Where do Seyferts get their Gas?

(and how it affects what we see in the central kiloparsec)

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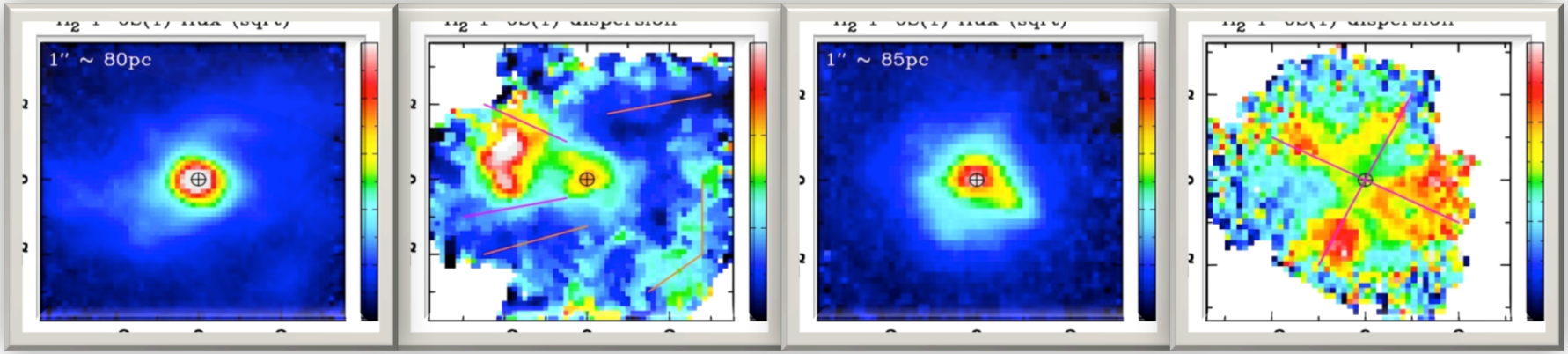
- Molecular Gas Structures: inflow & outflow
- Link to Environment & Host Galaxy Type



NGC 5643 NGC 6300

Where *might* Seyferts get their gas?

i) Major mergers

Increasing consensus that this is not dominant even at z~2, e.g.

- >50% of AGN at z~2 have undisturbed host (Kocevski+ 12)
- AGN at z~2 do not have enhanced star formation (Rosario+ 13)

ii) Minor mergers

- May be associated with low and intermediate luminosity AGN (Neistein & Netzer 14)
- In early type galaxies, may seed dust, which then continues to form in the accreted cold gas over long timescales (Martini+ 13)

