Black holes in low-mass bulges and pseudobulges

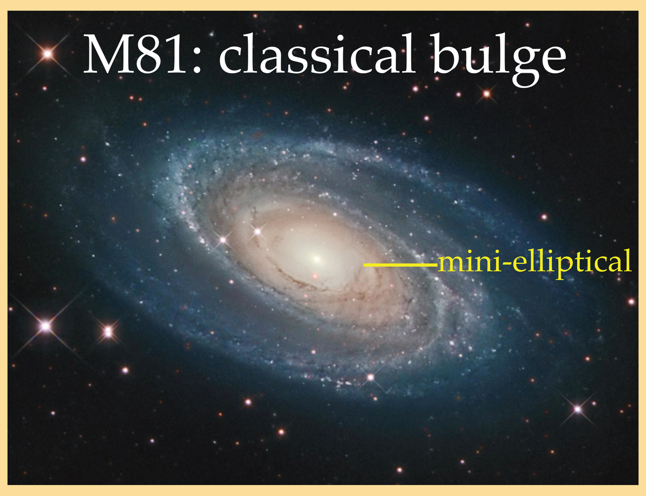
N. Nowak[1,2], R.P. Saglia[1,2], J. Thomas[1,2], P. Erwin[1,2], R. Bender[1,2]

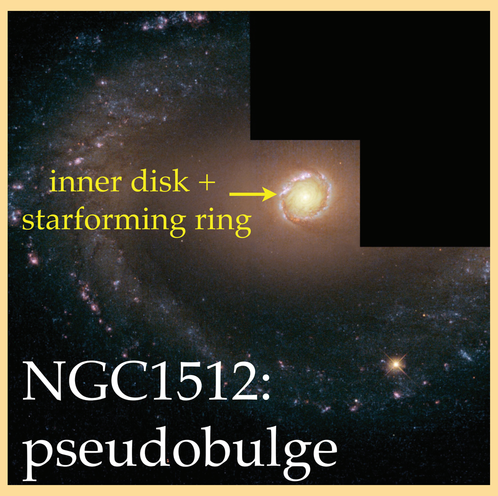
1 Max-Planck-Institut für extraterrestrische Physik, Giessenbachstrasse, 85748 Garching, Germany
2 Universitäts-Sternwarte, Scheinerstrasse 1, 81679 München, Germany

Over the past decade we have learned that probably all ellipticals and bulges contain central supermassive black holes (SMBHs). The mass of the SMBH correlates both with the mass of the bulge component (the SMBH mass is about 0.15% of the bulge mass) and with the velocity dispersion of the bulge. We are investigating whether these relations remain valid–or how they change–when galaxies with pseudobulges, very low-mass bulges or bulgeless galaxies are considered. Studying SMBH relations for both classical bulges and pseudobulges reveals the importance of different growth mechanisms (mergers vs. secular evolution) for the evolution of SMBHs. Low-mass classical bulges and bulgeless galaxies however may harbour seed black holes in their earliest evolutionary stages, and studying them is of paramount importance for understanding the link between bulge evolution and black hole growth.

Background

- All galaxies with a massive bulge component harbour a central supermassive black hole (SMBH).
- The mass of the SMBH correlates with bulge properties (bulge mass and velocity dispersion σ).
- These correlations are poorly constrained at the low-σ end (σ<120 km/s) and at the high-σ end (σ>300 km/s).
- It is not clear whether these relations remain valid 1. for galaxies different from normal ellipticals or classical bulges, like pseudobulges or bulgeless galaxies, or 2. for galaxies just in the phase of active bulge and SMBH growth, like e.g. merger remnants or AGN.
- We have already observed 7 pseudobulges (PBs), 4 low-σ galaxies and 1 merger remnant with SINFONI with the goal of tightening the M_{BH}-σ relation for these galaxies.





