Central supermassive black holes from SINFONI observations

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with

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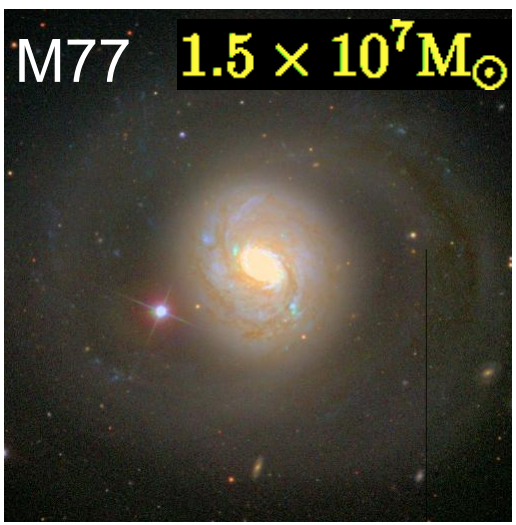
Gas and stars in Galaxies – A Multi-Wavelength 3D Perspective
Garching, 10th June 2008

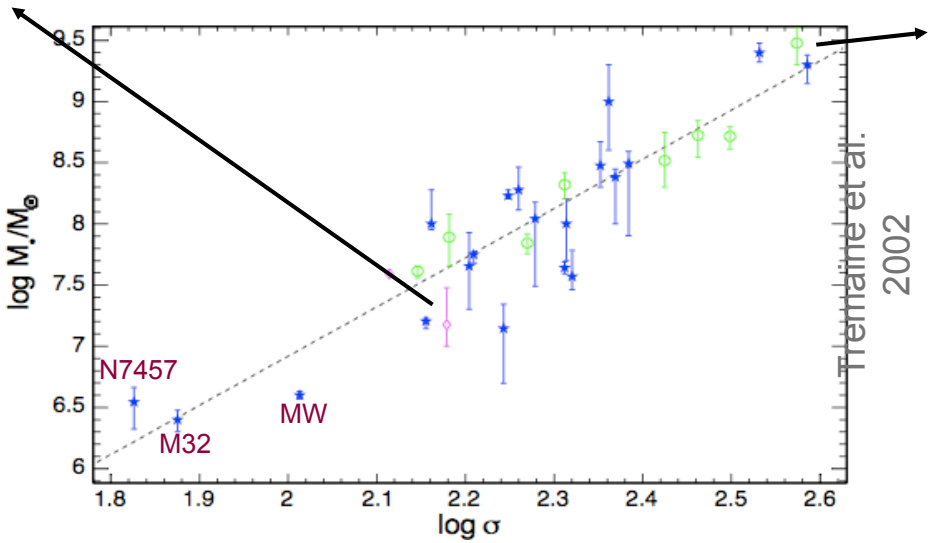
Outline

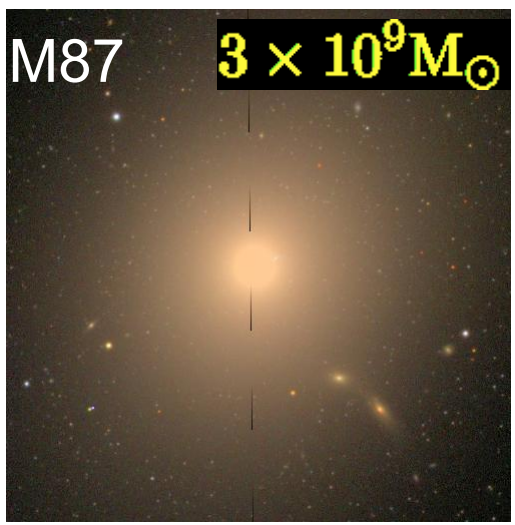
- Introduction: status of present direct (dynamical) SMBH mass measurements
- Near-IR integral-field observations of galactic nuclei with SINFONI
- What can we measure at the diffraction limit
- Dynamical Modeling
- The M_{BH}-σ relation
- Conclusions

Supermassive black holes

- All galaxies with a massive (classical) bulge component host a SMBH. The mass of the SMBH correlates with the velocity dispersion and the luminosity/mass of the bulge
- strong link between bulge formation and black hole growth





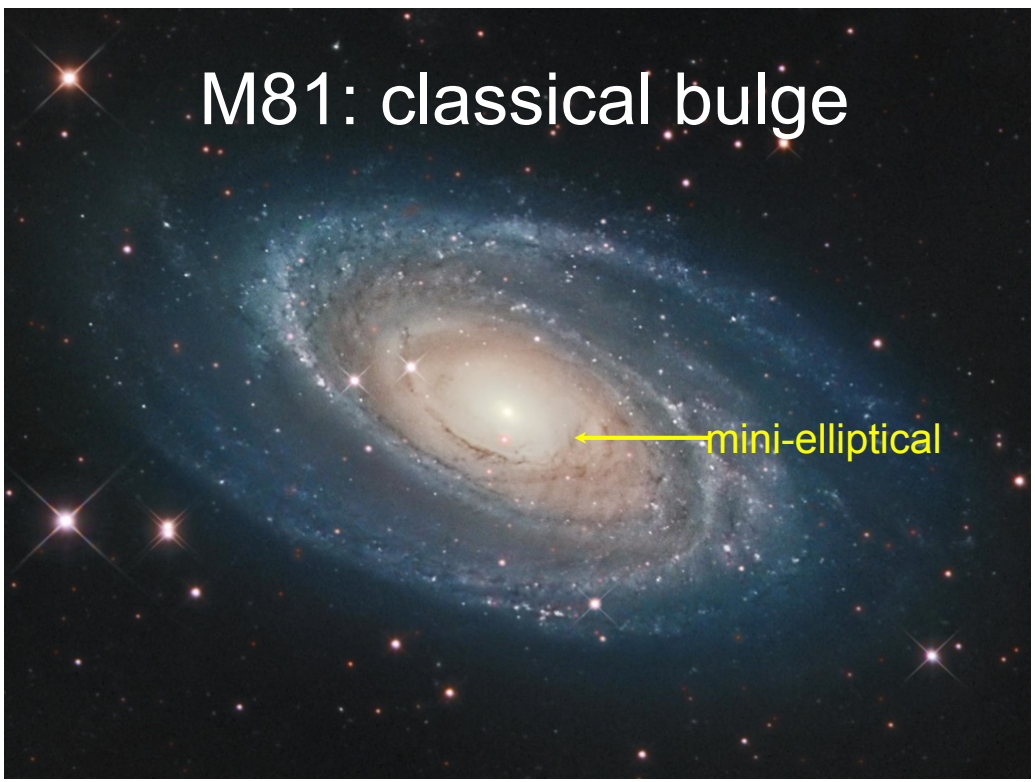


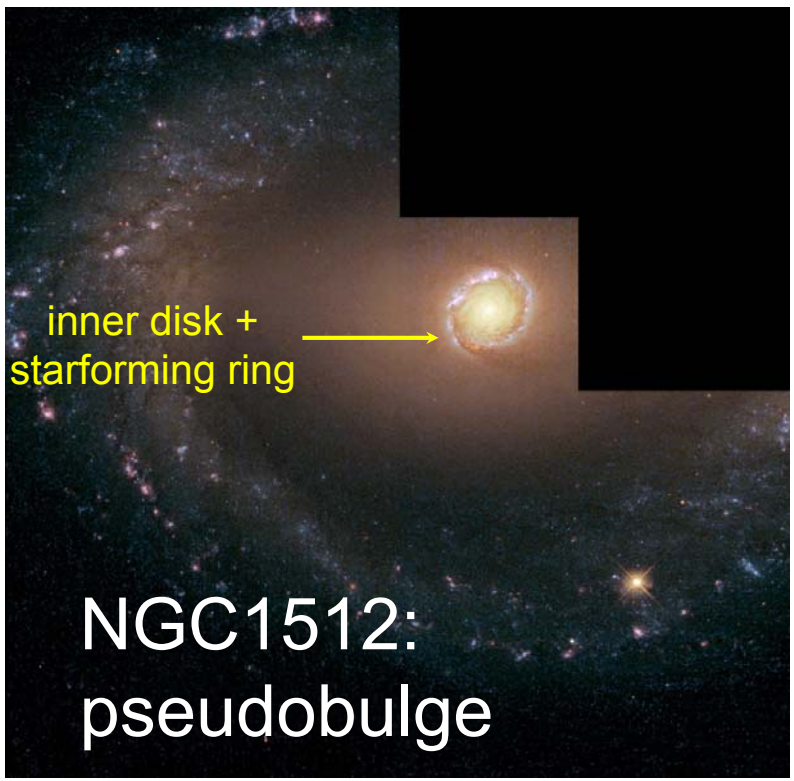
Classical- and pseudo-bulges

- Two different bulge-types:

  - *classical bulges*: mini-ellipticals, formed by mergers

  - *pseudobulges*: disk-like characteristics (e.g. rapid rotation), formed by secular evolution





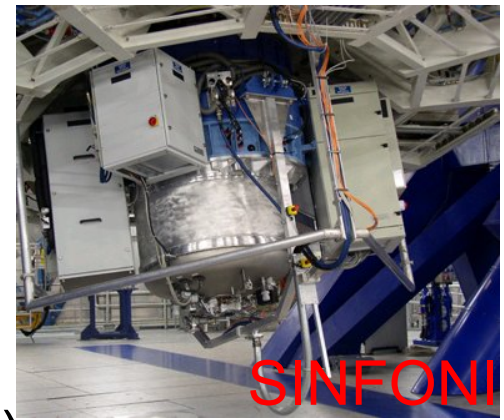
Status

- few dynamical SMBH mass measurements (~40), mostly normal, massive E
- low-σ (<120km/s) and high-σ (>300km/s) regime not very well constrained
- very few non-E's (pure disks, pseudobulges)
- few core ellipticals
- very few merger remnants and AGN
- Goals:
  - constrain M_{BH}-σ slope by measuring low- and high-σ range
  - measure M_{BH} for "special" galaxies

Problems

- direct (dynamical) M_{BH} measurements require a very high spatial resolution to resolve the sphere of influence (usually <<1”)
- high S/N (>30 per pixel) required (high surface brightness)
- strong dust obscuration in most disks, pseudobulges, AGN and merger galaxies
- in AGN: non-stellar emission dilutes spectral signatures
- dynamical modelling difficult if non-axisymmetries (bars) are present

SINFONI



- NIR-AO:
  - high spatial resolution <0.1”
  - less affected by dust
  - non-stellar contribution less strong (in AGN)
- SINFONI@VLT:
  - integral-field spectrograph SPIFFI+adaptive optics module MACAO
  - near-IR (1-2.5μm): *J*, *H*, *K* and *H*+*K*
  - FOV: 0.8” (25mas), 3.0” (100mas) and 8.0”
  - (250mas)
  - 32x64 spatial resolution elements
  - Spectral resolution in K: ~50 km/s
  - PARSEC: Na line laser, bright reference
  - “star” for AO observations

