THIRTY METER TELESCOPE

PSF Reconstruction for LGS MCAO

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1. Introduction

- PSFR is critical for diffraction limited astronomical AO science
  - Prime examples:
    1. Photometry/Astrometry on crowded star fields
    2. Deconvolution of extended objects
- Pioneered by Véran in 1997 and Flicker in 2003
  - Approach based on:
    1. Post-processing AO telemetry data
    2. Models of WFS measurement noise, DM fitting and WFS aliasing

2. Innovative Simulation model based approach to PSFR for LGS MCAO

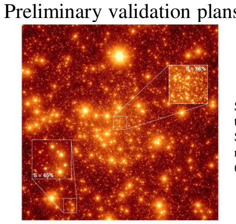
- OTF estimated at every field point as the product of long-exposure (LE) tip/tilt-removed (TTR) and tip/tilt (TT) OTFs (see Fig.3)
- TTR OTF estimate obtained by post-processing on-axis LGS WFS measurement covariance matrix:
  - Denoising
  - Phase reconstruction (simple un-regularized zonal least-squares reconstructor)
  - Fitting add up (aliasing can be omitted)
  - Post-processing performed identically on system and simulation LGS WFS telemetry !
  - Extrapolation from on-axis finite range LGS to off-axis infinite range science via structure function (SF) ratio
    - SF ratio provides robustness against r0 modeling errors !
  - TT OTF estimate obtained by post-processing low-order multi-NGS WFS measurement covariance matrix
    - Denoising
    - NGS mode reconstruction (typically 5 modes, consisting of global TT and focus/astig. on 2 DMs)
    - TT projection along science directions
  - Post-processing performed identically on system and simulation NGS WFS telemetry !
  - Balancing via TT OTF ratio
  - **Overall process requires accurate knowledge of Cn2, r0, LGS WFS signal level during science integration**
    - SLODAR, DM seeing estimator, seeing monitor

3. Performance evaluation with NFRIAOS simulation data (D=30m)

- J-band PSF FWHM: 8.6mas
- 30'' circular FoV
- 50s integration
- Zenith observations
- r0=18.6cm ("base") and 16.7cm ("09r0") i.e. seeing 0.55'' and 0.62'' at 500nm
- 4 different NGS asterisms (M_J: 17-20, see Fig.1, 50-80nm residual NGS mode WFE, 1-2mas residual TT WFE
- ~20% Strehl ratio (SR) variability across 30'' FoV (see Fig.2)
- 4 cases studied:
  1. Simulation perfectly matched to system
  2. 10% r0 modeling error
  3. Un-modeled 3mas RMS 2Hz TT jitter (corrected by NGS servo to -10dB in variance, i.e. ~68% in RMS)
  4. 20% LGS WFS signal level modeling error

4. Results

- Reconstructed PSF Enclosed Energy (EE) error largest near the origin, i.e. dominated by SR error
- Very uniform SR error across 30'' FoV (see Fig.4)
- **Percent level absolute and differential photometry errors achieved for cases studied** (see Figs. 4 and 5)
- Experimental validation mandatory
- Preliminary validation plans discussed with Gemini South



Simulated NFIRAOS K-band image of the Galactic Center for a 17'' x 17'' FoV. SR shown is for center of field and 8.5'' radial offset. Image credit: Leo Meyer (UCLA) and Matthias Schöck (TMT)

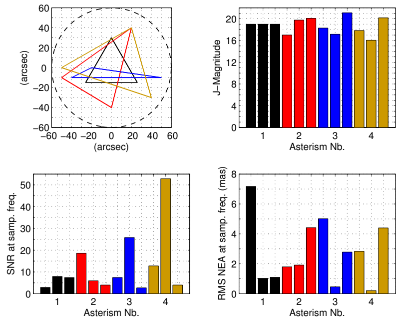


Fig.1 Sample NGS asterisms investigated, S/N ratios and noise equivalent angles (NEA)

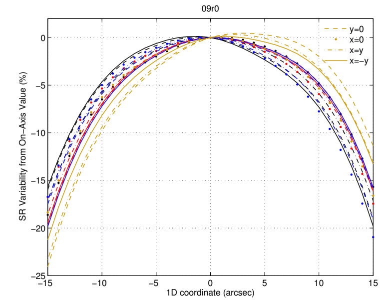


Fig.2 NFIRAOS J-band SR variability from on-axis value across 30'' FoV. The 4 different colors correspond to the 4 different NGS asterisms investigated and shown in Fig.1

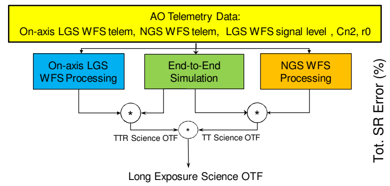


Fig.3 Top-level block diagram of PSFR algorithm

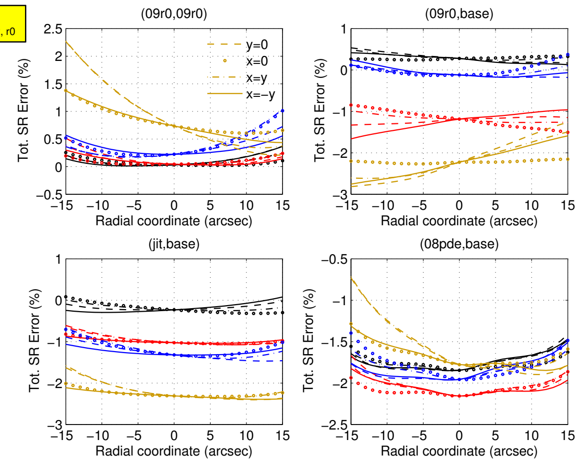


Fig.4 J-band PSFR SR error across 30'' FoV for ideal case of simulation matching perfectly system (upper left), 10% r0 modeling error (upper right), un-modeled jitter (lower left) and 20% LGS WFS signal level modeling error. Same color convention as in Fig.2

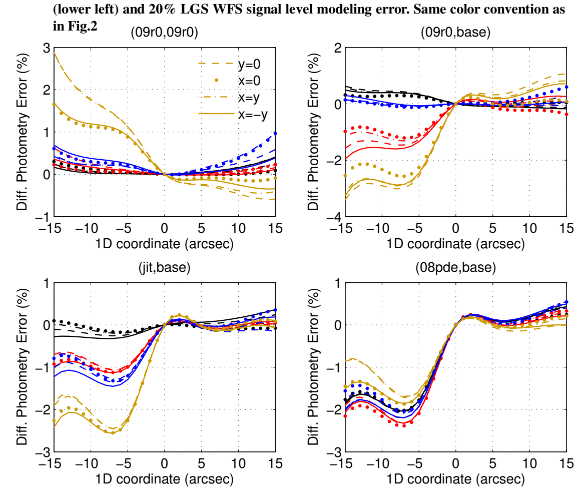


Fig.5 J-band differential photometry error resulting from PSFR errors for the 4 cases investigated. Same color and notation conventions as in Fig.4

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