VIS MCAO at the VLT AOF!

VLT AO-Community day
20-21 Sept., 2016

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T. Fusco, B. Neichel, LAM

Sep2015: AOF facts and considerations

- A deformable secondary mirror DSM with 1170 actuators, conjugated to ~ground

~20cm actuator spacing projected on M1

- Four laser guide stars 20w each, driving a 40x40 SHS for GLAO (4 WFSs in total).

GLAO for NIR and V

SCAO with NGS and

A Visible LGS MCAO system with 20 arcsec FoV (2DMs)

Consider using the 21cm spacing (and 4 20W laser) to push correction to shorter wavelengths.

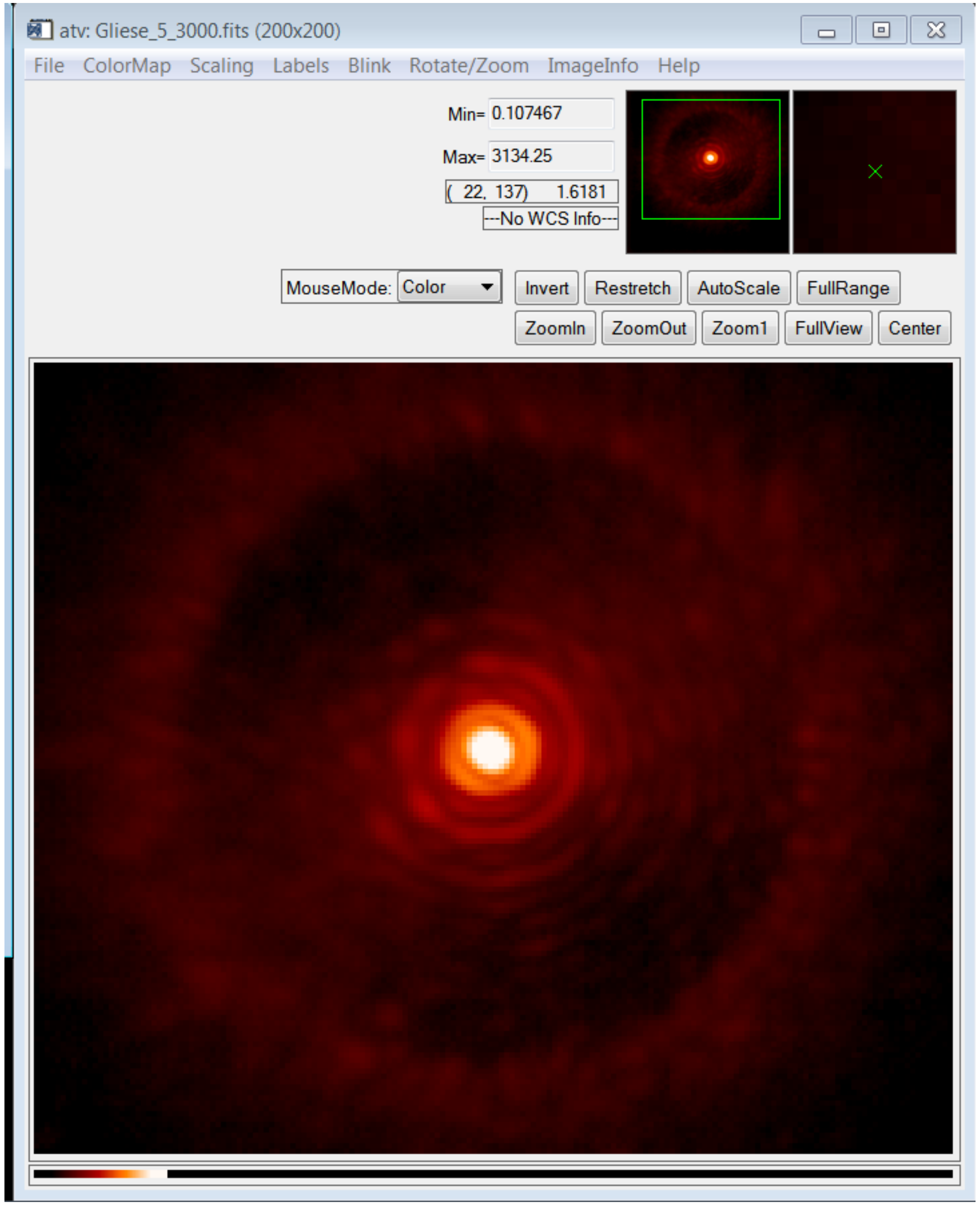
Adding post-focal DMs is changing the game => increase corrected FoV beyond limitation of natural angular anisoplanatism.

Correction in the visible……650nm images from Forerunner at LBT

similar images from SPHERE…

-well tuned 500 modes reconstructors
-NCPA compensated at 6 and 3 lambda/D
- in dome psfs with and without 0.8 seeing turbulence showing Strehl of 50%.

…visible is doable….



Advantages of visible observations w.r.t. NIR

A) Large visible detectors are cheap (compare to NIR), and detector quality is much better (dark current, cosmetic, warm and simple)

B) B) Sky background is small (1000 to 10000 times darker than K), difference with space is small too.

C) “low-noise” (<1e- RON) large (4k x 4k) and fast (10 frame/seconds) detectors already exist ! (e.g.Gach et al.)

C1: Post processing Tip-Tilt correction (100% sky coverage, images are re-centered post-facto)
C2: Higher order post-processing (e.g. multi-frame deconvolution) in order to recover some of the partial correction of the AO

=> C1,2 may relax significantly the constraints on the AO system !

VIS MCAO 4 VLT: talk summary

A first assessment of # of LGSs and # of DMs considering AOF availabilty i.e. 4LGSs and DSM (1170 acts)

E2E simulation exploring restricted parameter space for LGSs and DMs (assume VLT environmental parameters)

A 5(4) LGSs & 2 post-focal DMs optomechanical sketch.

compare VLT and HST PSFs at 650nm: SNR in R band filter

Conclusions about VIS MCAO performance (and FoV)

Basic limiting factors for VIS MCAO system

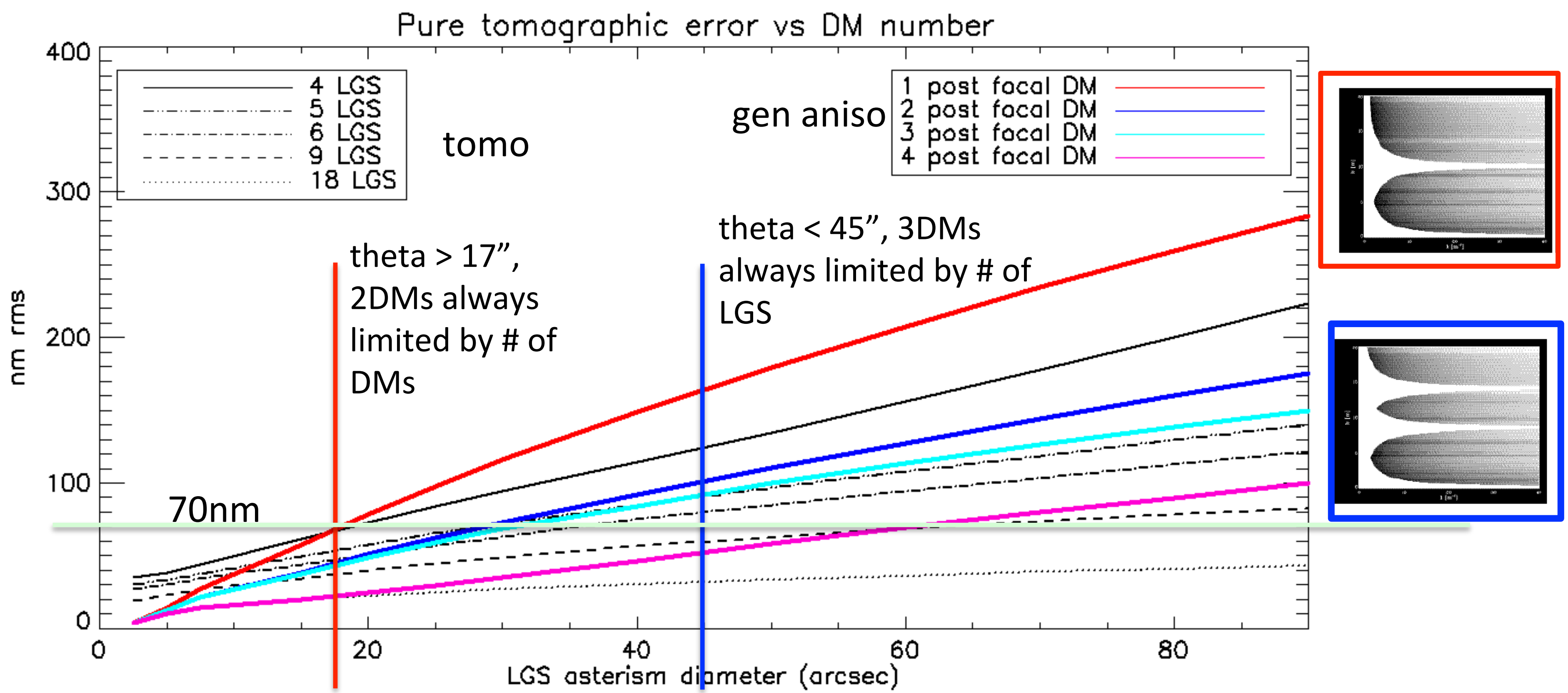
total wf error: we want to achieve ~ 30%SR at 650nm (e.g 30% of energy in a 2lambda/D patch), requires ~1rad^2 overall AO error. At 650nm 1 rad eq. to ~ 100nm

(1)generalized anisoplanatism (& fitting) error (# DMs, # Acts)

(2) tomographic error (# of LGS, theta of LGS)

Tomografic reconstruction and DMs correction efficiency

plot showing residual rms for WF reconstruction and DMs placements optimized for science FoV ~ eq. to LGS asterism

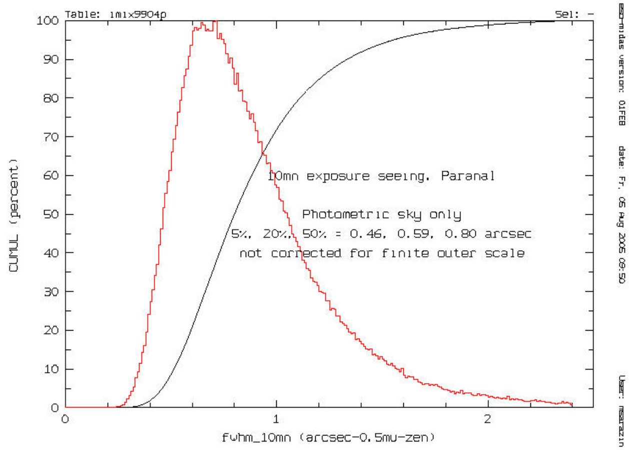


plot does not include fitting error (dact/ro)^5/3

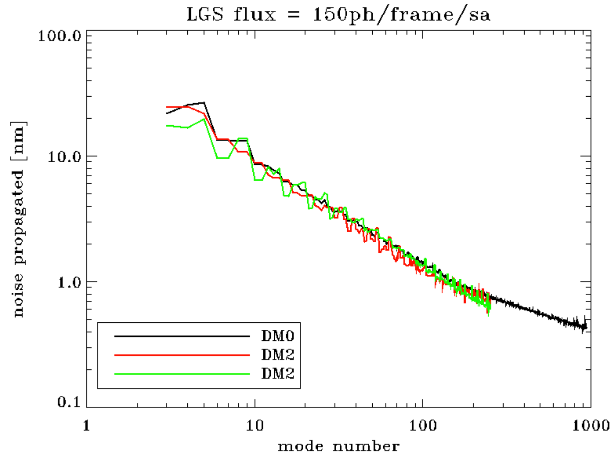
data from **T. Fusco, LAM**

Basic error budget

VLT AOF environmental parameters assumed.
-Expected fluxes for ESO AOF (~100phot/ms/sub, 40x40 sub)
-seeing = 0.73 arcsec
-L0 = 25 m



1) tomo+gen_anisoplanatis = ~90nm
2) DM fitting error ~ 50nm (DSM)
3) LGS photon noise ~ 50
4) TT residual NGS ~ 30nm (from E2E modal decomposition)



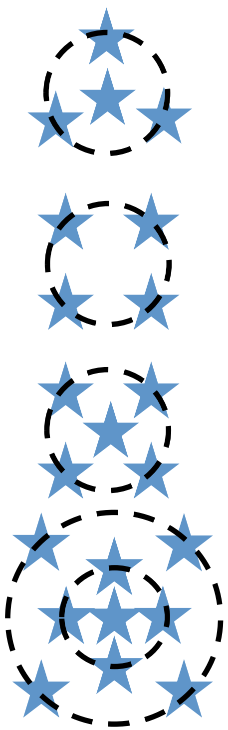
3DMs (2post focal & 5 LGS) sigma_tot ~ 125nn….
move to E2E simulations

E2E simulations main parameters

- **Atmosphere**:
  - Seeing (@zenith) 0.66”
  - L_0 25m
  - Cn2 ERIS profile (10layers)
  - zenith angle 30°
  - input wf std. dev. 1042nm
- **NGS**:
  - WFS: 2x2 SH
  - GS on-axis with R=12,19
- **LGS**:
  - WFS: 4, 5& 9 40x40 SH
  - asterism:
    - 4LGS@FoV (150fot/sub/frame)
    - 5LGS: 4@Fov + 1 on-axis (150fot/sub/frame)
    - 9LGS: 4@FoV + 4@FoV/2 + 1 on-axis (75fot/sub/frame)

