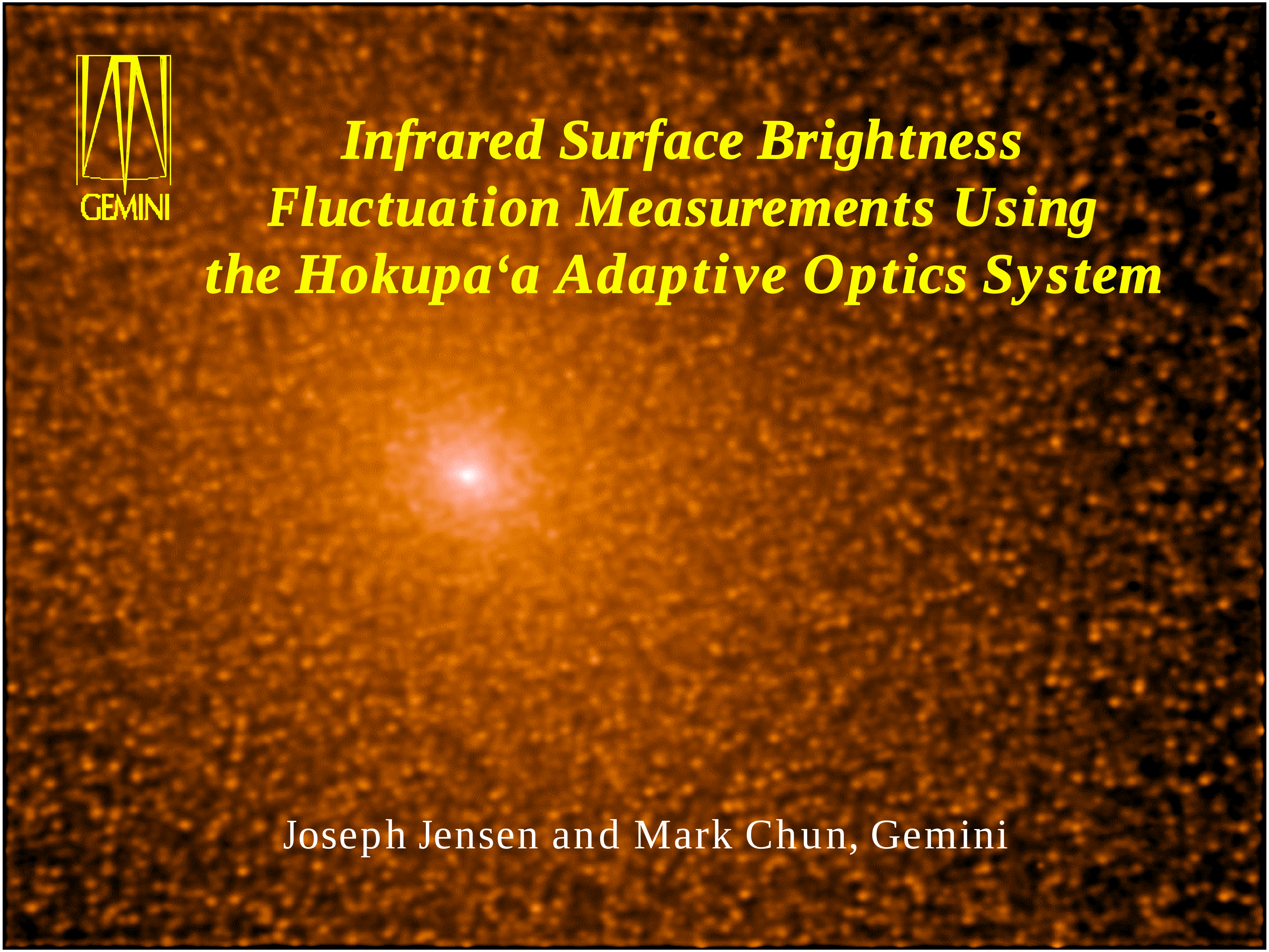
Infrared Surface Brightness Fluctuation Measurements Using the Hokupa'a Adaptive Optics System

Joseph Jensen and Mark Chun, Gemini



Overview

- IR surface brightness fluctuations (SBFs) are useful as a distance indicator to galaxies beyond 100 Mpc thanks to high-resolution imaging.

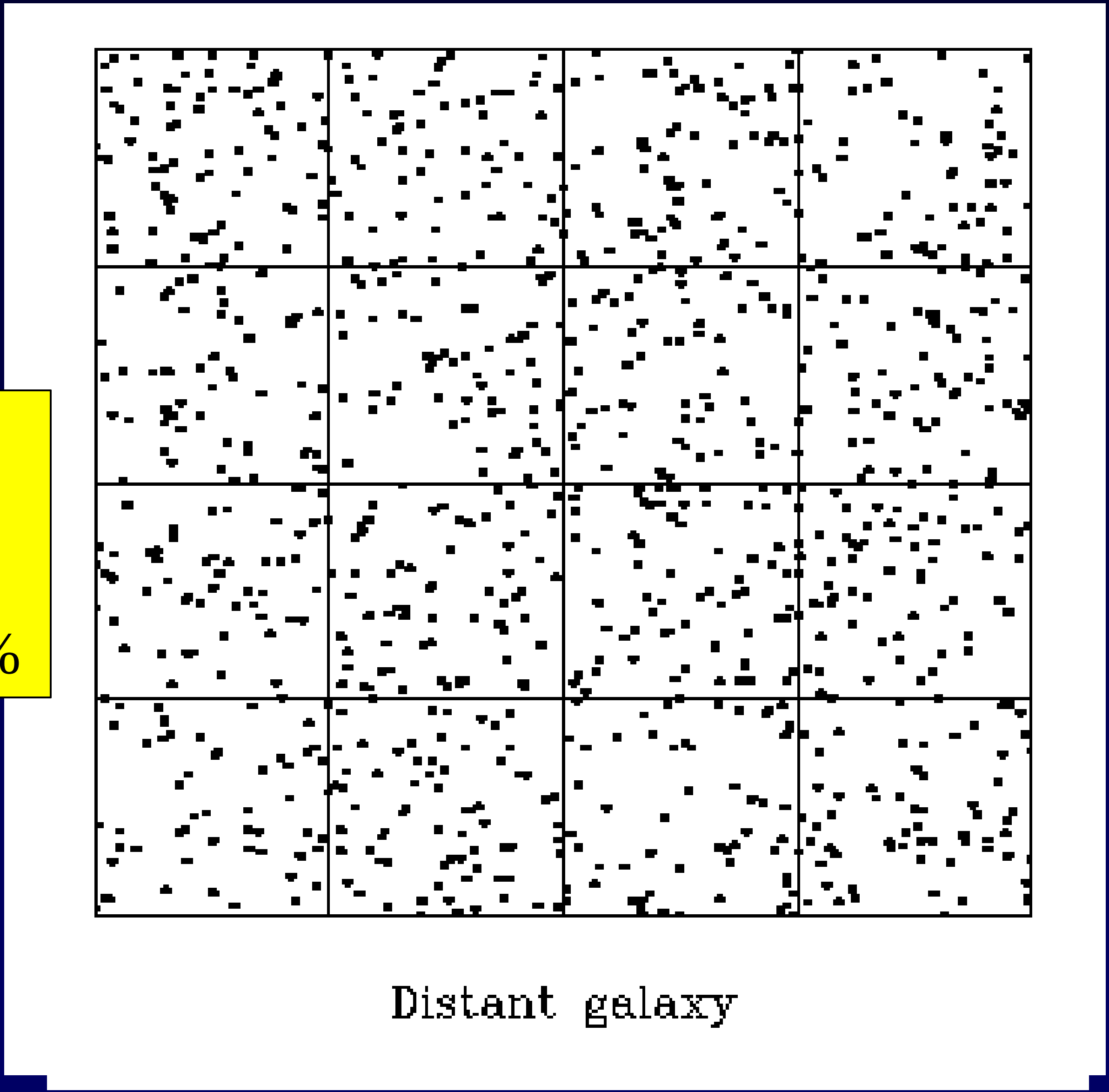
- Hokupa'a on Gemini can routinely produce image quality better than 0.1" FWHM using guide stars around 14^{th} mag. At 100 Mpc, a 10% distance measurement can be made in about 15 min on-source.

