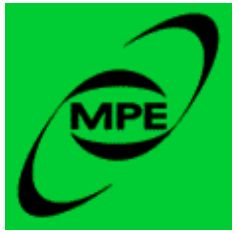
Nuclear Star Formation, The Torus, & Gas Inflow in Seyfert Galaxies



Richard Davies[1],

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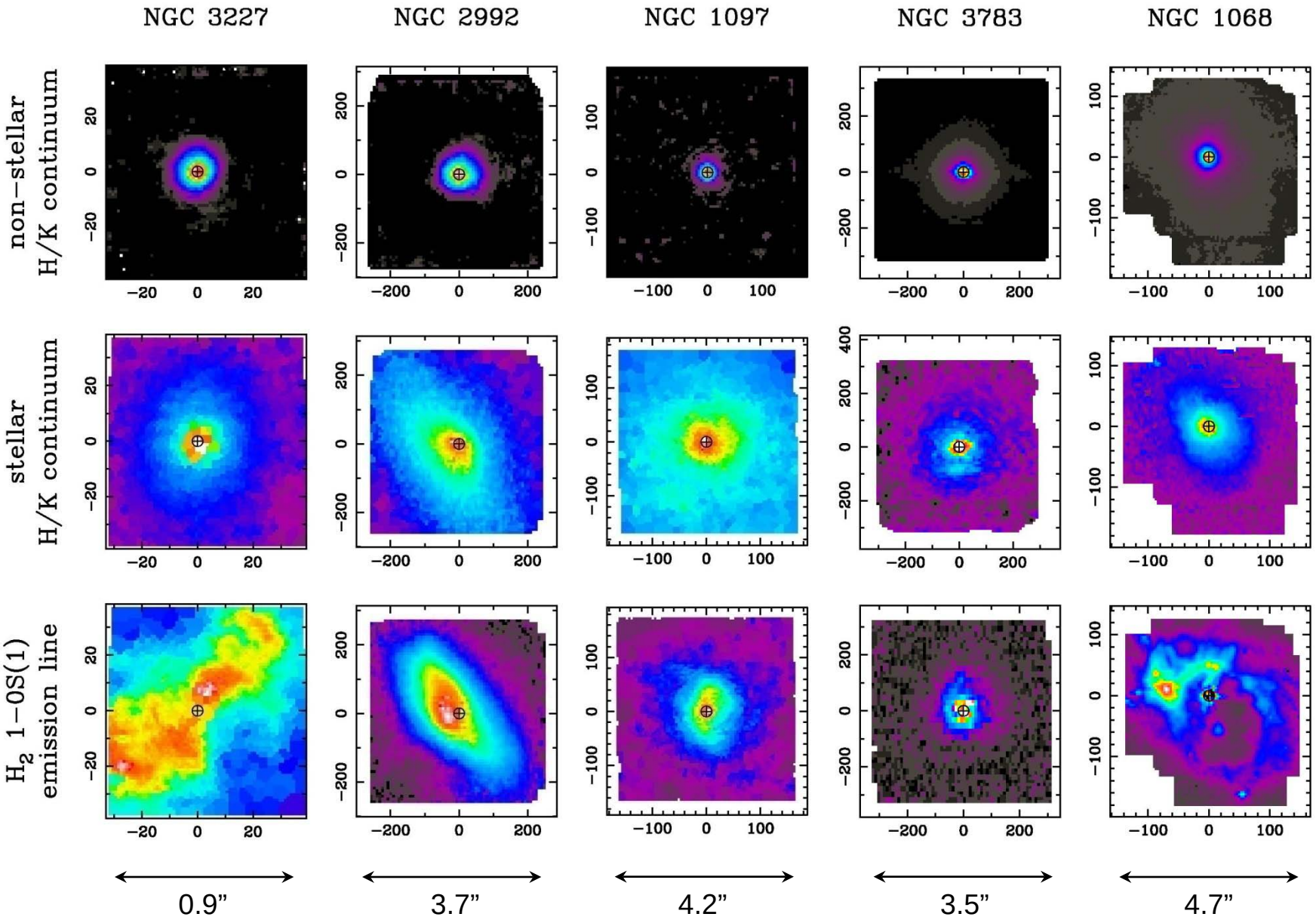
- Are there NSCs around nearby AGN?
- How does gas get from 1kpc to central 10s of pc?
- Is the gas creating these starbursts related to the torus?
- What is the impact of the starburst on the AGN?

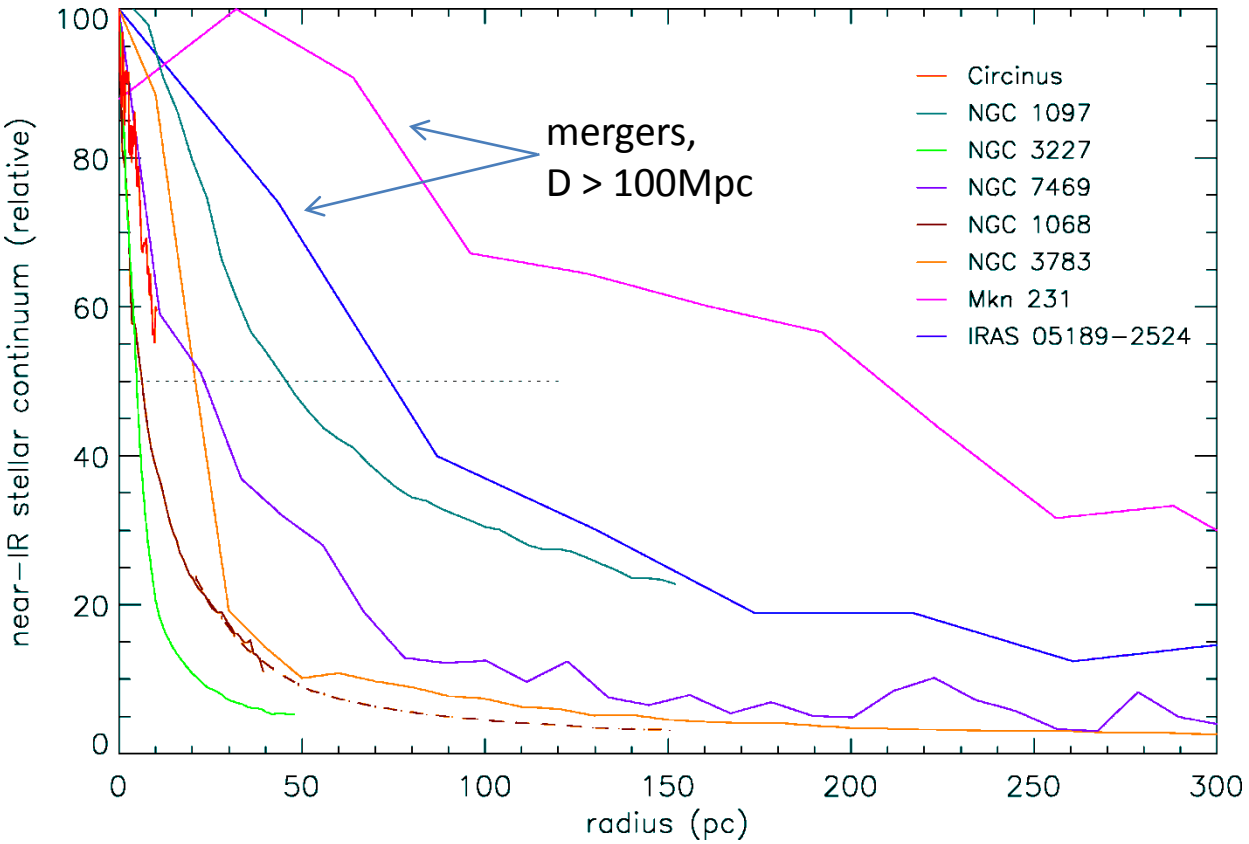
Adaptive Optics Integral Field Spectroscopy



