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Point Spread Function Reconstruction for Laser Guide Star Tomography Adaptive Optics

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Presentation Outline

- What is Adaptive Optics (AO) Point Spread Function Reconstruction (PSFR) ? Why is it important ?
- Basic idea developed by Véran in 1997
- Extensions to tomography AO
- Work done to date
- Work in progress

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What is AO PSFR ?

- Estimation of the science long-exposure OTF (Fourier transformed PSF) from AO system RTC telemetry
  - Problem reduced to estimation of residual science wavefront covar. matrix from RTC telemetry data
  - RTC telemetry data: error covar. matrix, traditionally in WFS space, but could equally be in DM actuator space
- Required in order to perform image de-convolution
- Essential to retrieve high angular resolution information in any AO astronomical science program
  - Photometry and astrometry
  - Precision orbits estimation at the Galactic Center, etc.

Basic idea developed by Véran JOSA A 1997

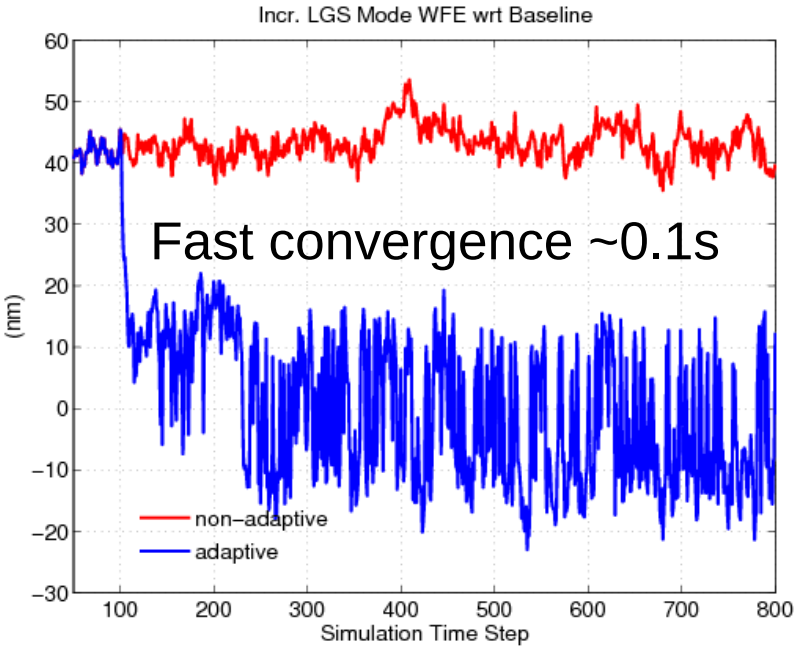
- RTC WFS measurement covariance matrix corrupted by noise and aliasing that need to be “taken out”
- Residual WFE left over and seen by WFS is servo-lag, obtained by mapping de-noised, de-aliased measurement covar. matrix onto DM actuator space with least-squares reconstructor
- AO telemetry does not see everything:
  - Anisoplanatism WFE (depends on Cn2 profile): angular (Fusco 2000, Britton 2006), focal (Flicker 2008) for LGS
  - DM fitting WFE
  - Non-common path aberrations (NCPA) (including instrument distortion errors)

