AO assisted spectroscopy with SINFONI

Richard Davies

Max Planck Institute for Extraterrestrial Physics

Adaptive Optics Calibration

- *PSF: how much detail? how to measure? should you use it to deconvolve your data*

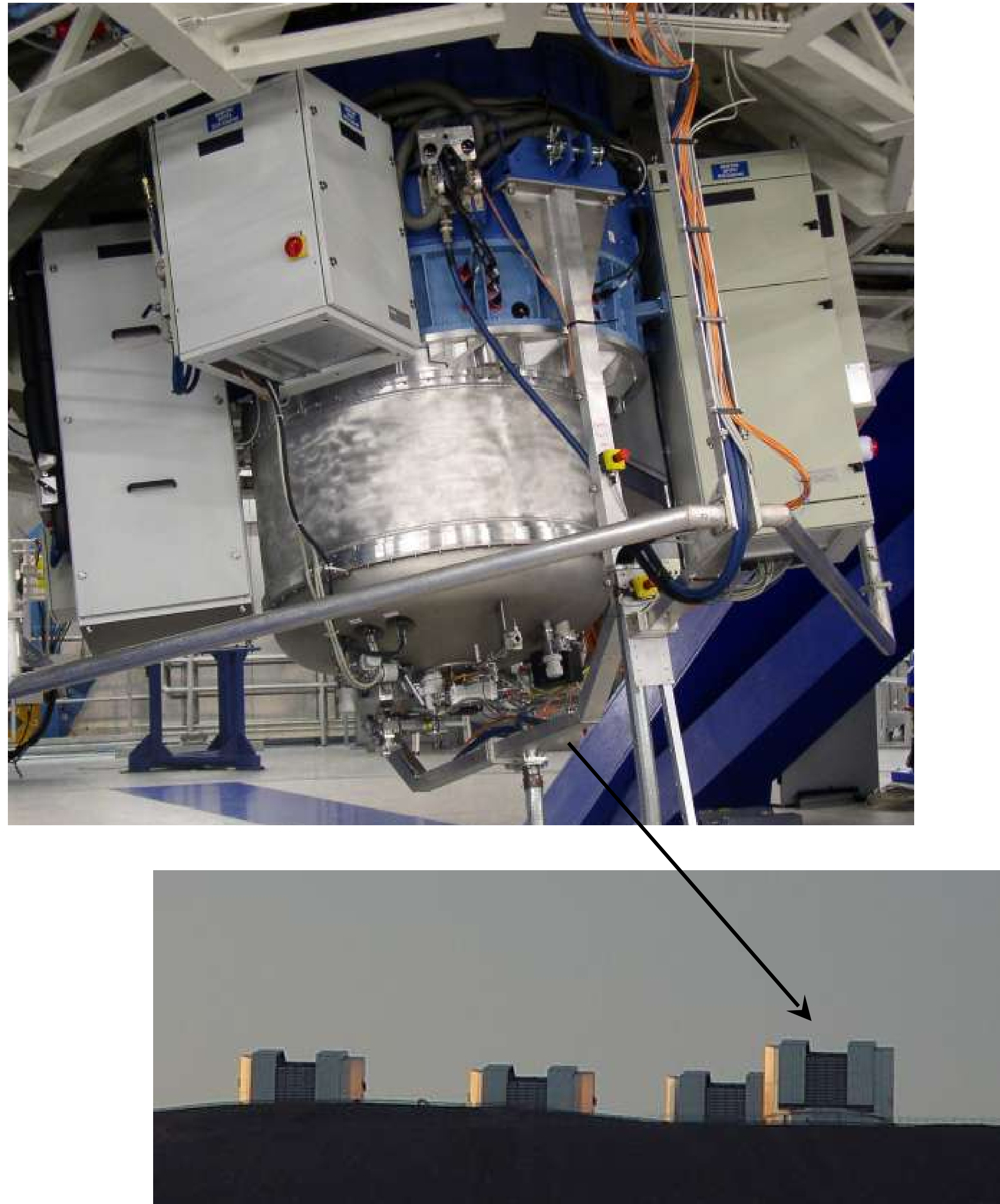
Near-IR IFU Calibration

- *sky subtraction*
- *wavelength calibration*

Alternative perspective on Calibration

SINFONI

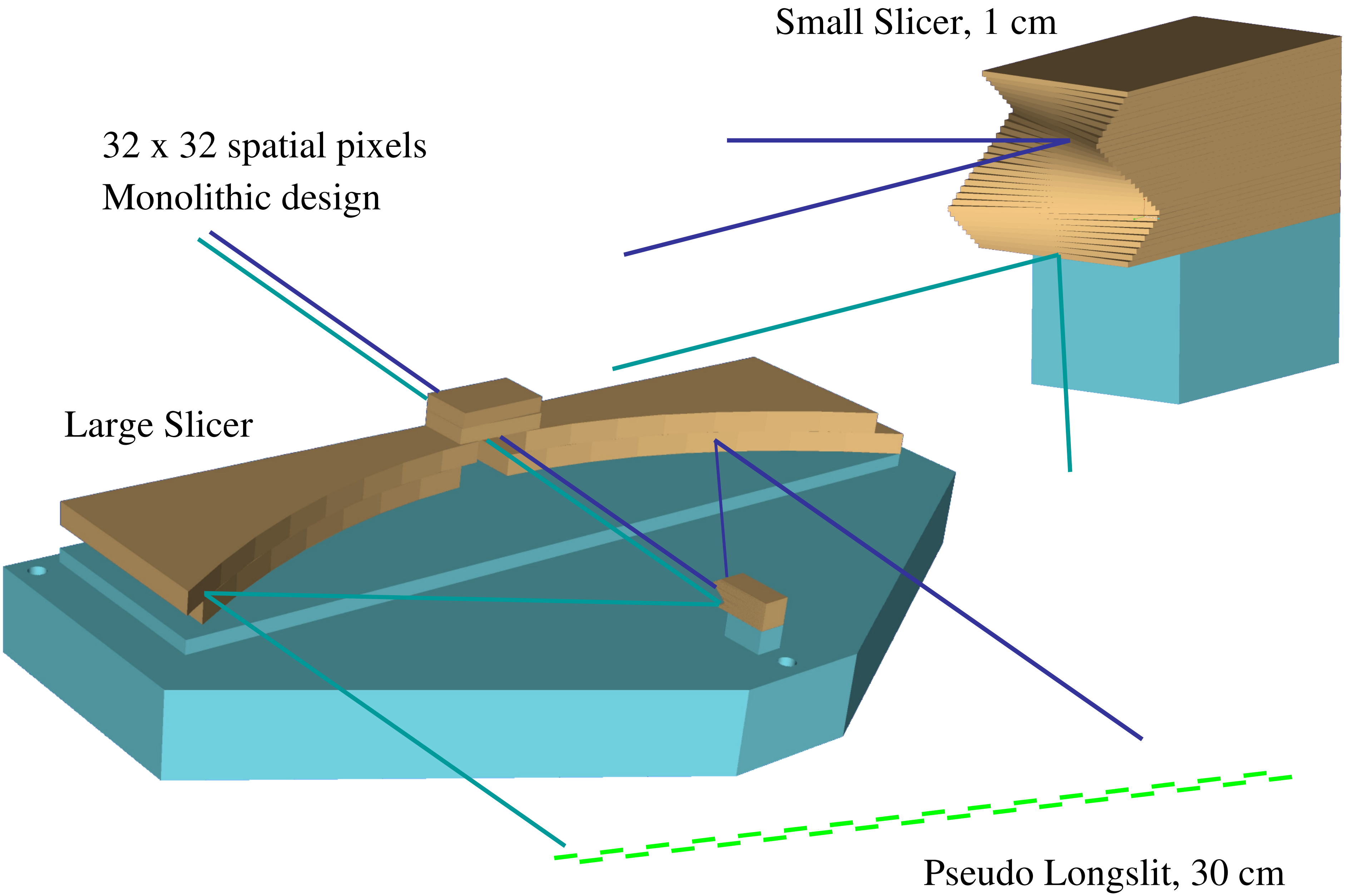
- *Adaptive optics near infrared integral field spectrometer at UT4*
- *camera SPIFFI developed by MPE with NOVA*
- *AO system MACAO developed by ESO*
- *can be used with LGSF (ESO,MPE)*
- *Regular operation since April 2005*
- *FoV: 1”×1”,3×3”,8”×8”*
- *wavelength coverage: J,H,K,H+K at R~1500-5000*



