WAVEFRONT SENSING IN THE VLT/ELT ERA V
AO WORKSHOP WEEK II
13TH - 15TH OCTOBER 2020

MCAO LGS SHS: selection of the number of sub-apertures

Guido Agapito[1*], Lorenzo Busoni[1], Jesse Cranney[2], Zoltan Hubert[3], Sylvain Oberti[4], Enrico Pinna[1], Cedric Plantet[1], Francois Rigaut[2], Daniele Vassallo[5], Valentina Viotto[5]

*guido.agapito@inaf.it

1 : INAF - Astrophysical Observatory of Arcetri
2 : Australian National University
3: Université Grenoble Alpes, CNRS, IPAG
4 : European Southern Observatory
5 : INAF - Astronomical Observatory of Padova

Number of sub-apertures in LGS SHS

We want more Sub-Apertures (SA):

- fitting error
- aliasing error (we cannot use spatial filters)

We want to save on the no SA:

- measurement noise error
- linearity and truncation (number of pixel per SA and their angular size)

fitting and aliasing

$$\sigma^2_{\text{fitting}} = 0.23\,(d/r_0)^{\frac{5}{3}}$$

$$\sigma^2_{\text{aliasing}} = 0.08\,(d/r_0)^{\frac{5}{3}} = 0.33\,\sigma^2_{\text{fitting}}$$

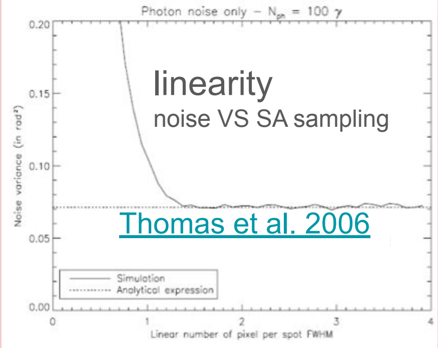
Rigaut et al. 1998

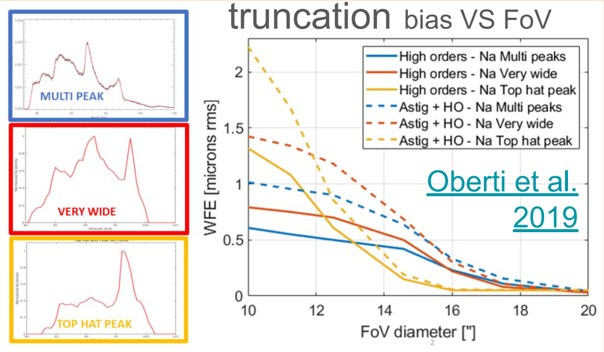
noise

$$\sigma^2_{\phi,N_{ph}} = \frac{\pi^2}{2\ln 2}\frac{1}{N_{ph}}\left(\frac{N_T}{N_{samp}}\right)^2$$

$$\sigma^2_{\phi,N_r} = \frac{\pi^2}{3}\frac{N_r^2}{N_{ph}^2}\frac{N_s^4}{N_{samp}^2}$$

Rousset 1999





So do we need simply to balance these errors?

Not only, other error terms (tomographic, generalized fitting, temporal, ...) could have an important role. Moreover we should consider a few additional points.

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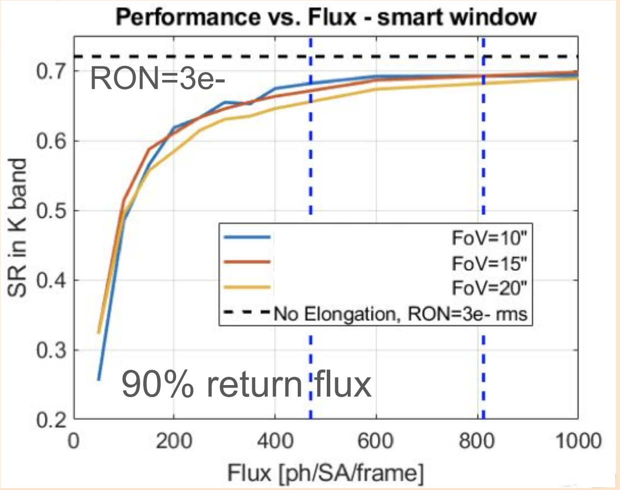
LGS spot truncation