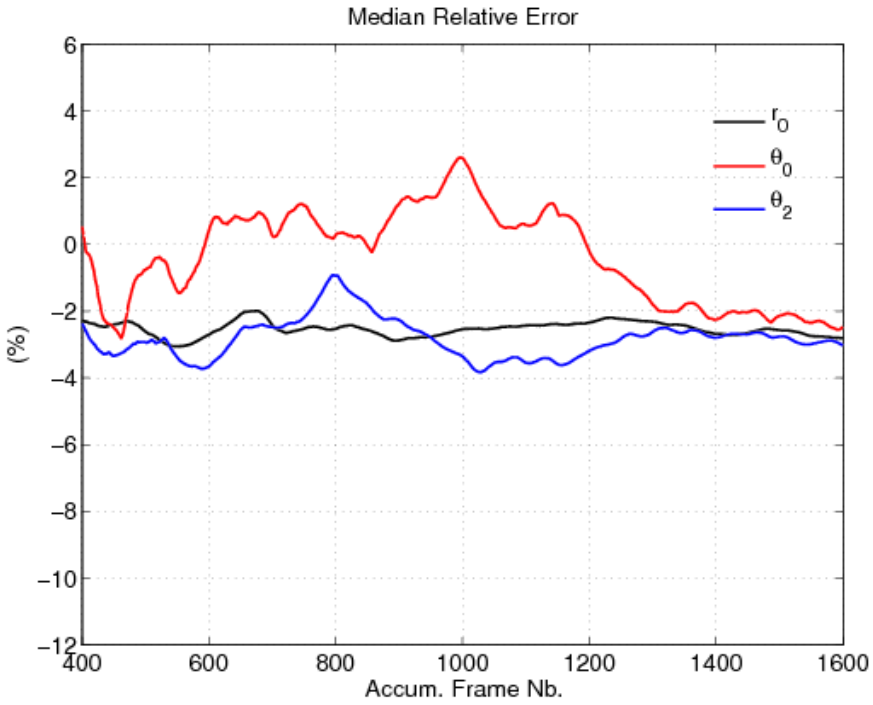
Extension to Laser Tomography AO

- What RTC telemetry data to use ?
  - WFS: mapping de-noised, de-aliased multi-WFS measurement covar. matrix onto DM actuator space with tomographic reconstructor off-line is impractical
  - **RTC does tomography for you, so use it !**
- Bonuses:
  - Uses RTC built-in SLODAR
  - Uses covar. matrix of summed LGS loop and NGS loop actuator error signals to preserve cross-coupling
- Off-line steps (require Cn2 profile) :
  - De-noise, de-alias with separate LGS mode and NGS mode covar. matrices
  - Compute unseen DM (generalized) fitting covar. matrices, either analytically in FD or by simulation

NFIRAOS built-in LGS SLODAR (Gilles, JOSA A 2010)

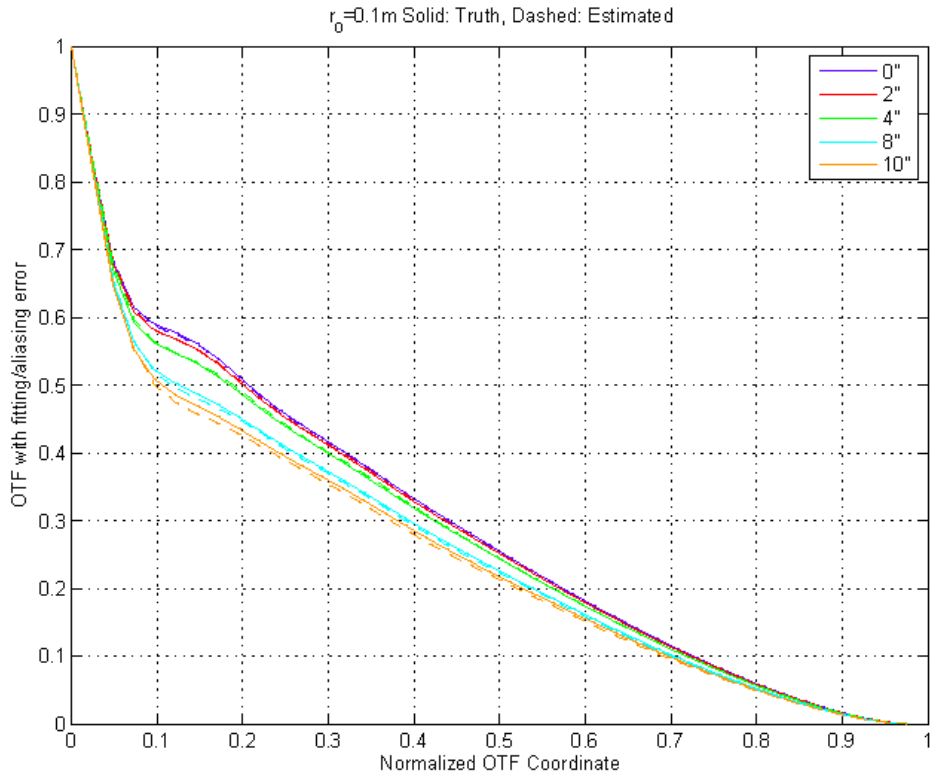
- 12-layer profile reconstructed in RTC from a pair of LGS WFS (1’ apart) pseudo open loop cross-covar.
- Insensitive to LGS tip/tilt/focus
- Adaptively binned in RTC to update 6-layer LGS tomography algorithm