SBFs and Adaptive Optics

- Surface brightness fluctuations can be used as a unique tool for measuring PSF variation
  - Surface brightness fluctuations are convolved with the point-spread function
  - You don't need to resolve individual point sources
  - SBFs in nearby galaxies fill the field so the PSF can be measured anywhere the S/N is high enough

Surface Brightness Fluctuations as a Distance Indicator

- Relies on the Poisson statistics of stellar populations
- The "standard candles" are red giant stars—relatively well-understood creatures
- Well calibrated empirically (using Cepheids)
  - —Accurate to better than 10%
- Fluctuation magnitudes compare well to predictions of stellar population models

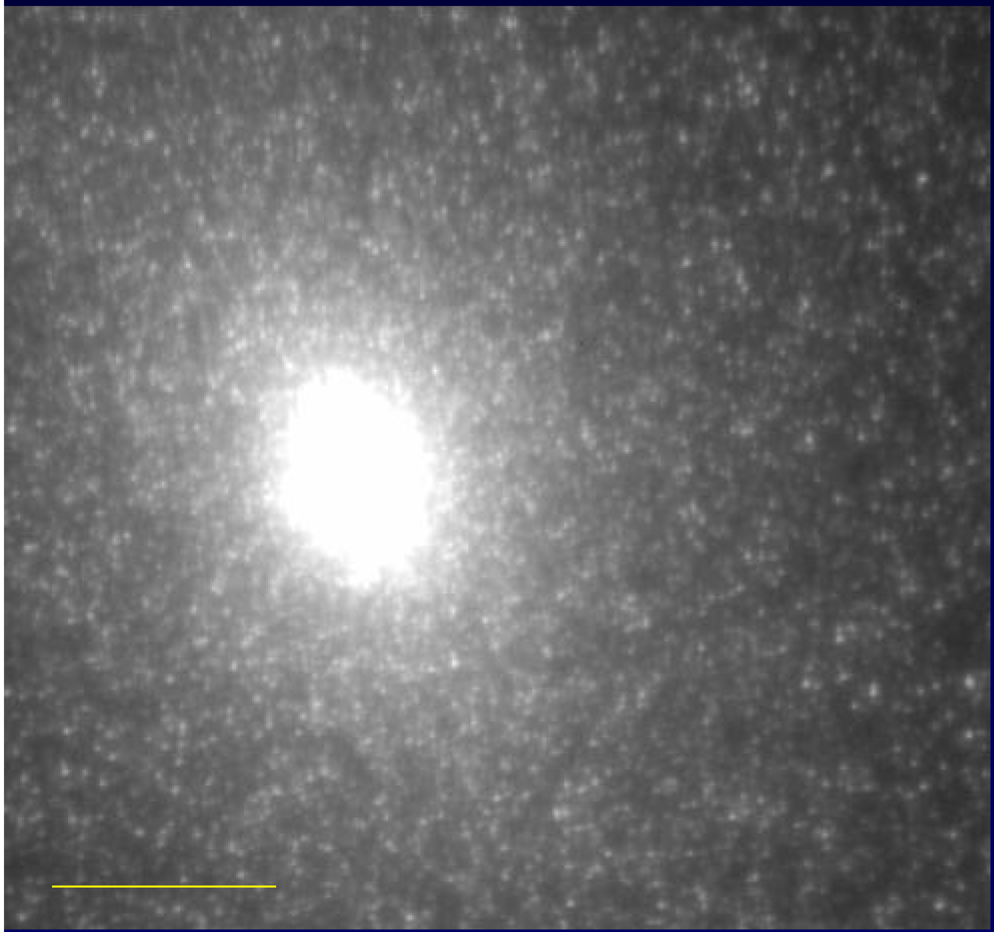


$\mu = 64$

$\sigma = 8$

$\sigma/\mu = 12.5\%$

Distant galaxies appear smooth compared to nearby ones.



M 32 (0.77 Mpc)

NGC 7768 (100 Mpc)

Why IR SBFs?

- Much less sensitive to extinction by dust
- 30 times brighter at *K* than at *I*

  (Red giants, the brightest stars in old populations, really are ***red!*** ***)***
- Seeing is much better in the near-IR (especially with AO)
- Integration time scales linearly with seeing
- Greater contrast of fluctuations with respect to globular clusters and background galaxies

➔ You can go much further using IR SBFs!

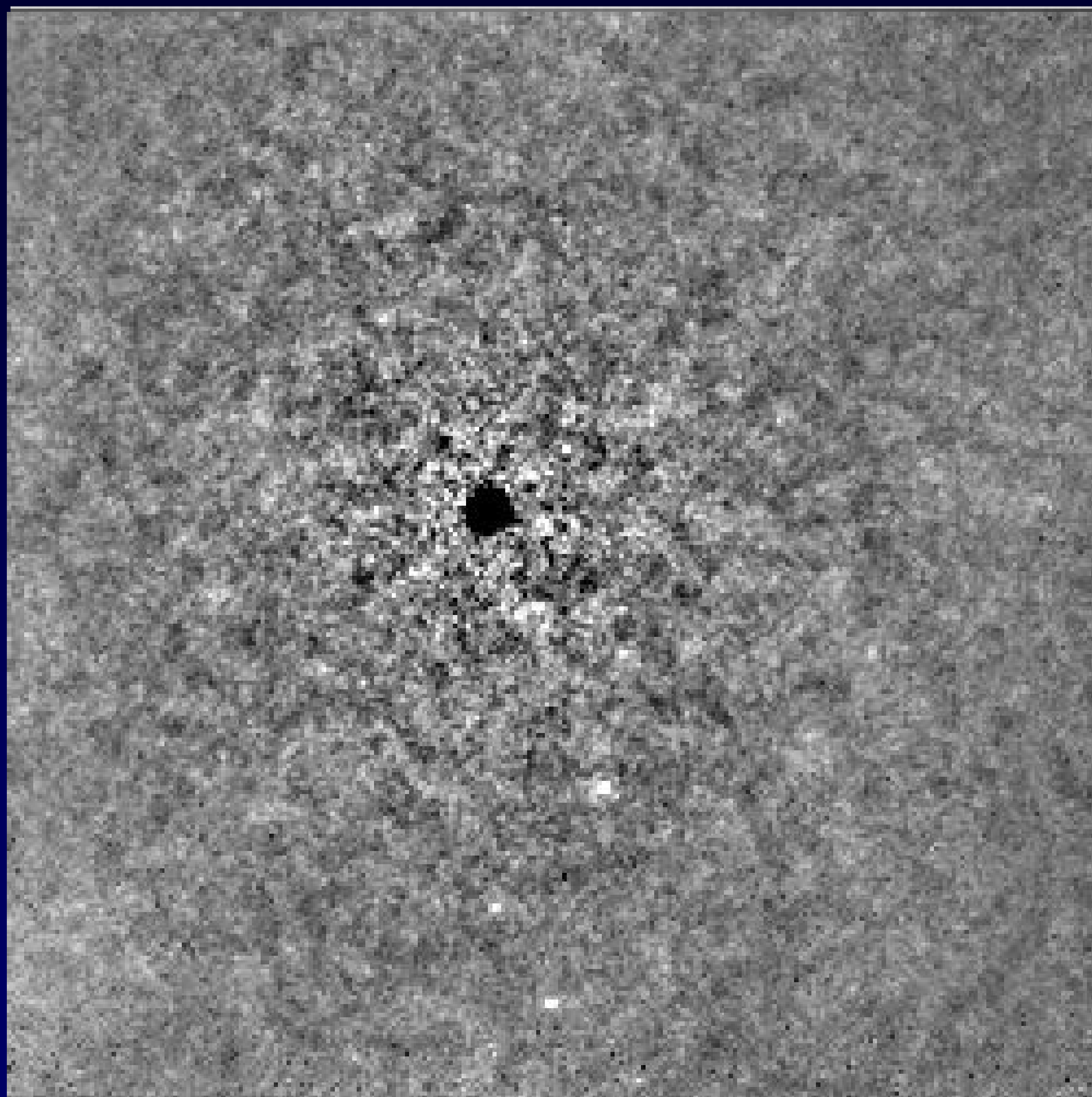
Potential Applications

- Determine the Hubble constant far enough out that peculiar velocities are negligible
- Establish the linearity of the Hubble flow out to 200 Mpc
- Explore the mass distribution in the local universe by mapping the peculiar velocity field
- Probe stellar populations in galaxies without resolving individual stars

