Black Hole masses with NIFS in LGS AO mode

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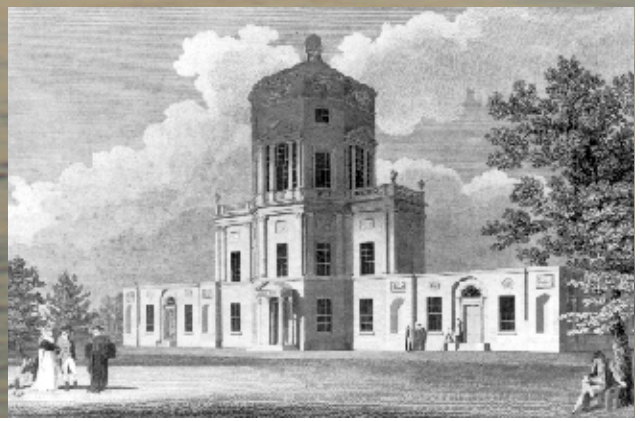


Intro

- Representative local M_{BH} - σ relation
- LGS AO: M_{BH} from the ground!!

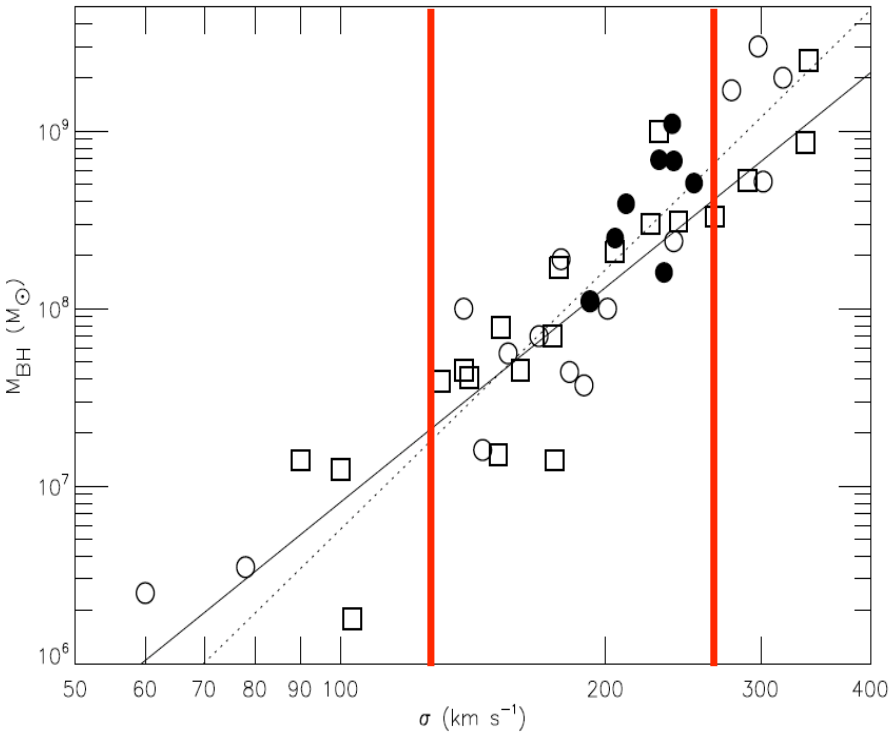
- Work done with:
  - Richard McDermid (Gemini)
  - Michele Cappellari (Oxford)
  - Atlas^{3D} team

Supermassive black holes

- Empirical relations with quantities on different scales:
  - $M_\bullet \sim L_{bulge}, \sim M_{bulge}, \sim \sigma_\star, \sim c$ (Magorrian et al. (1998).....)
  - Connection between 10^{-5} pc and 1kpc
  - Current sample not bias free! (Bernardi et al. 2007, Lauer et al. 2007)
- Co-evolution of SMBH and host galaxies:
  - Exploited by theoretical models of structure formation
  - Feedback models explain galaxy colour bi-modality
  - Large SMBH halts star-formation (Springel et al. 2005b, Cattaneo et al. 2006; Bower et al. 2006; Cox et al. 2006, Bower et al. 2006....)
- Key ingredients:
  - Slope
  - Scatter
  - Extent
  - Evolution

Atlas^{3D} BH project

- Goal: derive a <u>representative</u> M_{BH} - σ_e relation for early-type galaxies!
- Target under-populated regions of M_{BH} - σ_e relation
  - σ_e < 130 km/s and σ_e > 270 km/s
- Atals^{3D}: a volume limited sample
  - all nearby early-type galaxies
- Large scale IFU observations in hand!!
- High resolution campaign

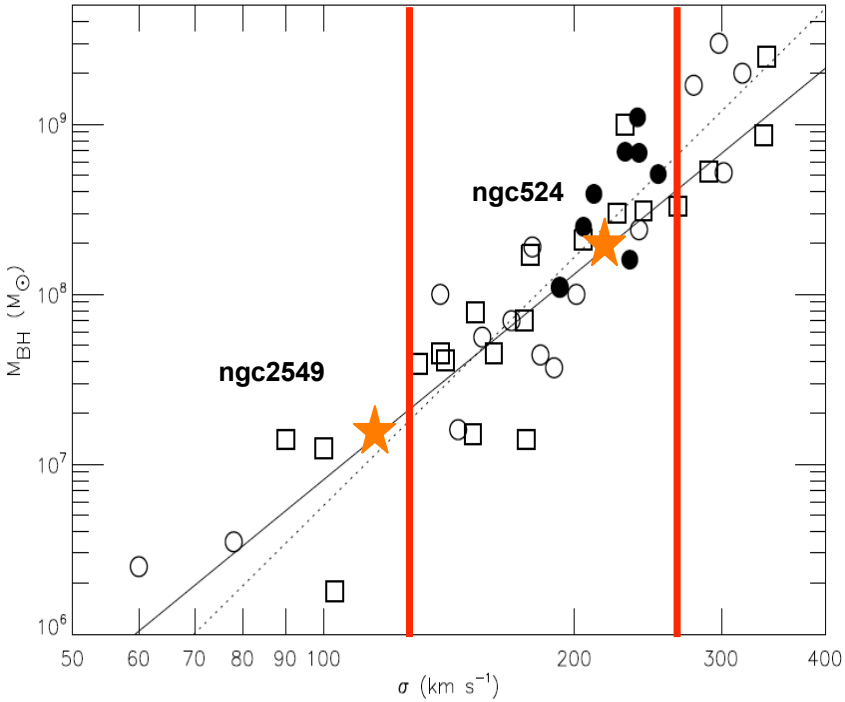


Cappellari et al. (2007)

Gebhardt et al. (2000) & Merritt& Ferrarese (2000)

