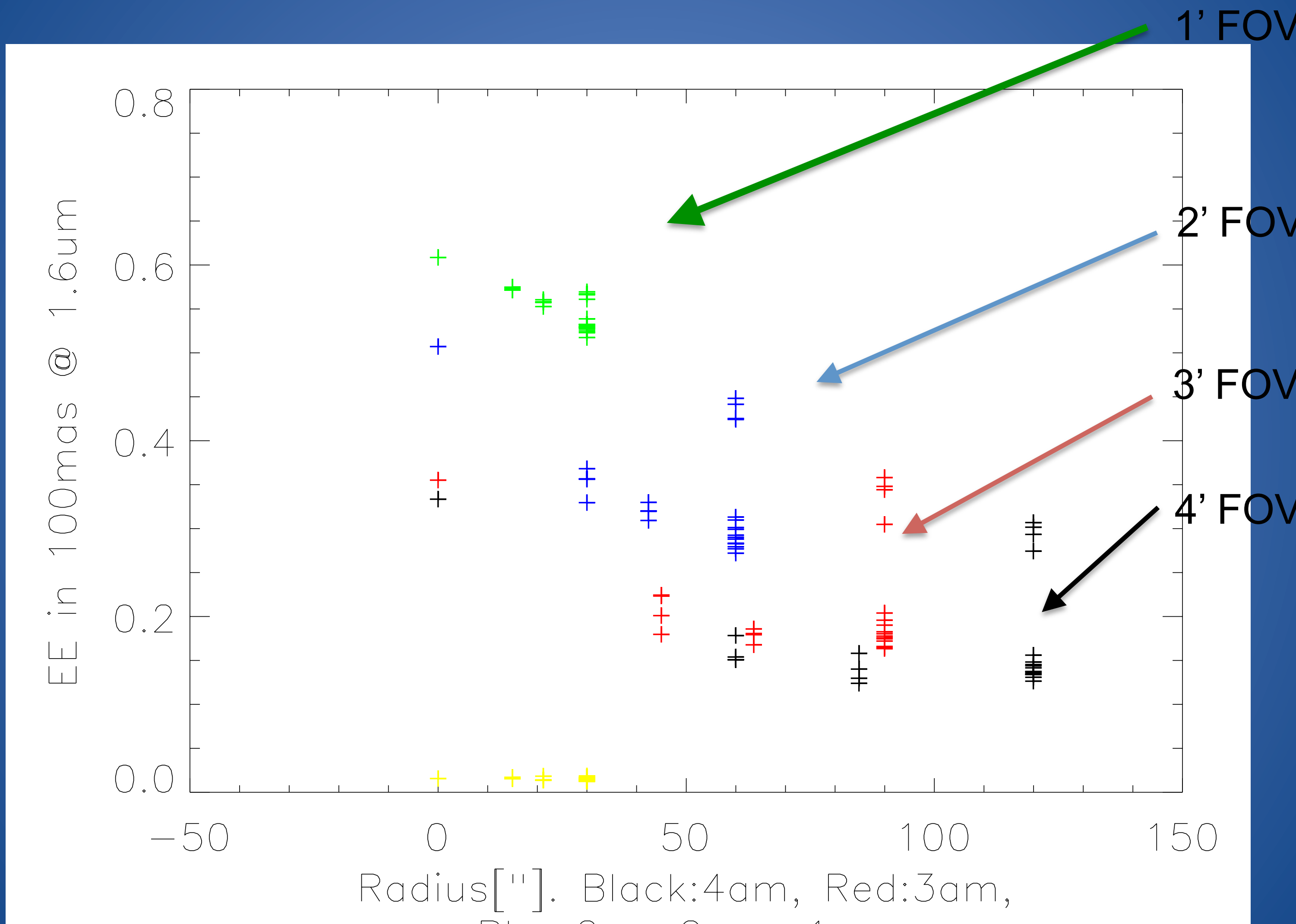
- AO can do better in near IR also:
  - Wider FOVs possible: diffraction limited 2-3-4’ full field FOV seems doable (opto-mechanics TBD)
  - MOAO is a proven concept that allows to probe an even wider field with IFUs (up to ~8’)
  - An AO assisted K-AO-mos, with diffraction limited (or nearly) IFUs would be doable (→ See Tim’s talk)
- Cost of science detectors may become an issue
- Remains to be seen how large FOV is opto-mechanically doable
- Same simulations as before, but look @ 1.6um

Near IR Strehl (1.6um)