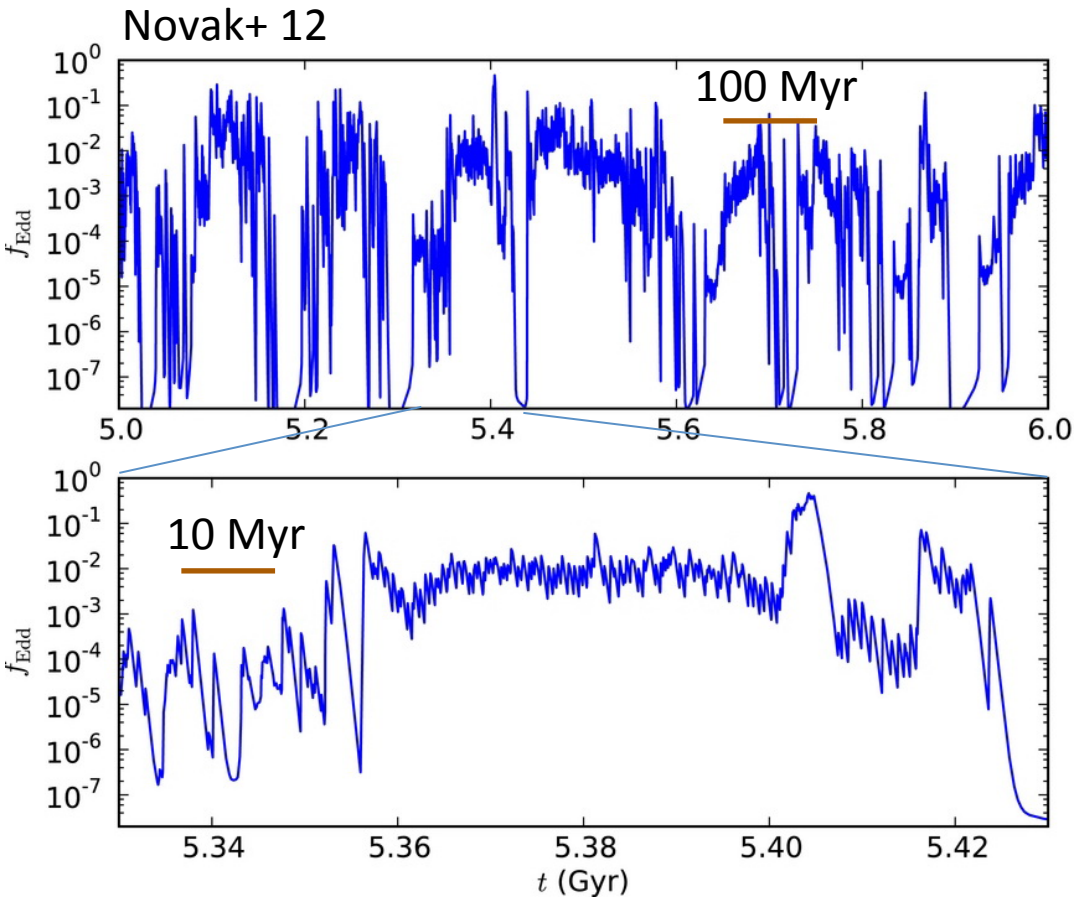
iii) Streamers

iv) Secular Evolution

- Trace impact of these processes in circumnuclear region & on AGN fuelling;
- Focus on H_2 kinematics in nearby AGN;
- Resolve inflow/outflow mechanisms on 10pc-1kpc scales;
- Physically motivate models of feeding & feedback.

Note about timescales

- Galaxy processes operate on long timescales (0.1-1Gyr)
- AGN variability occurs on short timescales (<10Myr)

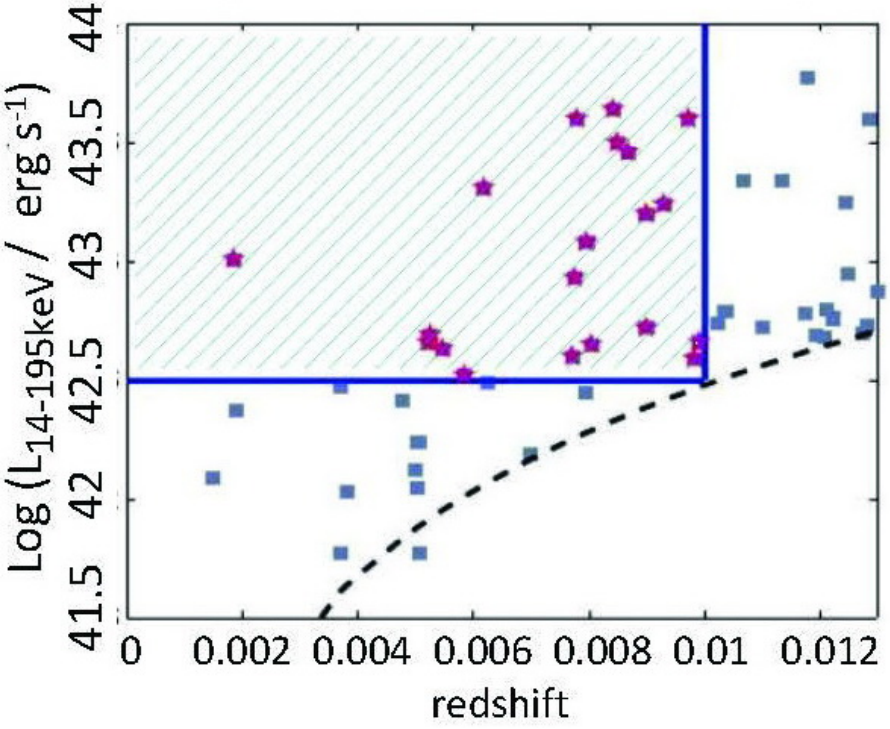


Circumnuclear regions of AGN:

- 100-150 km/s at 100 pc
- t_{dyn} ~ 2-3 Myr

but note also “Green Bean” galaxies (Schirmer+ 13, Keel+ 12)

Robust Statistics from a Complete Sample… coming soon



- Observe local AGN of similar luminosity to those at high redshift
- Swift BAT, 6 years all-sky monitoring:
  - 14-195keV measures direct emission from the AGN
  - least biassed with respect to host galaxy properties
- Complete volume limited sample of *all* such AGN accessible to VLT:
  20 AGN + inactive controls
- By the end of this semester: data on half the sample with SINFONI + XSHOOTER

