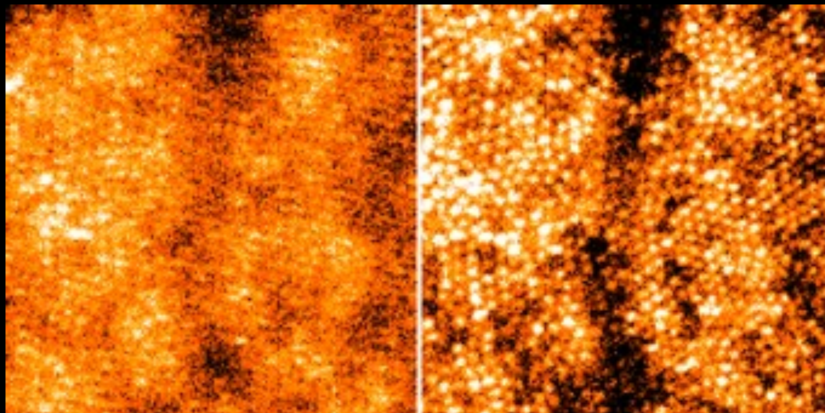
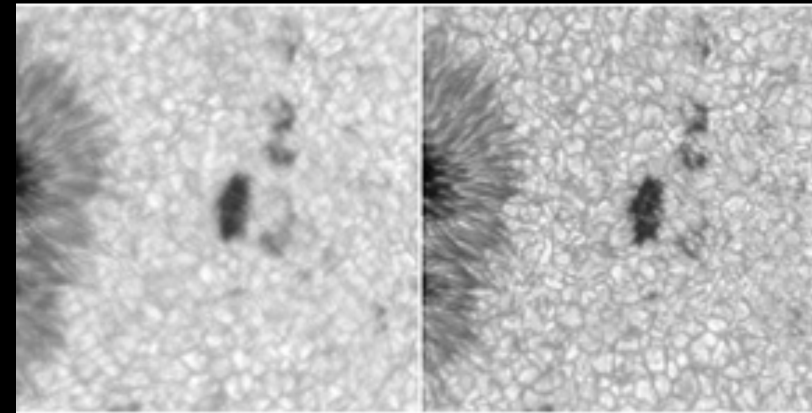
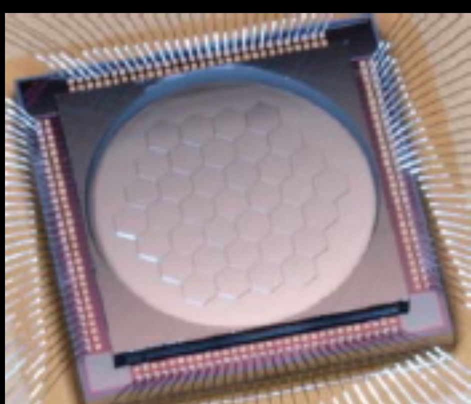