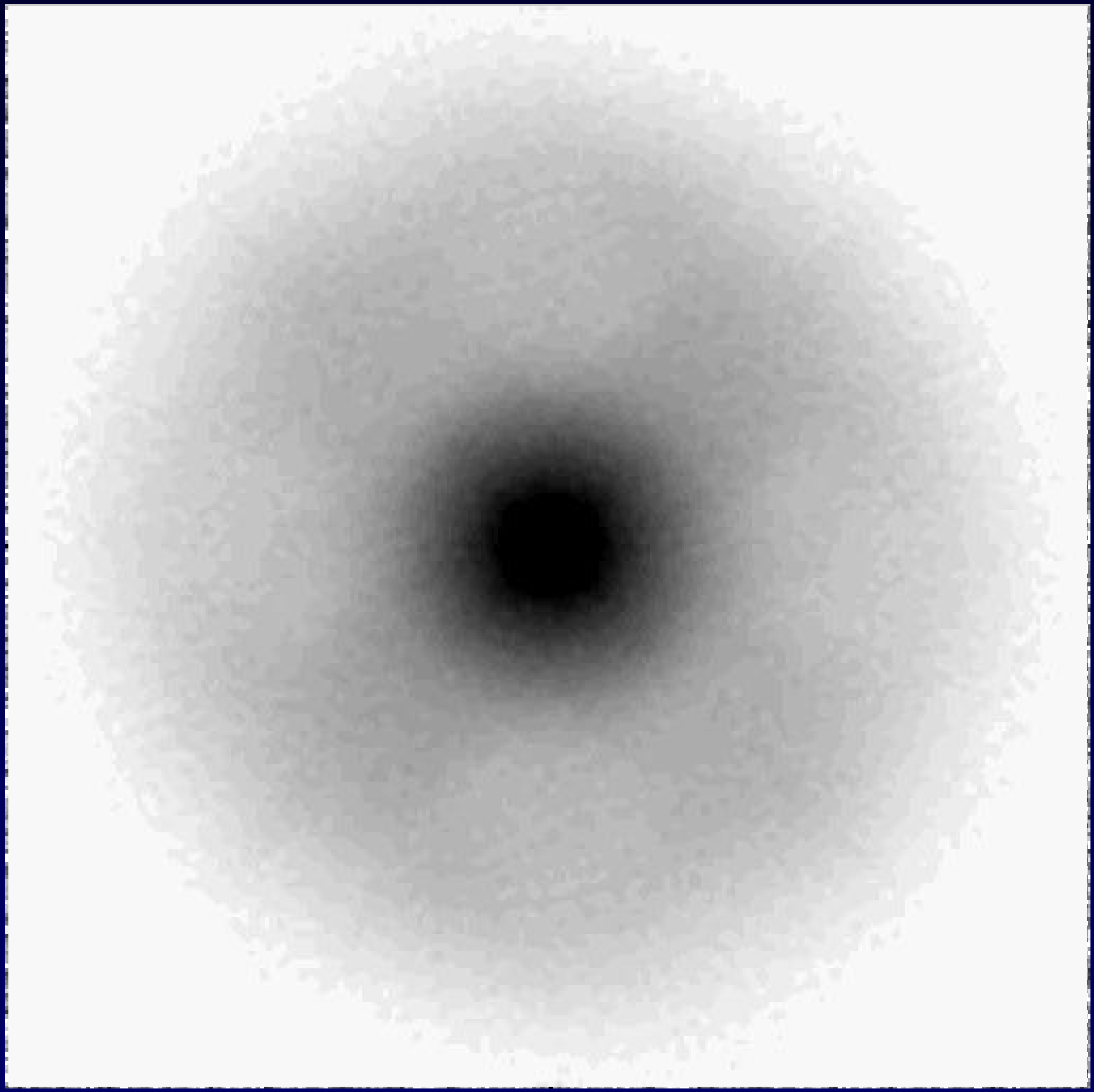
The basic procedure:

1) Get good, deep images of an elliptical galaxy
   - Use integer pixel registration to avoid correlations in the pixel-to-pixel noise
2) Subtract a smooth fit to the galaxy
3) Fourier-transform and compute the spatial power spectrum
4) Measure the power spectrum of the PSF
5) Fit the data spectrum to the sum of the scaled PSF power spectrum and a constant white noise component

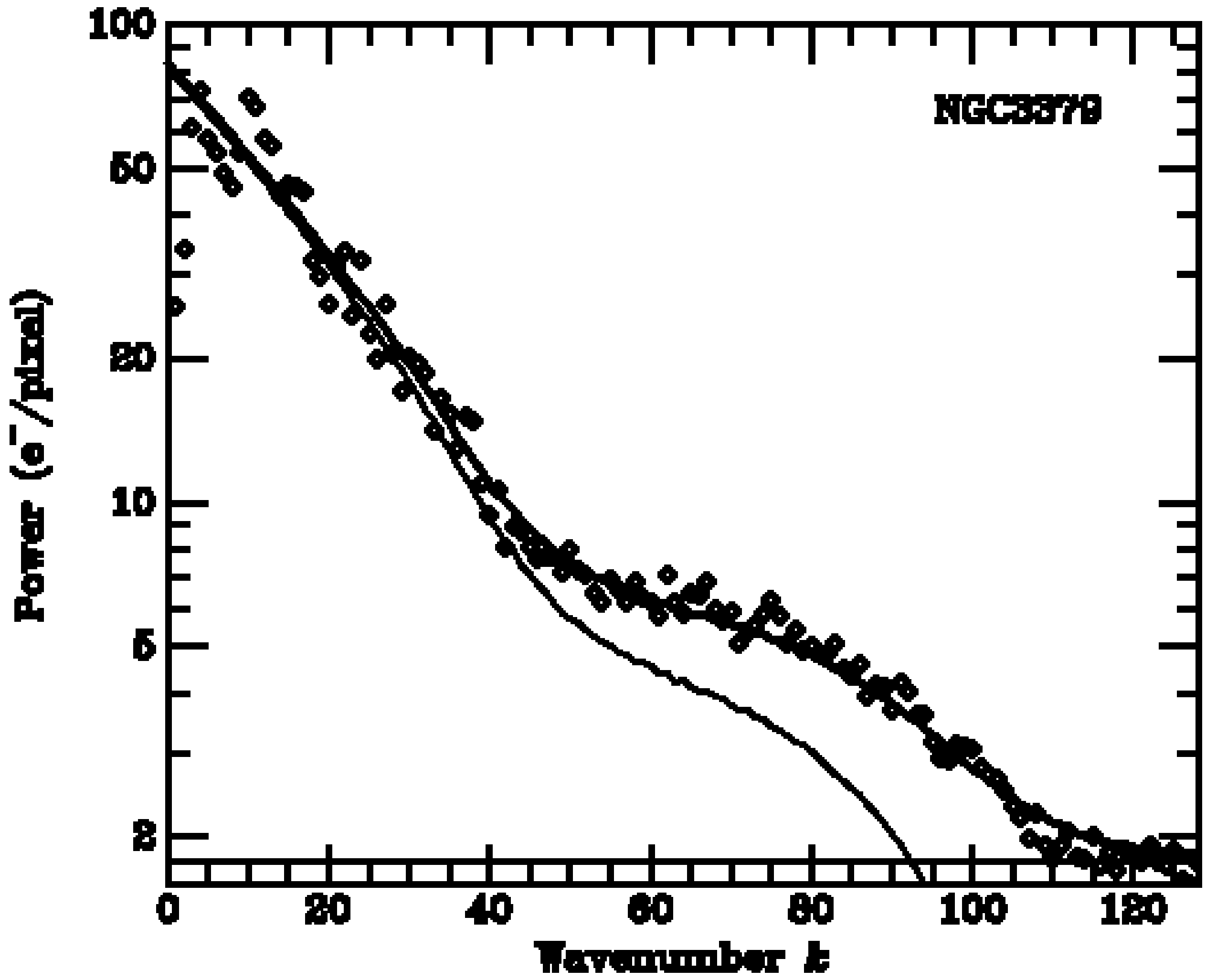
$$P_0 \times \mathrm{PSF}(k) + P_1$$



NGC3379



NGC3379



NGC3379
Power (e⁻/pixel)
Wavenumber k
100
50
20
10
5
2
0
20
40
60
80
100
120

H-band SBF Measurements

- To achieve minimal signal-to-noise at *H*, the integration time using Hokupaa on Gemini is:

