The Role of Environment in Fueling Seyfert AGN

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* Support from NSF AAG under award AST-1008042.

Goal: Trace inflow mechanisms on scales of 1kpc down to tens of parsecs.

Potential Seyfert AGN fueling mechanisms:

i. Major mergers

ii. Minor mergers

iii. Accretion of gas streamers

vi. Secular evolution

Several studies suggest *not* major mergers:

- **Over 50% of z~2 AGN in undisturbed host galaxies (Koceviski et al. 2012)**
- **AGN at z~2 *not* in galaxies with enhanced star formation (Rosario et al. 2013)**

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Potential Seyfert AGN fueling mechanisms:

i. Major mergers

ii. Minor mergers

- **Minor mergers may be associated with low and intermediate luminosity AGN (Neistein & Netzer 2014)**
- **Number required to account for dust in early type galaxies is 250 times greater than predicted (Simões Lopes et al 2007, Martini et al 2013)**

iii. Accretion of gas streamers

vi. Secular evolution

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Potential Seyfert AGN fueling mechanisms:

i. Major mergers

ii. Minor mergers

iii. Accretion of gas streamers

vi. Secular evolution

We focus on these using circumnuclear H_2 kinematics

Detailed Kinematics Required

- ✧ Imaging studies cannot differentiate between the relative roles of minor mergers, gas accretion (due to interactions or streamers), and secular evolution
- ✧ Detailed studies of the kinematics are needed
- ✧ Also need to look at spatial scales with relevant timescales:

✓ AGN duty cycle is 100 Myrs with flickering on scales of **1-10 Myrs** (e.g. Hickox et al. 2014)

✓ At r=100pc *v*=100-150 km s^{-1} (Hicks et al. 2013)

→ Dynamical timescale of **2-3 Myrs**, comparable to duty cycle

With local galaxies we can probe the central few hundred parsecs at the resolution needed to accurately measure the *nuclear gas and stellar kinematics*

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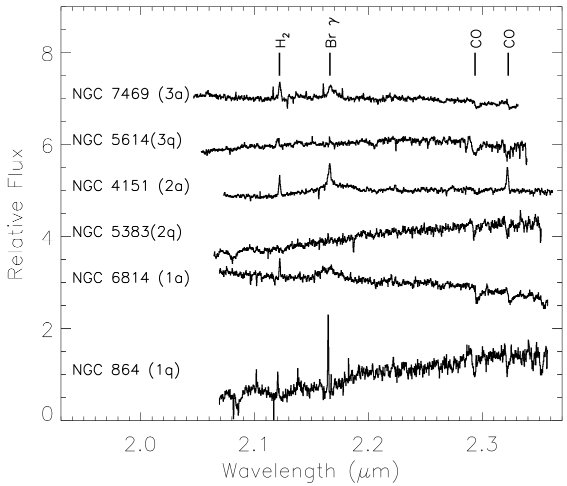
Matched Sample: Seyfert & Quiescent Galaxies

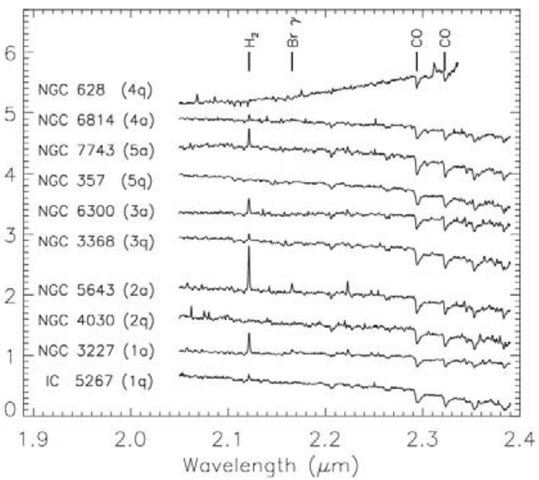
Galaxy pairs (from Martini et al. 2003) matched in large scale (>kpc) host galaxy properties:

galaxy type, optical luminosity, angular size, inclination, and distance

VLT SINFONI: 5 pairs <PSF FWHM>=58±25 pc

Keck OSIRIS: 3 pairs <PSF FWHM>=23±16 pc





Summary of Observations

	ID	Galaxy	PSF FWHM (pc)
SINFONI	1a	NGC 3227	56
Hicks et al. 2013 & Daives et al. 2014	1q	IC 5267	90
	2a	NGC 5643	40
	2q	NGC 4030	87
	3a	NGC 6300	40
	3q	NGC 3368	30
	4a	NGC 6814	57
	4q	NGC 628	28
	5a	NGC 7743	50
	5q	NGC 357	97
OSIRIS	1a	NGC 6814	18
extended high resolution sample	1q	NGC 864	12
	2a	NGC 4151	8
	2q	NGC 5383	32
	3a	NGC 7469	35
	3q	NGC 5614	47
	4a	NGC 3227	6
	4q	NGC 2406	--
	5a	NGC 4593	--
	5q	NGC 5614	--

