Feeding and Feedback in Nearby Active Galactic Nuclei

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- *In collaboration with: -*

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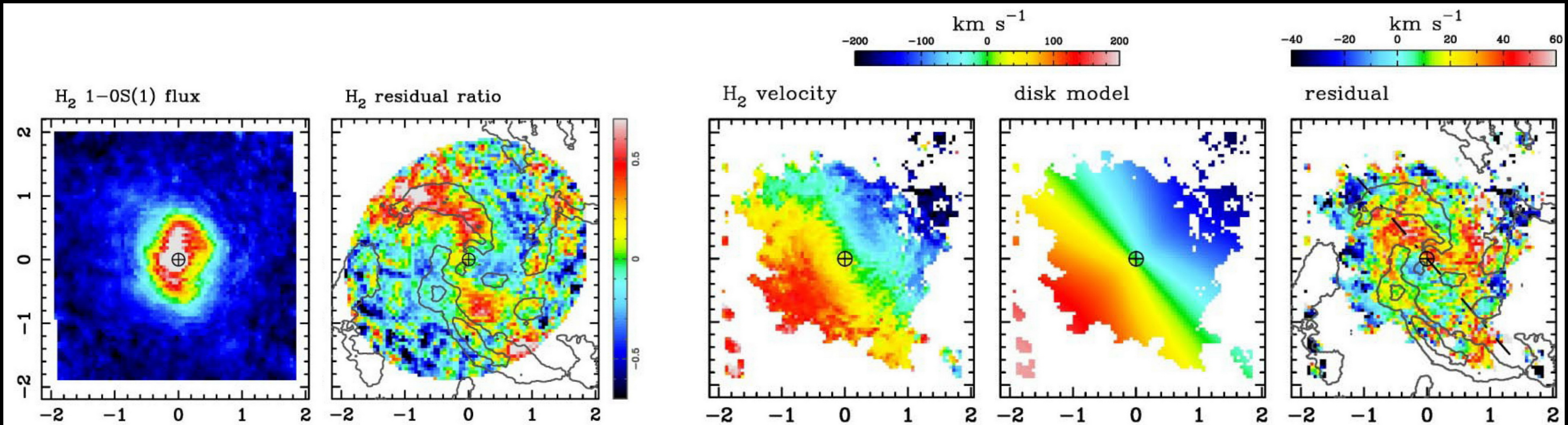
AO-assisted Integral-field Spectroscopy of Nerby AGN

Science	%	Examples
Inflows	37	Davies et al. 2009, Mueller-Sanchez et al. 2009, Davies et al. 2014, Riffel et al. 2008, 2009, Mueller-Sanchez et al. 2013, Lena et al. 2015, …
Outflows	49	Mueller-Sanchez et al. 2011, Storchi-Bergmann et al. 2013, Mazzalay et al. 2013, Riffel et al. 2013, Riffel et al. 2014, Davies et al. 2014,…
Torus	11	Hicks et al. 2009, Mueller-Sanchez et al. 2013, Mazzalay et al. 2014, Storchi-Bergmann et al. 2014, Burtscher et al. 2015
Nuclear Star formation	9	Mueller-Sanchez et al. 2006, Davies et al. 2007, Boker et al. 2008, Storchi-Bergmann et al. 2012
SMBH Masses	11	Davies et al. 2006, Neumayer et al. 2007, Nowak et al. 2007, Nowak et al. 2008, Gebhardt et al. 2011
Other (maser disks, dual AGN)	11	Engel et al. 2010, Medling et al. 2011, Fu et al. 2012, Greene et al. 2014, Mueller-Sanchez et al. 2015

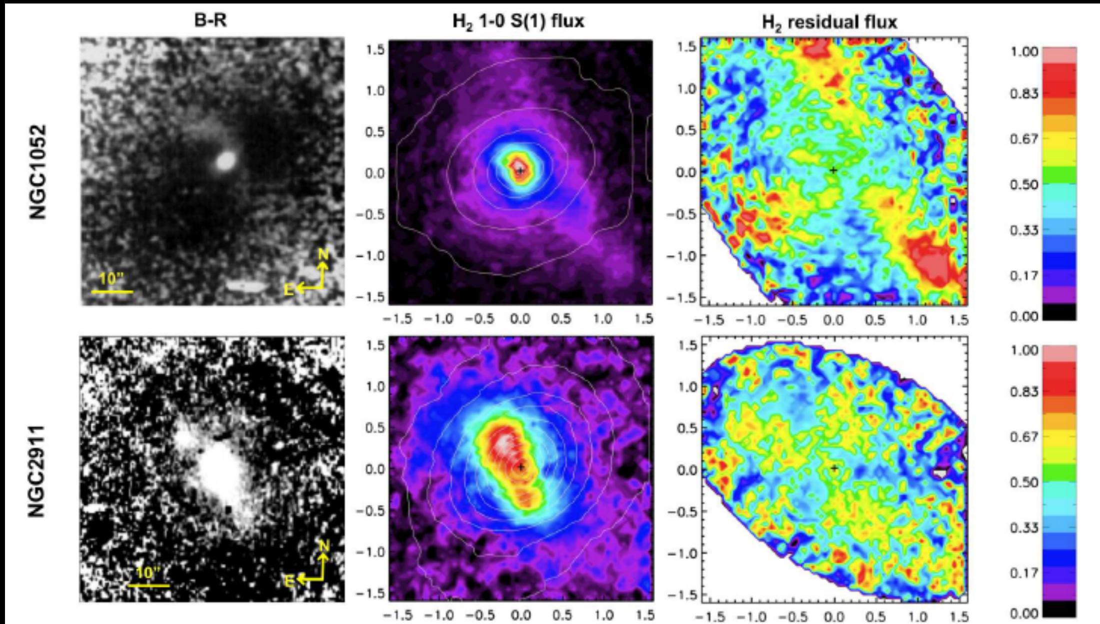
Gas inflow in NGC 1097



- Inner spiral with three photometric arms
- The gas kinematics reveal a strong non-circular velocity residual in the form of a 2-arm spiral. From linear theory, the projected LOS velocity pattern of an m-arm spiral is an (m − 1)-arm kinematic spiral
- The inflow rate to the central few parsecs is of order 0.1 M_sun yr−1. Given that there is of order 10^8 M_sun of gas within a radius of 500 pc, such a modest inflow rate would require ~1.0 Gyr.
- The inner spiral in NGC1097 appears to be driving gas inwards at a sustainable rate.