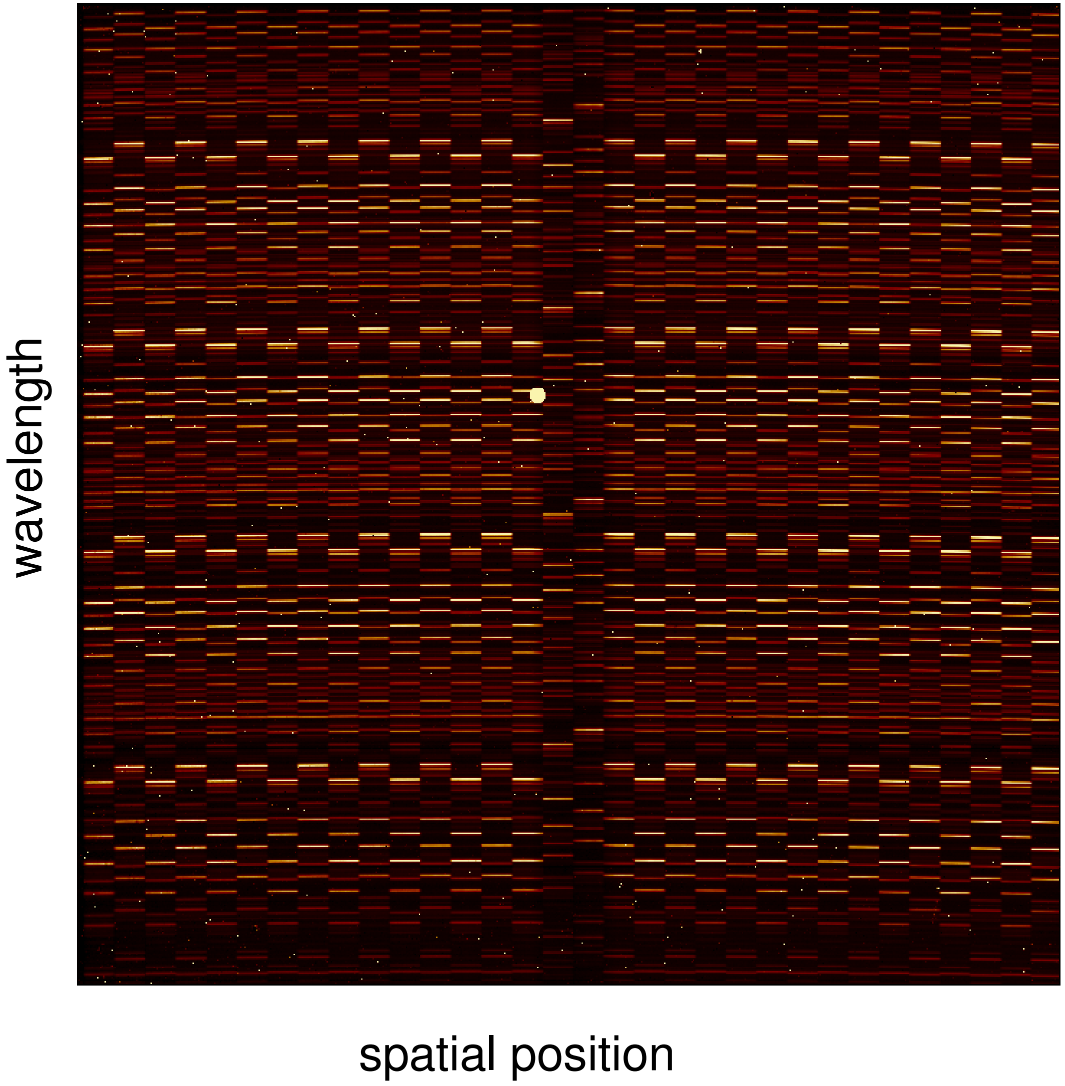
Bonnet et al. 2003, 2004

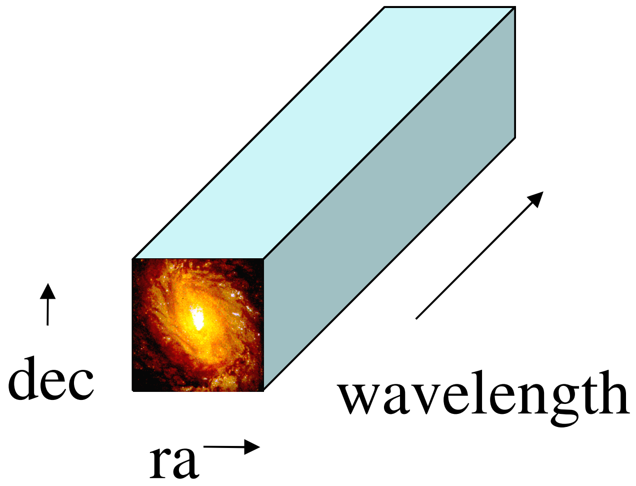
Eisenhauer et al. 2003, 2004

SPIFFI image slicer



SINFONI Data

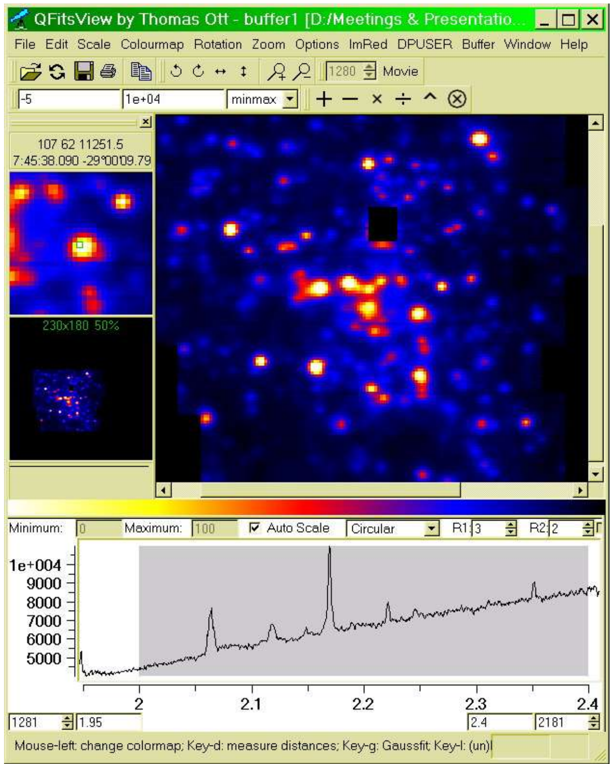




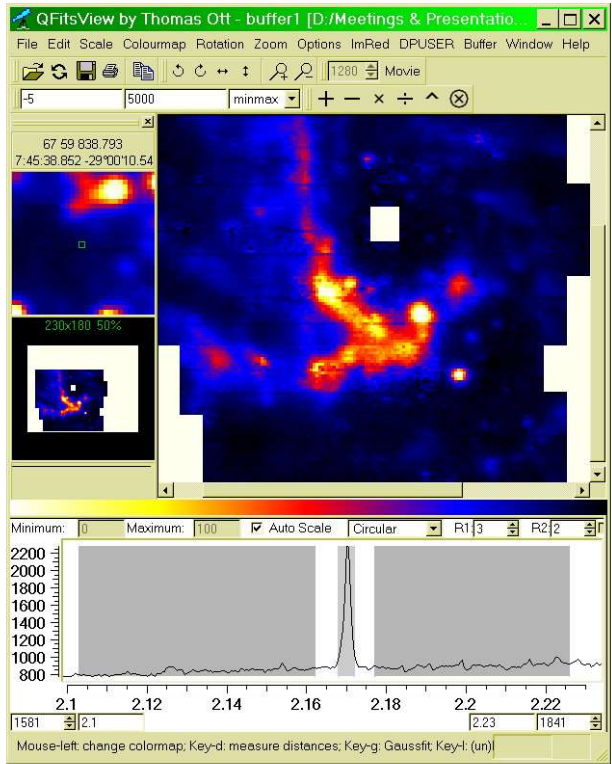
QFitsView

(Thomas Ott, MPE)

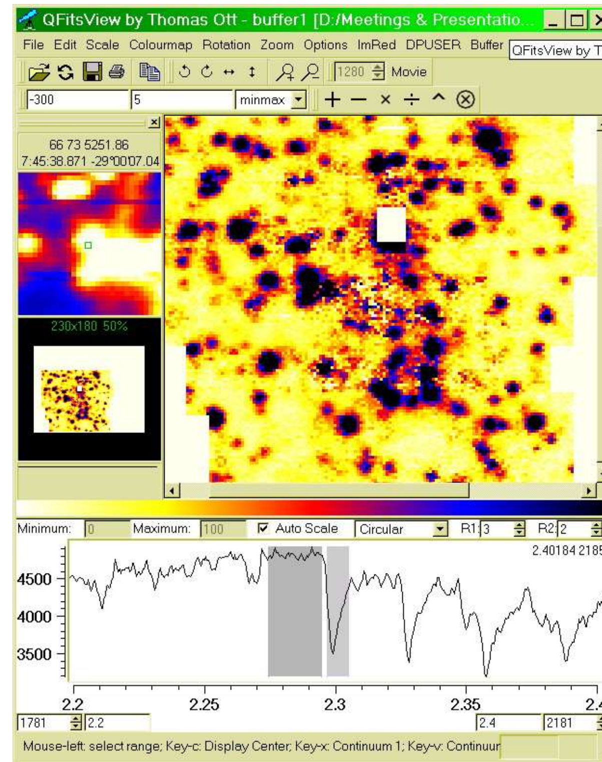
400MB mosaic of the Galactic Center



integrated flux



Br γ emission line map



CO2-0 absorption map

How should you measure the PSF?