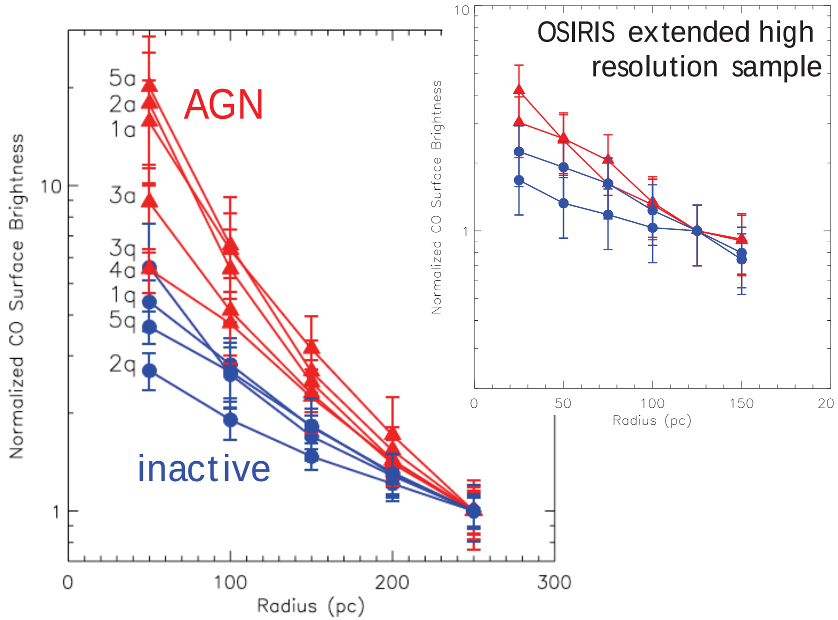
Comparison of Integrated Properties

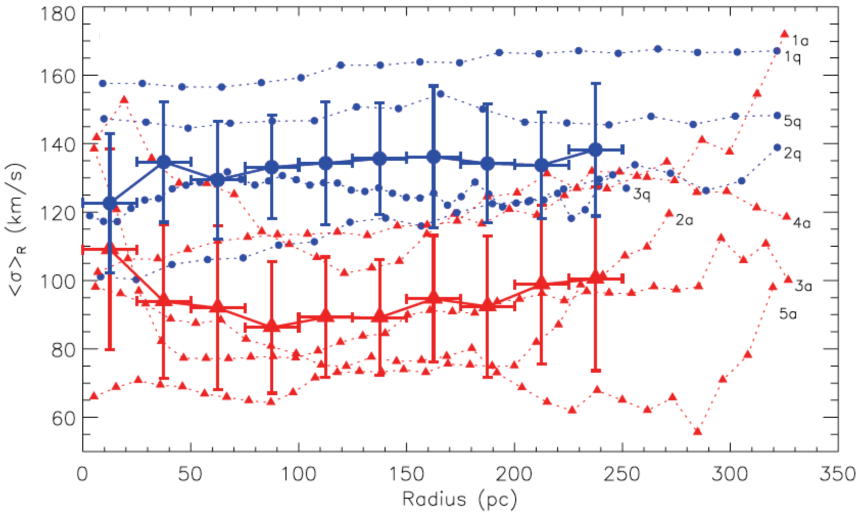
Seyferts systematically have:

(1) a more centrally concentrated nuclear stellar surface brightness

(2) a lower central stellar velocity dispersion

(r < 200 pc)