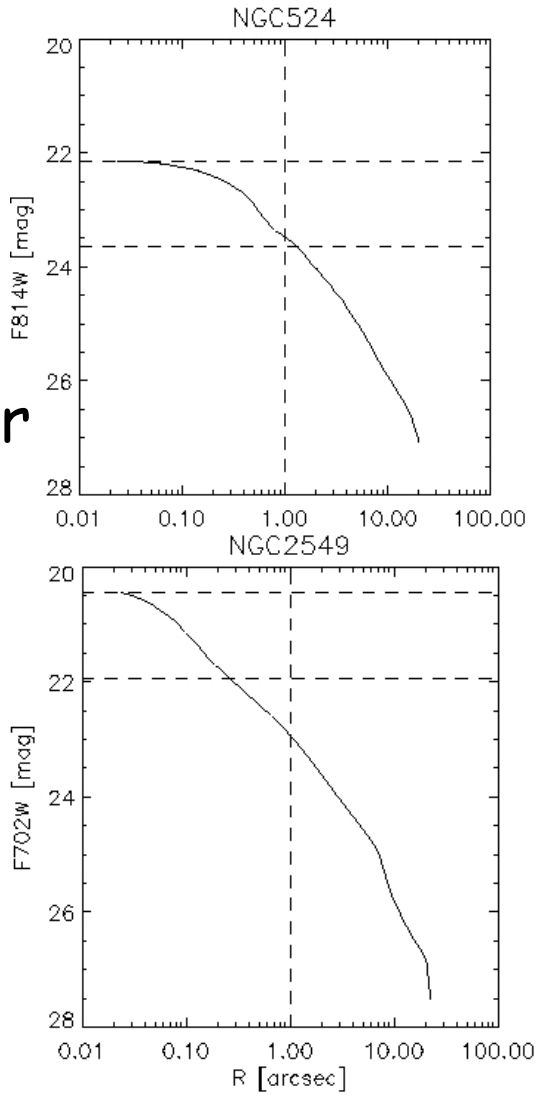
NIFS@GEMINI

- AO needed for small galaxies
- AO corrections:
  - 'higher-order' corrections: LGS
  - focus of LGS due to changing sodium layer: NGS
  - 'low-order' tip-tilt correction: NGS
- Not many suitable NGS
- NIFS + ALTAIR LGS without NGS?!
- Two test cases:
  - NGC524 σ_e= 222 km/s
  - NGC2549 σ_e= 119 km/s



LGS AO without NGS

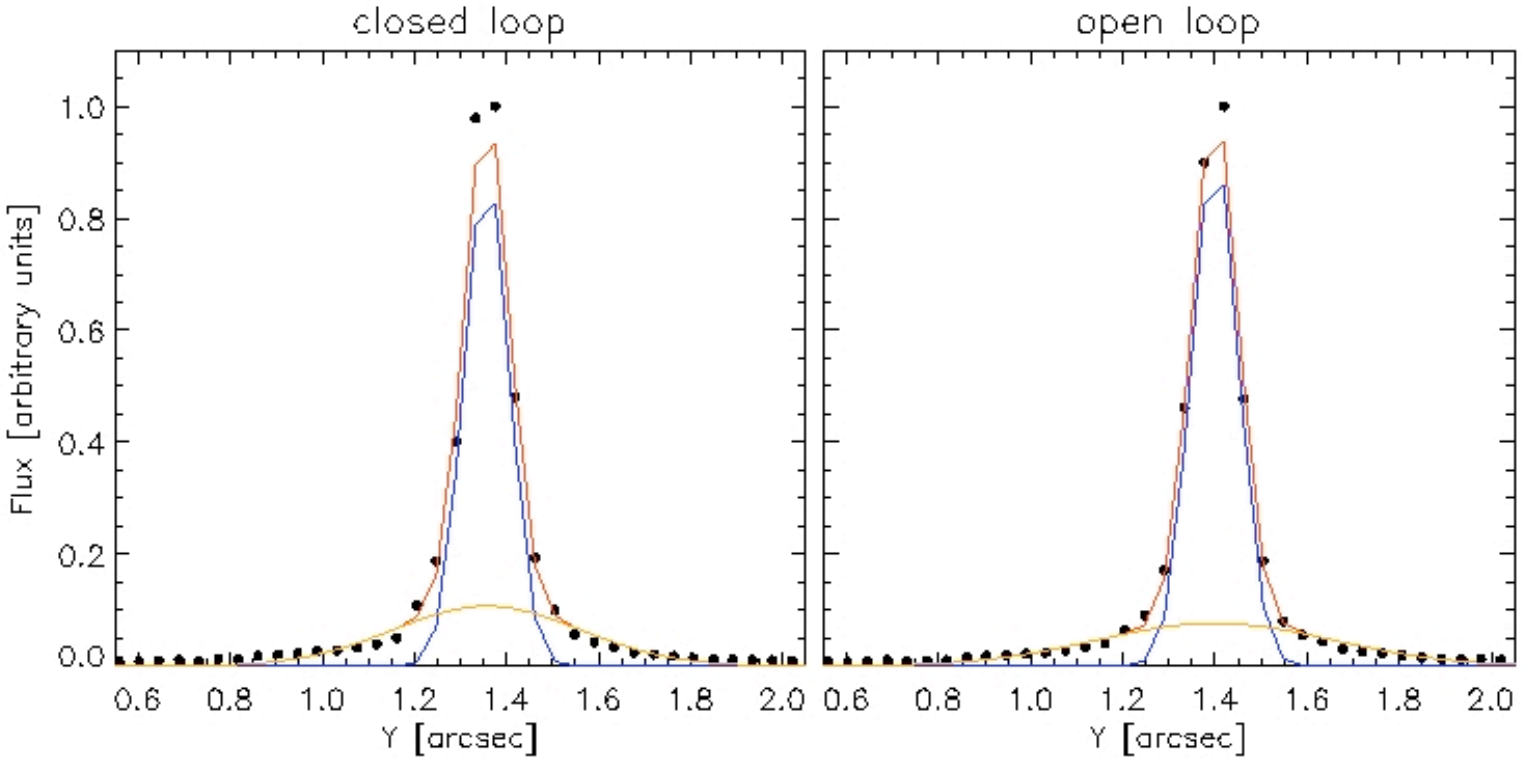
- No bright enough NGS nearby
- Tip-tilt correction on nuclei
- Adopted strategy:
  - Tune in LGS AO on a nearby (focus) star
  - Open focus loop & move to target
  - Observe target (LGS + tip-tilt from nucleus)
  - Focus is changed by following a model
  - Back to focus star to monitor PSF changes
- or No tip-tilt (Davies et al. 2008, VLT)