Observed galaxies

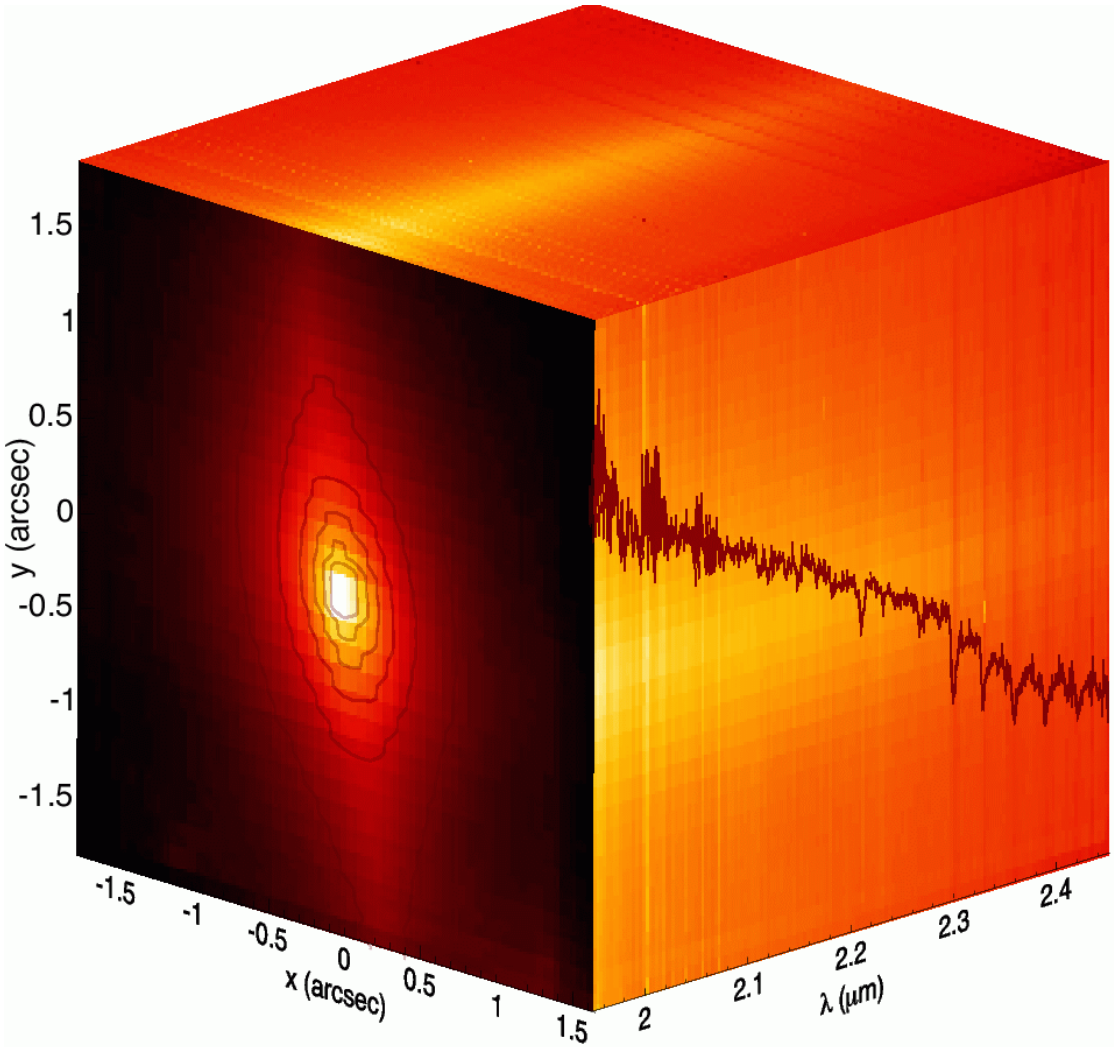
GTO time for SINFONI detectors and OmegaCam – R. Bender

Galaxy	D (Mpc)	0.1'' pc	σ (km/s)		d_{soi} ('')	resolution ('')	Type	nucleus
NGC1398	18	9	200	SBab	0.34	0.19..0.32	pseudo	Sy
NGC3368+	10	5	128	SBb	0.22	0.15..0.25	pseudo	LINER
NGC3627+	10	5	115	SABb	0.19	0.15/0.088	pseudo	Sy2
NGC4501	13	6	161	SBa	0.33	0.13	pseudo	Sy2
NGC4569	16	8	117	SABab	0.11	0.15	pseudo	Lin/HII
NGC4579	16	9	154	SABb	0.23	0.15	pseudo	Sy1.9
NGC4699	19	9	215	SABb	0.37	0.13	pseudo	Sy
NGC3412	11	5	101	SB0	0.11	0.13	low-σ	-
NGC3489	12	6	105	SAB0	0.12	0.08	low-σ	Sy2
NGC4486a*	16	8	110	dE	0.13	0.10	low-σ	-
NGC5102	4	2	65	SA0	0.10	0.12/0.07	low-σ	Stbrst/HII
Fornax A	18	9	228	E pec	0.44	0.12/0.08	core?	FRI

