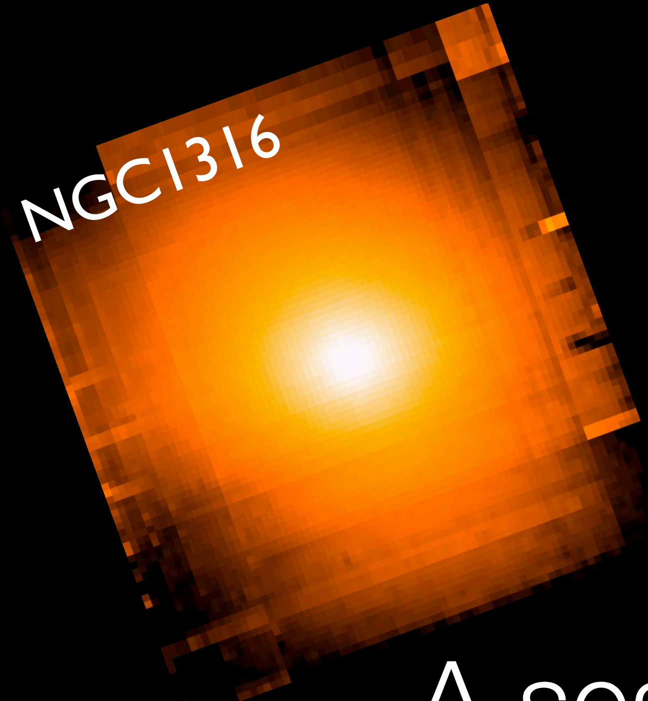
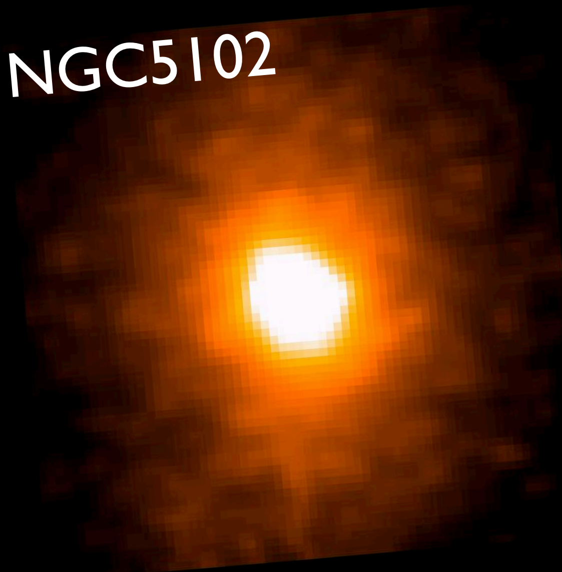
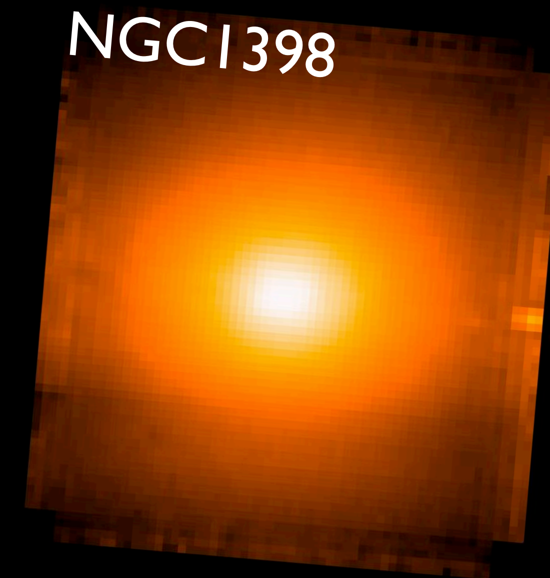
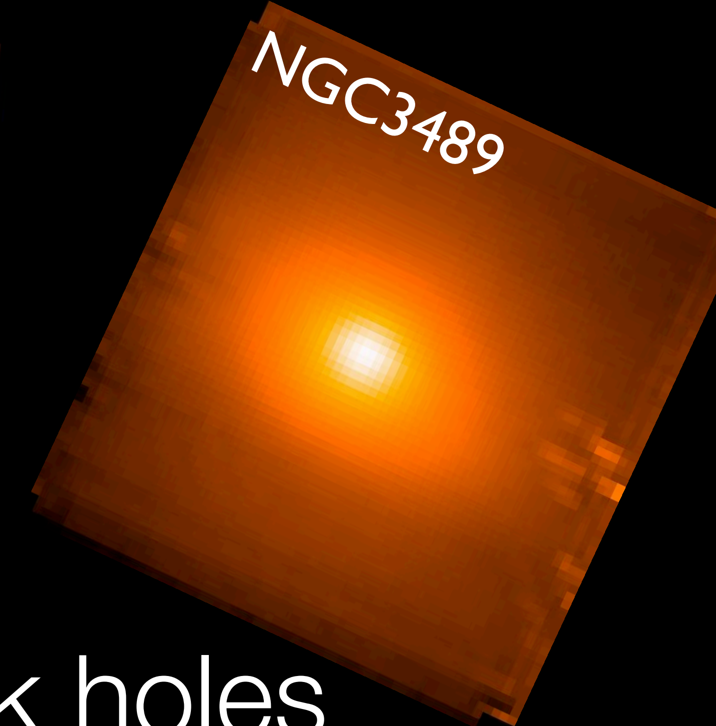




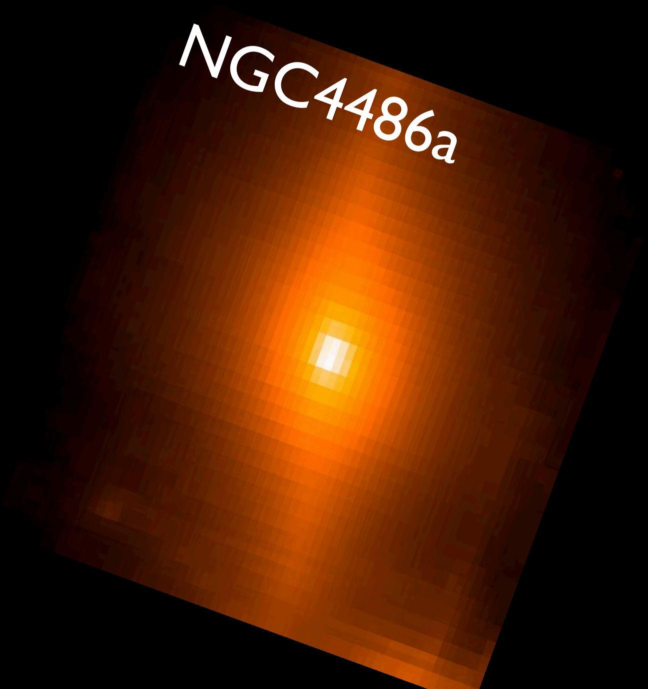


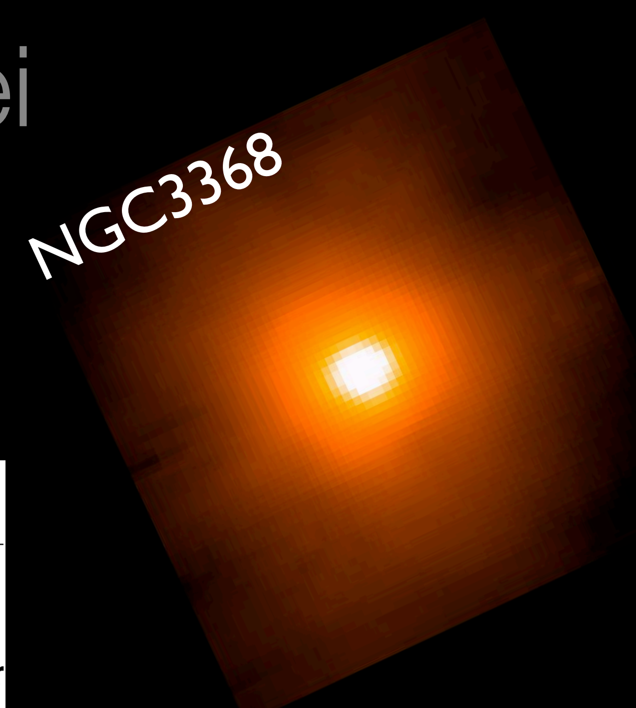


A search for supermassive black holes in pseudo- and low-mass bulge galaxies

Roberto Saglia, MPE, 14/12/2007

Start-up Workshop Physics of Galactic Nuclei





In collaboration with: Nina Nowak, Jens Thomas, Peter Erwin, Ralf Bender, Niv Drory, Ric Davies