Results from a matched sample of active & inactive galaxies

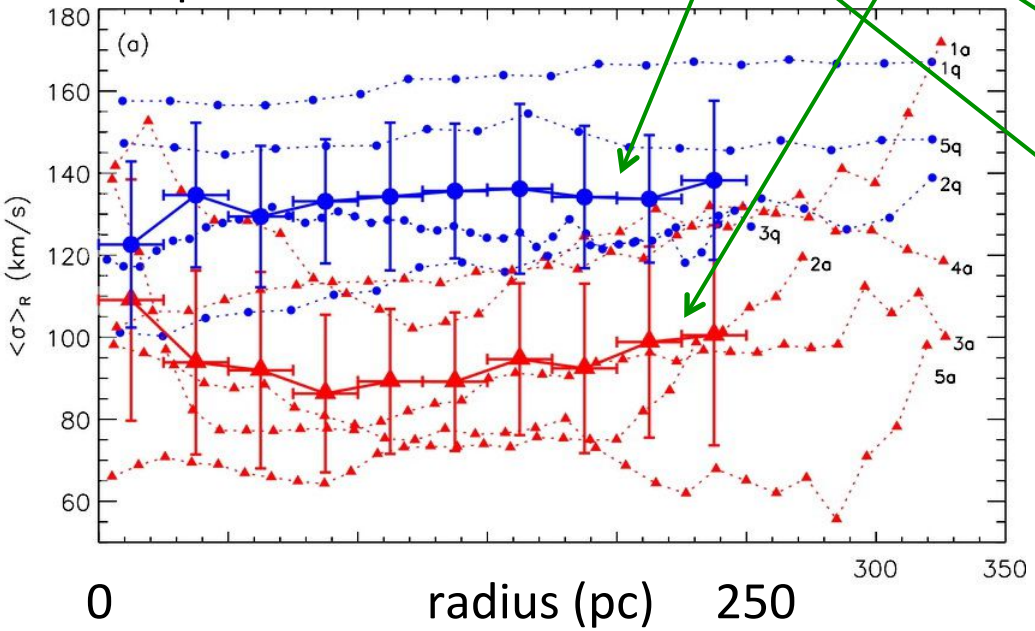
Hicks+ 13

- 5 galaxy pairs matched in large scale (>kpc) host galaxy properties: galaxy type, optical luminosity, angular size, inclination, distance
- VLT SINFONI *K*-band data, probing radii 50-250pc
- Systematic differences