Young Post-Starbursts around AGN

Davies+ 07

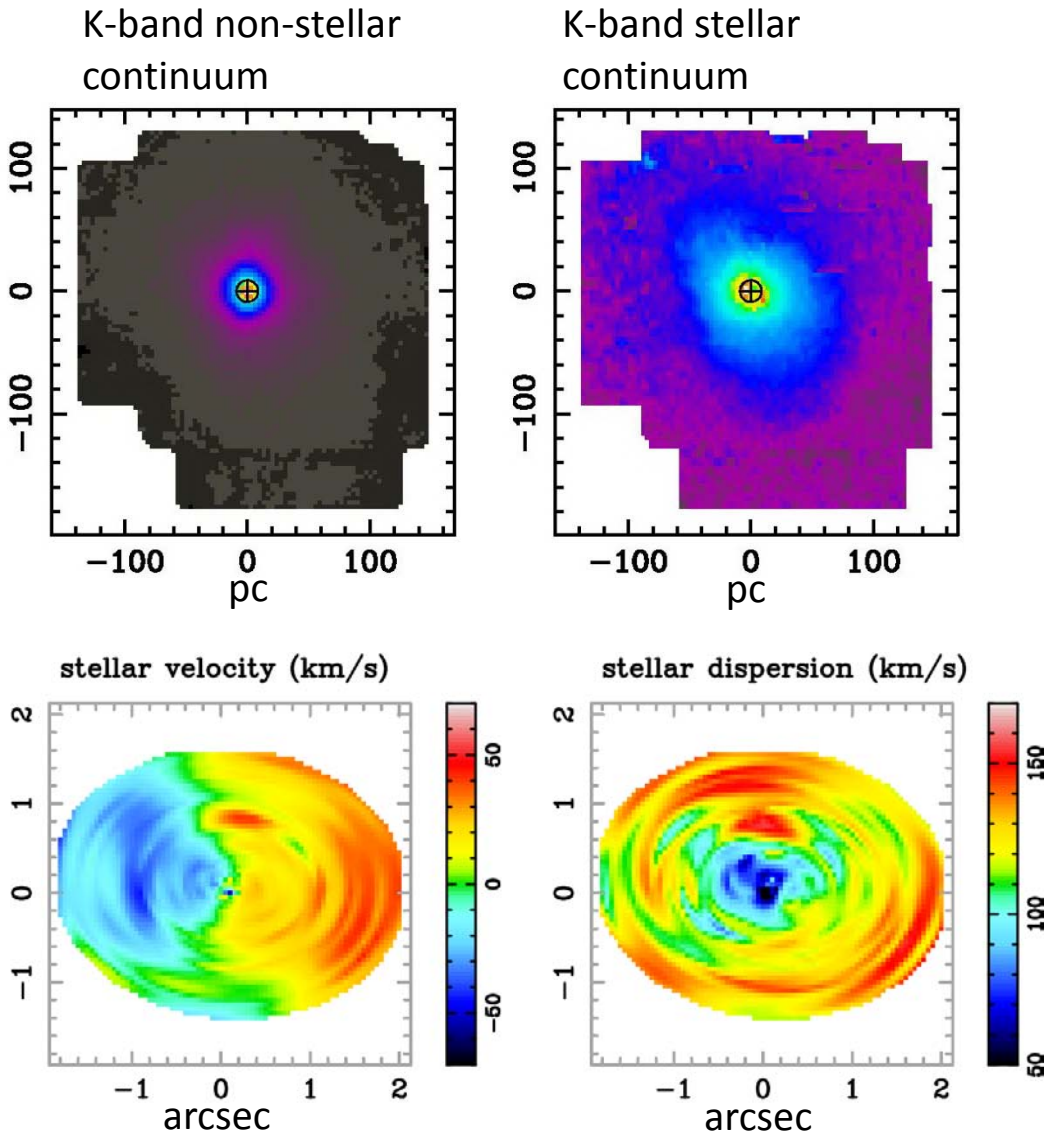
- nuclear stellar continuum resolved in all cases
- recent star formation, ages 10-300 Myr
- low $W_{Br\gamma}$ means star formation is no longer active



cf Cid Fernandes+ 04:

central ~200pc of 79 nearby Seyfert 2s;
1/3-1/2 experienced significant star formation in last few hundred Myr

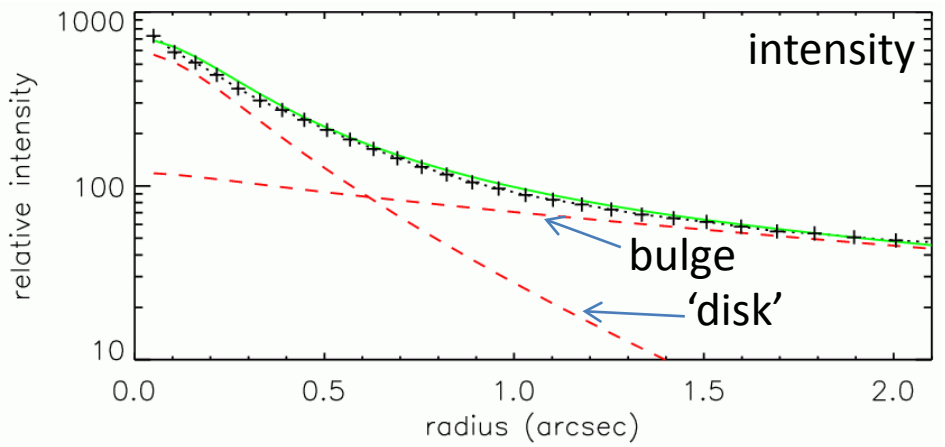
Nuclear Starburst in NGC1068

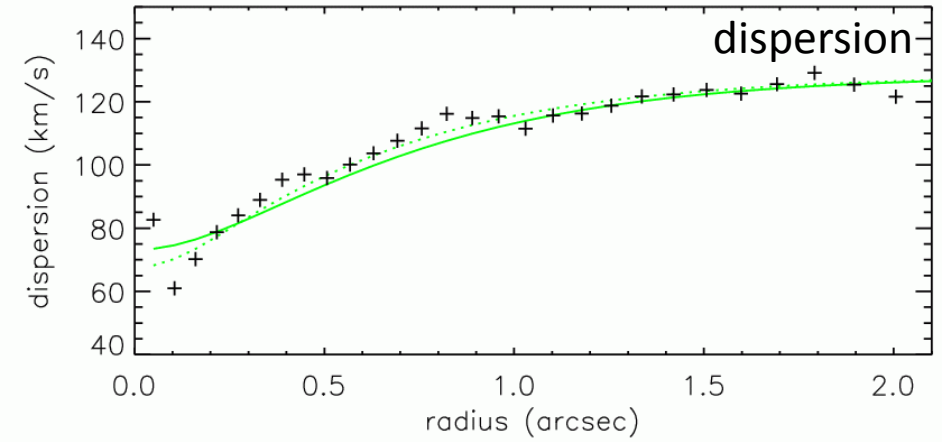


Davies+ 07

Star forming Region Size & Mass

fit intensity & dispersion simultaneously with bulge + 'disk'

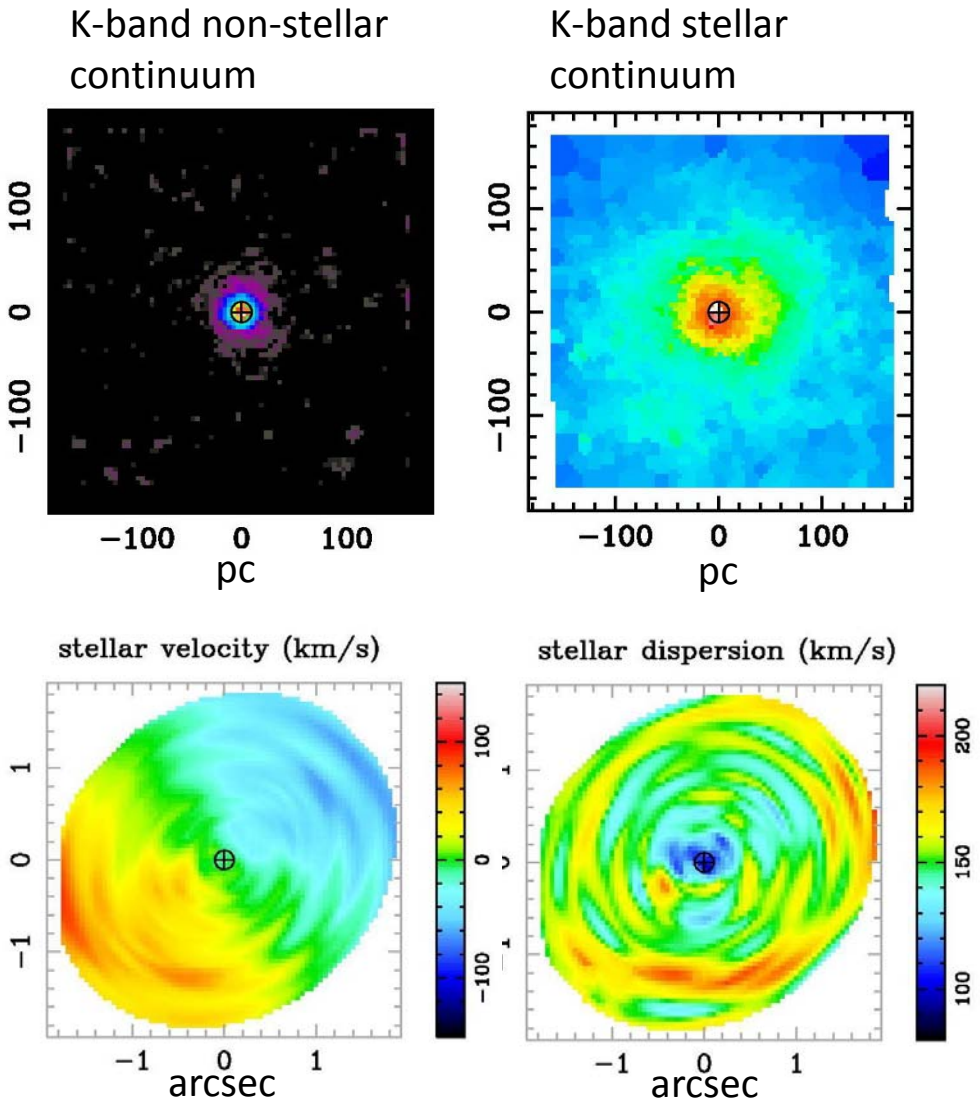




- for each component, fit:
  R_{eff}, n, I_0, σ
- bulge component
  R_{eff} & n similar to NICMOS profile
- nuclear 'disk' component
  R_{eff} = 0.51" = 36pc
  n = 1.6
  σ = 35-55km/s