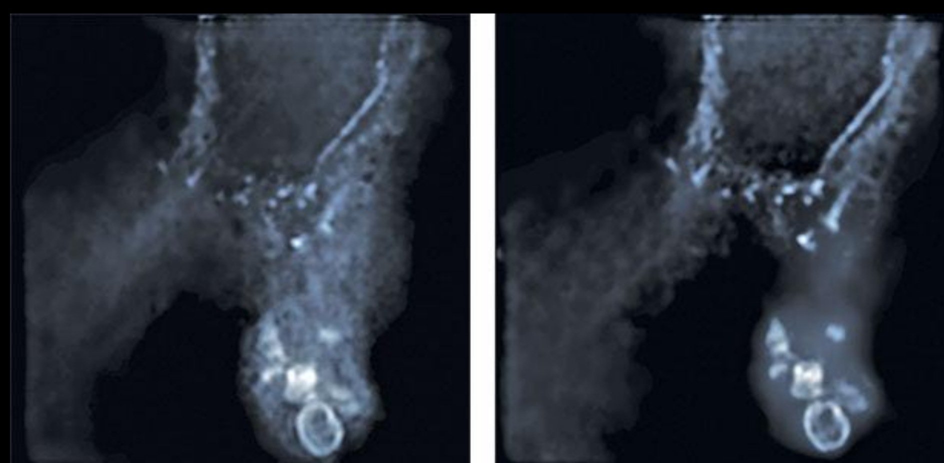


Adaptive Optics

Special Topic in Astrophysics

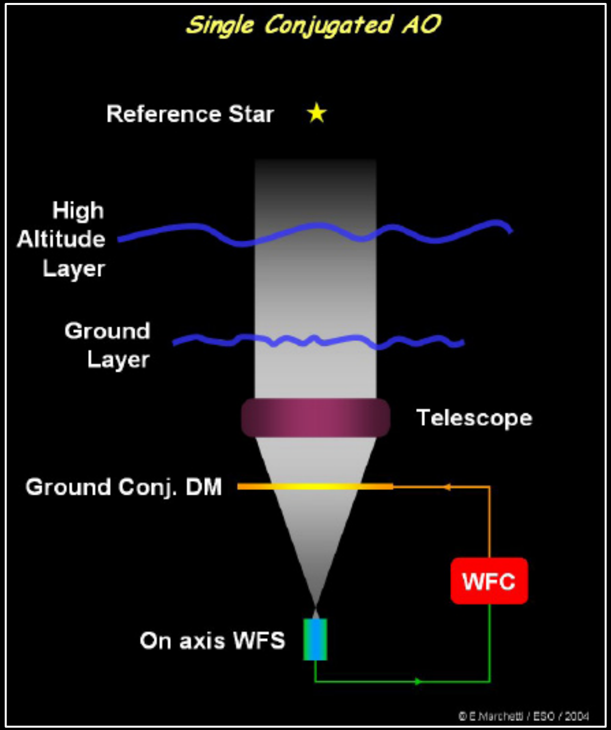
ASTRON 250 - Fall 2013





Beyond conventional AO

- Most of our discussions have been focused on conventional single conjugate AO (SCAO)
  - Single guide star (or 1 LGS + 1 NGS)
  - Single WFS
  - Single DM
  - Modest number of d.o.f.
  - Single layer corrected
    - Ground or high z



Beyond conventional AO

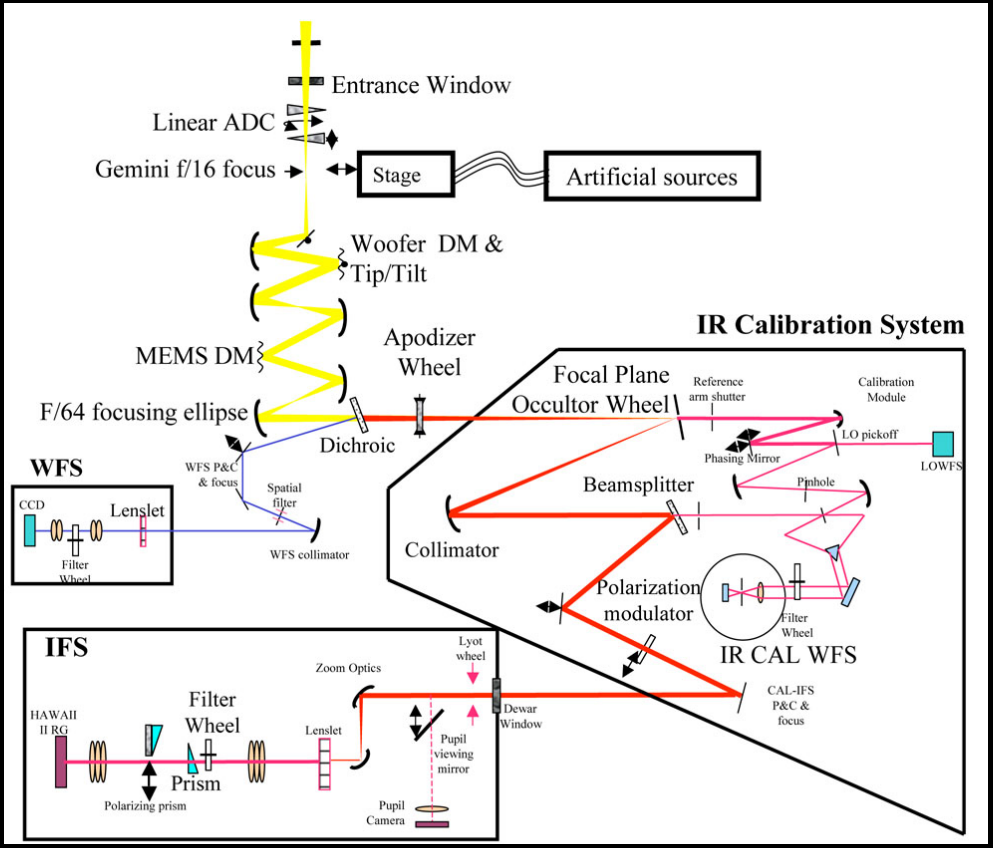
- SCAO has a number of limitations:
  - Small FOV, limited coverage
  - Spatially varying correction
  - Moderate Strehl ratios (≈50% in NIR)
  - Cone effect (for LGS)
- AO now exists in many different flavors to achieve different scientific goals
  - Particularly important in astronomy for “Extremely Large Telescopes” (30+ m), but could also be used in other fields

Extreme AO (XAO)

- Science goal: achieve very high contrast
  - Requires extremely stable and high quality PSF
- Technical goal: obtain extremely high Strehl ratio (≥ 90% in NIR)
  - Use high number of sensors/actuators (1000s)
    - DM = secondary mirror is an option
  - Run at very high frequency (≈1-2 kHz)
  - Good performance at visible wavelengths
- Only possible for bright stars

Extreme AO (XAO)

- Need to control/remove all sources of error, not just fitting/aliasing/temporal errors