MPE

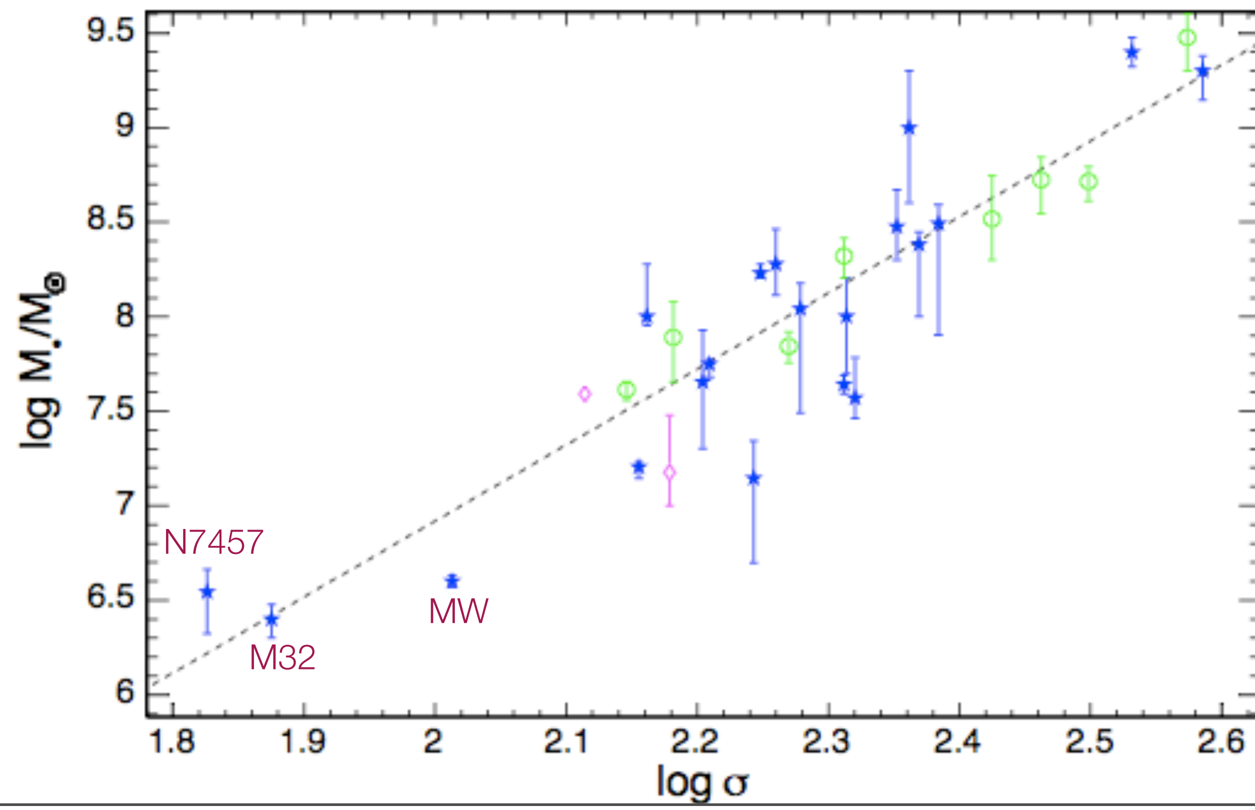
TUM LMU Excellence Cluster Universe

Overview

- Introduction
- Observations, Data Analysis & Dynamical Modelling
- Results:
  - NGC4486a
  - NGC1316
  - NGC3368
- Outlook

The M_{BH}-σ relation

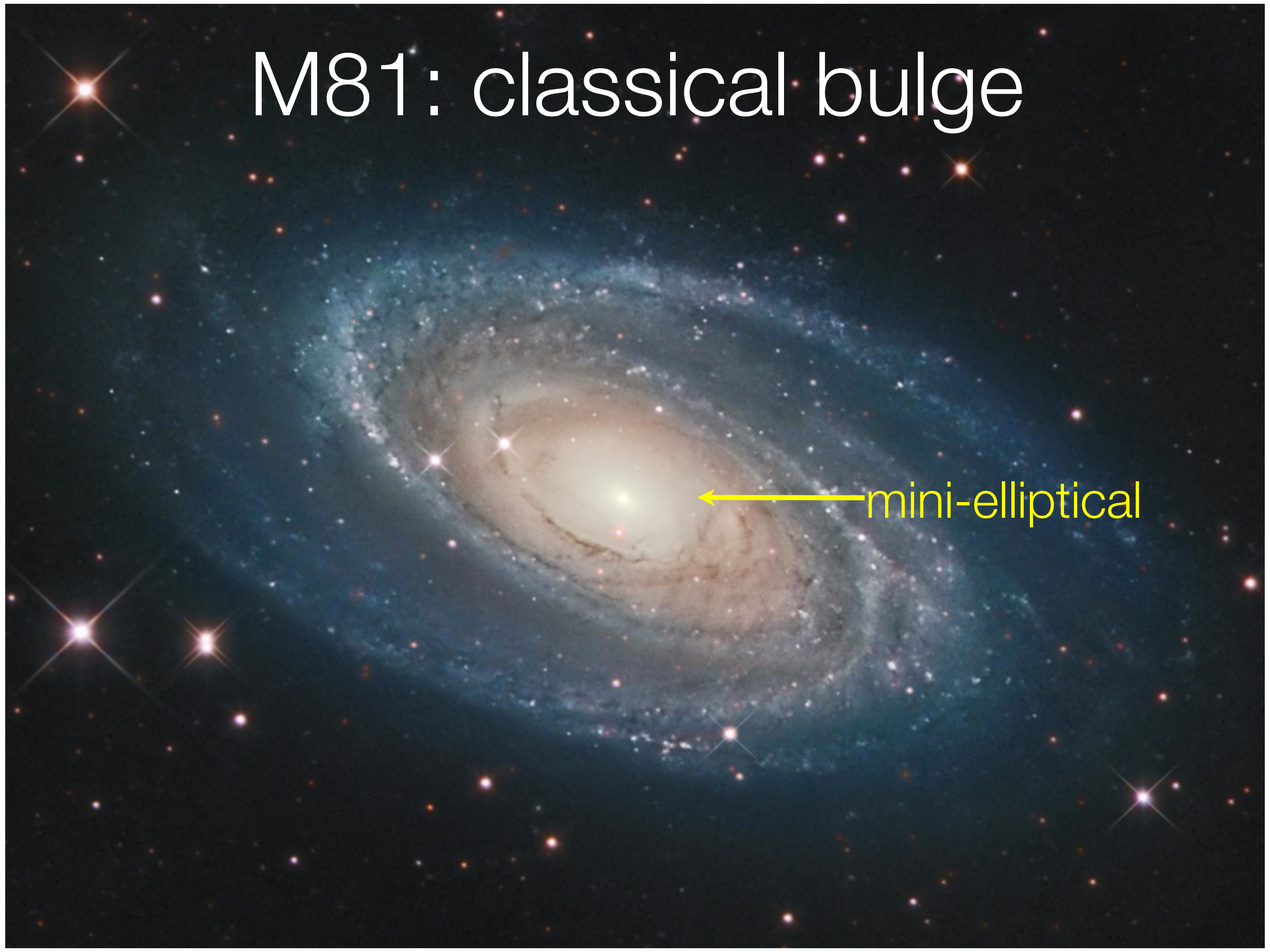
- mass of the SMBH correlates with bulge luminosity/mass ($M_{BH} \approx 0.002 M_{Bulge}$) and velocity dispersion (M_{BH}-σ relation)
  → strong link between bulge formation and black hole growth
- M_{BH}-σ relation well determined for massive galaxies, no clear restrictions on the slope for low-mass galaxies (σ < 120km/s)

