Fixed vs. variable LGS asterism cost/benefit study for NGAO
KAON # 427

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November 23, 2006

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1 Introduction:

At the NGAO point design retreat the NGAO Core Team saw the need for both narrow field and wide field asterism configurations. The natural question was raised as to whether the point design must have set of 3 fixed asterisms or should a continuously variable asterism.

1.1 WBS definition (from dictionary)

3.1.2.3.4 Variable versus Fixed LGS Asterism Geometry
Consider the cost/benefit of continually varying the LGS asterism radius vs. a fixed number of radii (e.g. 5", 25", 50"). Complete when LGS asterism requirements have been documented.

1.2 Assumptions

All plots and charts shown on the report conform to the science cases described in the NGAO proposal. All assumptions like turbulence charecteristics, WFS's noise, laser power/return etc. were based on the proposal as well. For this study we assume 5 LGS's in a quincunx formation with 3 NGS's in the field of regard. Two of the three NGS's are tip-tilt (TT) stars and one is a tip-tilt focus astigmatism (TTFA) star. Any other specific assumption for a subsection is stated therein.

1.3 Approach

To perform cost/benefit study, WFE is taken as the merit for benefit (lower the better) and a differential ballpark cost estimated between the two different configurations.

2 Observing Scenarios

2.1 Narrow fields

The premise of the study is based on the idea that one can obtain better correction of the TT, TTFA stars by obtaining a better tomographic estimate and optimize the on-axis Strehl for a given sky coverage. The science object is assumed to be on-axis (close to the central LGS). The TT and TTFA stars are assumed to be MOAO corrected.

2.2 Evaluation procedure

For a science target in the center of the field, the overall system WFE is minimized for a given sky coverage. The TT/TTFA star location determines the LGS asterism diameter. The WFE vs. (off-axis) TT star magnitude is plotted for the case where the TT star is corrected using MOAO.

Between the 3 sky coverage numbers most of the science observing scenario parameter space is covered.