- $M_{dyn} = 5\text{-}9\times10^7 M_{sun}$
- $M_{BH} \sim 1\times10^7 M_{sun}$ (Greenhill+ 96)
- $\Sigma_{dyn} \sim 2\times10^4\ M_{sun}/pc^2$
- $M_{dyn}/L_K \sim 4$ agrees with starburst age 200-300Myr (Davies+ 07)
- $M_{BH}/M_{stars} \sim 0.15$

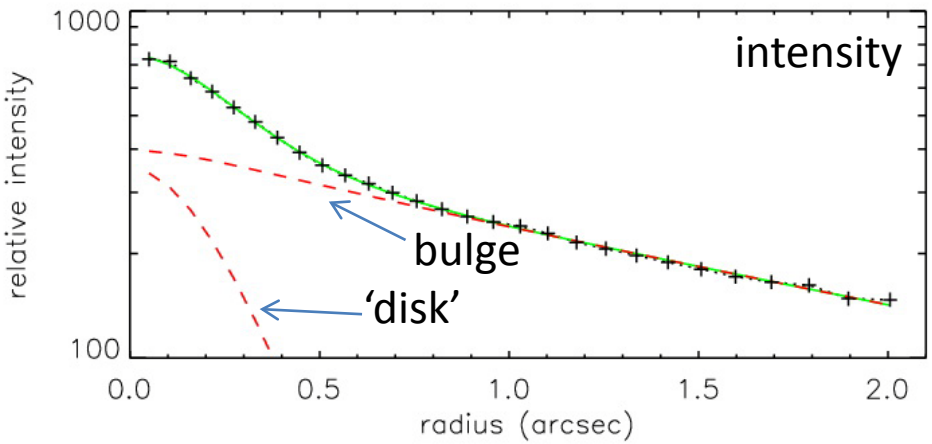
Nuclear Starburst in NGC1097

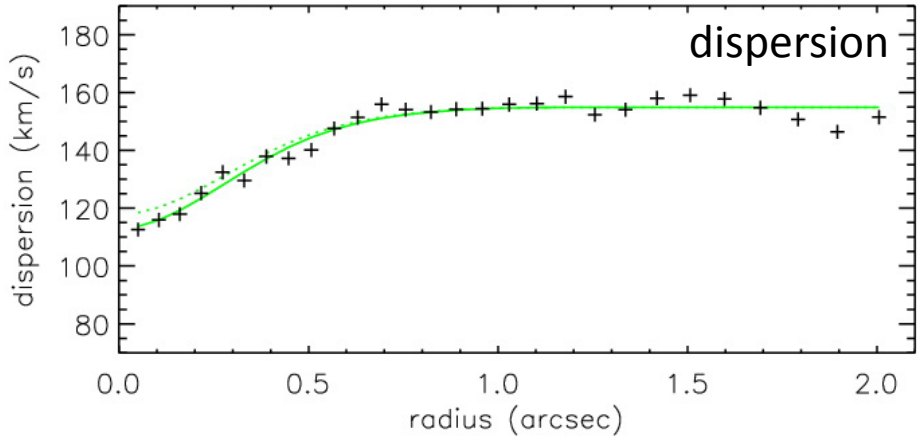


Davies+ 07, 09

Star forming Region Size & Mass

fit intensity & dispersion simultaneously with bulge + 'disk'





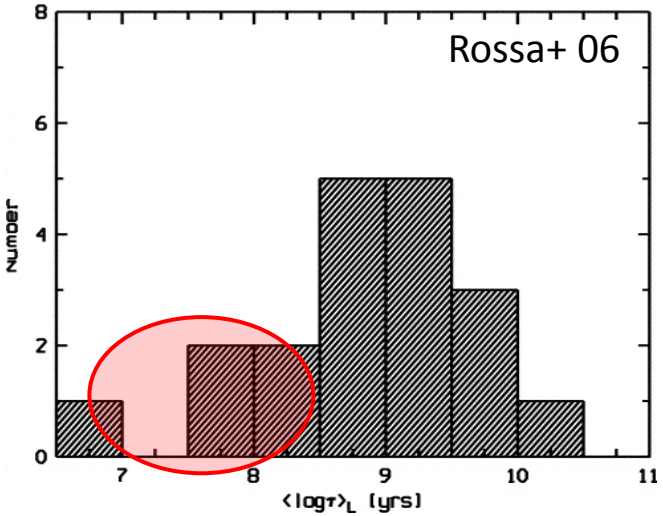
- for each component, fit:
  R_{eff}, n, I_0, σ
- bulge component
  R_{eff} & n similar to NACO profile (Prieto+05)
- nuclear 'disk' component
  R_{eff} = 0.28" = 24pc
  n = 0.8
  σ <~ 30km/s

- $M_{dyn} = 1\text{-}5\times10^7 M_{sun}$
- M_{BH}
  $12\times10^7 M_{sun}$ (Lewis+ 06, σ=196km/s)
  $5\times10^7 M_{sun}$ (using σ=155km/s)
- low stellar mass, consistent with young age ($M_{dyn}/L_K < 1$)
- $M_{BH}/M_{stars} > 1$

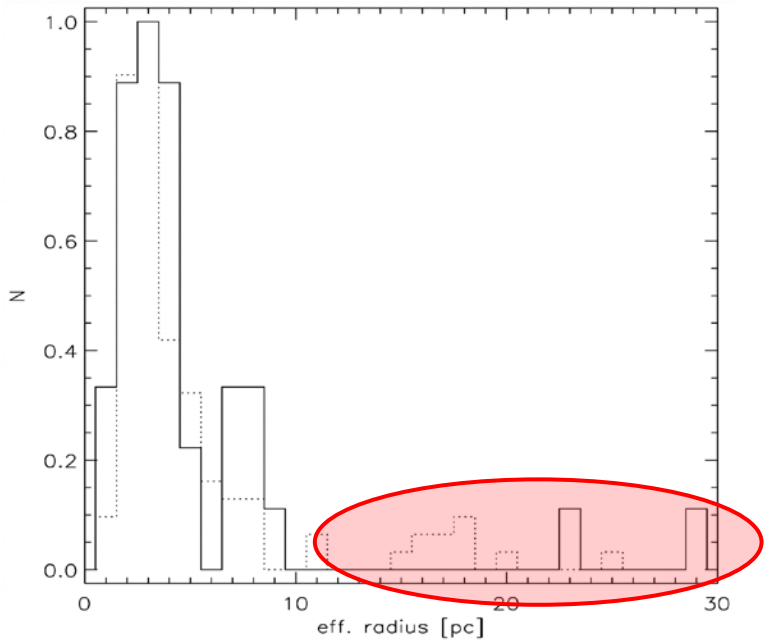
Are these ‘nuclear clusters’ ?

they lie towards upper end of size & mass range
and lower end of age range for nuclear clusters