Properties of Pseudobulges

- formation: secular evolution, i.e. via bar instabilities
- disk-like photometry, morphology & kinematics
- compound systems: cold massive PB combined with smaller hot spheroid, e.g. NGC3384 and NGC2787 (Erwin et al. 2003)

Black holes in pseudobulges

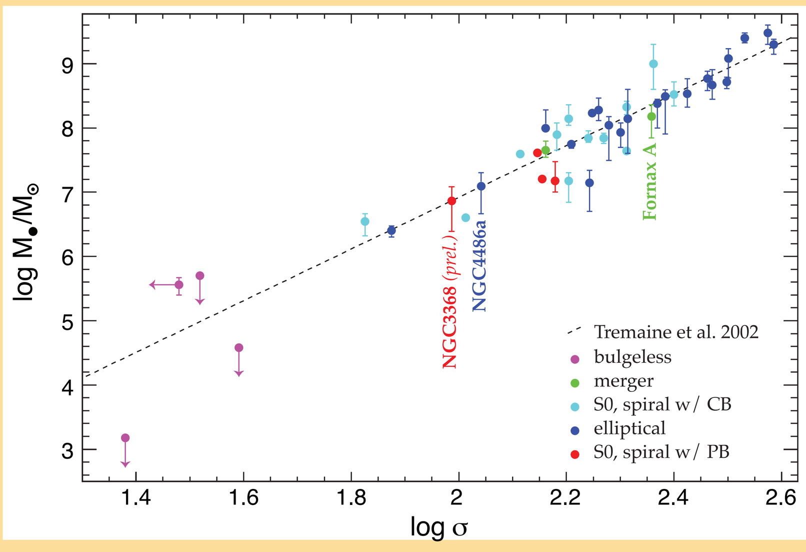
- do SMBHs in PBs grow via secular evolution instead of mergers?
- three measured SMBH masses in PBs, two of them in compound systems (NGC2787, NGC3384)

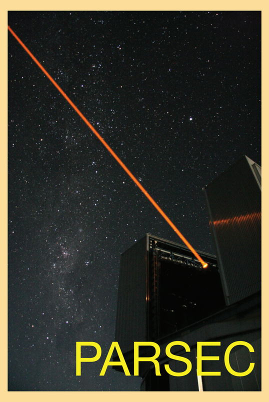
➔obtaining M_{BH} measurements for more galaxies with well-defined PBs is the key to resolving whether black holes scale with classical bulges (CBs) only, or also with PBs.

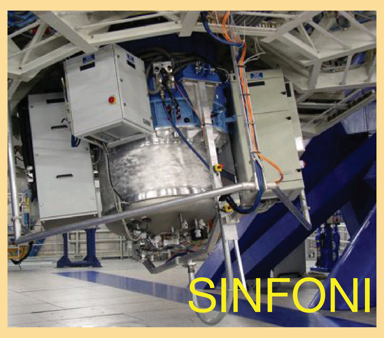
Black holes in bulgeless galaxies

- M_{BH}~$0.0015 M_{bulge}$ ➔ no BHs in bulgeless galaxies?
- only few studied cases, e.g. M33, NGC4395 $M_{BH} \neq 0.0015 M_{disk}$

➔determining the M_{BH}-σ slope in the σ<120km/s region down to very low-σ galaxies without bulge is important to infer black hole formation mechanisms







Observational difficulties

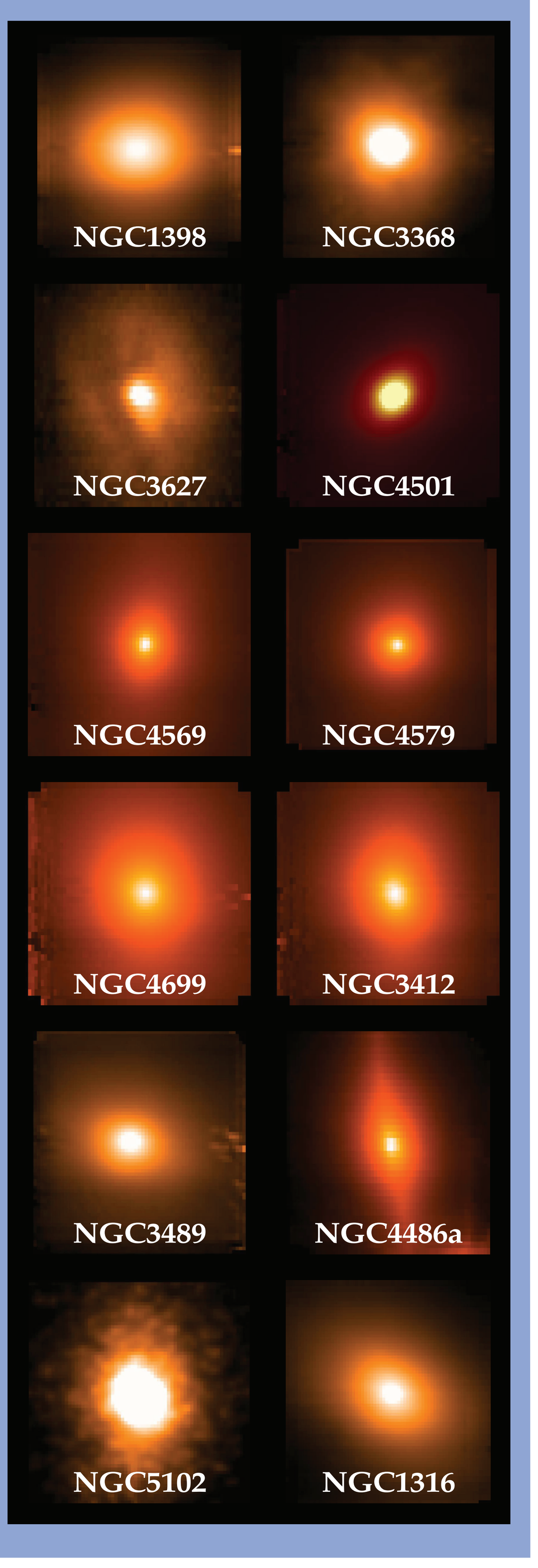
- small sphere of influence ➔high spatial resolution
- S/N>30 needed to measure kinematics reliably
- dust obscuration
- in AGN: dilution and distortion of absorption lines by non-stellar continuum and emission lines

