Point Spread Function (PSF) measurement, calibration and deconvolution.

CfAO Fall Retreat - 2002

Center Activities

- **Cross Theme discipline**
  - Necessary for vision science and for astronomical applications
- **PSF measurement**

  In order to calibrate, a PSF first needs to be measured.

  - Astronomy: nearby point source if one is available. However how does one deal with spatial variability of the PSF: Anisoplanatism (*Faber*, *Steinbring*, *Christou*).
  - Astronomy: no point reference available, use the wavefront sensor data to generate a statistical PSF for long exposure astronomical imaging (*Veran, Rimmele, Jolissaint, Marino*)
  - Astronomy: extract PSF from the data itself. e.g. “blind” deconvolution, photometric fitting algorithms (*Christou, Marchis, Pugliese, Koehler*)
  - Astronomy: using the PSF, e.g. forward modeling, deconvolution (*Larkin*)

Center Activities

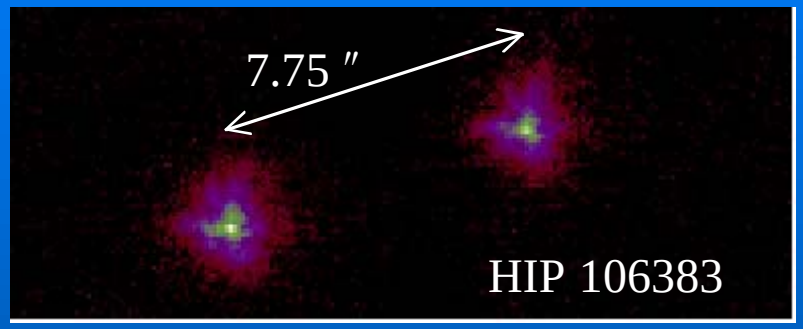
- Vision Science: no point source in the f.o.v., extract PSF from the data itself. e.g. “blind” deconvolution (*Christou, Marchis*)
- Vision Science: wavefront sensor measurements in either closed or open loop (*Williams, Roorda, Miller, Campbell*)

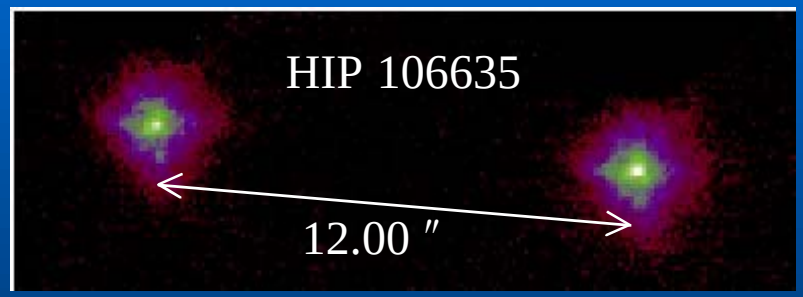
- **Other image processing activities**
  - Image registration and enhancement: what is the best method to align images with complex structure (e.g. retinal images) (*Milanfar, Farsiu, Miller, Jonnal, + others*) and how to use the inherent sub-pixel dither to increase resolution.
  - Image Remapping: Scanning techniques introduce a warping into the point-by-point reconstructed image further complicated by 3D effects, e.g. AOCSLO (*Hebert*)

Anisoplanatism: PSF Spatial Variability

- **Short-Exposure Measurements**
  - These permit measurements of differential tip-tilt motion (anisokinetic) as well as high-order anisoplantism, the change in structure of the PSF with separation. Comparison of differential tip-tilt motion to models permits improved understanding of the use of an off-axis guide star for LGS measurements. (*Christou et al.)*
- **Long-Exposure Measurements**
  - Understanding the effects of anisoplanatism over large fields when using LGS compensation. (*Steinbring et al.)*
- **Real-time telemetry & atmospheric measurements**
  - .Data is and will be taken at the focal planes of Keck and Gemini in conjunction with LIDAR measurements od the atmosphere. These combined measurements will strengthen the atmospheric models used to predict behaviour for larger apertures. (*Steinbring et al.)*

Low-order and high-order anisoplanatism within the Isoplanatic Patch





Data obtained from Lick Observatory AO System, August 2001. (2.2μm).

t_{exp} = 57ms 250 frames.