Stars traced by CO 2.3μm bandheads

Hicks et al. 2013

Comparison of Integrated Properties

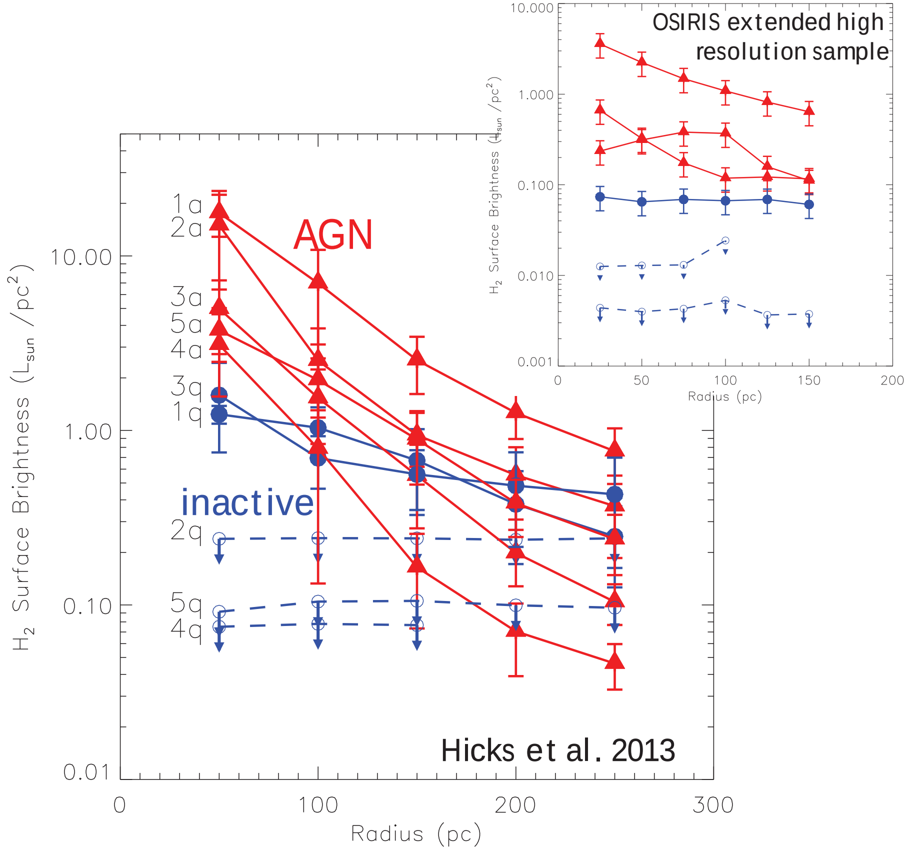
Seyferts systematically have:

(1) a more centrally concentrated nuclear stellar surface brightness

(2) a lower central stellar velocity dispersion (r < 200 pc)

(3) more centrally concentrated H_2 surface brightness profiles

(4) elevated central H_2 1-0 S(1) luminosity (r < 250 pc)



Molecular gas traced by H_2 1-0 S(1)

Comparison of Integrated Properties

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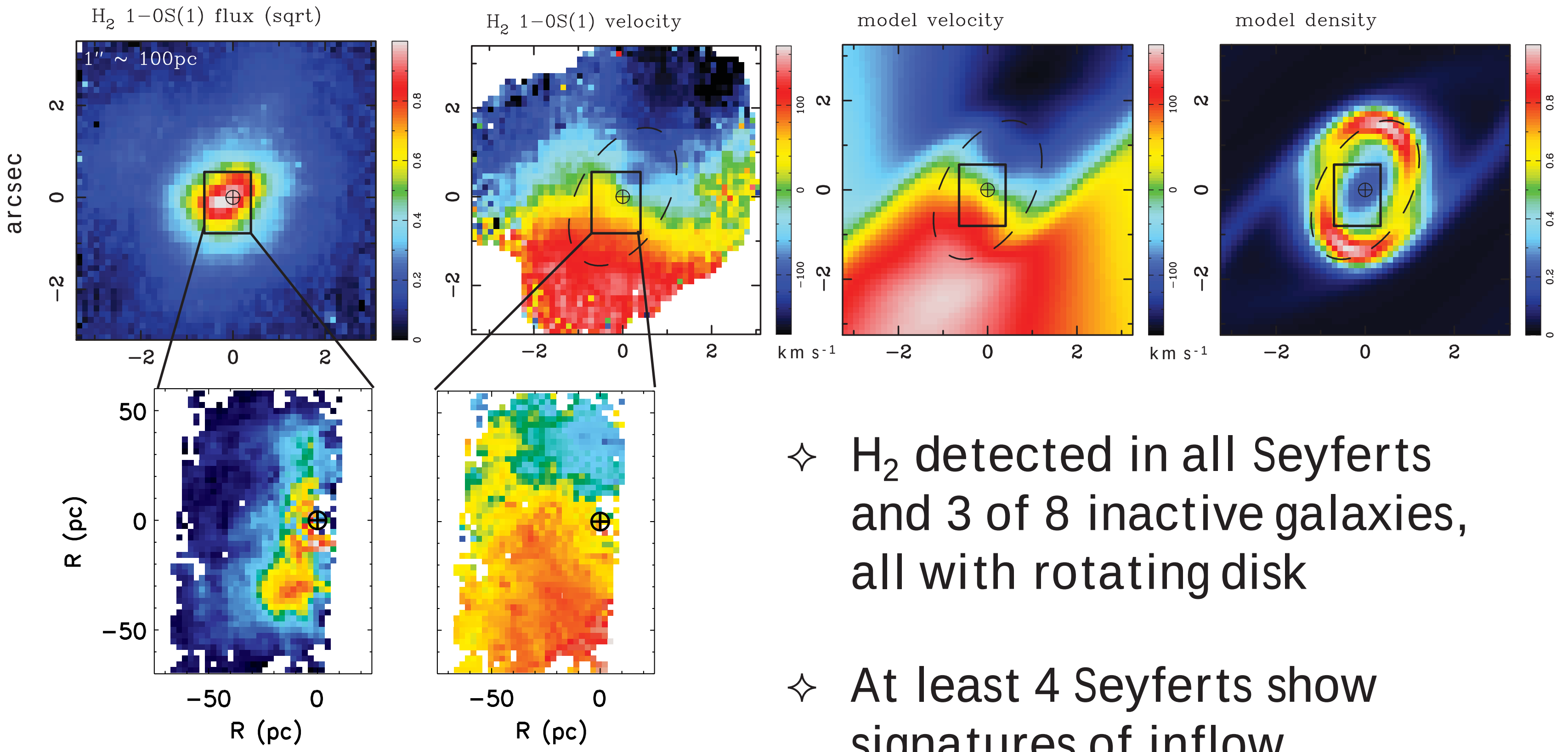
- dynamically cold (in comparison to the bulge) component of gas and stars on scales of hundreds of parsecs *in Seyferts*
- significant gas reservoir and a relatively young stellar population
- nuclear stellar population requires a supply of gas from which to form
  → inflow required