- **DM1** (ASM 1172 acts):
  - Height 0m
  - 945 KL modes
- **DM2** (ALPAO 241 acts)
  - Height 5000m
  - 252 KL modes
- **DM3** (ALPAO 241 acts)
  - Height 10500m
  - 252 KL modes

Asterisms:

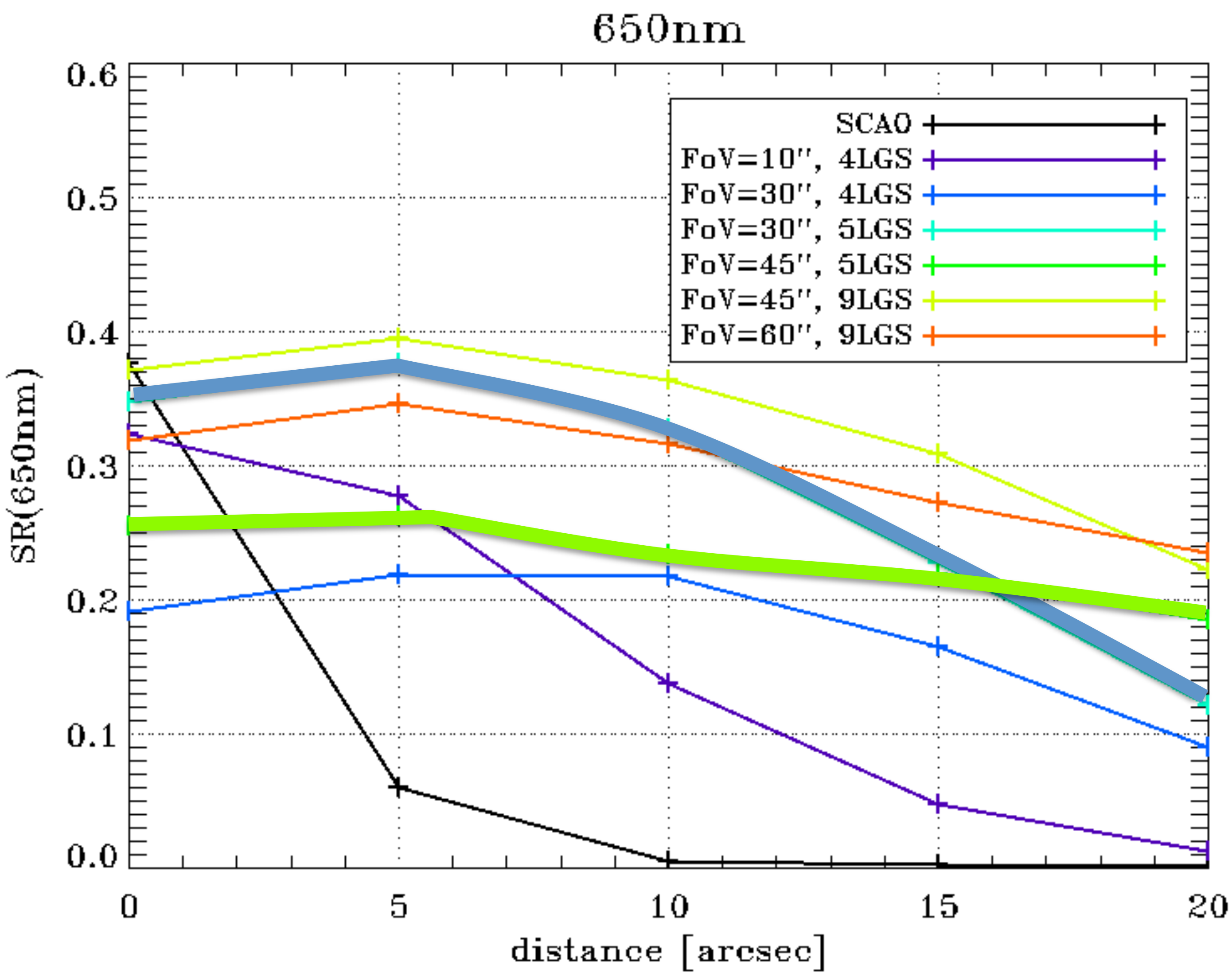


4+1 LGS ~ 3+1 LGS, may save central LGS, (TBC)

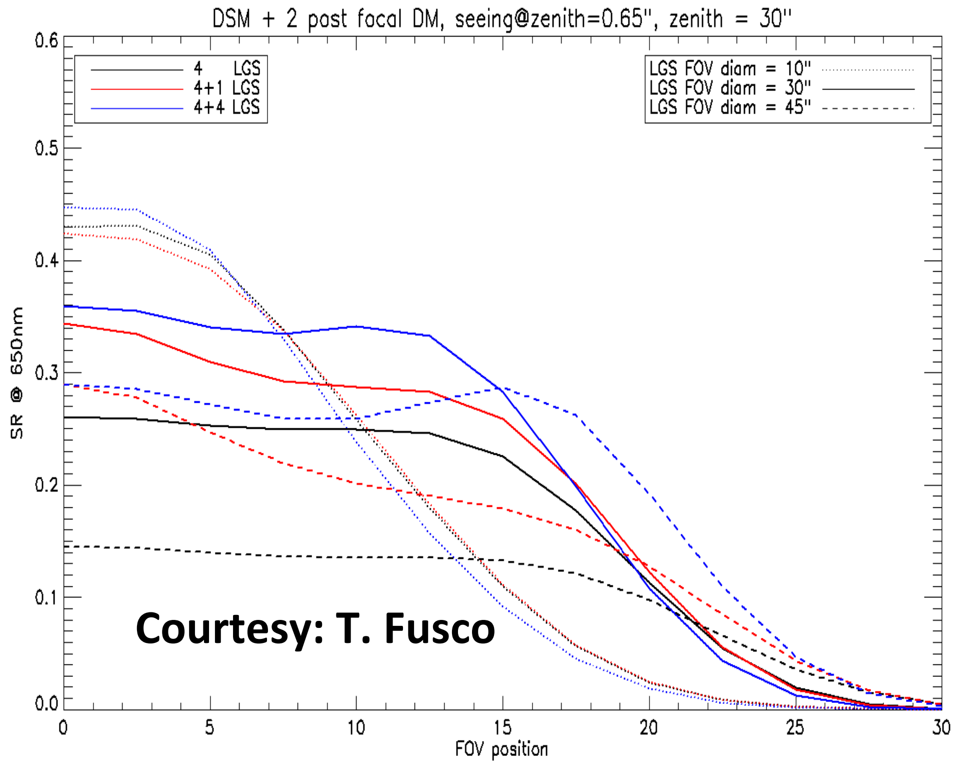
E2E results @650nm

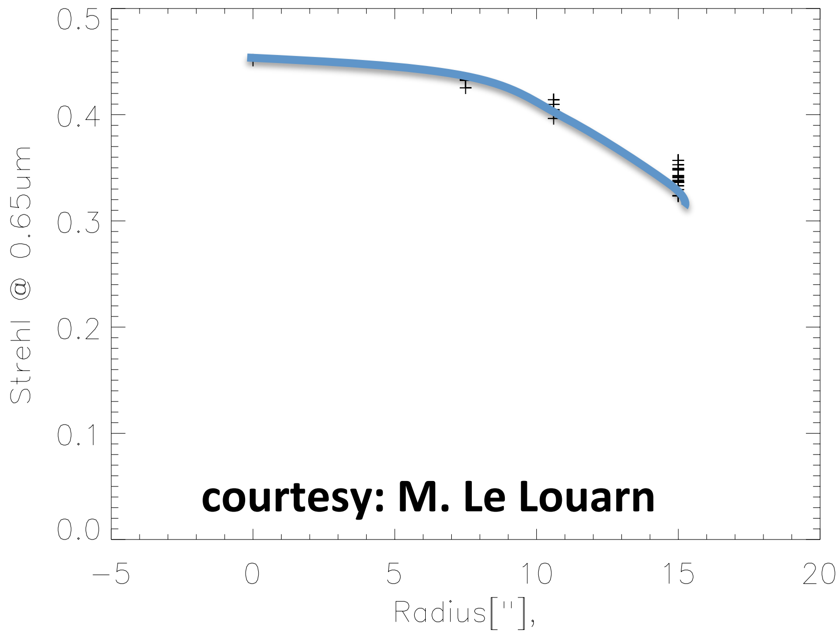
(1) bright LGS (x10); (2) bright NGS (mag 12); (3) centered NGS

Animation!



Results comparison

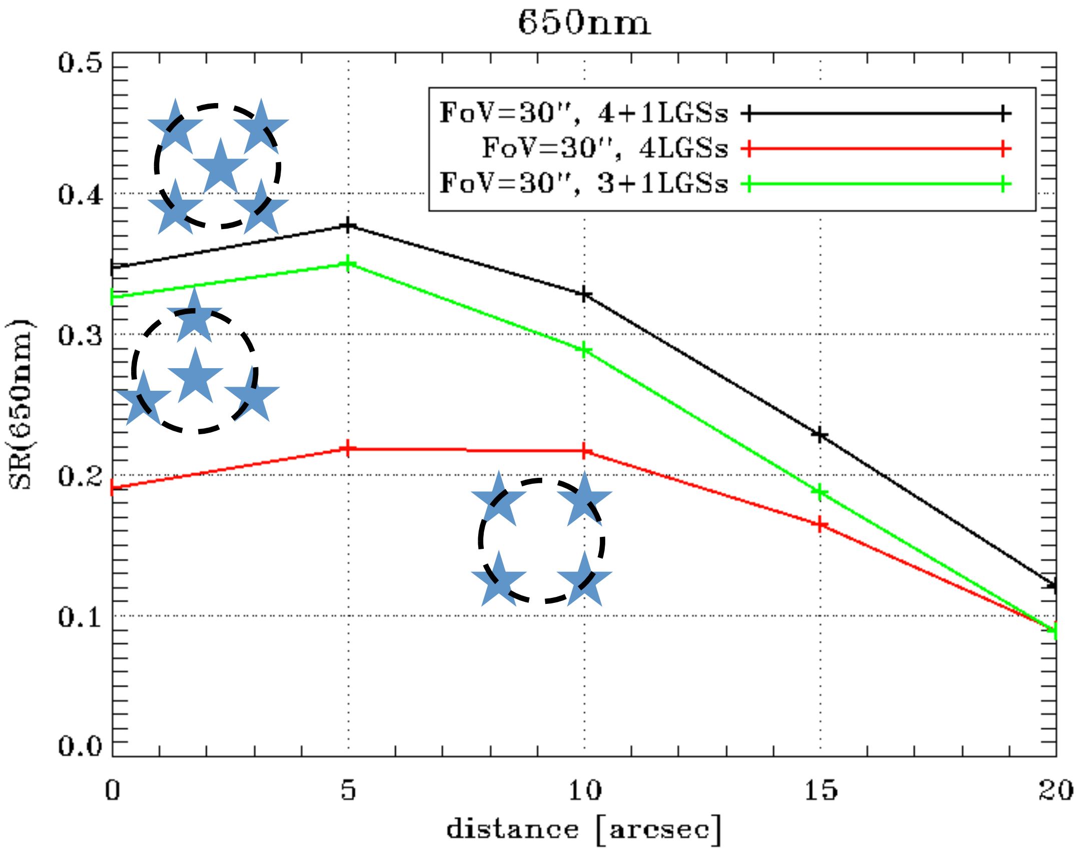


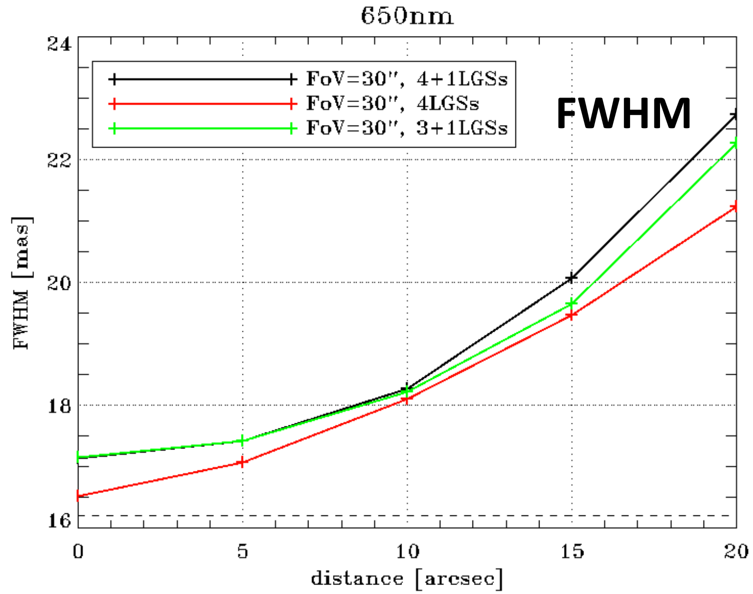


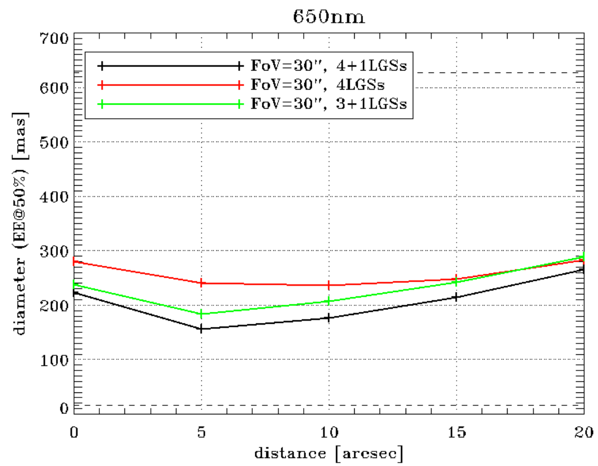
M Le Louarn & T. Fusco simulation results in agreement with Arcetri ones.