Davies et al. 2009

Nuclear Spirals in E/S0 galaxies



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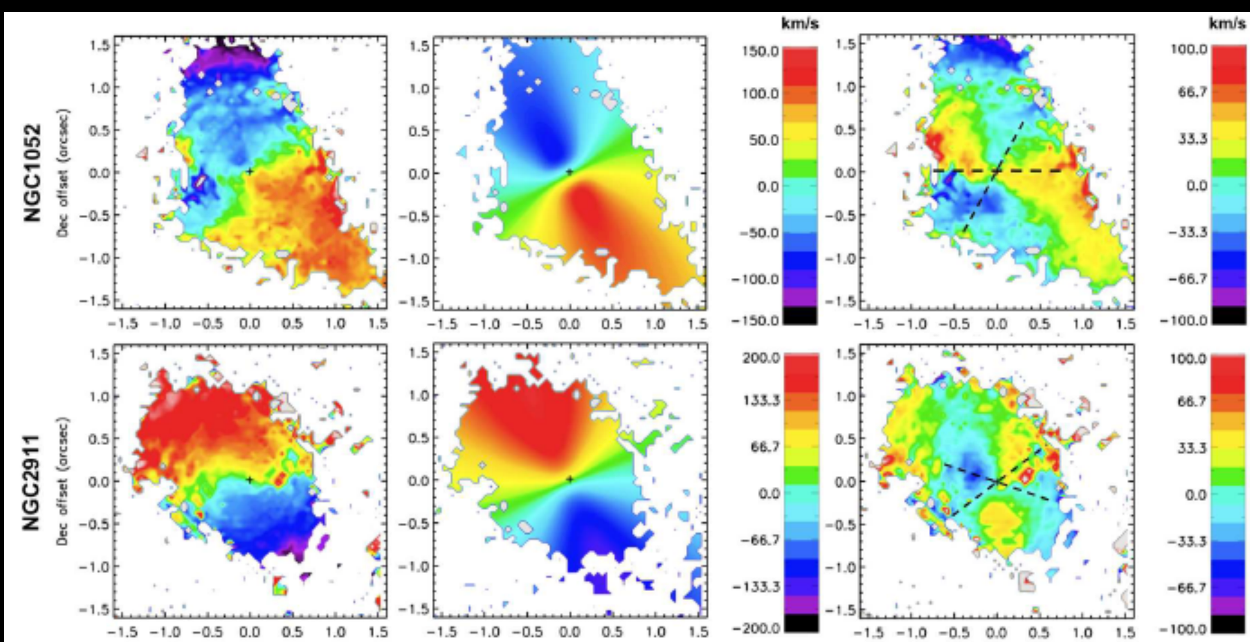
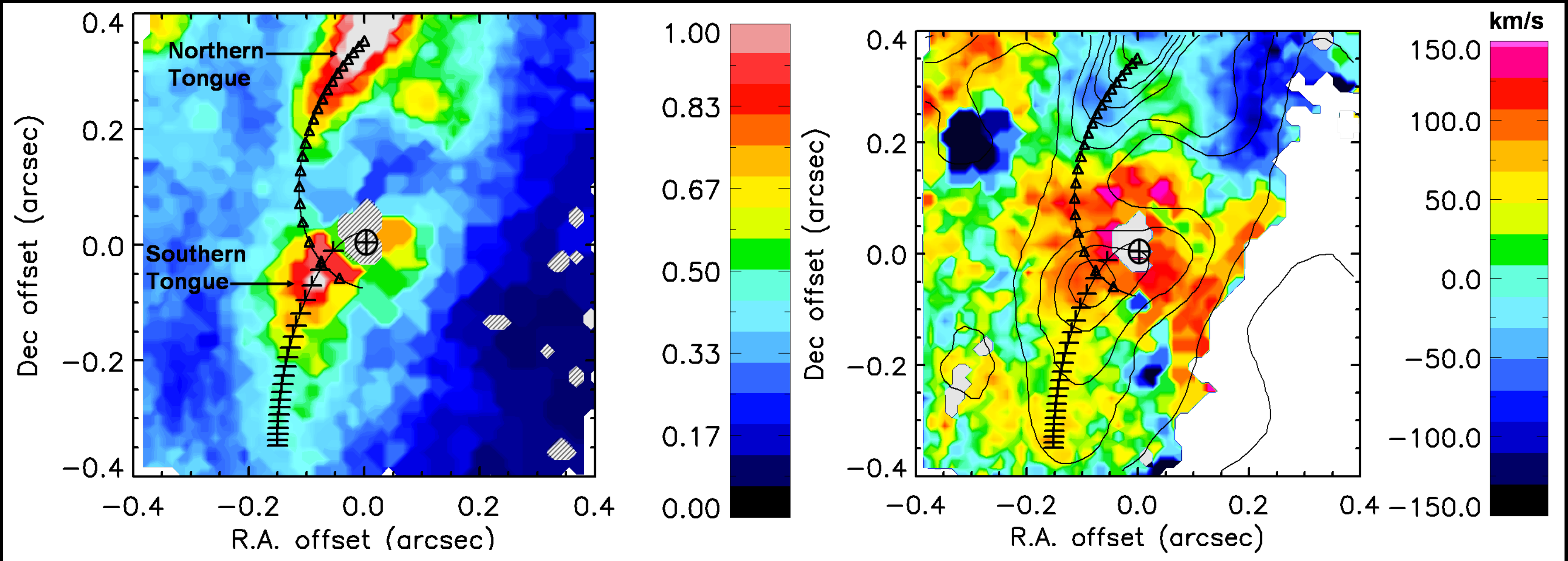


- The inflow rate to the central few parsecs is of order 0.1-1 M_sun yr−1.

Müller-Sanchez et al. 2013

Gas inflow in NGC 1068



- Filaments of gas extend from the ring at a radius of about 30 pc to the AGN
- The inflow rate to the central few parsecs is of order 15 M_sun yr−1. This is 2–3 orders of magnitude greater than that needed to power the AGN itself
- These models indicate that the infall timescale for a gas mass of 2x10^7 M_sun is about 1.3 Myr.
- This rapid inflow appears to be due to chance combination of circumstances, and is probably unsustainable

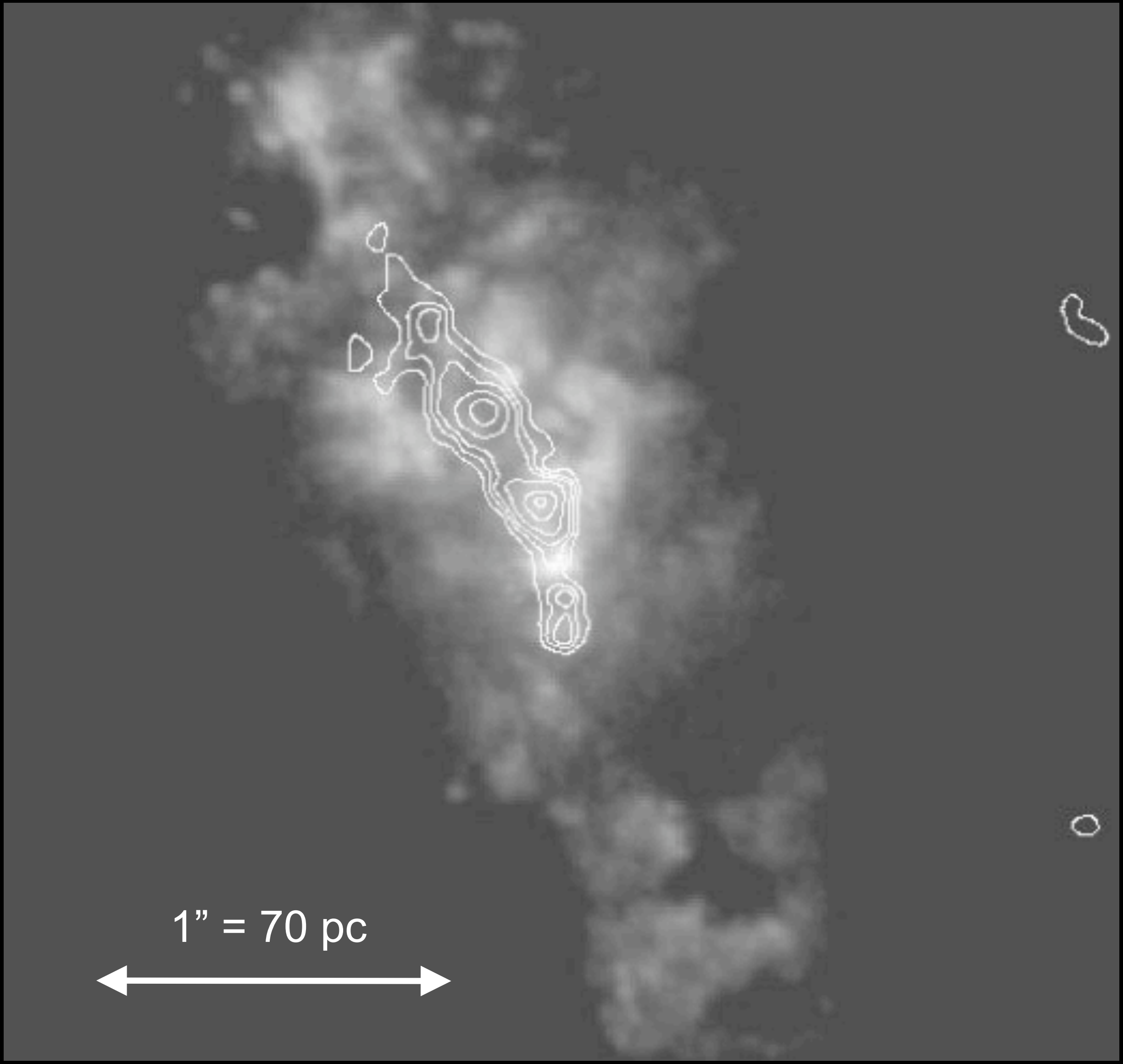
Müller-Sanchez et al. 2009

Inflows: Science with the TMT

- Observe for the first time the structures feeding the SMBH.