• use a star as a PSF reference – fine for seeing, but often not so good for adaptive optics data

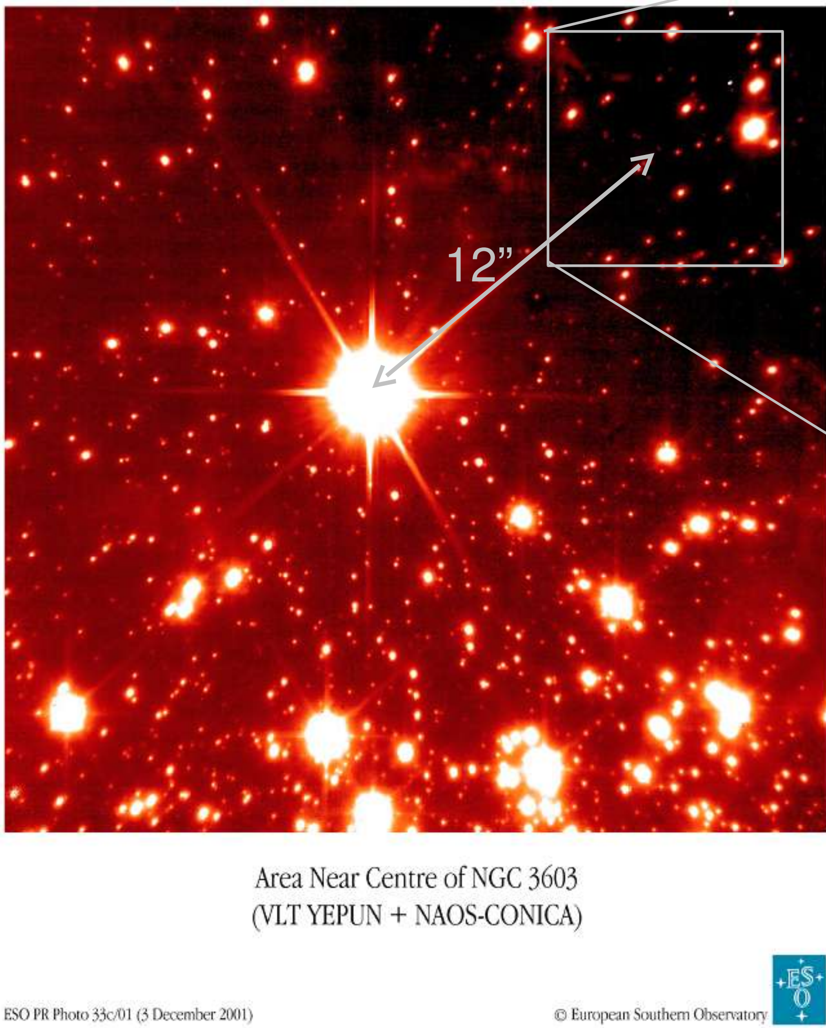
• use data from AO system to reconstruct PSF – unfortunately not implemented (but in progress for NACO – Yann Clenet's talk next)

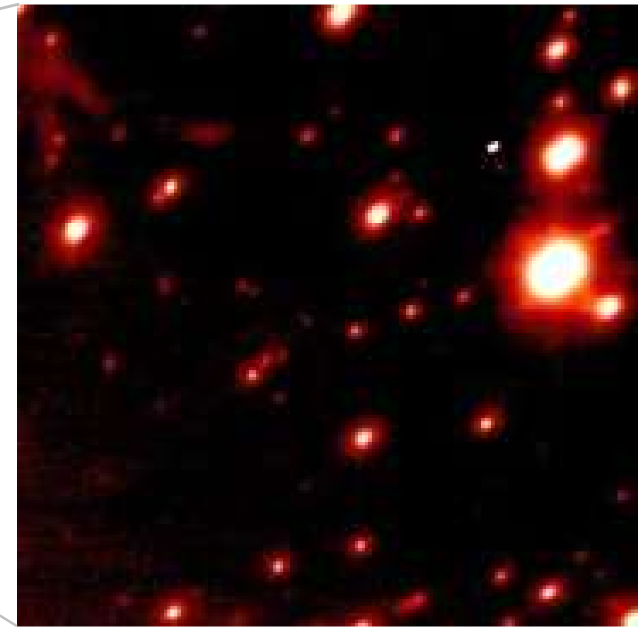
• extrapolate from surrounding stars – if there are any in the field of view (e.g. Cresci et al. 2006a,b)

• derive PSF from the science data itself (e.g. Davies et al. 2004a,b, 2006)

• derive it by comparison to other higher resolution data (e.g. Mueller Sanchez et al. 2006)

adaptive optics PSF: isoplanatic effects

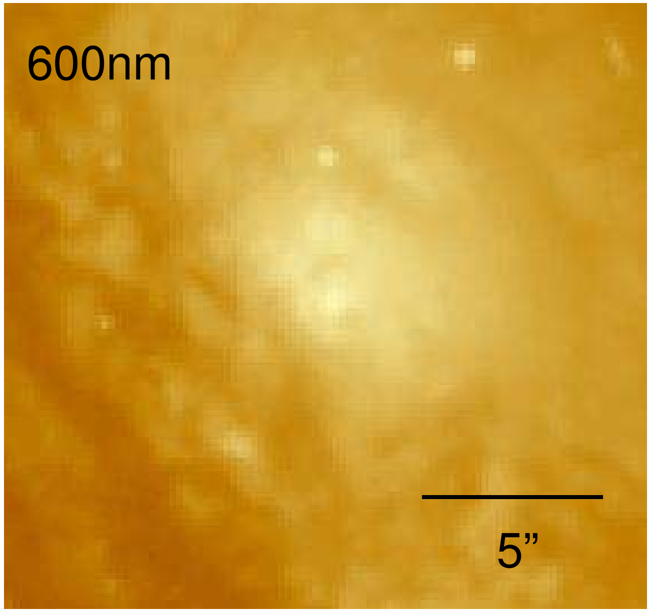


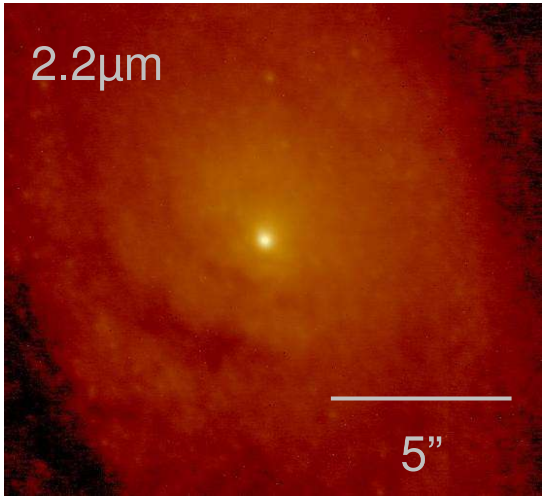


PSF changes as one moves further from the AO guide star

adaptive optics PSF: extended sources & background

Circinus Galaxy





optical: no bright point source for AO reference; and bright background.

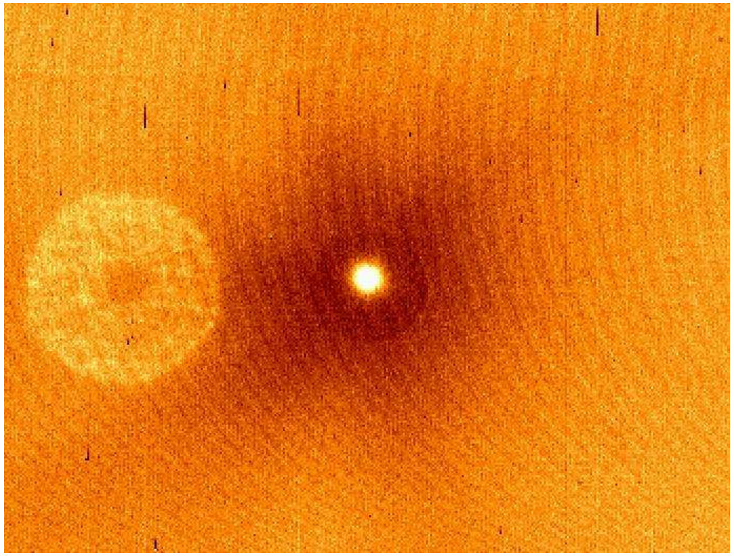
with an IR-WFS…

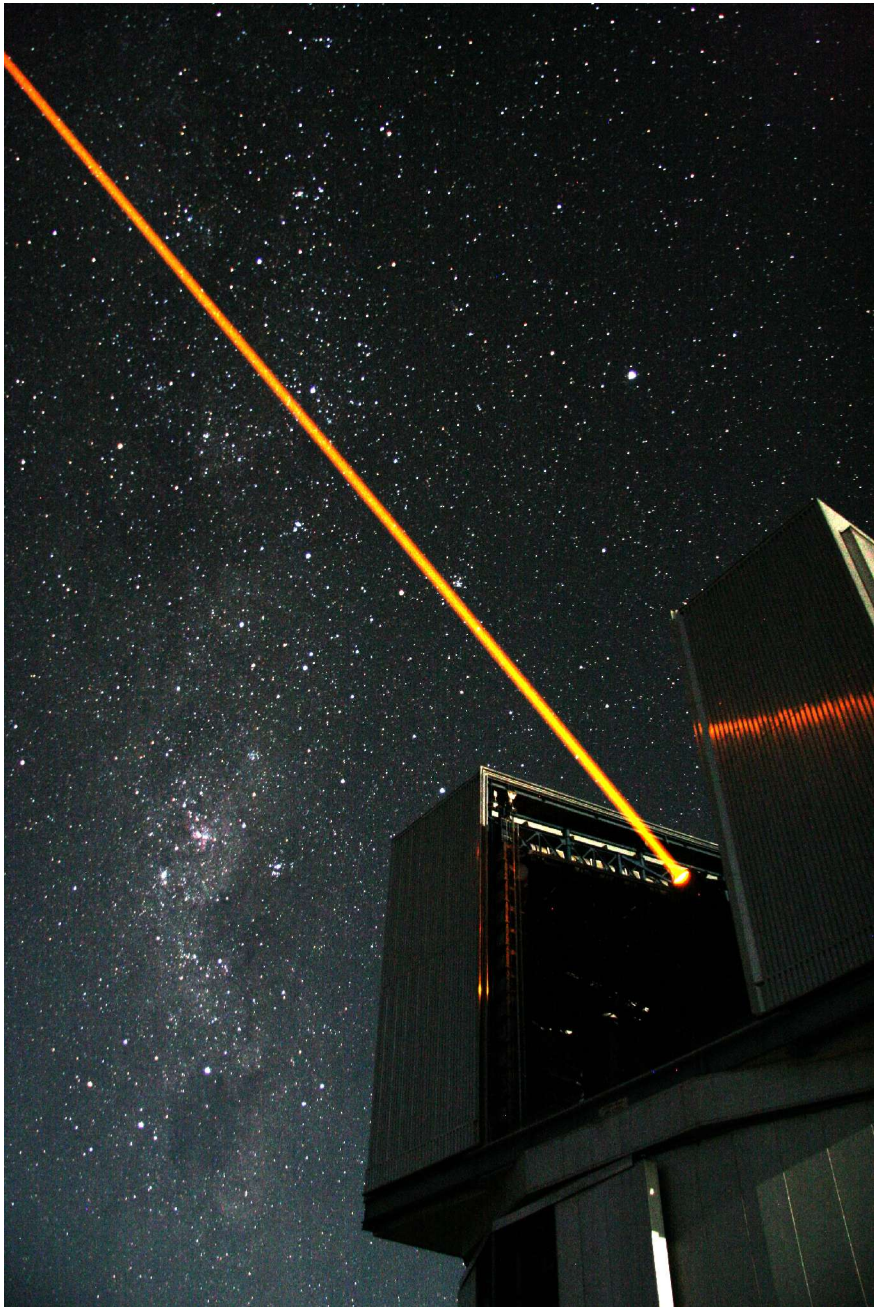
cannot reproduce these conditions with a PSF reference star