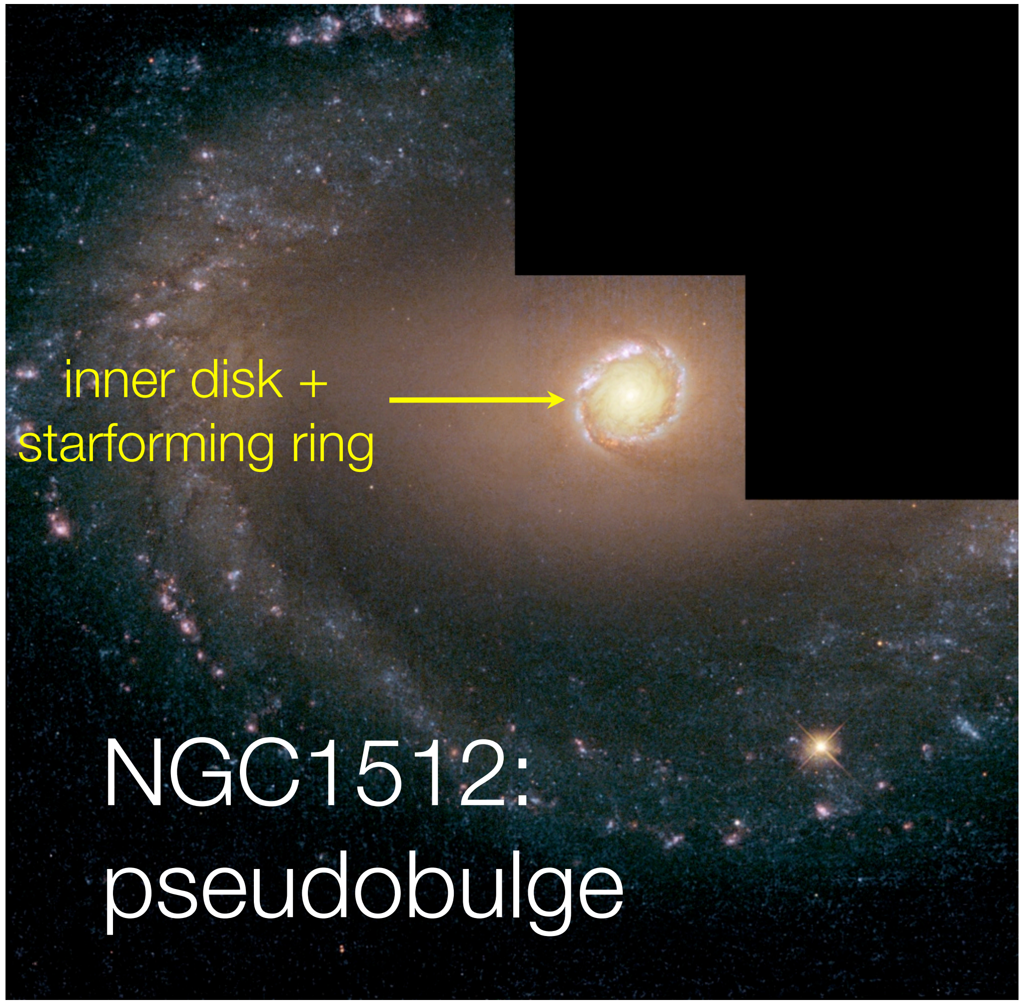


Tremaine et al. 2002

Classical- and pseudo-bulges

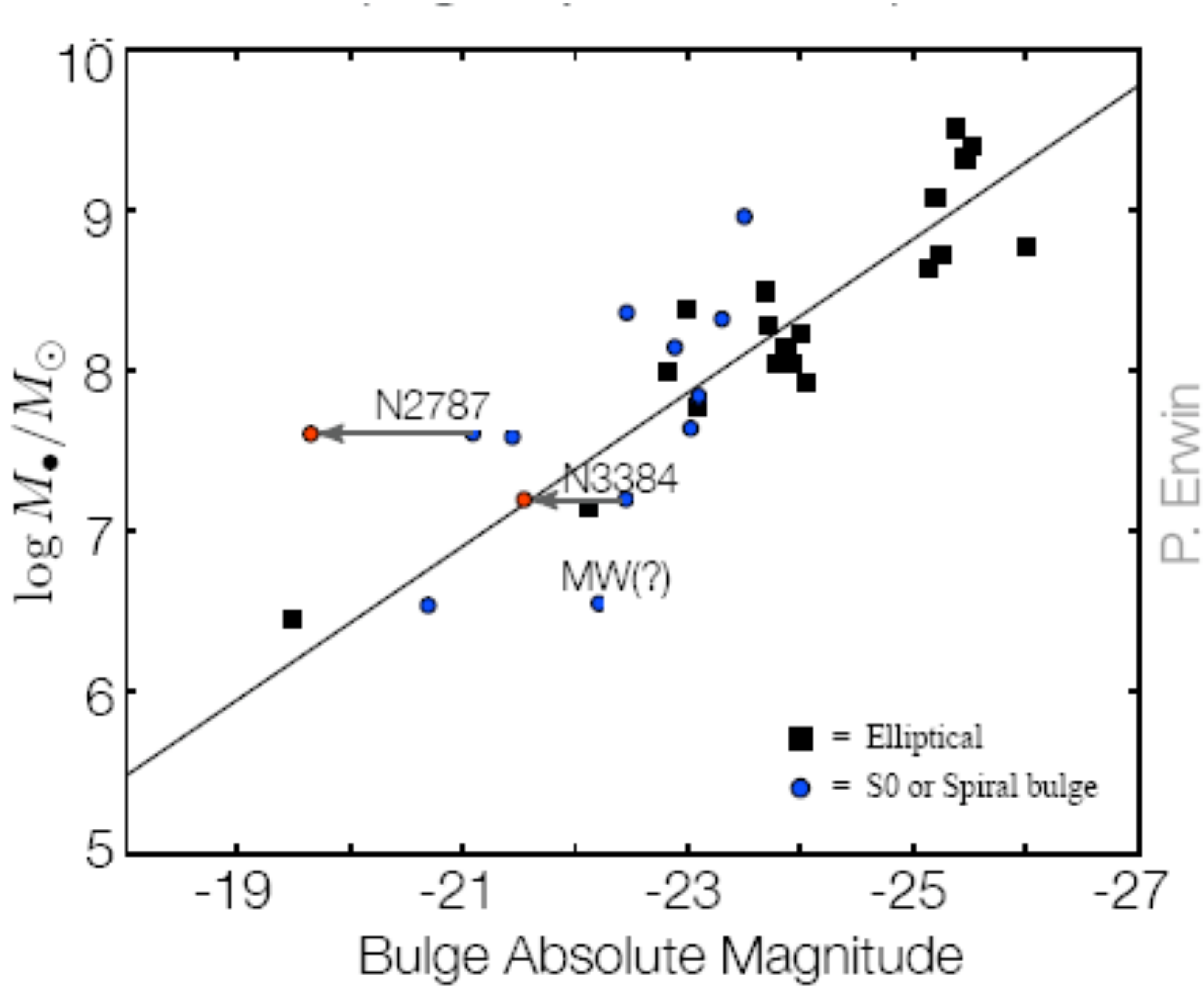
- two different bulge-types: *classical bulges* and *pseudobulges*
  - *classical bulges*: mini-ellipticals, formed by mergers
  - *pseudobulges*: disk-like characteristics (e.g. rapid rotation), formed by secular evolution





Classical bulges and pseudobulges

- bulges can have a classical and a pseudo component at the same time
- only two M_{BH} measurements in pseudobulges



Black holes in low-σ bulges and pseudobulges

- Goals:
  - measure M_{BH} for an increased population of low-σ galaxies
  - investigate if and how the M_{BH}-σ relation changes when only pseudobulges are considered
- most direct evidence for SMBHs: dynamics of stars inside the sphere of influence

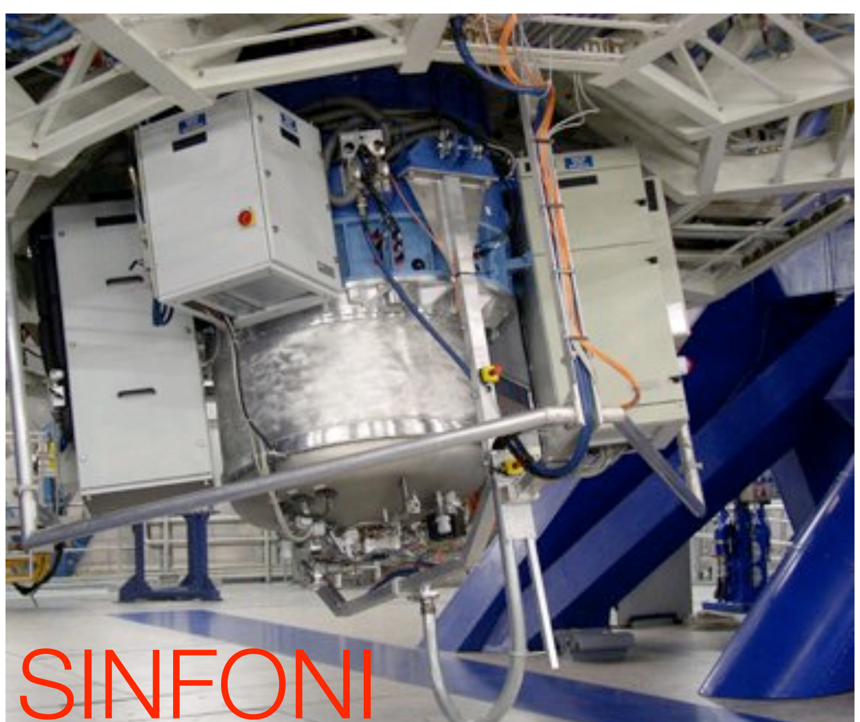
$$d_{soi} = \frac{2GM_{\bullet}}{\sigma^2}$$