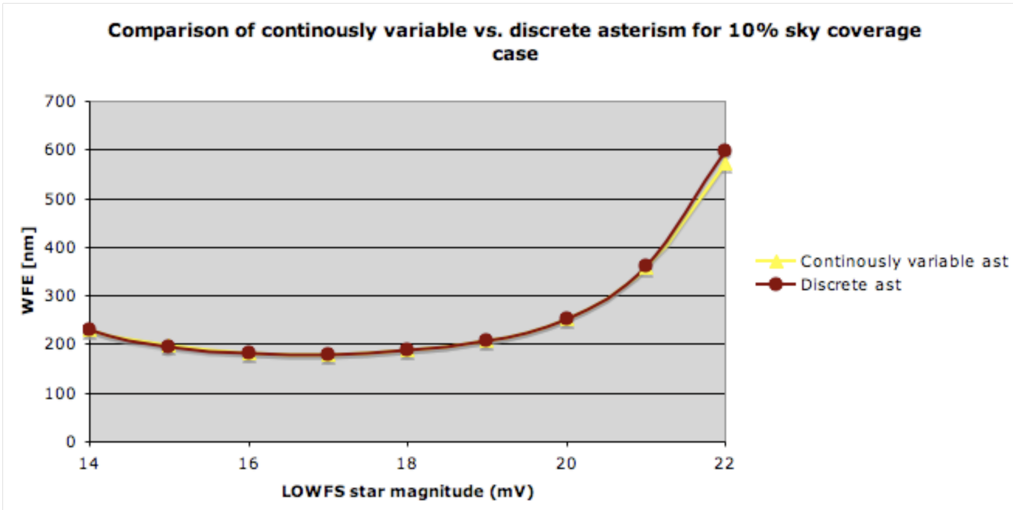

Figure 1: Wavefront error vs. TT star magnitude plot for 10% sky coverage case

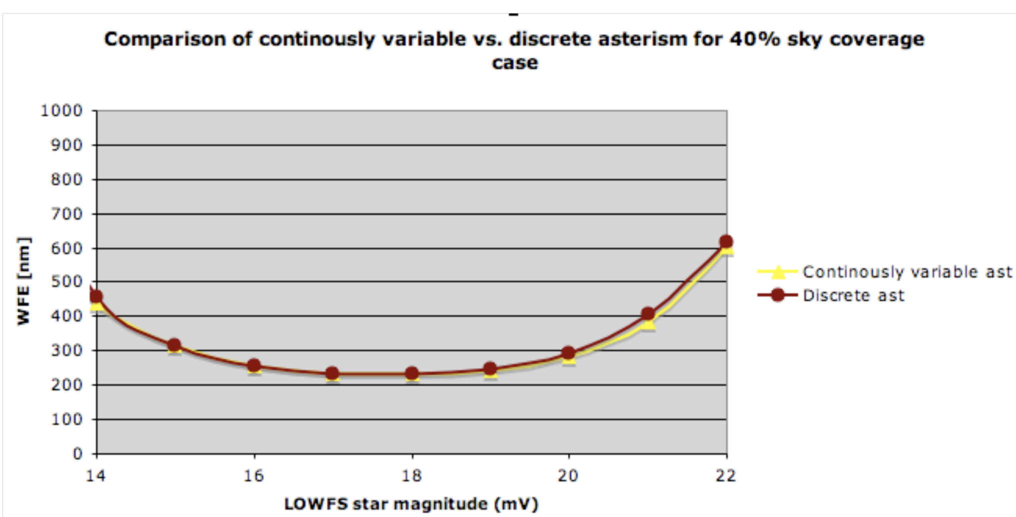

Figure 2: Wavefront error vs. TT star magnitude plot for 40% sky coverage case

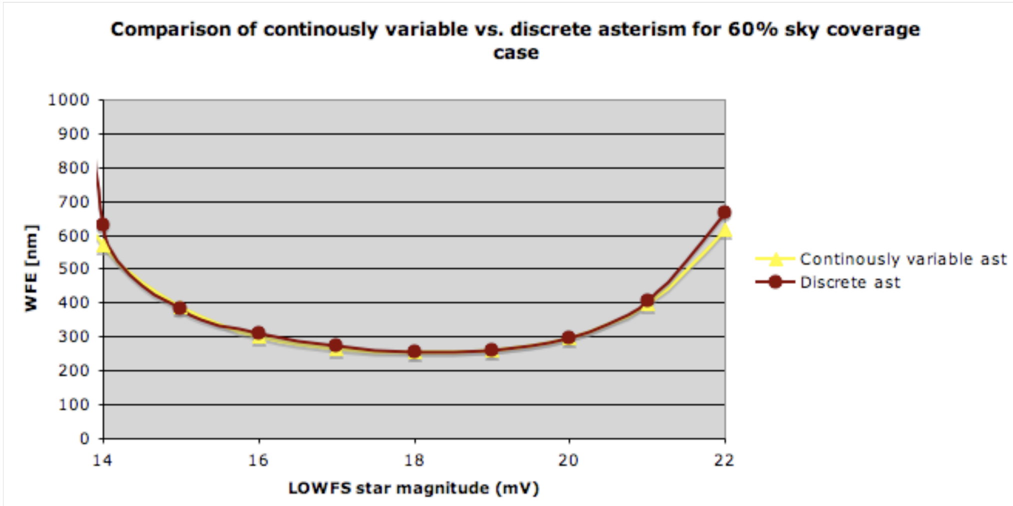

Figure 3: Wavefront error vs. TT star magnitude plot for 60% sky coverage case

2.3 Wide field MOAO case

The premise behind the idea of having a variable asterism in case of MOAO corrected TT/TTFA stars and MOAO science targets is to have an optimal asterism size to maximize the science object Strehl. The science target position was varied between 0-150 arcsec from the quincunx center and the nearest possible discrete asterism was chosen and in case of the variable asterism the asterism was opened up. A constant correction was assumed within asterism and a isoplanatic fallout outside of the LGS quincunx.