(More data taken Oct 2002 for a much wider range of separations – 5-16")

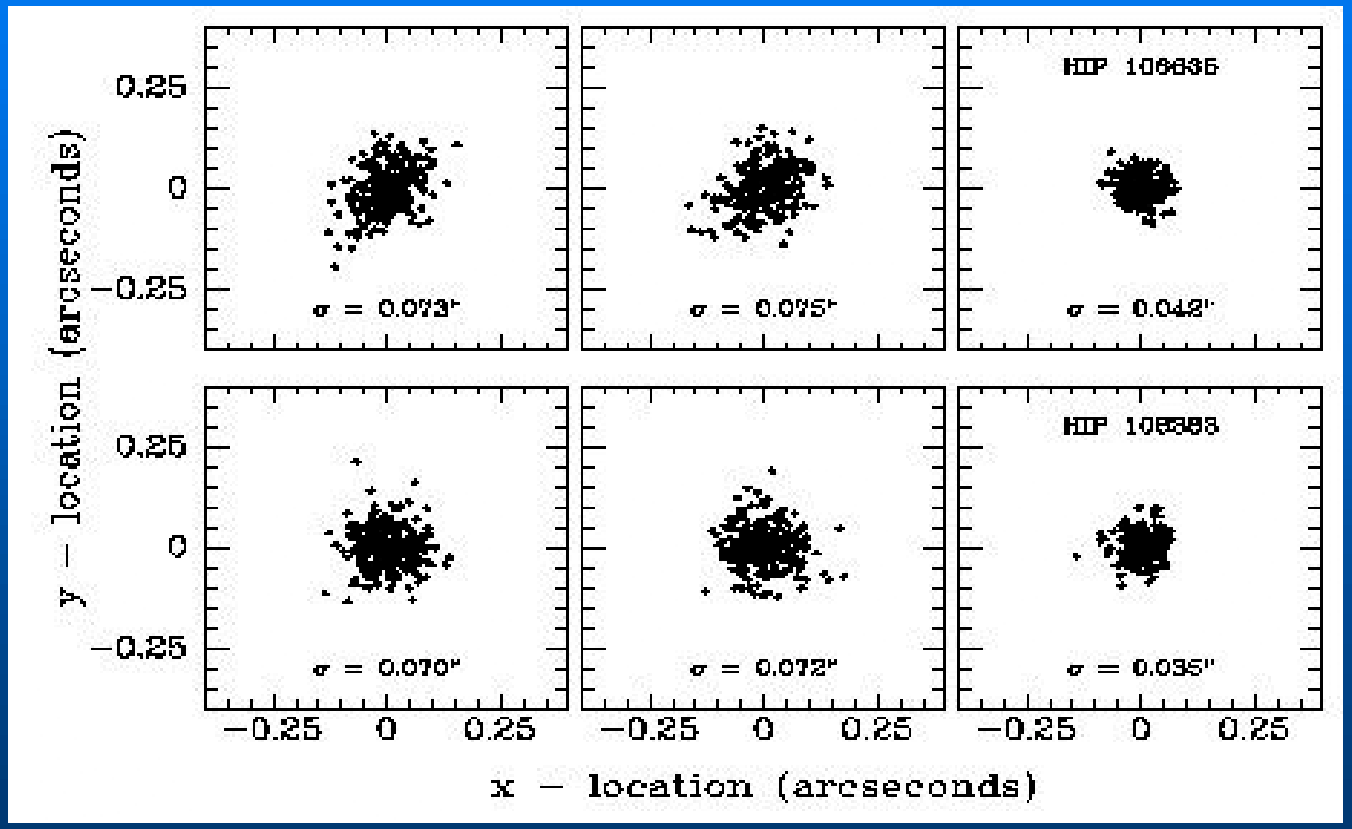
Anisoplanatism measurements

Strehl Ratio measurements

$$S_{\text{off-axis}} = S_{\text{on-axis}} \exp\left[-\frac{\grave{e}}{\grave{e}_0}\right]^{\frac{5}{3}}$$