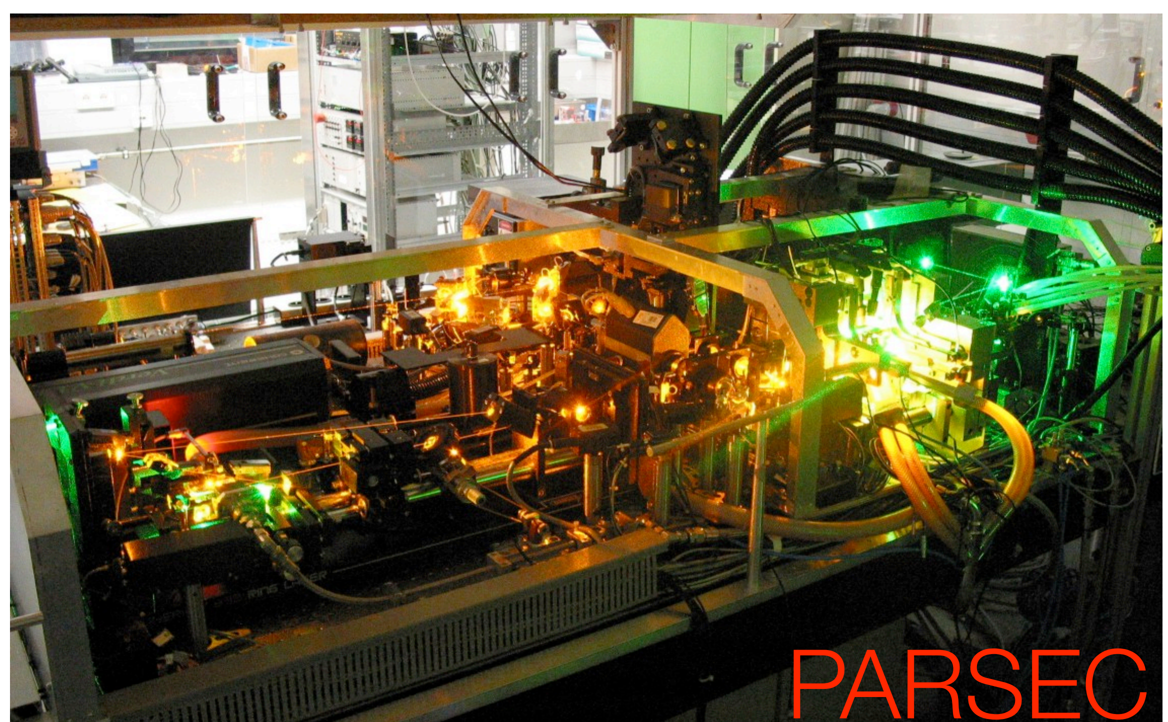
- (usually <<1” even for nearby galaxies)
- HST STIS: optical, 0.1” resolution, but dead

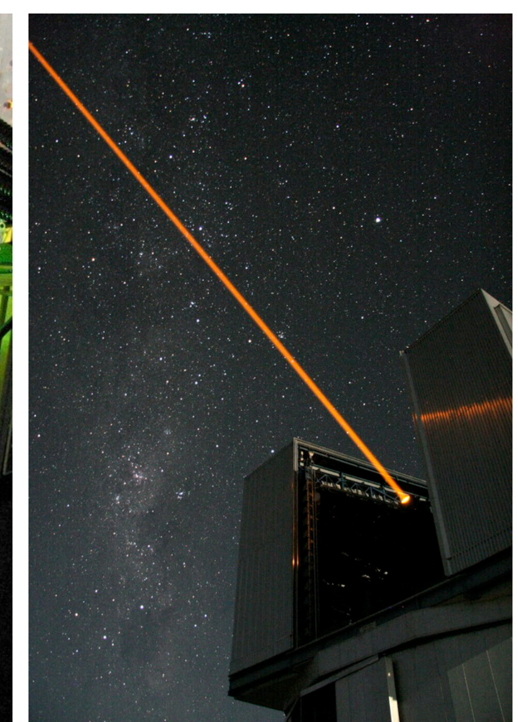
Ground-based AO can do a good job as well: diffraction-limited resolution (<0.1” possible), near-IR observations (dust)

SINFONI + the laser guide star PARSEC

- near-IR IFS SPIFFI + AO module MACAO at the VLT UT4
- delivers diffraction-limited resolution
- before March 2007: nearby bright guide star required (d<30”, R_{mag}<14)but only small fraction of the sky accessible
- now: laser guide star PARSEC allows the use of AO with a much larger number of objects







Observed galaxies

- focus on galaxies with a small classical bulge, pseudobulge or composite bulge
- main selection criteria: availability of NGS/TTS, sphere of influence, distance, K band surface brightness

Galaxy	D (Mpc)	σ (km/s)	d_{soi} (”)	Resol.(”)	type	NGS/LGS
NGC1398	18	200	0.34	0.19-0.32	pseudo	NGS
NGC3368	10	128	0.22	0.15-0.25	pseudo	LGS
NGC3627	10	115	0.19	0.15/0.09	pseudo	LGS
NGC3489	12	105	0.12	0.08	class.	NGS
NGC4486a	16	111	0.13	0.10	class.	NGS
NGC5102	4	65	0.10	0.12/0.07	class.	NGS
NGC1316	18	220	0.44	0.12/0.08	class.	NGS

Data Analysis

- SINFONI data reduction: SPRED (Schreiber 2004) and, more recently, also ESO pipeline
- Kinematics: maximum penalized likelihood method (MPL; Gebhardt et al. 2000) using the first two ^{12}CO bandheads, non-parametric LOSVDs with errors derived from Monte Carlo simulations
- high-resolution imaging data (e.g. HST):
  - dust-correction if necessary
  - bulge-disk decomposition if necessary
  - deprojection of the surface brightness under the assumption that the galaxy is axisymmetric

Dynamical Modelling

- Based on the Schwarzschild superposition technique, code of Thomas et al. 2004/2005
- 3 steps:
  1. Calculation of a gravitational potential with a trial black hole mass and stellar mass density
  2. Run representative set of orbits (2×7000) in this potential
  3. Repetition with systematically varied M/L and M_{BH}
- Luminosity density is exactly reproduced, the LOSVDs (not the parametrized moments!) are fitted
- The best-fitting parameters follow from a χ^2-analysis

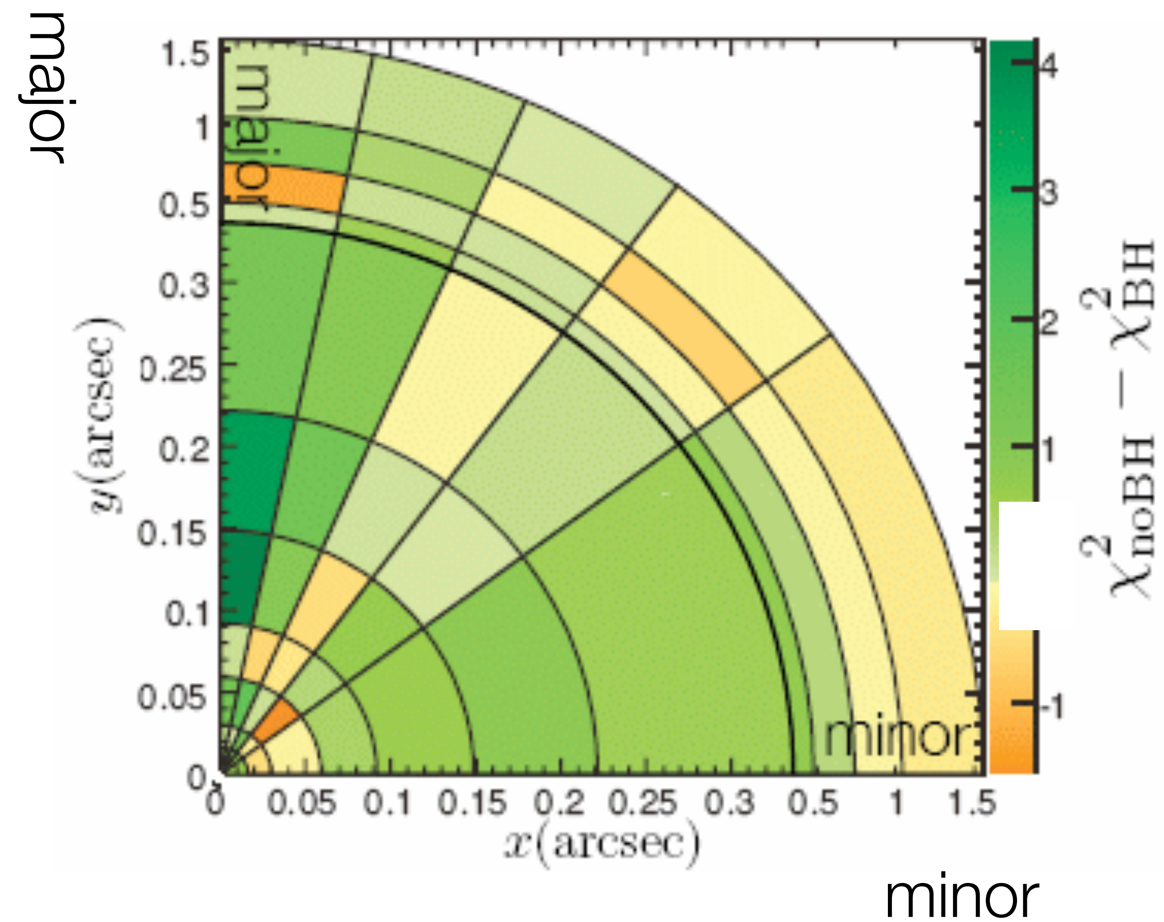
The black hole in NGC4486a

- best-fitting model (90%C.L.):