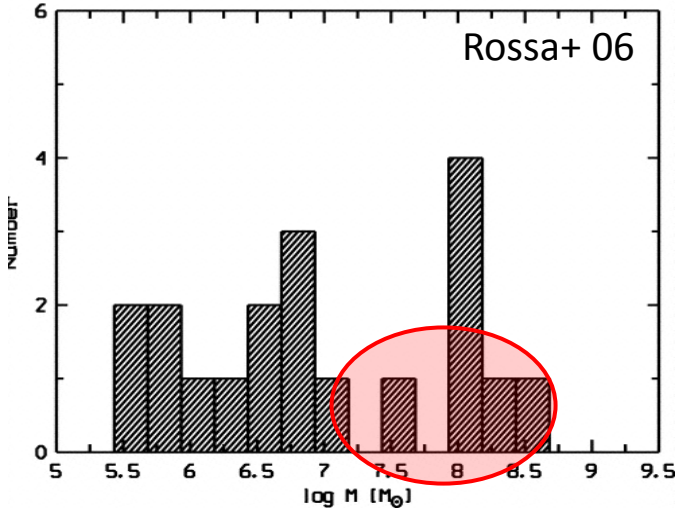
Rossa+ 06



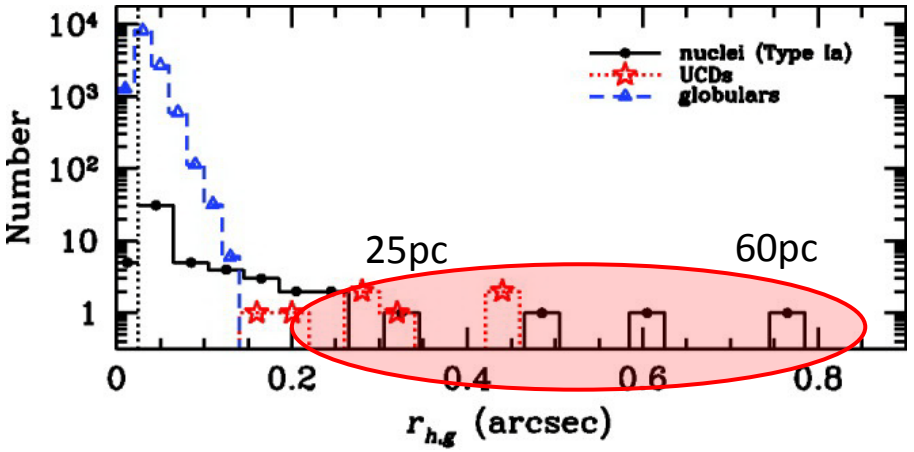
Böker+ 04



Rossa+ 06



Côté+ 06



Questions

- Are there NSCs around nearby AGN?
  - photometric & kinematic evidence for young post-starbursts
  - at the large/massive/young end of NSC range
- How does gas get from 1kpc to central 10s of pc?
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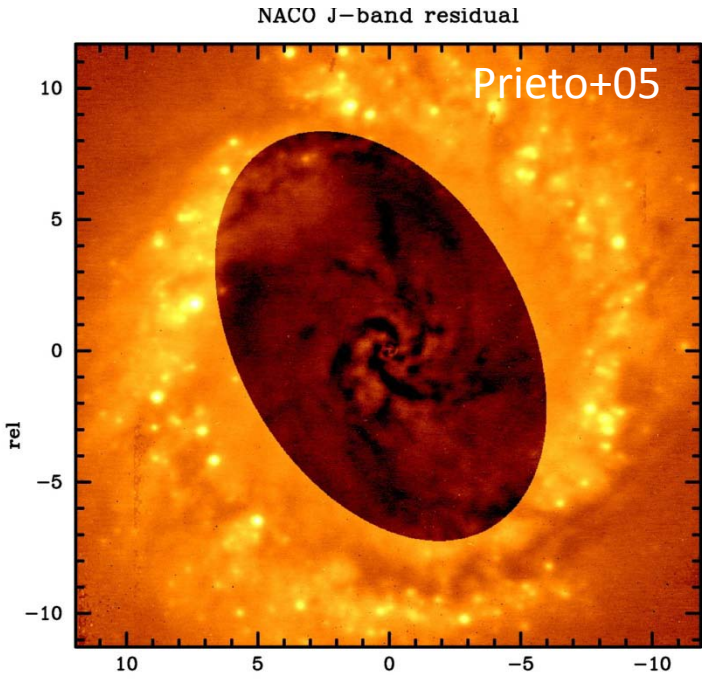
Nuclear Spiral in NGC1097

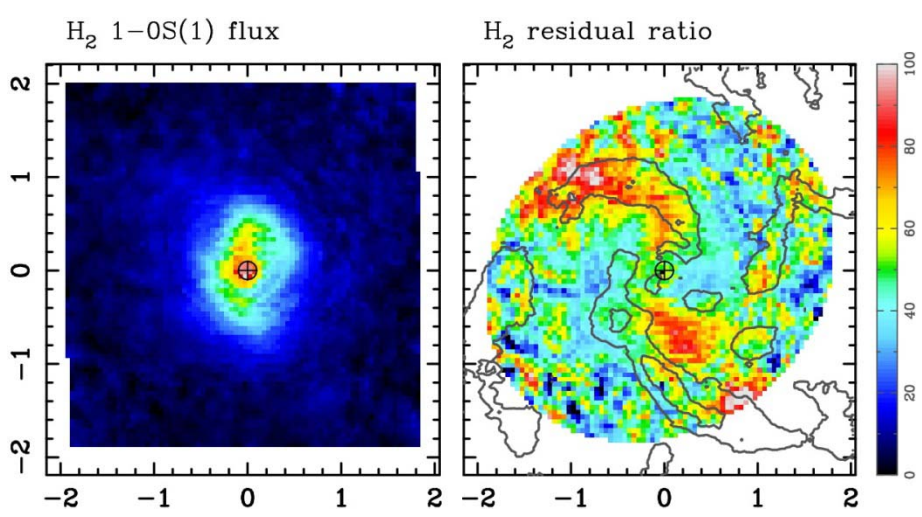
Prieto+ 05:

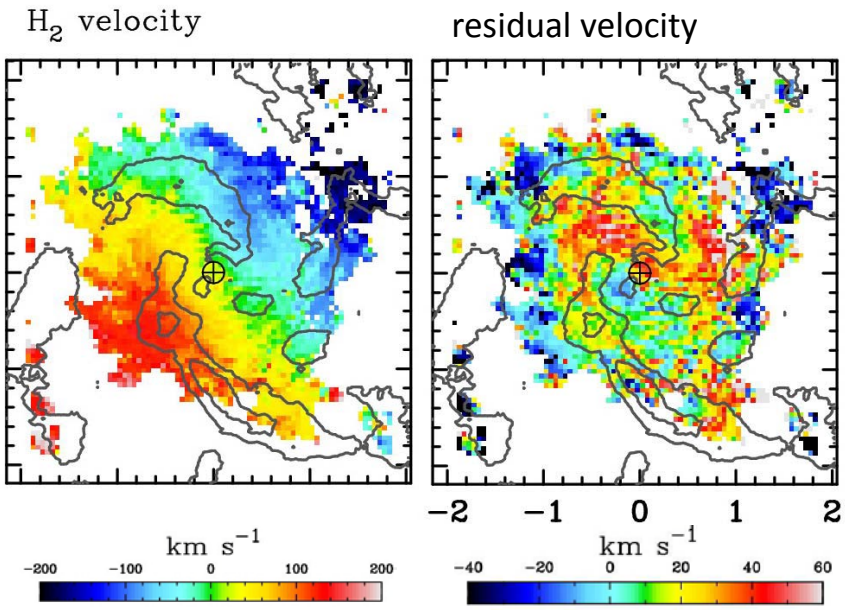
- 3 photometric spiral arms in stellar absorption

Davies+ 09:

- 3 spiral arms seen in gas emission, but
- 2 kinematic arms
- mass flow along arms ~ $1M_{sun}/yr$
- net inflow rate ~ $0.06M_{sun}/yr$





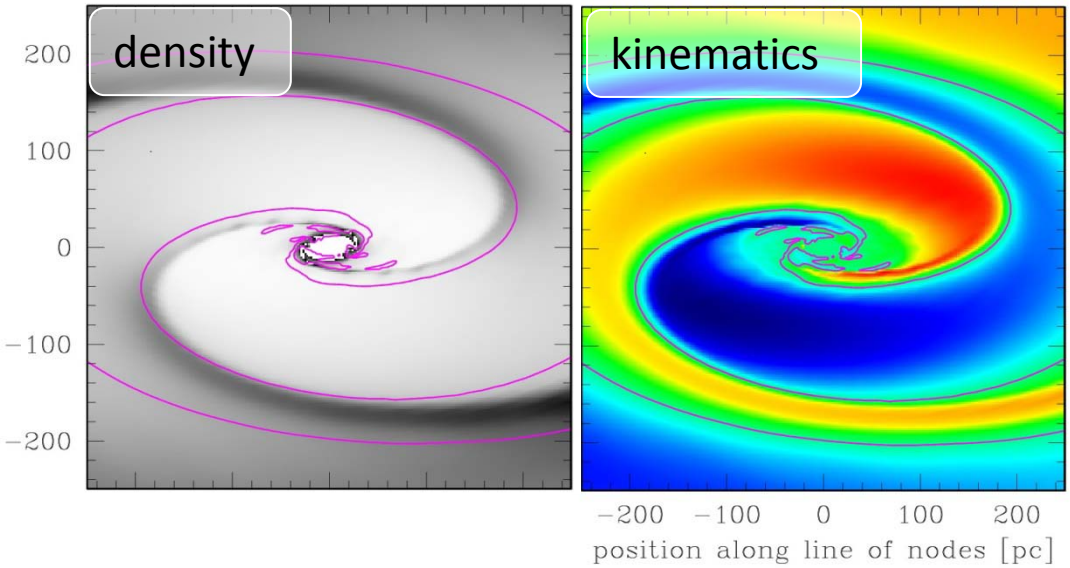


Spiral Driven Inflow

theory (also Witold's talk):

