Keck Adaptive Optics Note 504

NGAO Performance vs. Technical Field of View for LOWFS Guide Stars

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August 13, 2007

1. Introduction

The NGAO System Architecture Retreat, July 9-13, 2007, raised several questions regarding the technical field of view requirements for NGAO. The purpose of this note is to understand the performance compromises for NGAO that arise when limiting the technical field of view.

2. Technical Field of View (TFoV)

We define the TFoV as the field of regard on the sky from which the set of NGAO low-order guide stars can be simultaneously acquired into the low-order wavefront sensor (LOWFS) system, which typically uses natural guide stars to determine wavefront tilt not available in the laser guide star (LGS) high-order wavefront sensor (HOWFS) subsystem and to repair errors in the tomographic null modes arising in our multi-LGS HOWFS.

All fields of view in this note are circular diameters, assumed to be centered on the science target, in the direction of which the LGS asterism is formed by the LGS beam delivery system.

3. LOWFS Sharpening in J + H

We assume IR LOWFS stars are sharpened to (nearly) the diffraction limit by high-order MEMS-based DM's within each LOWFS sensor, using go-to control techniques characteristic of the Multi-Object AO (MOAO) paradigm. (Typical correction of the off-axis LOWFS stars in this study, while not checked exhaustively, is typically in the J-Strehl ~ 50% range. Even though the LOWFS are quite a distance off-axis, the error budget optimization allows the LGS asterism to be widened to continue to correct these off-axis stars (albeit with increasing tomography error).

An alternative approach to off-axis LOWFS sharpening, being considered, is to dedicate a sodium LGS to each LOWFS star, thus allowing the 'science LGS asterism' to not be pulled to so large a radius as is typically found in this study. Although the relative merits of a large LGS asterism or a 'point-and-shoot' LOWFS sharpening system remains uncertain, we assume here that the same LOWFS sharpening can be obtained in either scenario, so these results remain essential valid (as they, in fact, must if NGAO is to generally meet it's science requirements of very high on-axis near-IR Strehl ratio.)

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4. Model assumptions

These calculations have been conducted using v1.26 of the NGAO Wavefront Error (WFE) Budget Tool, adopting:

Atmosphere

Mauna Kea Ridge (MKR) "Median" 62.5th percentile seeing conditions
 (r_0 = 18 cm, θ_0 = 2.9 arcsec, d_0 = 5.24 m, all at λ = 0.5 μm)
and Mauna Kea Ridge (MKR) "Good" 87.5th percentile seeing conditions
 (r_0 = 22 cm, θ_0 = 4.0 arcsec, d_0 = 7.33 m, all at λ = 0.5 μm)

Average turbulence-weighted wind speed of 9.5 m/s
 (f_G = 24.7 Hz)
Outer scale = 50 meters

HOWFS
- 6 LGS in a "5+1" asterism geometry (of variable radius)
- A total of 90W of SOR CW laser-like return
  - T = 0.6 transmission on uplink
  - 4e9 /cm^2 abundance
  - T = 0.44 transmission on downlink
  - FWHM = 1.8 arcsec (center projected)
- 64 x 64 subapertures
- CCID56 WFS detector QE
  - 5.9 e- read noise at ~1200 fps frame rate

LOWFS
- 3 NGS stars corrected using the MOAO technique (LOWFS m_V refers to the brightest NGS)
  - 2 TT + 1 TTFA (on brightest star)
- M-type NGS
- J+H LOWFS sensing bands (T = 0.24)
- H2RG in ROI mode readout
  - 4.5 e- read noise at ~700 fps (quad-cell) frame rate
  - 0.1 x 0.1 arcsec pixels
  - Perfect K-band rejection
- Only tomography error internal to LGS asterism
  - Additional classical anisoplanatism error outside of LGS asterism

Target
- Faint compact source science program (such as KBO observations)
- Zenith angle = 18 degrees
- 300 second exposure (with 0.75 mas / min total mechanical drift = 3.75 mas fixed tip/tilt error)
- Science band ADC (but no ADC in the LOWFS)
- Single-conjugate AO correction
  - Science evaluation at off-axis angle of 5 arcsec
- 30% sky coverage at all galactic latitudes
  - (when TFoV is clamped, fainter and fainter NGS are selected).

5. Results

The summary of our trade study, for two different atmospheric models (MKR "Median" and "Good" conditions) is shown in Figure 1 (with supporting values in the Appendix).