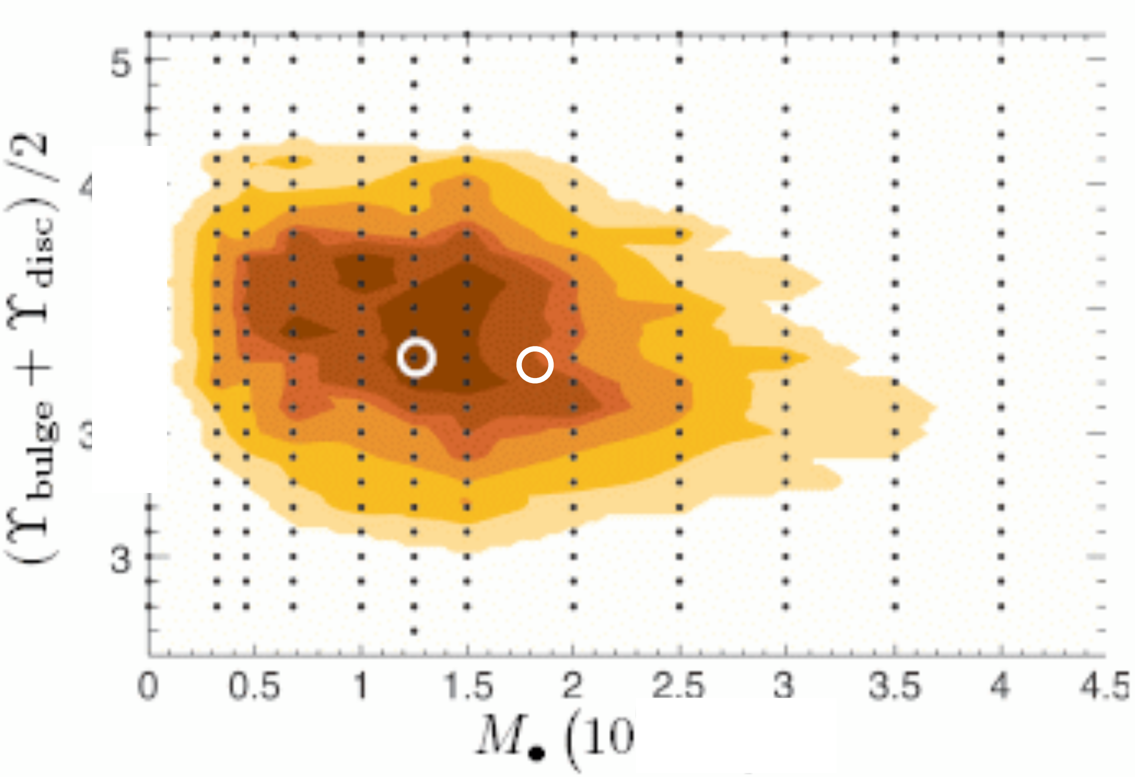
$$M_\bullet = 1.25^{+0.75}_{-0.79} \times 10^7 M_{\mathrm{e}}$$

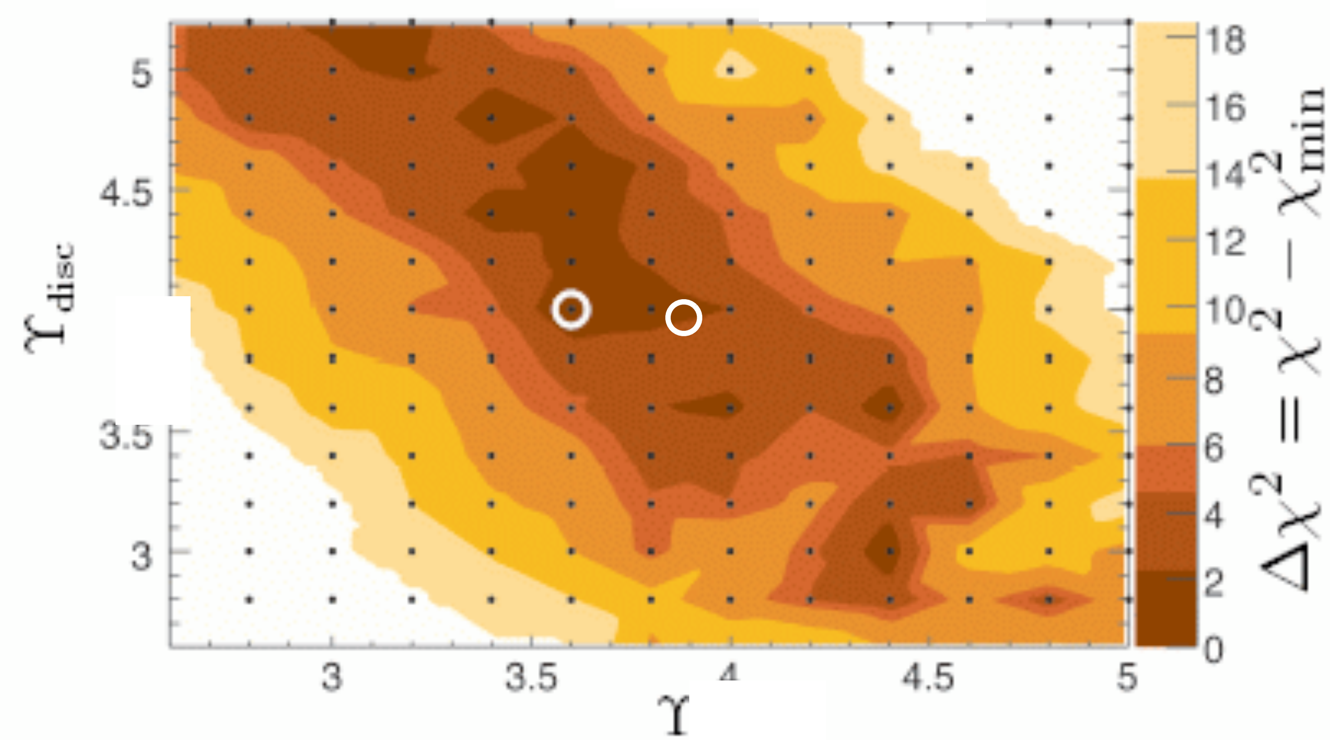
$$\Upsilon_{disk} > 2.8, \Upsilon_{\mathrm{bulge}} = 2.6 \ldots 4.6$$