LGSF

Simpler to measure PSF since AO reference always the same for all targets & isoplanatic effects small

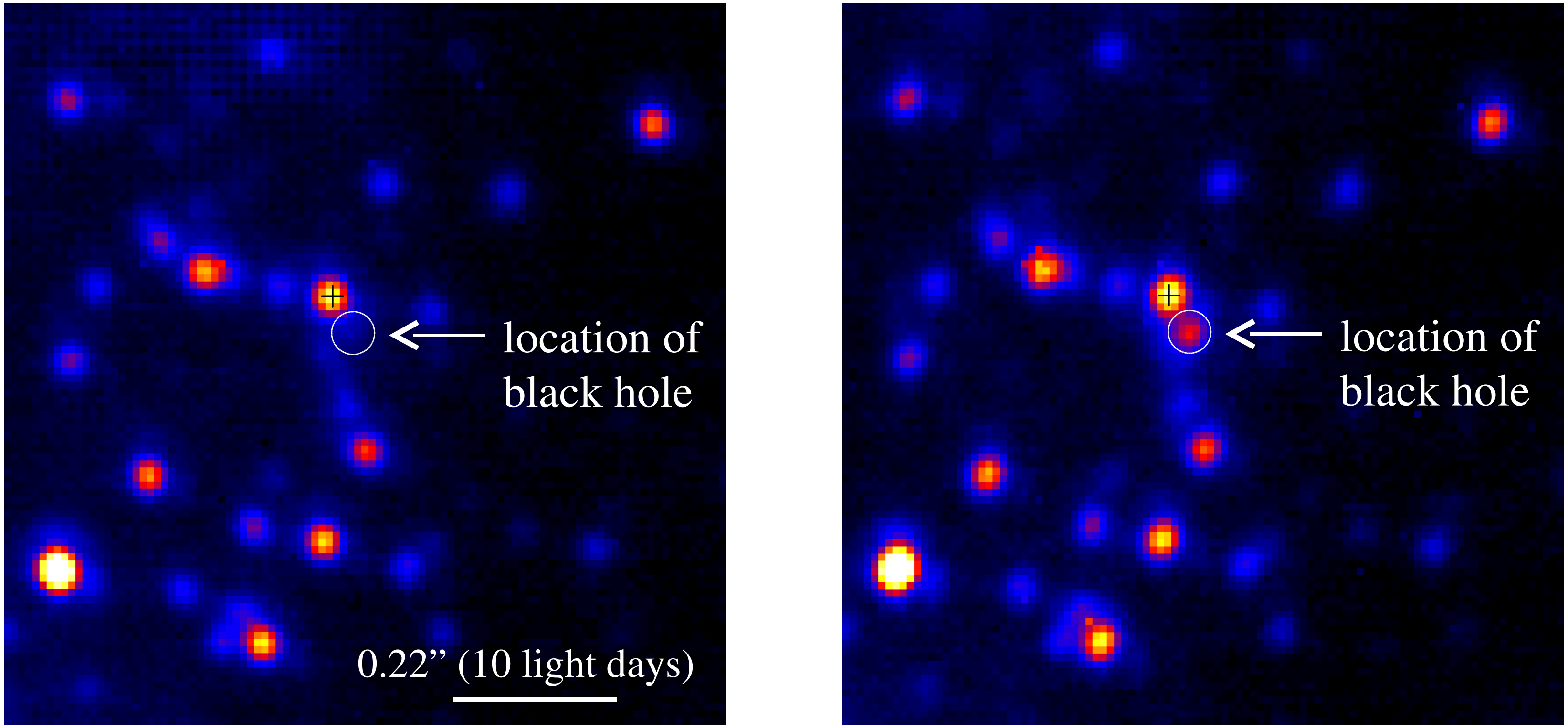
Just need to add residual jitter from tip-tilt star (which is easy to do afterwards).





How accurately do you need to know the PSF?

Galactic Centre



May 09, 2003: NACO (VLT) H-band, 40 mas resolution (adaptive optics), 1 min per image (Genzel et al. 2003)

Details of PSF not necessary; halo anyway extends over large fraction of the 1” field; so extract spectrum in small aperture and subtract local background.

Do you need to deconvolve the data?

observation = PSF convolved with intrinsic shape

can either convolve or deconvolve to estimate intrinsic shape

either

deconvolve observation with PSF

but - messy inverse problem
- noise amplification
- still have a (smaller) PSF in deconvolved data
- necessary if there is no model for intrinsic source shape

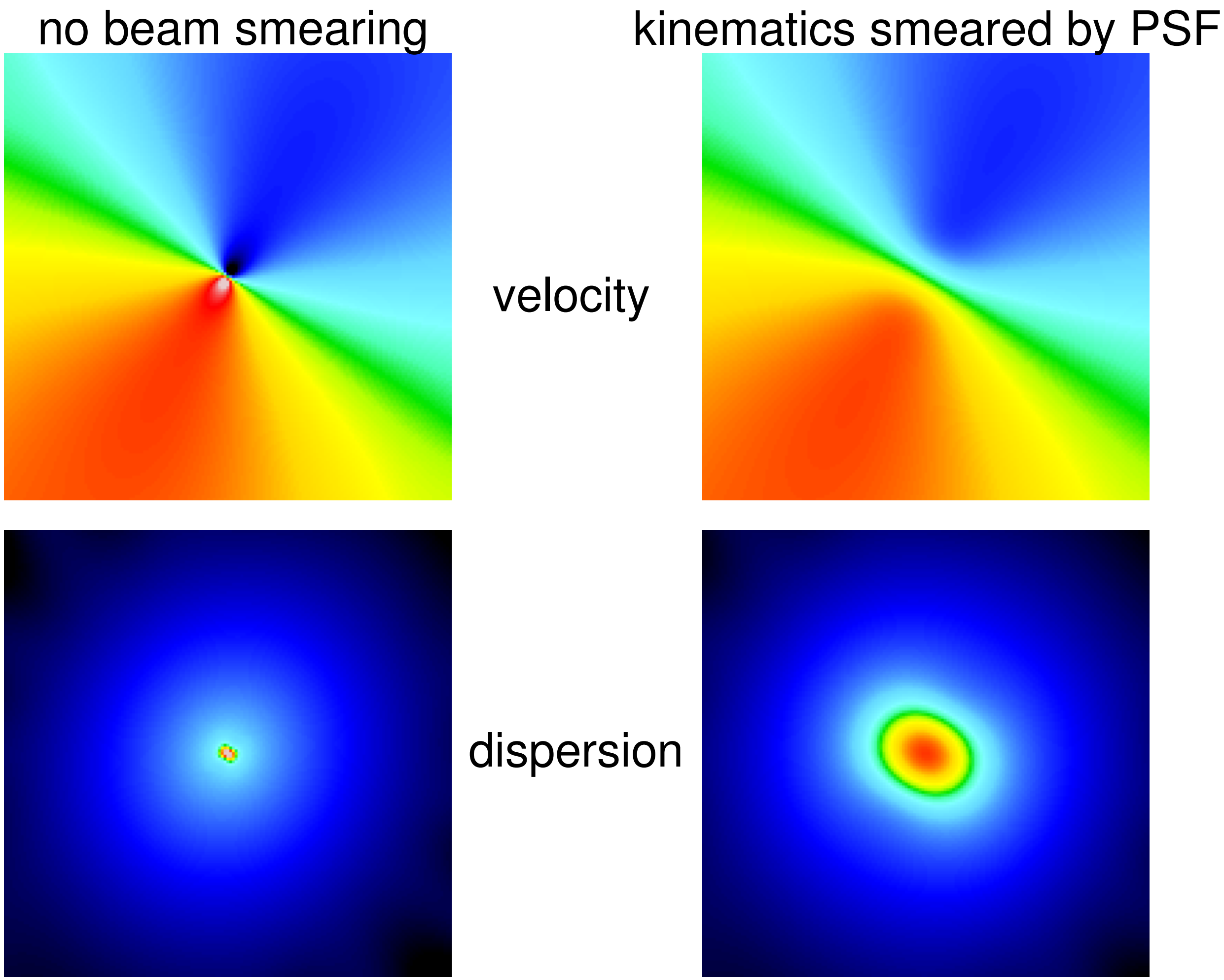
or

convolve analytic model of intrinsic source distribution with PSF
- can use simple PSF such as combination of Gaussians to match core & halo