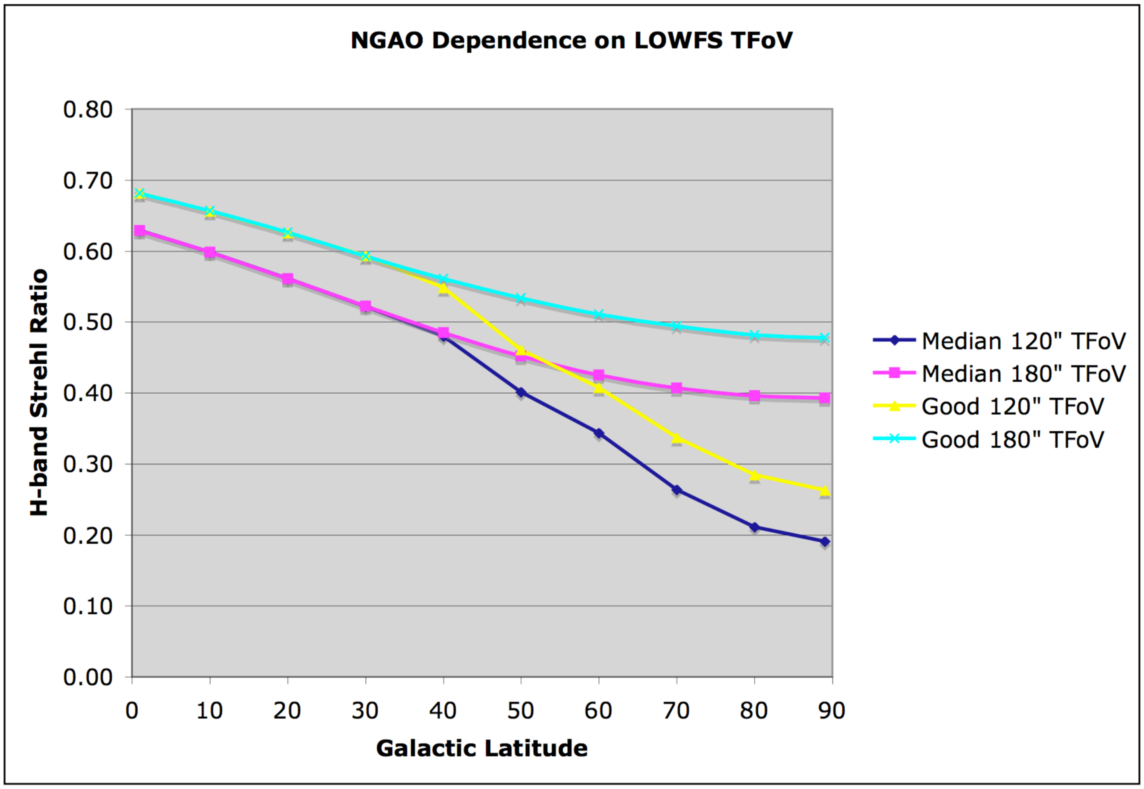

Figure 1. Summary of TFoV trade study.

Figure 1 is interpreted as the H-band Strehl ratio performance vs. galactic latitude under our assumptions, when the TFoV is set to be either 180" diameter (smoother curves) or 120" (disjointed curves). We see that for b ~ 40 degrees (or higher) there is a performance penalty only having a 120" TFoV. Near the galactic pole (b = 90), the penalty for median seeing is approximately a factor of two reduction in H-Strehl (19% vs. 39%).

[In fact, we find that the 180" TFoV is an artificial limit imposed above b = 80 degrees, but the effect appears to be quite minor.]

A similar curve for H-band ensquared energy is shown in Figure 2, for NGAO median seeing conditions. As before, going to high galactic latitude results in opening up of the LGS asterism in order to correct for LOWFS stars. In this case, assuming a deployable IFU instrument, we can tolerate larger tip/tilt errors, so ensquared energy loss is not as rapid when the TFoV is limited to 120".