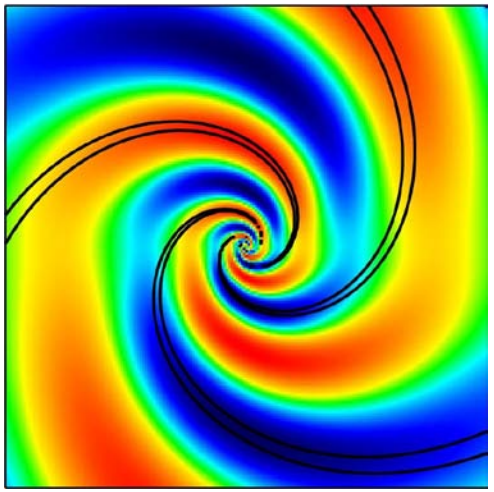
an *m*-arm photometric spiral is associated with an *(m-1)*-arm kinematic spiral

2-arm spiral



3-arm spiral

contours: arms
colours: kinematics



Maciejewski 04, Davies+ 09

using IFUs to study residual gas kinematics in circumnuclear region is new.

see also

- Fathi+ 06, Storchi-Bergmann+ 07, 09, Riffel+ 08, 09
- SINFONI data for 10 active & inactive galaxies (Hicks+ in prep)

Questions

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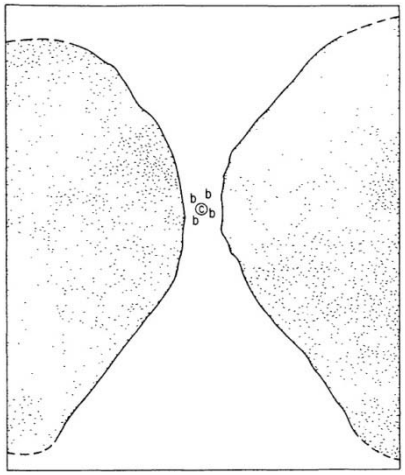
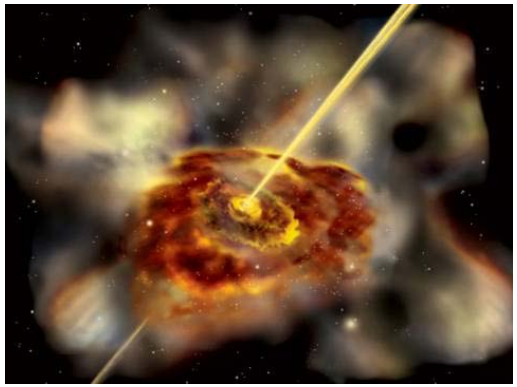
Molecular Gas & Torus Properties

What are the minimum criteria for the torus?

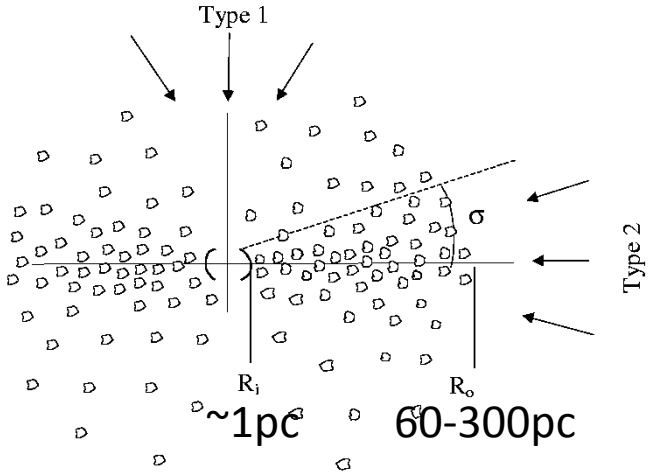
- consists of molecular gas (& dust)
- compact, size tens of parsecs
- optically thick, so as to obscure AGN when viewed edge on
  (column density at least $10^{22}cm^{-2}$)
- vertically extended, by several parsecs, so as to provide
  collimation for ionisation cones



Antonucci (1985)



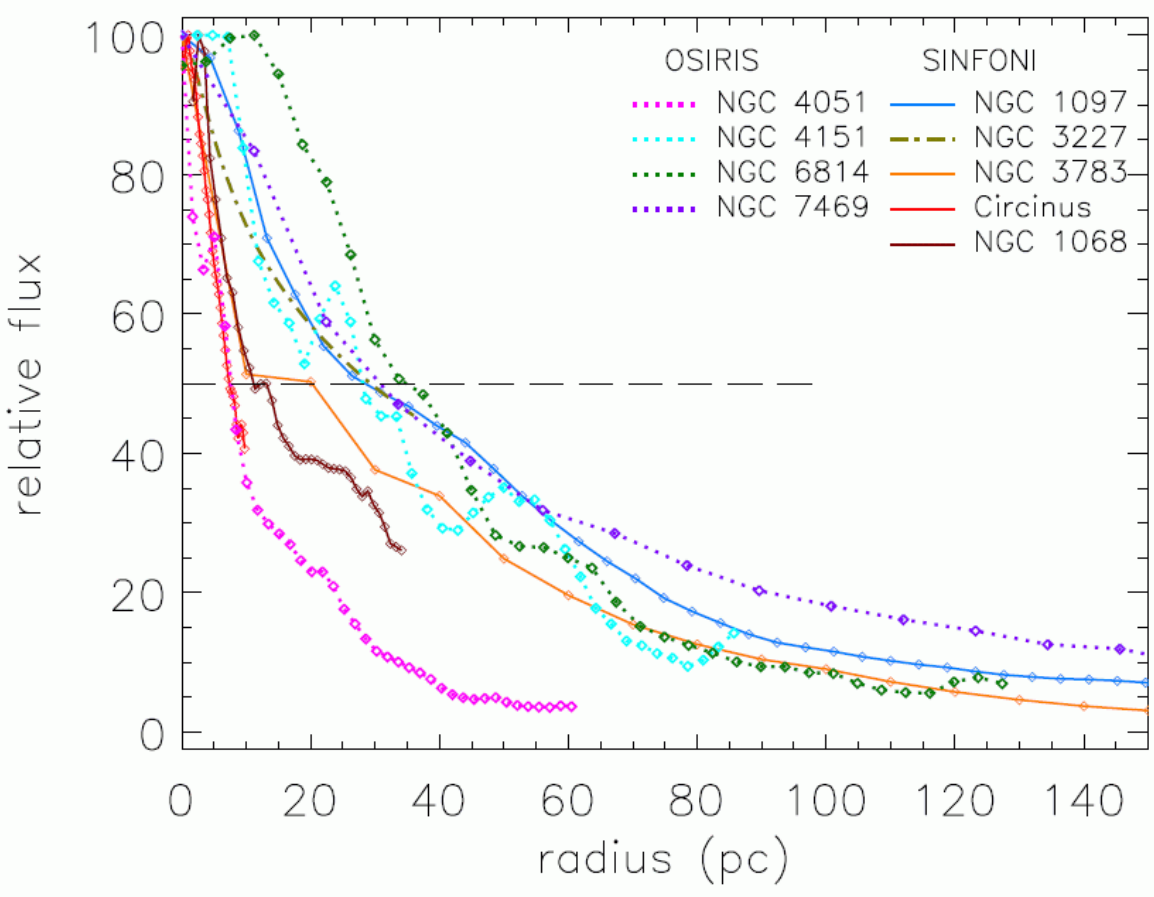
NASA E/PO, Sonoma State University, Aurore Simonnet



Nenkova et al. (2002), Elitzur (2004) , etc

Radial Distribution of Molecular Gas

- compact concentration of gas at the nucleus
- inner region is just a high surface brightness continuation of a larger scale structure
- HWHM 10-30pc



Hicks+ 2009

Column density of Molecular Gas

can't use:

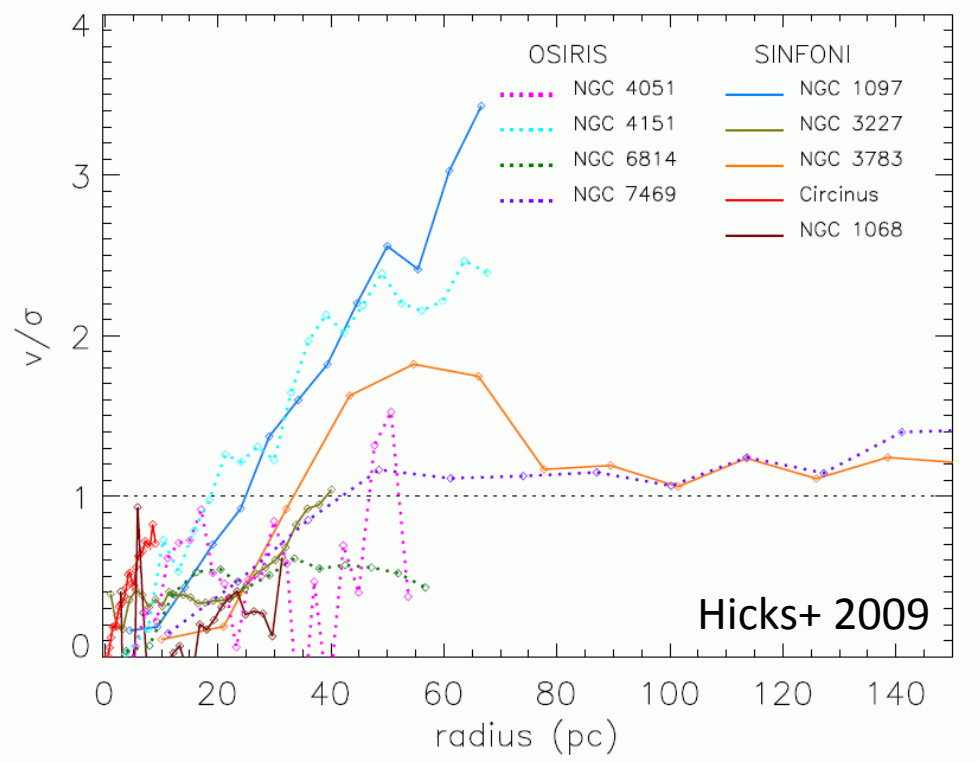
- molecular line luminosities (X-ray chemistry)
- 1-0S(1) H_2 luminosity (hot gas at edges of clouds)

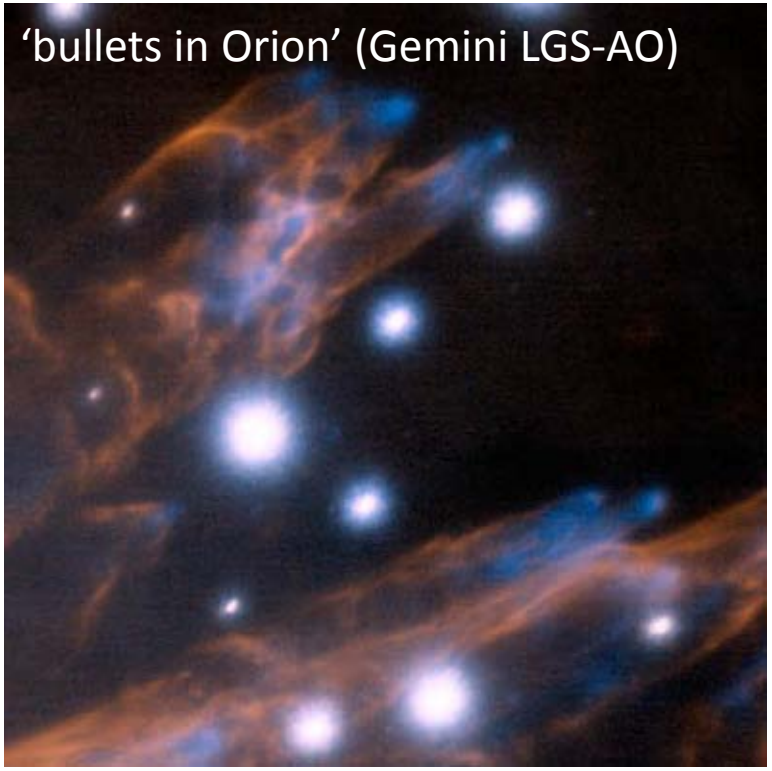
instead:

- estimate $M_{dyn} \sim (V^2+3\sigma^2)\ R / G$
- adopt a gas fraction f_g
  - spiral galaxies 5-25 %
  - local starburst & ULIRGs 10-20 %
  - $L_{CO\ 2-1} \rightarrow M_{gas}$ 1-30 % in 4 of our sample
    1-15 % in 5 NUGA galaxies
- f_g=10% implies $n_H > 5\ \ 10^{23}\ cm^{-2}$ within 30 pc
  ($\Sigma_{gas} \sim 4000\ M_{sun}/pc^2$) Hicks+ 2009

Scale height of Molecular Gas

- at centres, v/σ <1 and σ_{gas} ~ 50-100 km/s
- but 1-0S(1) emission is strongest for shock speeds 20-40 km/s
- there are high dispersion 1-0S(1) lines in Orion: 'bullets' (e.g. Tedds 1999)
- bulk cloud motions must account for σ_{gas} in AGN
- distribution must be vertically extended



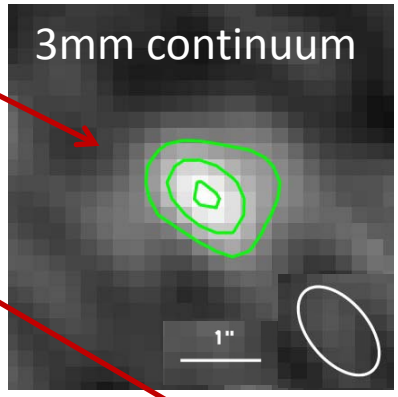


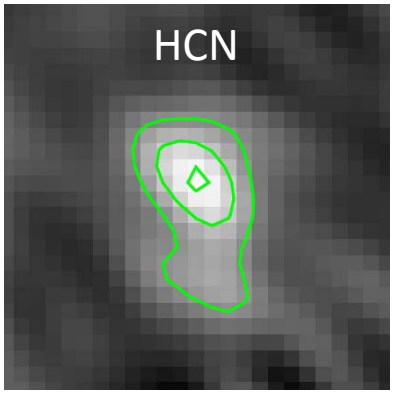
Dynamical State of Dense Gas

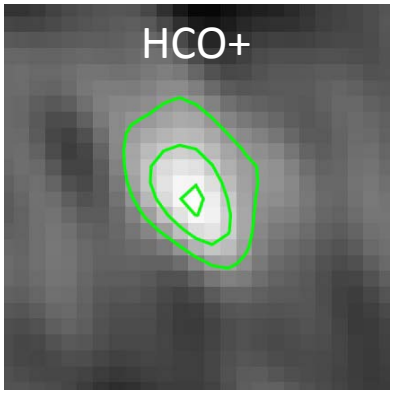
- HCN observations probe dense >3×10^{4}cm^{-3} gas
- <1" resolution from PdBI – NGC 3227, 2273, 4051, (6951)
- Directly observable constraints:

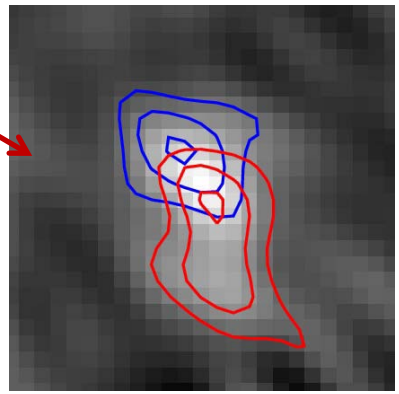
1. major & minor axis size, & PA
2. separation & PA of red/blue channels
3. integrated line width