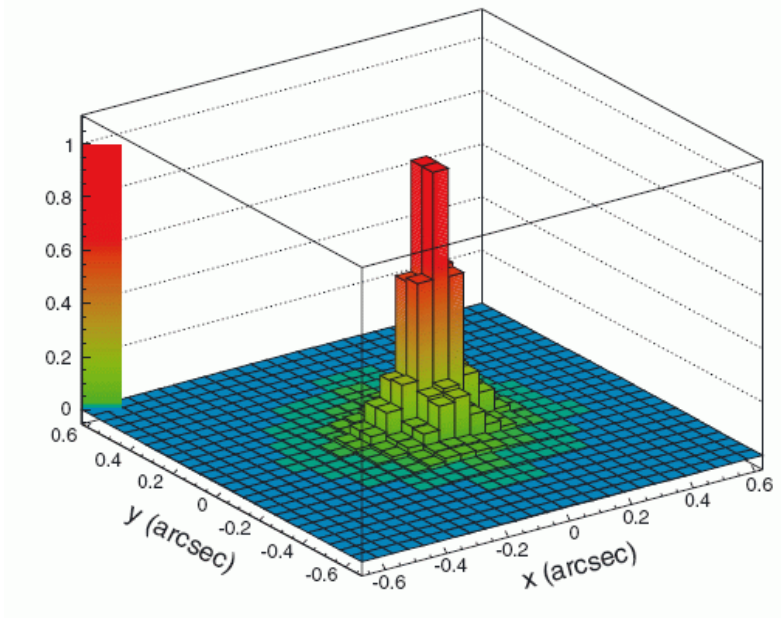
*Nowak et al. 2007, MNRAS, 379, 909

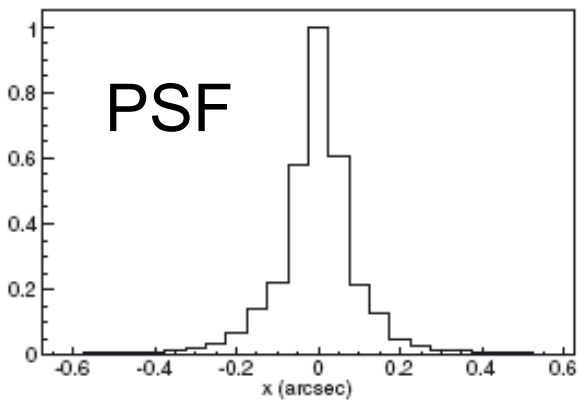
+ Laser Guide Star used

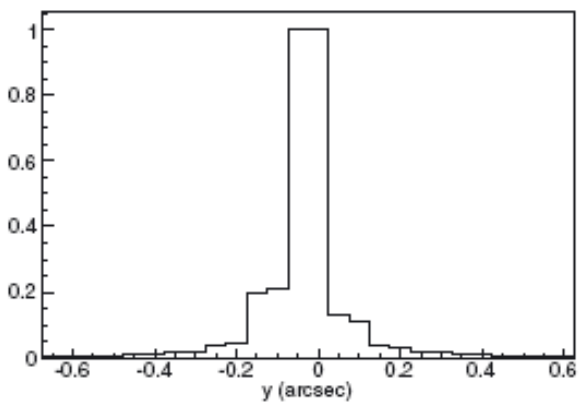
The 3D datacube



NGC 4486a

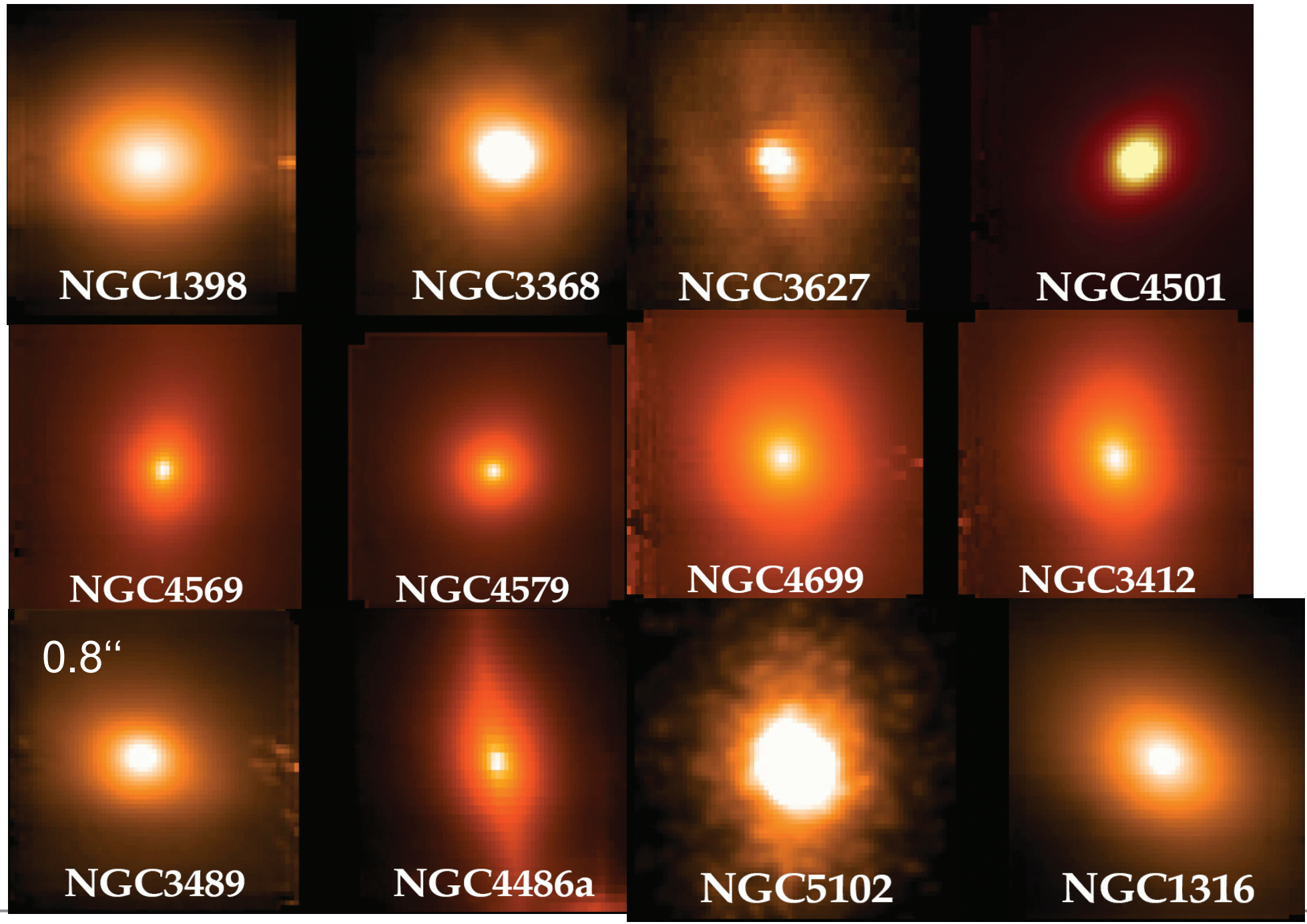






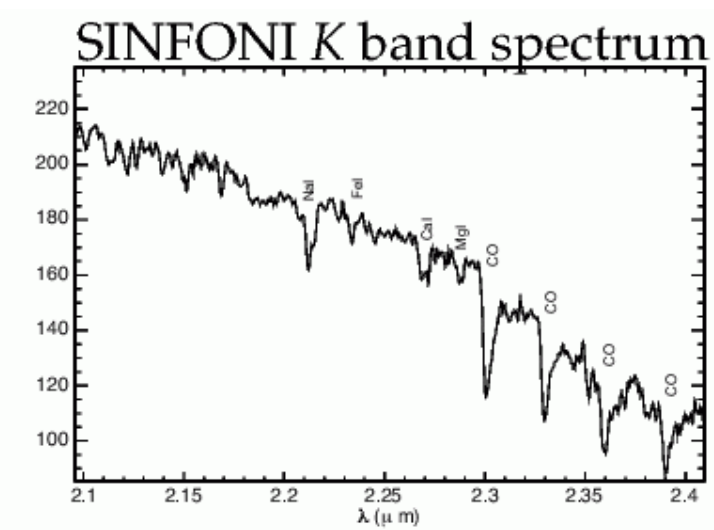
Data Reduction:
spred/gasgano

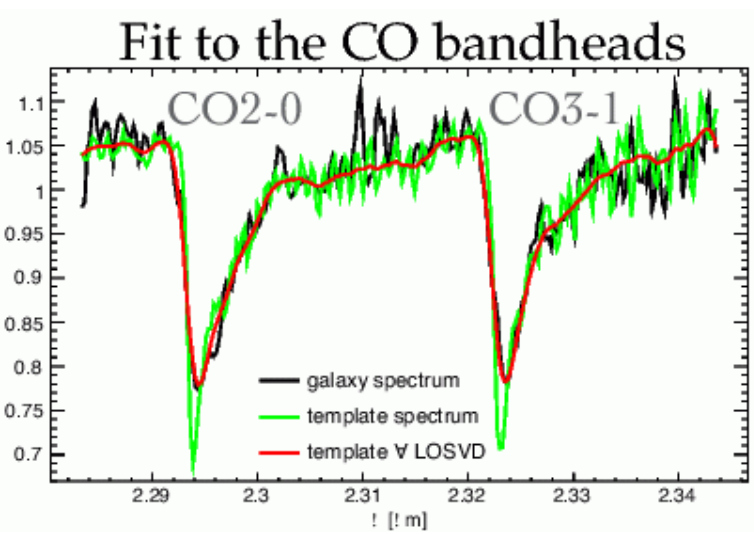
Stellar continuum

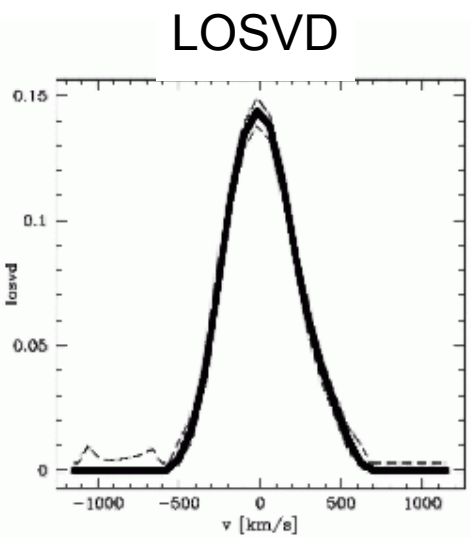


Stellar Kinematics

- Maximum penalized likelihood method (Gebhardt et al. 2000): non-parametric fit of template spectra convolved with line-of-sight velocity distribution (LOSVD)
- strongest spectral features in *K* band: CO bandheads