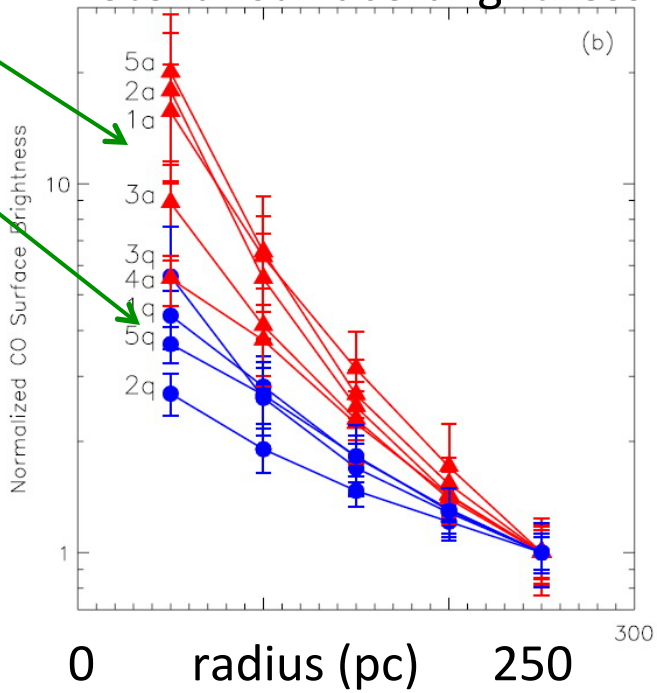
inactive

active

Stellar velocity dispersion



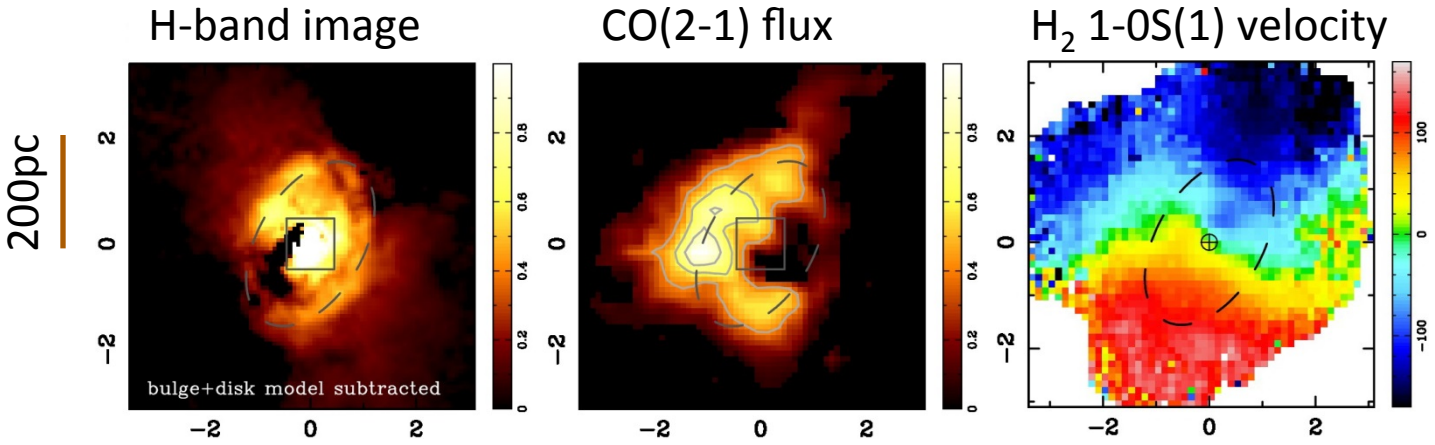
Normalised K–band Stellar surface brightness



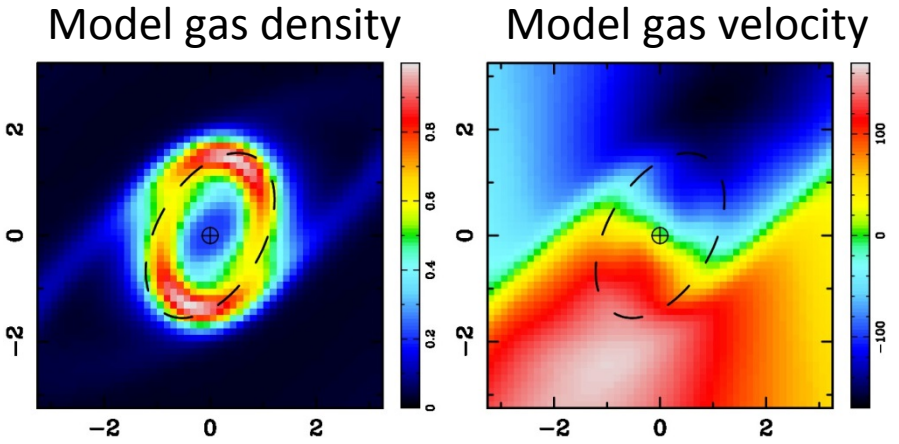
Spatially resolved H_2 kinematics: inflow

NGC 3227

Large scale bar stimulates circumnuclear spiral/ring which drives inflow



- Model S20 from Maciejewski 04
- Bar & host geometry matched to NGC 3227
- Scaling factor applied to spatial scale & velocities