3 Implications

3.1 Opto-mechanical

1. About 40 mm of travel is required to move from a 50 arcsec at the focal plane.
2. For a set of 3 discrete asterisms one may be able to get away with a stage that is repeatable but not very accurate. The position may be externally calibrated once in a while.
3. For the continuously variable asterism case we need accurate stages.
4. Most importantly, the minimum error allocated for LGS asterism deformation in the NGAO proposal is 5 nm. And this corresponds to 0.1 arcsec change in radius of the entire asterism as shown by Figure 7! The HO WFS positioner need only position to this accuracy.
5. If we have a Uplink Tip Tilt (UTT) with a minimum resolution of 0.1 arcsec. the WFS's have to be positional tolerance becomes loose. Commercial mirrors with 1 μrad resolution (about 0.001 arcsec on sky).

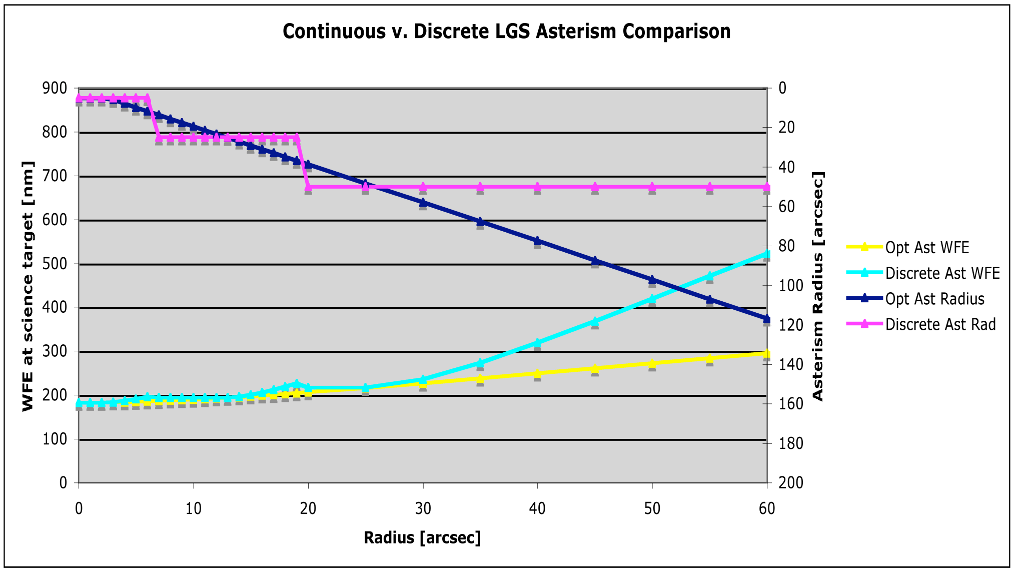

Figure 4: Wide field MOAO case where the science target is off-axis, with a brightest TT star of m_v=17 are assumed to be within the field of 30 arcsec (corresponds to 10% sky coverage).

6. The tolerance corresponding to 0.1 arcsec is 70 microns. This makes the tolerance on the mechanical stages quite loose.

The loose tolerance on the mechanical stages suggests that HO WFS can be positioned with ease whether it is used in continuous or discrete asterism mode.

The main cost driver will the angular matching of the incoming beam by the HO WFS.

3.2 Real Time Computer (RTC) implications

Discrete asterism requires reconstructors for the three asterisms, perhaps updated with some (quasi) real time ${C_n}^2$ profile measurement.

Continous asterism requires the reconstructor to be updated every time the asterism radius changes and based on a (quasi) real time ${C_n}^2$ profile measurement.

Don said that the RTC implications will not be too taxing! But a quantitative measure will be useful for detailed costing.