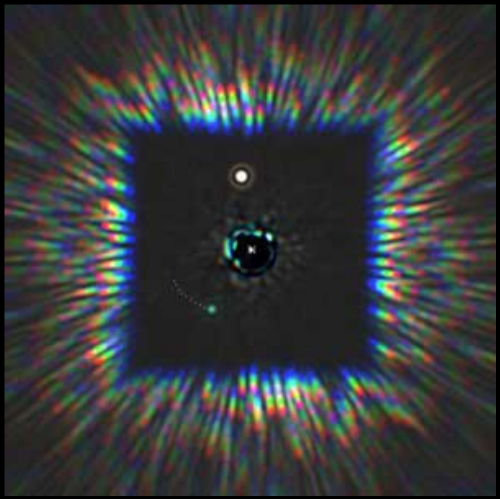


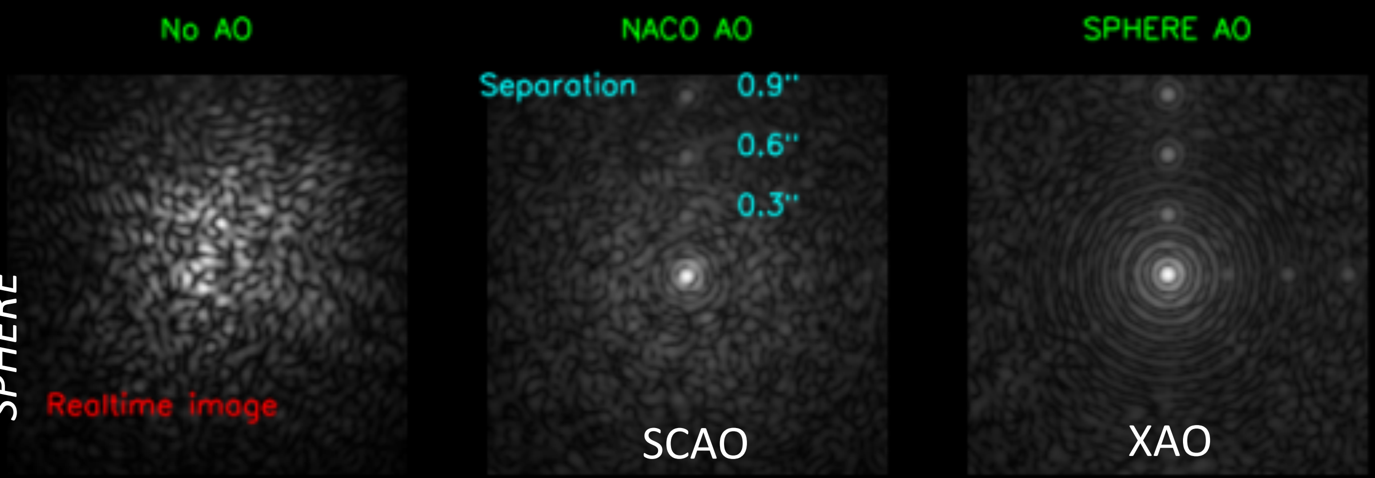
GPI

Extreme AO (XAO)

- Gemini Planet Imager (GPI)
- SPHERE (ESO VLT)
- SCExAO (Subaru Telescope)
- LBT AO
- MagAO (Magellan Telescope)