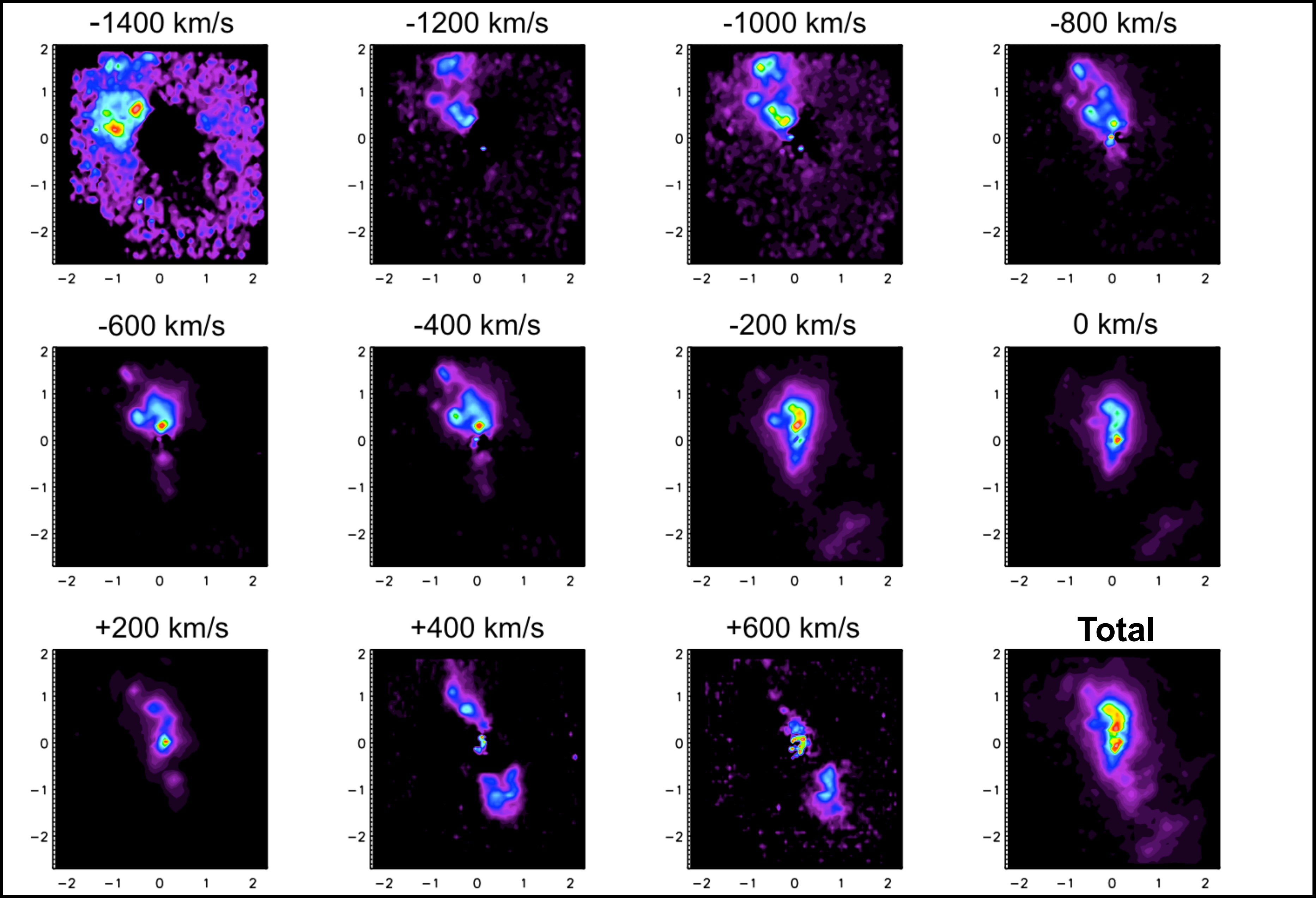
- Compare inflow rates to ~1 pc with mass accretion rates to the SMBH.

The NLR and CLR in NGC 1068



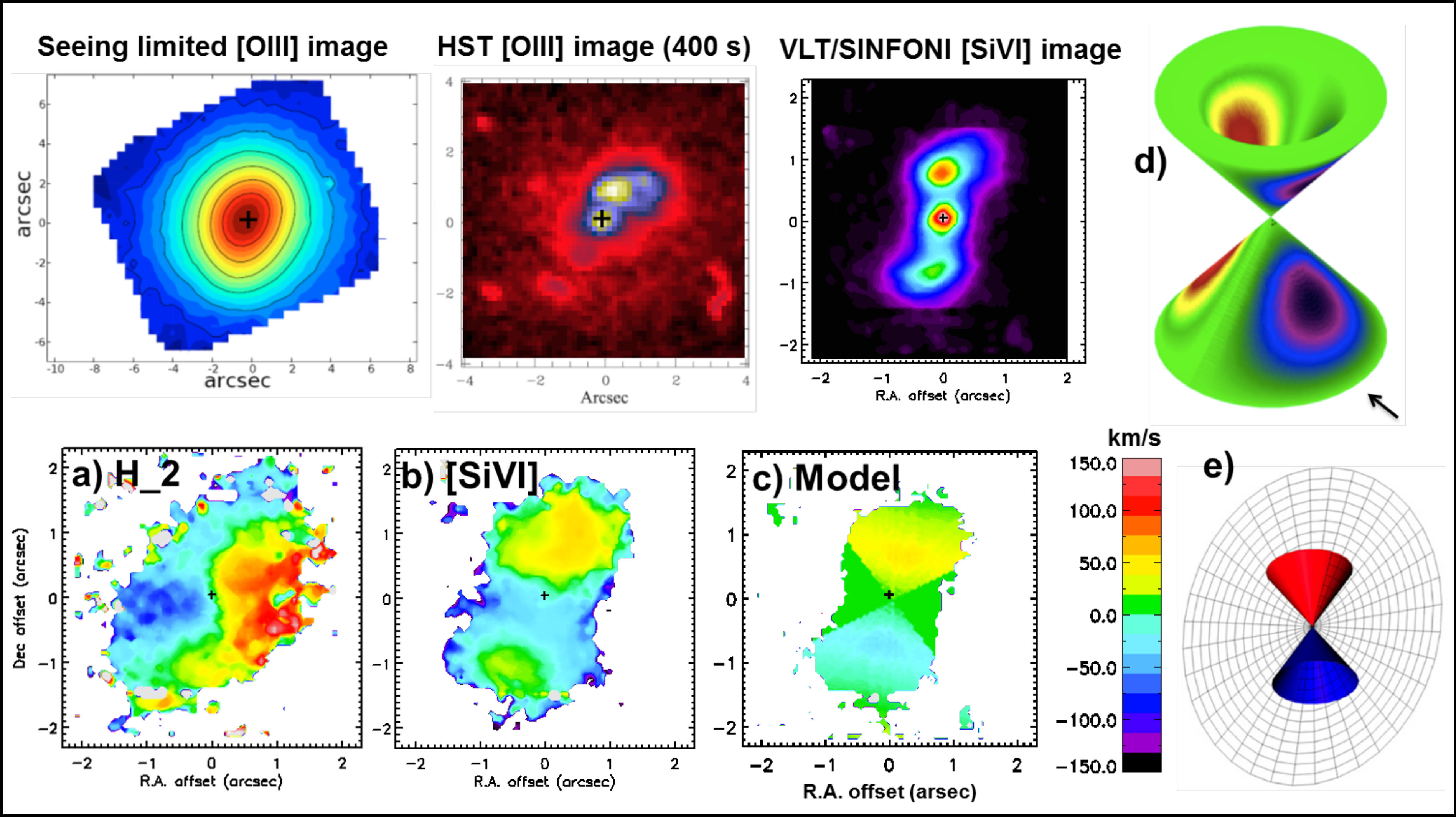
Allignment between radio jet and ionized gas, Gallimore et al. 1996