Spatially resolved H_2 kinematics: inflow

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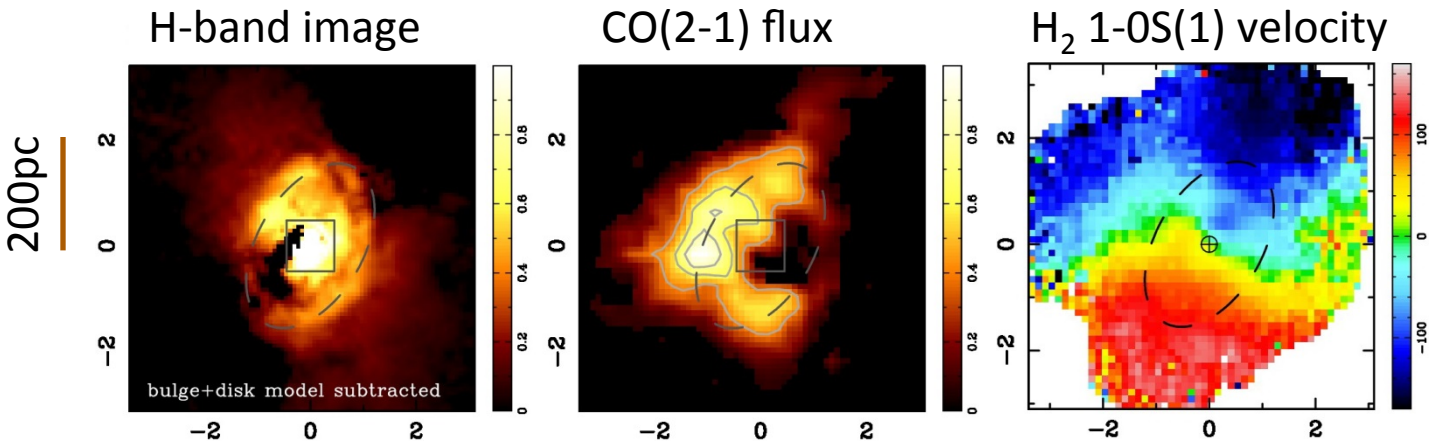
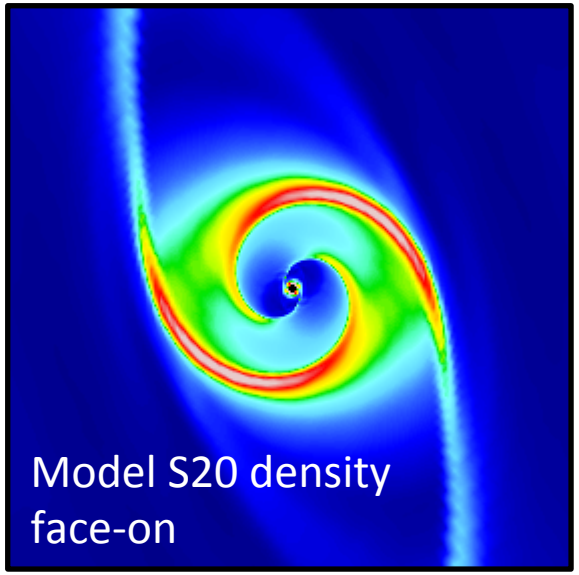
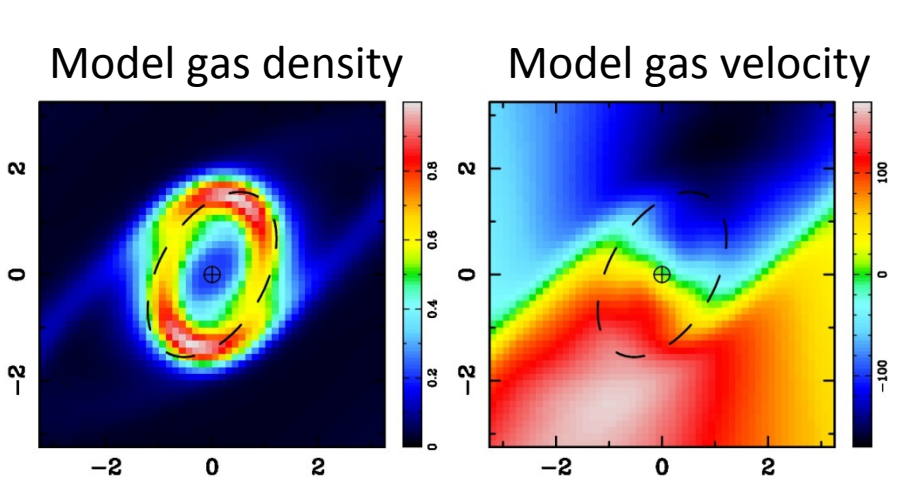