Solution: near-IR AO observations with SINFONI@VLT

Observations and first results

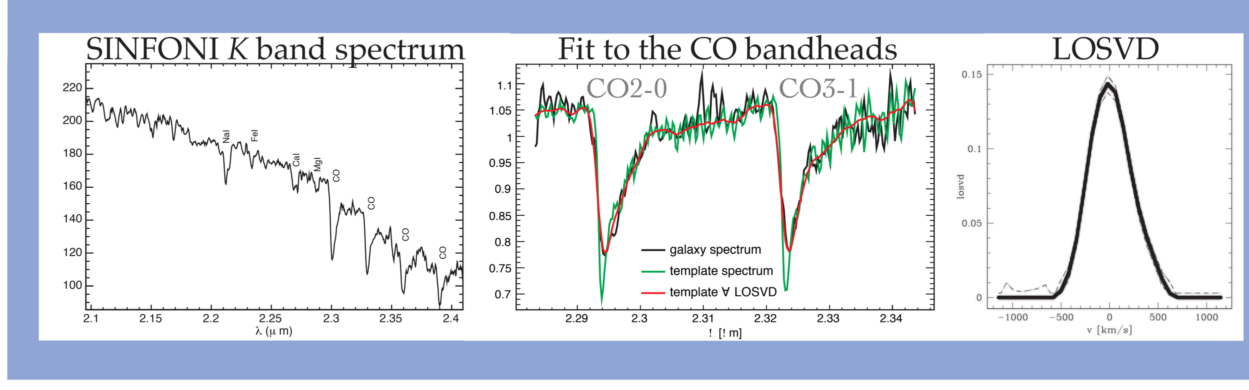
We observed 7 PBs, 4 low-σ galaxies and 1 merger remnant with SINFONI (Spectrograph for INtegral Field Observations in the Near Infrared) at the VLT using adaptive optics (AO), two of the galaxies with the laser guide star PARSEC and the others in natural guide star mode:

Galaxy	D (Mpc)	σ (km/s)	d_{soi} (″)	resolution (″)	type
NGC1398	18	200	0.34	0.19..0.32	pseudo
NGC3368	10	128	0.22	0.15..0.25	pseudo
NGC3627	10	115	0.19	0.15/0.088	pseudo
NGC4501	13	161	0.33	0.13	pseudo
NGC4569	16	117	0.11	0.15	pseudo
NGC4579	16	154	0.23	0.15	pseudo
NGC4699	19	215	0.37	0.13	pseudo
NGC3412	11	101	0.11	0.13	low-σ
NGC3489	12	105	0.12	0.08	low-σ
NGC4486a	16	110	0.13	0.10	low-σ
NGC5102	4	65	0.10	0.12/0.07	low-σ
Fornax A	18	228	0.44	0.12/0.08	merger