Outflows in the NLR/CLR of NGC 1068



Müller-Sanchez et al. 2011

The Asymmetric Bipolar Outflow in NGC 3081



Müller-Sanchez et al. 2015a, ApJ, submitted

Mass Outflow Rates and Kinetic Energy

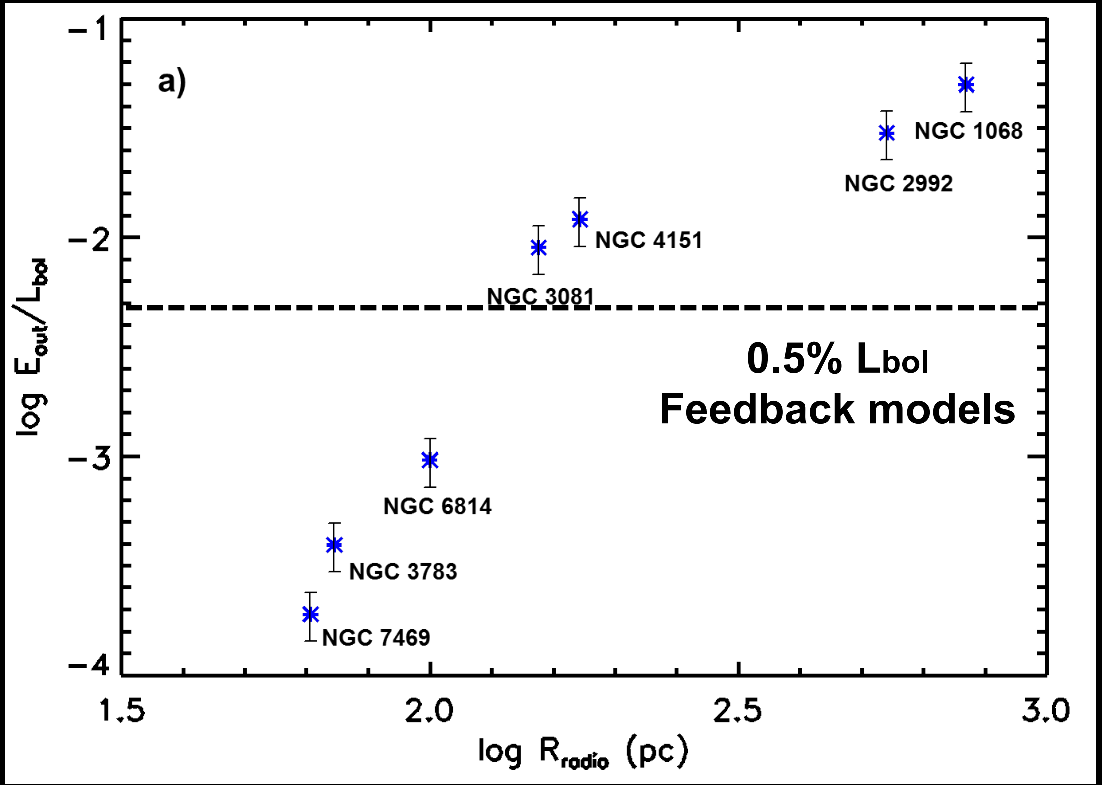
Galaxy	A^{a} (10^4 pc^2)	$\dot{M}_{out}$ ($M_\odot$ yr^{-1})	$\dot{M}_{acc}$ ($M_\odot$ yr^{-1})	$\dot{E}_{out}$ (10^{42} erg s^{-1})	L_{bol} (10^{42} erg s^{-1})	$\dot{E}_{out}/L_{bol}$	Ref.[b]
NGC 1068	2	9	0.015	5	88	0.05	1
NGC 2992	200	120	0.015	2.5	85	0.029	2
NGC 3783	4	2.5	0.03	0.07	180	0.0004	1
NGC 4151	8	9	0.01	0.65	55	0.012	2
NGC 6814	25	7.5	0.014	0.08	80	0.001	2
NGC 7469	11	4	0.04	0.06	250	0.0002	1

$M_{out} = 2n_e m_p A V(r) f \quad [M_{sun}\ yr^{-1}]$

$M_{accr} = L_{bol}/\eta c^2 \quad [M_{sun}\ yr^{-1}]$

$E_{out} = M_{out}(V(r)^2 + \sigma^2)/2 \quad [erg\ s^{-1}]$

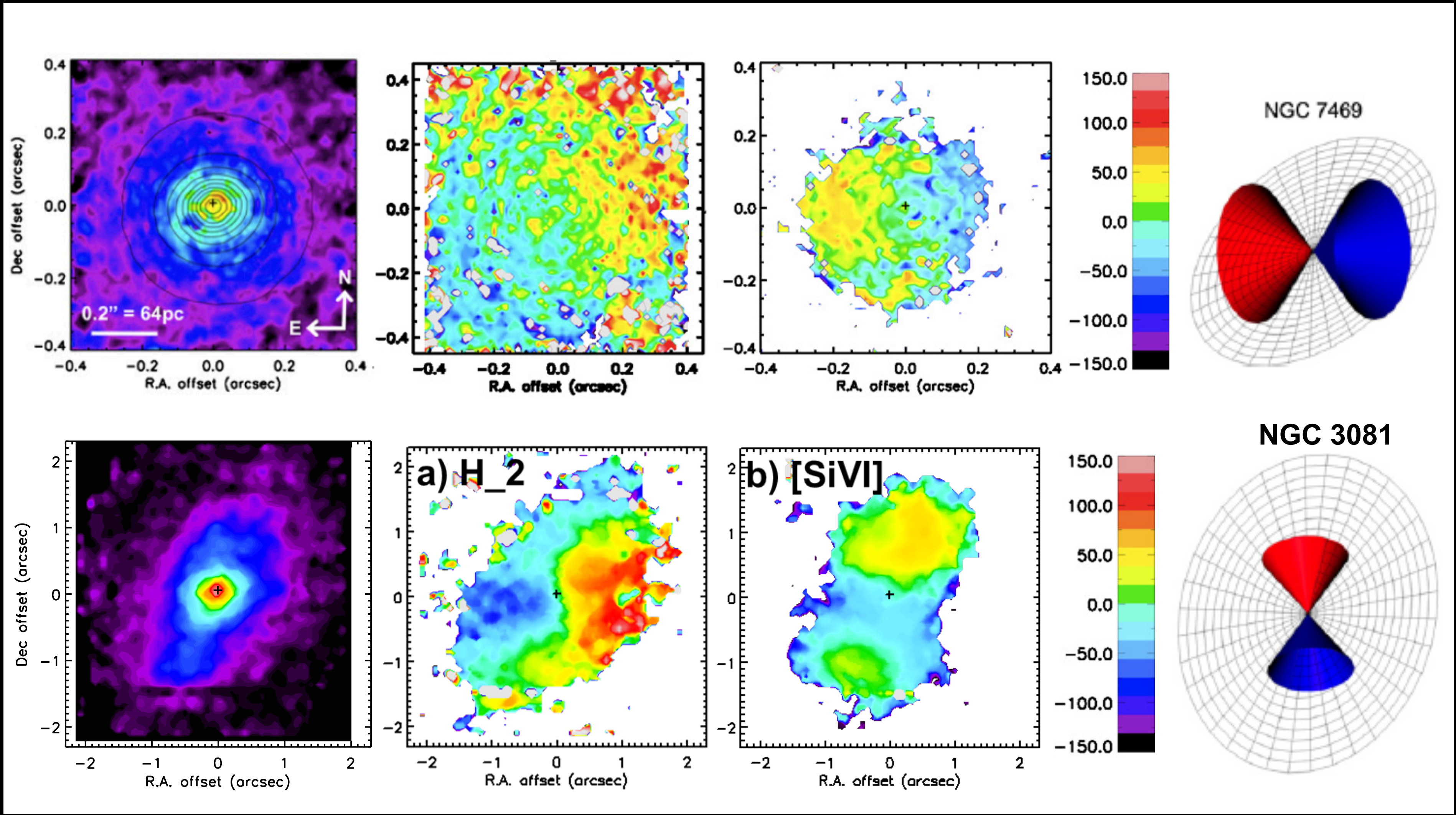
where A is the area of one cone, V(r) in km/s and η=0.1