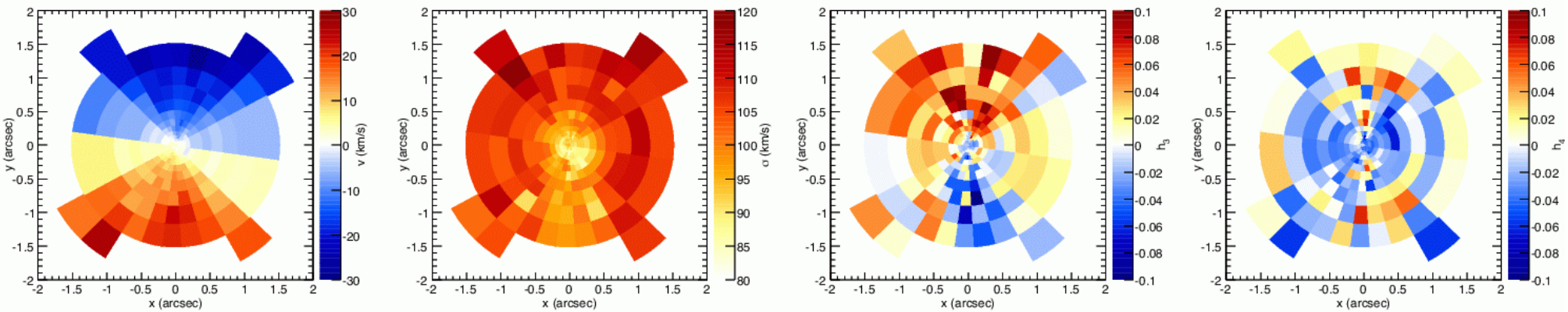


In the following: Gauss-Hermite Parametrization V, σ, h_3, h_4

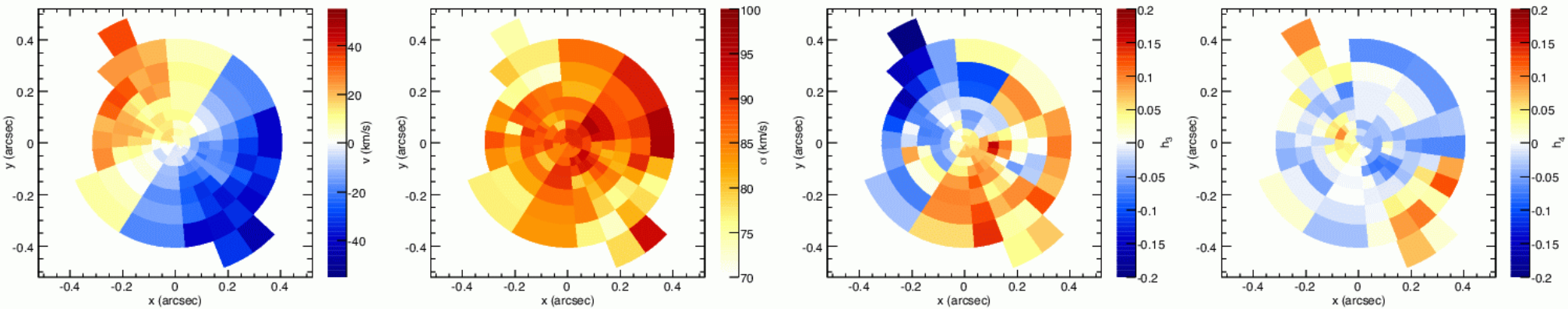
Stellar velocity fields

V σ h3 h4

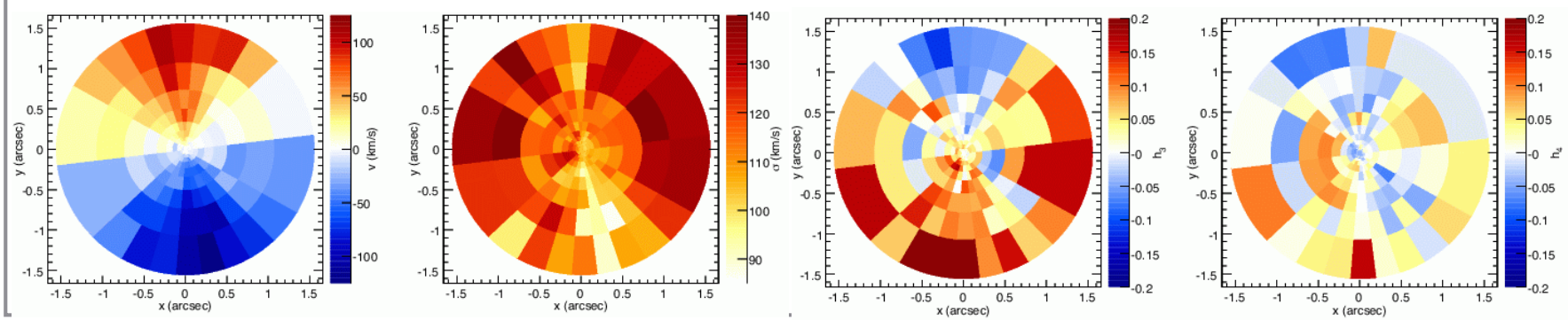
NGC 3368



NGC 3489



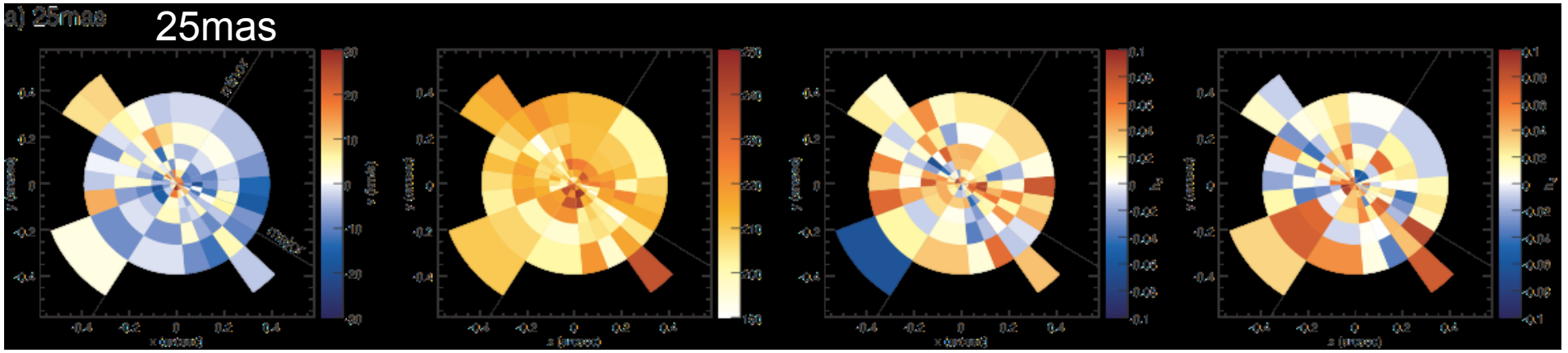
NGC4486a

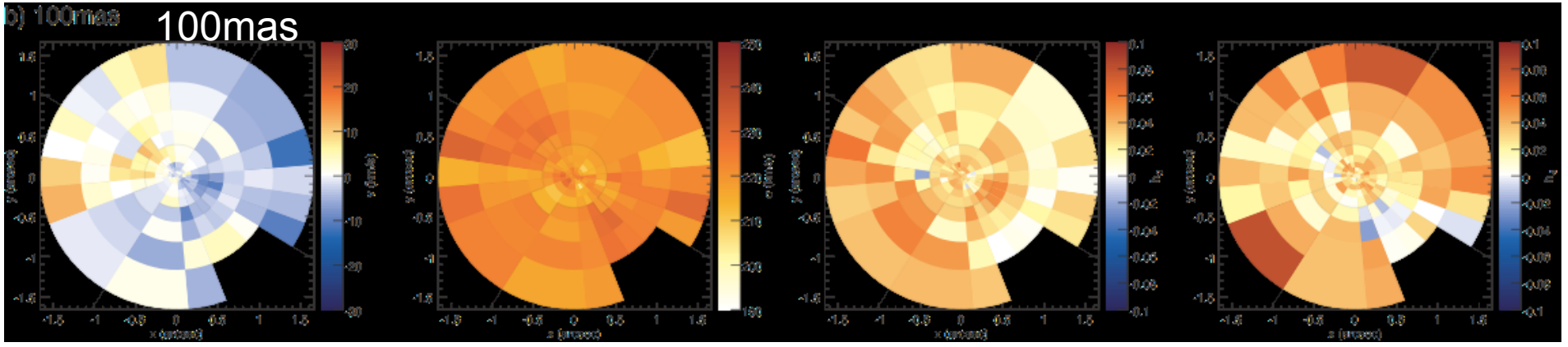


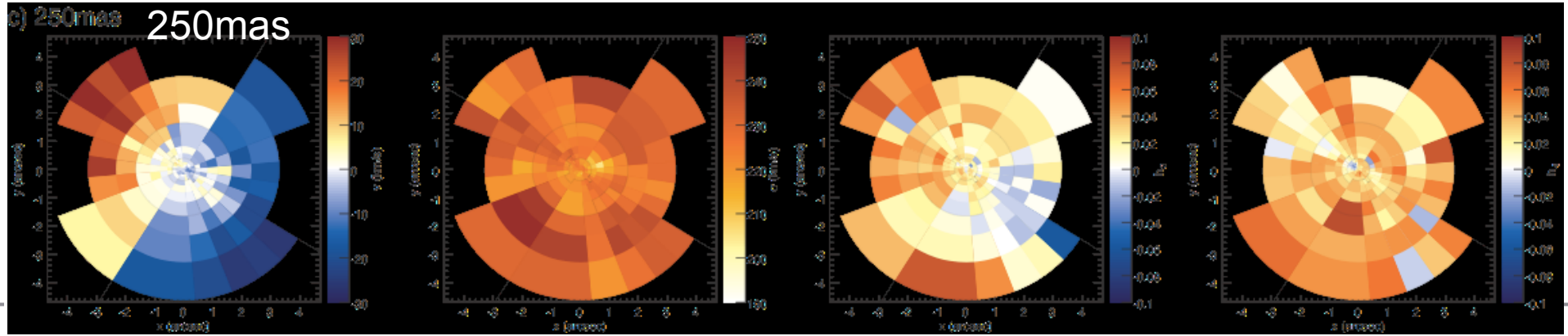
Kinematics of NGC1316

Nowak et al. almost submitted

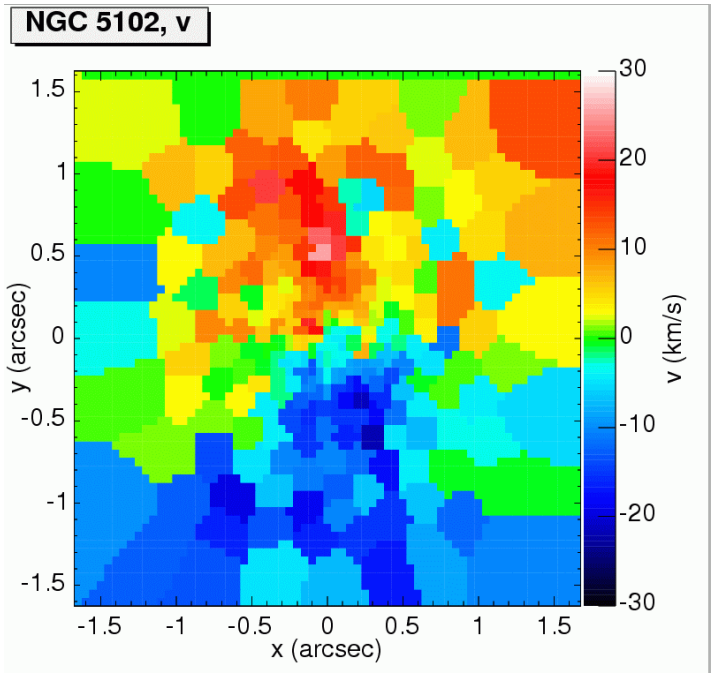
v σ h_3 h_4

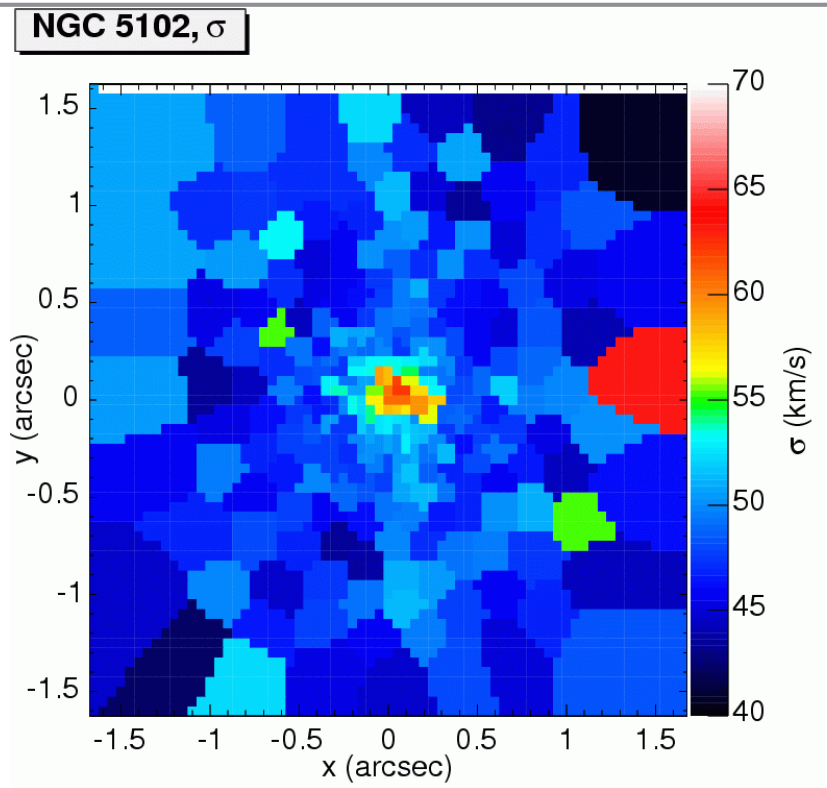


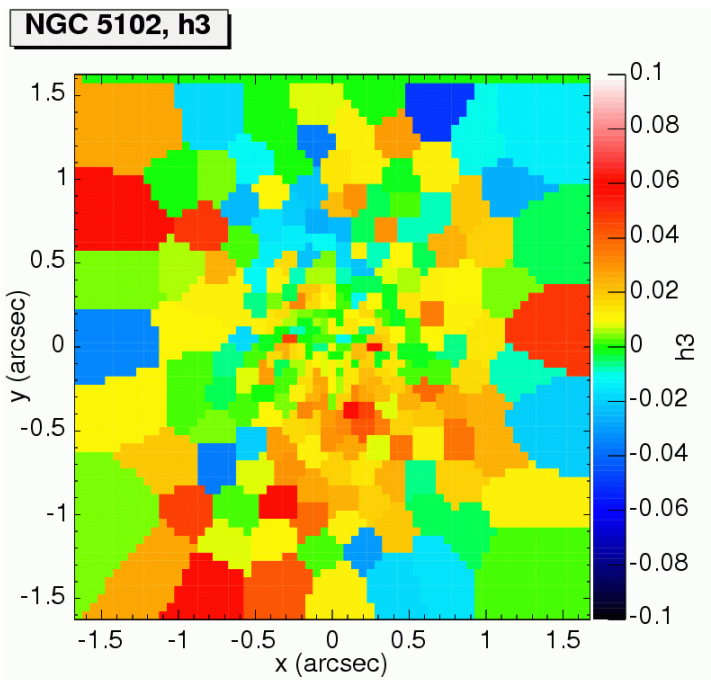