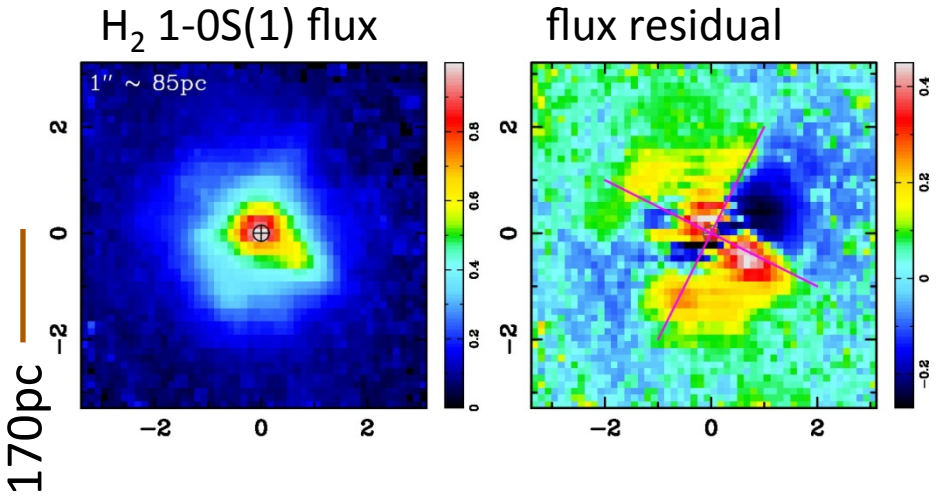




Spatially resolved H_2 kinematics: outflow

NGC 6300

Circumnuclear molecular disk with molecular outflow superimposed



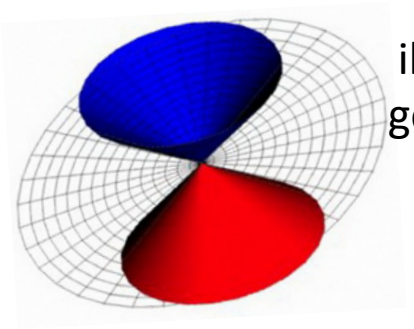
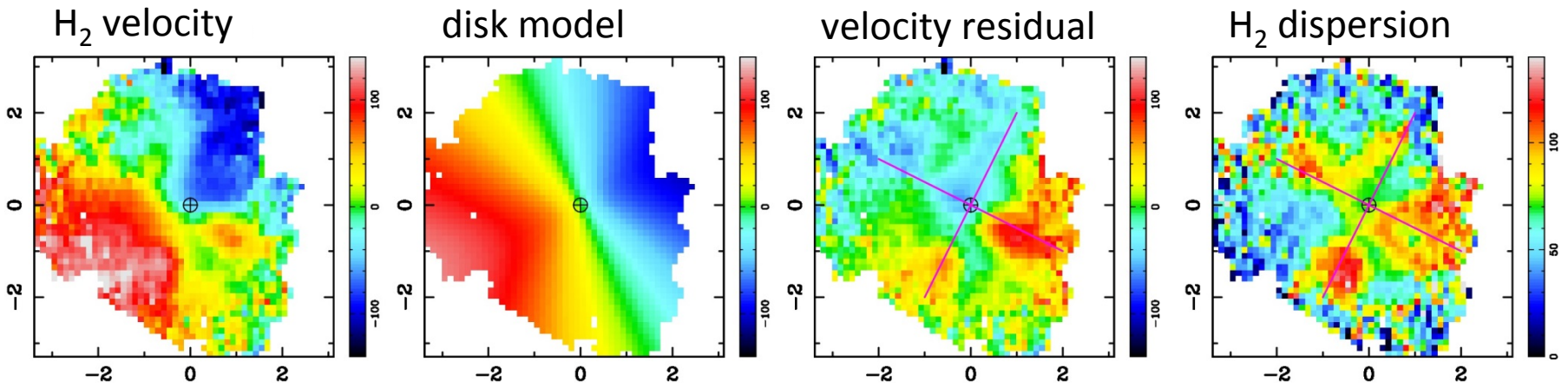


illustration of geometry (not a model)



Spatially Resolved Molecular Outflows

- H_2 outflows seem to occur when **outflow is tilted over** enough that it intersects, or is close to, the disk plane (which is quite common).

- **H_2 outflow speeds ~150 km/s**
  - less than ionised gas (200-2000 km/s): clouds are ablated & ionised, in which form gas is more easily accelerated.
  - less than escape velocity (~1500 km/s): gas will fall back.

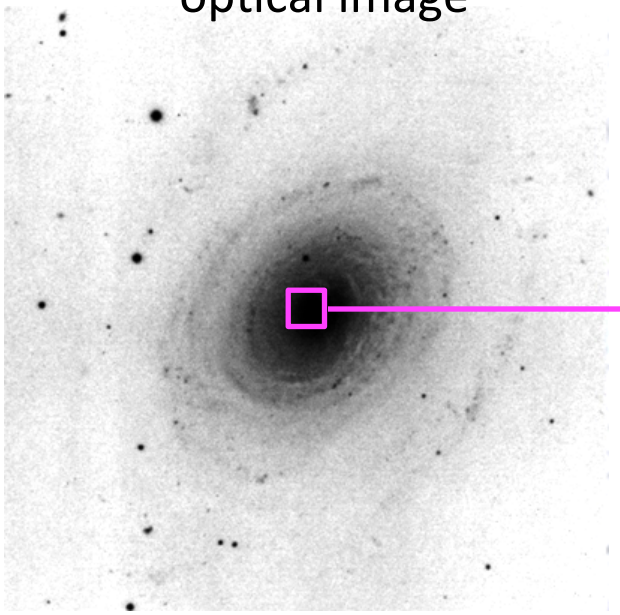
- **H_2 outflow rates of order 10 M_{sun}/yr**
  - could drive 10^7-10^8 M_{sun} outwards in 1-10 Myr; can affect circumnuclear region, but not global host properties.