(Briefly) Effects of:
(1) off axis NGS, (2) flux of NGS, (3) flux of LGS, (4)3+1 ~ 4+1 (when LGS is concerned)

3+1 ~ 4+1 (when LGS is concerned...)



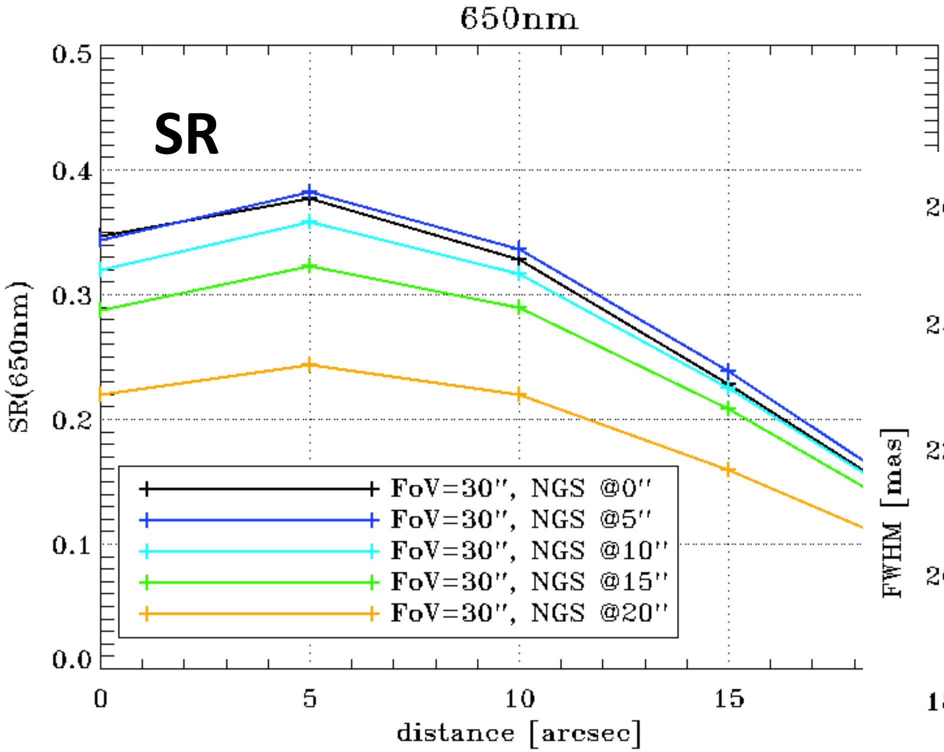


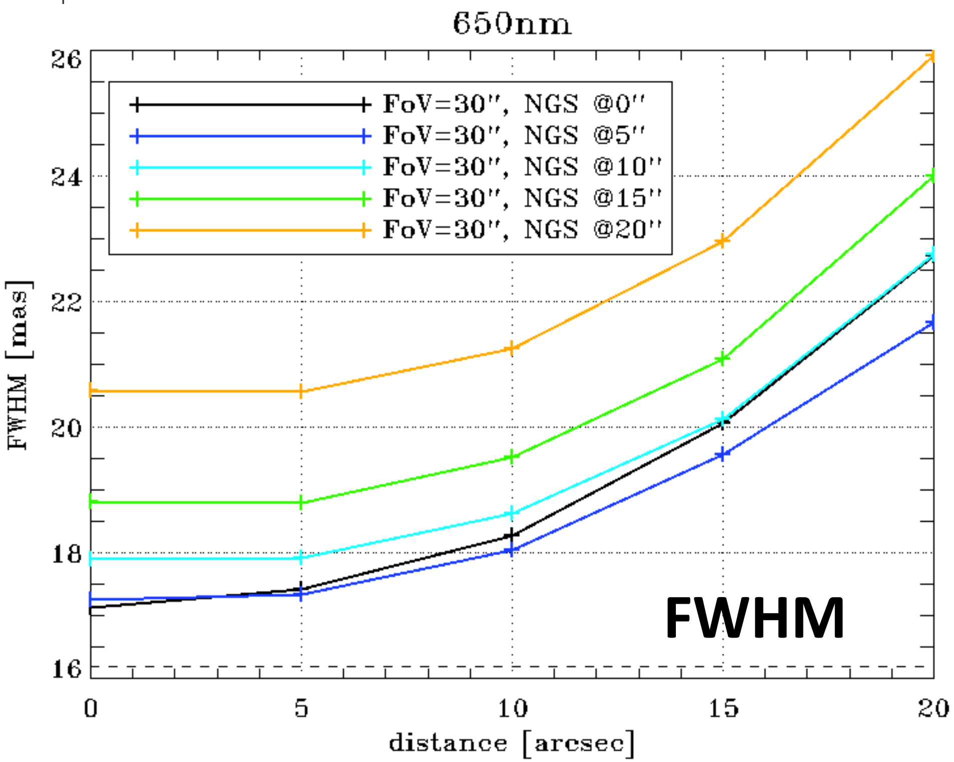


Bright LGS (x10)
Bright NGS (R=12)
On-axis NGS

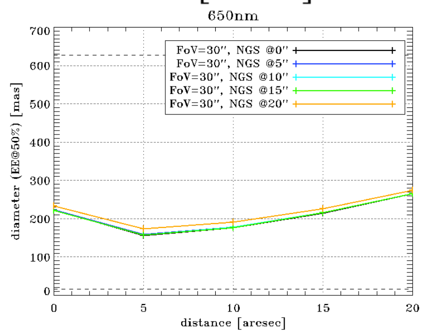
performance of 3+1 LGSs is slightly worse than 4+1 but 3+1 is doable with present 4 LGS of AOF

Bright NGS off axis

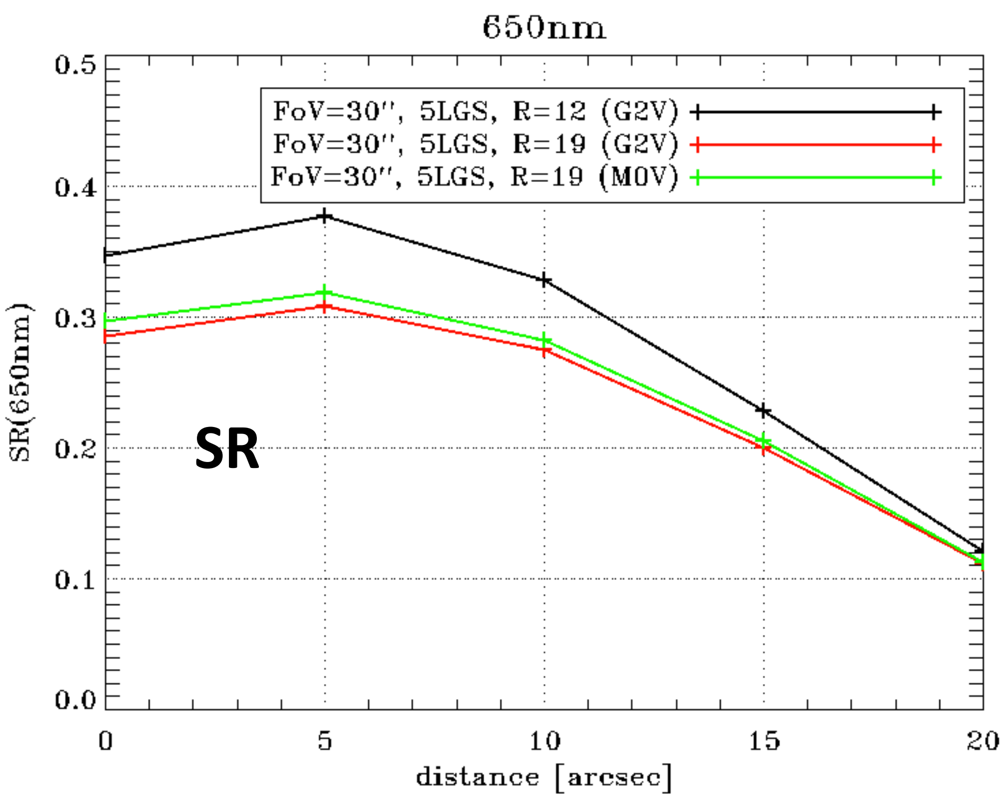


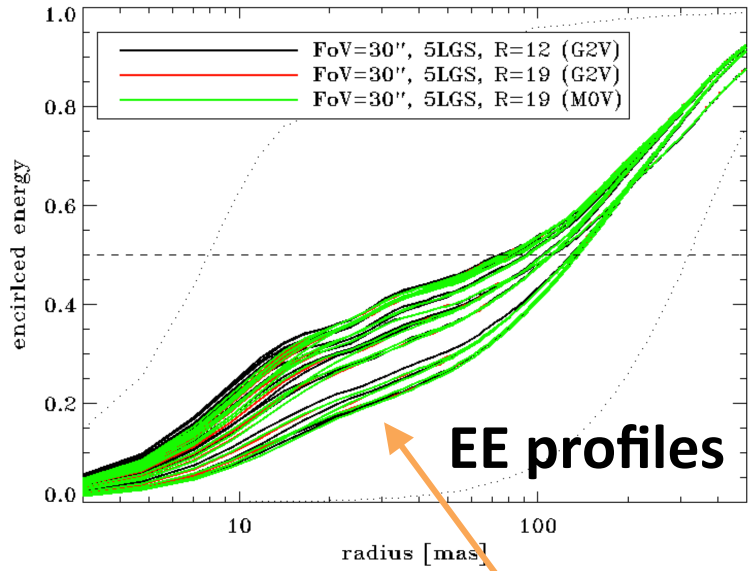


EE 50%

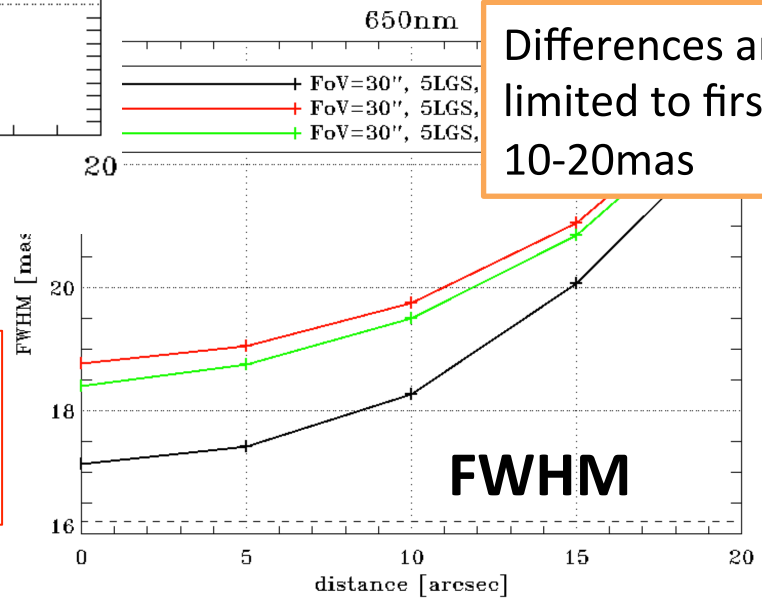


Faint NGS on axis: results @650nm





Differences are limited to first 10-20mas

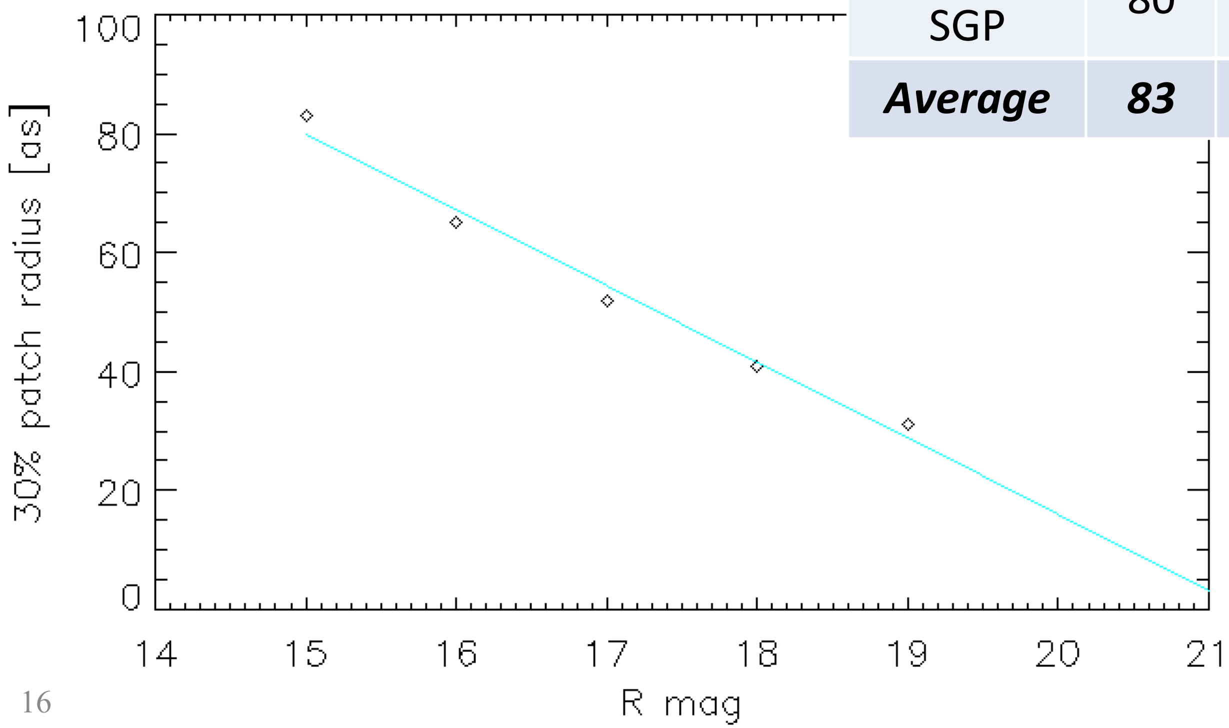


R mag 19th gives slightly reduced SRs over the FoV, H band source should improve results