Müller-Sanchez et al. 2011, 2013

Interaction of the Outflows with the Local ISM

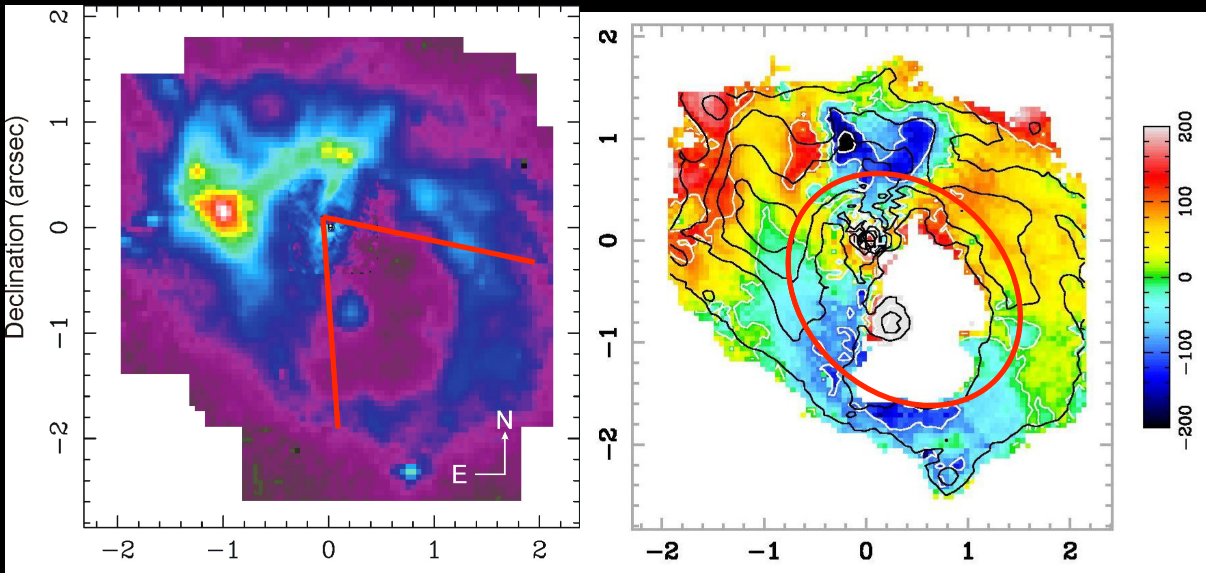
I. No significant Interaction

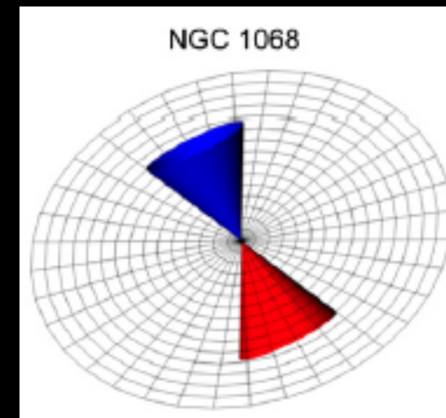


Müller-Sanchez et al. 2011, 2015a

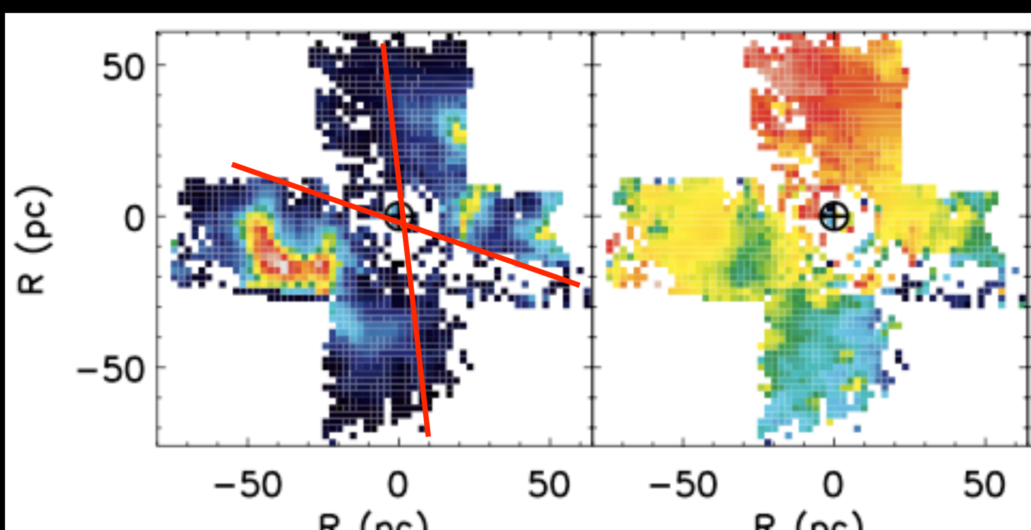
Interaction of the Outflows with the Local ISM