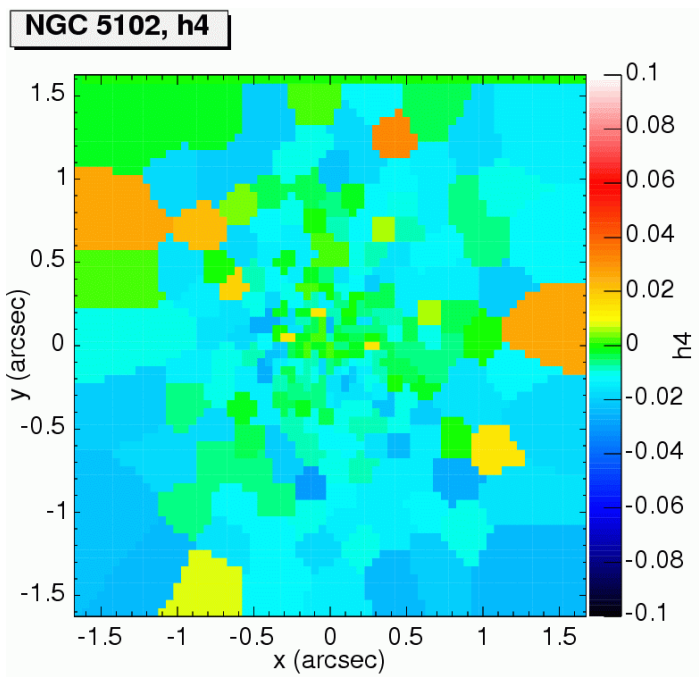


NGC 5102: σ~65 km/s





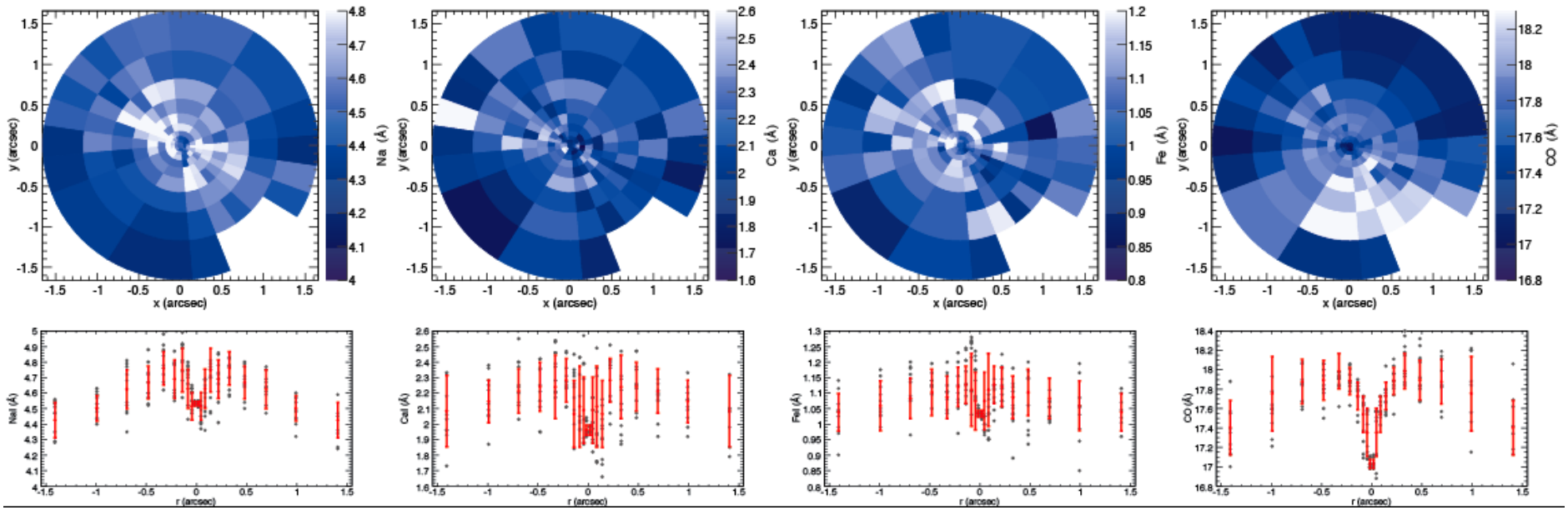




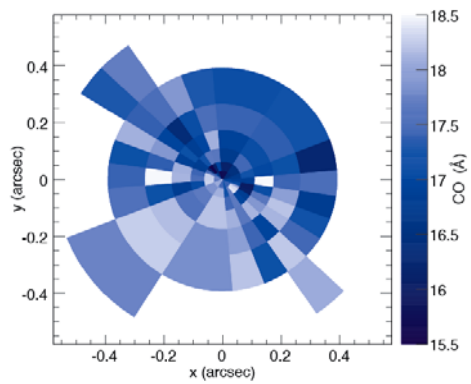
Line indices

NGC1316

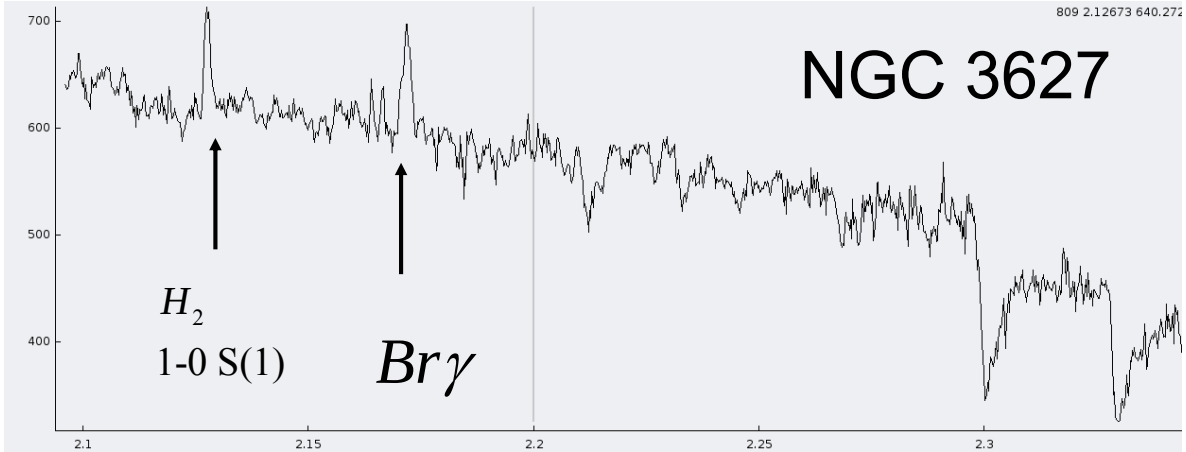
Na I Ca I Fe I CO(2-0)



- near-IR (*K* band) indices: Na I (2.21μm), Ca I (2.26μm), Fe I (2.23μm), CO (2.29μm)
- spectral synthesis models not yet available, but soon?



Credit: Silva, Kuntschner, Lyubenova

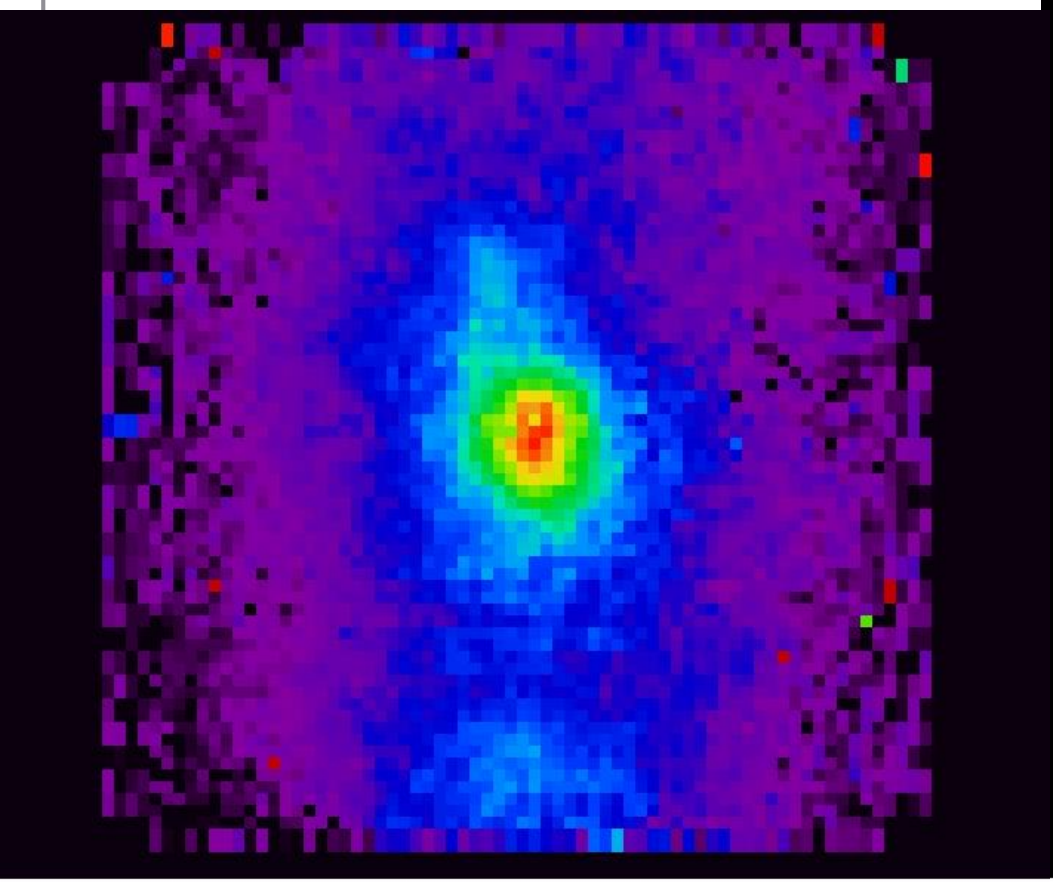


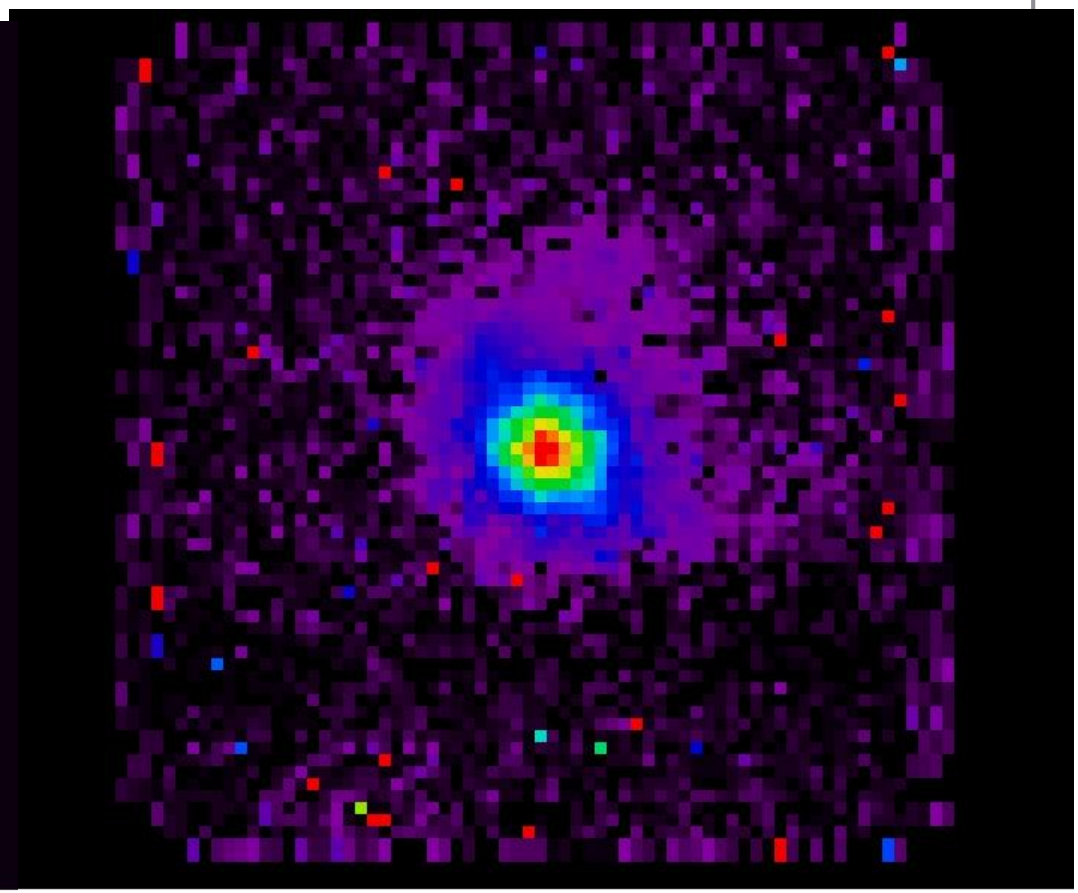
Gas emission

No flux calibration done yet, do not ask for gas masses!

H_2 1-0 S(1) λ (μm)