LGS AO without NGS

Focus star before and after 1h: 30% strehl

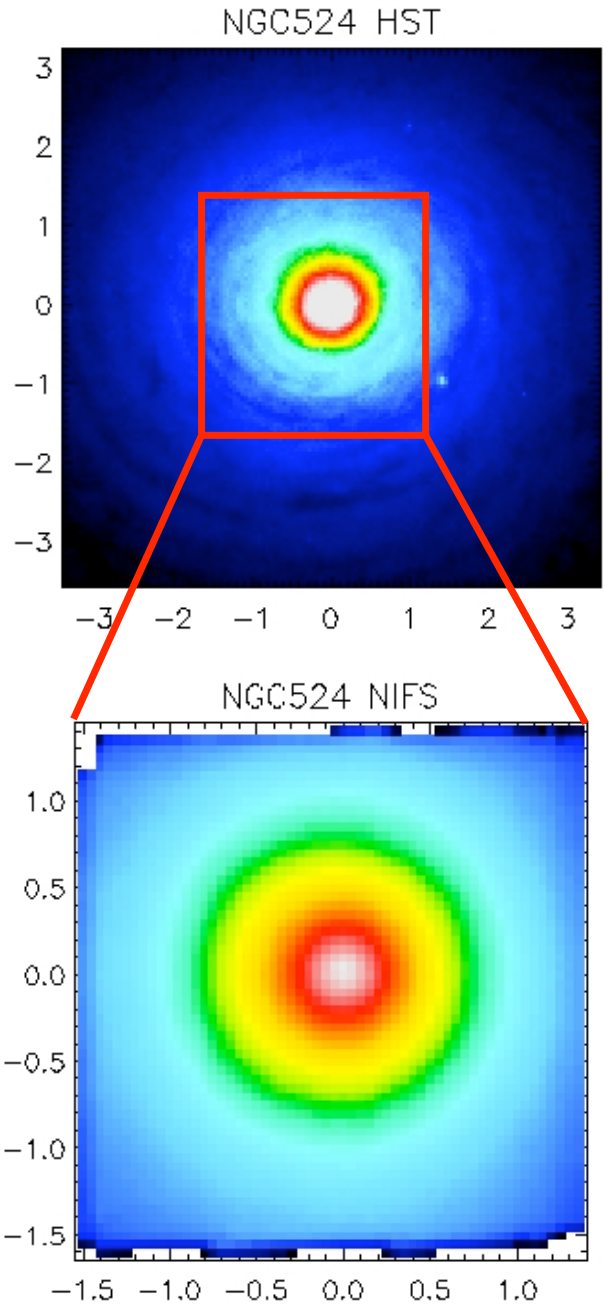
fwhm1 = 0.11″	fwhm1 = 0.12″
fwhm2 = 0.48″	fwhm2 = 0.60″



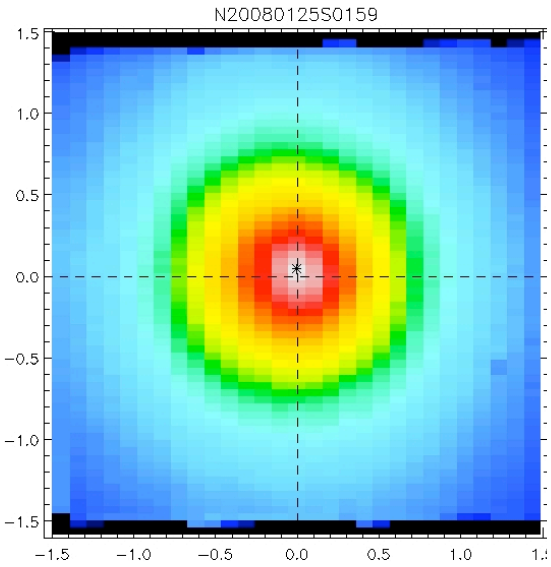
NGC524 observations

- NIFS
  - FoV: 3″x3″ at 0″.042x0″.103
  - R ~ 5000 (~30 km/s at 2.2 μm)
- 20x10min expos on target
- Obj-Sky-Obj-Obj-Sky-Obj
- 10 high quality frames, 7 ok, 3 not useful
- Typical natural seeing: 0″.45 - 0″.75