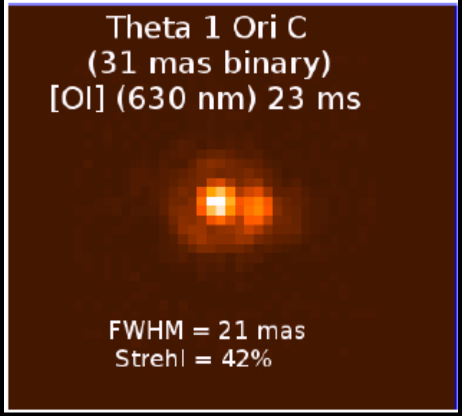
GPI





SPHERE

MagAO

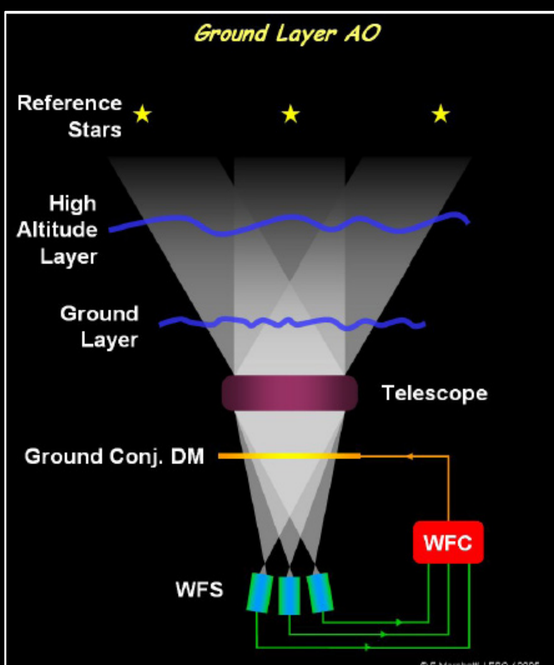


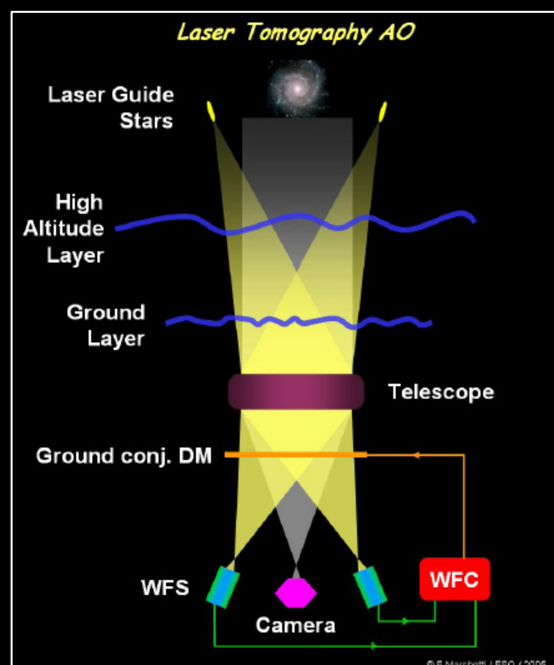
Ground-layer AO (GLAO)

- Science goal: improve image quality over large FOV (>> θ_0), but not up to diffraction limit
- Technical goal: decrease uniformly FWHM by factor of 2-4 ("super-seeing")
  - Use multiple guide stars
  - Single DM conjugated to ground layer: neglect turbulence from high atmosphere

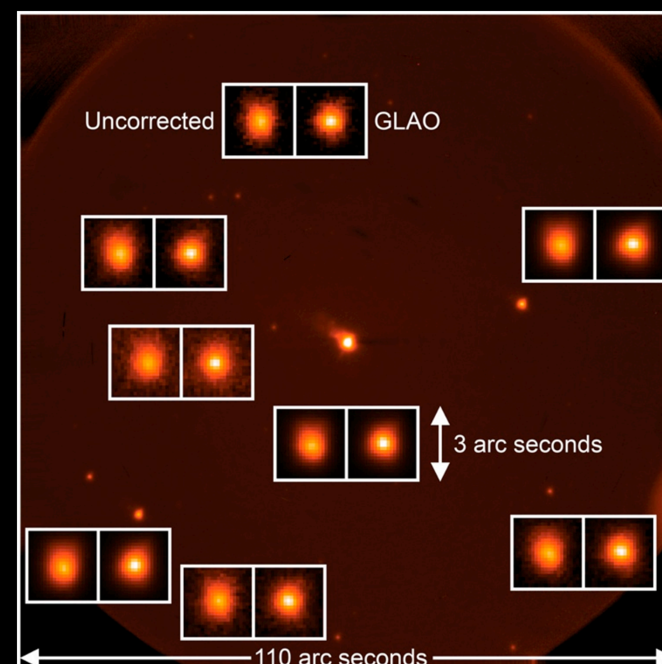
Ground-layer AO (GLAO)

- Possibly of interest to all ground-based telescopes (better image quality)
- Requires tomographic reconstruction