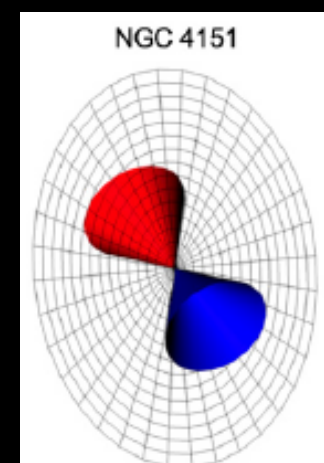
II. Cavities of Molecular Gas





Mueller-Sanchez et al. 2009

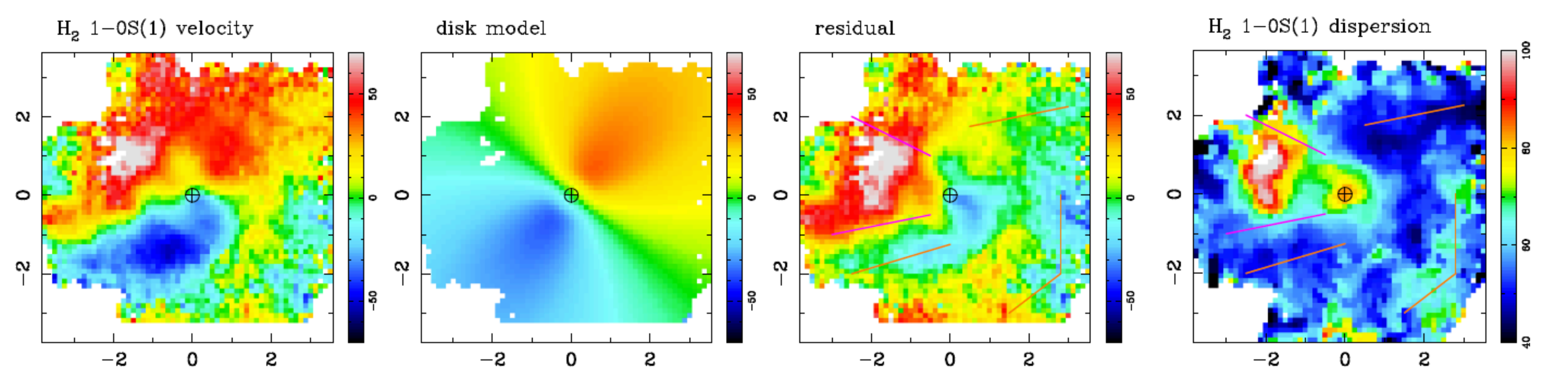




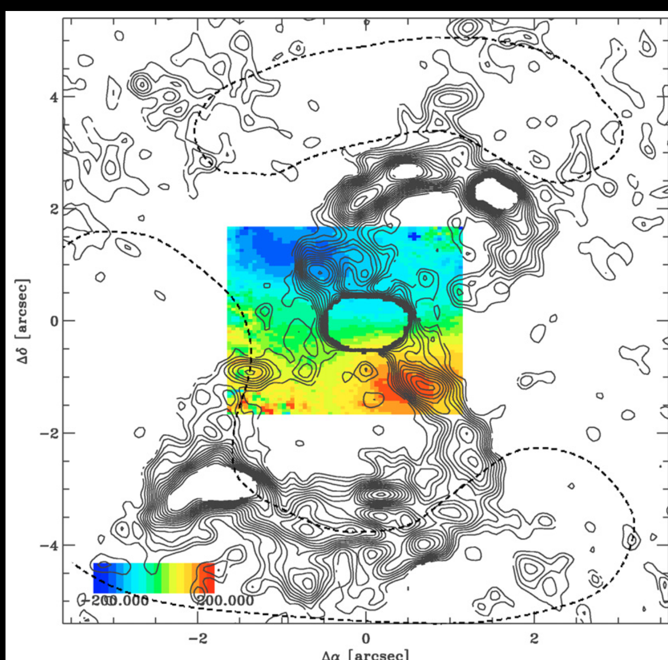
Hicks et al. 2009

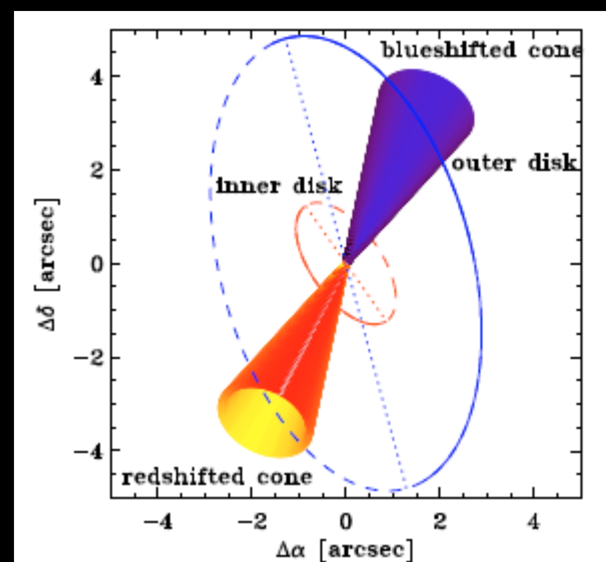
Interaction of the Outflows with the Local ISM

III. Molecular Gas is Entrained in the Outflows



NGC 5643, Davies et al. 2014





NGC 2992, Friedrich et al. 2010

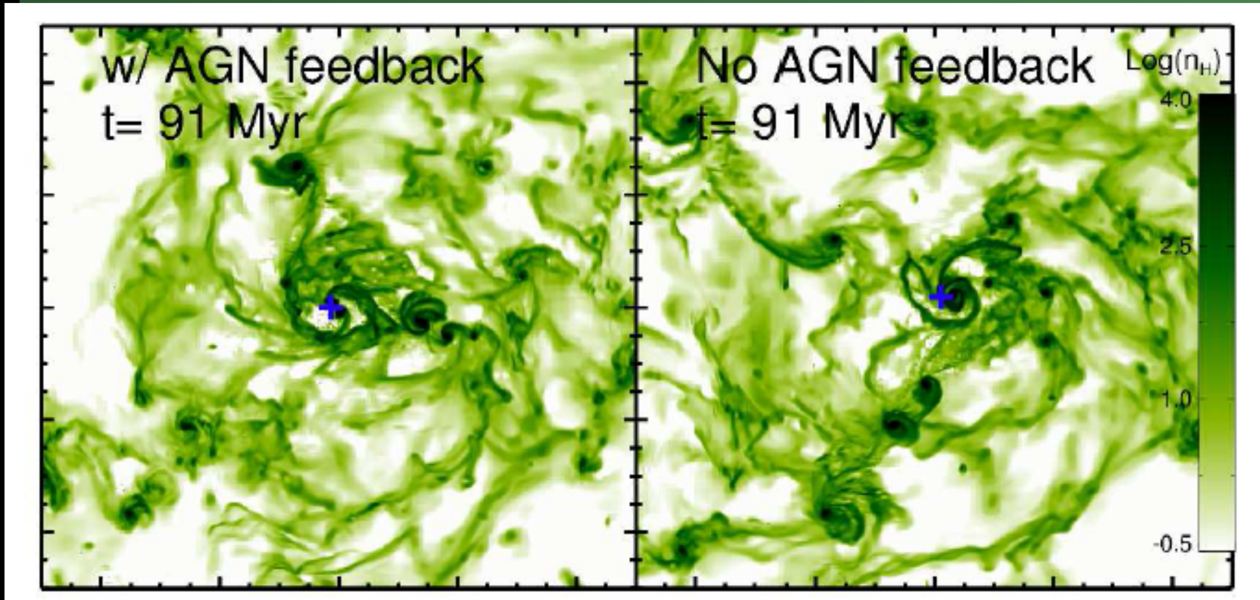
Outflows: Science with the TMT

- Observe at small spatial scales the interaction of the outflows with the ISM

- Identify primary acceleration mechanism (radiation pressure, magnetic fields, or thermal winds)

- Investigate the role of radio jets

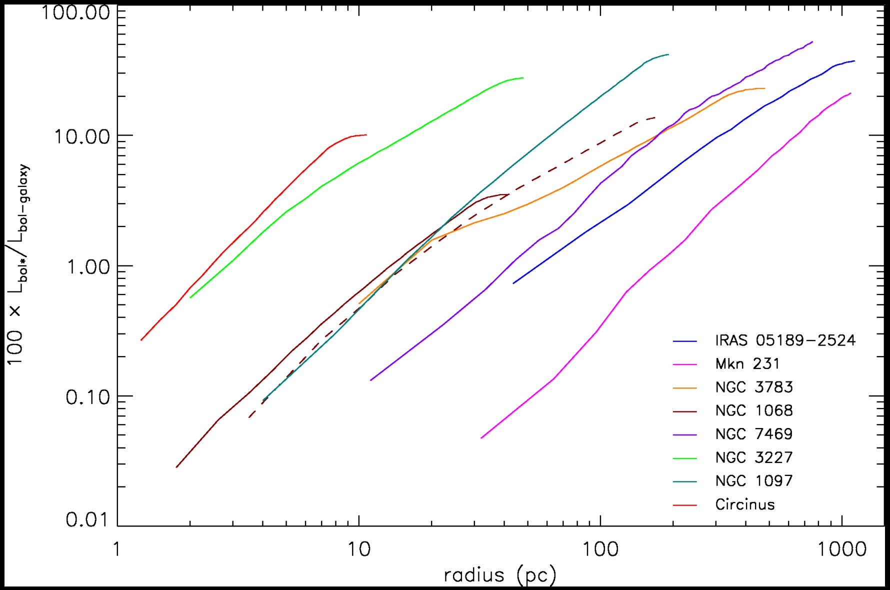
- Estimate the contribution from star formation