System SC: tip tilt reference star

$3x10^4$ random directions in 5° radius circle around Galactic Poles. GSC and NOMAD catalogues

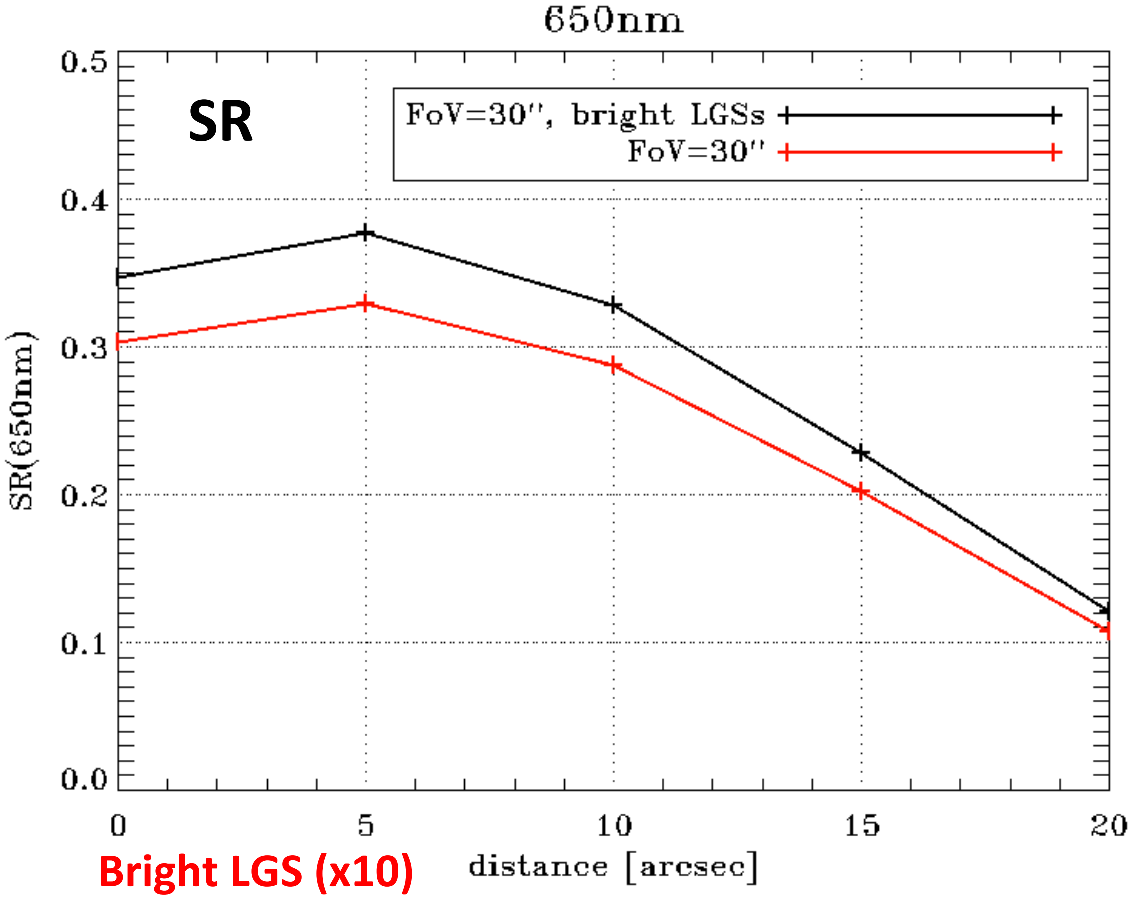
FoV for 30% sky cov.@GP	R<15	R<16	R<17	R<18	R<19
	[as]	[as]	[as]	[as]	[as]
GSC NGP	86	67	53	41	29
NOMAD NGP	81	64	51	40	31
GSC SGP	84	66	51	40	30
NOMAD SGP	80	63	50	41	33
Average	***83***	***65***	***52***	***41***	***31***

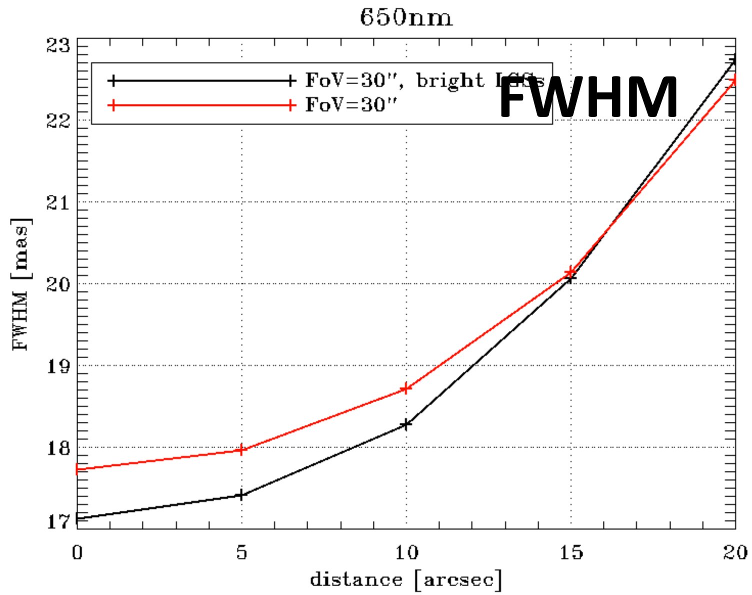


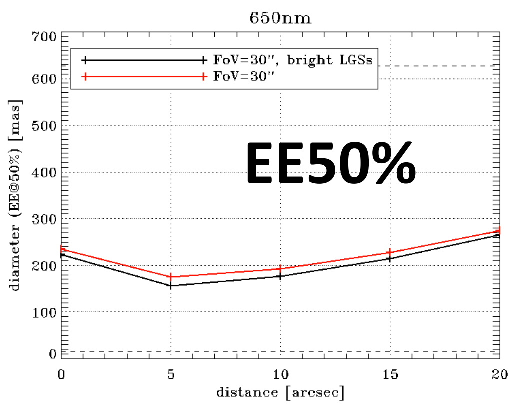
using post processing with fast readout VIS CCDs to reduce needs for NGS star

real LGS fluxes: results @650nm

FWHM







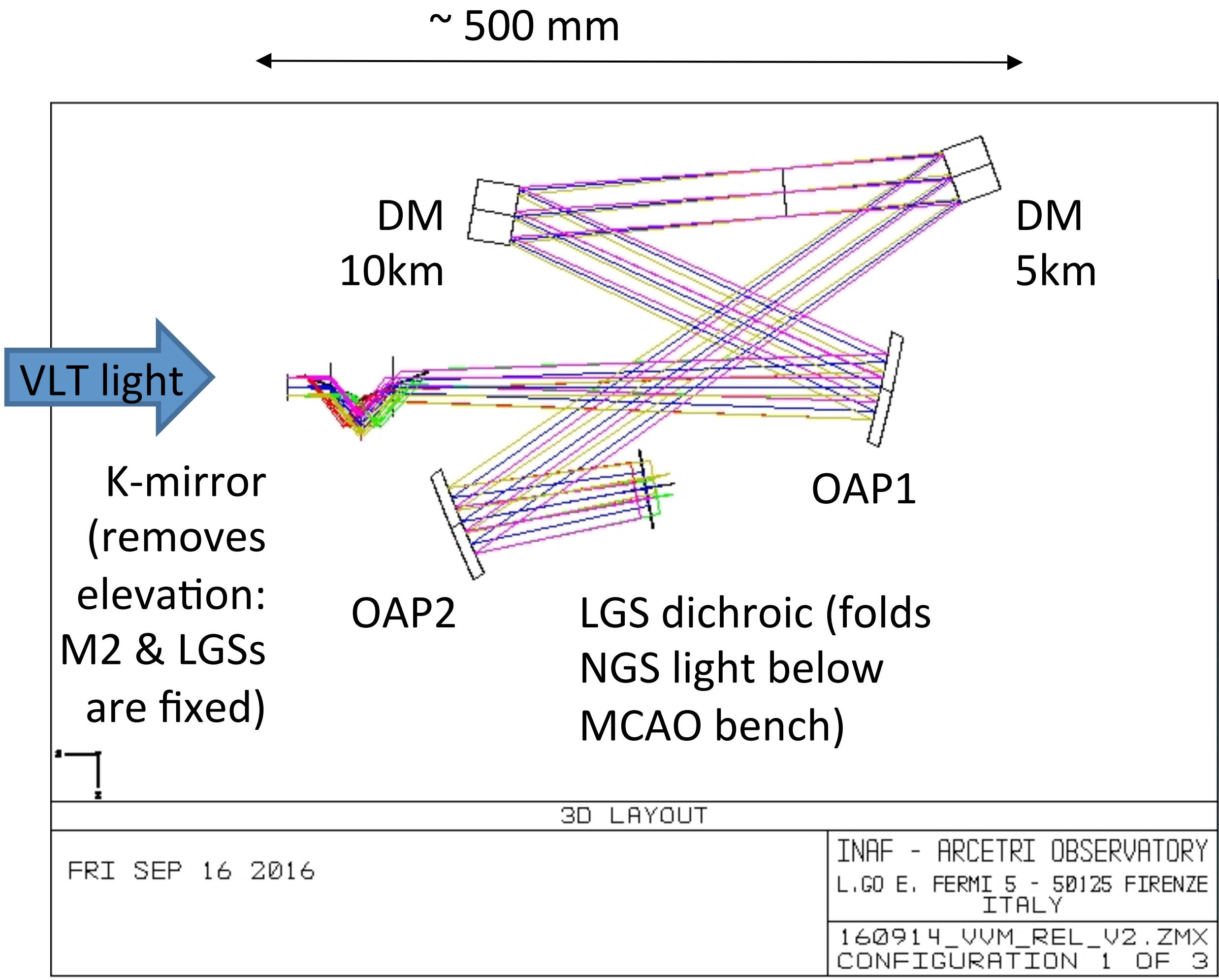
Bright LGS (x10)
VS
True flux LGS
Bright NGS (R=12)
On-axis NGS

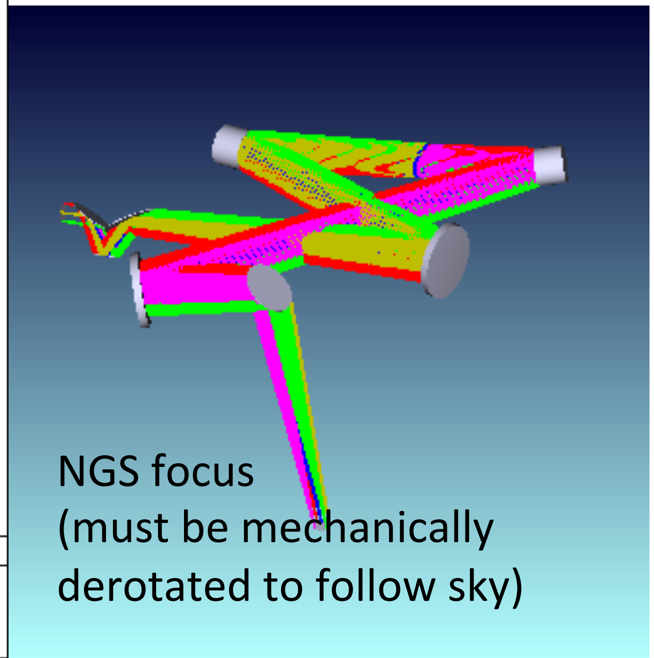
Case with the largest variation found

Opto-mechanics

2post focal DMs
4+1 (3+1), 8+1 LGS
1 or more NGS (VIS or NIR)