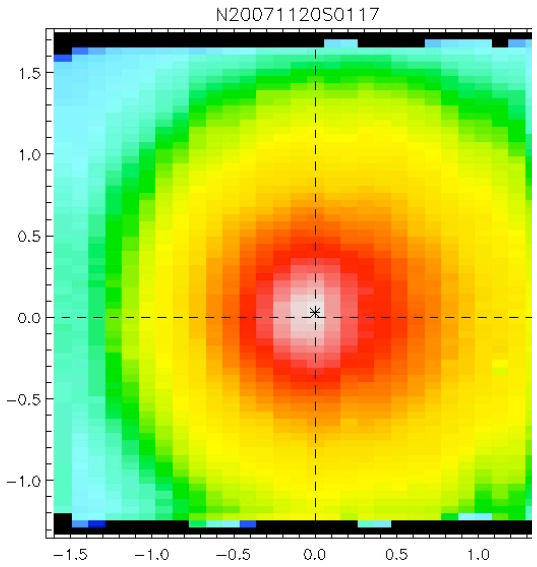
NGC524



Good frame



Bad frame

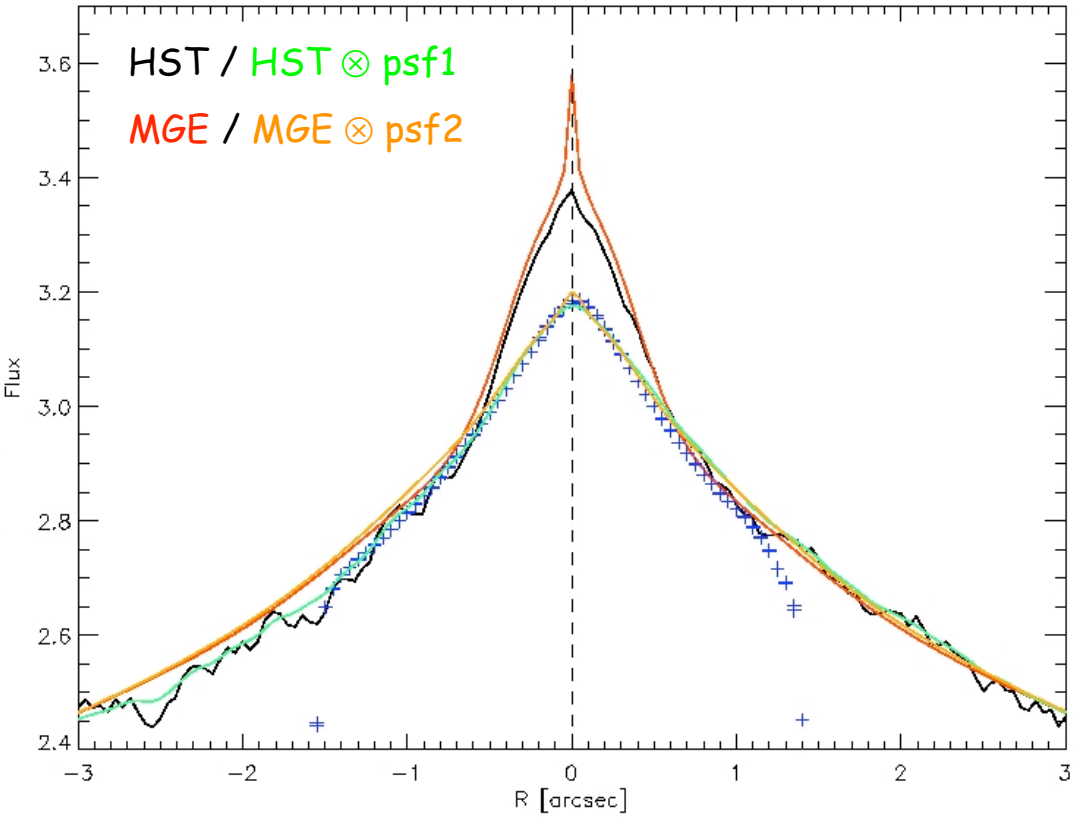


Estimating PSF

- Diffraction limit: fwhm = 0".07
- Comparison with HST image (psf~0".05)
- Comparison with Multi-Gaussian-Expansion model (deconvolved) (Emsellem et al. 1994, Cappellari 2002)
- Convolve test image with a double Gaussian
- Compare with NIFS data cube
- Used for non-AO data: Emsellem et al. (2004), McDermid et al. (2006), Shapiro et al. (2006)

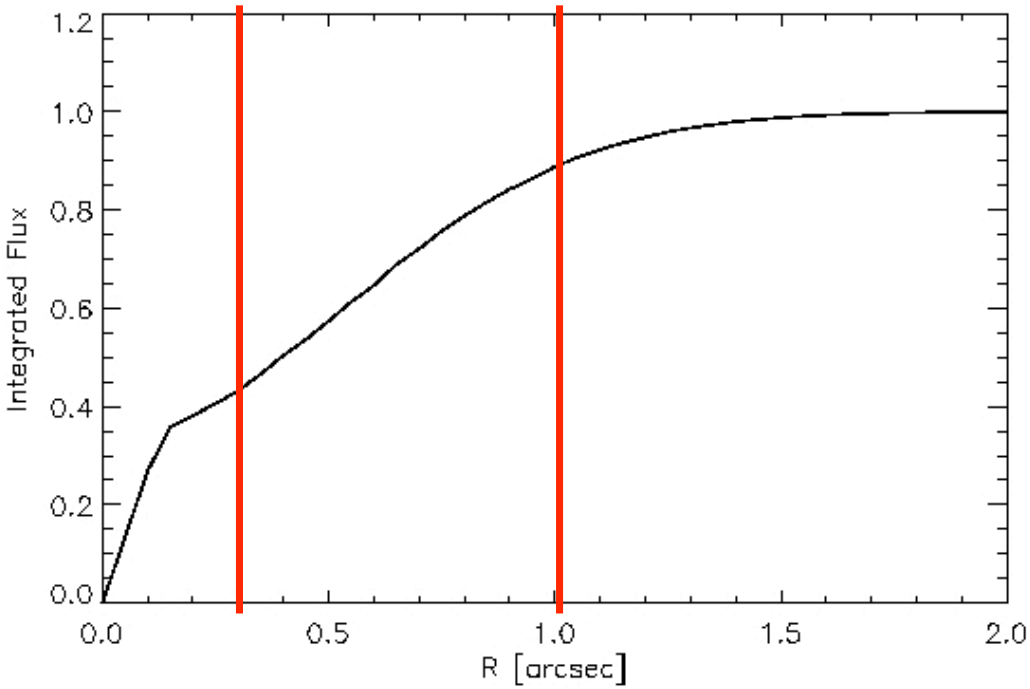
Estimating PSF II

- HST (psf1):
  - $Fwhm_1$ = 0.12 ± 0.01
  - $Fwhm_2$=1.25 ± 0.09
  - I_1=0.335 ± 0.08
- MGE (psf2)
  - $Fwhm_1$ = 0.09 ± 0.02
  - $Fwhm_2$ = 1.36 ± 0.04
  - I_1 = 0.284 ± 0.05

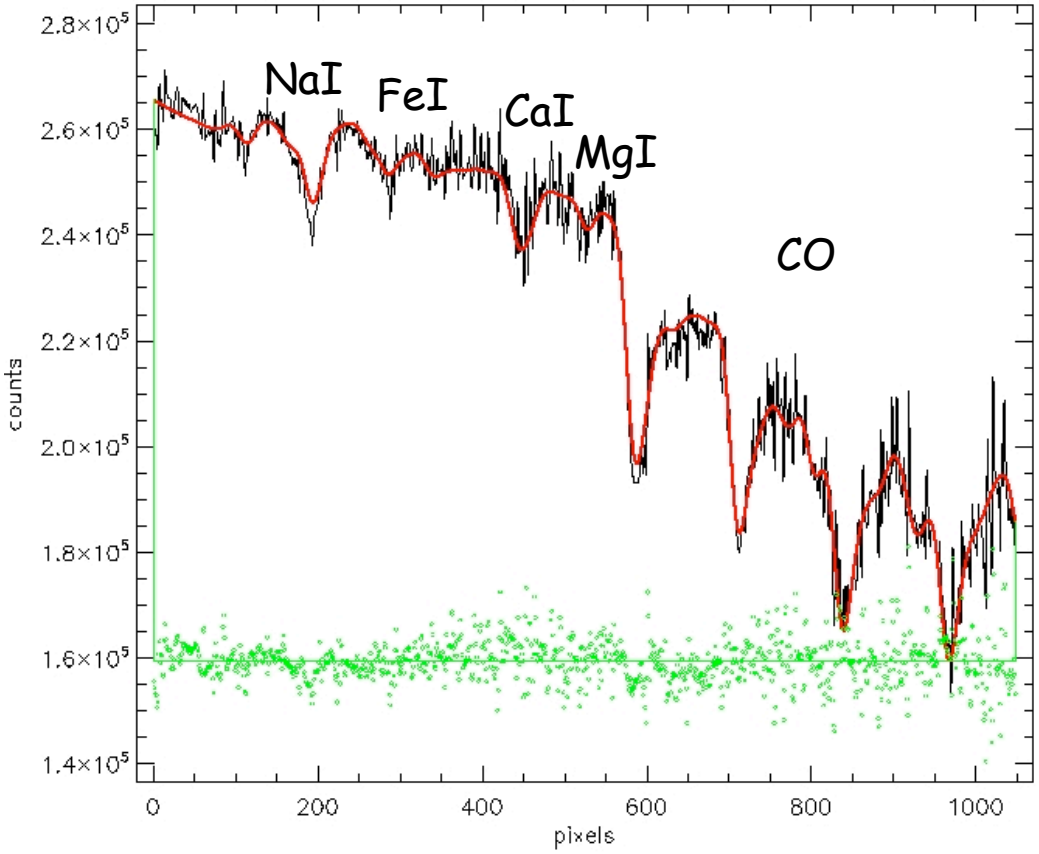


How good is the correction?