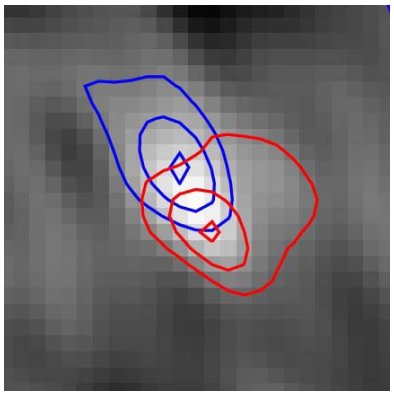
Sani+ in prep

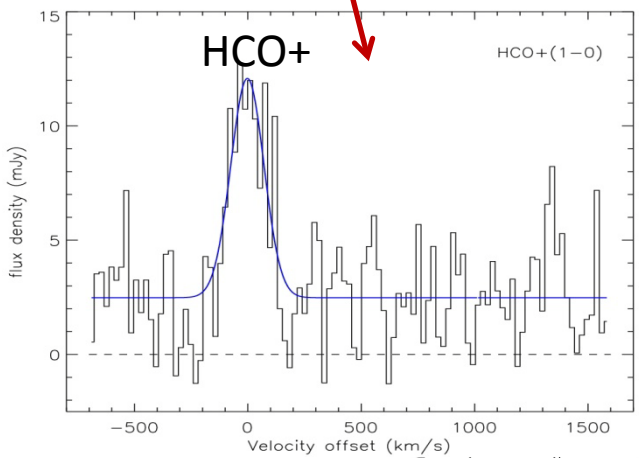


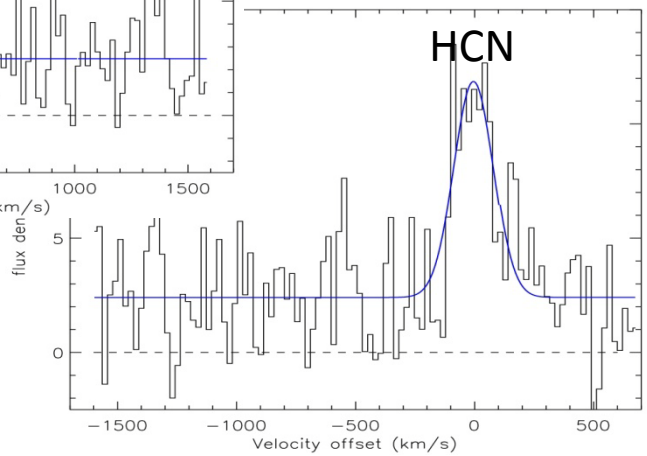












Dynamical Models of HCN

- inclined disk – Gaussian distribution
- add additional dispersion if required
- elliptical beam (beam smearing is a key aspect of dynamical models)

thin disk

- Gaussian & uniform distributions yield similar results
- linewidth is only ~2/3 of that observed

thick, rapidly rotating disk

- can reproduce all characteristics
- dispersion due to a combination of beam smearing of velocity gradient as well as $V/\sigma=R/H \sim 2\text{-}4$
- intrinsic dispersion is 25, 45, 50km/s for HCN & HCO^+ (Sani+ in prep)

55 & 80-95km/s for 1-0S(1) (Hicks+ 09)

--> dense gas has a thick distribution

Questions

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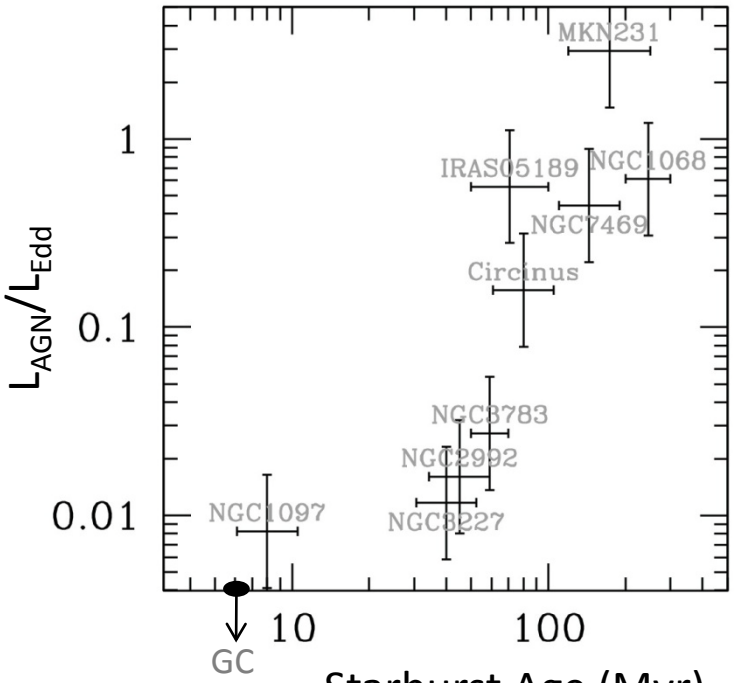
  - other methods?
- Is the gas creating these starbursts related to the torus?
  - gas exhibits necessary characteristics (size, column density, thickness)
  - associated with large scale structure of the torus
- What is the impact of the starburst on the AGN?

Starburst – AGN connection

There is a delay of 50-100 Myr between starburst & AGN activity

rough estimate of L_{AGN} based on $0.5L_{bol}$



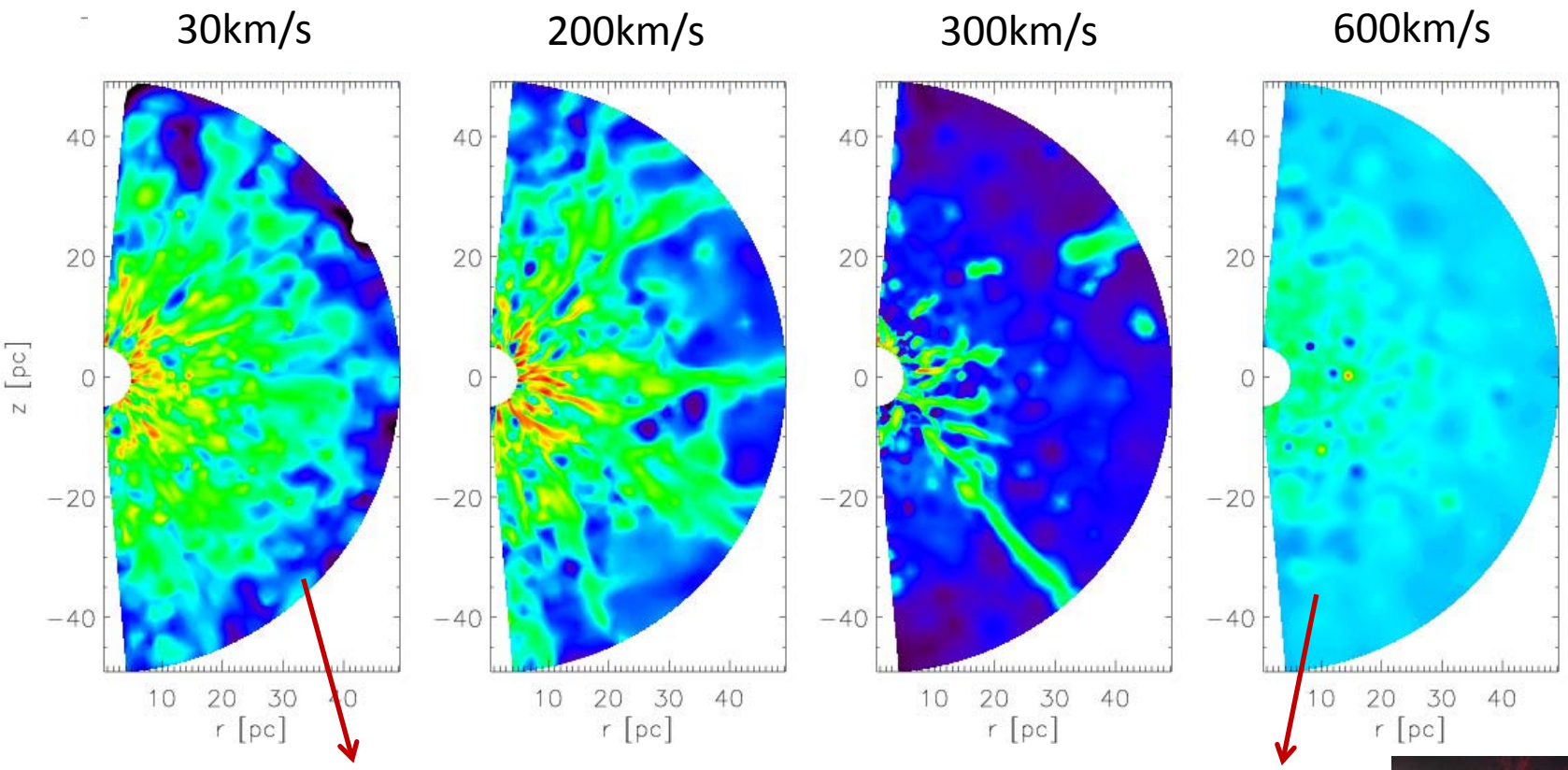
Davies+ 2007

best estimate of time since most recent star forming episode began

Hydrodynamical Simulations

Schartmann 07, Schartmann+ 09, 10; also Marc's talk

- study impact of a nuclear star cluster on torus evolution
- parameters as for NGC1068 – as scaling for a typical Seyfert



stars of 1-8M_{sun} reach AGB phase after ~50Myr; winds have speeds of 10-30km/s and remain bound