MCAO relay arrangement

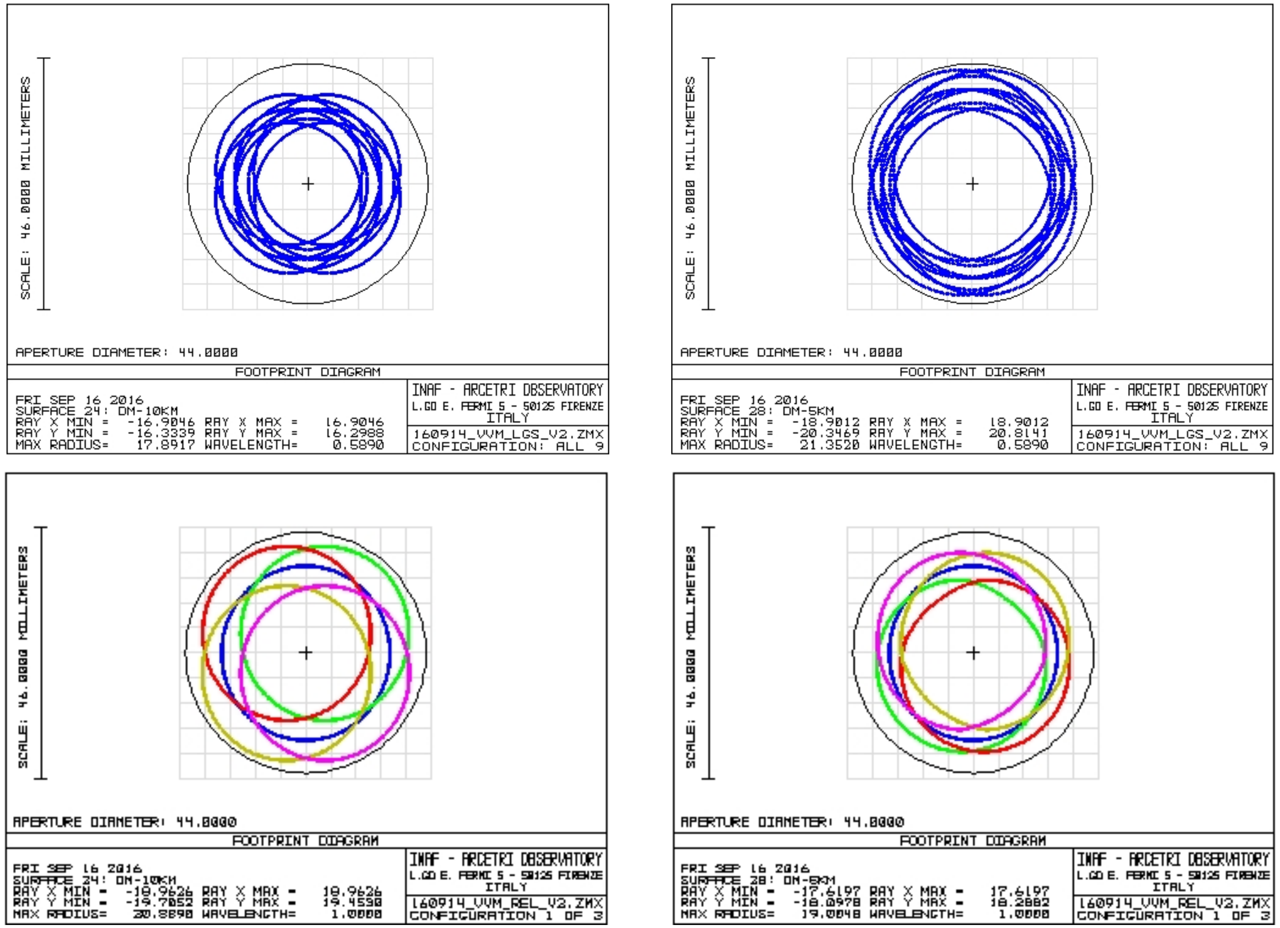




NGS and LGS footprints on DMs

DM @ 10km
Diam max = 44mm

DM @ 5km
Diam. max = 44mm

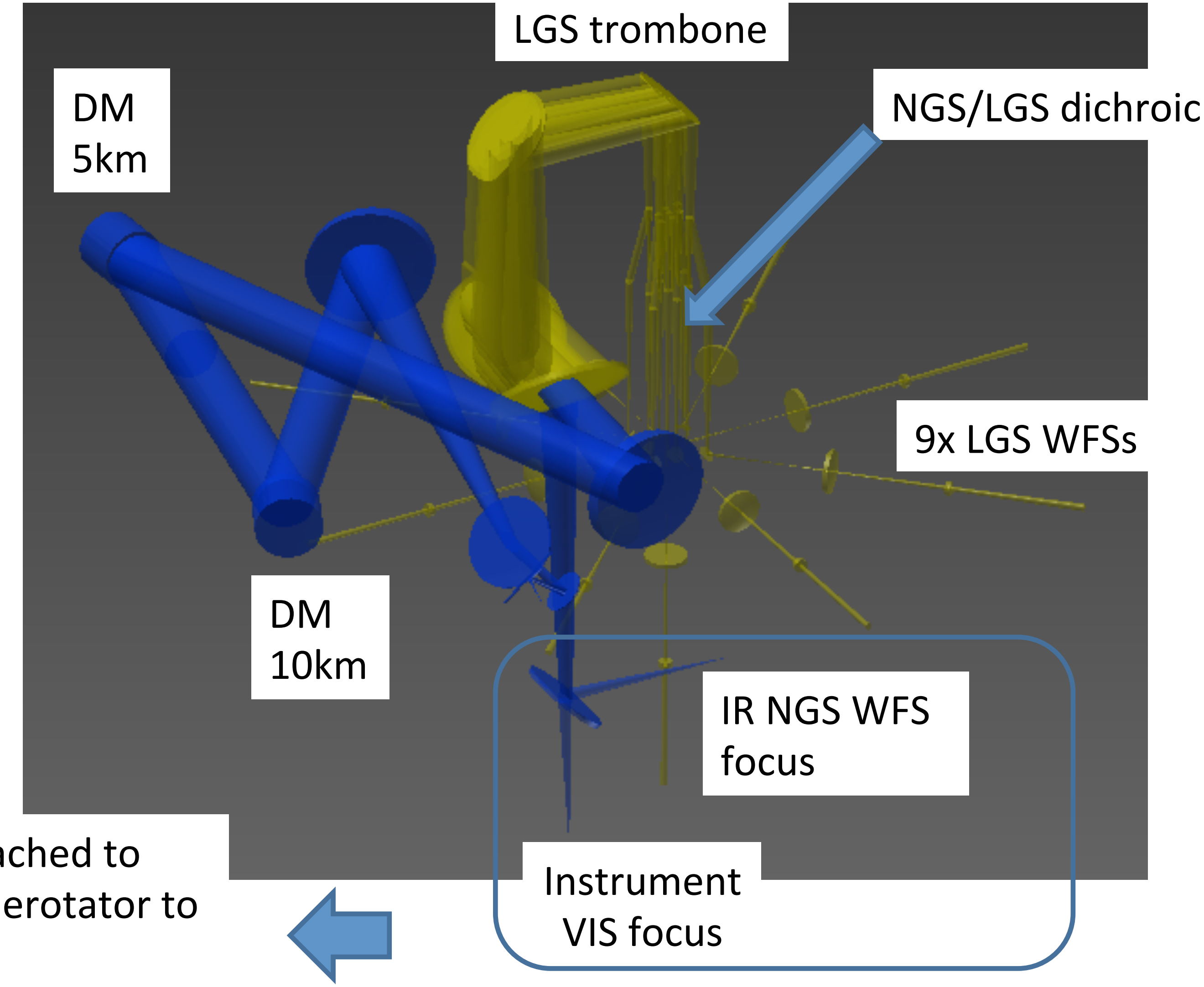


9x LGS footprint:
Max 22.5’’ off-axis

NGS footprint:
Max 22.5’’ off-axis

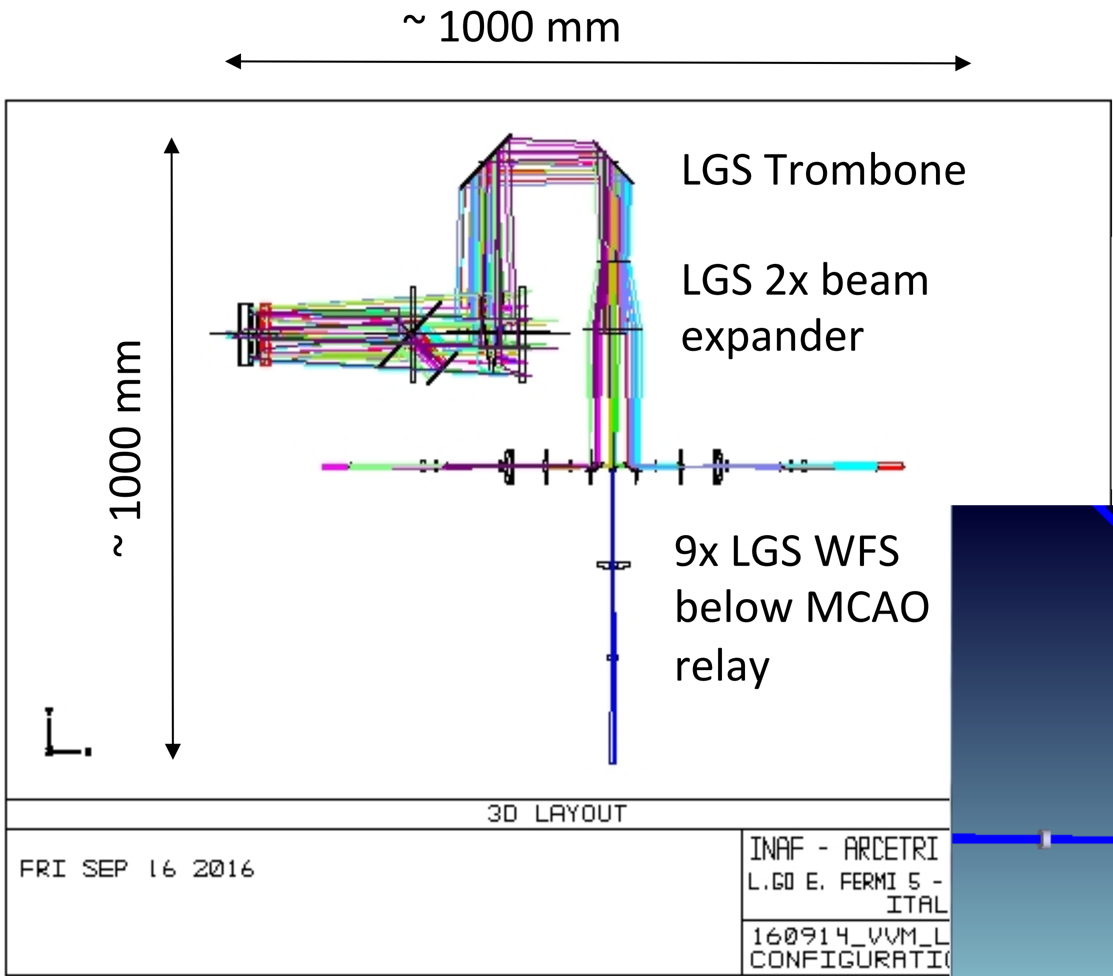
MCAO bench & LGS 9x WFSs arrangement

Blue = NGS + LGS light path
Yellow = LGS light path

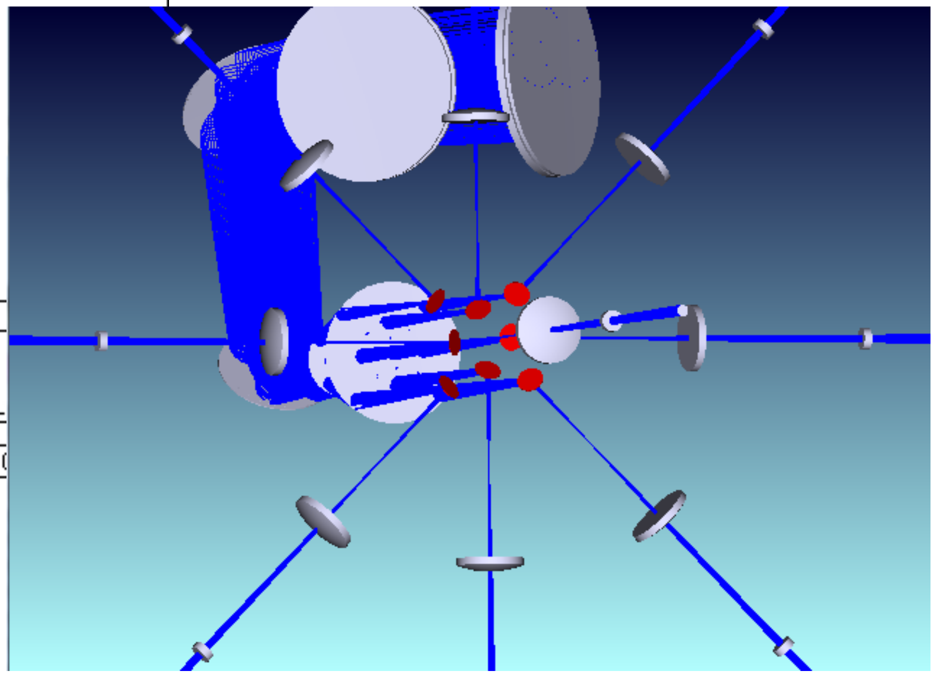


NGS part attached to mechanical derotator to track sky

9x LGS pickoff



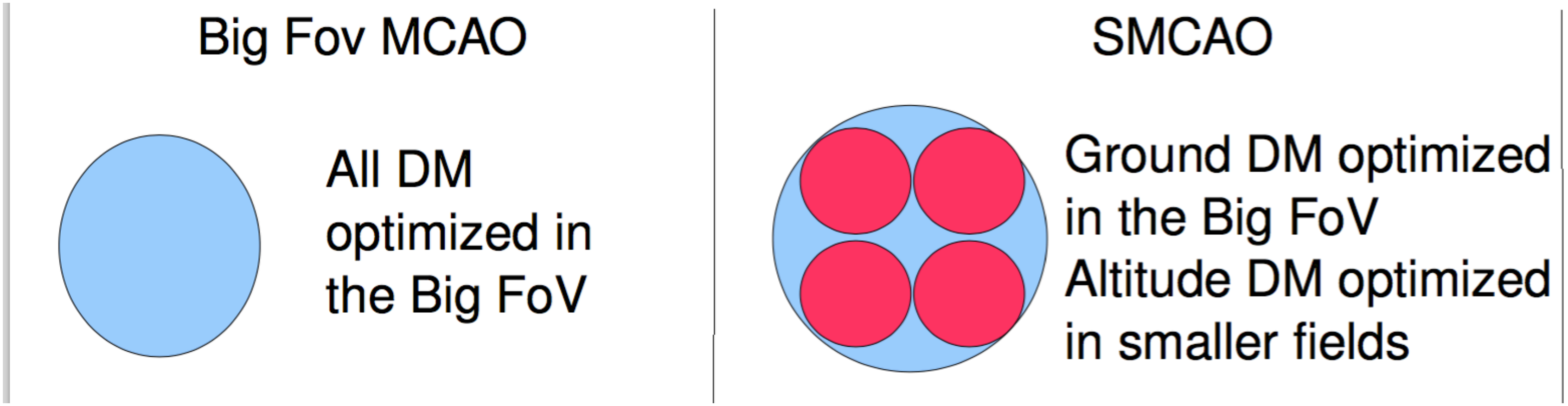
8x pickoff mirrors (in red) for 11.25’’ and 22.5’’ off-axis LGSs (10mm diameter)
On-axis LGS is transmitted



from 45x45 arscec to 90x90

3DMs: DSM + 2 post focal DMs, 5 LGS (4+1)

possibilities for a double size FoV like 90x90 with same performances:
1) option a: MCAO system with a 4-5 post focal DMs and ~10LGS
2) option b: a 2x2 45x45 arcsec a) 2 post focal DMs b) 5WFS/LGS (4+1) tiled, a total of 9LGS
3) option c:….