Same system as in visible, but looked at in IR

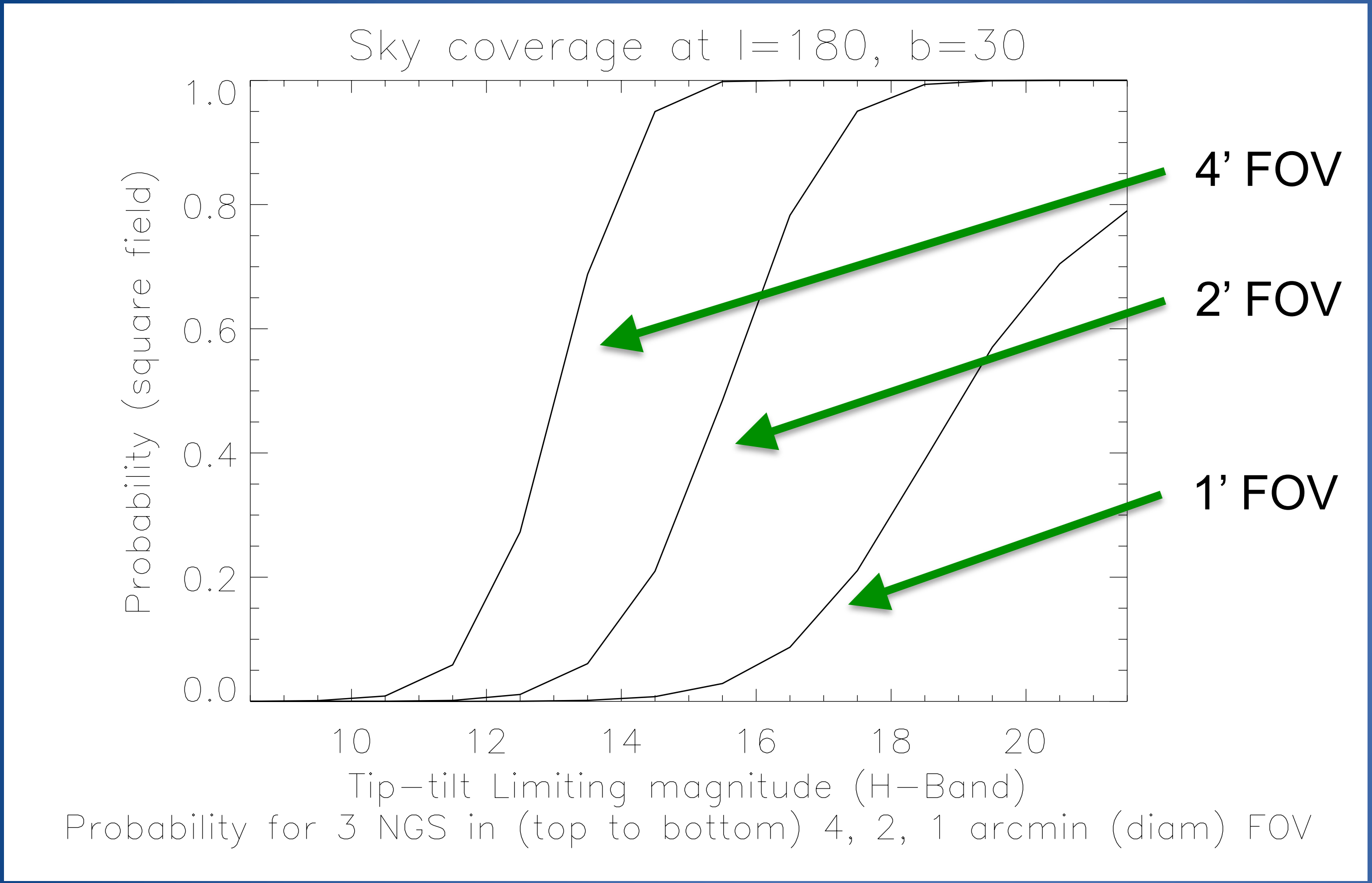
Near IR MCAO (1.6um)



More "classical" view of AO, with strong gain in EE

Yellow: seeing

FOV and Sky coverage (3NGSs)



What about tip-tilt less mode ?

→ Seeing improvement only (in visible)

→ OR using 1 NGS only (degraded mode)

Is sky coverage very important ?! To increase:

- Increase patrol FOV → More optics, larger (& more) DMs…
- Correction in the WFS path → More complexity, cost,…
- Use less TT-stars (→ accept more variation of PSF)

→ Sky coverage needs to be define soon, because it's a driving parameter

MCAO vs. MOAO

- In the IR, do you need:
  - Full medium sized field (a la MUSE) → MCAO
  - Multi-IFU very large field (a la K-MOS) → MOAO
- MOAO allows to have a much wider field, but in patches
- MCAO allows a smaller full field
- MOAO in visible: seems challenging for now (?)
- Both techniques yield roughly similar performance for a given field. Allowing segmentation of field for MOAO is the key difference, not really tomography.