- LGS only correction
  - SFO star: 0".12 / 0".6
  - NGC 524: 0".12 / 1".2
- Tip-tilt jitter
- Strehl
  - Comparison with diffraction limited psf
  - 12%
- Encircled energy
  - 40% within 0".2
  - 90% within 1"

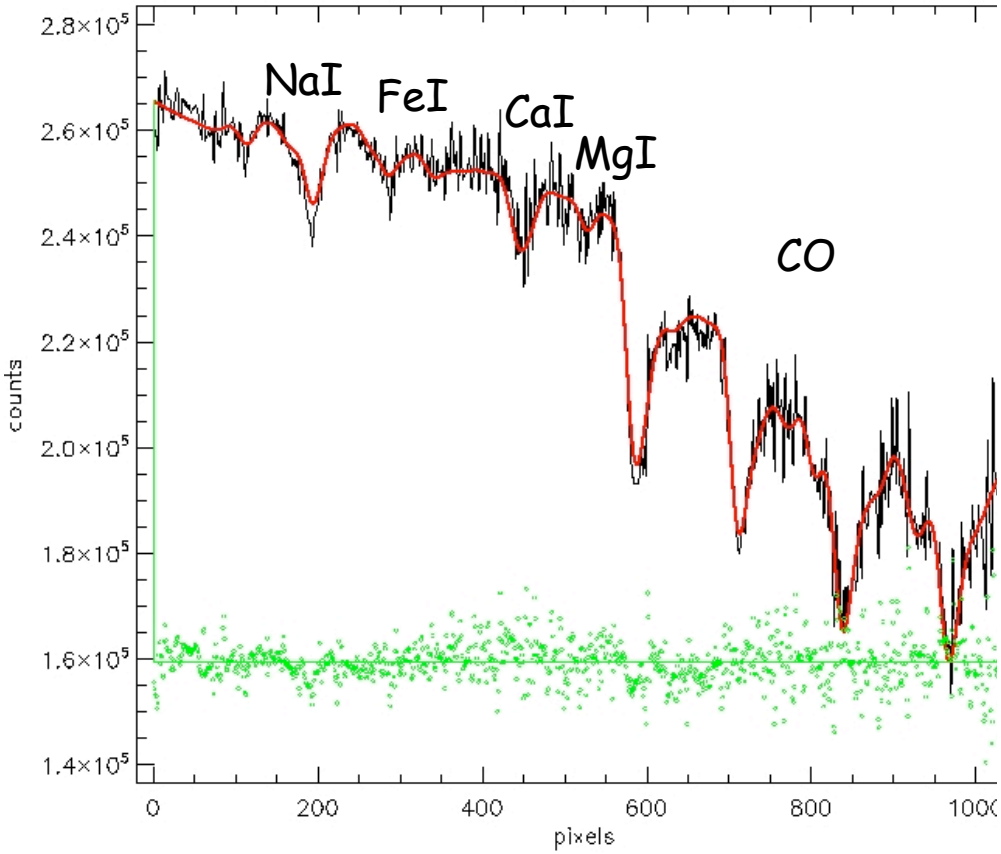


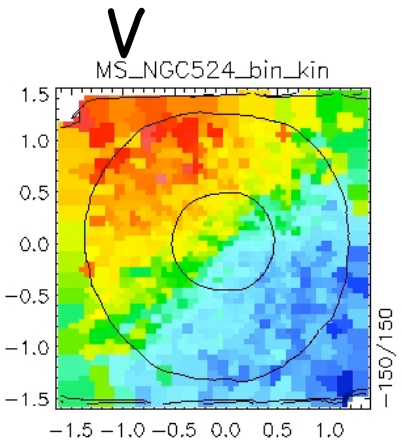
NIFS view on NGC524

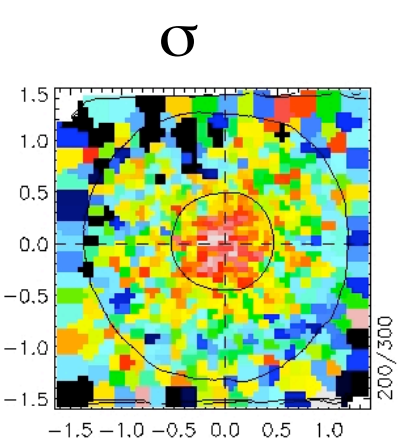


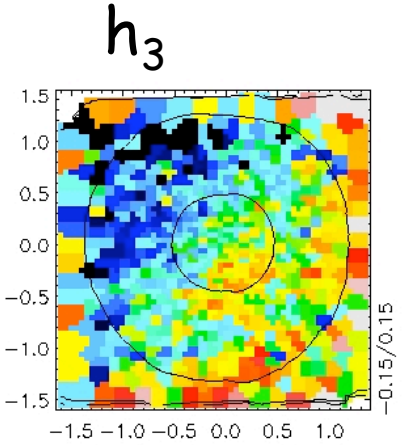
- Velocity templates: Winge et al. (2008)
- 30 GNIRS spectra
- $\sigma \sim 26$ km/s
- pPXF (Cappellari & Emsellem 2004)