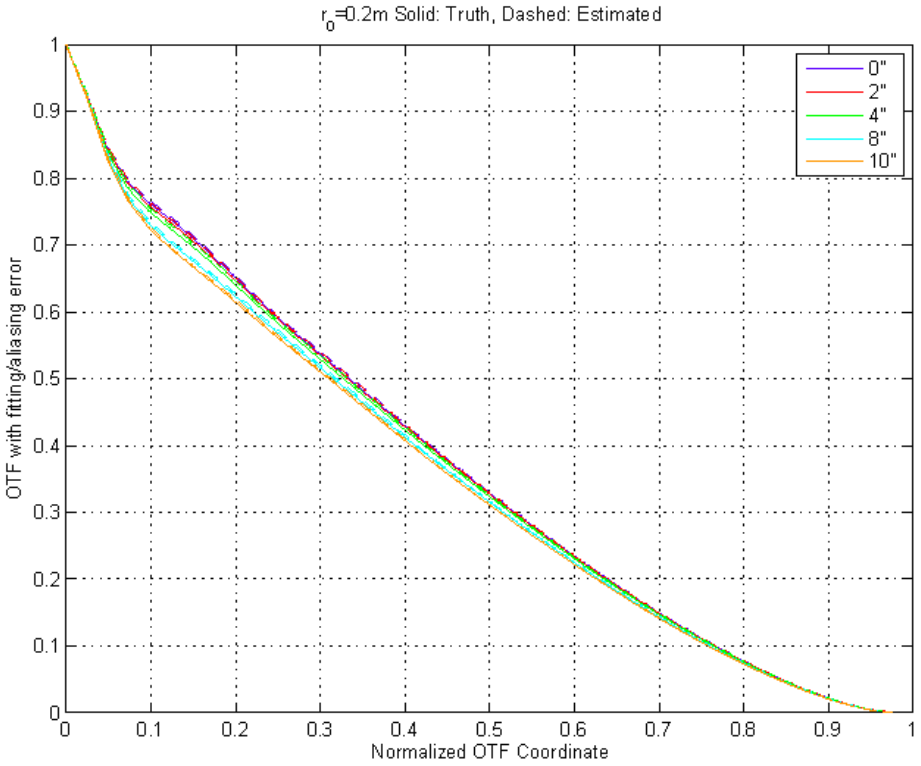


Work done to date on tomography approach

- Successfully validated on- and off-axis for classical NGS AO and NGS MCAO (6-layer tomography performed using NFIRAOS RTC CG algorithm)



(a) r_0=0.1m. On axis Strehl error is -0.47%.