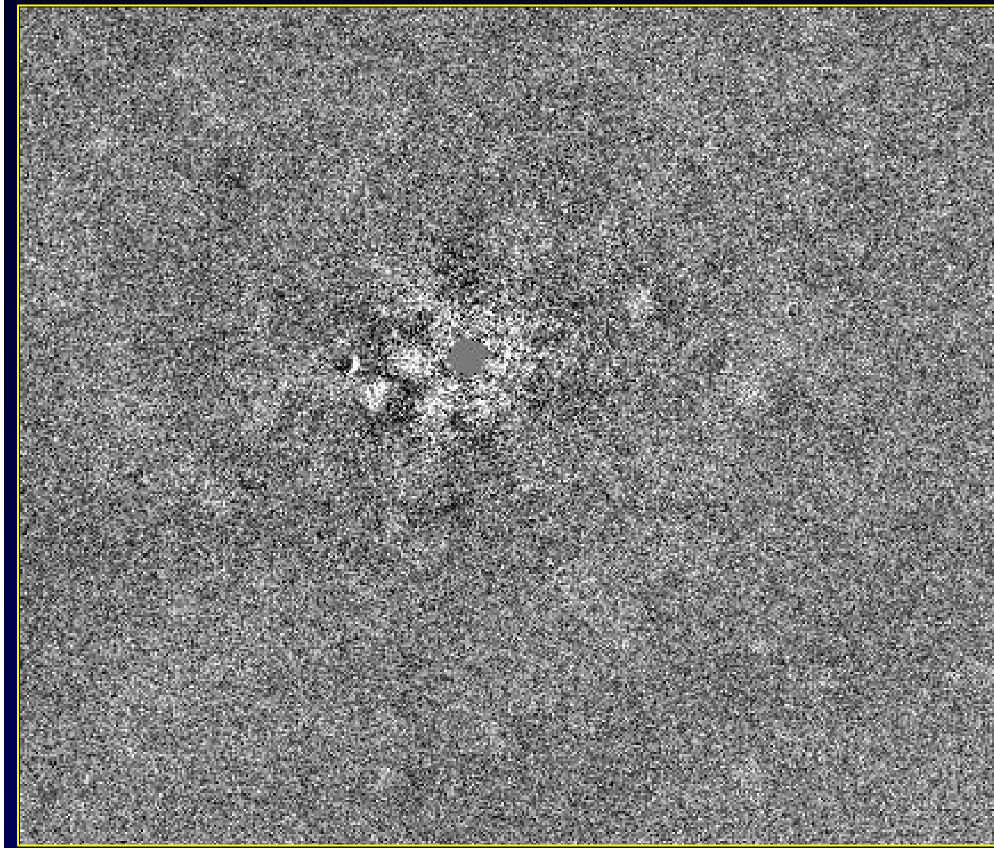
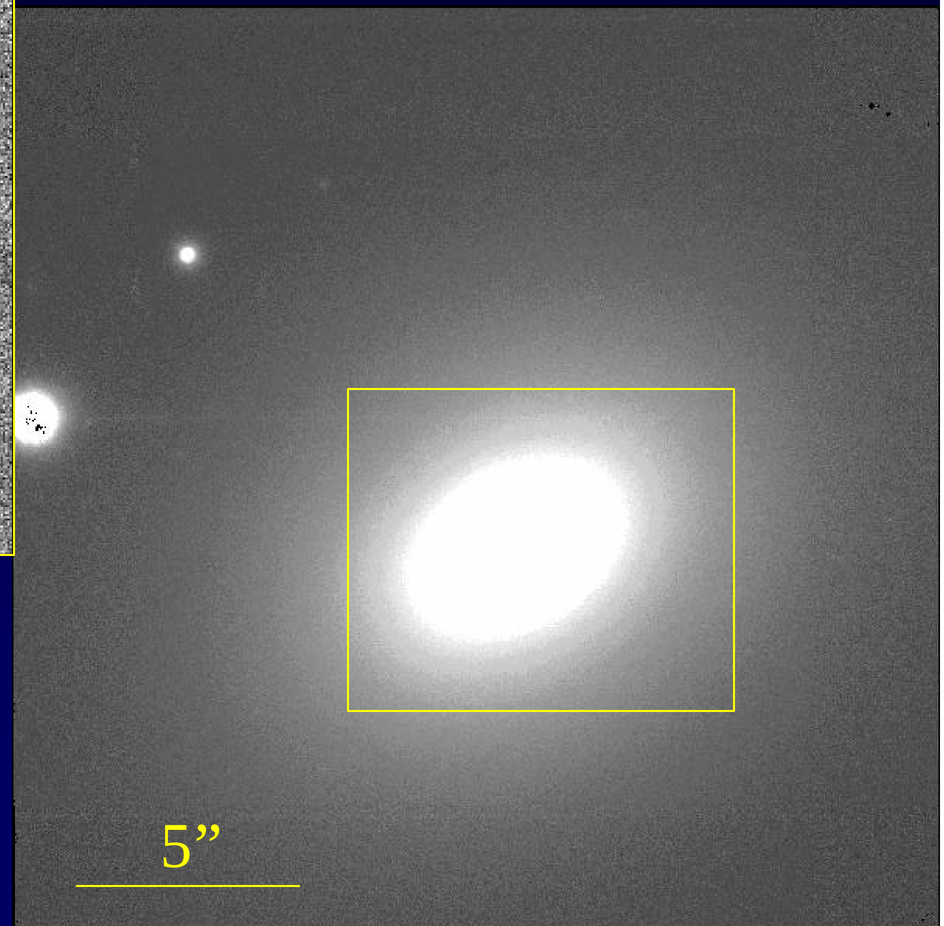
$$t\ (\mathrm{sec}) \approx 200 \times (cz\ /\ 1000\ \mathrm{kms}^{-1})^2 \times s\ (``)$$

  - → At Virgo, 30 sec will do
  - → For PSF measurements across the whole field of view, increase the exposure times by a factor of a few

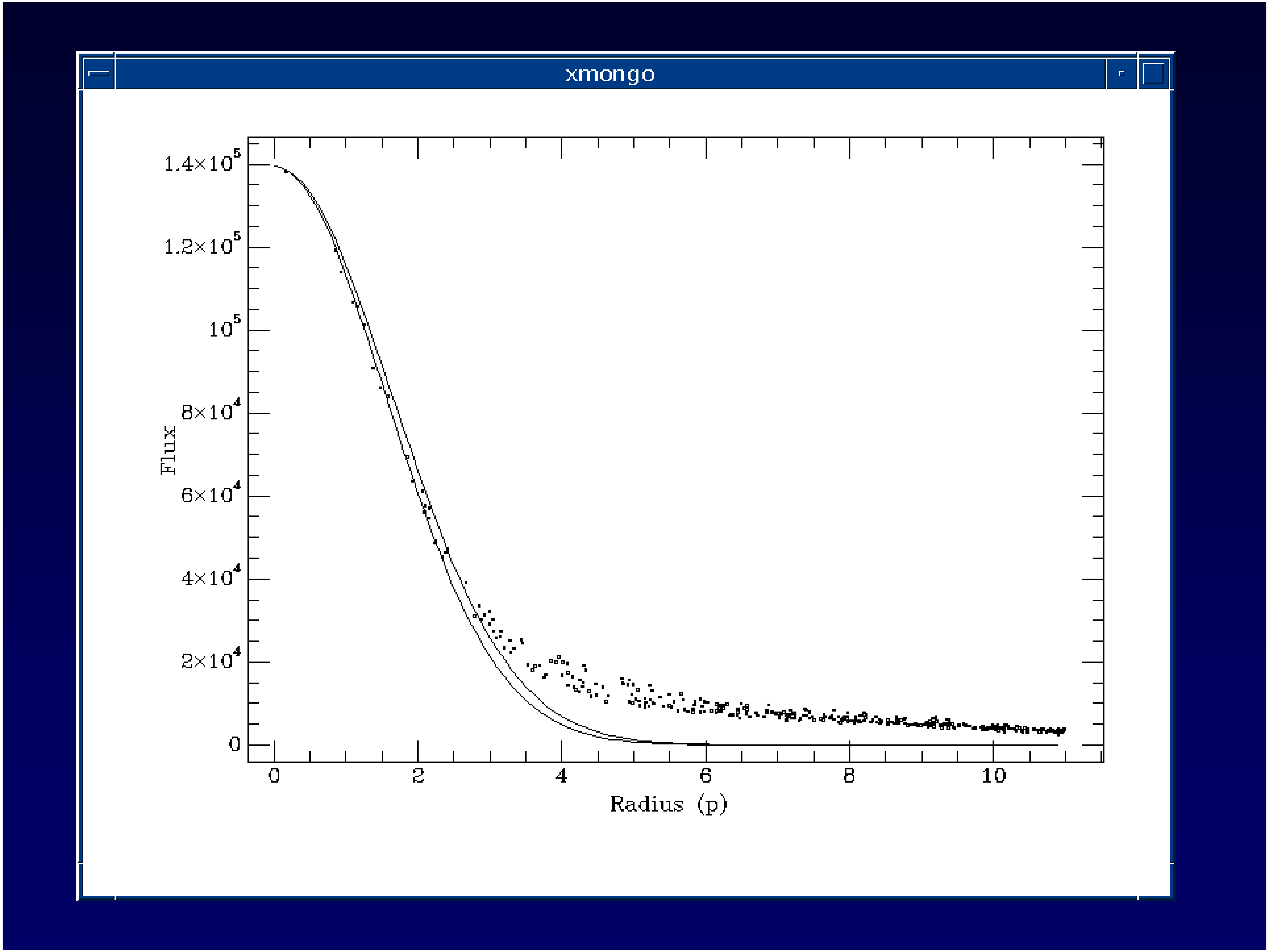
AO SBF Difficulties

- Spatial PSF variation
  - — Empirical and analytical PSFs can do the trick
  - — Or, the other way around: can SBFs be used to assess the level of PSF variation?

- Availability of natural guide stars
  - — Need relatively bright stars to get good correction
  - — Elliptical galaxy nuclei are typically too extended—M32 has a particularly high central surface brightness

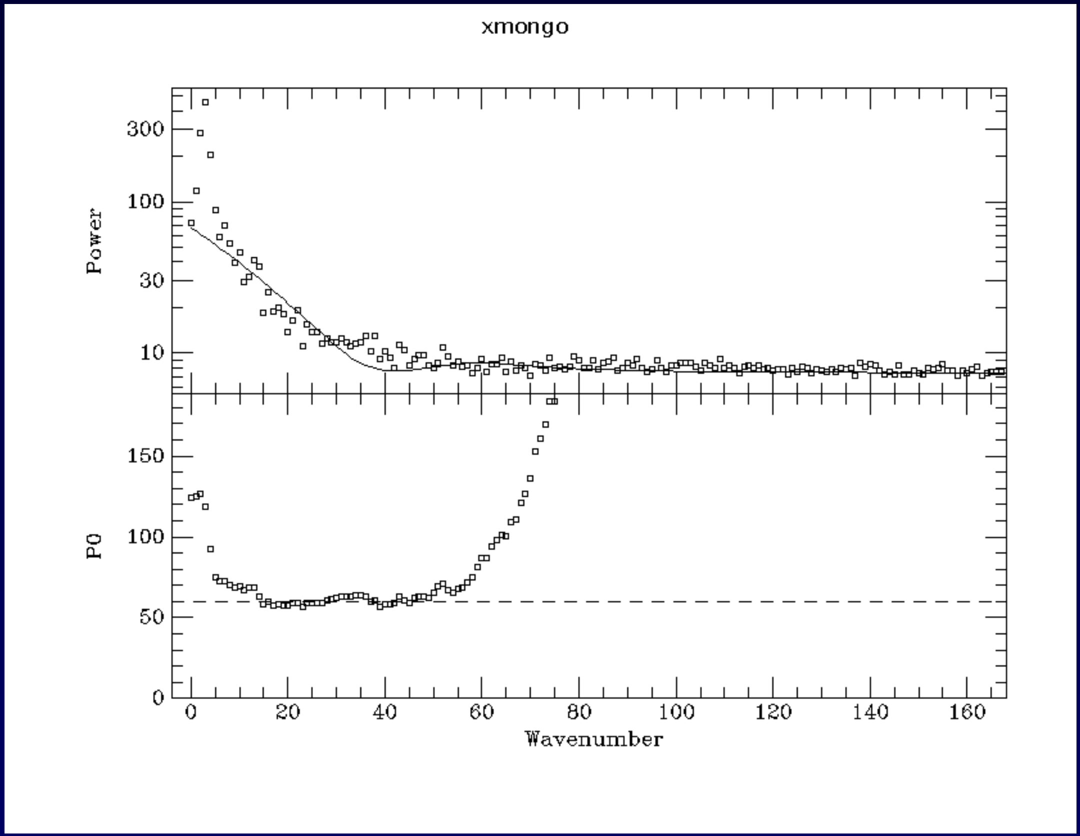
NGC 7768 (100 Mpc)