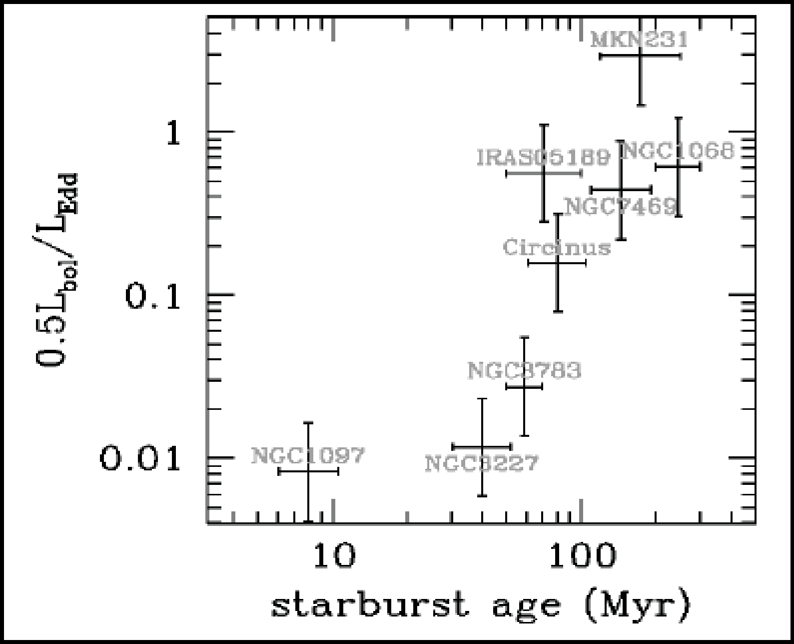


Gabor & Bournaud 2014

Nuclear Star Formation in AGN

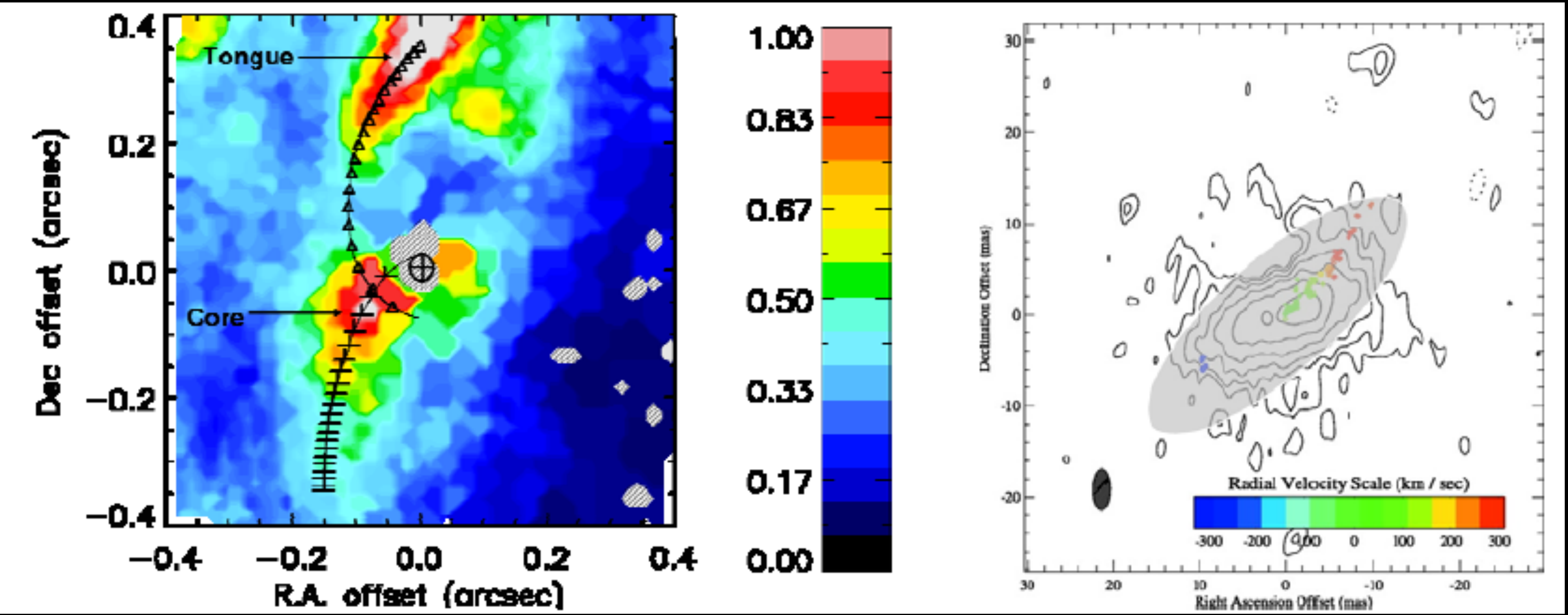
- Recent star formation in nuclear disks of size ~50pc
- Starburst luminosity is a few percent of AGN on scales <10pc, but comparable to AGN on kpc scales
- On small scales, starbursts are very intense & short lived
  - Brγ equivalent width
  - Supernova rate
  - Mass-to-light ratios
- Suggestion of a delay between starburst activity & AGN activity





Davies et al. 2007

The Torus in NGC 1068



Mueller-Sanchez et al. 2009

Obscuration

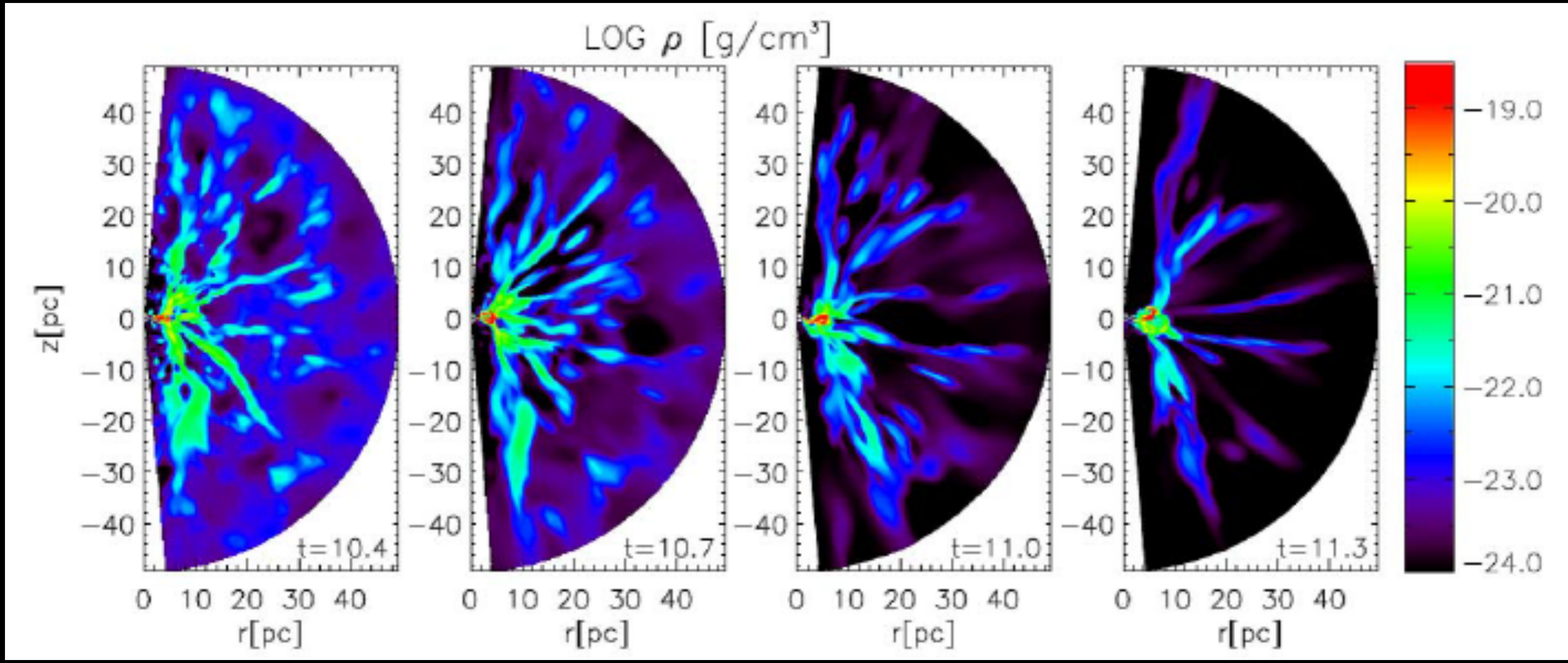
- Molecular gas/dust in front of the nucleus
- Size scale similar to mid-IR observations and models
- PA similar to other components
- Gas is optically thick
- Clumpy medium