$Br\gamma$



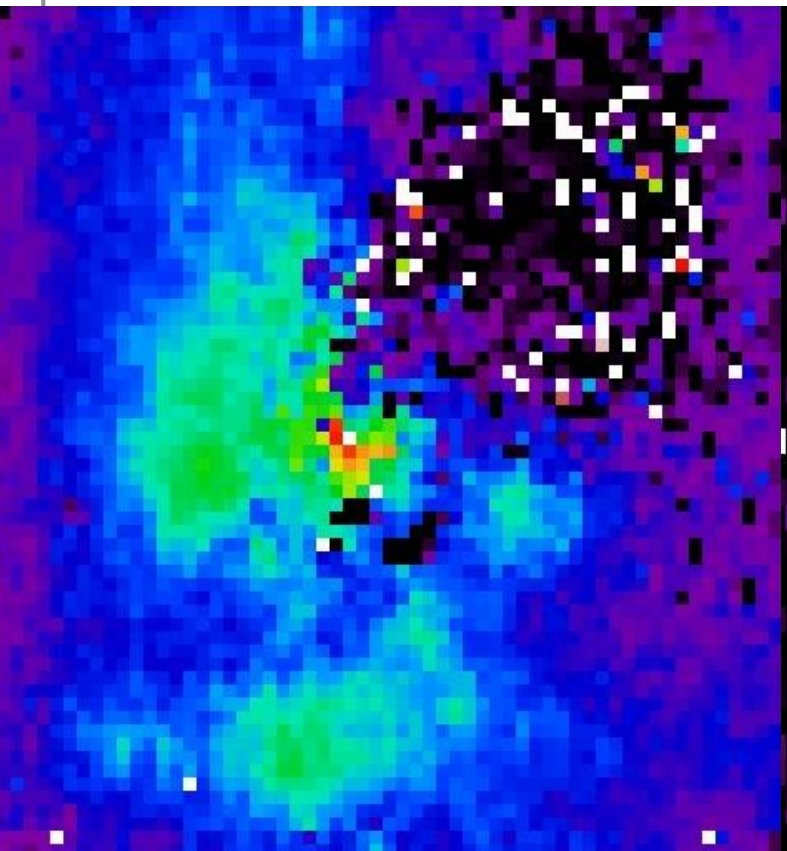


Gas maps

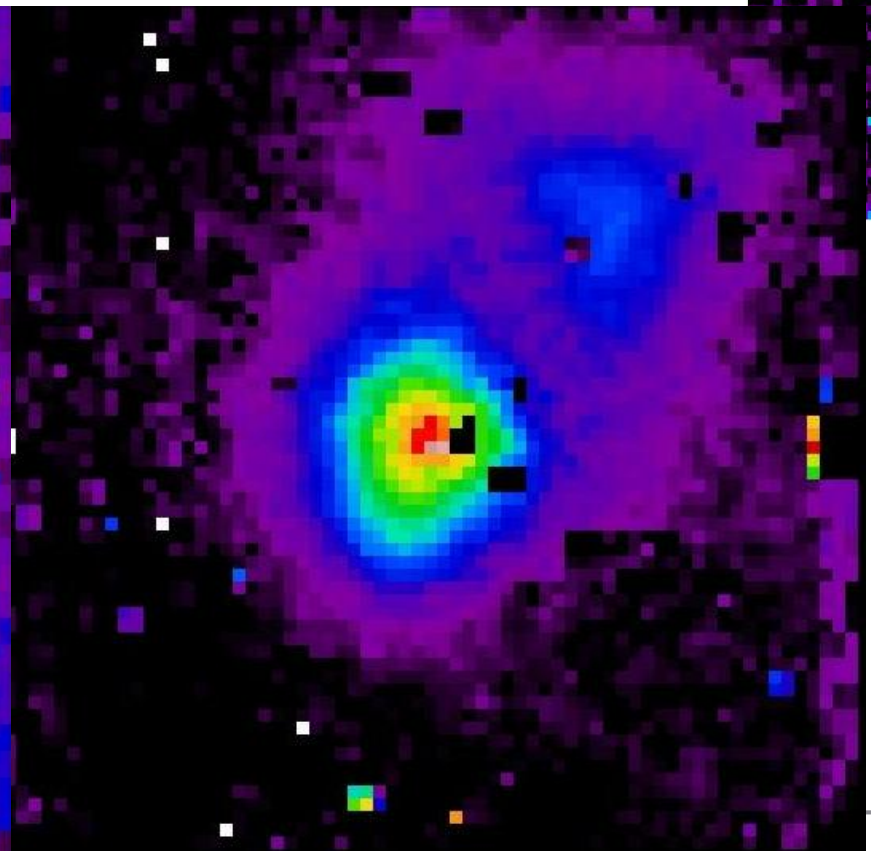
H_2 1-0 S(1)

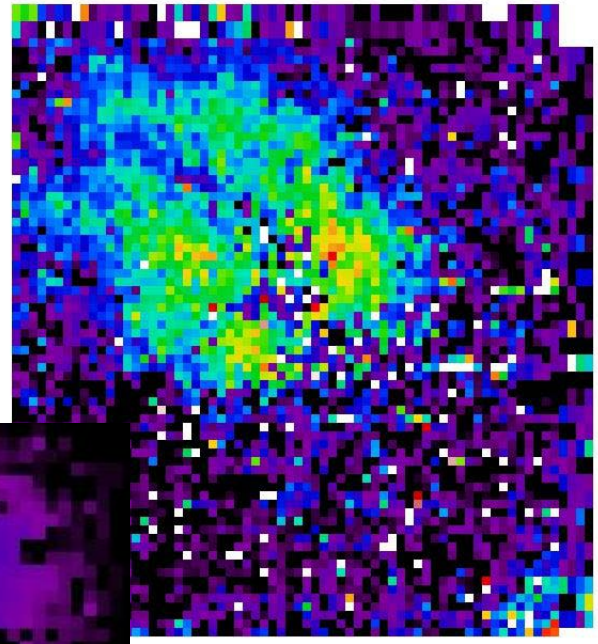
No emission detected in NGC 1398, NGC3412, NGC3489 NGC4486a, NGC4501, NGC4699, NGC 5102