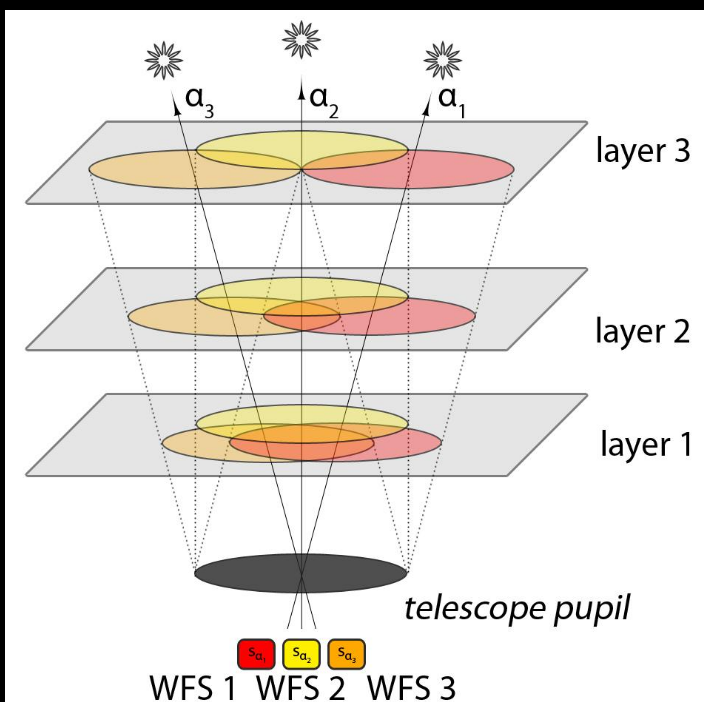


MMT

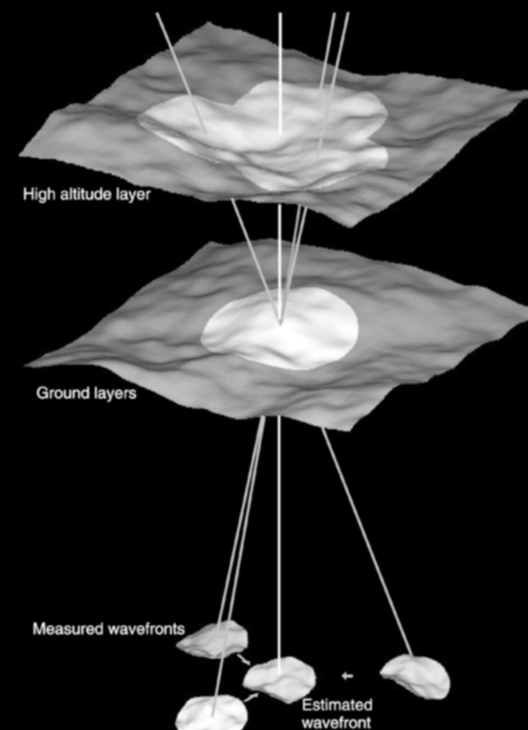


Tomographic reconstruction

- Different lines of sight intercept turbulent layers at different location, in principle enabling to separate contributions



Helin & Yudytskiy (2013)

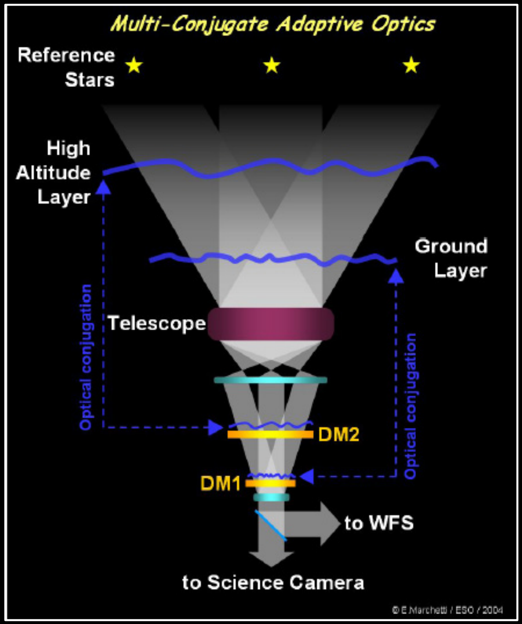


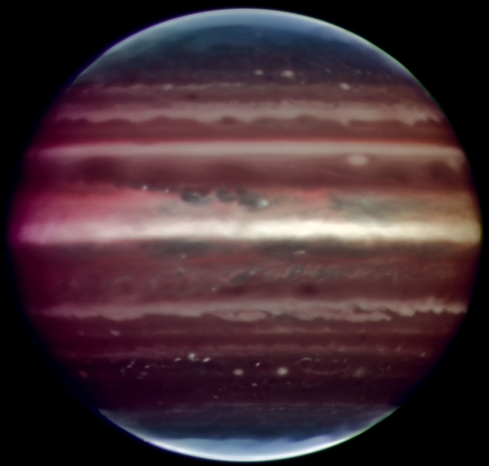
Ragazzoni et al. (2000)

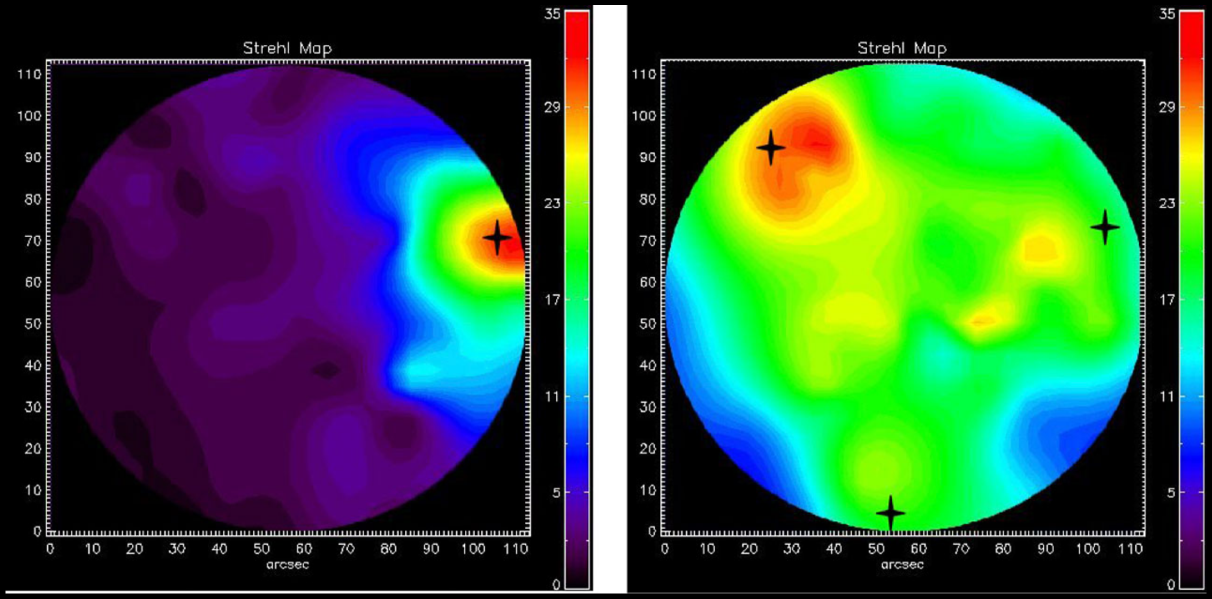
Multi-Conjugate AO (MCAO)