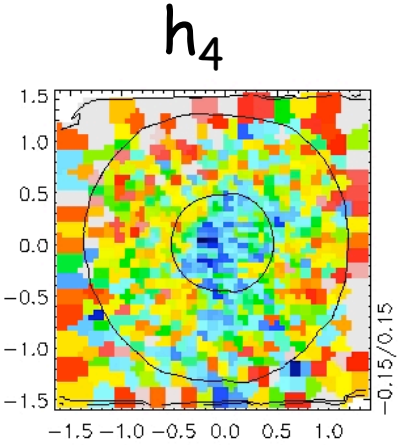
NIFS view on NGC524



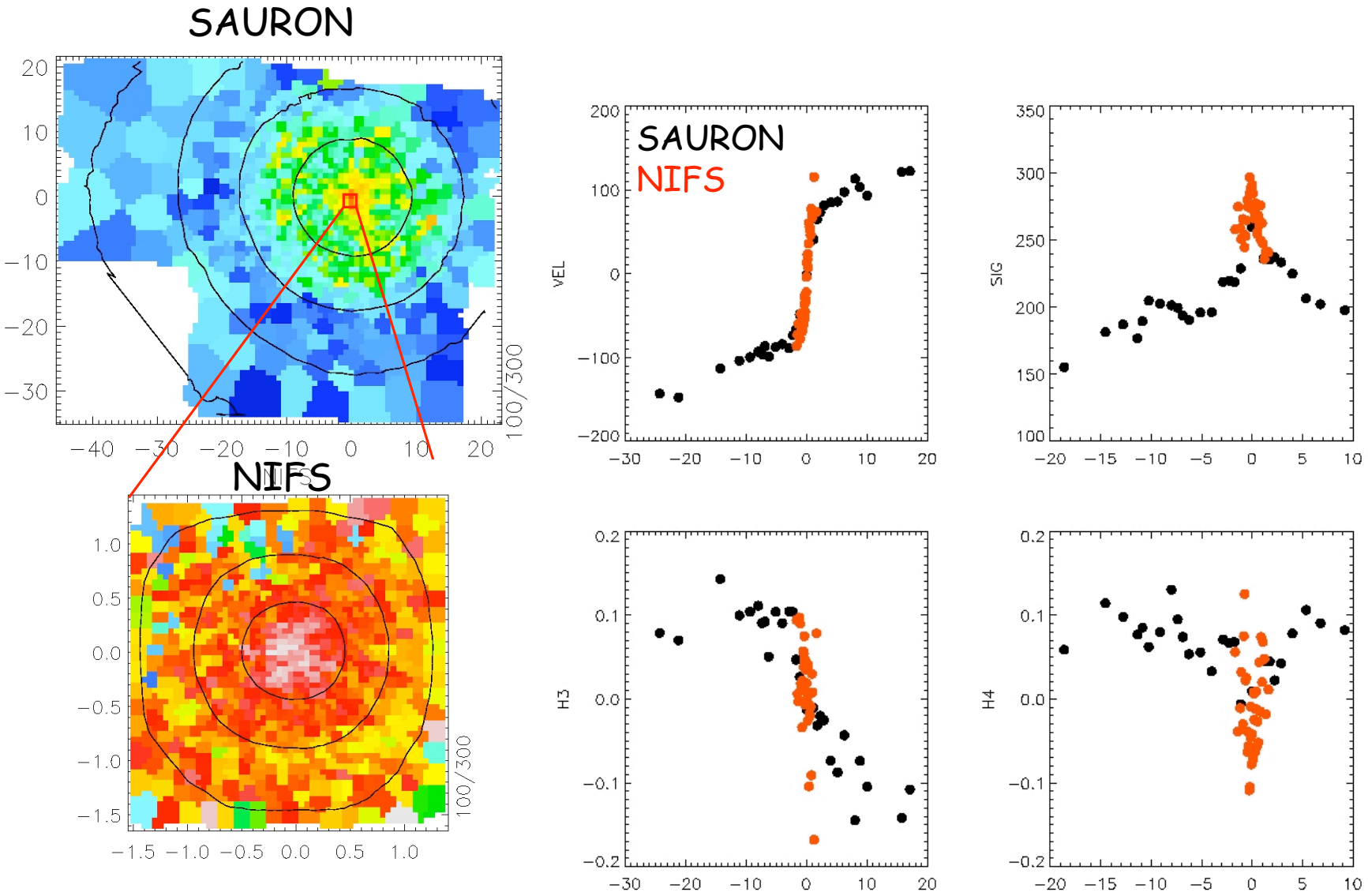




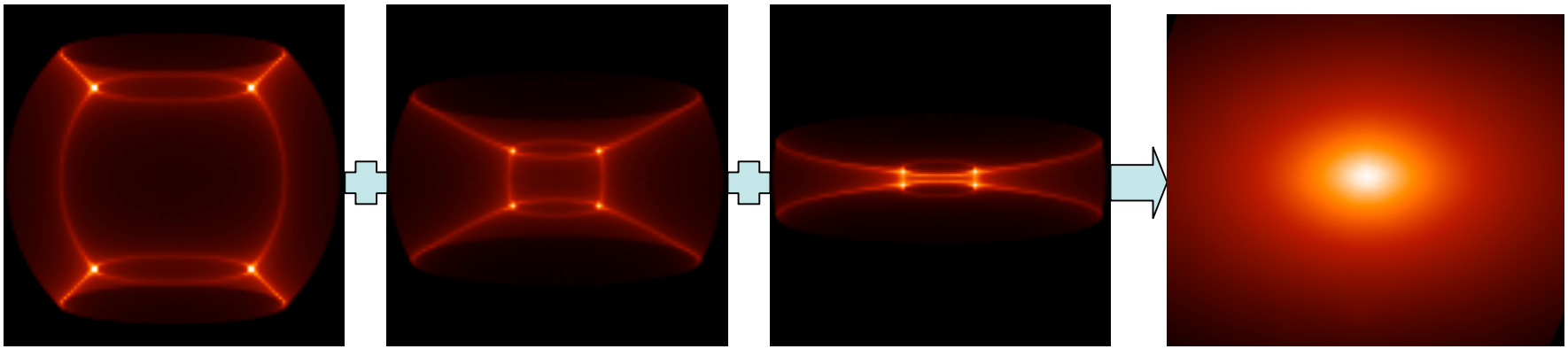




Comparison with SAURON



Schwarzschild's method



images of model orbits

Observed galaxy image

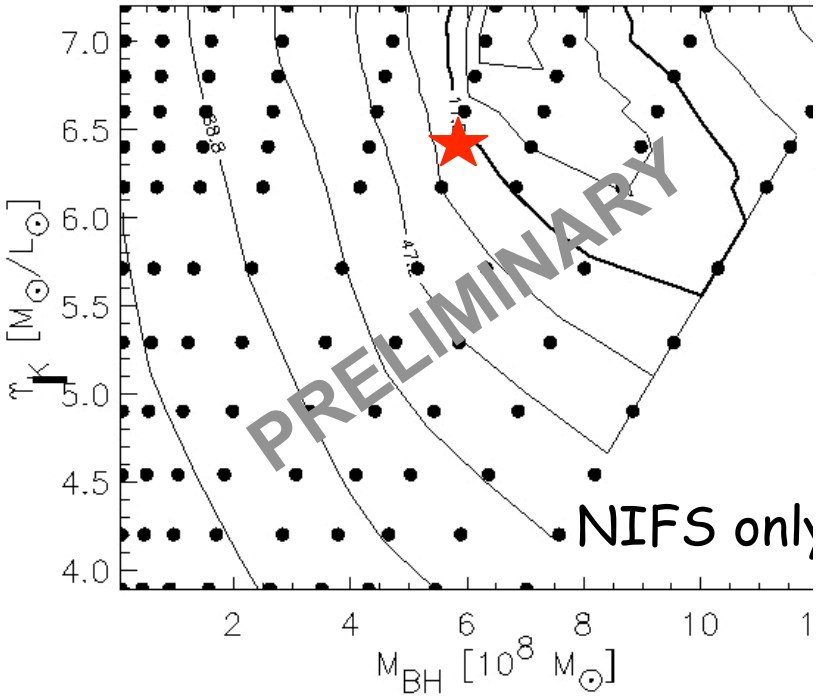
- Stellar dynamical modelling:
  → representative orbit library (Schwarzschild 1979,1982)