xmongo
Flux
Radius (p)
1.4×10^5
1.2×10^5
10^5
8×10^4
6×10^4
4×10^4
2×10^4
0
0
2
4
6
8
10

Spatial Variation of the PSF

A good PSF measurement is needed for SBF analysis:

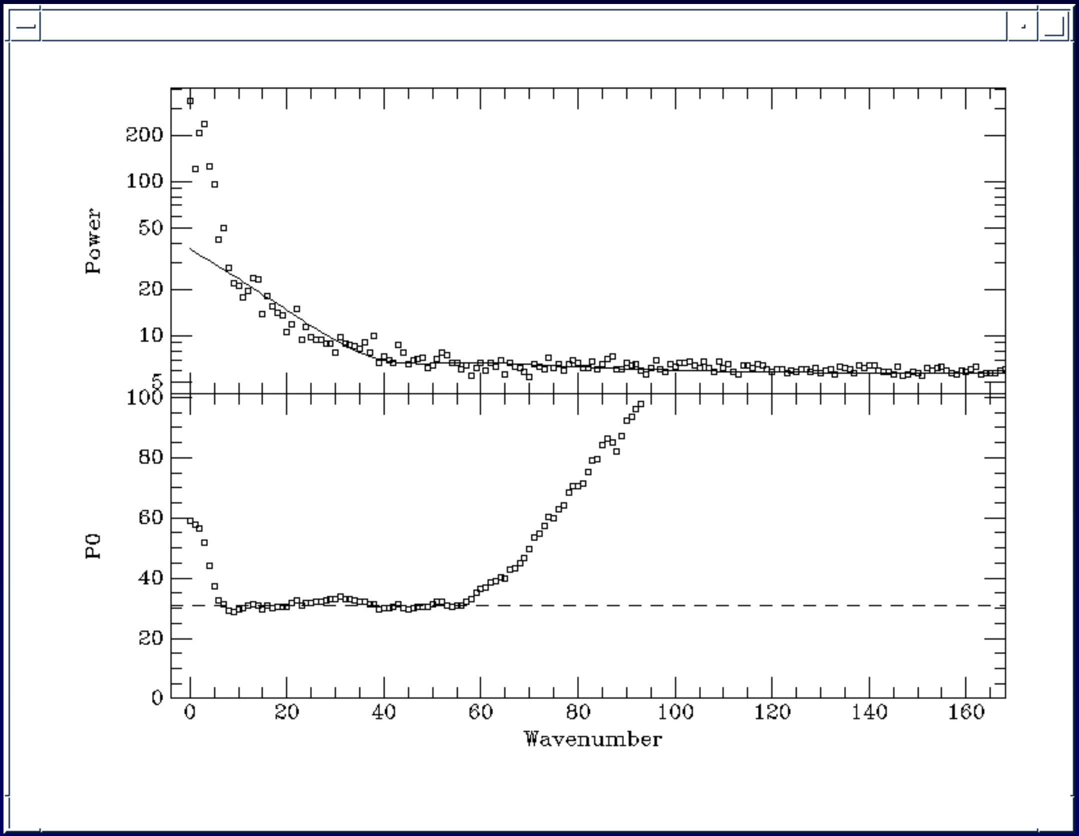
Note that the empirical PSF for NGC 7768 doesn't quite match the data.



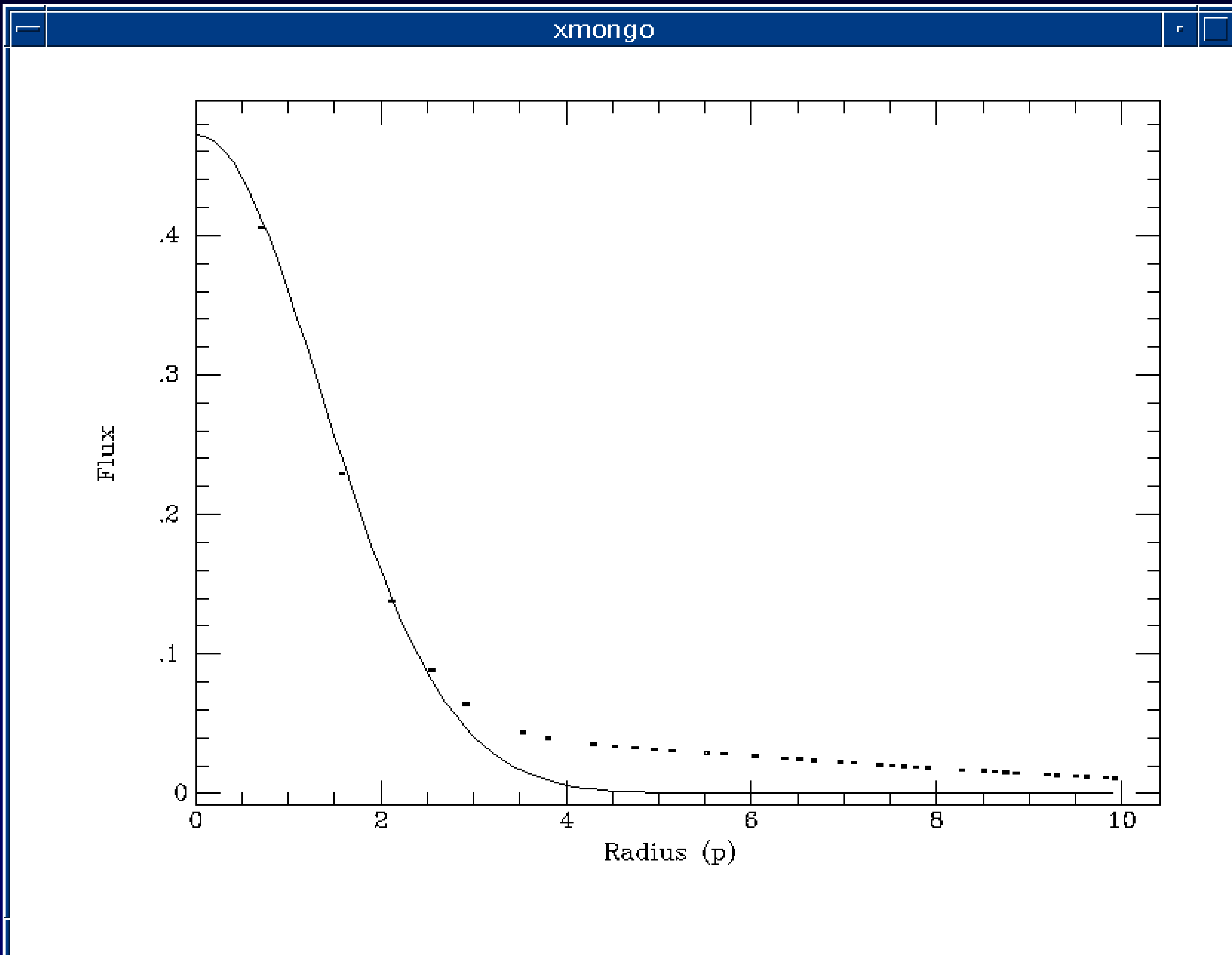
Spatial Variation of the PSF

A good PSF measurement is needed for SBF analysis:

Model PSF composed of two Gaussians does better

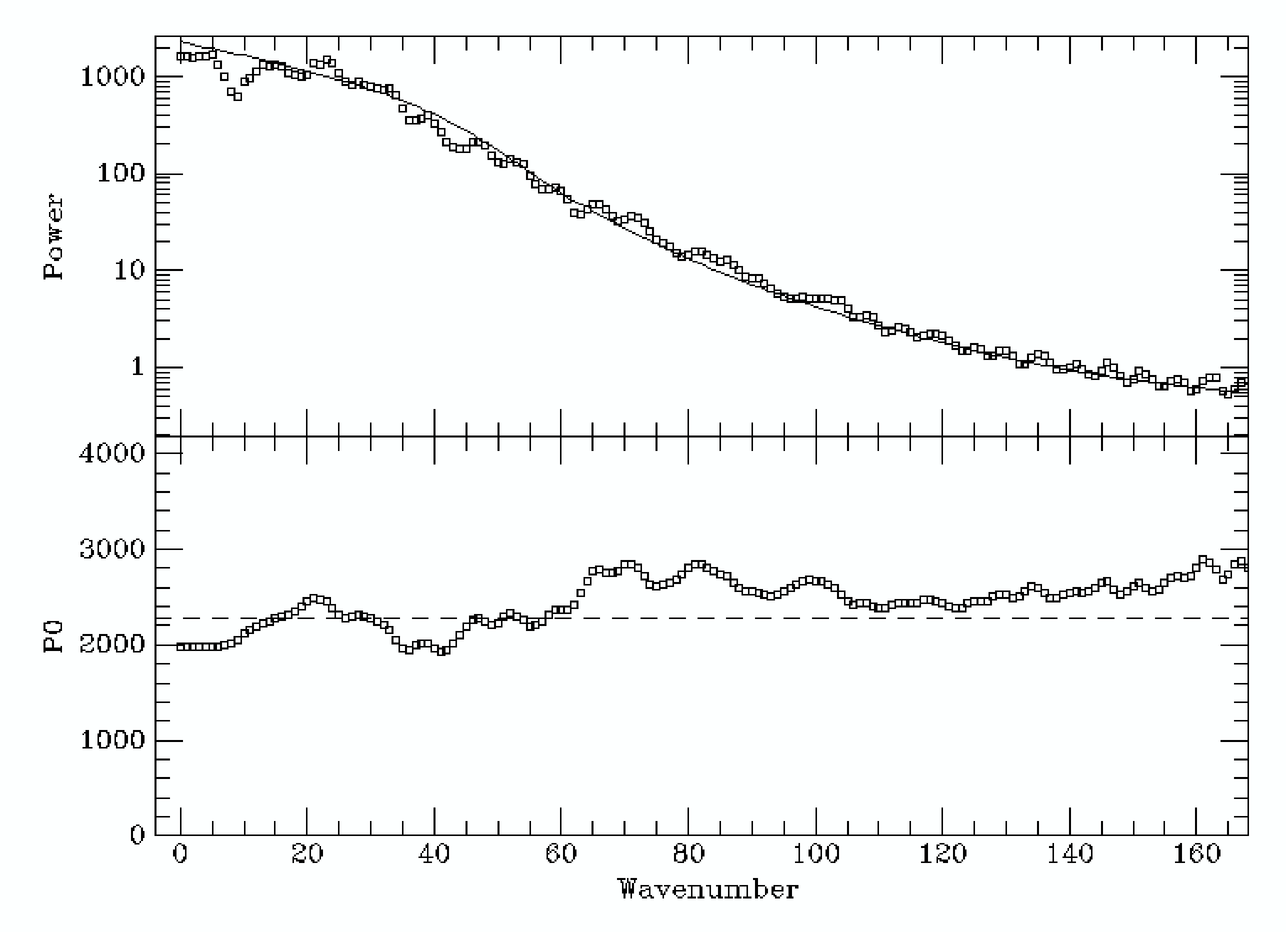


(Better PSF libraries, analytical PSF models, and deeper data to allow measurements at a larger range of radii from the AO guide star will help)


xmongo
Flux
Radius (p)
0
.1
.2
.3
.4
0
2
4
6
8
10

Analytical PSF fit to M32

Very high-S/N spatial power spectrum for M 32 fitted with a model PSF composed of two Gaussians