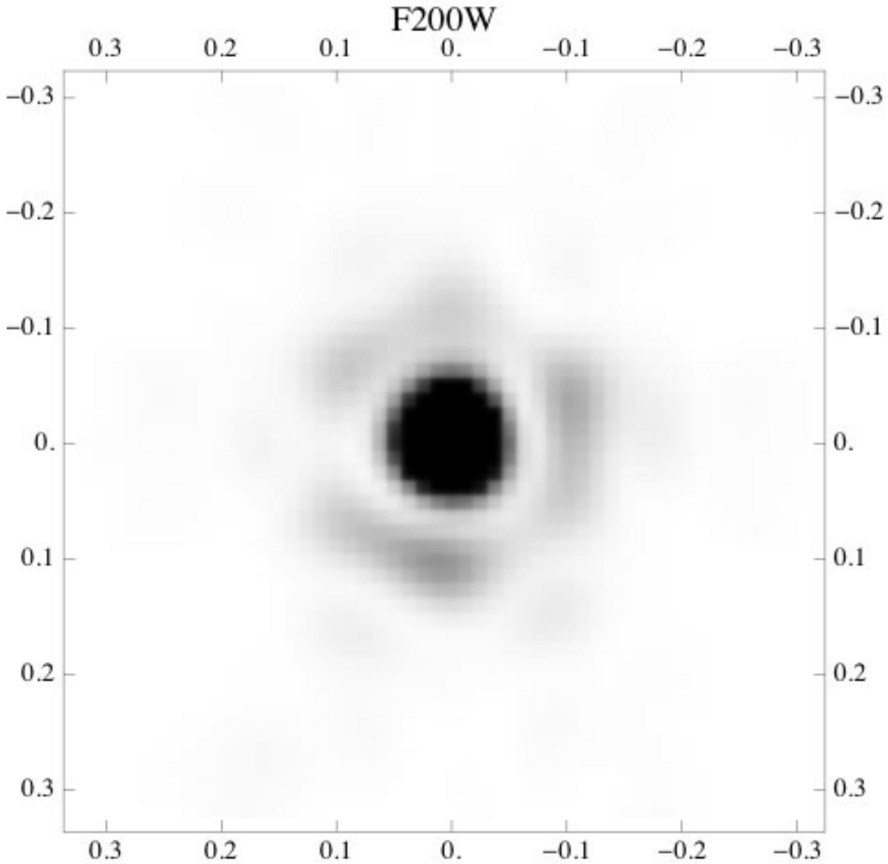
Already discussed in the past by R. Ragazzoni & B. Neichel

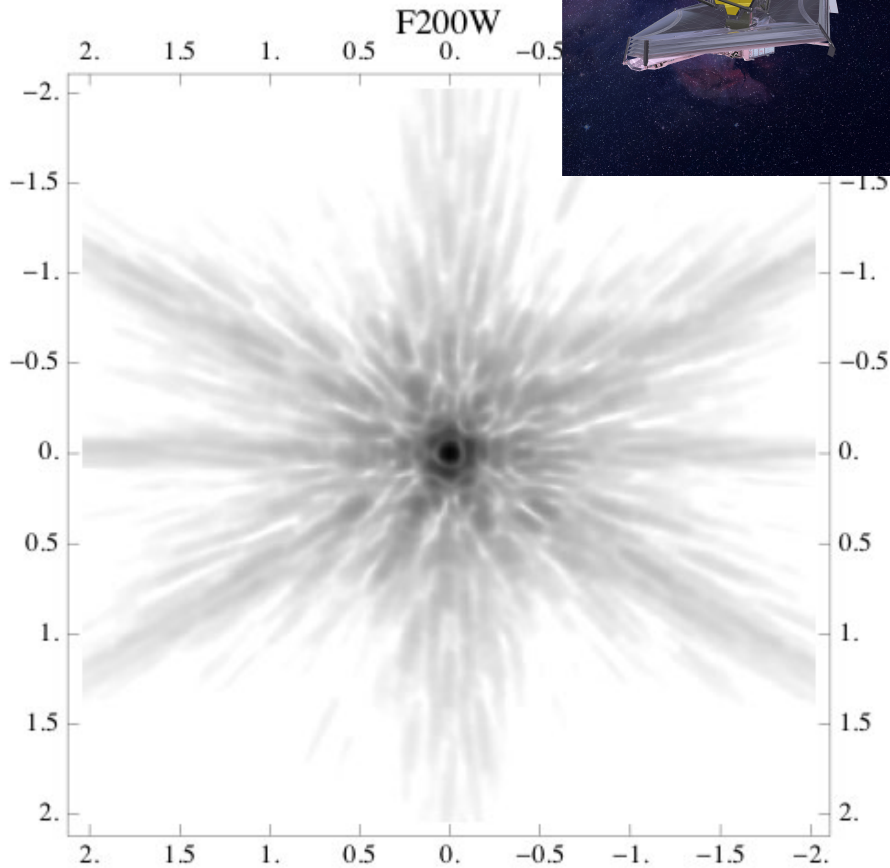
figure from **B. Neichel, LAM**

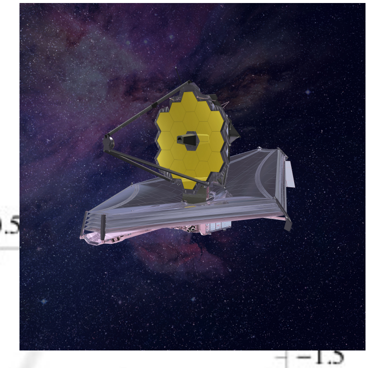
HST and VLT VIS comparison

JWST in VIS

https://jwst.stsci.edu/instrumentation/telescope-and-pointing/image-quality-and-psfs







"JWST will be diffraction limited at 2μm, defined as having a Strehl ratio >0.80. JWST will achieve this image quality using using periodic wave-front sensing and control of the primary mirror. The observatory and pointing-control system are designed to limit image motion to less than 7 milliarcseconds during observations."

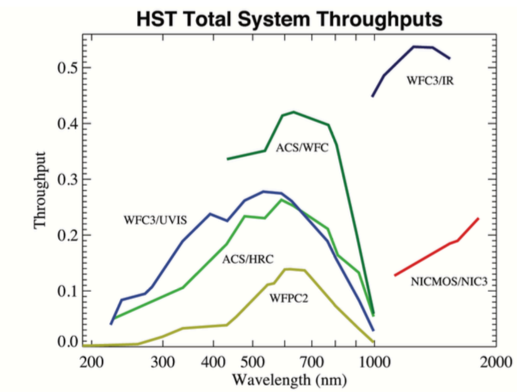
80% SR at 2um => 142nm rms, this gives a 15% SR, assuming no tip tilt residual error.

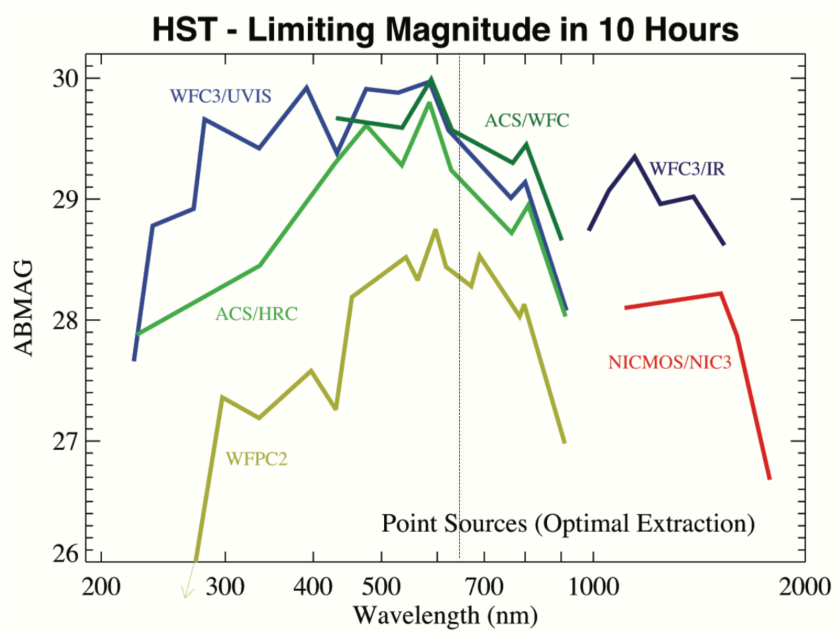
HST & VLT VIS MCAO

Table 4.2: Imaging at Optical Wavelengths (350 nm - 1000 nm).

	WFC3/UVIS	ACS/WFC
FOV area (arcsec^2)	162" x 162" (26,183)	202" x 202" (40,804)
Broad-band throughput[1] @ B,V, I, z	0.23,0.28, 0.16, 0.09	0.34,0.41, 0.36, 0.20
Pixel scale (arcsec)	0.040	0.049
Number of pixels	4k x 4k	4k x 4k
Read noise (e$^-$)	3.1	4
Dark current (e$^-$/pix/hr)	7	22
Number of filters	49	27
Number of full-field filters	32	12
Number of quad filters	17	15
Number of polarizers	0	6

we are referring to ACS/WFC in the following discussion





Limiting magnitudes for point sources in 10 hours.

VLT MCAO VIS vs HST/WFC

Object detected flux for R=25:

- VLT = 20.0ph/s
- HST = 2.0ph/s

Background flux:

- VLT = 846ph/asec^2/s
- HST = 35ph/asec^2/s

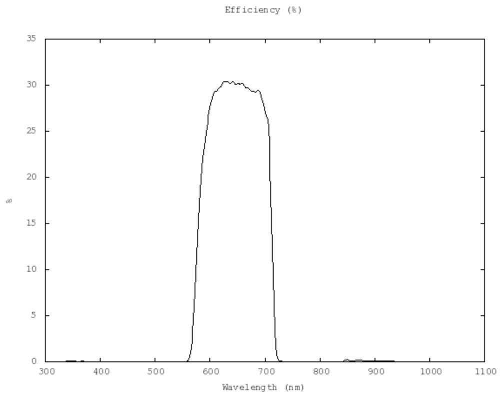
Plate Scale:

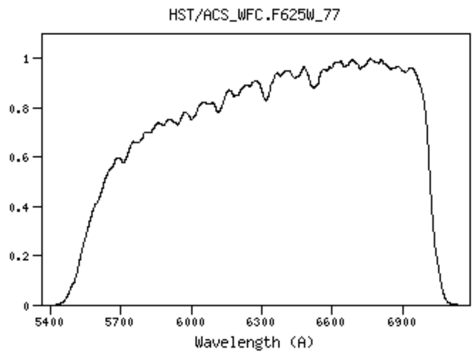
- VLT = 10mas
- HST/ACS-WFC = 50mas

RON:

- VLT = 2e-/pixel
- HST/ACS-WFC = 8e-/pixel

Throughput in simulations
HST ACS-WFC F625W-77~0.4, [548-707]
VLT (VIMOS R filter) ~0.3, [558-730]



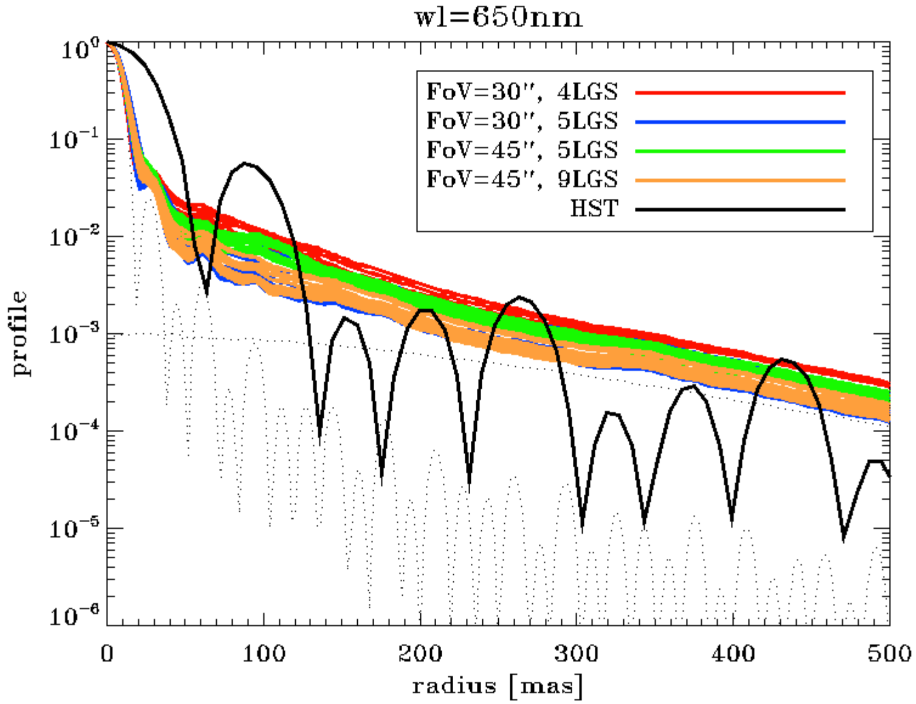


$$SNR = \gamma_{source} \Big/ \sqrt{\gamma_{source} + \gamma_{bckg}\rho^2 + \sigma_{ron}^2 * n_{pix}}$$