NGC 4569



NGC 4579



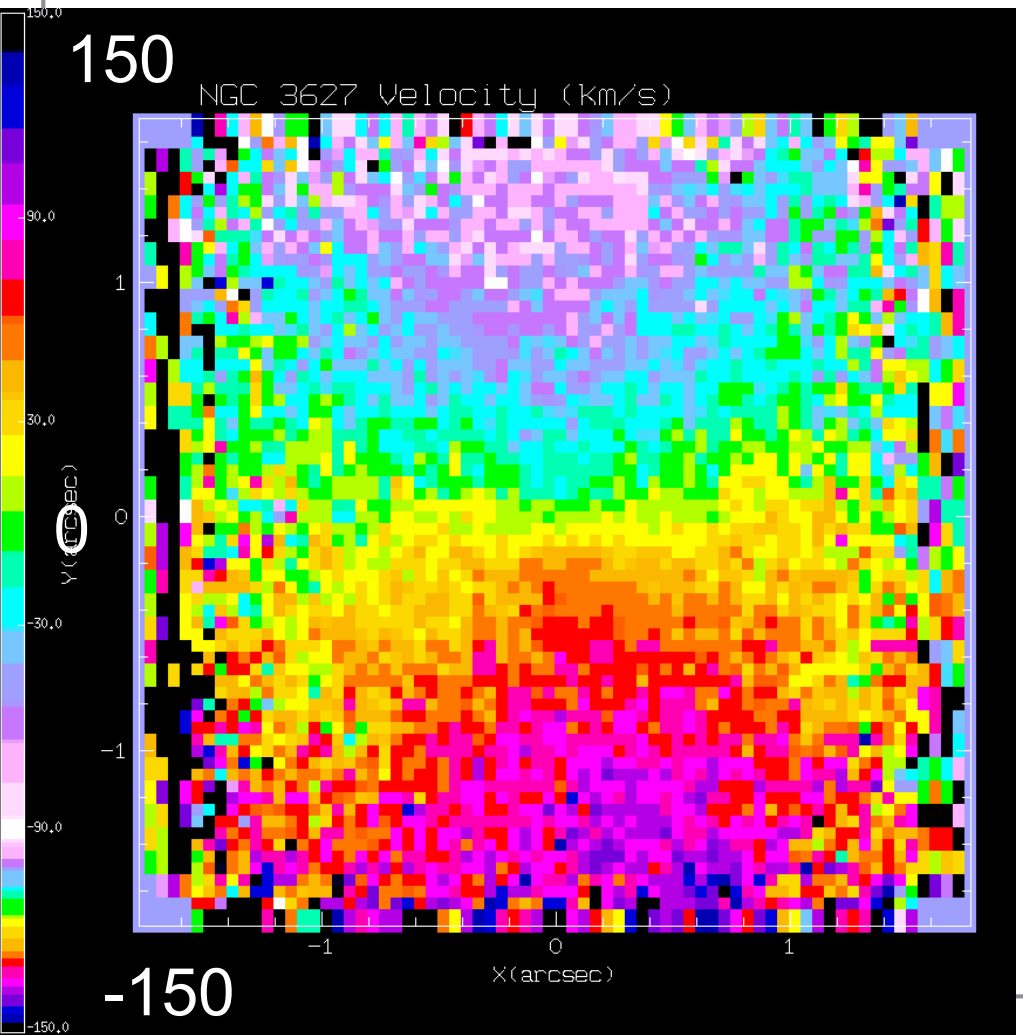


NGC1316

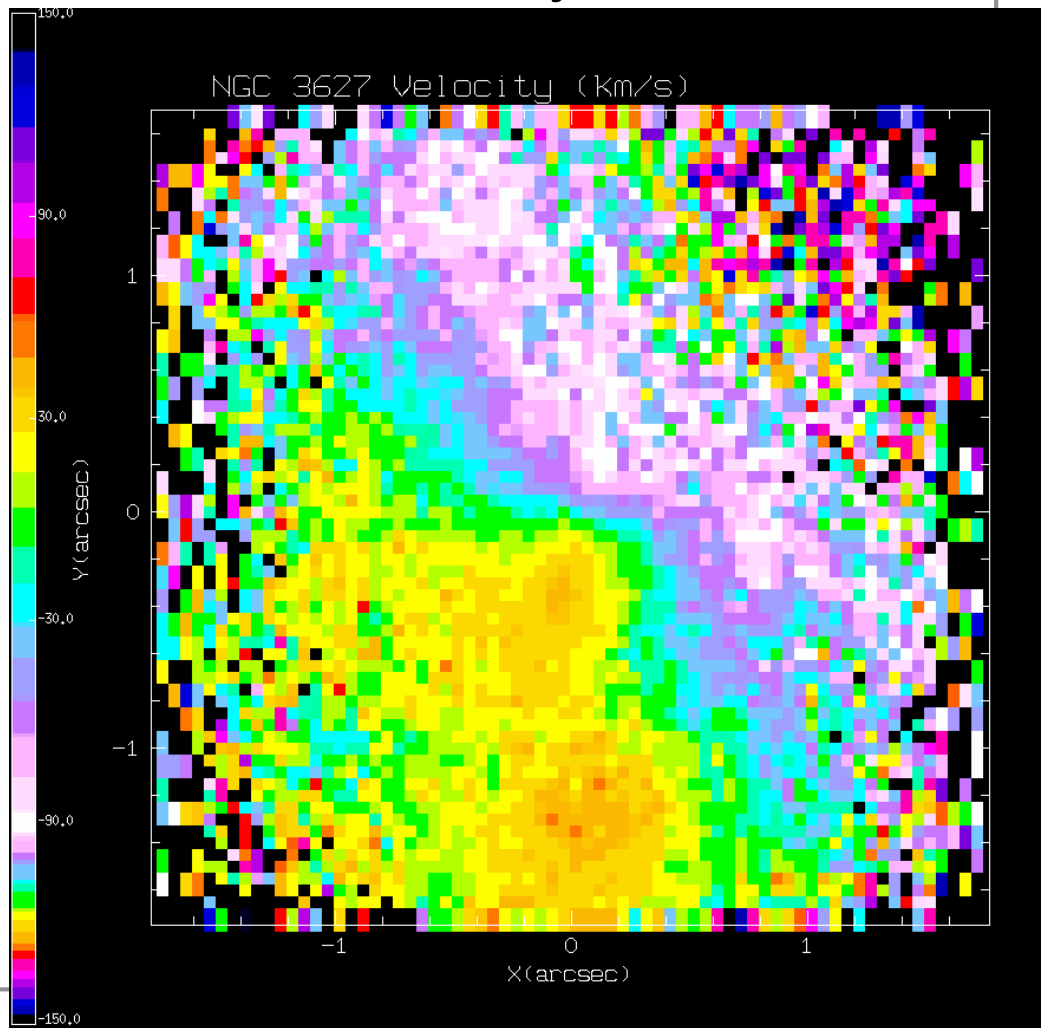
Gas Kinematics: NGC 3627

Gas might not trace the gravitational potential

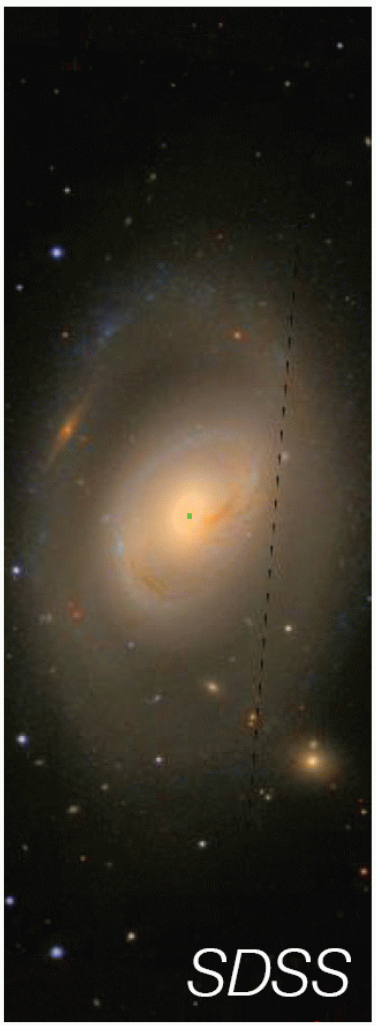
Stellar Velocity Field

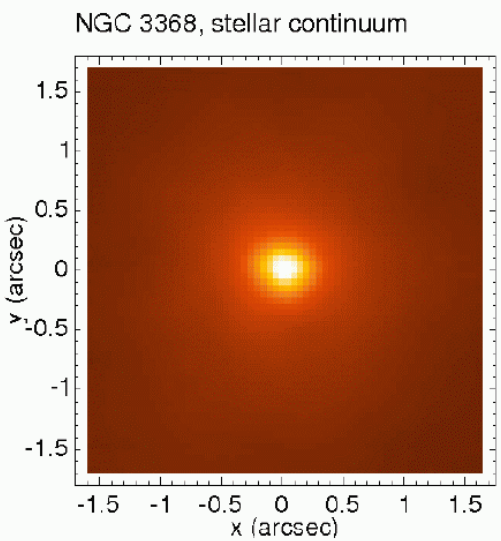


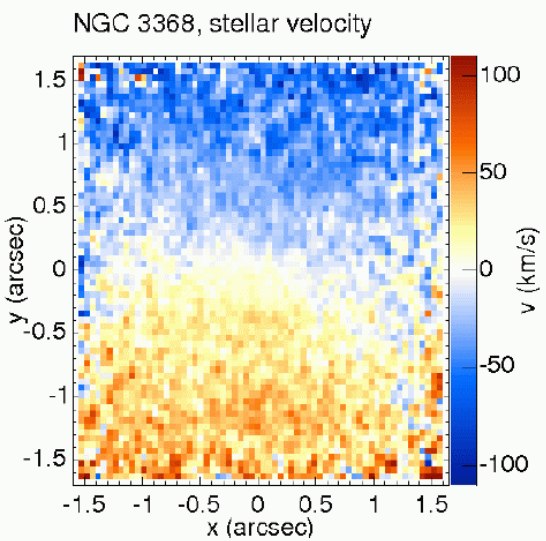
H2 Velocity Field

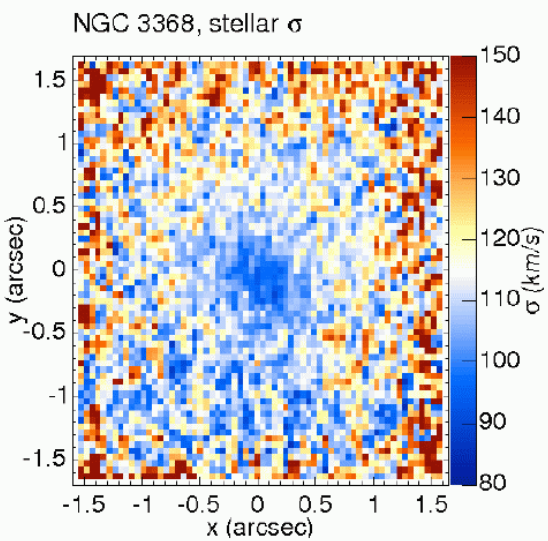


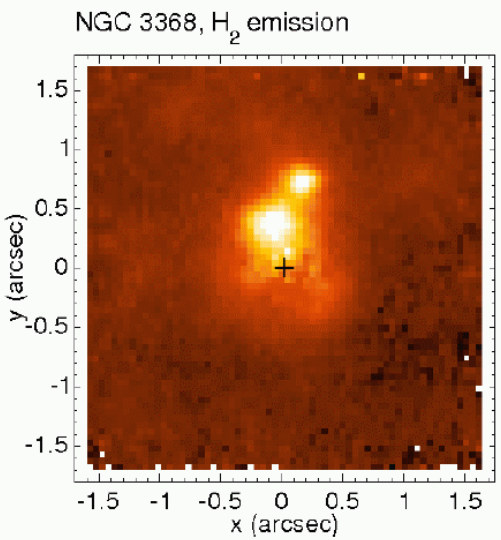
Counterrotating gas in NGC 3368

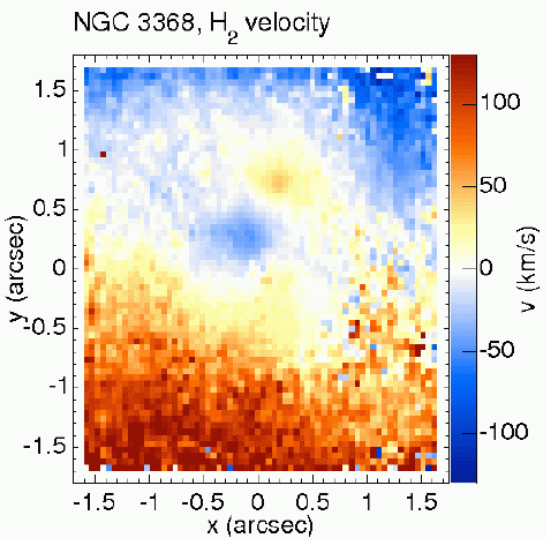


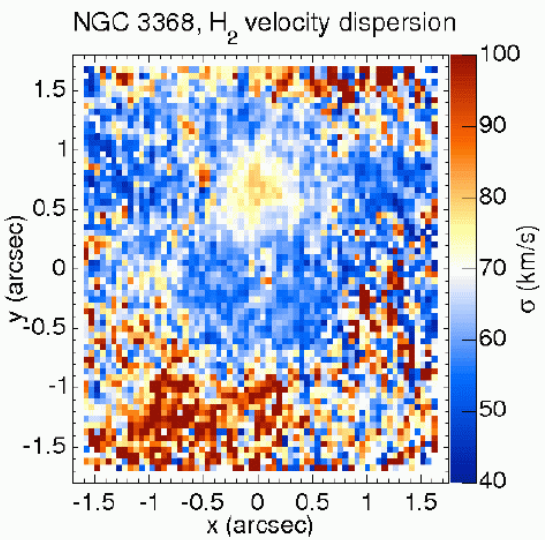












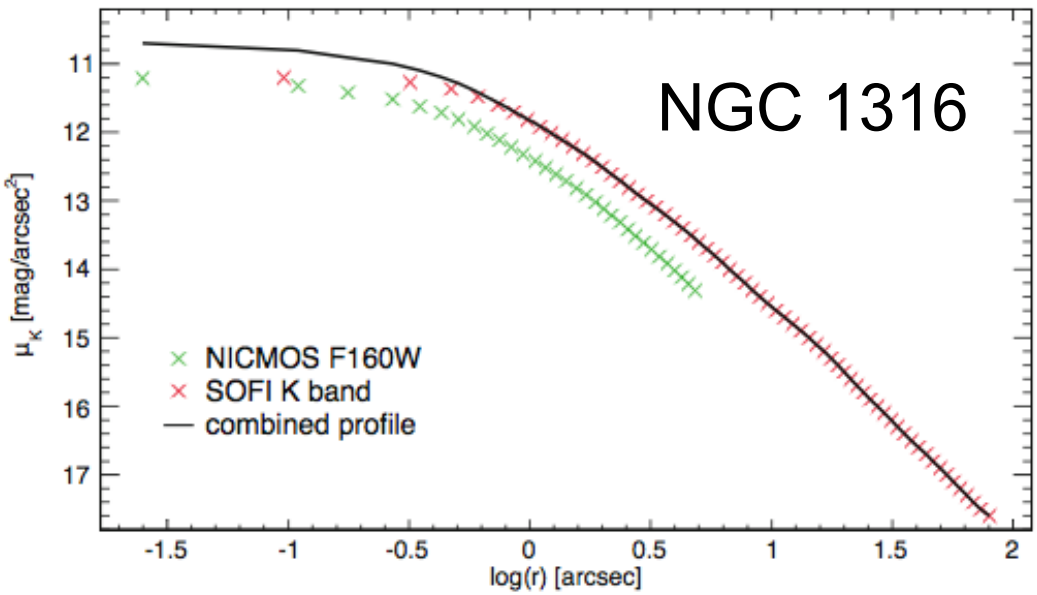
Stellar dynamical modelling

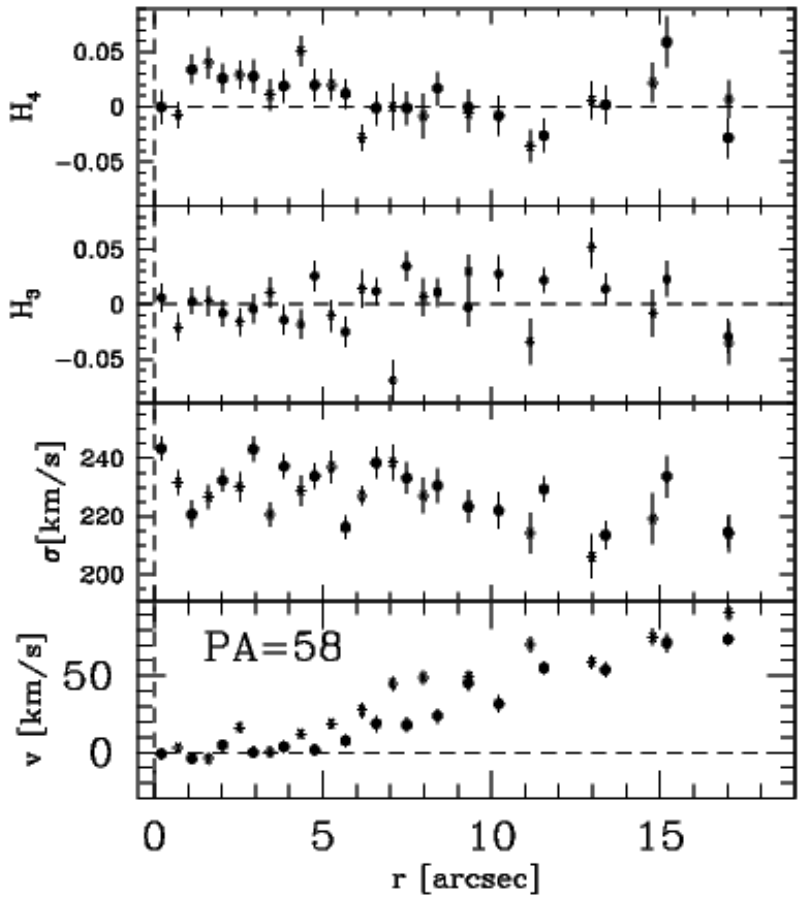
- Schwarzschild (1979) orbit superposition technique (Gebhardt et al. 2003, Thomas et al. 2004/5):

- gravitational potential (from light distribution of stars) + assumed mass-to-light ratio M/L + assumed M_{BH}
- generate orbit library (~2x7000 orbits)
- find weighted superposition of orbits that reproduce light distribution and best fits the LOSVDs
- repeat with systematically varied M/L and M_{BH}
- best-fitting M/L and M_{BH} follow from χ^2 analysis