fast ejecta: OB winds (GC) & supernova (M82) blow gas out

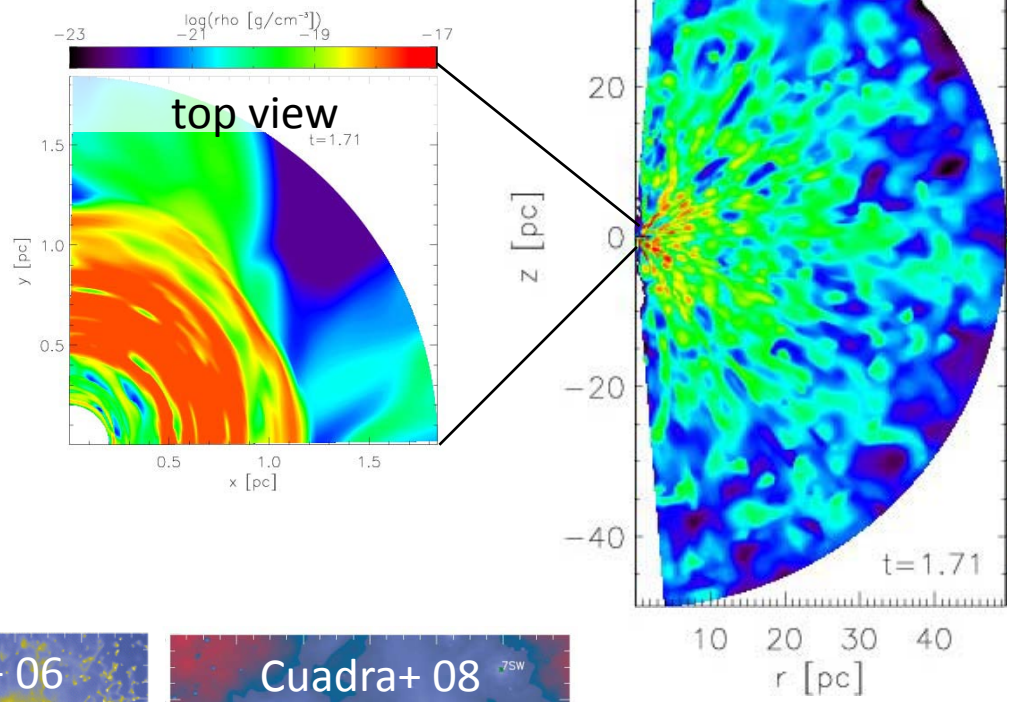
Formation of a Compact Turbulent Disk

cold dense filaments stream inwards and form a compact turbulent disk.

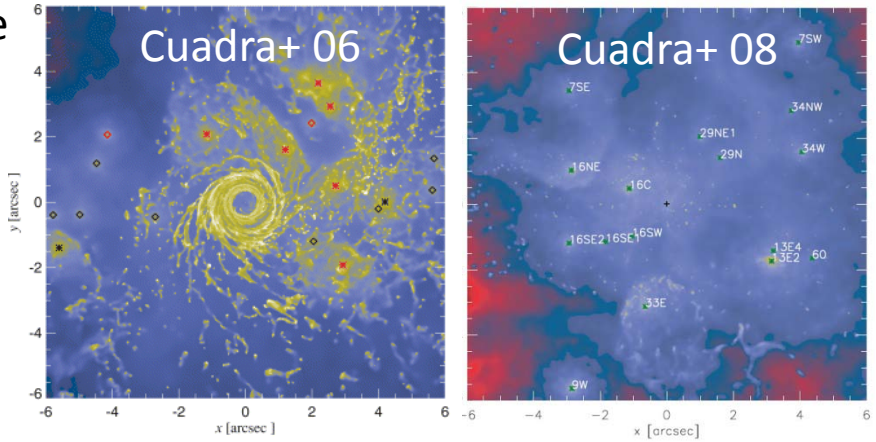
disk extension is 0.5-1pc, comparable to size of maser disk (Greenhill+ 96)

gas mass in disk ~$10^6 M_{sun}$

Schartmann+ 10

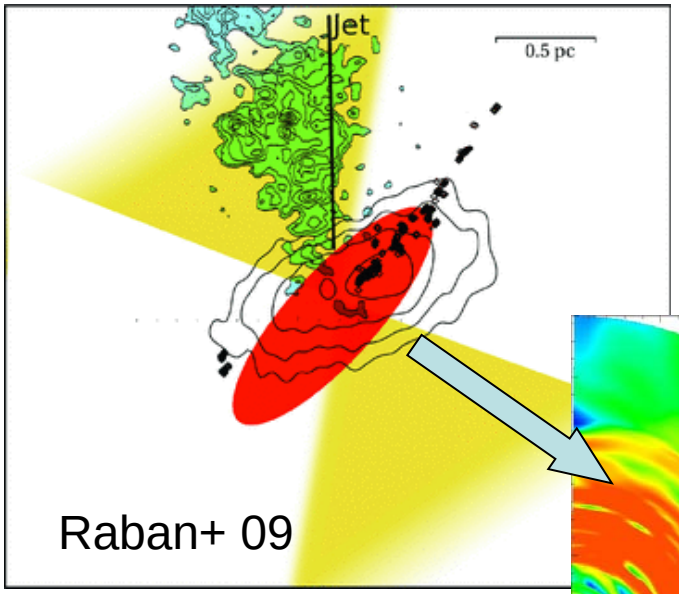


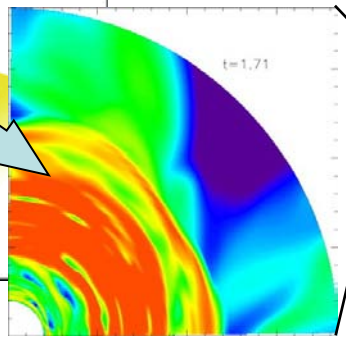
same processes operate in the GC on scales 100 times smaller



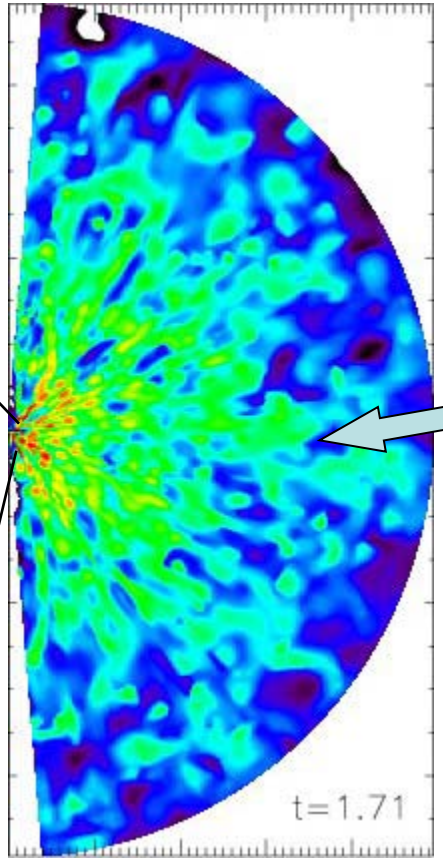
Linking scales: from 10-50pc to 1pc

VLTI image reconstruction

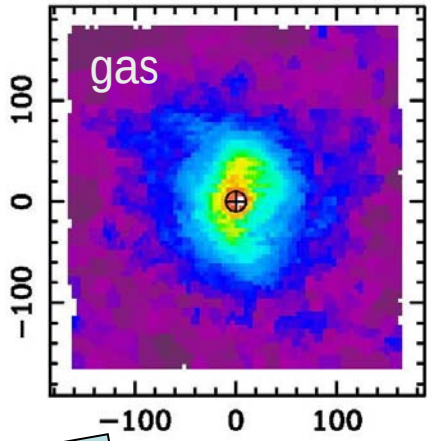


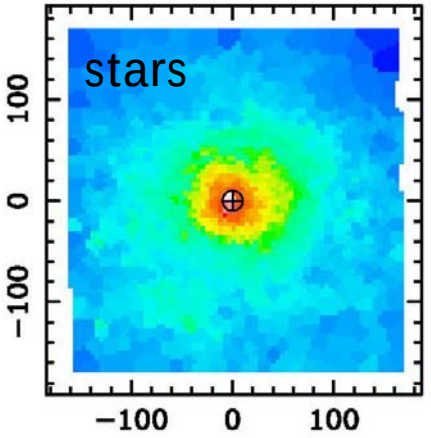


Schartmann's simulations



AO images of gas & stars





If these are 2 components of the 'torus', they imply that it is a dynamical structure

Davies+ 09, Schartmann+ 10

Conclusions

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  - at the large/massive/young end of NSC range
- How does gas get from 1kpc to central 10s of pc?
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  - other methods?
- Is the gas creating these starbursts related to the torus?
  - gas exhibits necessary characteristics (size, column density, thickness)
  - associated with large scale structure of the torus
- What is the impact of the starburst on the AGN?
  - fast stellar ejecta blow gas out; slow winds can accrete to small scales
  - form a compact turbulent disk: link from 30pc (AO) to <1pc (VLTI)
- Question
  - is this applicable to all NSCs, or are they a mixed bag of phenomena?