Hicks et al. 2013

Kinematic Analysis: Inflows

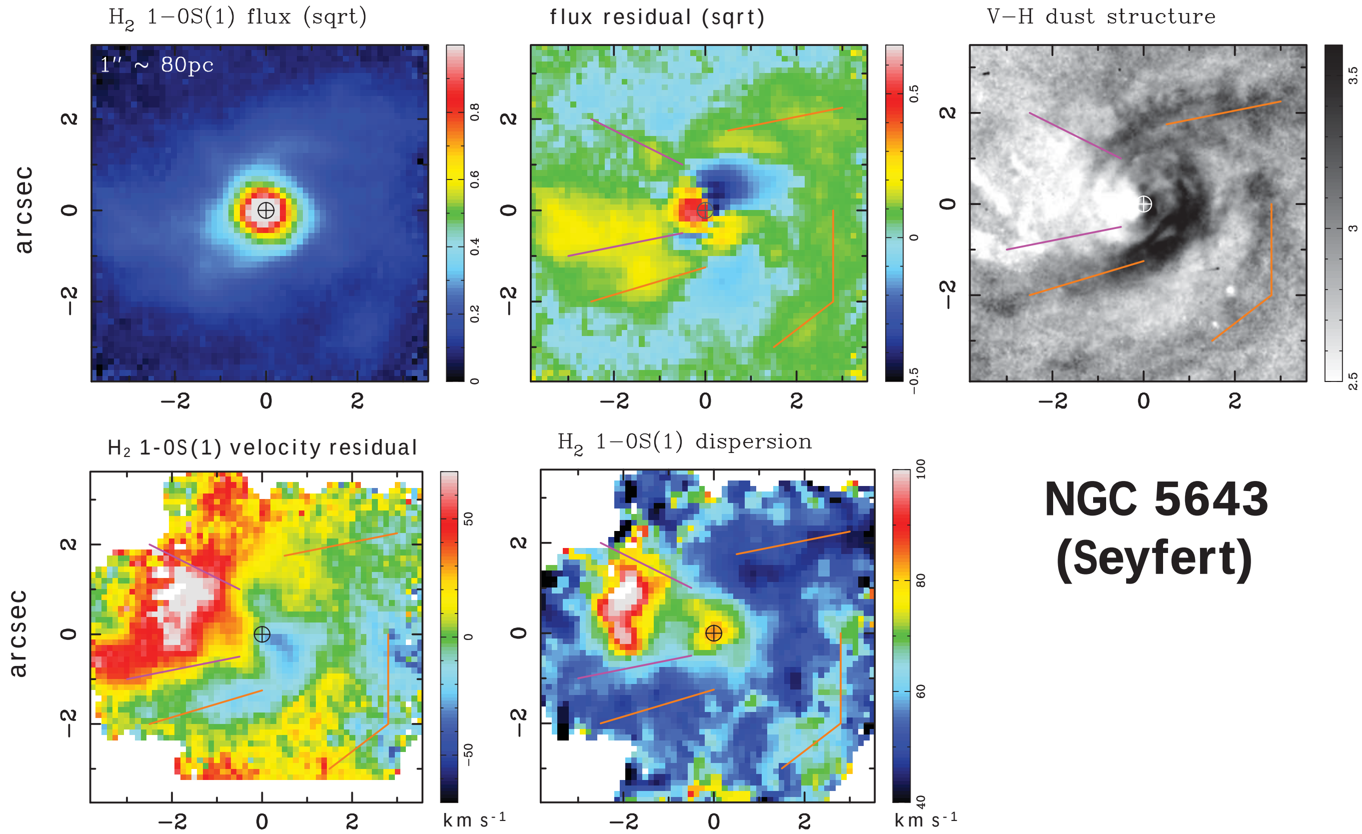


hydrodynamical models qualitatively verify that for **NGC 3227** there is **inflow in a bar** that settles in a nuclear ring

- H_2 detected in all Seyferts and 3 of 8 inactive galaxies, all with rotating disk
- At least 4 Seyferts show signatures of inflow
- Inflow along large scale bars in at least 2 Seyferts