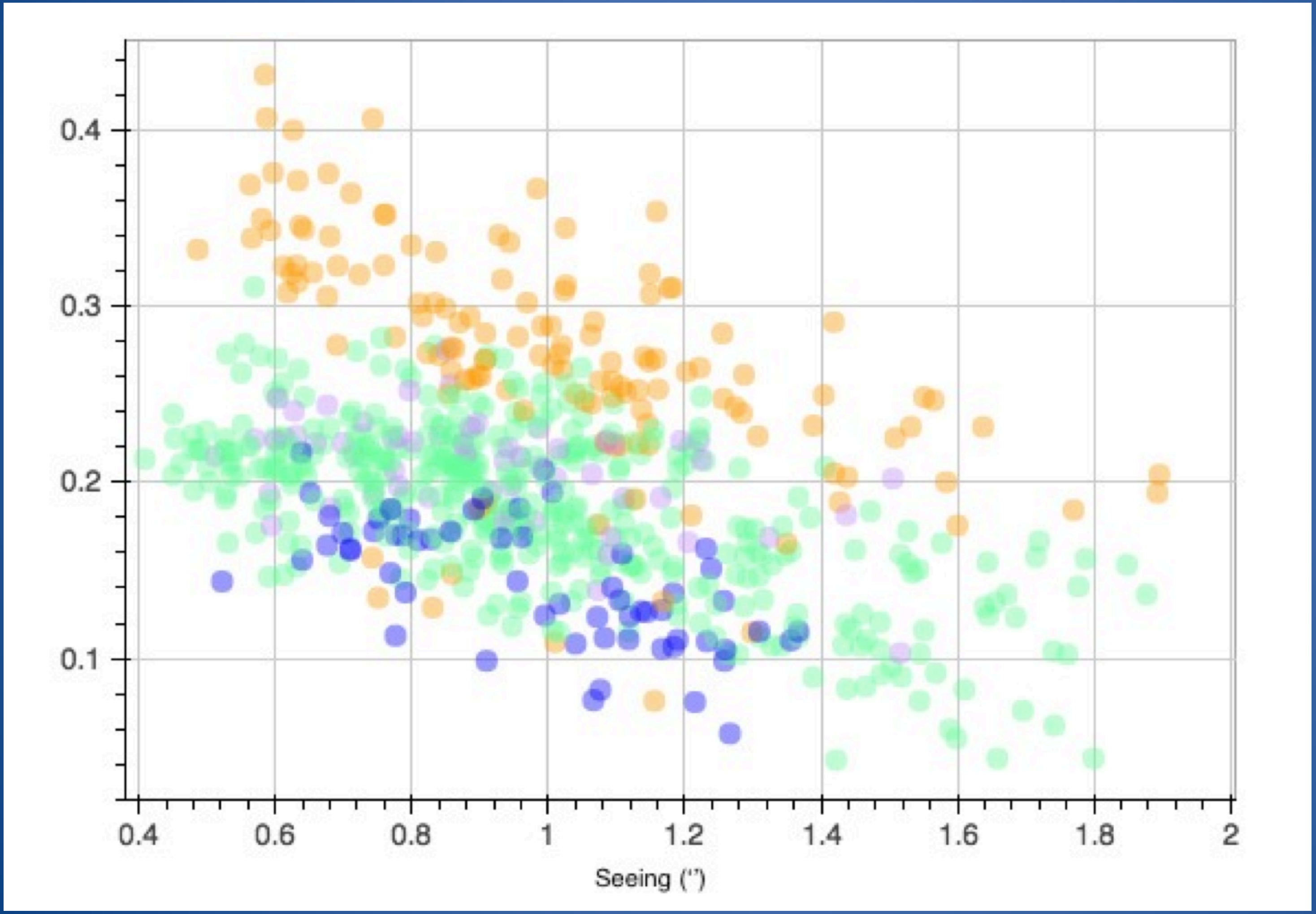
Current Limitations

- Visible AO Performance limited by number of LGSs & number of DMs
  - Those are limited by money & complexity
  - DM pitch, LGS power, WFS detectors, RTC power, should not be limiting for visible (famous last words)
- Sky coverage is still a limitation: need to increase FOV further to get 100%, or accept (significant) performance degradation (1 NGS or TT-less).
- Tomography is now fully demonstrated (both MOAO and MCAO).
- MCAO in visible: technology / cost
  - 4-5 LGSs (adding more becomes very expensive)
  - 2-3 DMs (total) seems reasonable
- → Opto-mechanical design & cost for larger fields than presented here (and even 3-4' is probably a stretch) seem challengin
- For MOAO, modular approach
  - More money → More IFUs
  - Because of larger FOV, LGSs + NGSs for WFSing is a possibility
  - Complexity is still very high, so complexity, mass, cost are probably the limit

Conclusions

- Visible MCAO seems a promising avenue
  - 30’’ → 2’ → 4’ FOV (depending on required correction)
  - Number of DMs, LGSs have strong impact on performance & cost
- → Talk by Esposito et al.
- Other option: MCAO in the near IR (a la Gems, but perhaps larger FOV)
- Third option MOAO in near-IR
  - → More on this by Morris et al.