Kinematics

must convolve a model with a PSF; but PSF can be simple

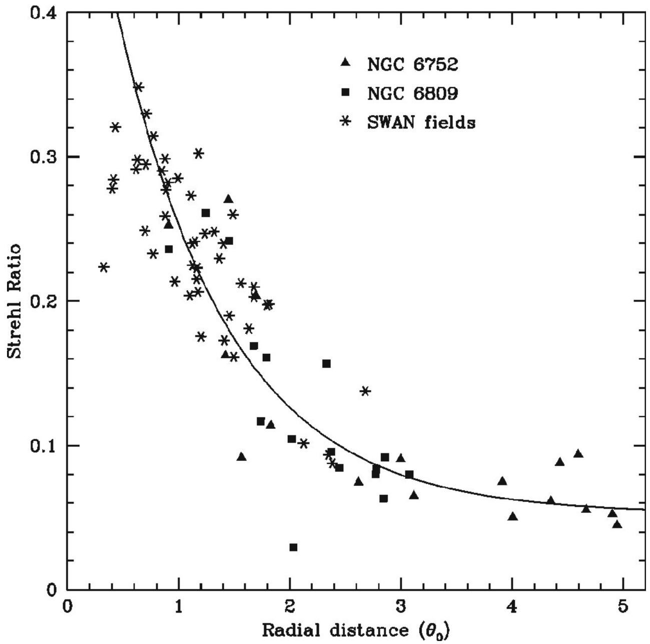
e.g. inclined disk with black hole



Simple model for isoplanatic PSF

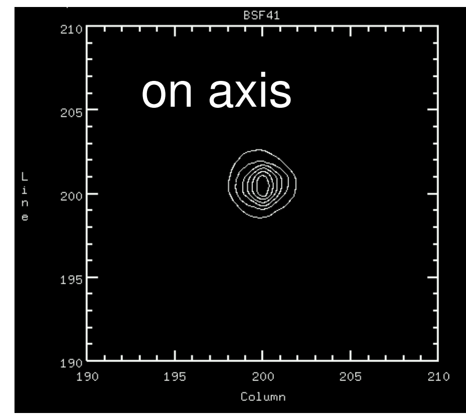
Cresci et al. (2006a)

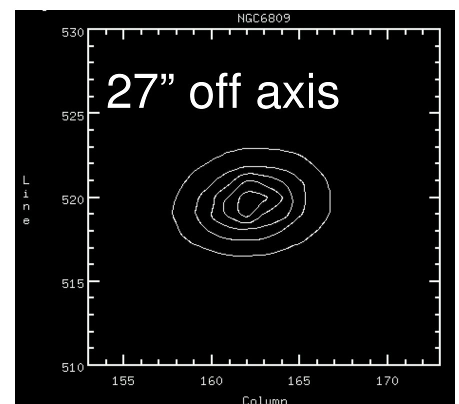
on axis PSF convolved with Gaussian, for which σ_x and σ_y are fixed functions of θ_0 and long axis points to reference star

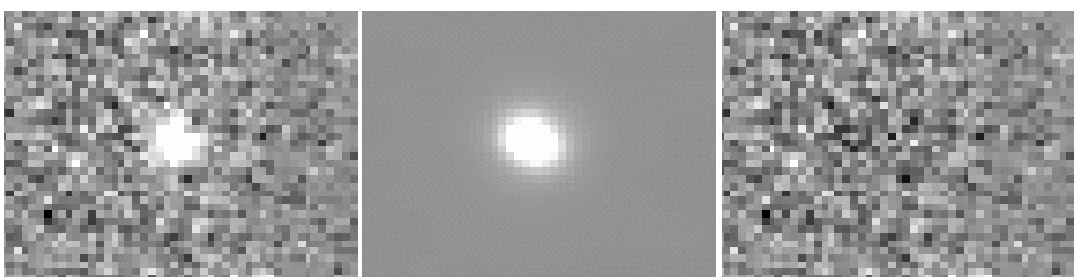


SR ~ $\exp[-(\theta / \theta_0)^{5/3}]$

$<\theta_0> = 12.7''$ in K for 18 fields



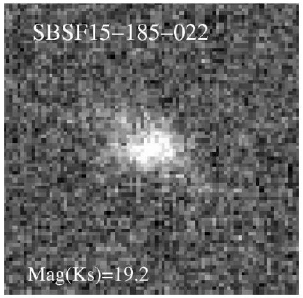




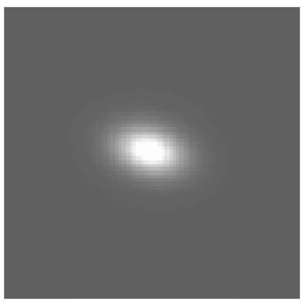
Original PSF *Model PSF* *Residuals*

Galaxy Morphology

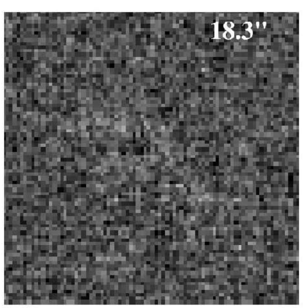
Cresci et al. (2006a,b)



original

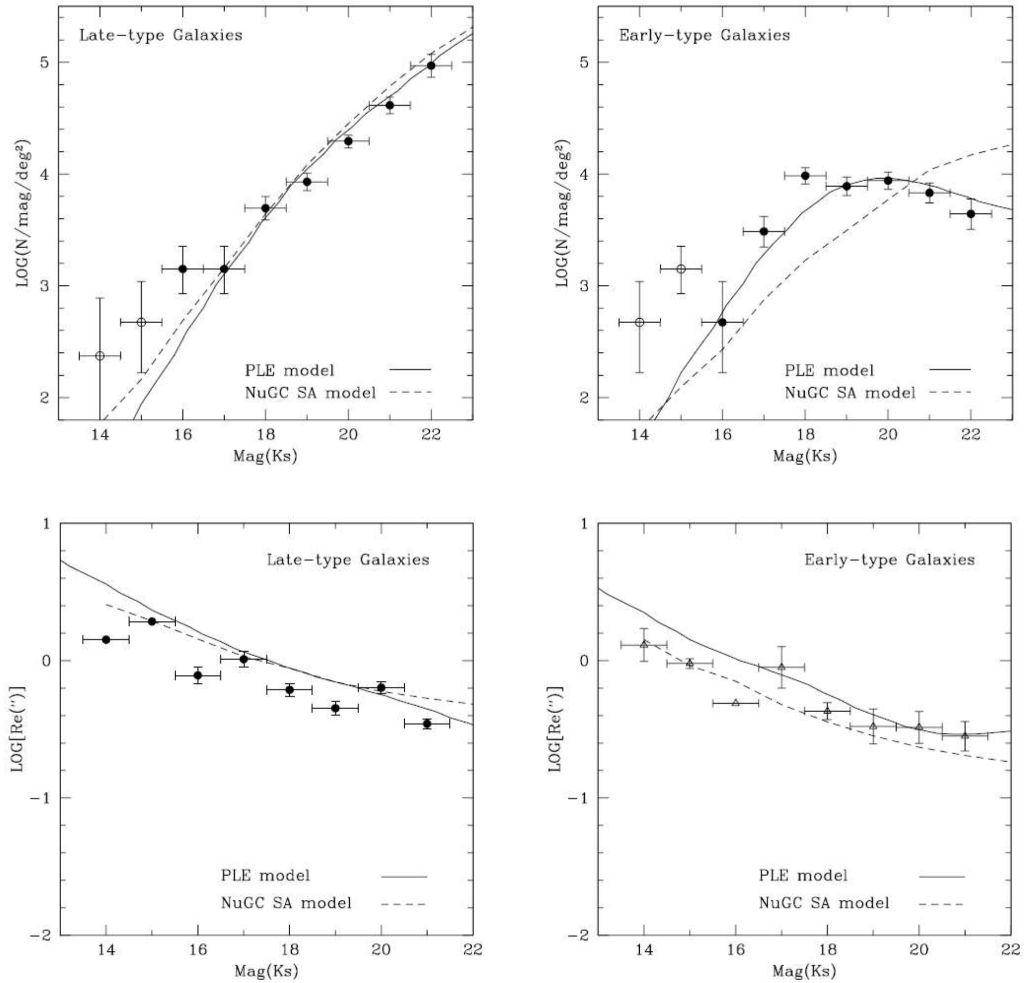


model



residual

determine whether galaxies are disk-like or elliptical to K~22 with <10% uncertainty