- models without central black hole are excluded at the 4.5σ level



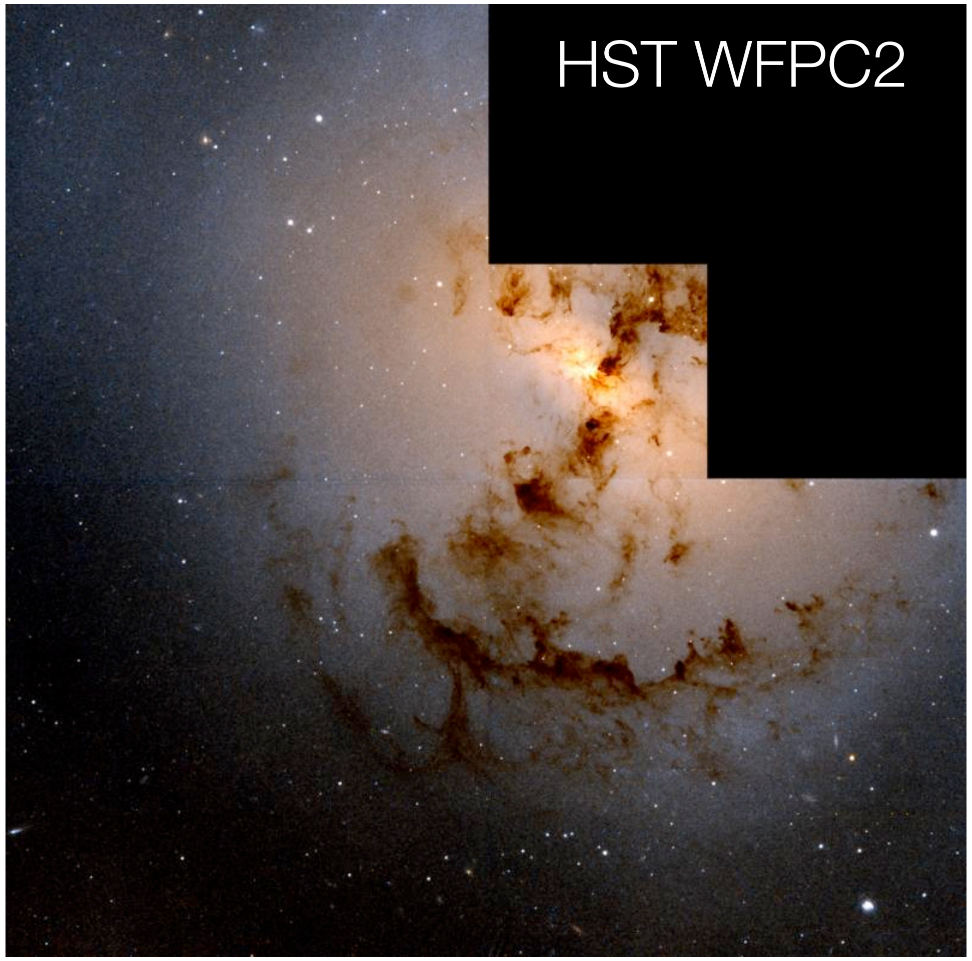
Nowak et al. 2007, MNRAS 379, 909

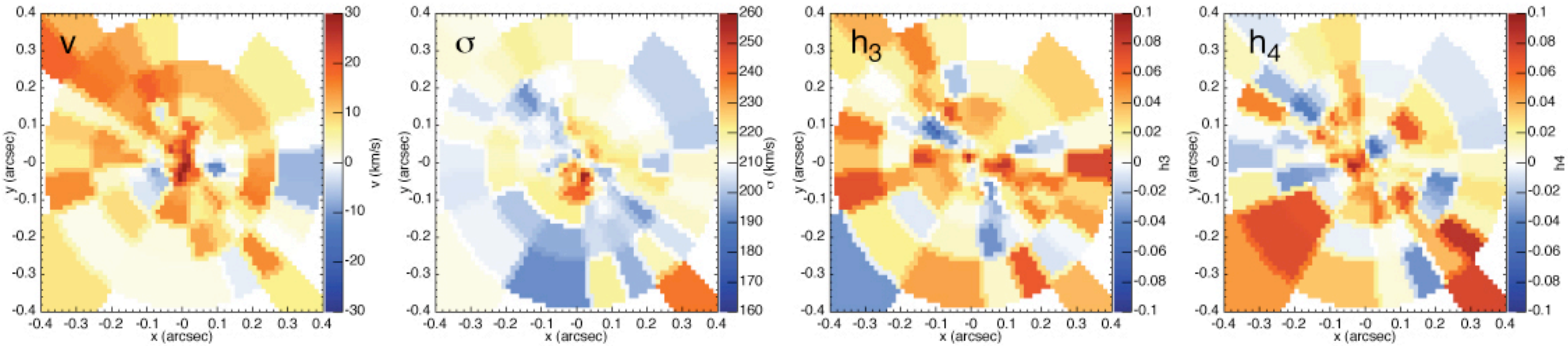




The black hole in Fornax A

- merger remnant, D=18.6Mpc
- 3rd brightest radio object in the sky, giant radio lobes
- 140min SINFONI K band (25mas): unusual kinematic structure in the centre
- surface brightness profile: ground-based low-res K band image (NTT Sofi) + HST NICMOS H band image (both dust corrected)