Spatially resolved H_2 kinematics: external accretion

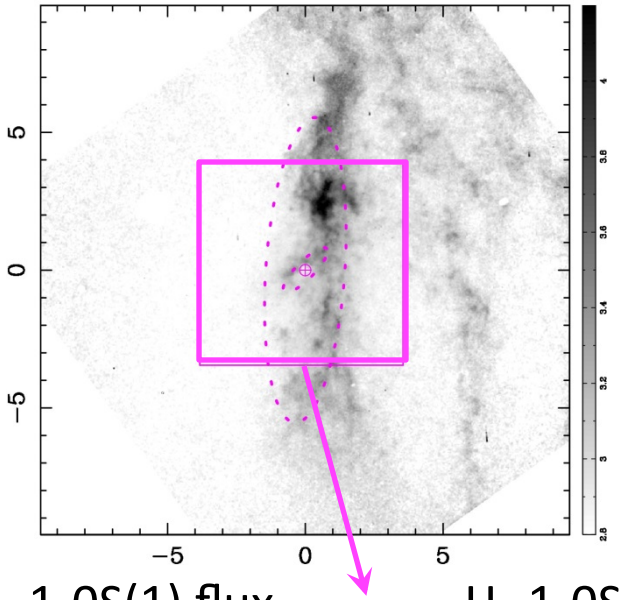
IC 5267

Complex dust structures; counter-rotating molecular disks/rings

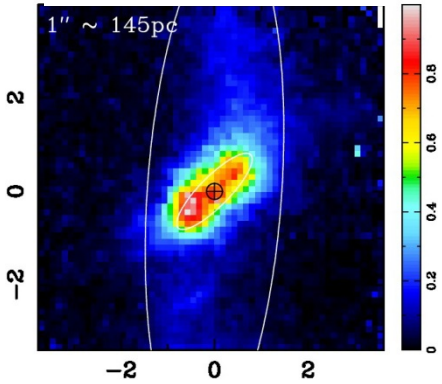
optical image



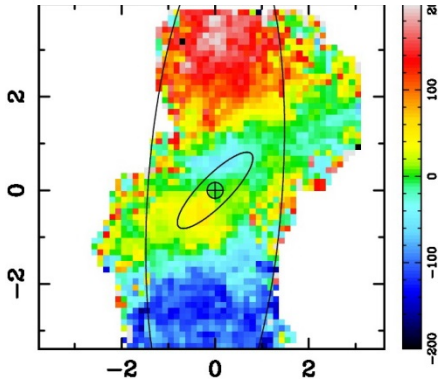
V-H dust structure



H_2 1-0S(1) flux



H_2 1-0S(1) velocity



- Inner H_2 structure:
  Same orientation as host
- Vertical dust/H_2 structure:
  Ring extending from 300-800pc

Linking small scales and (very) large scales

From our sample of 10 active & inactive galaxies:

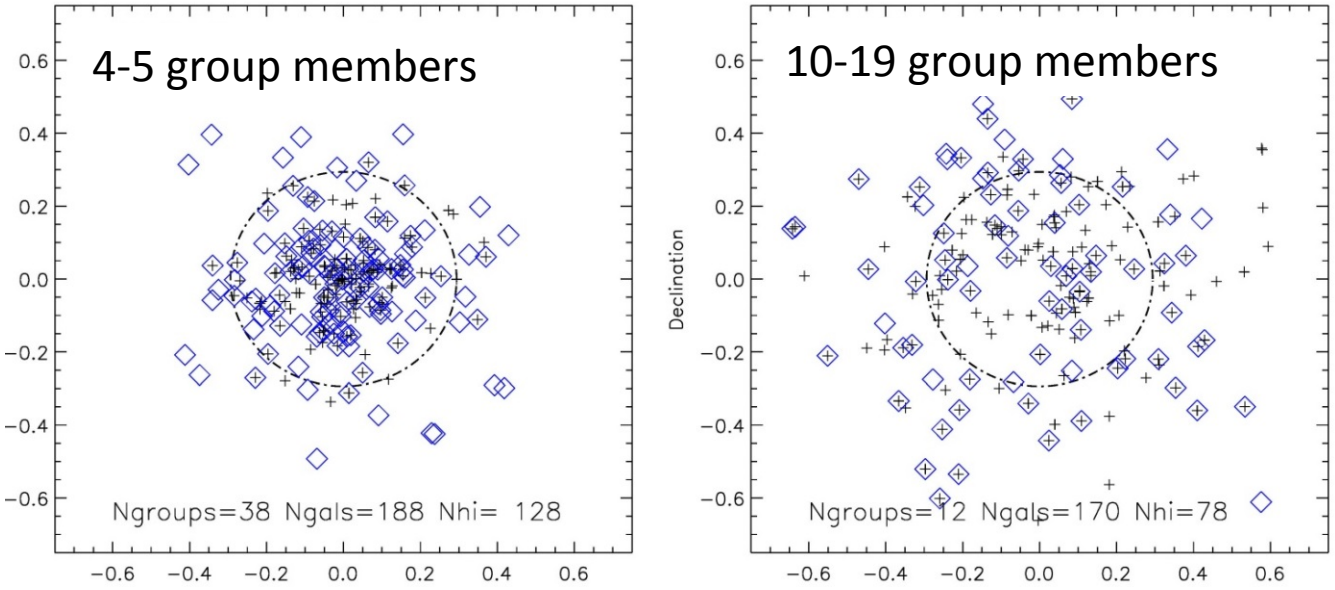
- All 3 undisturbed galaxies without circumnuclear molecular disks are inactive.
- All 3 undisturbed AGN have circumnuclear molecular disks and dust structures classed as spirals (and a large scale bar to drive it): ***secular inflow***.
- All 4 galaxies with chaotic circumnuclear dust structures (which may be super-imposed on an H_2 disk) are in groups with ~10-15 members: ***external accretion***.

SUMMARY OF H_2 PHENOMENA, DUST STRUCTURES, AND ENVIRONMENT

	Galaxy	rotating disk	dust[a]	environment[b]
active	NGC 3227	X	C	group of 13–14
	NGC 5643	X	GD	isolated
	NGC 6300	X	C	undisturbed, group of 9
	NGC 6814	X	GD	isolated
	NGC 7743	X	LW	undisturbed
inactive	IC 5267	X	C	group of 11–14
	NGC 4030		TW	undisturbed; group of 4?
	NGC 3368	X	CS	group of 9–14
	NGC 628		N	undisturbed; group of 7?
	NGC 357		N	undisturbed; group of 6?

The HI view of group environment

Hess & Wilcots 13 Location & fraction of galaxies & HI sources in groups.



- HI mass function is flatter in groups (Kilborne+ 09)
- As group membership increases, the fraction of galaxies with HI decreases and these tend to be less centrally concentrated (Hess & Wilcots 13)
- Galaxies falling into groups experience impact of dense environment for first time: 'pre-processing' via interactions tidally strips gas into IGM (Wilcots 09)

Two modes of inflow fueling AGN

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

It implies (i) presence of gas in both active & inactive galaxies

(ii) gas & stars should always be co-rotating

Late type hosts

Dumas+ 07 & Westoby+ 12 samples:
10 AGN: gas & stars co-rotating in all (some misalignments to 55°)

8 controls: gas detected in 6, co-rotating with stars

Two modes of inflow fueling AGN

External accretion (minor mergers or streamers) is seen more easily, and has more impact, in early-types without a plentiful supply of gas.

It implies (i) a source for the gas, e.g. 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+ 07 & Westoby+ 12 samples:

11 AGN: all with gas detections

8 also with stellar rotation: 5 co-rotating gas

3 counter-rotating gas

6 controls: gas detected in only 2

Conclusions from local Seyferts

Molecular Inflows

- **2 modes of fueling**: secular evolution & external accretion
- We see **kinematic evidence for external accretion** in 2 galaxies.
- Link between **circumnuclear structures & *environment*** (supported by HI studies): external accretion happens in groups with 10-15 members.
- Link between **circumnuclear structures & *host type***: external accretion is more easily seen in early type galaxies without their own gas; secular inflow dominates in late types with a plentiful supply of gas.

Molecular Outflows

- Can occur in disk galaxies, if the **outflow is tilted** and intersects the disk plane.
- Outflow speeds & rates are modest: **gas cannot escape and will fall back**.