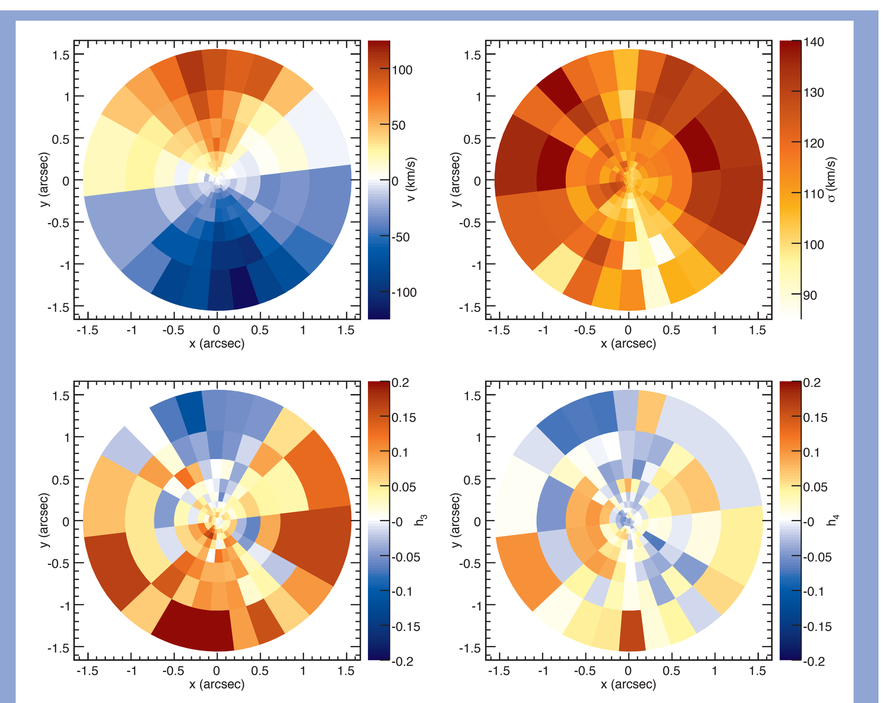
Data analysis: kinematics

The line-of-sight velocity distributions (LOSVDs) are extracted from the first two CO bandheads at >2.29μm using the maximum penalized likelihood method (Gebhardt et al. 2000) and late-type stars observed with SINFONI as templates.

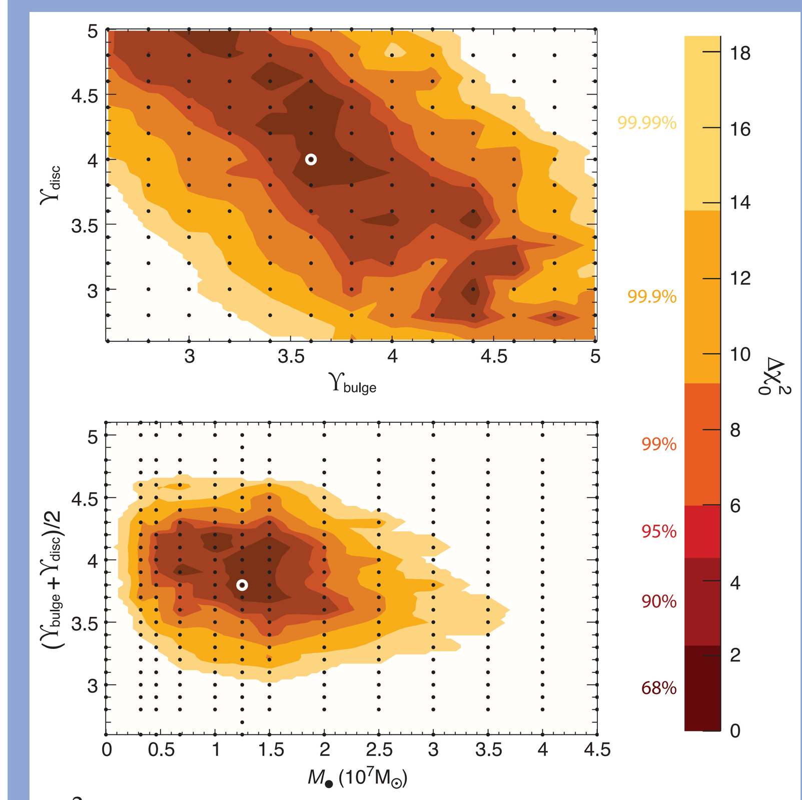


The SMBH of NGC4486a

- small, low-luminosity elliptical in Virgo at a distance of 16 Mpc
- almost edge-on nuclear disk of stars and dust
- bright AO guide star 2.5″ from centre
- good AO performance (PSF~0.1″)



Stellar kinematic fields of NGC4486a. The data are binned using a radial and angular binning scheme.