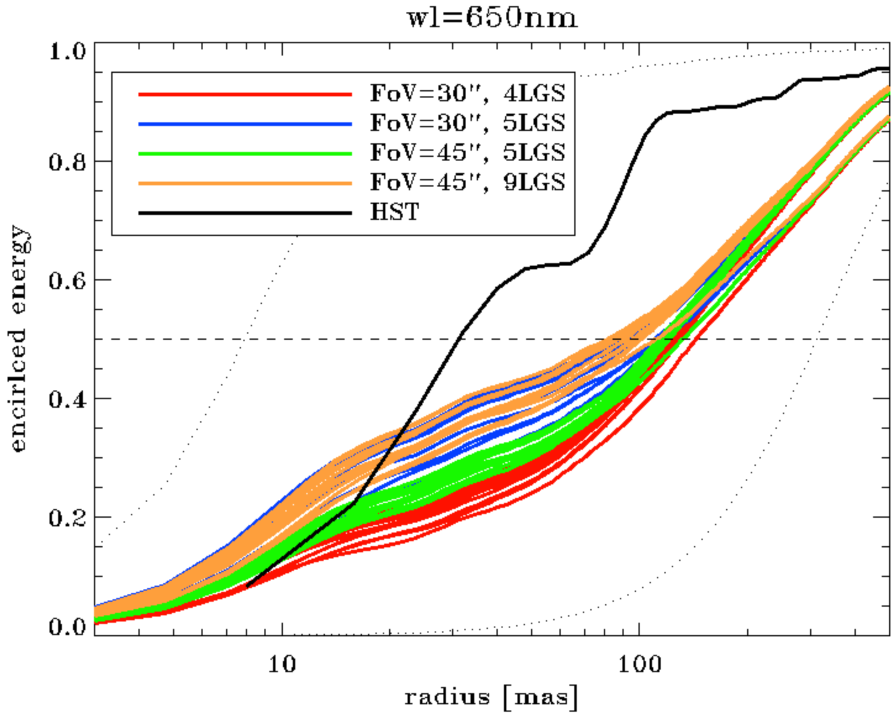
Results @650nm

(1) real LGS flux, (2) NGS 12mag (3) NGS on axis

RAW Contrast



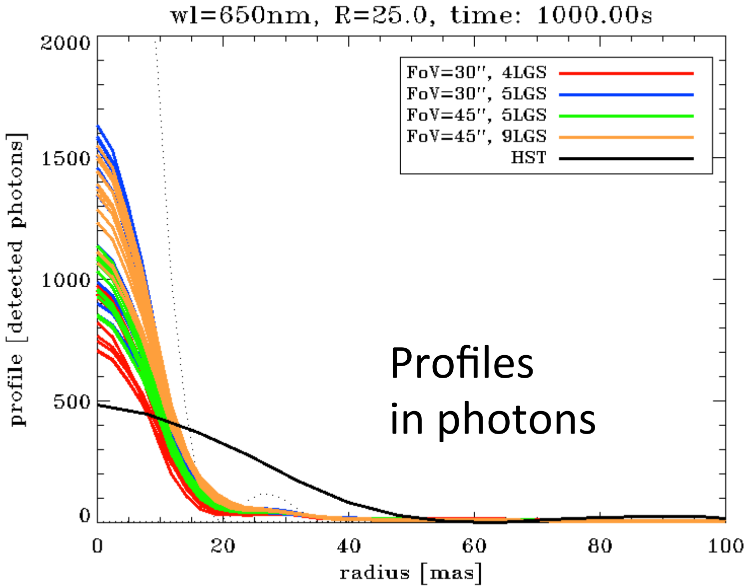
Encircled Energy %

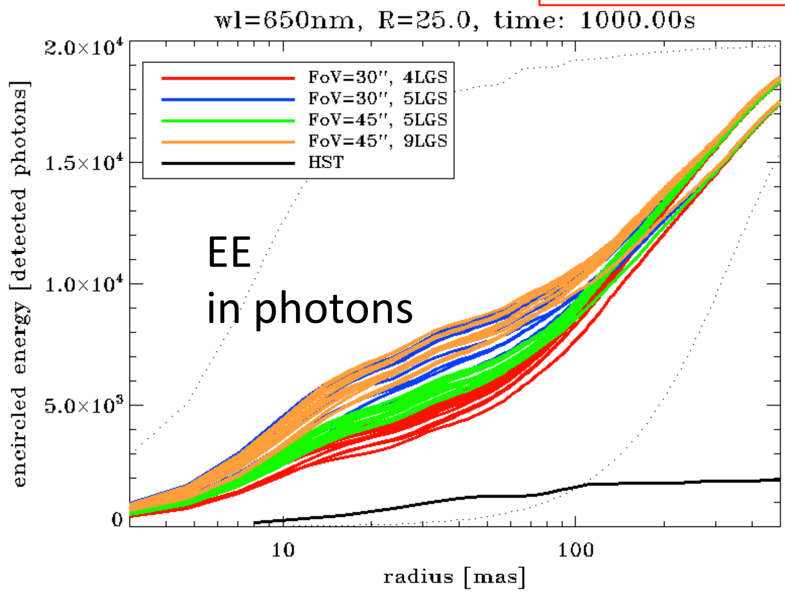


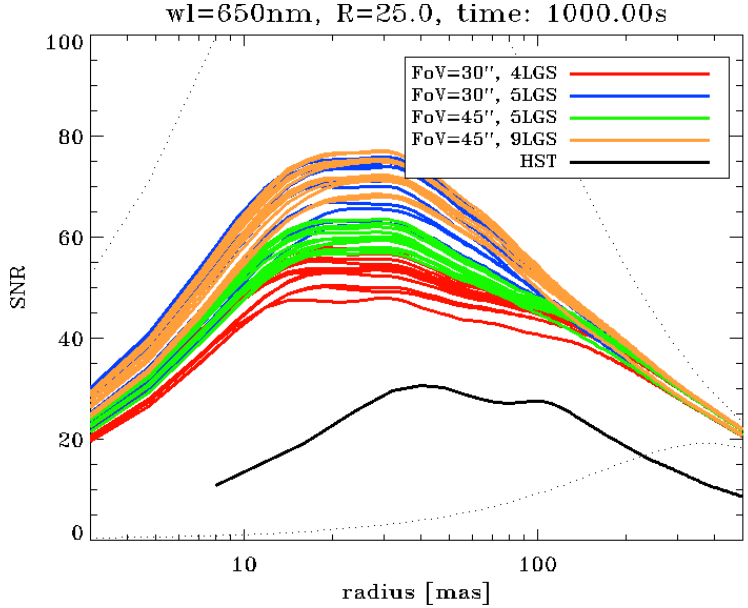
curves of the same color represent profiles in different position of the FoV always given as diameter

Source R=25 @650nm, bright NGS

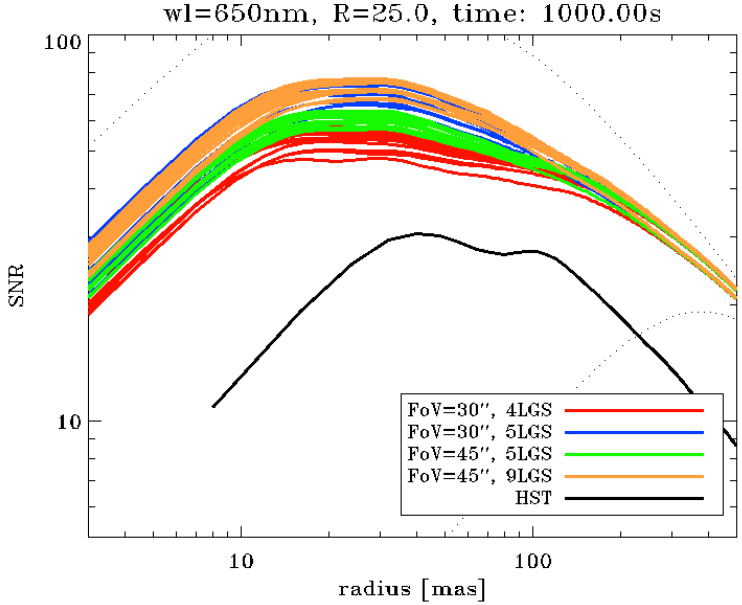
Real LGS flux
Bright NGS (R=12)
On-axis NGS





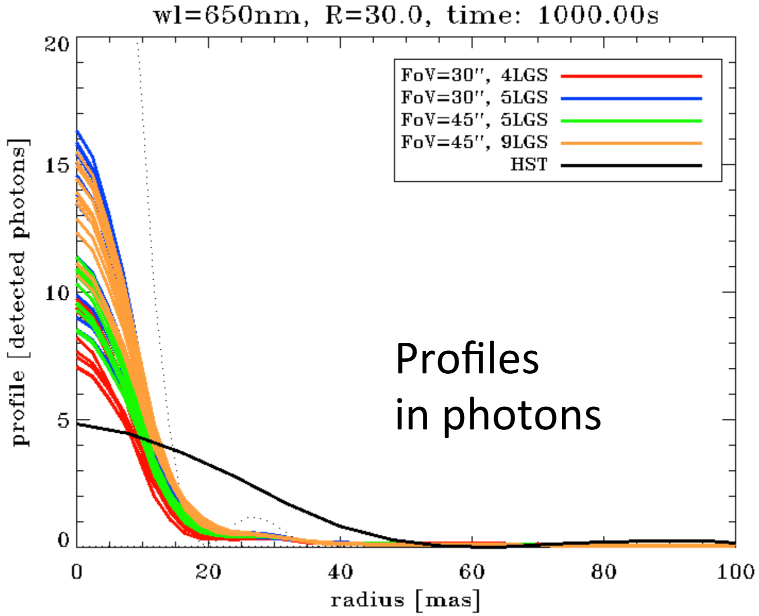


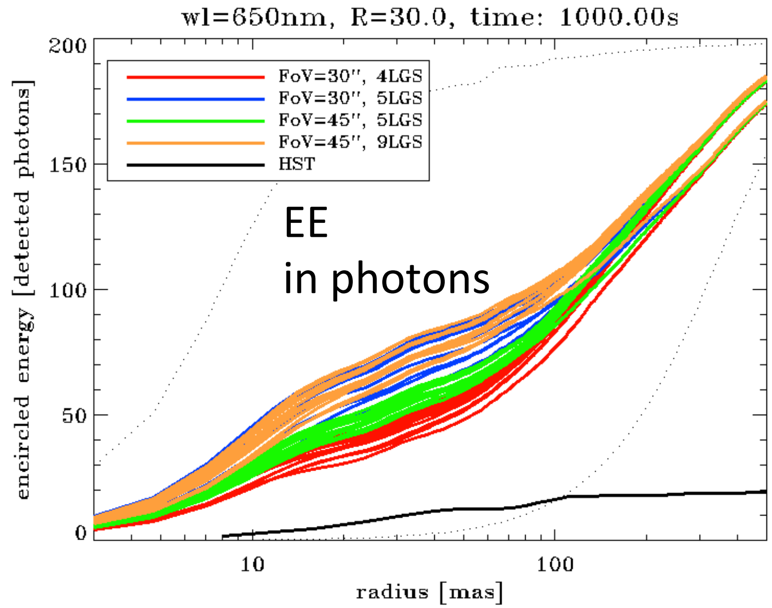
SNR
← y-Linear
→ y-Log

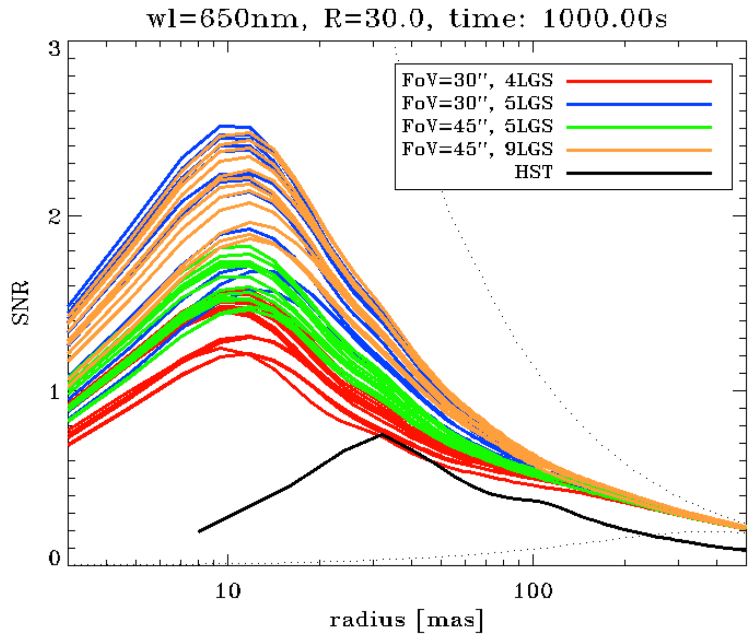


Source R=30 @650nm, bright NGS

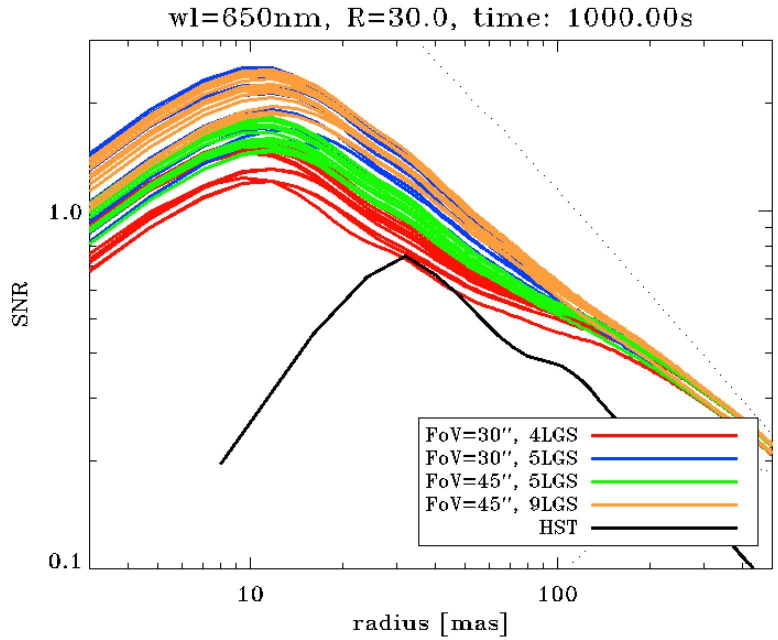
Real LGS flux
Bright NGS (R=12)
On-axis NGS