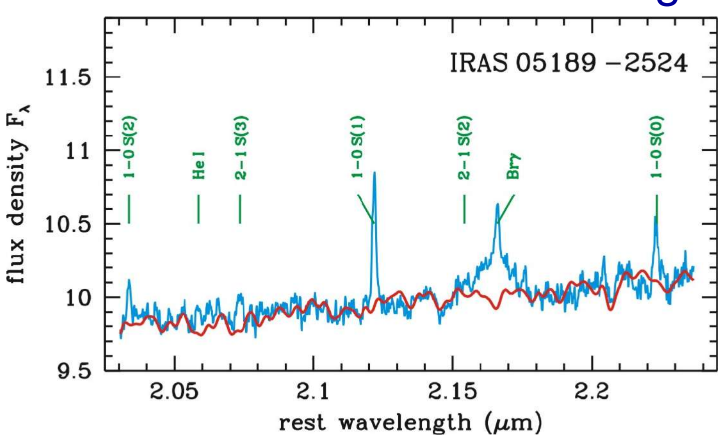


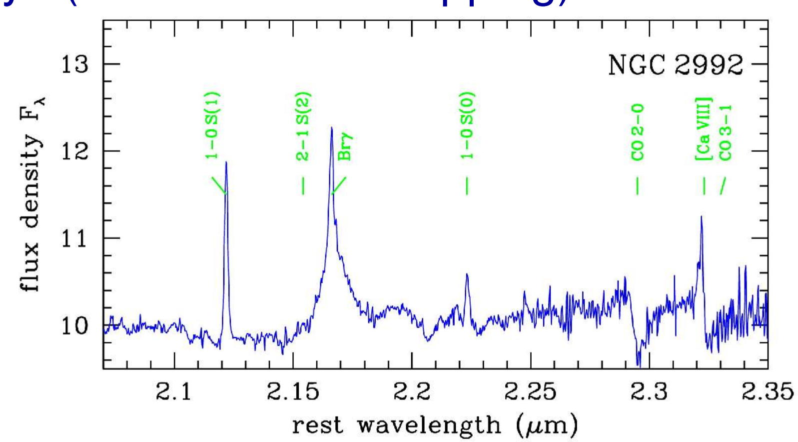
Measuring the PSF from the science data

Davies et al. 2004a,b & 2006, Mueller Sanchez et al. 2006

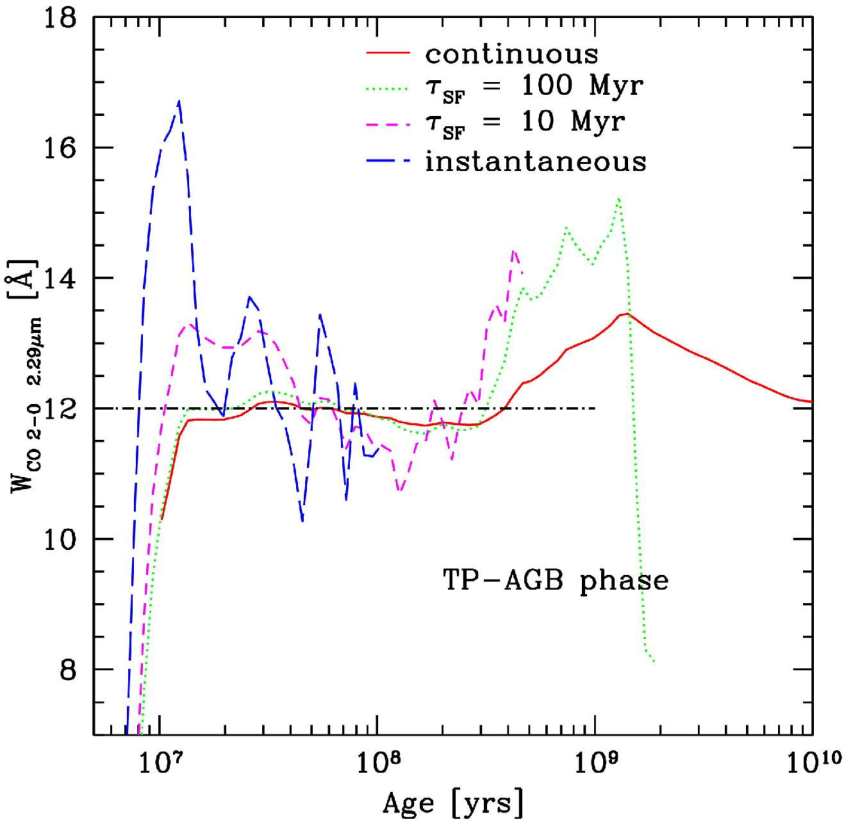
object	*type*	*Mpc*	*resolution*	
Mkn 231	ULIRG, Sy1, QSO	170	0.176”	145pc
IRAS 05189–2524	ULIRG, Sy1	170	0.12”	100pc
NGC 2992	Sy1	33	0.30”	48pc
NGC 3783	Sy1	42	0.18”	37pc
NGC 7469	Sy1	66	0.085”	27pc
NGC 1097	LINER, Sy1	18	0.245”	21pc
NGC 3227	Sy1	17	0.085”	7pc
NGC 1068	Sy2	14	0.085”	6pc
Circinus	Sy2	4	0.22”	4pc

BLR size ~ few light days (reverberation mapping)

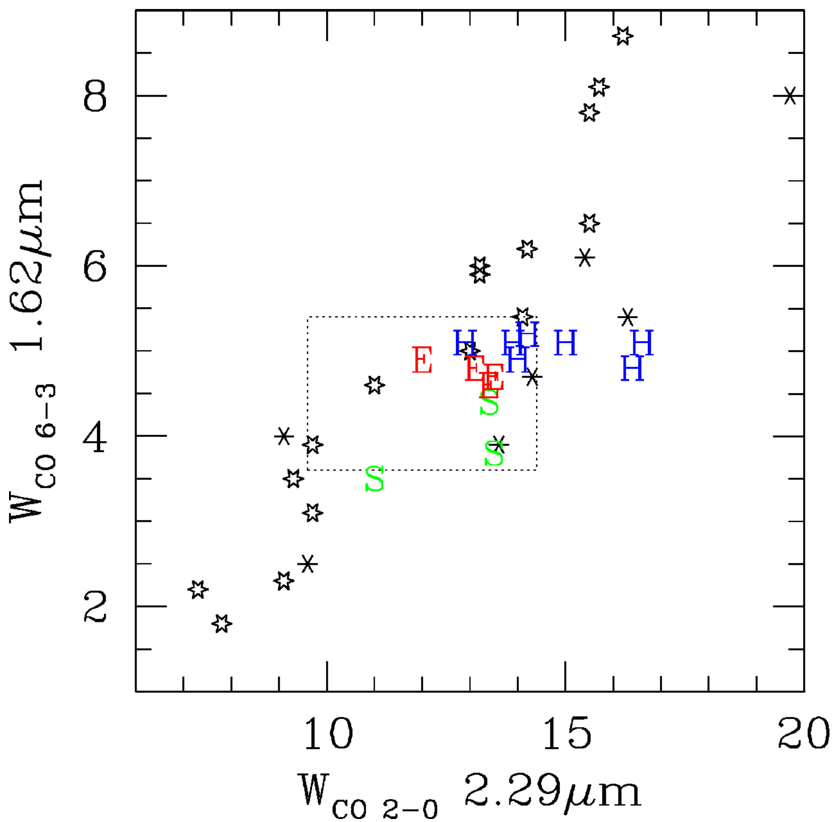




CO equivalent width: measuring stellar continuum



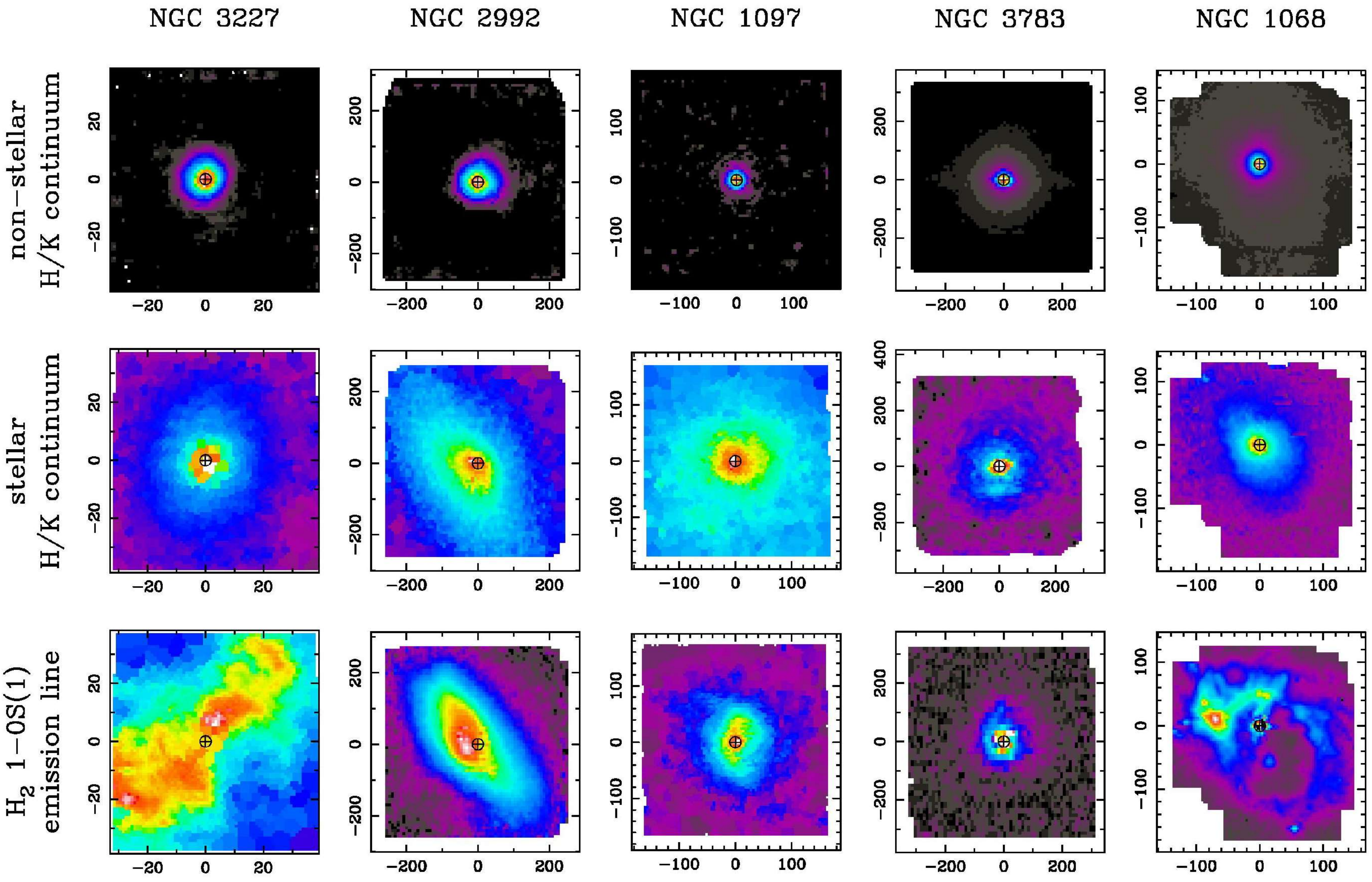
'STARS' stellar cluster models
W_{CO6-3} ~ 4.5Å & W_{CO2-0} ~ 12Å