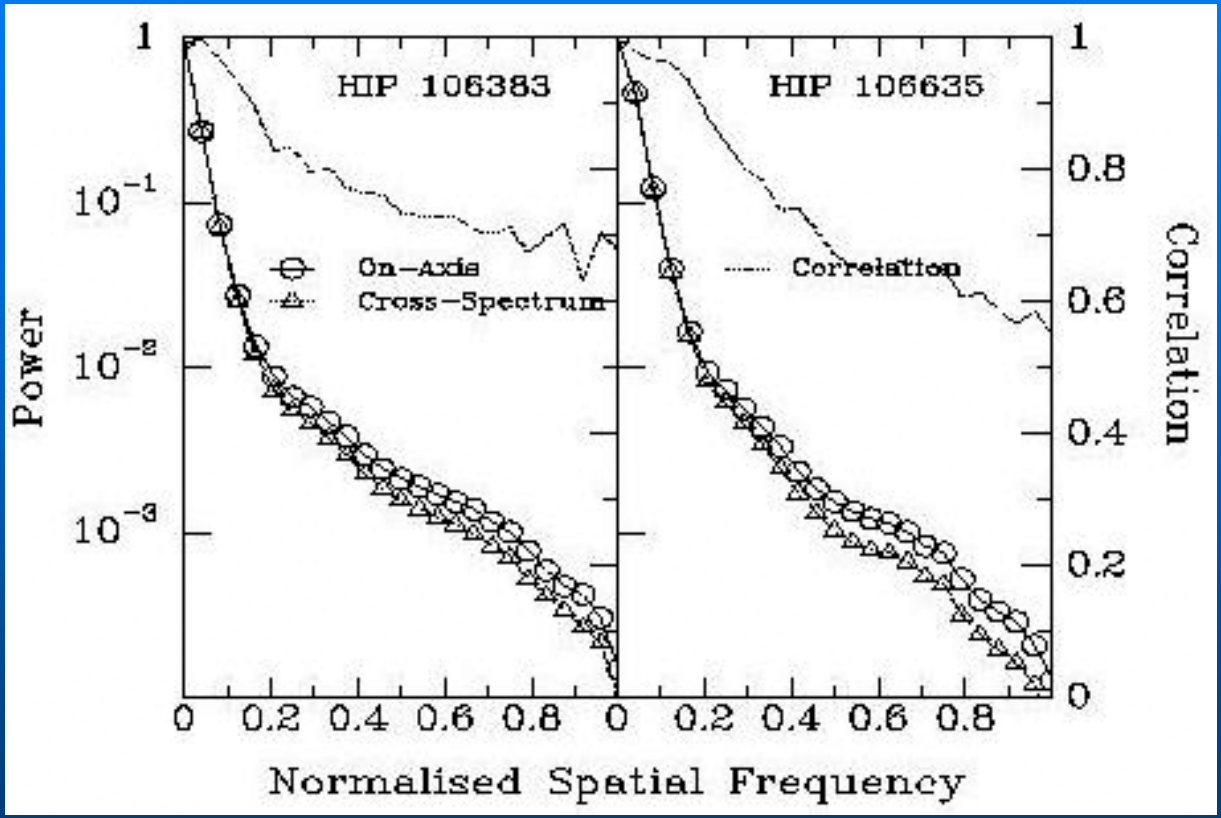
Binary Star	Loss in Strehl Ratio	Isoplanatic angle θ_0
HIP 106383	0.89 ±0.15	28.1″
HIP 106635	0.74 ±0.13	24.7″