- Science goal: obtain diffraction-limited images over large FOV (>> θ_0)
- Technical goal: correct turbulence at all elevations over whole FOV (modest Strehl)
  - Use multiple guide stars
  - Use 2 or more DMs
- Requires tomographic reconstruction

Multi-Conjugate AO (MCAO)



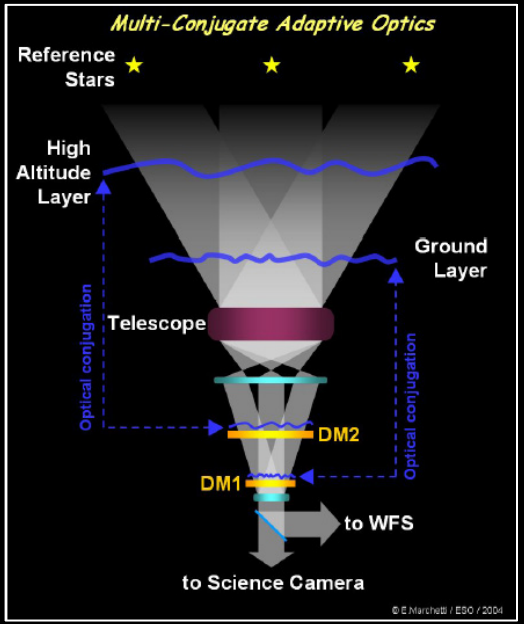


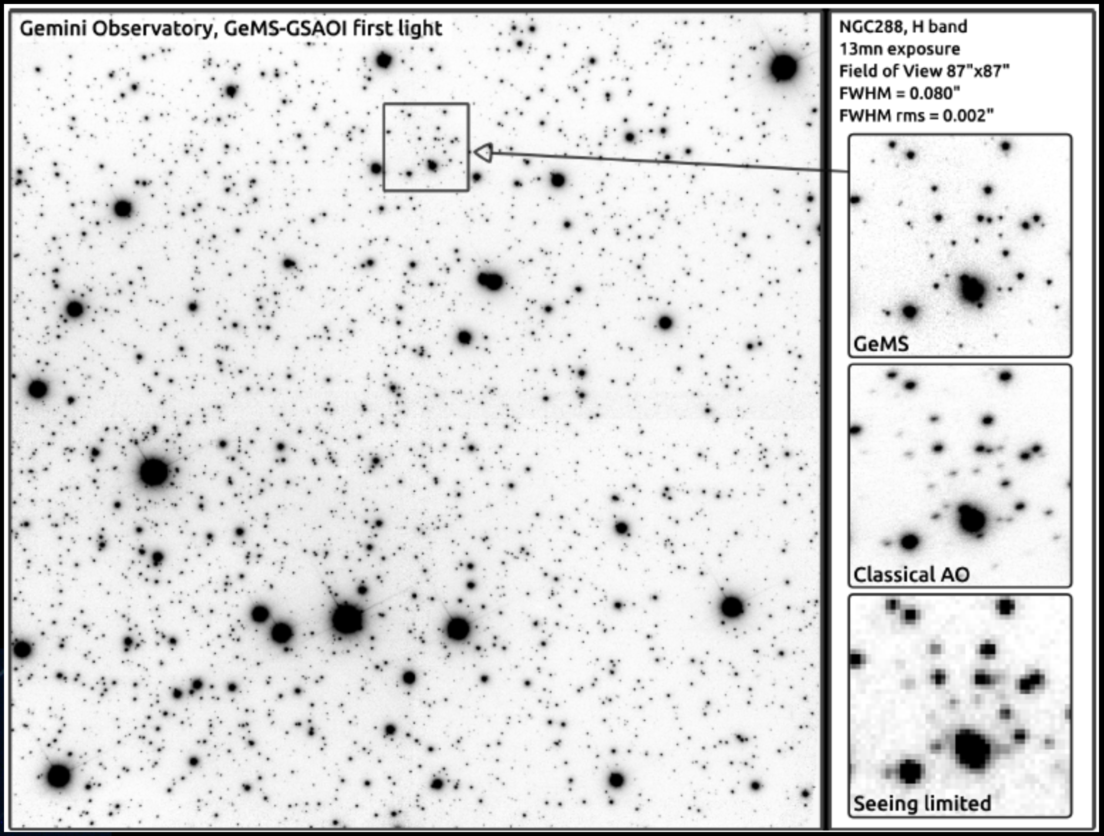


SCAO

MAD (3 NGS, 2 DM)

Multi-Conjugate AO (MCAO)