adapted from Oliva et al. 1995

- non-stellar continuum has intrinsic size 1-2pc so gives you the PSF
- can correct for dilution & estimate stellar continuum without knowing anything about the stellar population

PSF estimation



OH subtraction

Davies (2007, MNRAS in press)
see also poster by A. Modigliani

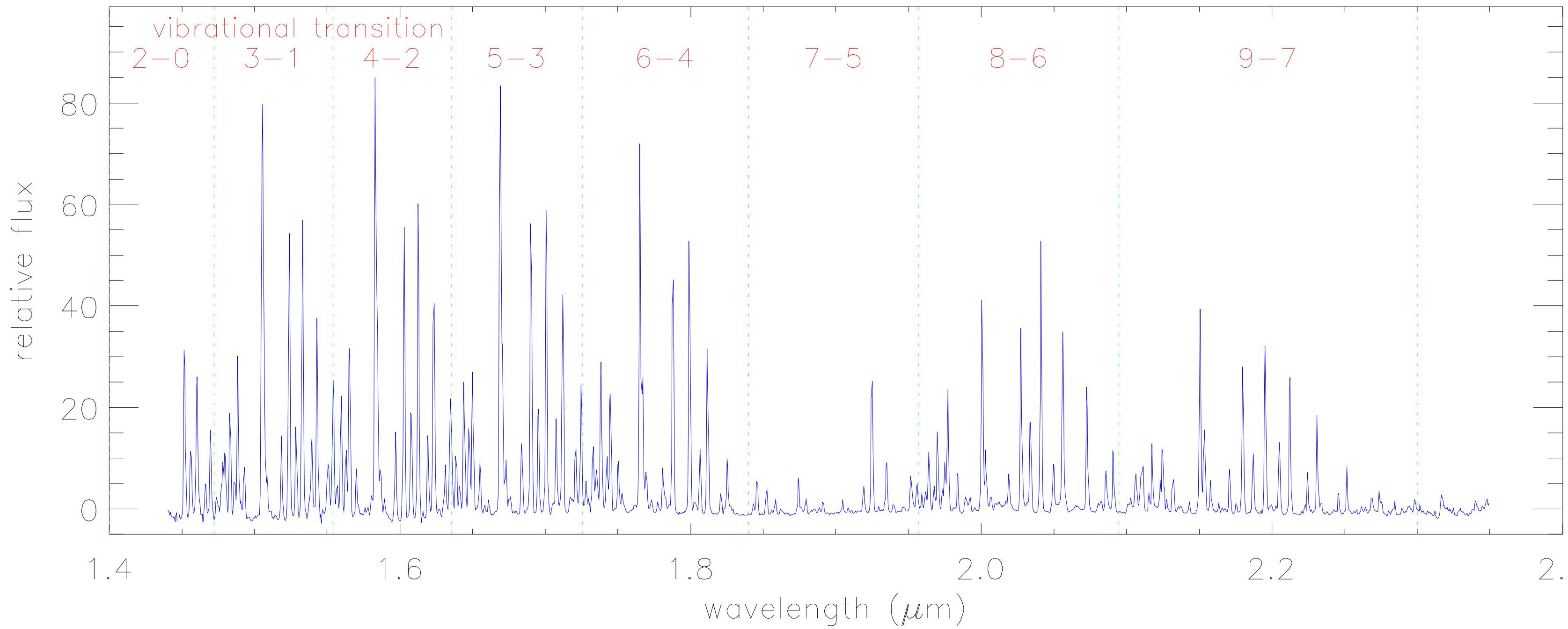
small field of view so need to nod to sky

OH lines up to 1000 times brighter than sky background between them

variations of flux & ratios on timescales of 1-2 minutes

OH subtraction

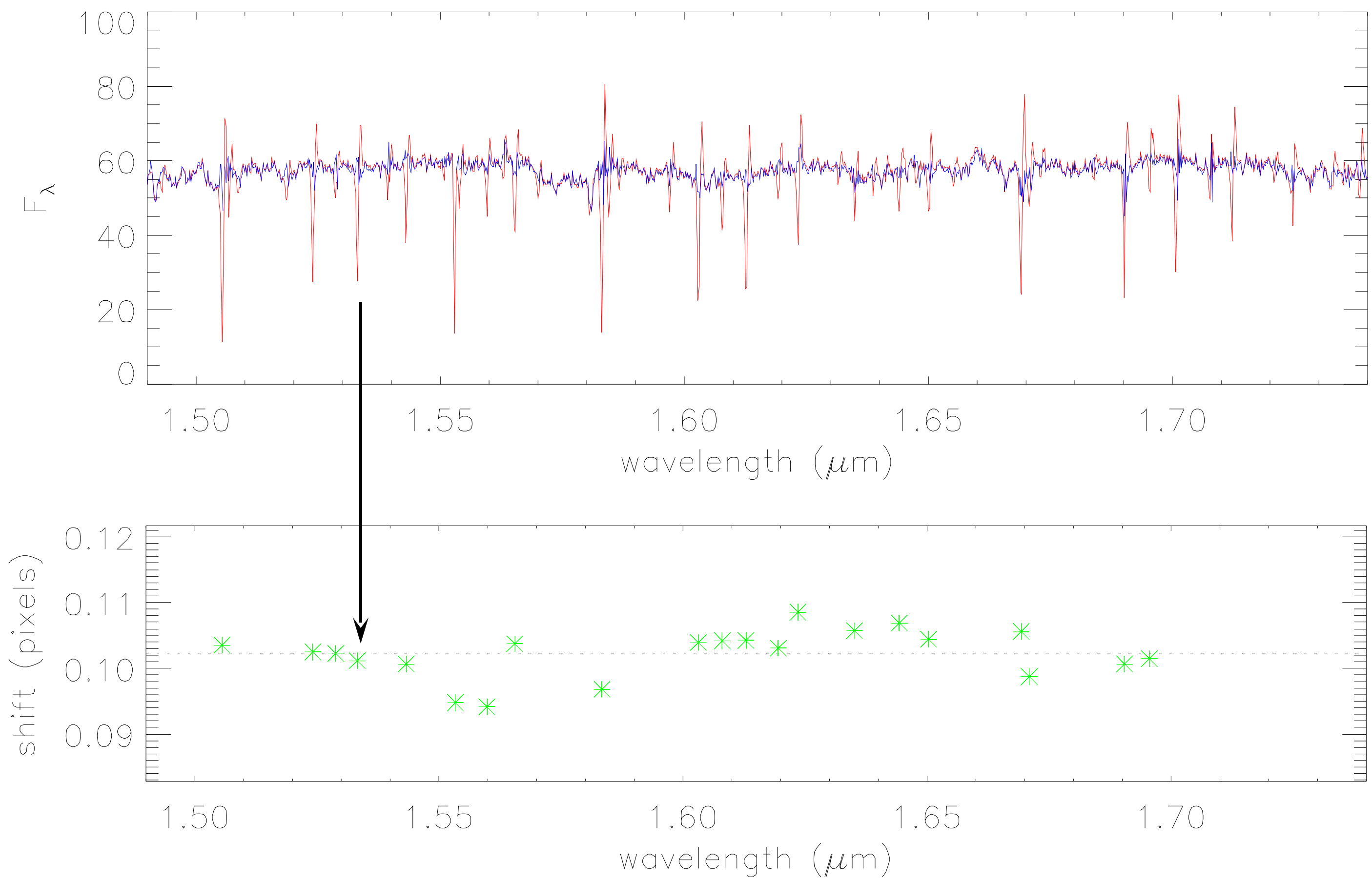
Davies (2007, MNRAS in press)
see also poster by A. Modigliani



most of variation between vibrational transitions, which fortuitously can be separated by wavelength, allowing one to scale each segment separately