4 Other considerations

4.1 There are many concerns pertaining to LGS HO WFS focus requirements:

- LGS (differential) defocus between the 5 beacons due to projection geometry

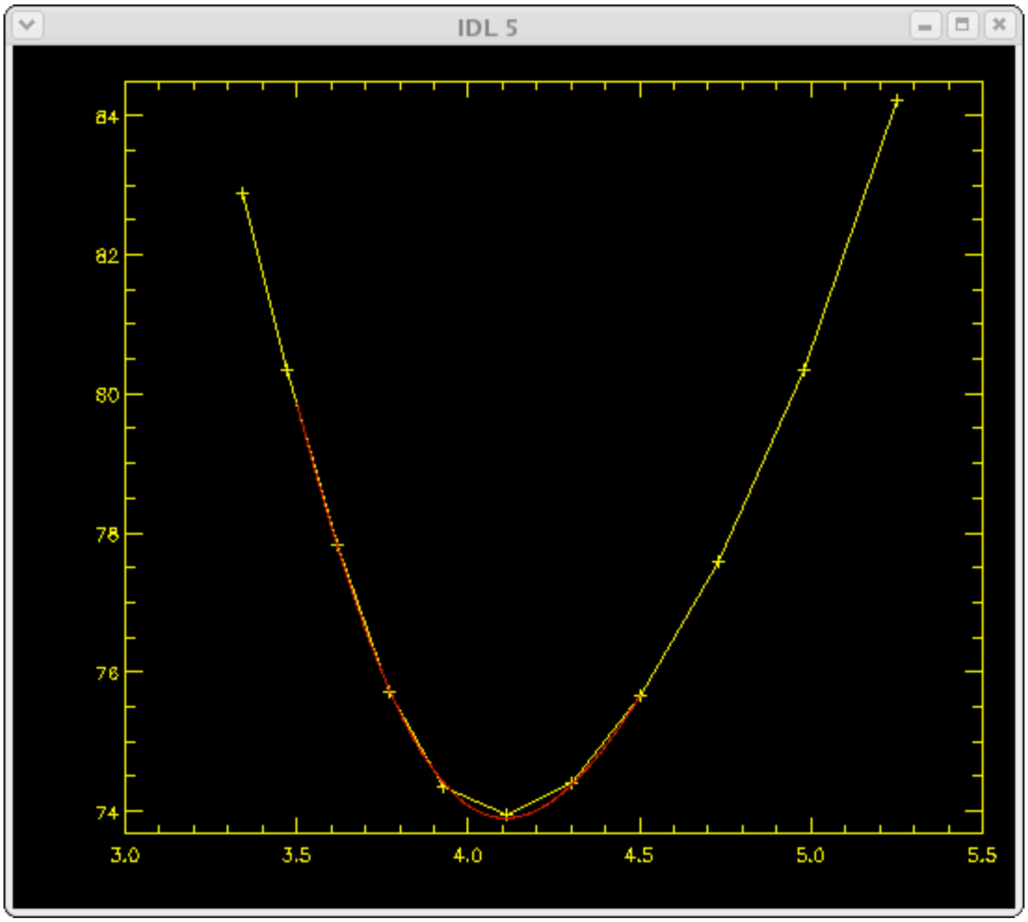

Figure 5: Wide field MOAO case where the science target is off-axis, with a brightest TT star of m_v=17 are assumed to be within the field of 30 arcsec (corresponds to 10% sky coverage).