Low-order anisoplanatism within the Isoplanatic Patch



Differential image motion ≈ 26% - 33% of the diffraction-limit - negligible

High-order anisoplanatism within the Isoplanatic Patch

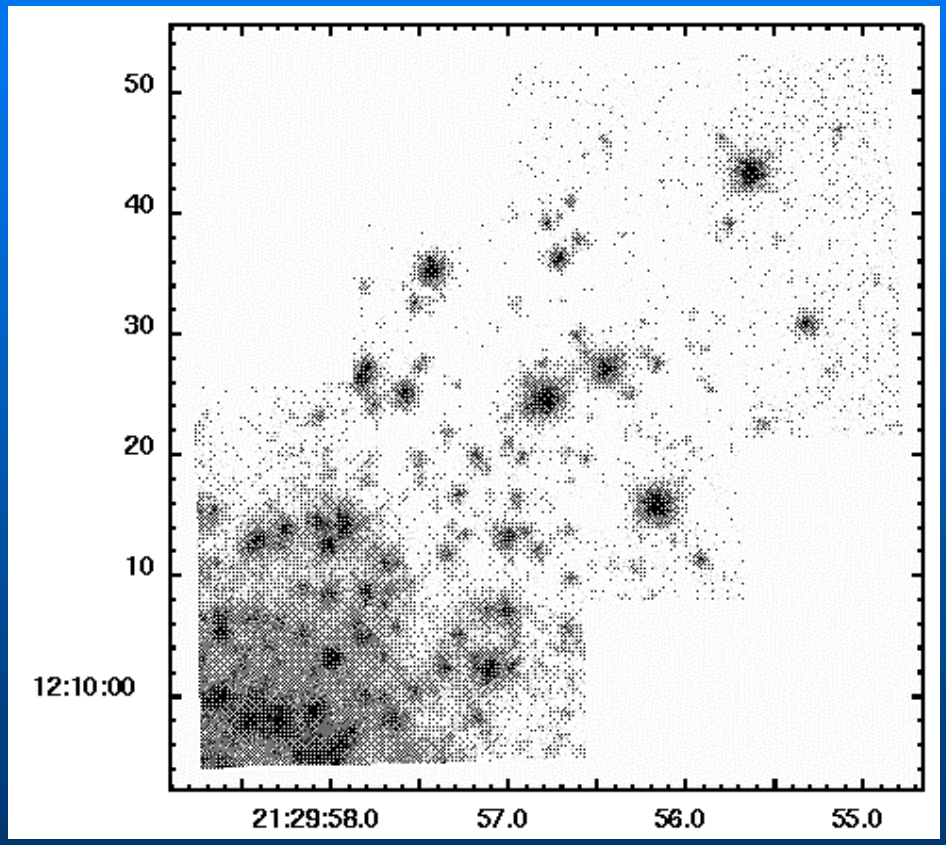


The Isoplanatic Parameter

Loss of high-spatial frequency information reduces effectiveness of deconvolution procedures.

$$\gamma(\vec{f}) = \frac{\langle P_2(\vec{f}) P_1^*(\vec{f}) \rangle}{\langle P_1(\vec{f}) P_1^*(\vec{f}) \rangle} = \frac{\langle P_2(\vec{f}) P_1^*(\vec{f}) \rangle}{\langle |P_1(\vec{f})|^2 \rangle} = \frac{\langle XS(\vec{f}) \rangle}{\langle |P_1(\vec{f})|^2 \rangle}$$

Characterizing the AO Off-Axis PSF: Status Report - NGS



Lick AO natural guide-star mode (September 2000)

K-band mosaics of M15 over 7 hours per night for two nights

r_0 measurements from WFS telemetry

Windspeed measurements from nearby weather tower

Prediction of PSF variation based on semi-empirical method, reduces error from about 60% in FWHM down to about 20%

(Steinbring, et al., 2002, PASP, 114, 1267)

Characterizing the AO Off-Axis PSF: Status Report - LGS