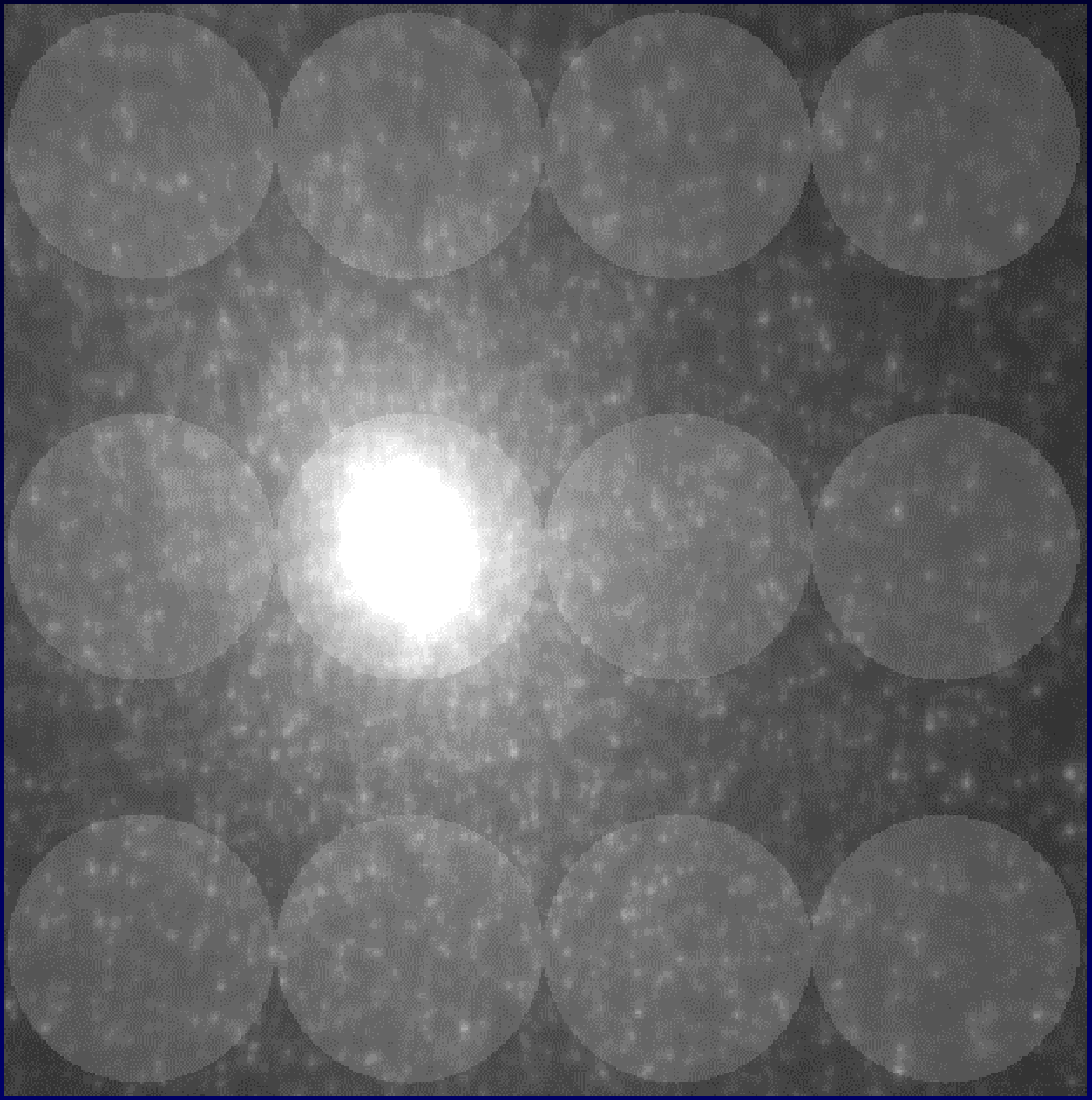


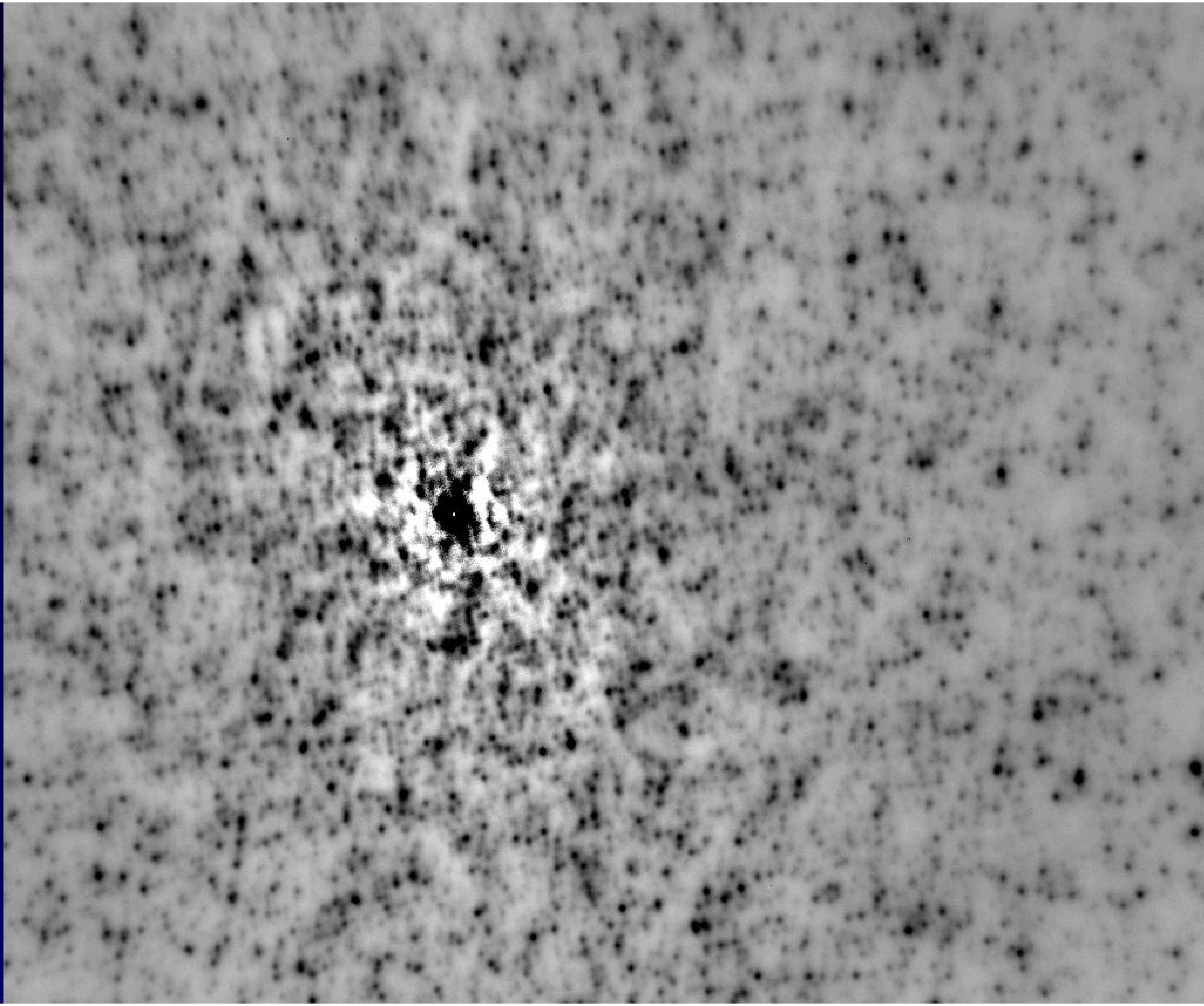
Using SBFs to Measure PSF Variations

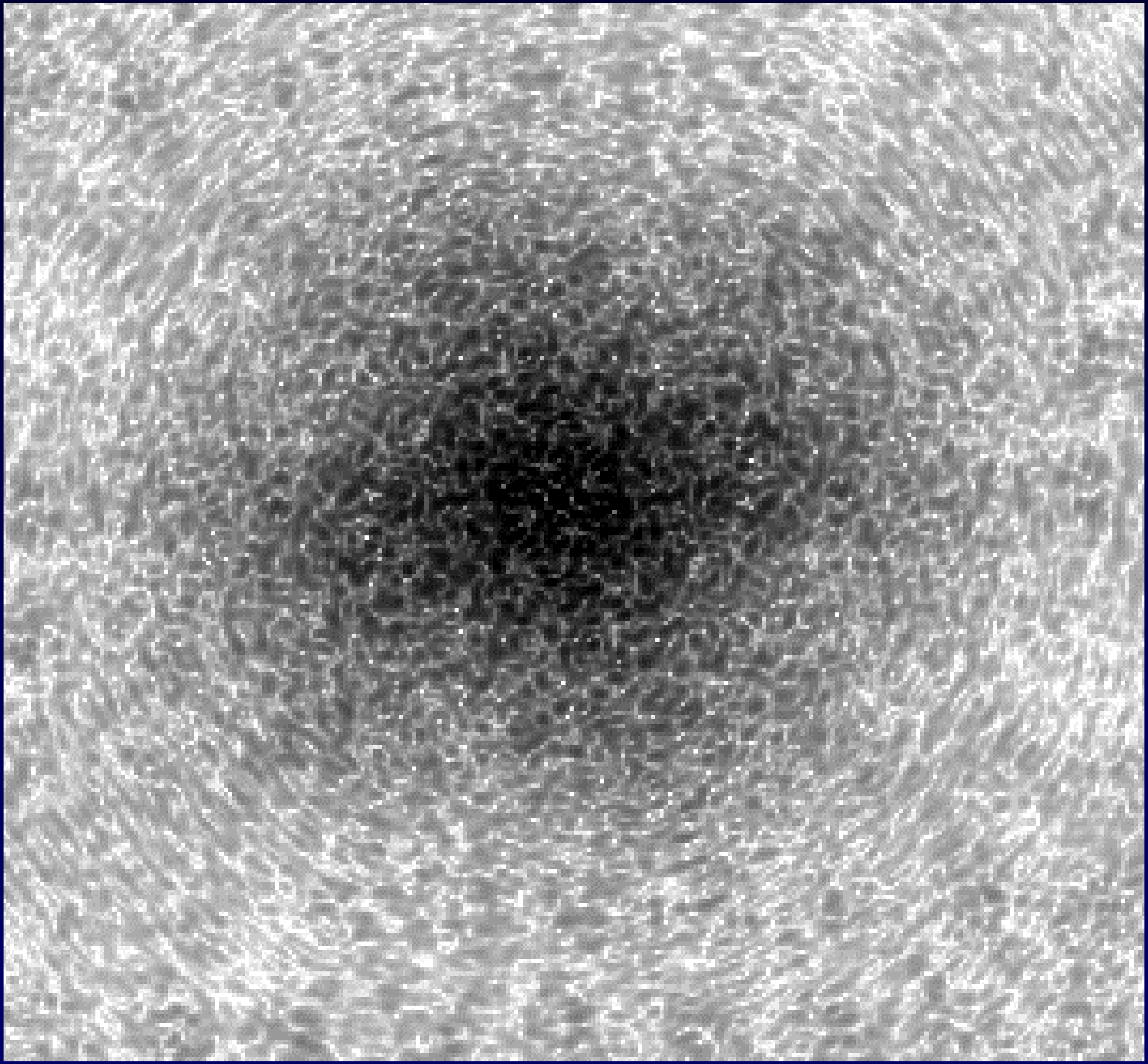
- Point sources are pixel-to-pixel Poisson fluctuations, not individual stars, convolved with seeing
- Does not rely on clean separation of PSF stars from neighbors (in fact, you *want* the stars blended!)
- Power spectrum is statistical combination of many PSF measurements
- Only M32 Hokupaa data is high enough in S/N over the whole field of view to be useful
- NGC 7768 serves as a two-point test

M32 K’