Truncation can be mitigated, examples:

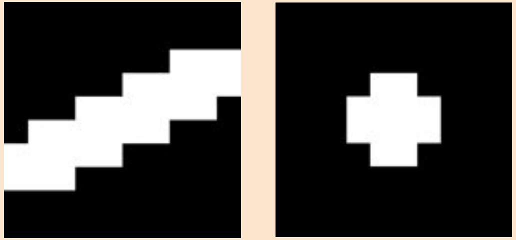
- priors and noise correlation Tallon et al. 2008
- centroiding algorithms Lardiere et al. 2010
- missing tails Clare et al. 2020



MAORY baseline is to use a combination of smart windowed CoG and priors and noise correlation from Tallon et al. 2008 to work with FoV <20arcsec (Oberti et al. 2019).

Smart windowed CoG

elongated spots — not elongated spots

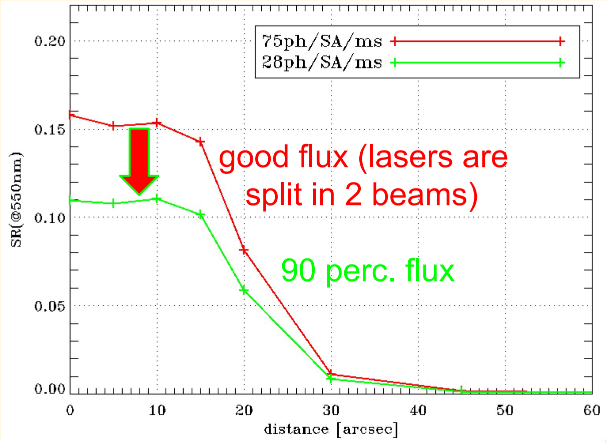


Flux and Noise

Some options can mitigate limited flux issue, examples:

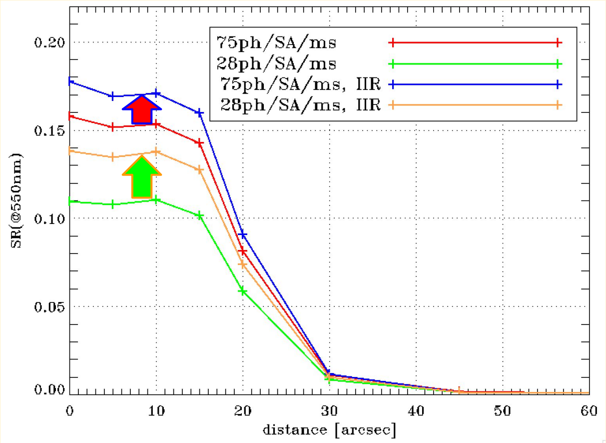
- better CoG algorithms (ex: Gilles et al. 2006).
- high order optimized temporal filters (ex: Agapito et al. 2012, SPIE and Opt. Exp.).
- increasing int. time and using predictive control (ex: Cranney et al. 2019).

V band SR



Performance in **MAVIS** simulation going from a good flux condition to the 90 percentile one degrades significantly, but can be improved using "well tuned" IIR filters instead of integrators.