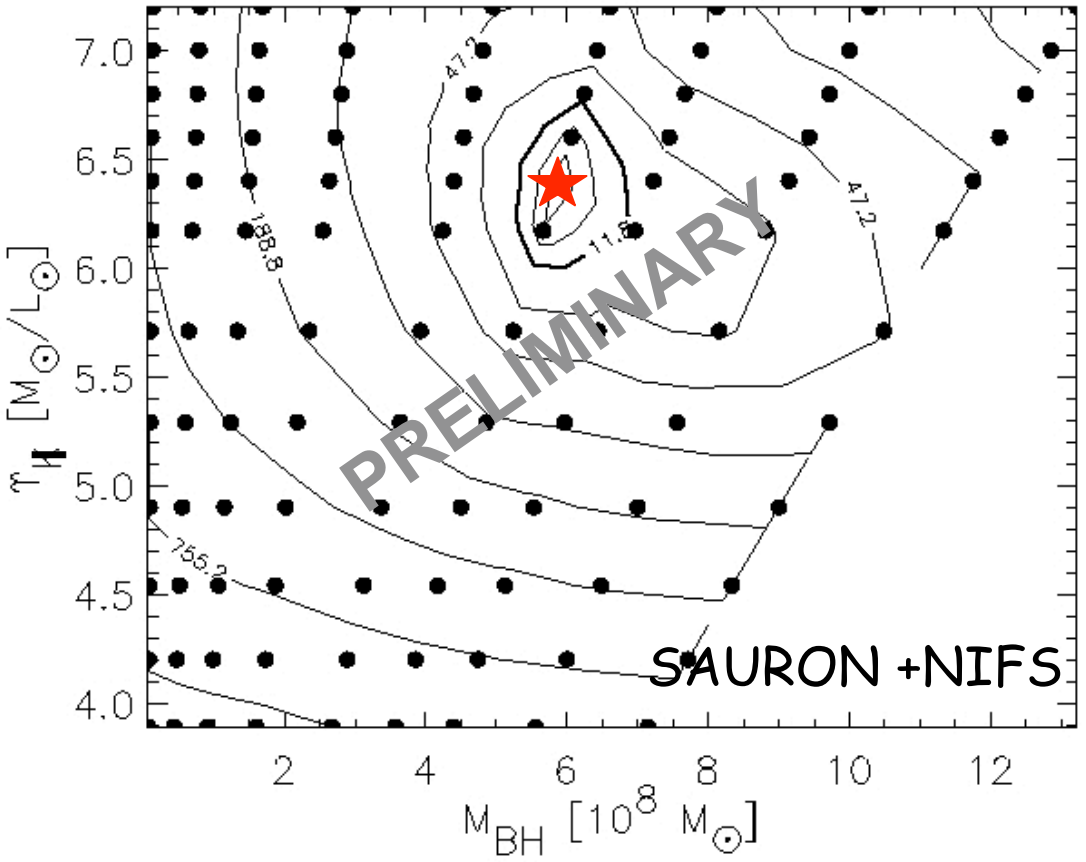
  (Richstone&Tremaine 1988, Rix et al. 1997, van der Marel et al. 1998, Cretton et al. 1999, Cappellari et al. 2002, Gebhardt et al. 2003, Valuri et al. 2004, Thomas et al. 2004, Davies et al. 2006, Cappellari et al. 2006, van den Bosch et al. 2008)
- $2x21x8x7x6^3 = 508032$ (dithered in groups of 6^3)
- Optimal superposition to reproduce observables:
  - distribution of light and 2D kinematics (up to h_6)

M_{BH} in NGC524

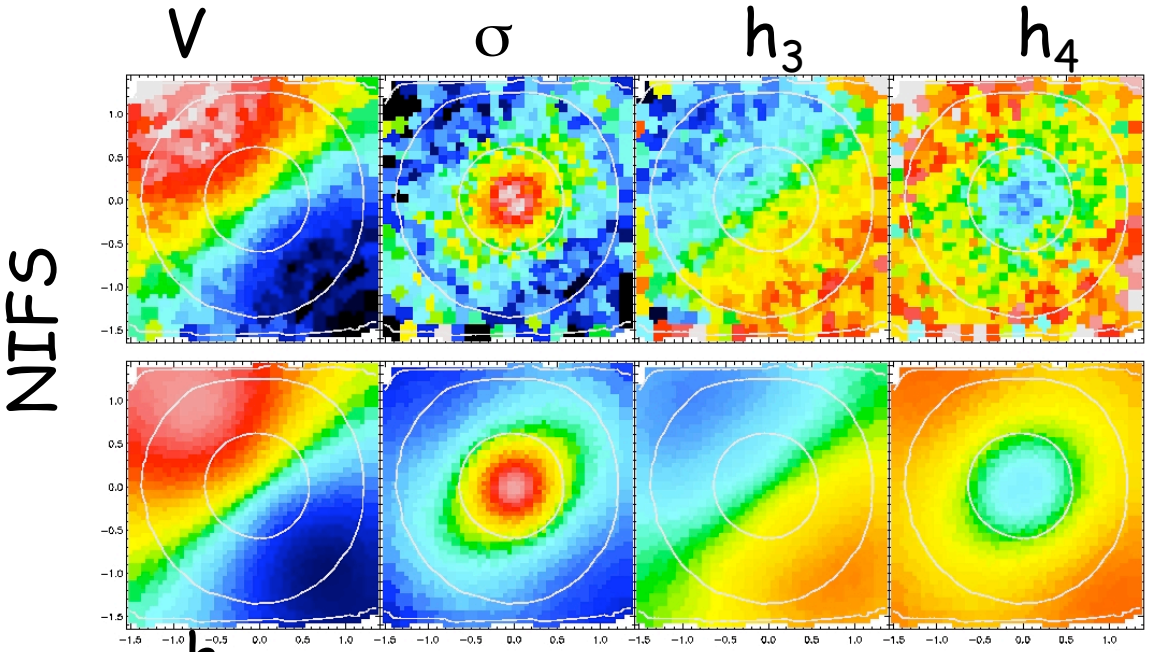
NIFS only
- M\L - M_{BH} degeneracy
- M_{BH} > 6x10^8 M_{sun}
- No constraints on orbital structure