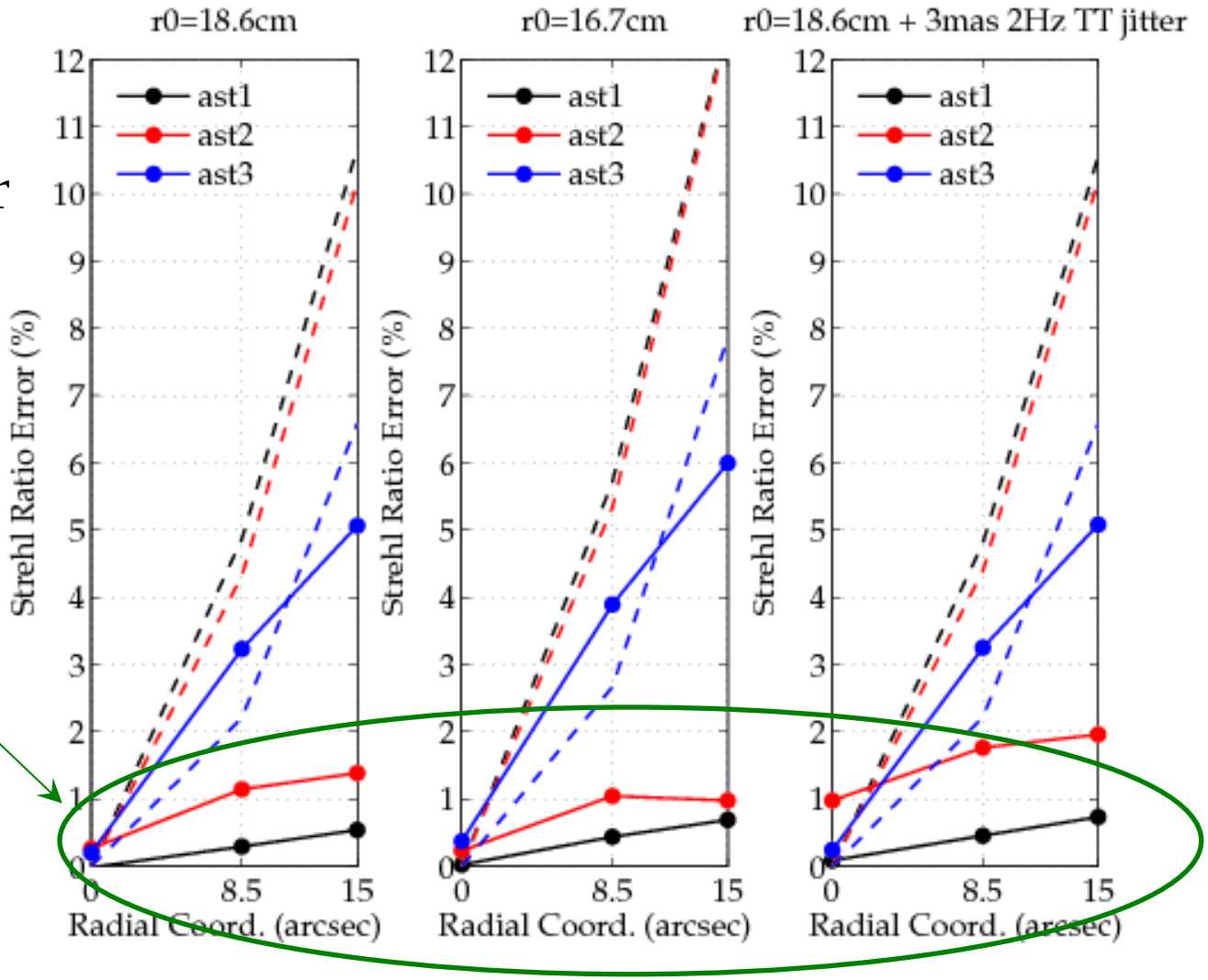
(d) r_0=0.2m. On axis Strehl error is -1.3%

Less natural extension

- RTC telemetry data: single LGS WFS measurement covar. matrix, and NGS mode error covar. matrix
- Off-line steps (require Cn2 profile estimate):
  - De-noise, de-alias LGS WFS covar. matrix
  - Map onto wavefront space by appropriate reconstructor
  - Extrapolate to science (LGS mode tomography error)
  - Compute unseen DM (generalized) fitting cov. matrix
  - De-noise, de-alias NGS mode error covar. matrix and sum to LGS mode covar. matrix

Preliminary Assessment of LGS/NGS-mode decoupling

- Dashed curves are science SR variations. Indicate diff. photometry error when using on-axis PSF off-axis
- PSF variability reduced ~10X
- NFIRAOS 2% Diff. Photometry Req. met provided all PSFR errors fit within a ~1% SR error budget !



LGS-to-Science Extrapolation

- Key: work with Structure Function (SF) matrix. Trivially computed with linear operations on the covariance matrix.
- Compute a LGS-to-science “SF filter”, expressed as a SF ratio, computed by simulation (fed by average Cn2 profile)
  - Proven to be robust against seeing model error, since both LGS and LGS mode science SF scale as the negative 5/3th power of the Fried parameter
- Note: alternative approach to SF is to use a log OTF (aperture-averaged SF)
  - Proven to be equally insensitive to seeing model error

NGS-mode error covariance matrix de-noising and de-aliasing

- Common step to both approaches
- De-noising is challenging for dim NGS asterisms
- De-aliasing is challenging. Successful method hasn't been found yet. Ignoring aliasing penalizes SR estimate by ~4-8% error for median sky coverage NGS asterisms for NFIRAOS, blowing up photometry error budget…

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Work in progress

- NGS mode aliasing covar. matrix or ways to reduce aliasing
- End-to-end performance and robustness assessment of both approaches for NFIRAOS (LGS MCAO)

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