upgrade temporal filters



Optics for 39m telescope - a short blanket on a cold night

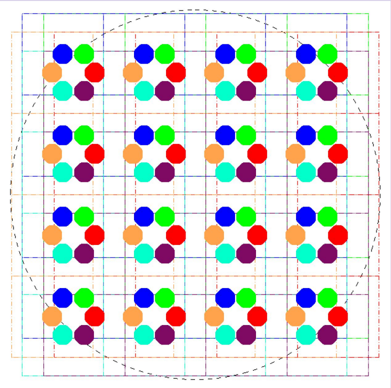
- 8m telescopes:
  - no major issue: a 40×40 SA with 6” FoV on 6×24μm pixels (good for **MAVIS**) requires a Lenslet Array (LA) with F# 25 (that can be easily manufactured) and a 240pixel detector.
- 39 telescopes:
  - A 78×78 SA with 20” FoV on 20×9μm pixels (good for **MAORY**) requires a LA with F# 3.7 (this is out of the standard ranges, f#5-100) and a ~1600pixel detector.
  - A 160×160SA with 20” FoV on 20×4.5μm pixels requires a LA with F# 3.7 (with a “miniaturized” f=340μm and d=90μm), a 3200pixel detector (15mm) and spots close to diffraction limits (3.7*589nm=2.18μm=~0.5pixel).

Super-resolution

- We have multiple WFSs and multiple line of sights.
- We can use our multiple WFSs to get an higher sampling:
  a. this is present on a certain altitude ranges thanks to the different line of sight.
  b. can be tuned by introducing shifts and rotations between WFSs.

a. MAORY like conf. at M4 altitude

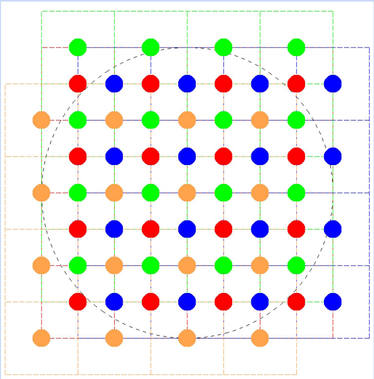
with 6LGSs, 45arcsec angle give 0.13m shift that is 26% of a 0.5m SA



“free” increase of resolution on M4 (600m)

b. 4 LGSs@0m, with shifts [SA]:

● [0.0, 0.0] ● [0.0, 0.5]
● [0.5, 0.0] ● [-0.5,-0.5]



it doubles resolution in both x and y direction

Simulations

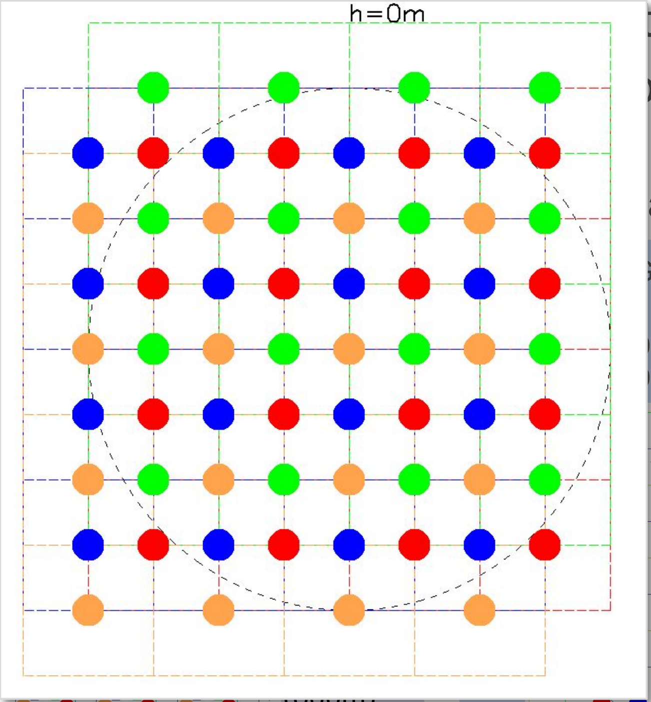
Test cases: 8m telescope nd 6LGSs (shifts and rotations scheme chosen is not optimal, just a first attempt):

8x8SA	177nm (HO modes)
8x8SA S.	132nm (HO modes)
8x8SA R.	133nm (HO modes)
8x8SA R.&S.	135nm (HO modes)
12x12SA	135nm (HO modes)

8x8SA can give better performance than 12x12SA case.