Torus models

- Fritz et al. (06): 17pc
- Schartmann et al. (05): 5pc radius (70pc outer)
- Hoenig et al. (06): 17pc

Science with the TMT

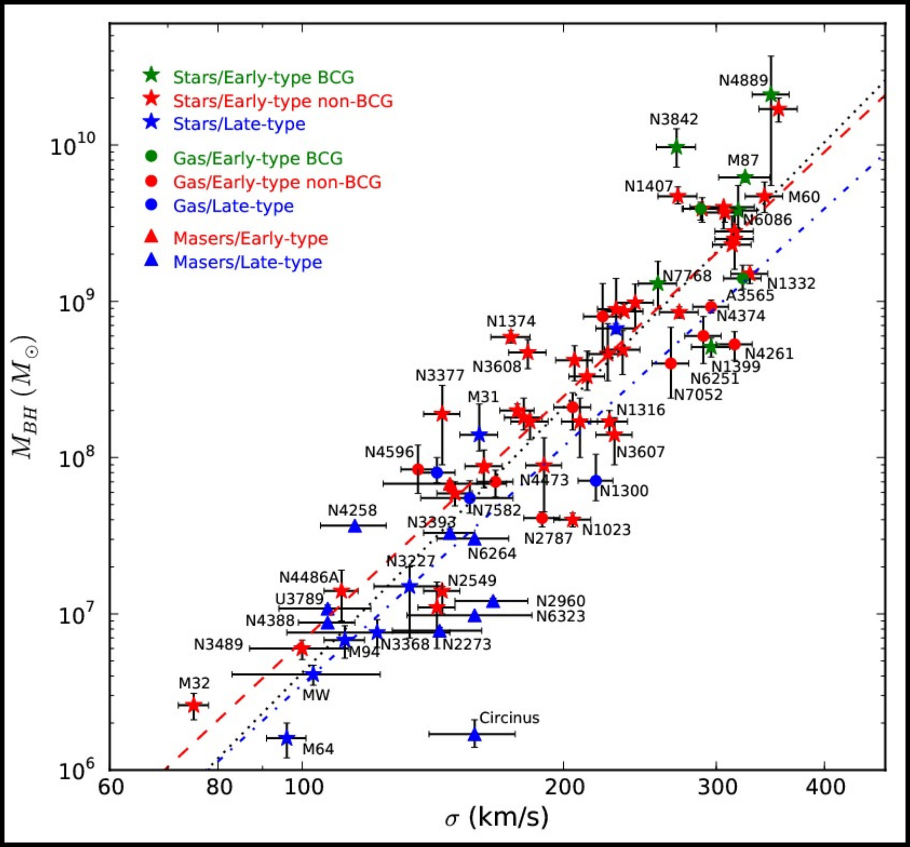
- Resolve the central stellar cluster and, in some cases, separate individual star-forming regions in the central 0.5-5 pc. Apply spectral synthesis models to infer the age and properties of the stars.
- Obtain for the first time an image of the molecular torus. Does it have substructure: a larger scale diffuse part and a small scale dense turbulent disk?
- Impact of stellar evolution on the feeding of AGN



Schartmann et al. 2005

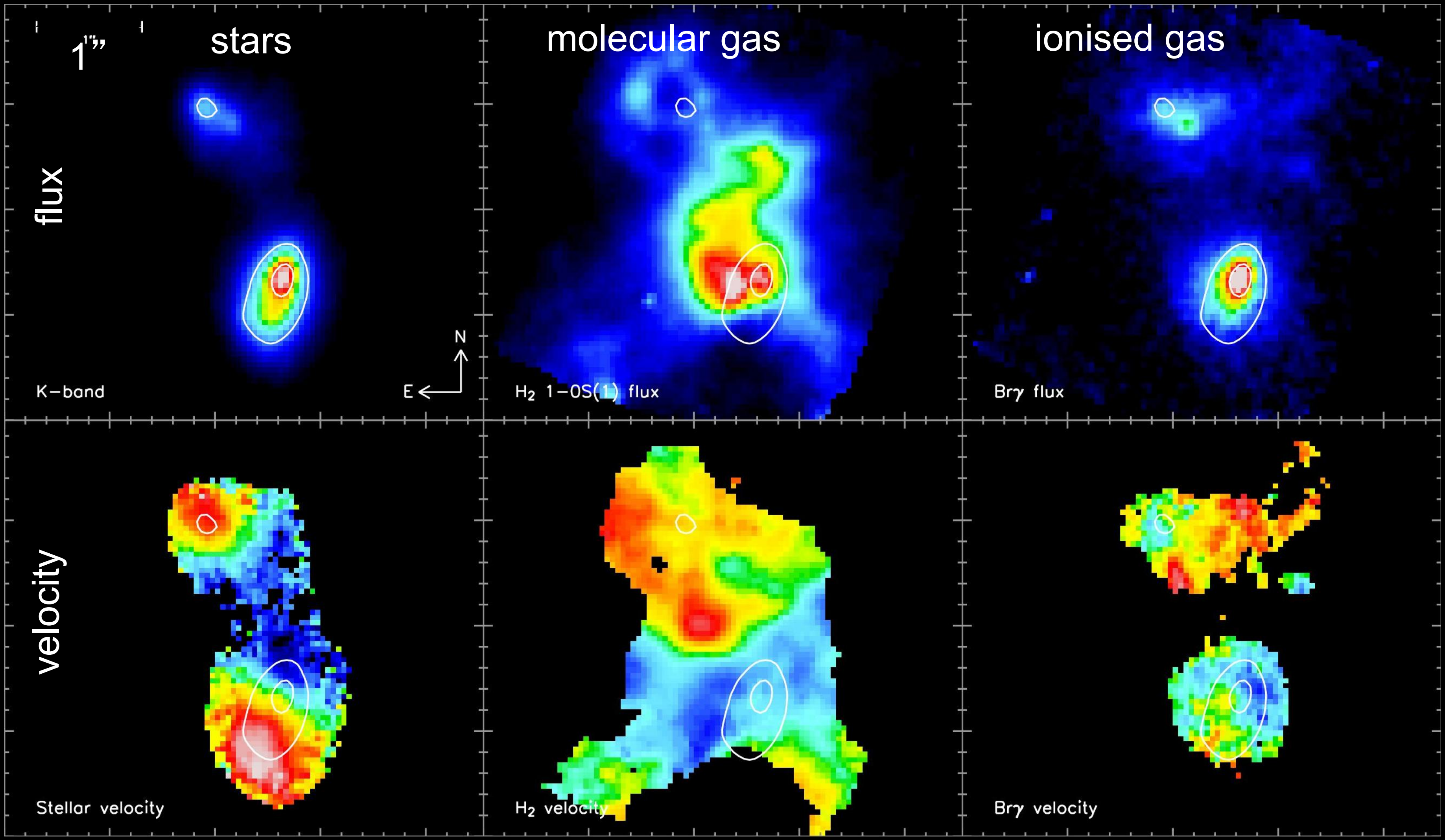
Black Hole Masses

TMT will be able to resolve the radius of influence of the black hole in a typical Seyfert galaxy harbouring a MBH~10^7 Msun out to a distance of ~50Mpc



McConell & Ma 2013

Examples of LGS-AO: prototypical merger NGC6240



Future Prospects

- Large survey of nearby AGN (KONA survey)
- Simpler and more efficient dynamical models (BH masses)
- New and exciting science (BLR, binary SMBHs, …)