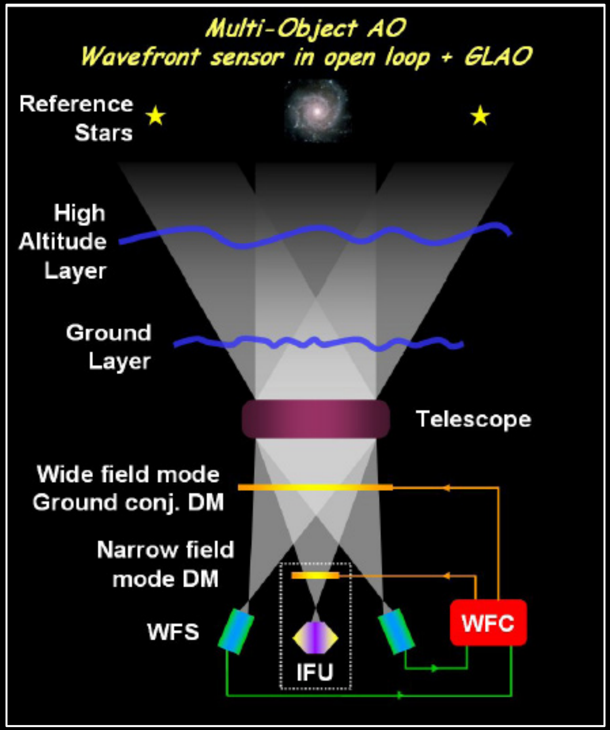
GeMS (5 LGS + 3 NGS. 3DM)

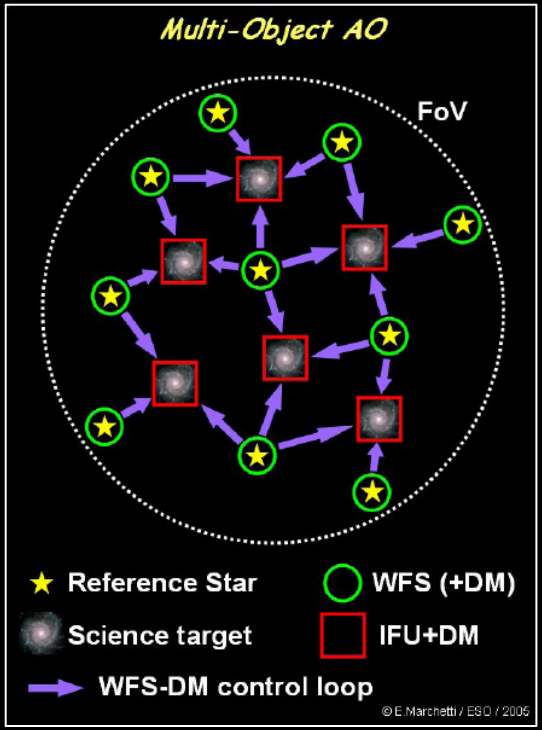
Multi-Object AO (MOAO)

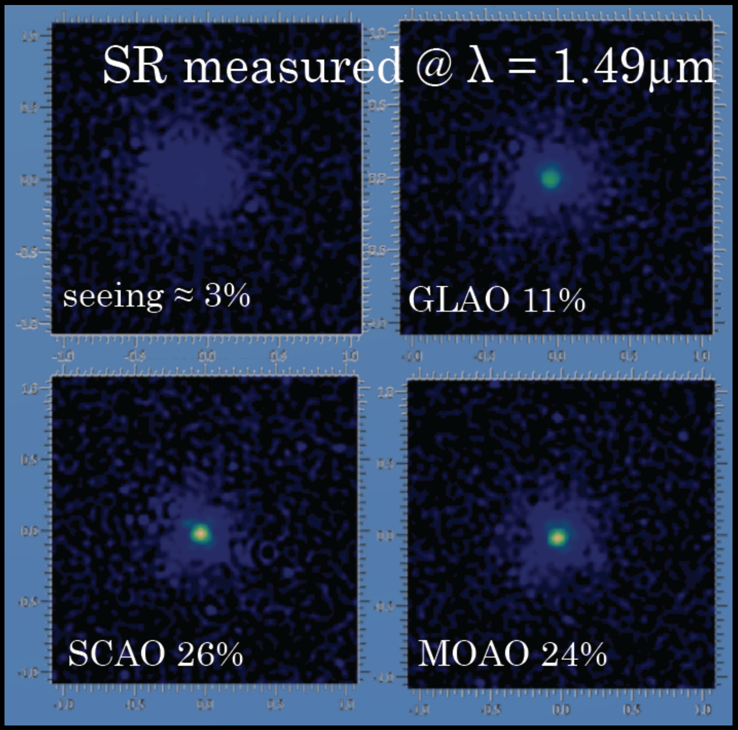
- Science goal: combine AO with small-FOV multi-object observations over large FOV
- Technical goal: decrease FWHM in discrete number of small spots
  - Multiple guide stars
  - Multiple DMs (one per science FOV)
  - One extra ground-layer DM can help
- Requires tomographic reconstruction
- Complex optical set-up and control (open loop)

Multi-Object AO (MOAO)

- Achieving SCAO-equivalent correction in open loop is possible!