Kinematic Analysis: Outflows

- At least 4 Seyferts have spatially resolved molecular outflows (+1 with indirect evidence)

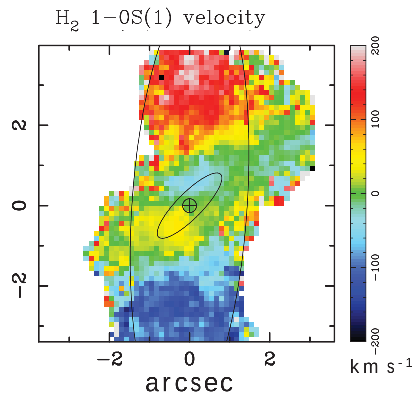


NGC 5643 (Seyfert)

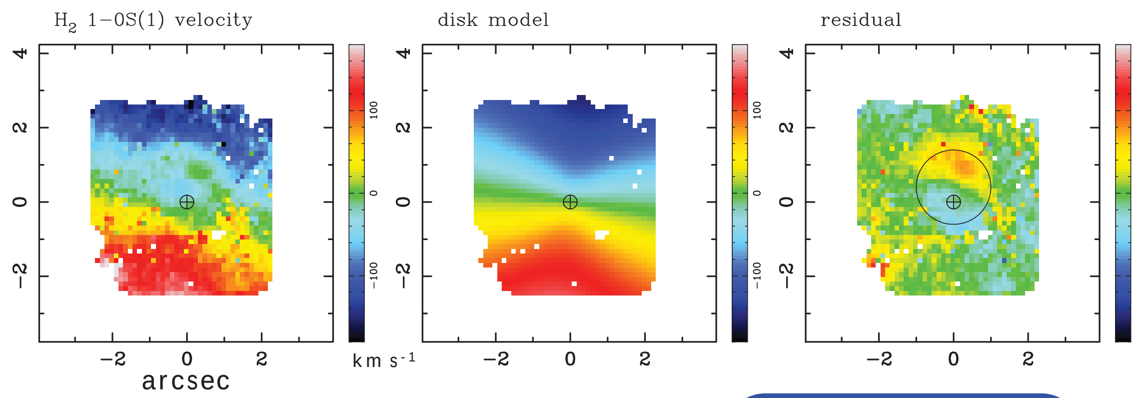
Inactive Galaxies: Counter Rotation

- Two inactive galaxies with H_2 detected have counter rotating molecular components

IC 5267



NGC 3368

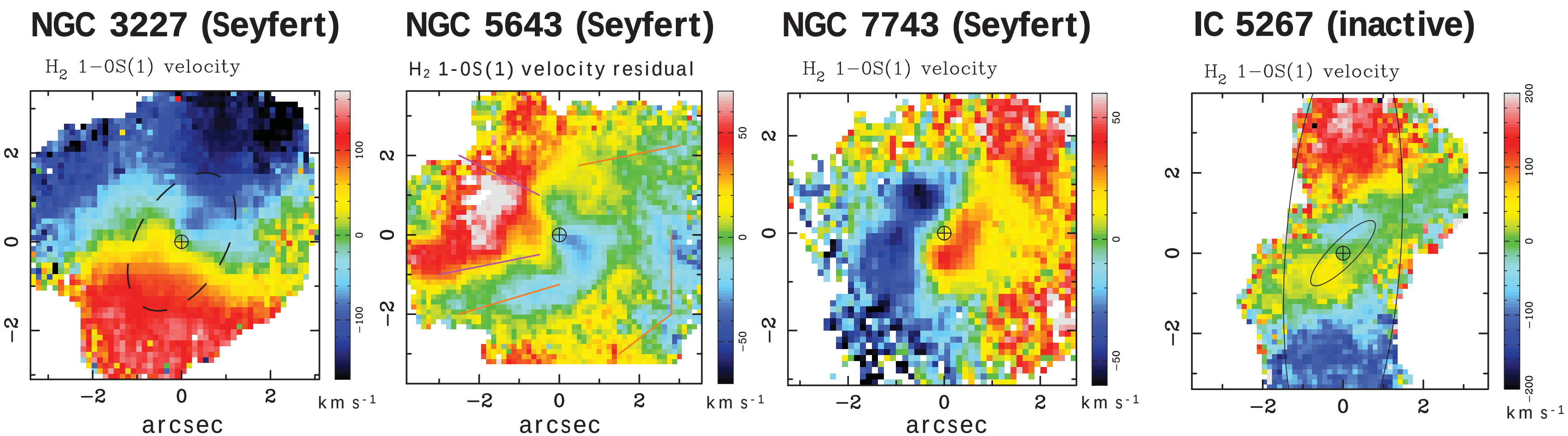


- Implies external accretion of molecular gas

AGN in an off state?