$\Delta\chi^2$ as a function of (top) Υ_{bulge} and Υ_{disc}, minimized over $M_\bullet$; (bottom) $M_\bullet$ and $(\Upsilon_{bulge}+\Upsilon_{disc})/2$. The black points are the models we calculated and the coloured regions are the confidence intervals for two degrees of freedom.

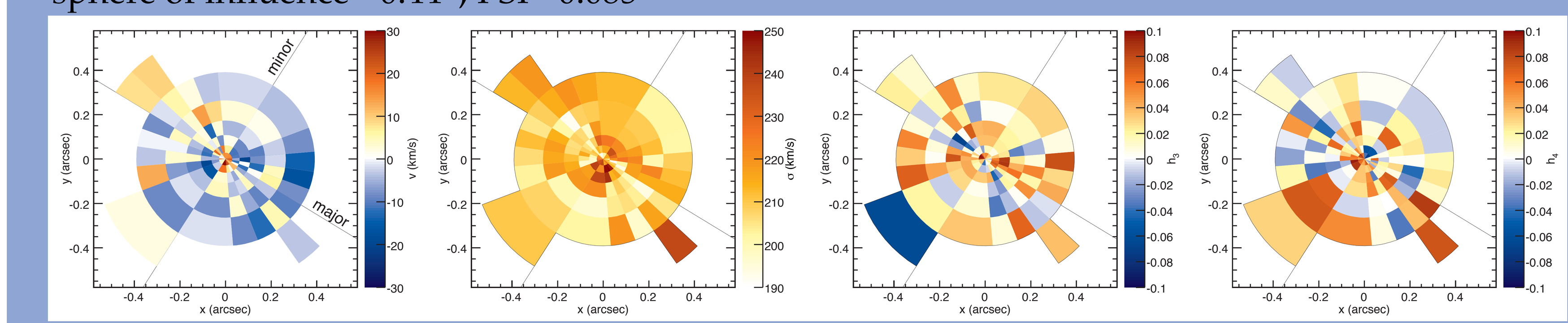
Dynamical modelling:

- Schwarzschild (1979) orbit superposition technique (Thomas et al. 2004, 2005)
  - gravitational potential (stars, assumed mass-to-light ratio Υ, assumed M_{BH}
  - generate orbit library (2x7000 orbits)
  - find weighted superposition of orbits that match light distribution and kinematics
  - repeat with systematically varied Υ and M_{BH}
- The best-fitting model gives $M_{BH}=1.25^{+0.75}_{-0.79}\times10^7 M_\odot$ and $\Upsilon_{bulge}=3.6$, $\Upsilon_{disk}=4.0$ (90% C.L.)

Nowak et al. 2007, MNRAS 379, 909

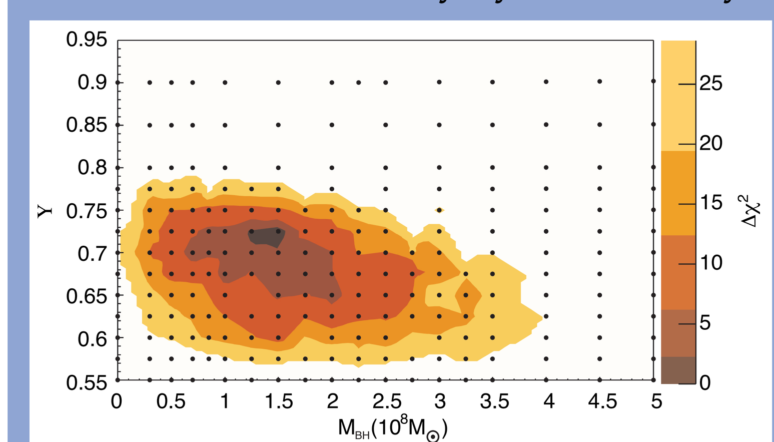
The SMBH of NGC1316 (Fornax A)

- merger remnant in the outskirts of the Fornax cluster (*D*=18.6 Mpc)
- radio galaxy (FRI) with giant radio lobes
- nucleus became dormant in the last ~0.1Gyr, now very low-luminosity AGN
- nucleus used as AO guide star, observation with 0.8″, 3″ and 8″ field of view
- sphere of influence ~0.44″, PSF~0.085″



Kinematics of Fornax A:

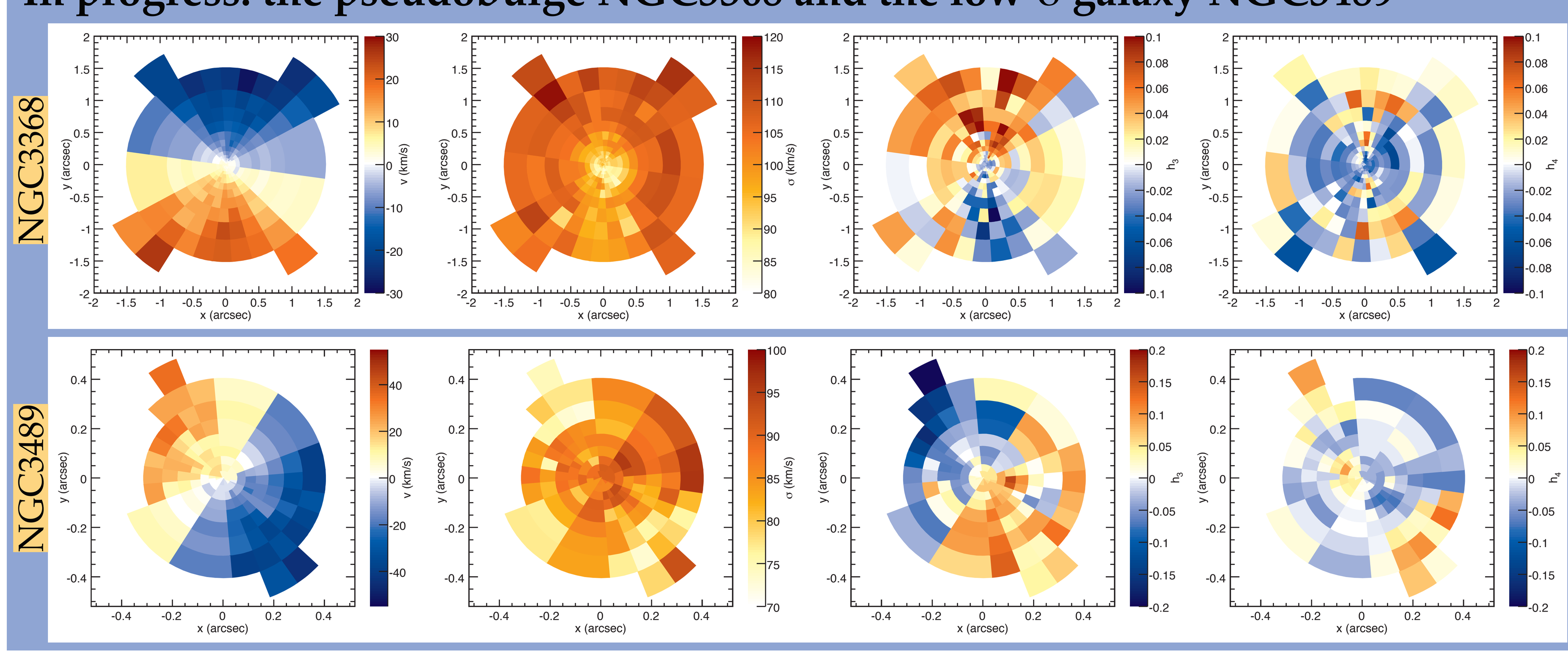
- central velocity rise due to small amount of [CaVIII] emission (not seen in spectra)
- no rotation in the central ~3″, relatively strong rotation outside
- two velocity dispersion maxima separated by thin, elongated minimum
- σ–minimum caused by dyn. cold subsystem with different stellar population and/or the AGN



Dynamical modelling:

- 0.8″ and 3.0″ field of view SINFONI data + longslit kinematics
- inner radial bins (AGN signature) excluded
- The best-fitting model gives $M_{BH}=1.5^{+0.25}_{-0.80}\times10^8 M_\odot$ and Υ=0.7±0.025 (90% C.L.)
- same result when inner bins included
- consistent results for single quadrants and single datasets

In progress: the pseudobulge NGC3368 and the low-σ galaxy NGC3489



Summary & Outlook

- all measured black hole masses agree with the M_{BH}-σ relation
- analysis and dynamical modelling of the observed galaxies is under way
- future SINFONI observations will focus on high-σ (σ>300km/s) end and core ellipticals
- other properties that can be learned from our SINFONI data:
  - pseudobulge kinematics
  - origin, distribution and kinematics of gas (e.g. H_2)
  - stellar populations via NIR line indices: Na I, Ca I, FeI, Mg I, CO(2-0)

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