wavelength correction

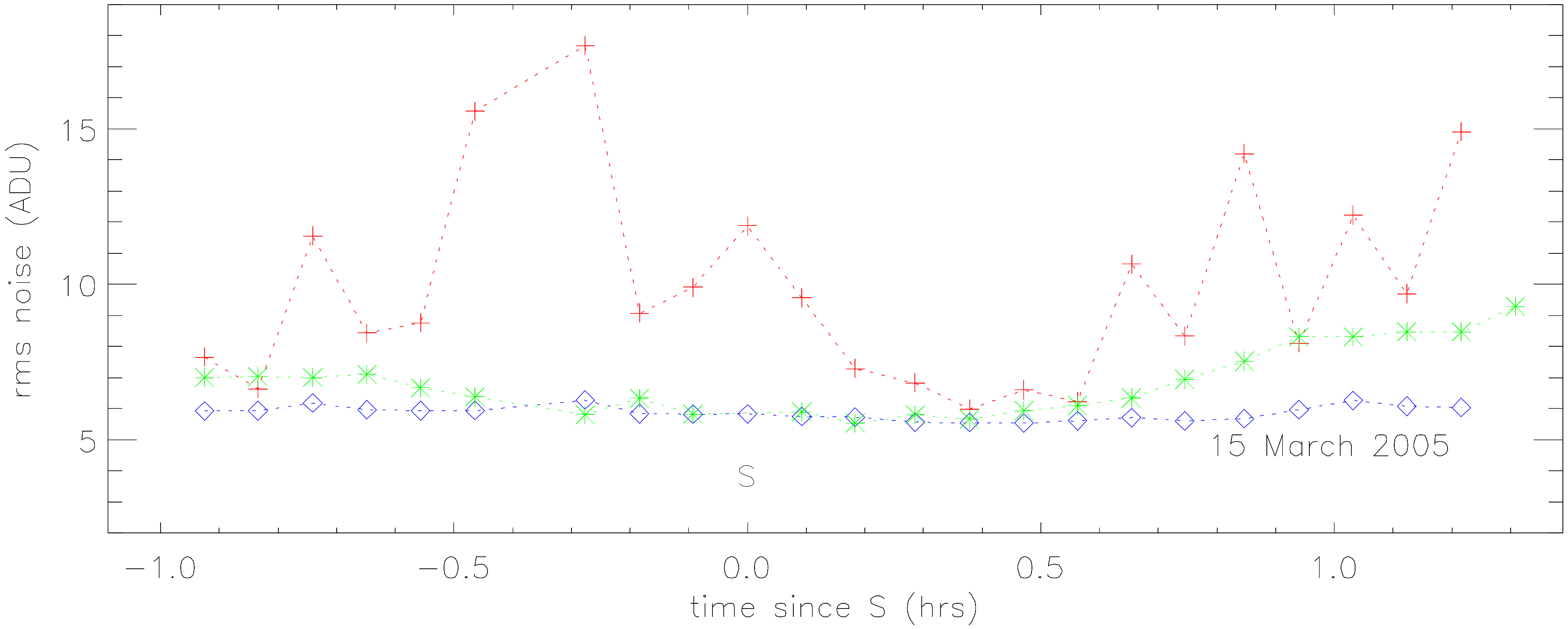
Davies (2007, MNRAS in press)
see also poster by A. Modigliani



shift of ~0.1pixels is enough to produce bad P-Cygni residuals

OH subtraction

Davies (2007, MNRAS in press)
see also poster by A. Modigliani



SINFONI H-band 5-min integrations of a (almost) blank field

red: simple subtraction of sky using frame taken immediately afterwards

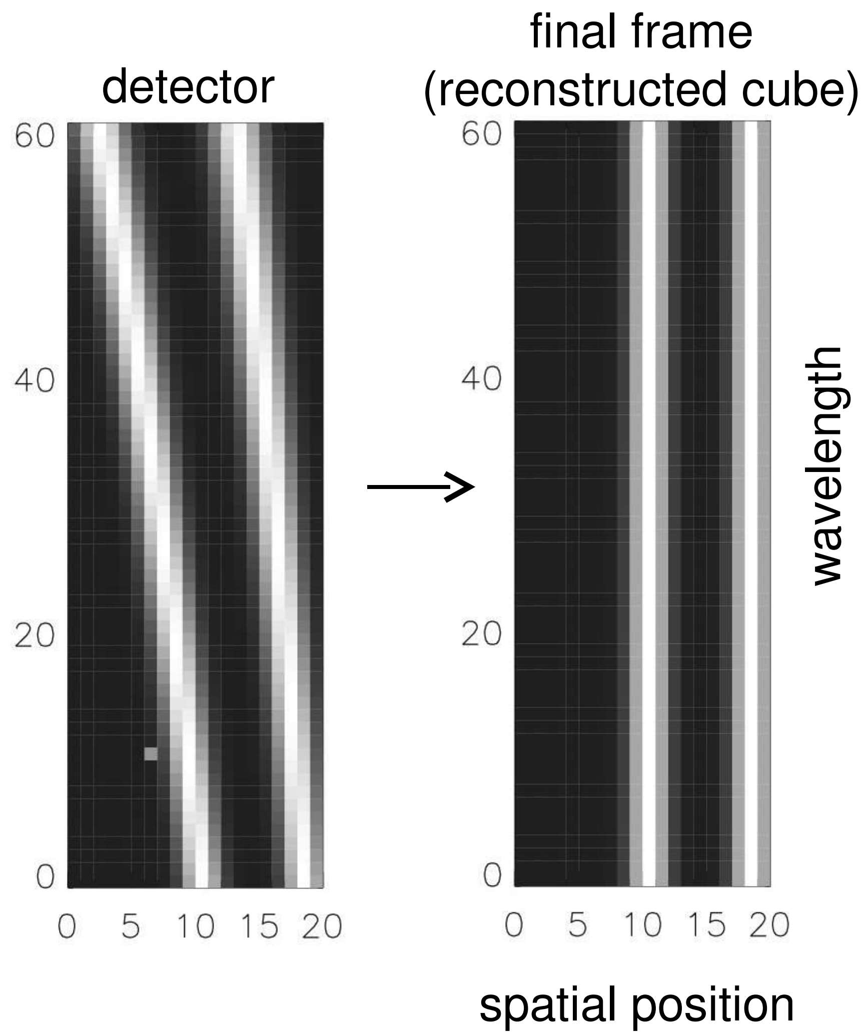
blue: advanced subtraction of sky using frame taken immediately afterwards

green: advanced subtraction of sky using the same sky frame in every case

An alternative perspective on calibration

standard view:
create mathematical functions (polynomials) which enable one to correct spectral & spatial curvature on the detector

alternative view:
create look-up tables which associate each measured value with its spectral & spatial position in the final (reconstructed) frame



An alternative perspective on calibration

specify regular grid in final frame

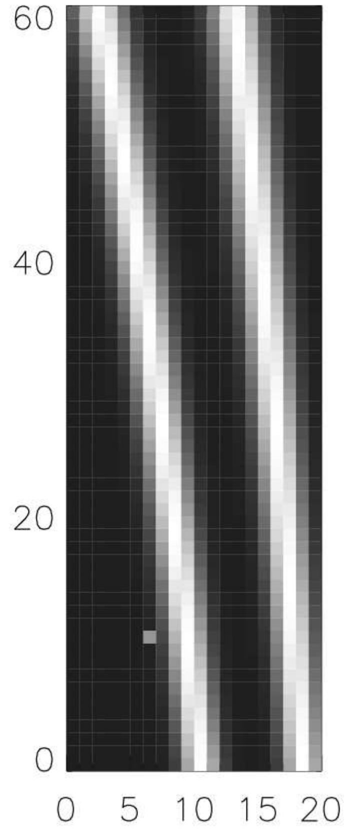
detector provides irregularly spaced samples final frame (whose positions are specified by calibration frames)

interpolate regular grid from these samples

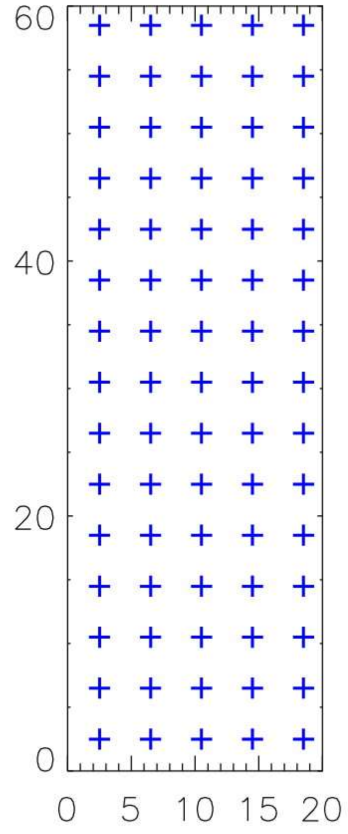
simply ignore bad pixels

afterwards, measure any offset (e.g. in wavelength); adjust calibrations appropriately; re-interpolate from raw data

detector



final data
(reconstructed cube)



An alternative perspective on calibration

final frame – *regularly* gridded x,y, λ positions where we want to know data values

calibration frames – lookup tables for *irregularly* spaced x,y, λ of each pixel on detector

detector frame – data values for these *irregularly* spaced x,y, λ sampling positions

create a list of sample points – their values & positions in the final frame – so that the data is dissociated totally from the detector frame.
i.e. the observations & calibrations simply give you:

$value_0, x_0, y_0, \lambda_0$
$value_1, x_1, y_1, \lambda_1$
…
$value_n, x_n, y_n, \lambda_n$

each point in final frame is interpolated from sampled points in its local neighbourhood

advantages:

single interpolation in 3 dimensions
combine frames during interpolation
choose sampling of reconstructed data (e.g. to match another instrument)
smooth data during reconstruction (e.g. if data is really noisy)
etc…

Summary / Conclusions

- can use a simple approximation to adaptive optics PSF & still get valid results

- there maybe ways to extract PSF information from the science data

- convolution of a model is often better than deconvolution of the data

- OH subtraction can be improved (& observing efficiency increased)

- thinking about calibrations in a different way can bring many advantages