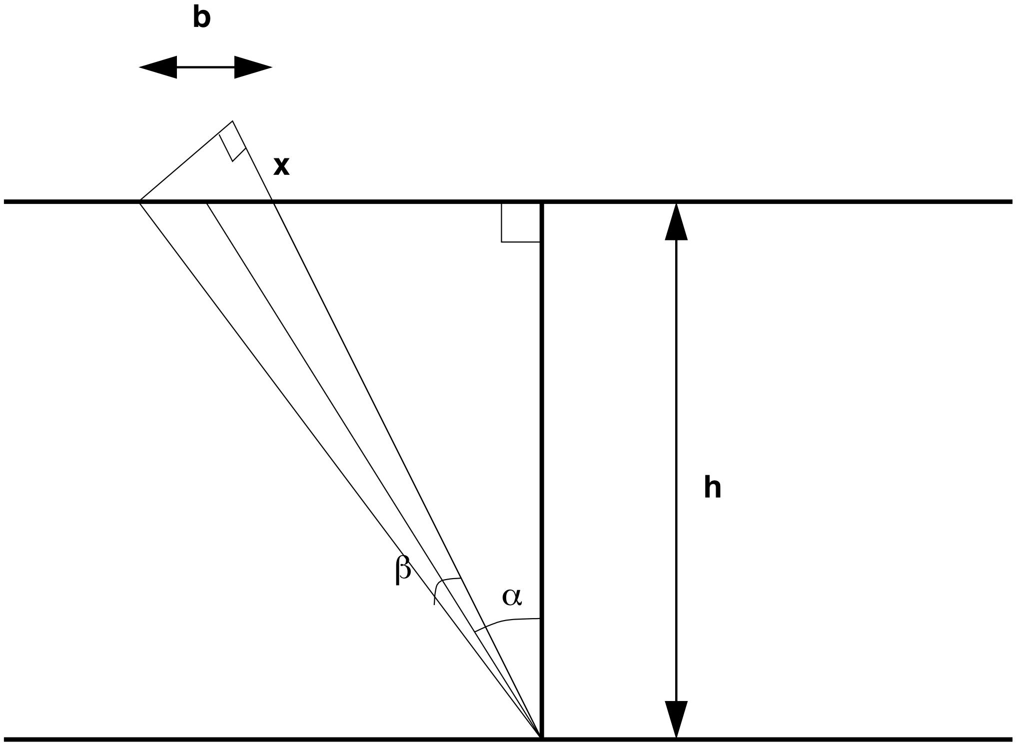

Figure 6: Figure showing focus variation for a quincunx configuration

- LGS defocus due to global Na layer shifts
- LGS defocus due to Na layer density fluctuations.

4.2 Parametric representation of the effect of defocus

$$\text{x} = btan(\alpha)$$
$$\text{b} = \frac{h}{cos\alpha} \; \frac{\beta[arcsec]}{206264.81[arc-sec/rad]}$$
At 45-deg. off zenith and 50" LGS asterism radius ...
$$\text{x} = \text{b} = 61.707 \text{ mm}$$
So, at the focal plane:
$$\frac{1}{f^2} = \frac{x}{x'}$$
$$x_1' = \frac{f^2}{x} = \frac{150^2}{90000-150-61.707}$$
$$x_2' = \frac{f^2}{x} = \frac{150^2}{90000-150}$$
$$\delta x = x_1' - x_2' = 0.17 \text{ mm [defocus at focal plane]}$$