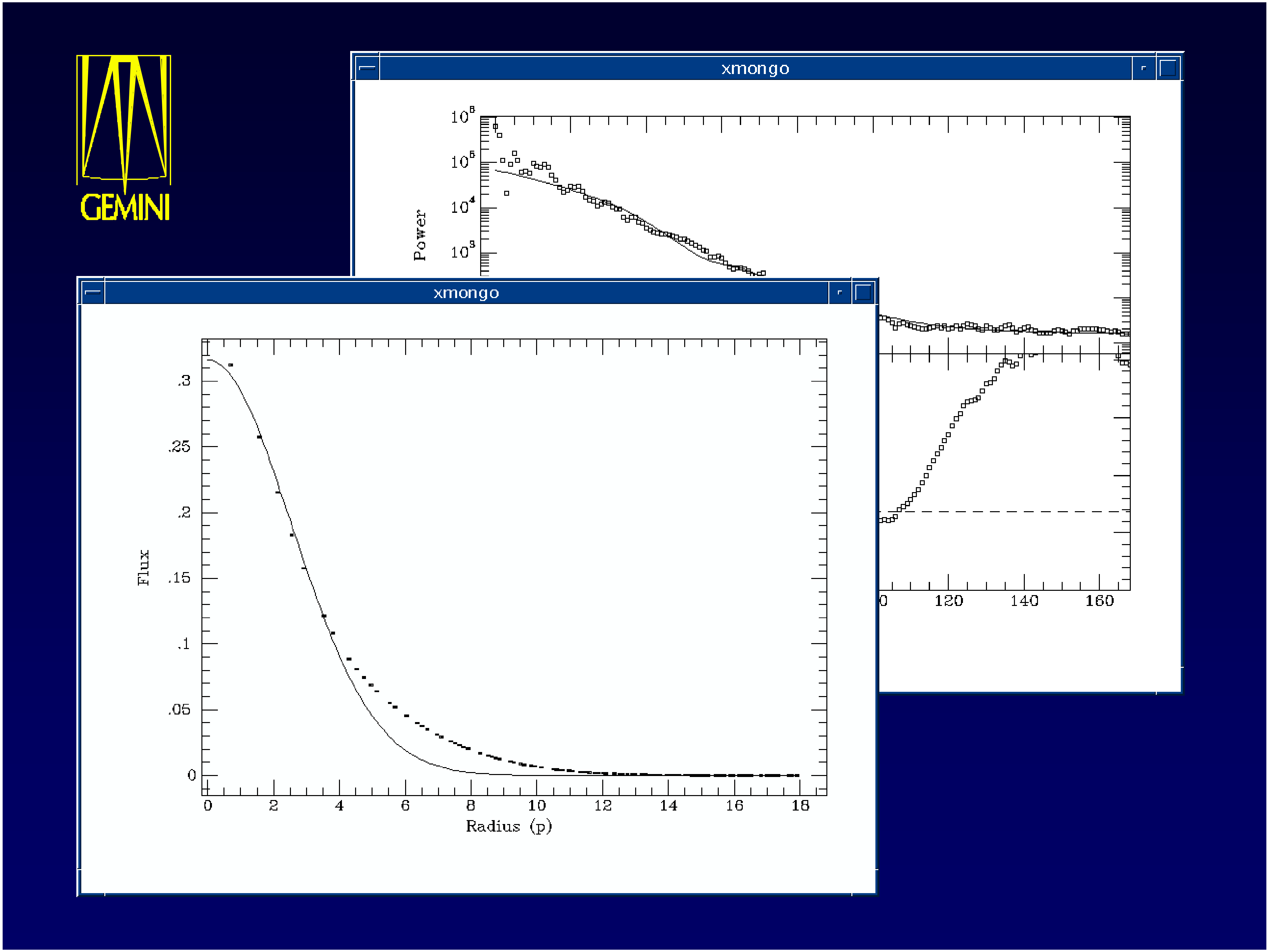
GEMINI

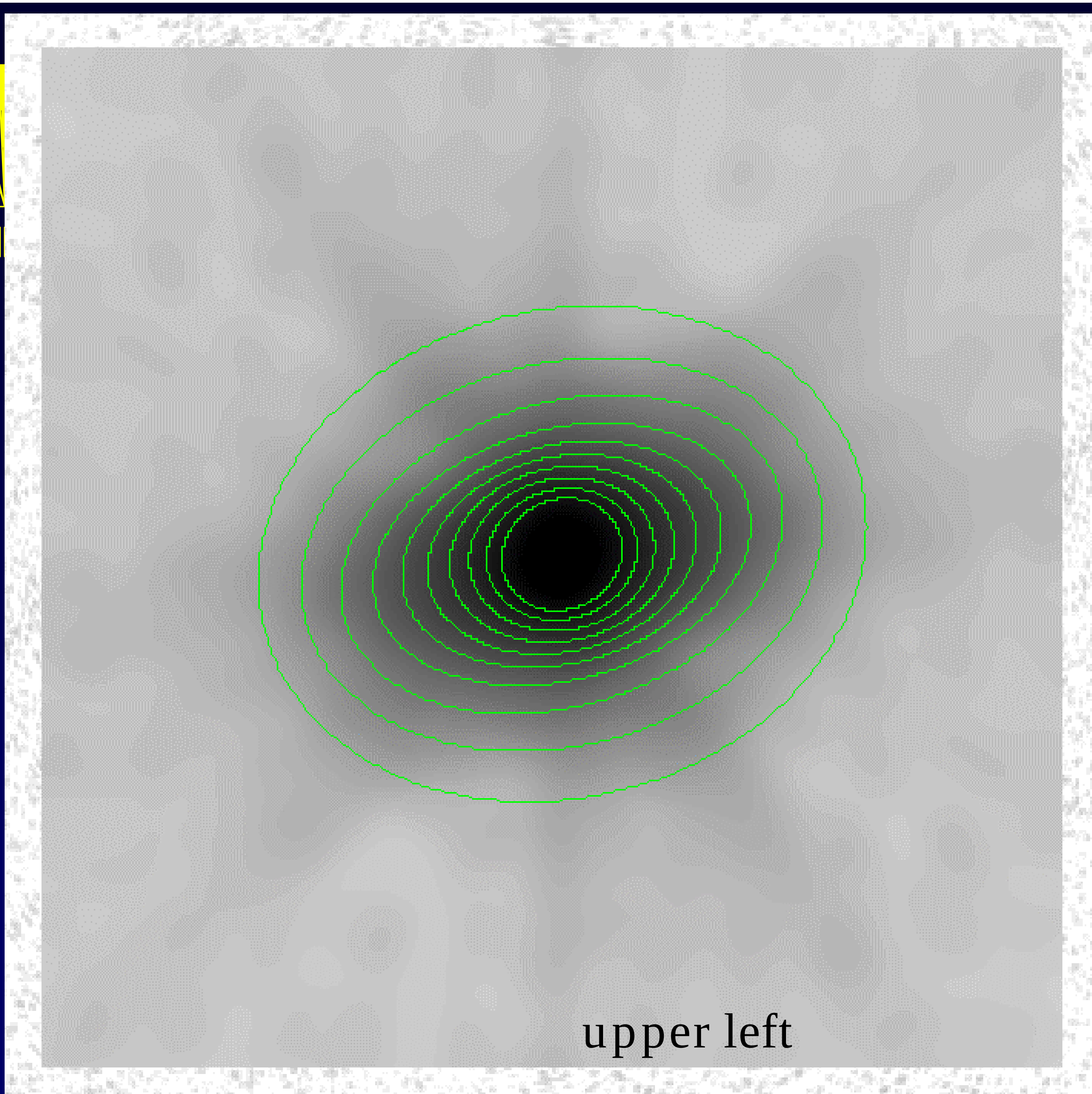


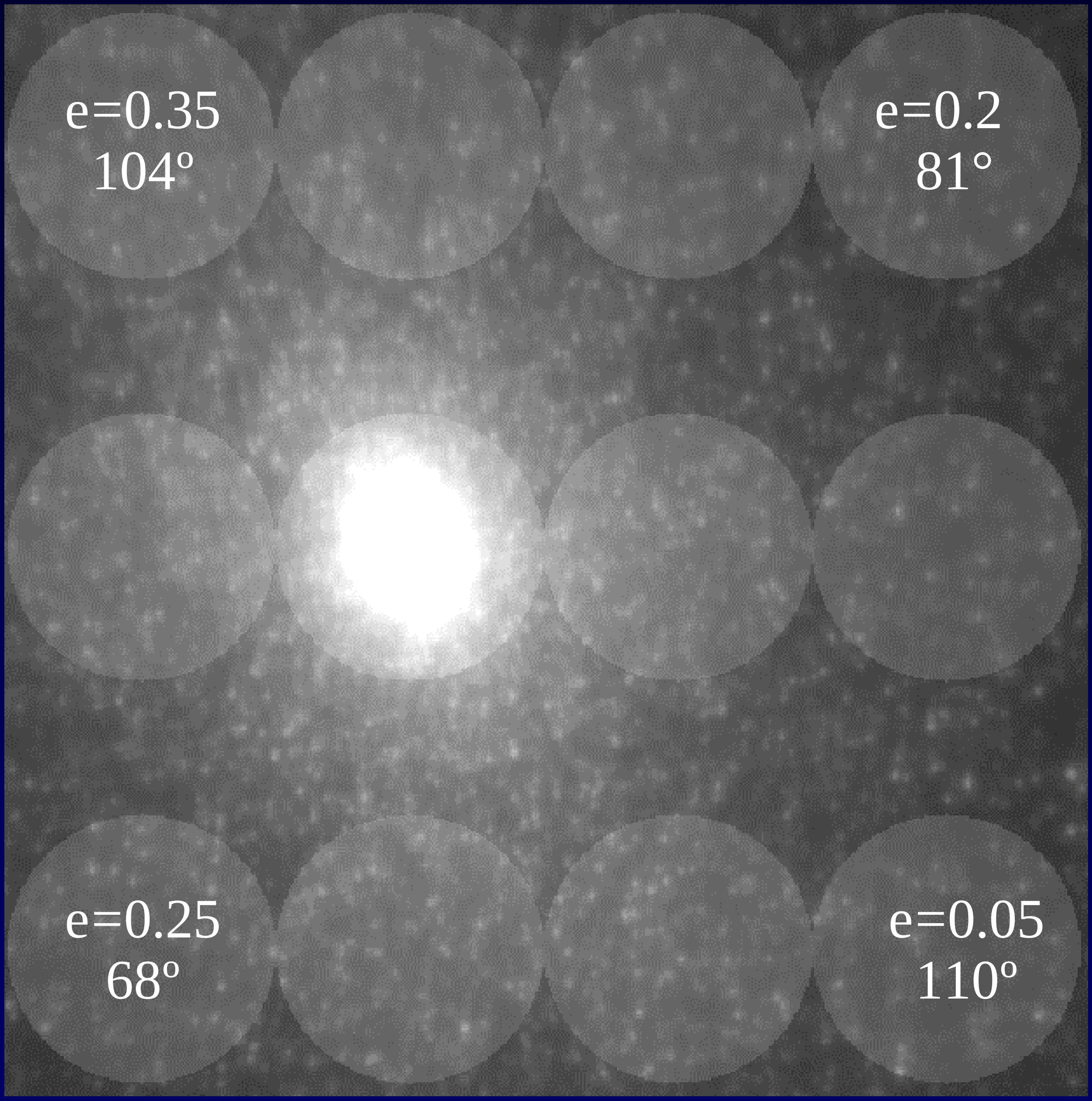




Spatial power spectrum, center


GEMINI
xmongo
Power
120
140
160
xmongo
Flux
.3
.25
.2
.15
.1
.05
0
0
2
4
6
8
10
12
14
16
18
Radius (p)


upper left


e=0.35
104º
e=0.2
81°
e=0.25
68º
e=0.05
110º

Summary

- AO-corrected images can be used to measure SBFs in very distant galaxies

- The spatial power spectrum of the fluctuations is proportional to the power spectrum of the PSF

- Images of nearby bright, smooth galaxies (ellipticals or S0s) can be used to measure the spatial variation of the PSF core and halo, and the ellipiticity of the core.