- configurations are quasi-stable → a small perturbation would likely result in significant gas inflow

Rotating Stellar Disks and Complex Molecular Gas Kinematics

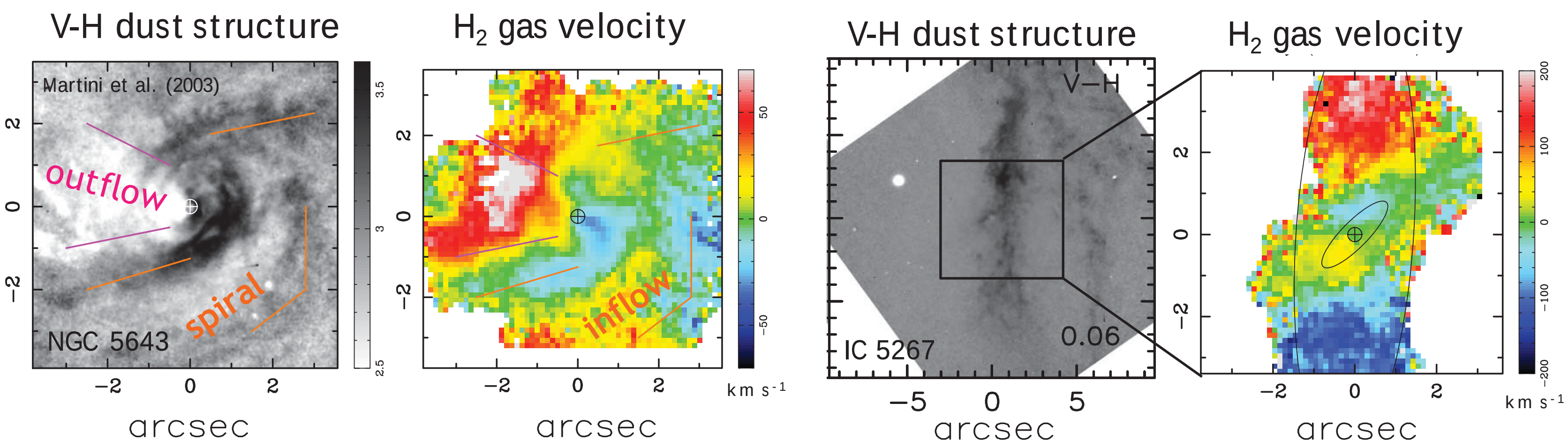


Sample of 16 galaxies with matched host galaxies:

8 Seyfert &
8 inactive galaxies

	Seyferts (8)	Inactive (8)
stellar disk unperturbed	all 8	all 8
H_2 detection	all 8	3
rotating disk	all 8	all 3
inflow	at least 4	
outflow	at least 4	
perturbed		2

Linking Small Scales with Environment



- All undisturbed galaxies without circumnuclear molecular disks are inactive.
- Isolated or otherwise undisturbed AGN have circumnuclear molecular disks and dust structures classified as spirals (and a large scale bar to drive it): *secular inflow*.
  - Seen in *late type* galaxies where the gas supply is plentiful
- Galaxies with chaotic circumnuclear dust structures (which may be superimposed on an H_2 disk) are in groups with ~10-15 members: *external accretion*.
  - Most easily detected in *early type* galaxies lacking their own gas supply

Early versus Late Type Galaxies

External accretion is seen more easily in early-types without a plentiful supply of gas.

Implications: (i) a source for the gas, in the form of a group with 10-15 members
(ii) paucity of gas in inactive galaxies vs presence of gas in AGN
(iii) gas & stars should sometimes be counter-rotating

Early Type Hosts

Dumas et al. 2007 & Westoby et al. 2012 samples:

11 AGN:	all with gas detections 8 also with stellar rotation: 5 co-rotating gas 3 counter-rotating gas
6 inactive:	gas detected in only 2

Secular inflow requires a large scale disk to supply the gas (i.e. late type host).

Implications: (i) presence of gas in both active & inactive galaxies
(ii) gas & stars should always be co-rotating