Super-resolution

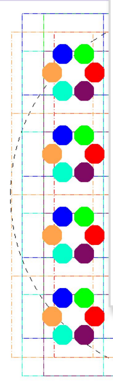
- We … tiple line of sights.
- We … get an higher sampling:
  a. … range … .
  b. … and ro…



...but over all altitudes sampling changes a lot!

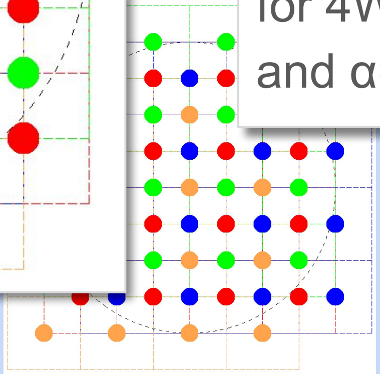
example: from 0 to 10000m for 4WFSs with 0.5m SA and α=45arcsec

a. MAO…
with 6LGSs…
that is 26%…



…(600m)

…GSs@0m
….0]
….0]



resolution in both x and y direction

…scope nd 6LGSs
…scheme chosen
…first attempt):

		(HO modes)
…	…nm	(HO modes)
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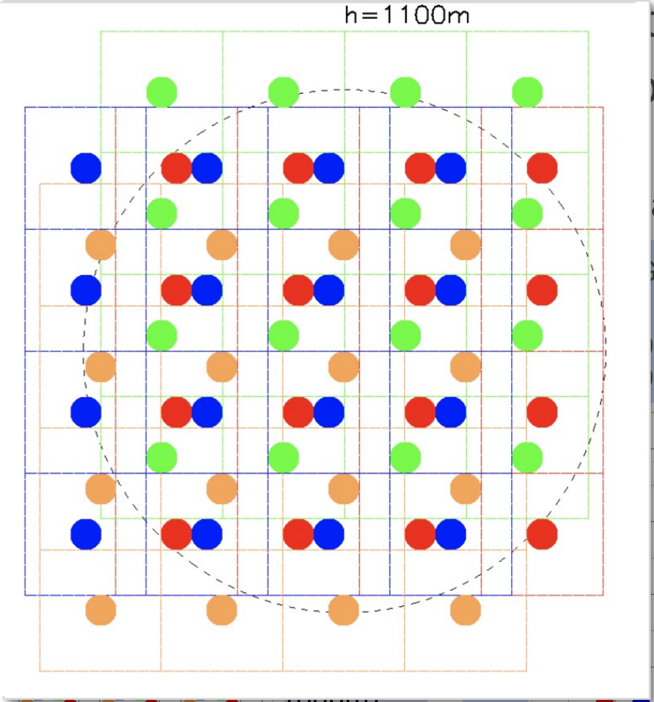

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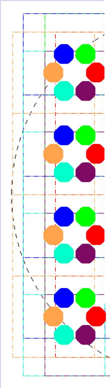
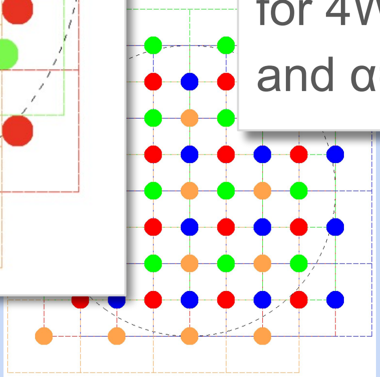


(600m)

…GSs@0m
….0]
….0]



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Conclusion

- Several limiting factors work against increasing the no SA:
    - limited number of pixel of high QE, low RON and fast RO cameras.
    - limited (even if high) flux from LGS.
    - requirements on large and well sampled FoV.
    - requirements of fast lenslet arrays (39m case).
- but:
    - tomographic and generalized fitting errors can dominate the error budget.
    - we can take advantage of:
        - “smart” control to reduce truncation.
        - “smart” temporal control to reduce noise propagation.
        - the multiple WFSs to increase the actual resolution of the MCAO system.