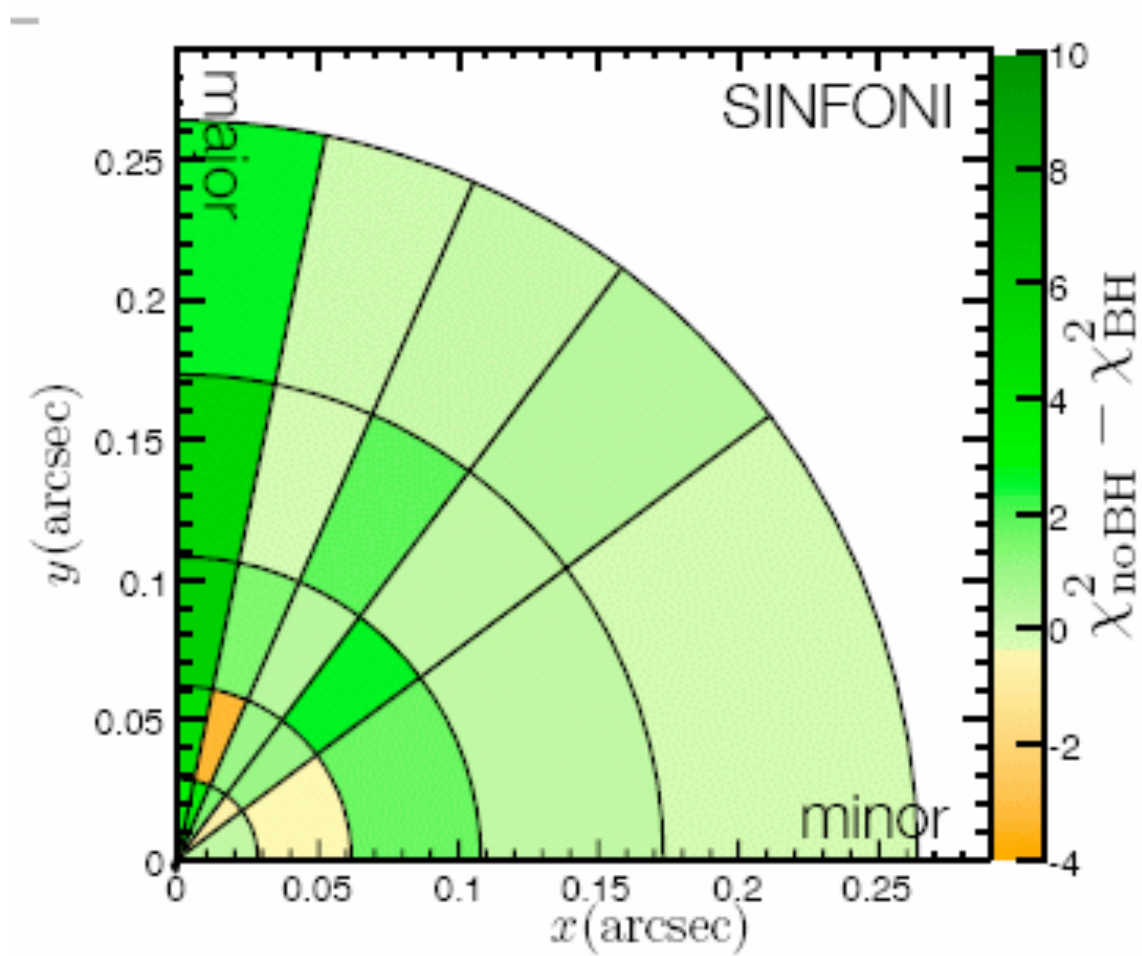


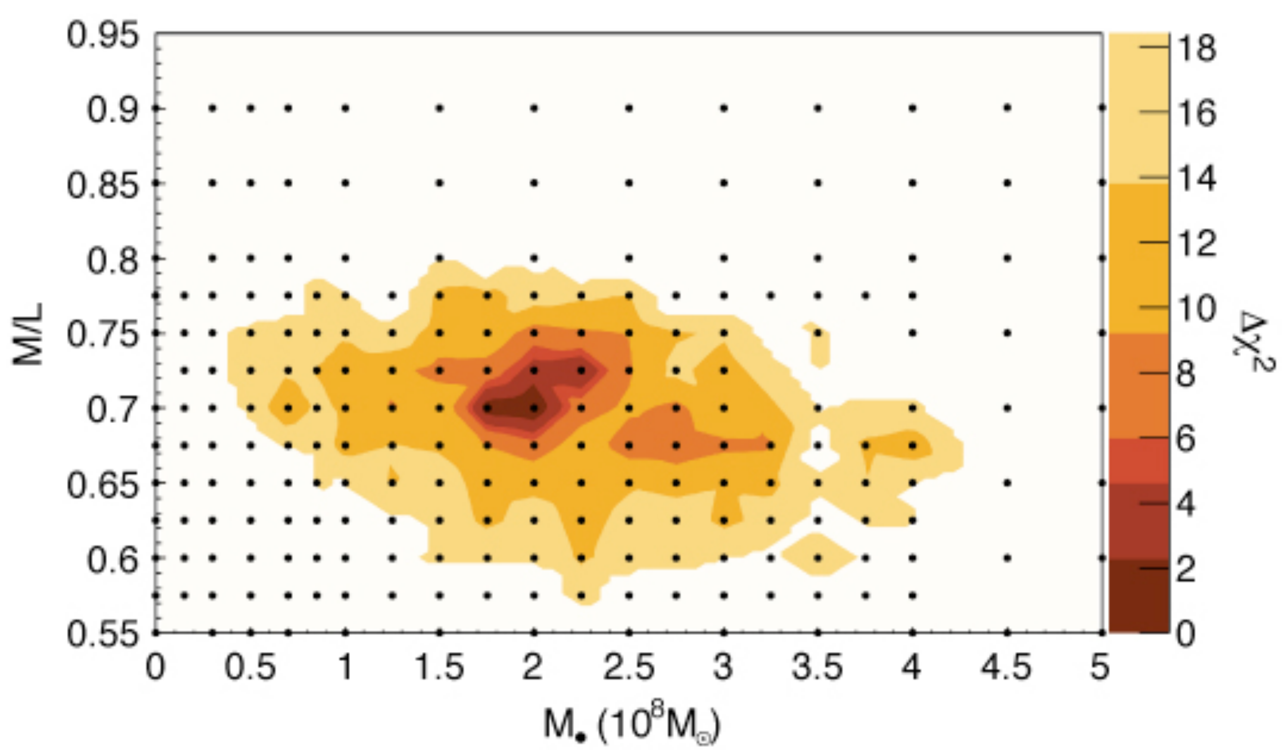
The black hole in Fornax A

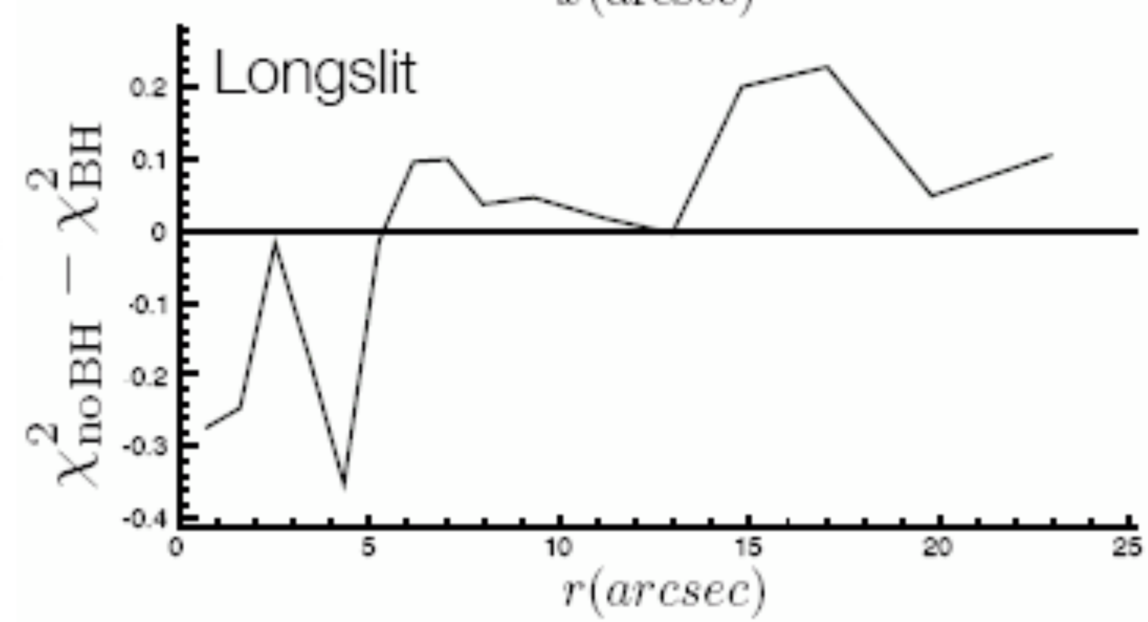
- best-fitting model (90% C.L.):
-

$$M_{\bullet} = 2.0^{+0.25}_{-0.25} \times 10^{8} M_{e}, \Upsilon = 0.7$$

- total Dc^2~38 (>5σ, from SINFONI data alone)
- largest $\Delta\chi^2$ along the major axis

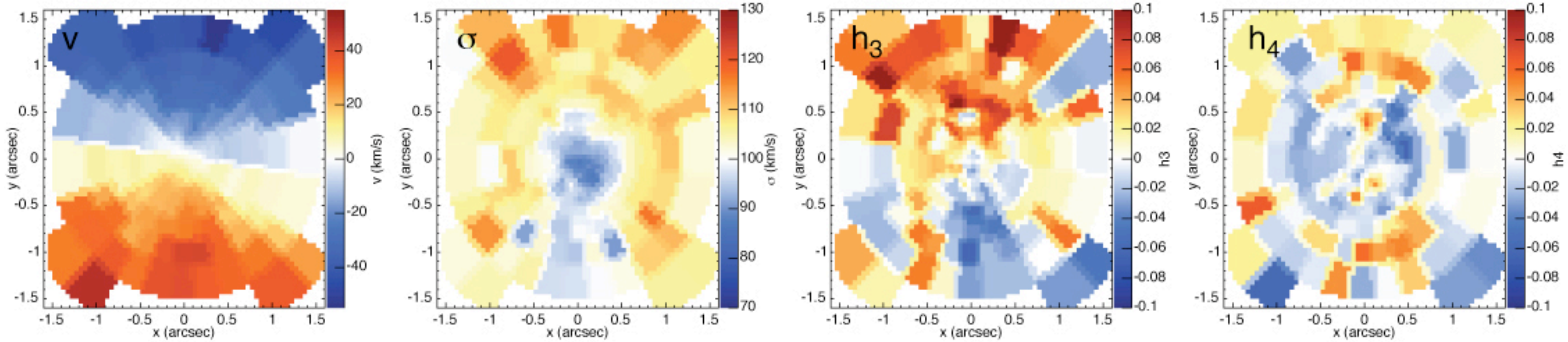






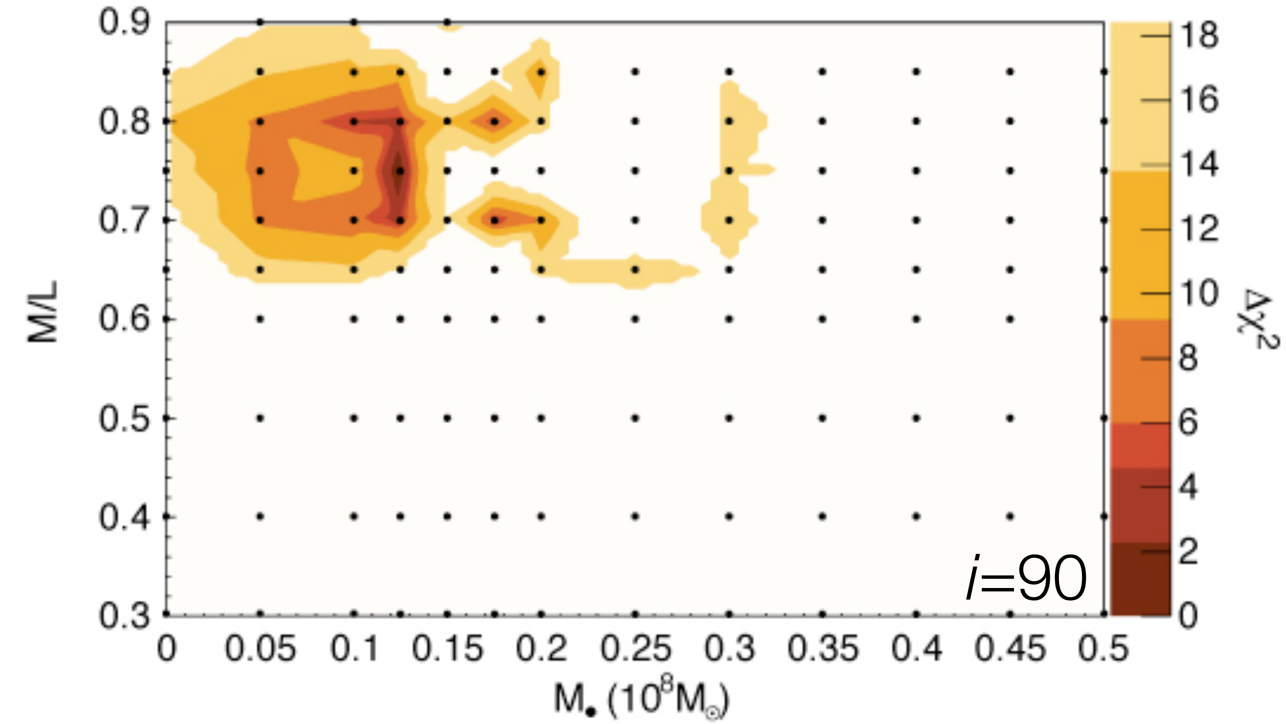
NGC3368

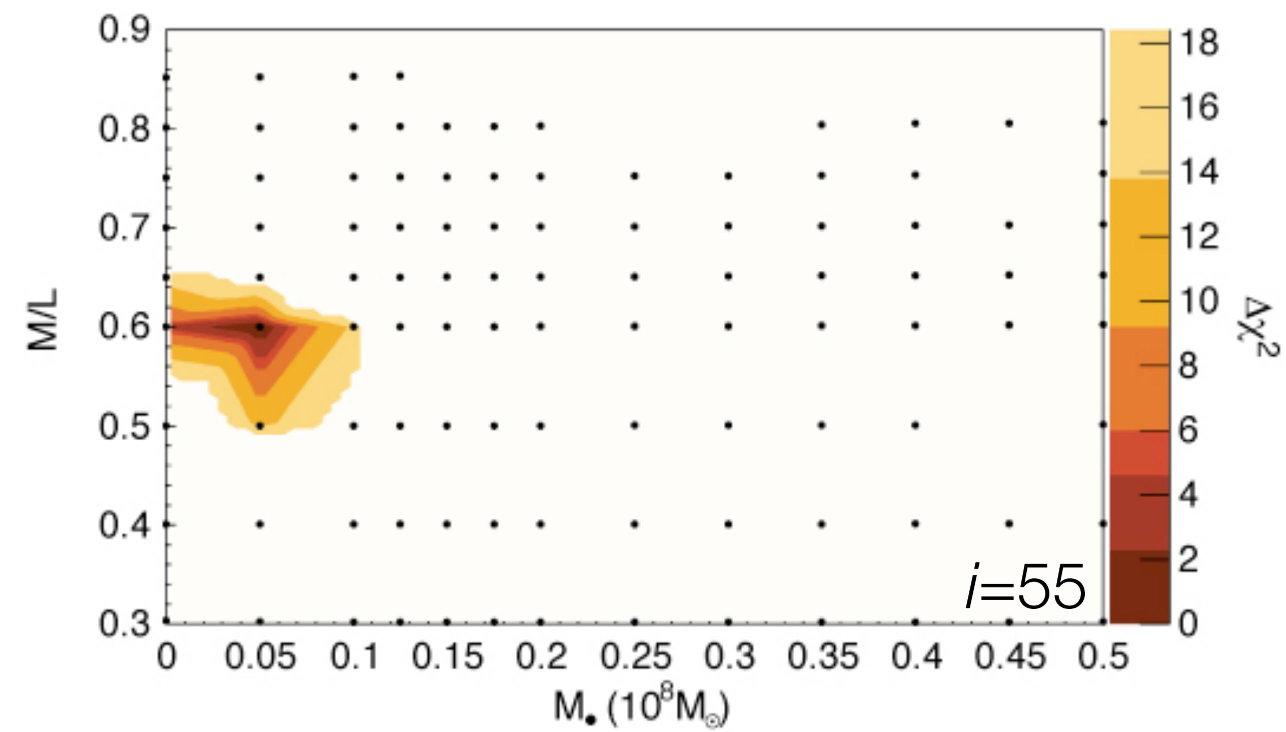
- Sab galaxy (D=10.4Mpc) in the Leo group with a pseudobulge + tiny classical bulge
- double-barred
- 140min SINFONI K band (100mas) with LGS: cylindrical rotation, σ drop in the centre
- optical longslit data (Heraudeau 1999): σ significantly larger (dust?)
- surface brightness: models for disk and small classical bulge from dust-corrected NICMOS and SDSS images