Photometry and longslit data

dust-corrected SOFI and NICMOS images

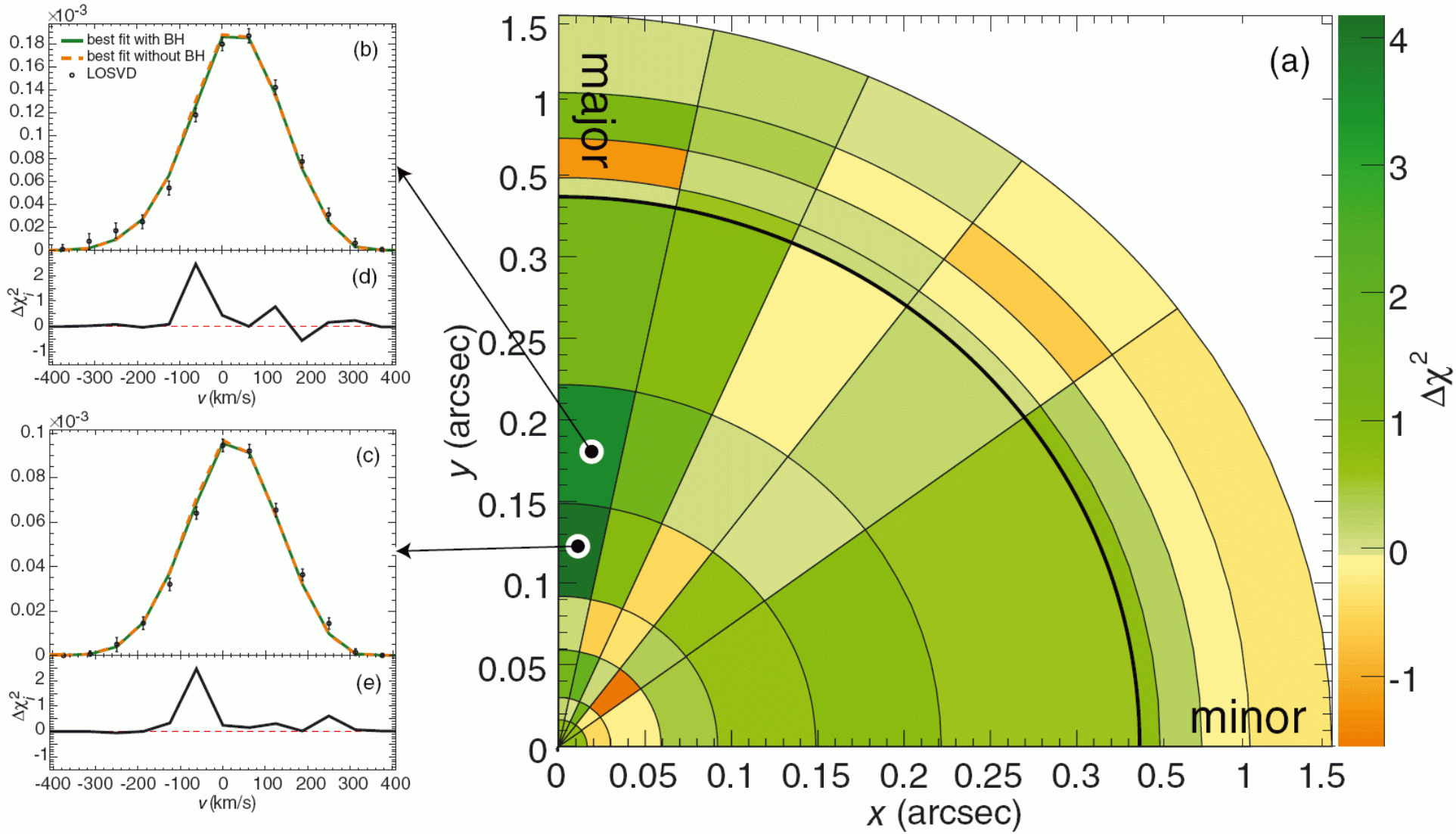




Siding Spring 2.3m, CaT region

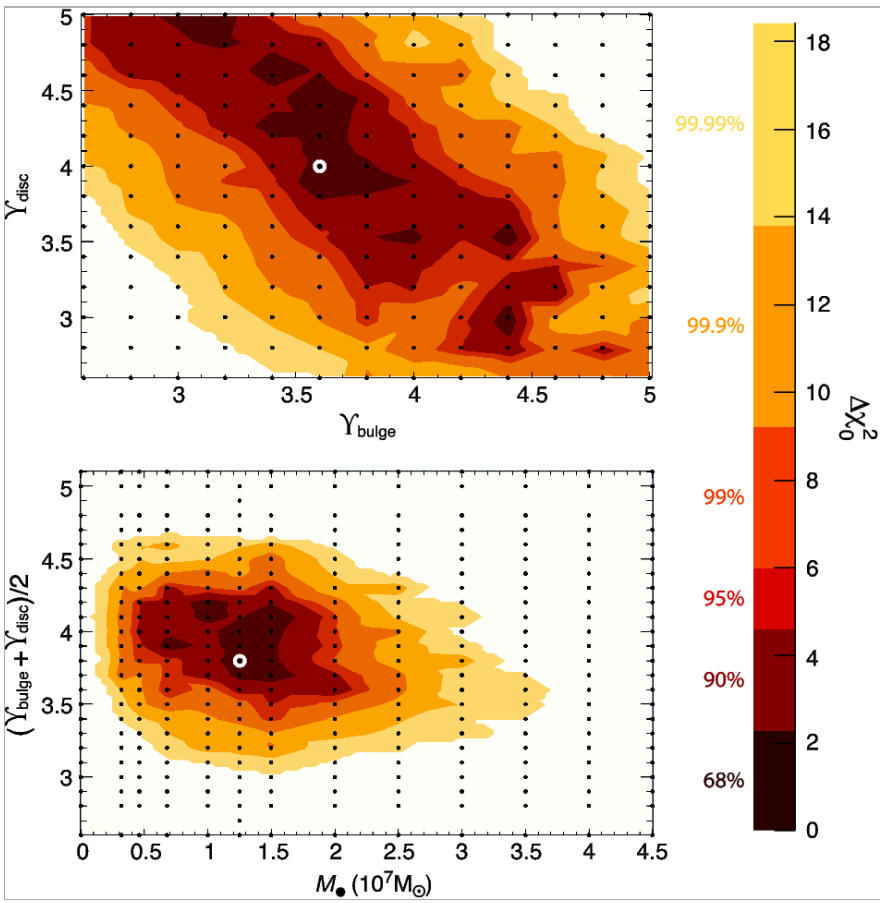
Best-fit model

NGC4486a

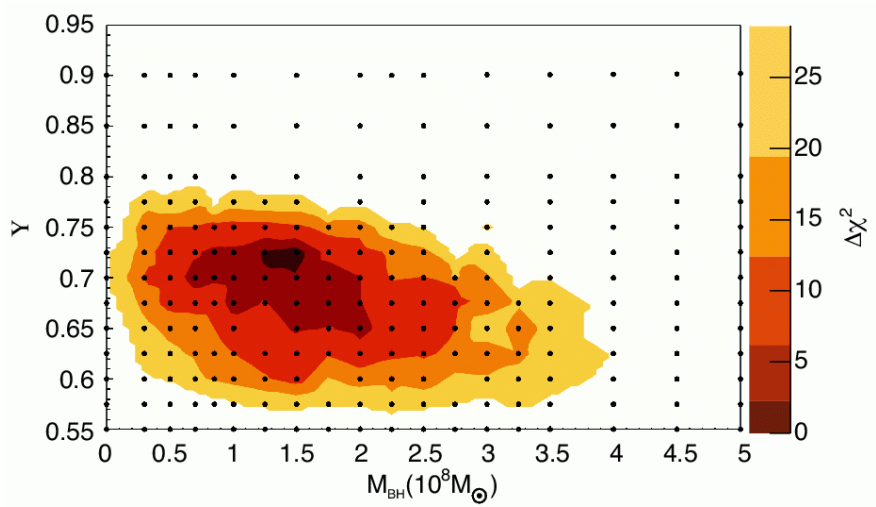


Black hole masses

NGC 4486a



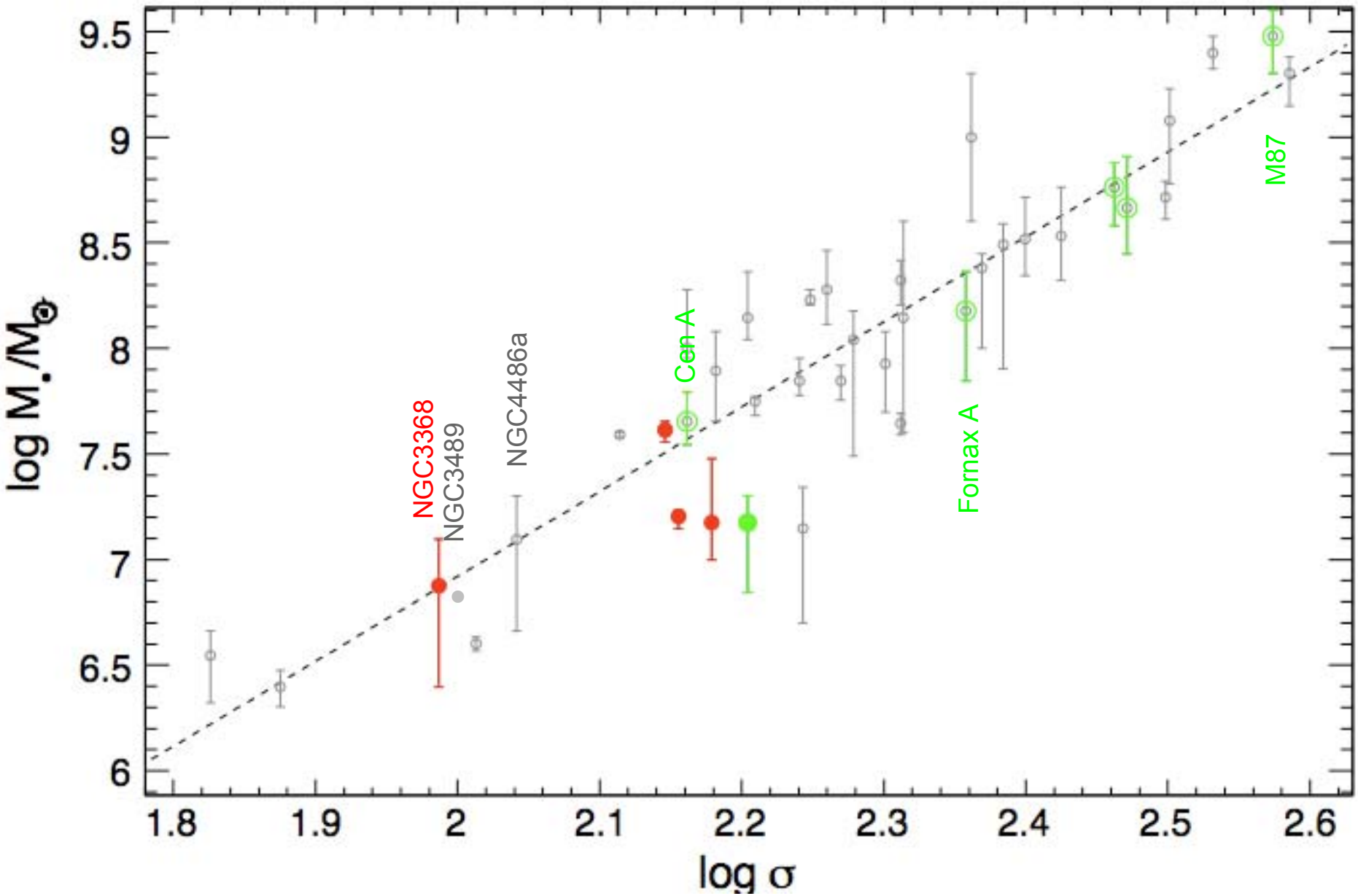
NGC 1316



NGC 1316	$1.5^{+0.25}_{-0.80} \times 10^8 M_\odot$
NGC 3368	$6.3 \times 10^6 M_\odot$
NGC 3489	$6.8 \times 10^6 M_\odot$
NGC 4486a	$1.5^{+0.75}_{-0.79} \times 10^7 M_\odot$

8 more to come
in the next months!

The $M_\bullet - \sigma$ relation



Conclusions

- SINFONI delivers diffraction-limit 2D spectra that probe well the central regions of local galaxies
- 12 galaxies with low σ and/or pseudo/classical bulges and/or merger remnant/AGN observed with SINFONI
- Stellar (and gas) kinematics measured to constrain
- the mass of the central supermassive black hole
- Gas emission detected in 5 galaxies
- Modeling of 4 galaxies confirms predictions of the
- $M_\bullet - \sigma$ relation
- From Period 82 on: observations of local giant Es with σ>300 km/s and/or cores.