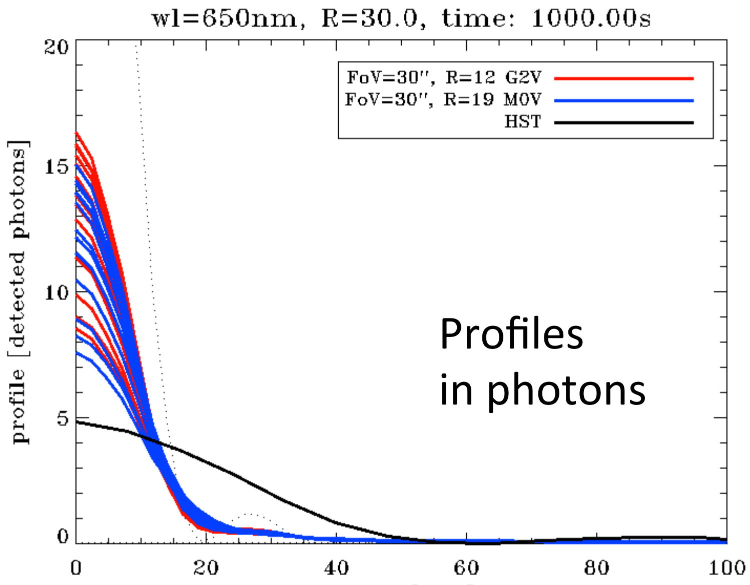


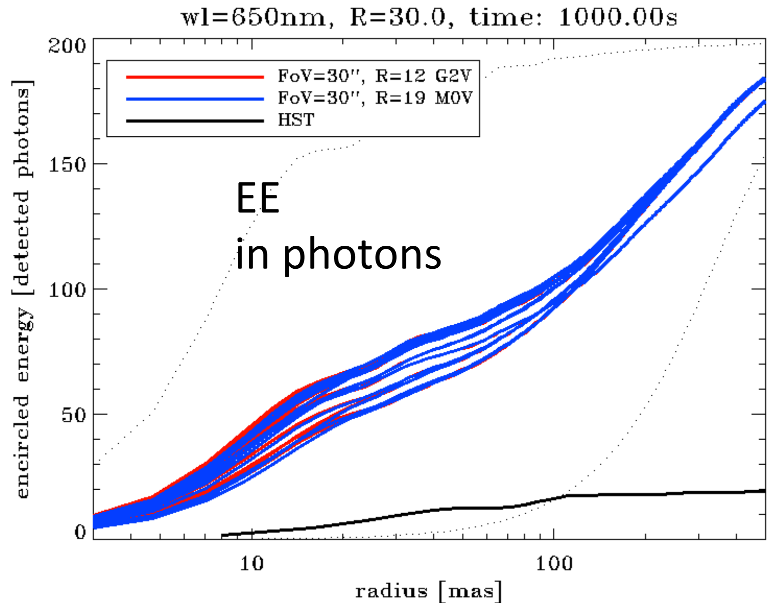
SNR
← y-Linear
→ y-Log

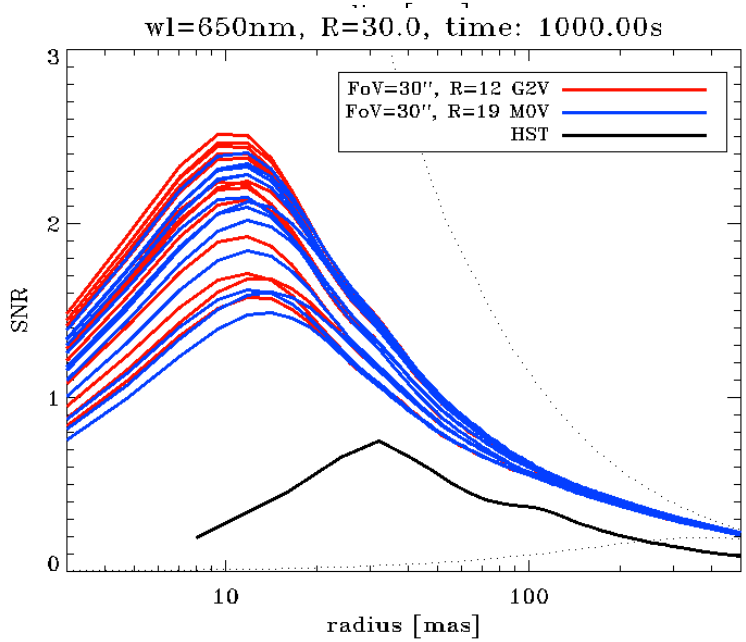


Source R=30 @650nm, faint NGS

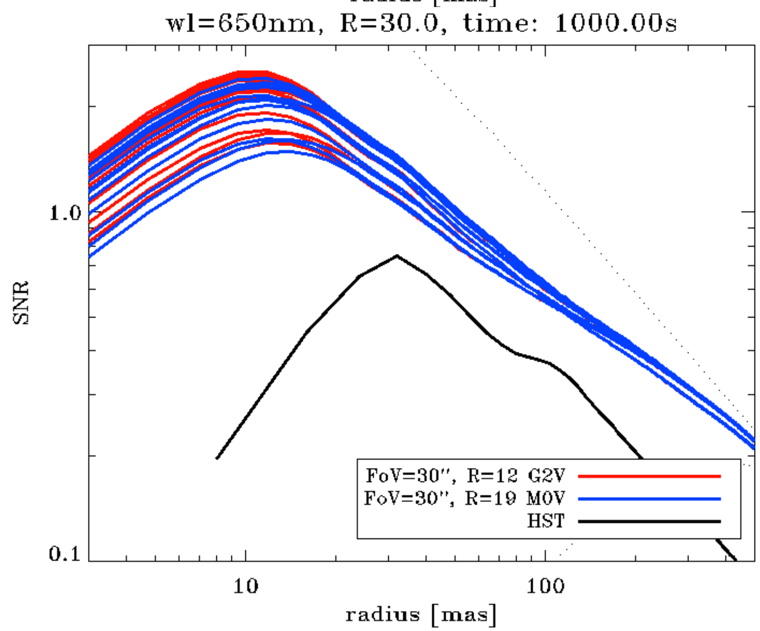
Real LGS flux
Bright and Faint NGS
On-axis NGS







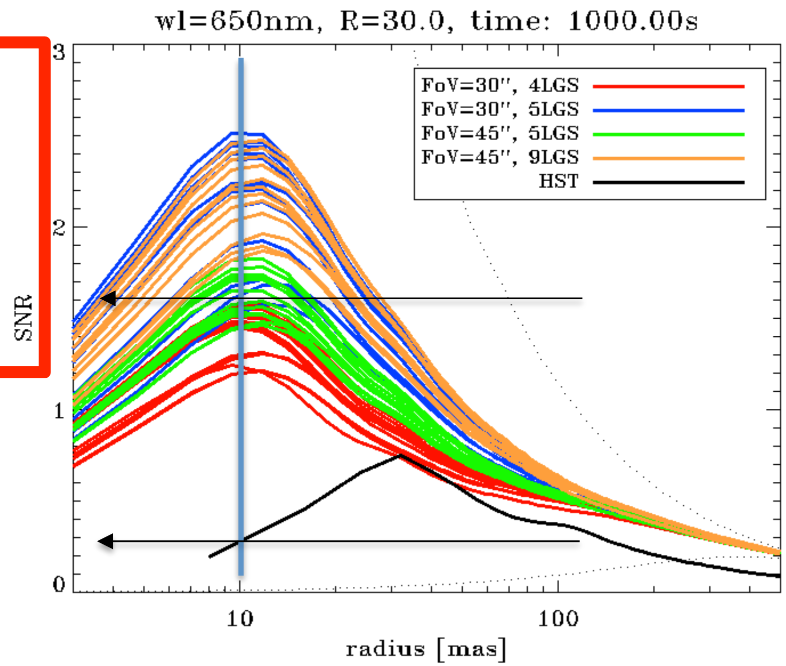
SNR
← y-Linear
→ y-Log



Resuming comparison: dt=1000s

source R mag	SNR HST ACS/WFC		SNR VLT VIS MCAO		SNR ratio	Exp. time
	10mas	50mas	10 mas	50mas		
25	13	30	49	55	3.8-1.8	14.4-3.4
30	0.28	0.56	1.6	0.77	5.7-1.9	32.5-1.7

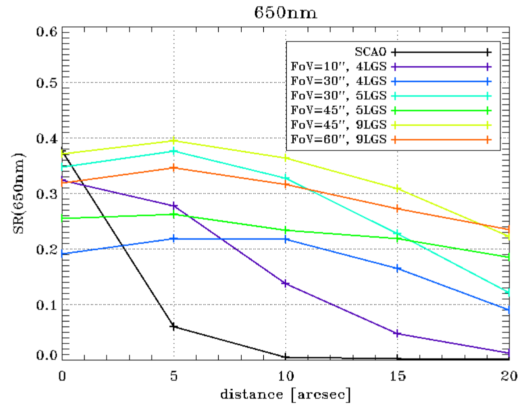
- ➢ 30 mag R star at SNR =5
- ➢ VLT ~ 10^4s (2.7h) over 20mas disk
- ✧ HST ~ 8e4s (22h) over 100mas disk
- ✧ HST ~ 3.2e5s (88h) over 20mas disk



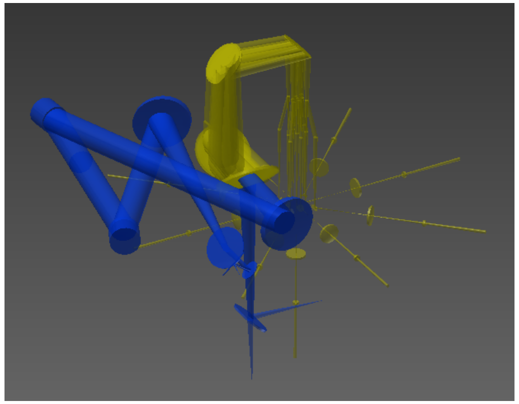
corrected FoV is 30x30 or 45x45 with minor losses in performance (2 post focal DMs, 5 LGS)

Conclusions I

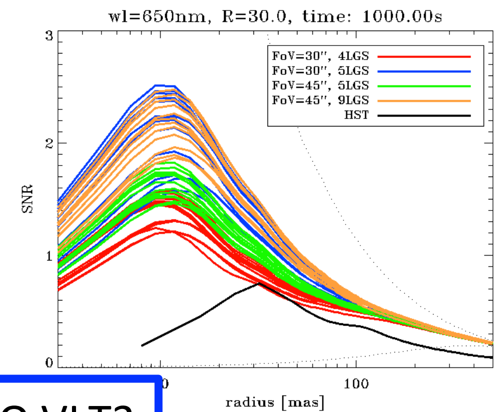
- error budgets and E2E simulations shows that AOF HW ASM + 4LGS plus 2 small (50mm) post focal DMs provides a good MCAO system for VIS (650nm), <SR> 30% for 30” diameter.



- 2 post focal DMs, 4+1 LGS (30” or 45”) and 5 WFSs 40x40 subapertures. A first compact 1m x 1m x 1m arrangement for optomech is outlined.

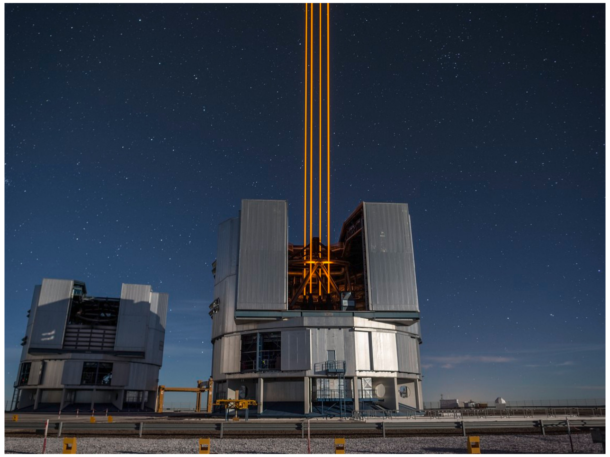


- on a 30mag source (in 1000s) VLT achieves better SNR than HST. Up **to 6 times on 10mas rad** and up to **1.9 on 50mas** rad. VLT detects 30 mag at SNR=5 in **2.7h** against HST **22h**.



2 years post-doc position available at LAM to work on Wide Field AO VLT3

Conclusions II



The VIS MCAO at VLT (does benefit a lot from AOF existing HW):

(1) it provides good performance compared to HST, detects mag 30 in ~ 3h (HST ~20h) at 5x the HST spatial resolution (10mas).
(2) it is designed using commercial DMs and parts, seems of limited complexity and cost.