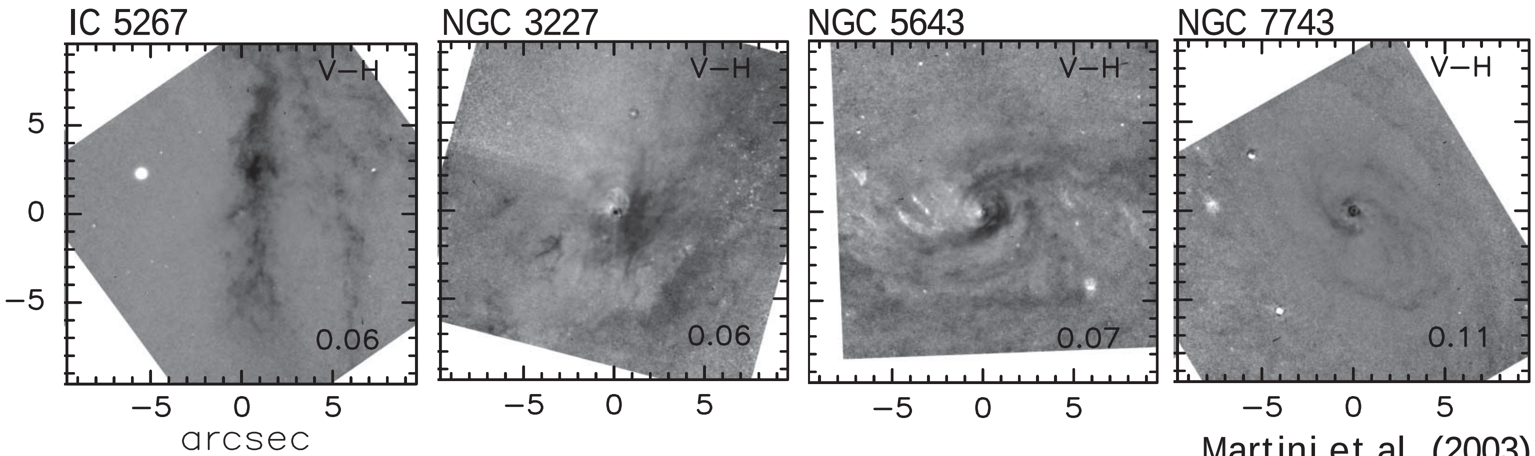
Late Type Hosts

Dumas et al. 2007 & Westoby et al. 2012 samples:

10 AGN:	gas & stars co-rotating in all (some misalignments)
8 inactive:	gas detected in 6, co-rotating with stars

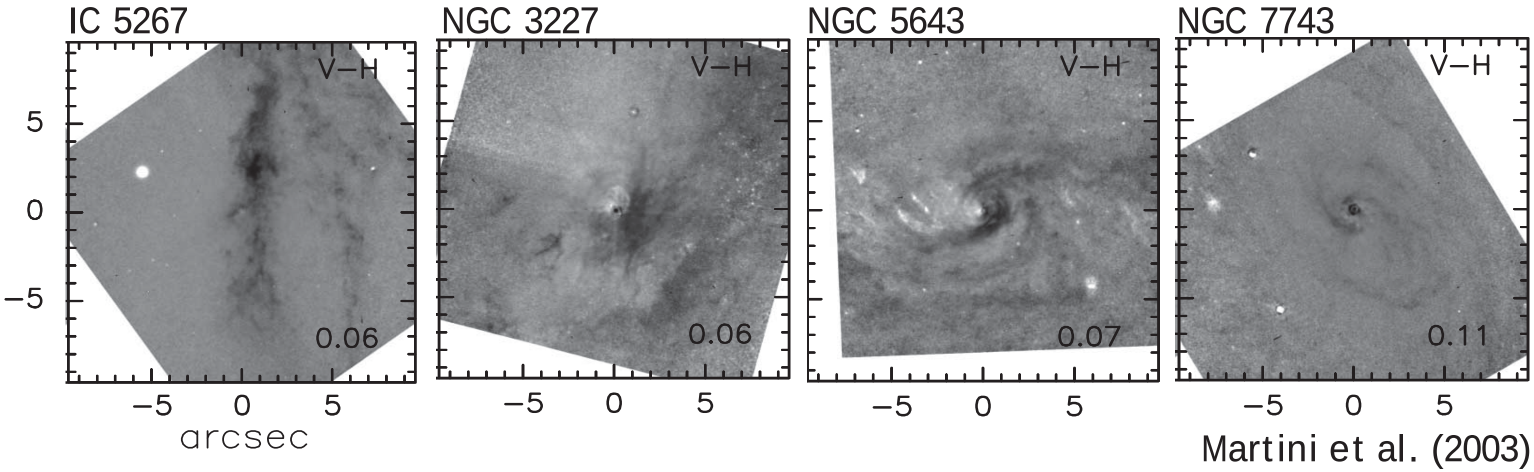
Linking Small Scales with Environment

dust structure	molecular gas	nuclear activity	driver of activity	host type	predicted environment
none	none	none	…	early or late	isolated
spiral	disk rotation	either	secular processes	late type	isolated
chaotic	chaotic (e.g. counter rotating)	either	external accretion	either, but more easily detectable in early type	groups with 10-15 members



Martini et al. (2003)