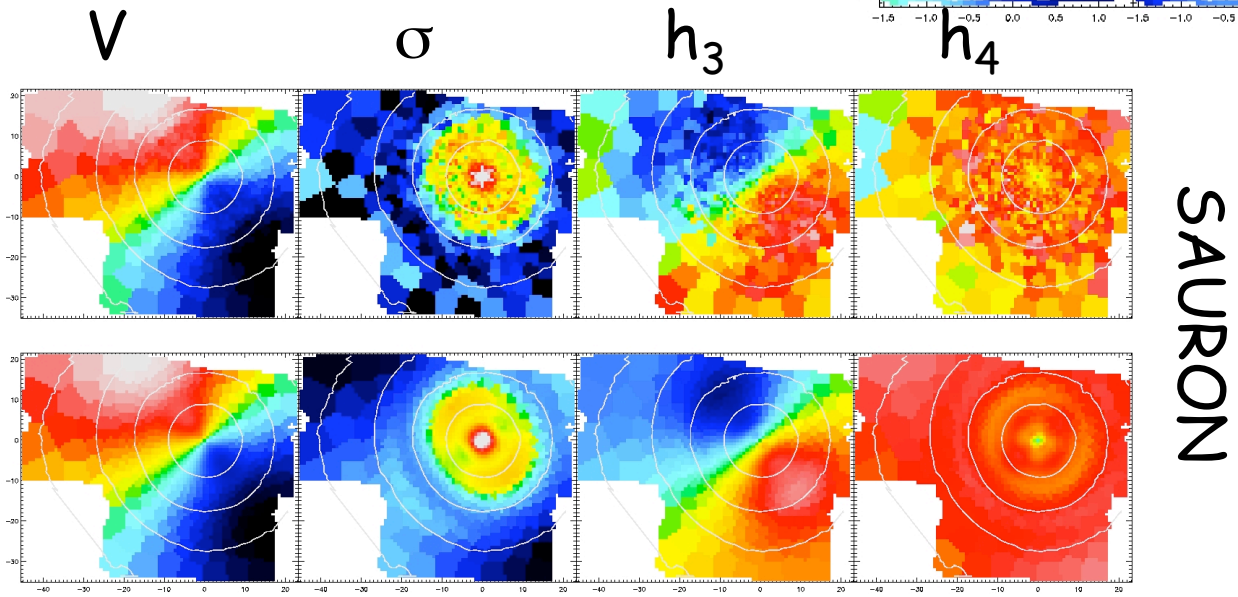
- M_{BH} = (5.9 ± 1)x10^8 M_{sun}
- M/L_I = 6.4 + 0.4



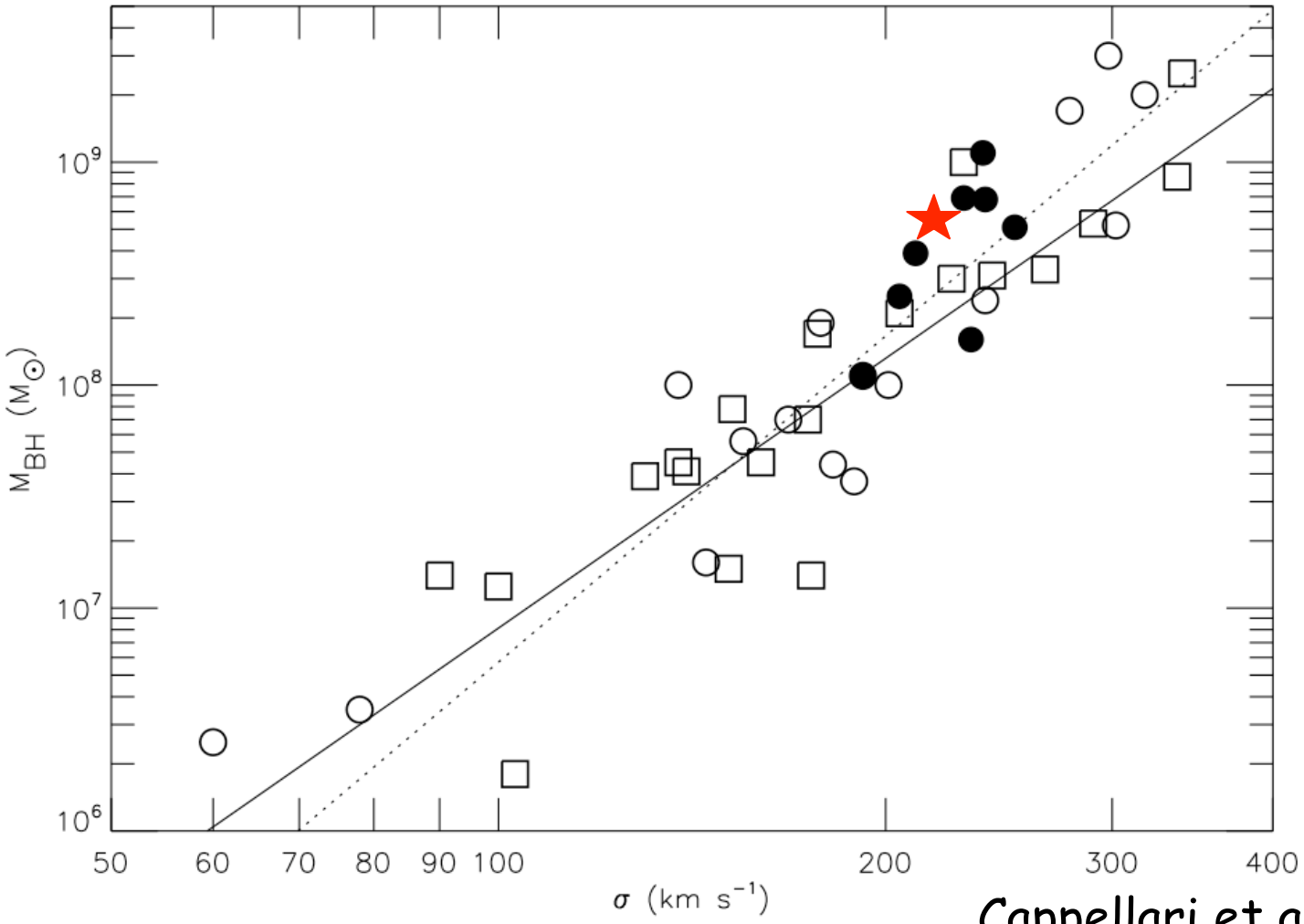


Data model comparison





M_{BH} - σ relation



Cappellari et al. (2007)

Conclusions

- Limited LGS AO can deliver considerable correction to PSF
  - 0".5-0".7 natural --> 0".1- 0".2 LGS
- Large scale IFU: breaking M/L -Mbh degeneracy!!!! CRUCIAL!
- Our method opens skies for similar studies => ***Atlas^{3D} Black Holes***
- NGC 524: M_{BH} = 5.9 x 10^6 M_{sun}