PSF reconstruction for NAOS

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ESO objectives

- To deliver reconstructed PSF for the AO present and future systems
  - Shack Harmann: NAOS-CONICA
  - Curvature: MACAO (SINFONI, VLTI)
  - Pyramid (VLT/Planet Finder ?)
  - Laser Guide Star
    - Shack Hartmann (NACO)
    - Curvature (SINFONI)
  - Ground Layer AO (MUSE)
  - MCAO (MAD)
Curvature: PSF reconstruction studies

- Contract with ASTRON (Netherlands) to deliver a reconstructed PSF for SINFONI
  - Cf. talk of F. Rigal
PSF reconstruction studies for NAOS

- Observatoire de Meudon (D. Gratadour & E. Gendron)
  - Cf. Damien’s talk

- ESO (Y. Clénet & M. Kasper)
  - Adaptation of the software written by R. Weiss (MPIA) for the ALFA AO system
NACO

- Deformable mirror: 185 actuators
- Shack Hartman wavefront sensors
  - Visible WFS: 14x14 and 7x7 subpupils
  - Infrared WFS: 14x14 and 7x7 subpupils
- Modal control
  - Modes: Karhunen-Loève modes computed within the deformable mirror space \( \rightarrow \) not the "atmospheric" Karhunen-Loève modes
  - Number of controlled modes:
    - 159 in the 14x14 configurations
    - 42 in the 7x7 configurations
NACO

- Infrared camera
  - 1-5 μm
  - 1024x1024 pixels
  - Well sampled from J (1.25 mm) to M’ (4.8 mm)

- Attached to the fits file: modal covariance matrices computed from
  - The voltages: $C_{mm}$
  - The slopes: $C_{\hat{e}\hat{e}}$

- In the header fits file: average values of $L_0$, $r_0$, $\tau_0$ and global noise as estimated by the RTC
The ALFA software

- Cf. S. Egner’s talk
- Modes: atmospheric Karhunen-Love functions
- Residual covariance matrix: computation from slopes measurements
- Noise: computation by temporal autocorrelation of slopes measurements
- $r_0$: computed from simulations and slopes measurements
PSF computation

\[ \text{OTF}(\tilde{\rho} / \lambda) = \text{OTF}_{\text{static}}(\tilde{\rho} / \lambda) \cdot \text{OTF}_{\parallel}(\tilde{\rho} / \lambda) \cdot \text{OTF}_{\perp}(\tilde{\rho} / \lambda) \]

- \( \text{OTF}_{\text{static}} \): fiber image or from calibration PSF

- \( \text{OTF}_{\parallel,\perp}(\tilde{\rho} / \lambda) = \exp\left(-\frac{1}{2} \overline{D}_{\phi_{\parallel,\perp}}(\tilde{\rho}) \right) \)
\[
\mathbf{D}_{\phi_{\varepsilon}^{\parallel}} = \sum_{i,j}^{m} \left\langle \varepsilon_i \varepsilon_j \right\rangle \cdot U_{ij}(\vec{\rho})
\]

- \( U_{ij}(\vec{\rho}) = \frac{\int P(\bar{x})P(\bar{x} + \vec{\rho})(M_i(\bar{x}) - M_i(\bar{x} + \vec{\rho}))(M_j(\bar{x}) - M_j(\bar{x} + \vec{\rho}))d\bar{x}}{\int P(\bar{x})P(\bar{x} + \vec{\rho})d\bar{x}} \)

- \( P(\bar{x}) \): pupil function
- \( M_i(\bar{x}) \): NACO modes

**NACO modes: computed from**
- Measured influence functions of the DM (Zygo)
- A modal matrix

\( \rightarrow 12720 \) \( U_{ij} \) functions (6.7 Go for 256x256 arrays)
\[ \overline{D}_{\phi\epsilon}(\bar{\rho}) = \sum_{i,j}^{m} \langle \epsilon_i \epsilon_j \rangle \cdot U_{ij}(\bar{\rho}) \]

- \( C_{\epsilon\epsilon} \): covariance matrix of the mirror component of the residual phase

- \( C_{\epsilon\epsilon} = C_{\hat{\epsilon}\hat{\epsilon}} - C_{nn} + C_{rr} \)
  - \( C_{\hat{\epsilon}\hat{\epsilon}} \): residuals
  - \( C_{nn} \): noise
  - \( C_{rr} \): aliasing
Residual PSF ($C_{\hat{\varepsilon}}$)

- $C_{\hat{\varepsilon}}$ attached to the CONICA fits file
- First estimation
Noise ($C_{nn}$)

- First step: will be estimated with the ALFA software: temporal autocorrelation of slope measurements
  
  → need for simultaneous slopes measurements (not implemented)

- Available in the NAOS RTC database and will be delivered
**Aliasing \((C_{rr})\)**

- Will be computed from simulations by modeling the NAOS Shack-Hartmann

- Negligeable?
  - In close loop: \(C_{\varepsilon\varepsilon} = C_{\hat{\varepsilon}\hat{\varepsilon}} - C_{nn} + C_{rr}\) (Veran et al 97)
  - In open loop: \(C_{\varepsilon\varepsilon} = C_{\hat{\varepsilon}\hat{\varepsilon}} - C_{nn} - C_{rr}\) (Kasper et al 00)
\[ \overline{D}_{\phi_{\perp}} (\vec{\rho}) = \left( \overline{D}_{\phi_{\perp}} (\vec{\rho}) \right)_{D/r_0=1} \cdot (D / r_0)^{5/3} \]

- First estimation with KL functions
- Next, will be computed from simulations: retrieving from turbulent phase screen their projection on the mirror space

- \( r_0 \): given in the CONICA fits file
Conclusion

- For NAOS: still to compute
  - The noise
  - The aliasing
  - The non controlled modes

- Define a common user interface for all ESO AO systems

- ESO open to collaboration for NAOS and other AO systems