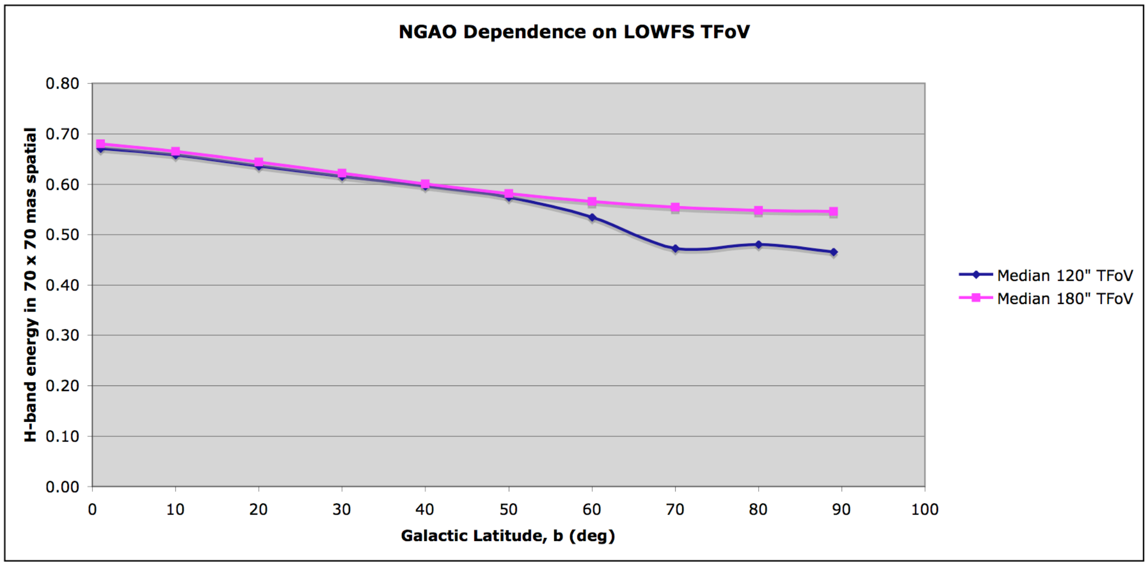

Figure 2. Ensquared Energy for the Extended Groth Strip science case, for different b.

6. Acquisition Efficiency

As NGS become fainter, they will require more time to acquire into the NGAO LOWFS subsystem. It is therefore not entirely equitable to reduce the NGS brightness to whatever faintness is necessary to meet the 30% sky coverage specification. Although point source sensitivities were not, as of this writing available, we presume that acquisition of NGS fainter than $m_V = 21.5$ will be objectionable time-consuming. In the Appendix, we highlight these situations with red background.

7. Conclusion

Based on this analysis, we conclude that science performance would be significantly impacted with a TFoV of only 120 arcsec for galactic latitude greater than b = 40 in median NGAO seeing conditions. A TFoV of 180 arcsec allows selection of the optimally selected combination of NGS off-axis distance and brightness, under the assumptions stated above.

Although we have not explored other TFoV values, we believe that an intermediate TFoV of 150 arcsec diameter would still significantly degrade b = 90 performance (perhaps by 10% absolute reduction of H-Strehl), so a TFoV = 180 arcsec is recommended.

Appendix

The following tabular values were produced for this study, where we interpret TT star mV less than 21.5 as objectionable, in effect saying that 30% sky coverage at these galactic latitudes and these assumptions is not practical.

30% sky coverage fixed   6 LGS beacons / total of 90W CW return (could be less return, not limited by laser power here).

clamped at 180" TFoV   MKR Median Seeing

b	optimum search radius (arcsec)	TT error (mas)	SR H	TT star mV
1	32.64	5.56	0.63	18.93
10	39.08	6.30	0.60	19.30
20	47.82	6.85	0.56	19.62
30	56.96	7.56	0.52	19.91
40	66.41	8.32	0.48	20.13
50	75.09	9.04	0.45	20.30
60	82.19	9.64	0.43	20.43
70	87.41	10.09	0.41	20.51
80	90.00	10.44	0.40	20.57
89	90.00	10.57	0.39	20.63

clamped at 180" TFoV   MKR Good Seeing

b	optimum search radius	TT error mas	SR H	TT star mV
1	35.54	5.14	0.68	18.70
10	44.78	5.84	0.66	18.89
20	52.88	6.21	0.63	19.28
30	62.53	6.87	0.59	19.57
40	72.36	7.38	0.56	19.80
50	81.50	7.81	0.53	19.97
60	86.75	8.33	0.51	20.21
70	90.00	8.63	0.49	20.39
80	90.00	9.03	0.48	20.58
89	90.00	9.16	0.48	20.63

clamped at 120" TFoV   MKR Median Seeing

b	optimum search radius (arcsec)	TT error (mas)	SR H	TT star mV
1	32.84	5.61	0.63	18.9
10	39.03	6.34	0.60	19.3
20	47.66	6.85	0.56	19.6
30	56.86	7.69	0.52	19.9
40	60.00	8.61	0.48	20.5
50	60.00	11.25	0.40	21.3
60	60.00	13.20	0.34	21.8
70	60.00	16.91	0.26	22.3
80	60.00	20.11	0.21	22.5
89	60.00	21.65	0.19	22.6

clamped at 120" TFoV   MKR Good Seeing

b	optimum search radius	TT error mas	SR H	TT star mV
1	39.20	5.16	0.68	18.4
10	43.39	5.86	0.66	19.0
20	54.15	6.30	0.63	19.2
30	60.00	6.71	0.59	19.7
40	60.00	7.78	0.55	20.5
50	60.00	10.43	0.46	21.3
60	60.00	12.01	0.41	21.8
70	60.00	14.65	0.34	22.3
80	60.00	17.01	0.28	22.5
89	60.00	18.16	0.26	22.6