CANARY

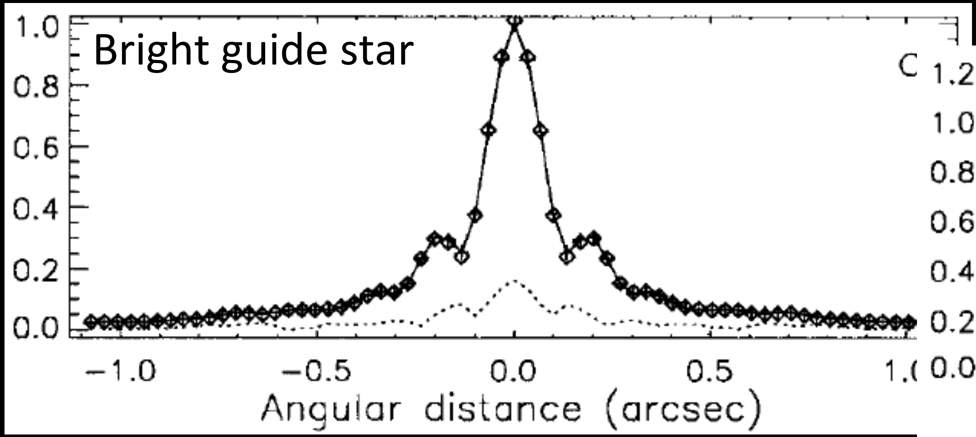
AO post-processing

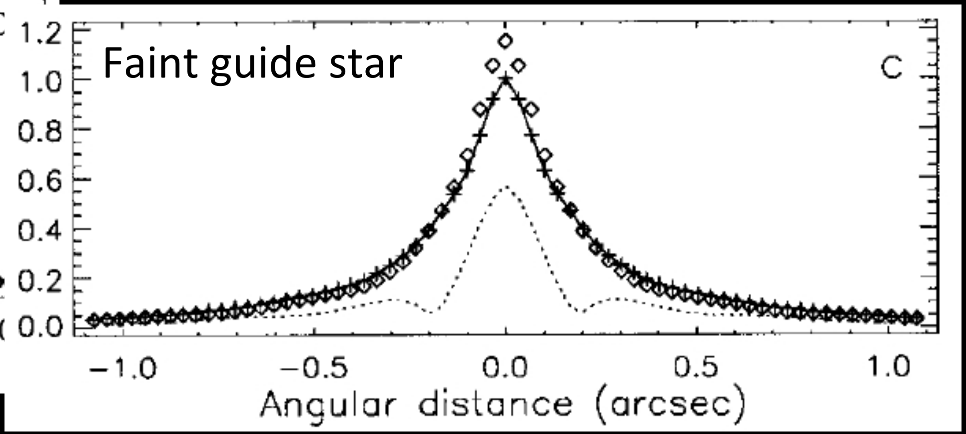
Doing science with AO

- AO acts as a "pre-instrument", feeding "normal" instruments
  - Same data analysis as normal observing
- However, precise knowledge of PSF is needed
  - A simple Gaussian/Voigt model does not work!
- Not an easy task:
  - Off-axis point sources suffer from anisoplanatism
  - Non-contemporaneous observations probe a different realization of the turbulence

Predicting the PSF

- One can/should use data from the AO system itself (WFS data, DM commands, ...) to predict the PSF
  - Works well for high SNR cases, but fails for faint guide stars due to noise propagation





Véran et al. (1997)

Post-processing techniques

- Many techniques can be applied, depending on the scientific goal:
  - Improved "data reduction" (e.g., alignment of individual images)
  - Image filtering (e.g., edge sharpening)
  - Forward model fitting (need to know PSF!)
  - Deconvolution (need to know PSF!)

Deconvolution

- Two main families:
  - "regular" assumes PSF is known
  - "myopic"/"blind" treats PSF as a (partial) unknown
- All techniques rely on "penalty terms" and regularization methods
  - Positivity
  - Continuity
  - Smoothness
  - Finite support (PSF has to be λ/D in size)

Deconvolution

- Deconvolution can/should also take advantage of "diversity" whenever possible:
  - Multiple images with same set-up
    - Different realizations of noise/turbulence/AO correction
  - Multi-wavelength (simultaneous) images
    - Use knowledge about chromatic behavior of object
    - Use dual polarization imaging
  - Multi-aperture images (e.g., concentric annuli)
    - Simultaneous images with different resolutions and enforce continuity in spatial frequency domain

Deconvolution

- Many existing algorithms:
  - Maximum Likelihood
  - Lucy-Richardson (Richardson 1972, Lucy 1974)
  - CLEAN (Högbom 1974) [ten Brumelaar 1996]
  - IDAC (Jefferies & Christou 1993) [Christou 1999]
  - MISTRAL (Mugnier et al. 2004)
  - AIDA (Hom et al. 2007)
  - …

Next week readings

- AO and laser propagation (J. Ballesta's presentation)
- Course wrap-up