NGC3368

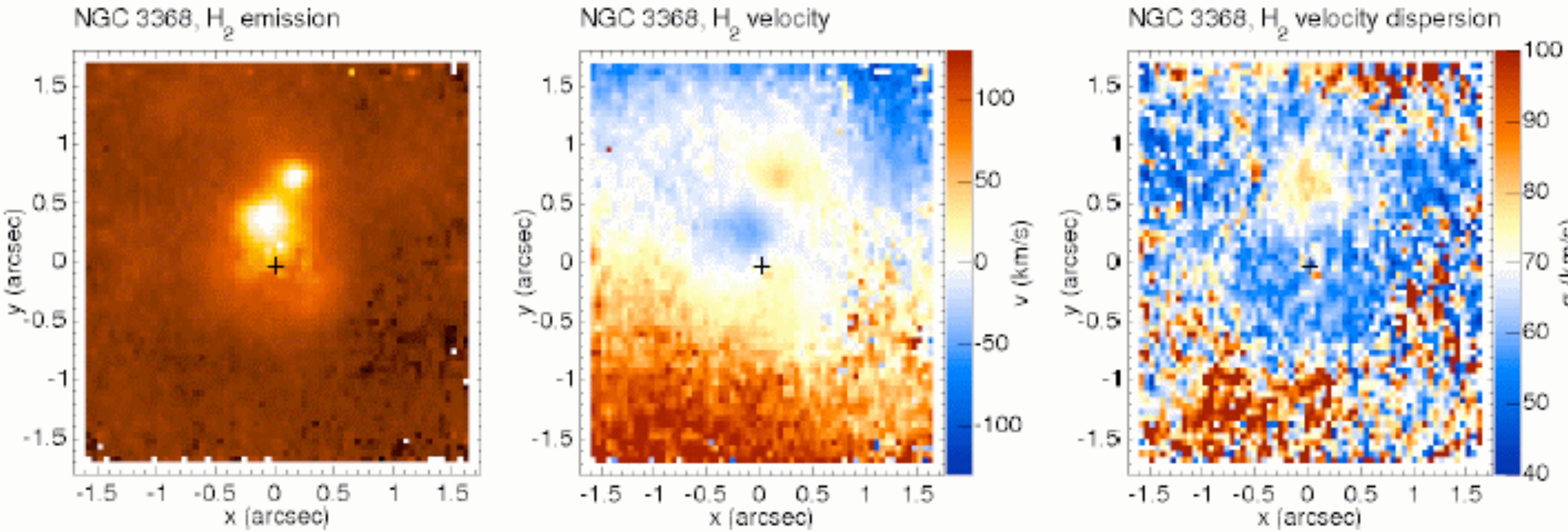
- Dynamical modelling is under way, (same M/L for bulge and disk, edge-on):
- models with *i*=55: M_{BH} $M_\bullet \approx 1 \times 10^7 M_e$ compatible with 0, but fits much worse than with *i*=90
- ToDo: calculate models
  - with different M/L_{bulge} and M/L_{disk}
  - with a dark halo
  - and investigate inclination effect (simulations)
    - huge parameter space!



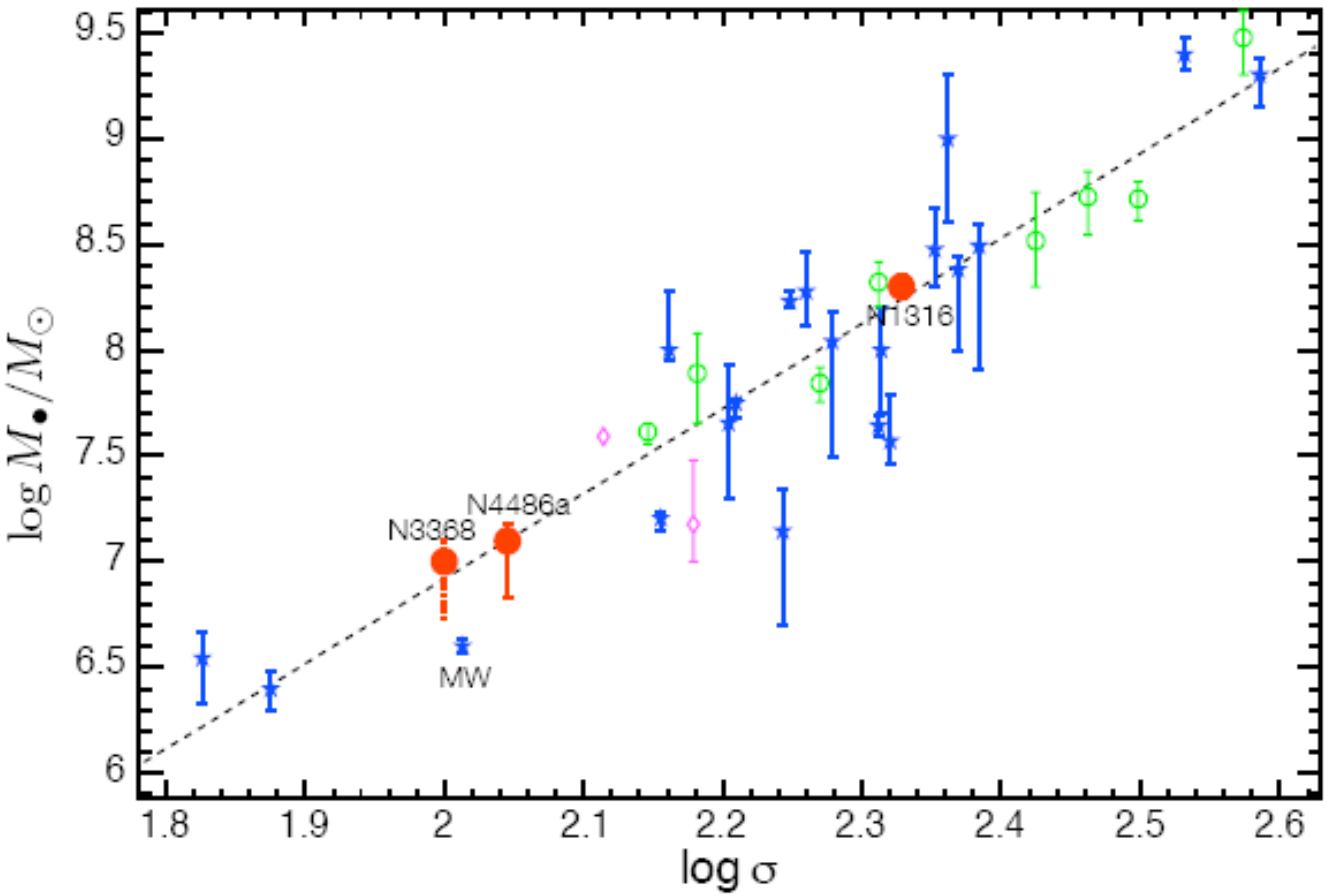


NGC3368

- molecular hydrogen in NGC3368:
- 2 counterrotating clouds of infalling H_2 gas



- Our results are consistent with the M_{BH}-σ relation of Tremaine et al. 2002!



Outlook

- more galaxies will be observed soon (6 nights in March/April 08): the pseudobulges NGC4371 and NGC3351 and the classical bulges M83, NGC3412, NGC4569, ...
- velocity dispersion measurements for more nearby spiral galaxies needed to create a larger sample of pseudobulge/small bulge galaxies (e.g. with the Hobby-Eberly telescope in Texas)
- completion of a statistically significant sample of black hole mass measurements in pseudobulges and small classical bulges within the next few years
- other things that can be learned from our SINFONI data: pseudobulge kinematics; origin, distribution and kinematics of gas (e.g. H_2); stellar populations, ...