Probing Kinematics via HST Dust Maps

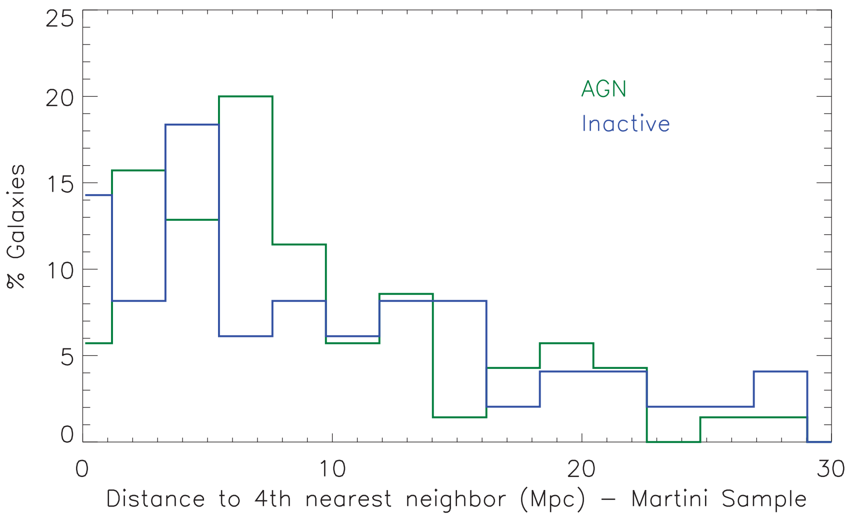


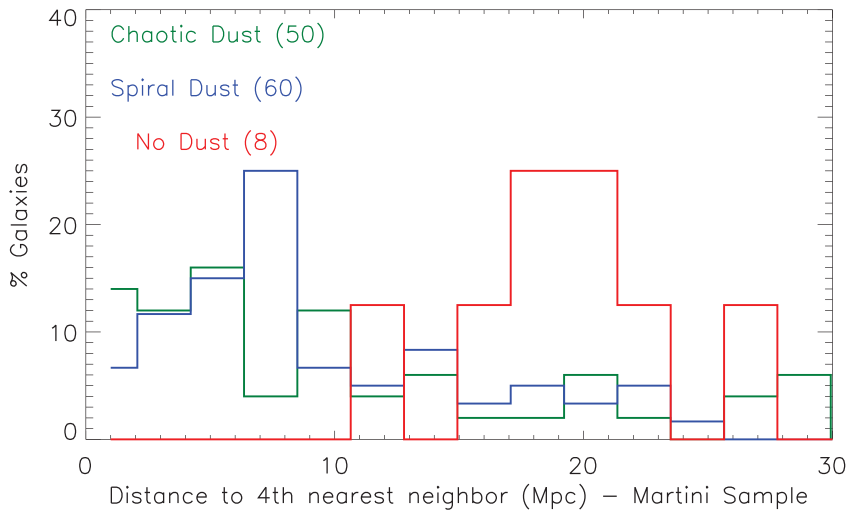
Martini et al. (2003)

- Martini et al. 2003 classified the nuclear dust structures of 123 galaxies imaged with HST
- A subset of these form a matched sample from which little was found to correlate with nuclear activity.
- Hunt & Malkan 2004 did a similar analysis with 250 galaxies imaged with HST and also found little correlated with nuclear activity.

Probing Kinematics via HST Dust Maps

Quantifying environment by determining the distance to the 4^{th} nearest neighbor (e.g. McGee 2013, Peng et al. 2010).





Use a subsample of tracer galaxies from 2MASS Redshift Survey (Huchra et al. 2012) that have $K_S < -24.3$ and a line of sight v±500 km/s from the target galaxy

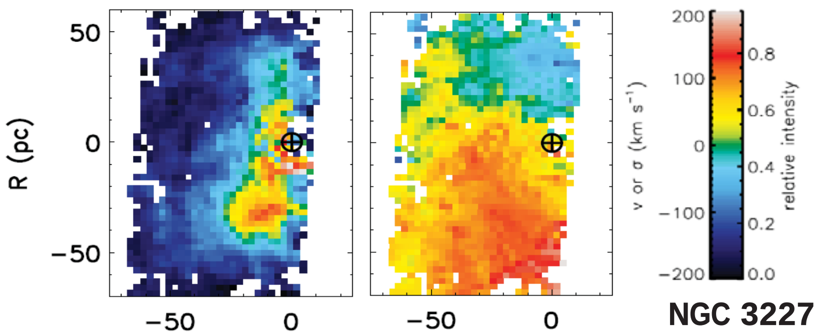
Larger Sample: Improved Statistics

future integral field spectroscopy + AO samples

- Sample of **20 active + 20 inactive** with SINFONI AO (Davies et al. 2015)
  - Volume limited sample of nearby active galaxies selected by their 14–195 keV luminosity
  - Stellar population also characterized using XShooter data
- **KONA** (Keck OSIRIS Nearby AGN) **Survey** (Hicks, Müller Sánchez, Malkan, et al.)
  - Sample of 40 nearby AGN: 21 Seyfert 1s + 19 Seyfert 2s

*** Posters: KONA details at poster S319p.11*
first results at Erickson, P. (DJp2.11), Kade, K. (DJp2.18), Smits, H. (DJp2.23)

HST imaging is available for about half of the galaxies in these two samples and the rest we hope will be obtained in the near future to solidify the correlation of nuclear dust structure with inflow mechanism.



NGC 3227