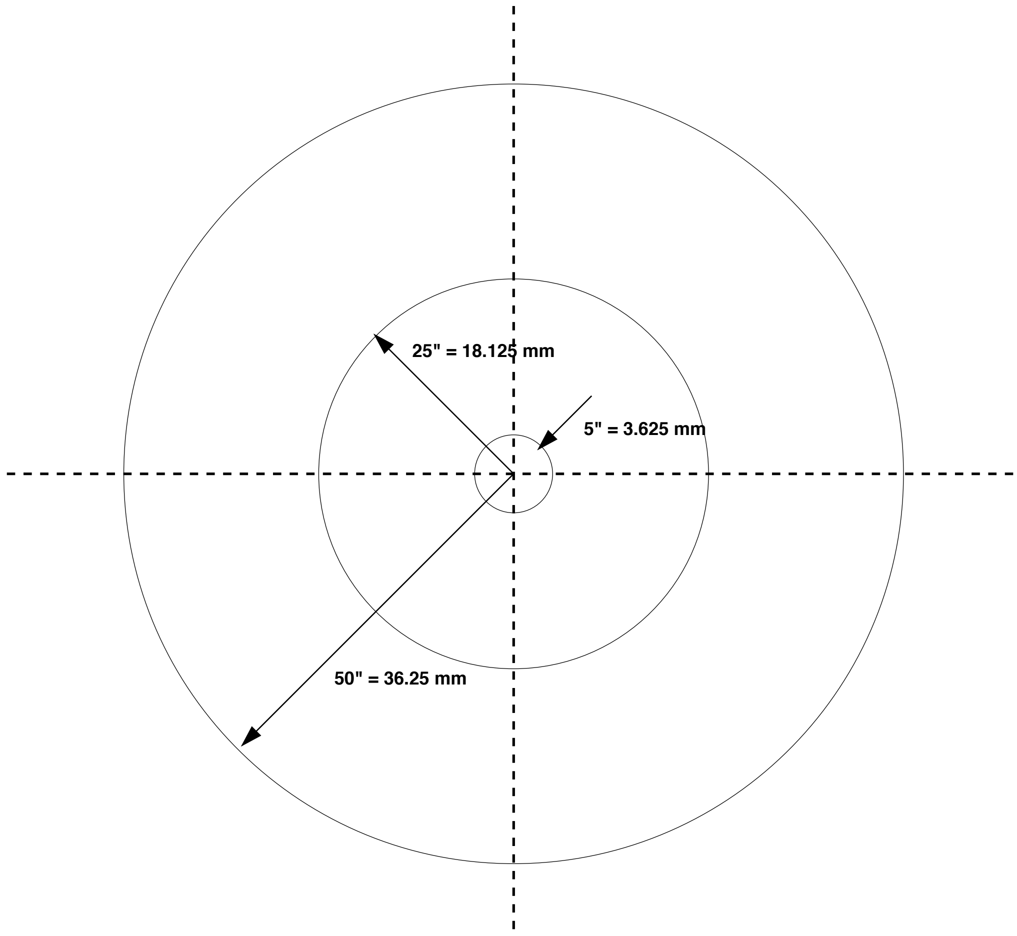

Figure 7: Schematic showing the asterism radii for 5, 25 and 50 arcsec at the focal plane.

4.3 Optical design considerations

4.4 Plate scale calculations

13.66 × 10.949 corresponds to 1 radian.

Therefore, plate scale = $\frac{13.66 \times 10.949}{206{,}264.81 arc-sec/rad}$ = 0.725 mm/arcsec.

i.e., LGS spots are separated by 40 mm for 50" radius beacons.

Ideally a telecentric system would be most cost effective as far as the HO WFSs are concerned. But if we can't get a telecentric system, more work has to be done to see as to how one can pick off the LGS spots and keep the DM and lenslets registered to each other.

5 Laser Launch implications

Uplink tip-tilt mirrors can be obtained from `http://www.ballaerospace.com/fsm_tfsm.html`. These have very fine resolution. The BTO/LLT sub-system must be able to accommodate the continuous change from 5 to 50 arcsec asterism. The differential cost between that and having a splitting mechanism that just facilitates 5, 25 and 50 arcsec must be considered as part of section 3.3.4 (3.3.4.1, 3.3.4.2, and 3.3.4.3) of the WBS.

6 Conclusions

Continuously variable asterism:

- There is little performance benefit in narrow field performance
- There is a significant performance benefit for d-IFU science when the mismatch between asterism and target radius exceeds 20 arcsec
- Cost overhead in optomechanical hardware is small.
- Real-time and supervisory control software costs will dominate.
- Also any laser launch costs that may arise due to a continuously variable asterism should be evaluated.i

Software and laser launch costs allowing, we should assume continuously variable asterism in the system design.