MOAO is a proven concept for IR



H-band Strehl with Canary on sky,
Green: MOAO, Orange: SCAO, Blue: GLAO

Gendron et al., SPIE 2016

MOAO on Sky – Raven

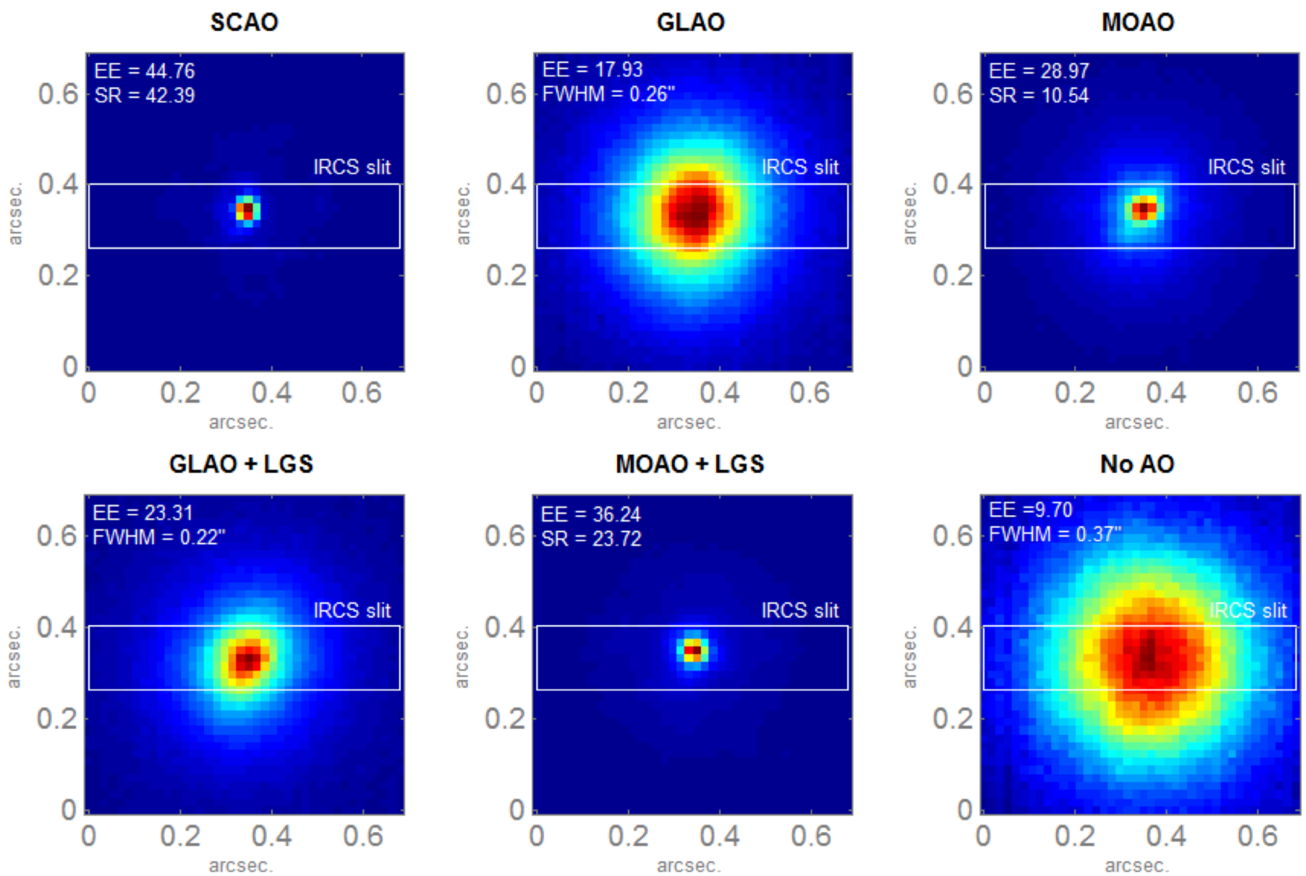


Figure 5. Science camera images, ensquared energy (EE) and Strehl ratios (SR) or FWHM achieved during daytime with the Calibration Unit in J-band. EE is computed in 140mas, the width of IRCS slit. NGS asterism is 2–arcminute wide, NGS R magnitudes are 11.5, 12.1 and 12.1. The camera frame rate is 250Hz.

Lardiere et al, 2014