The Impact of Nuclear Star Formation on Gas Inflow to AGN

Richard Davies[1],

R. Genzel[1], L. Tacconi[1], E. Hicks[1], H. Engel[1], A. Sternberg[2], F. Mueller Sánchez[1,3], M. Schartmann[1], W. Maciejewski[4], B. Vollmer[5]

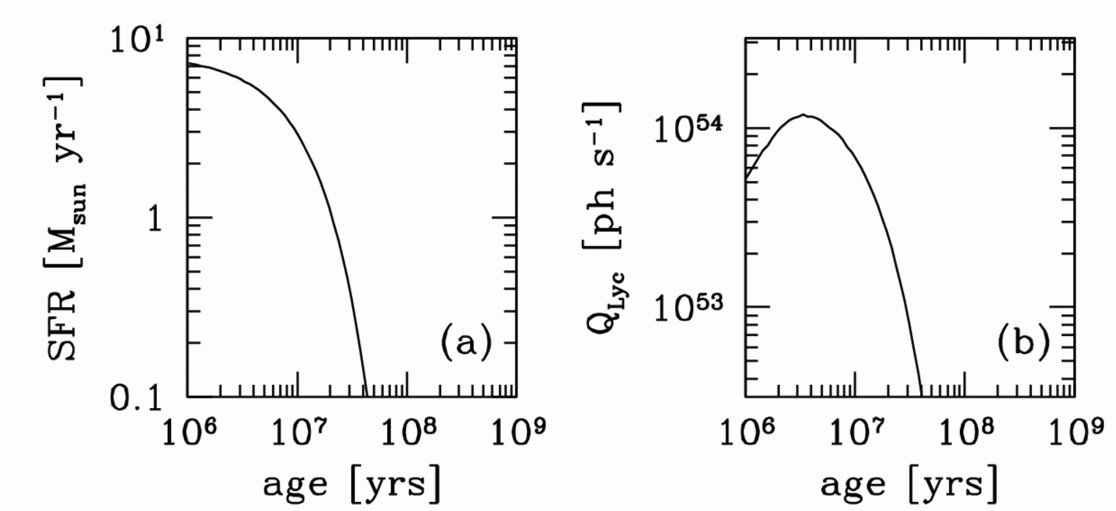
[1] Max Planck Institute for Extraterrestrial Physics, Germany
[2] University of Tel Aviv, Israel
[3] Instituto de Astrofisica de Canarias, Spain
[4] Liverpool John Moores University, UK
[5] Observatoire astronomique de Strasbourg

Star formation around AGN

SINFONI observations show evidence for recent, intense, but short-lived (& now ceased) starbursts on scales <30pc around AGN

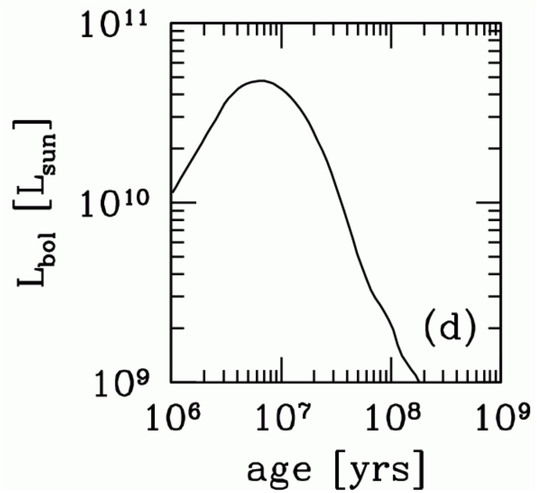
Davies+ 07

exponentially decaying star formation rate, τ_{SF}=10Myr



Brγ flux drops rapidly

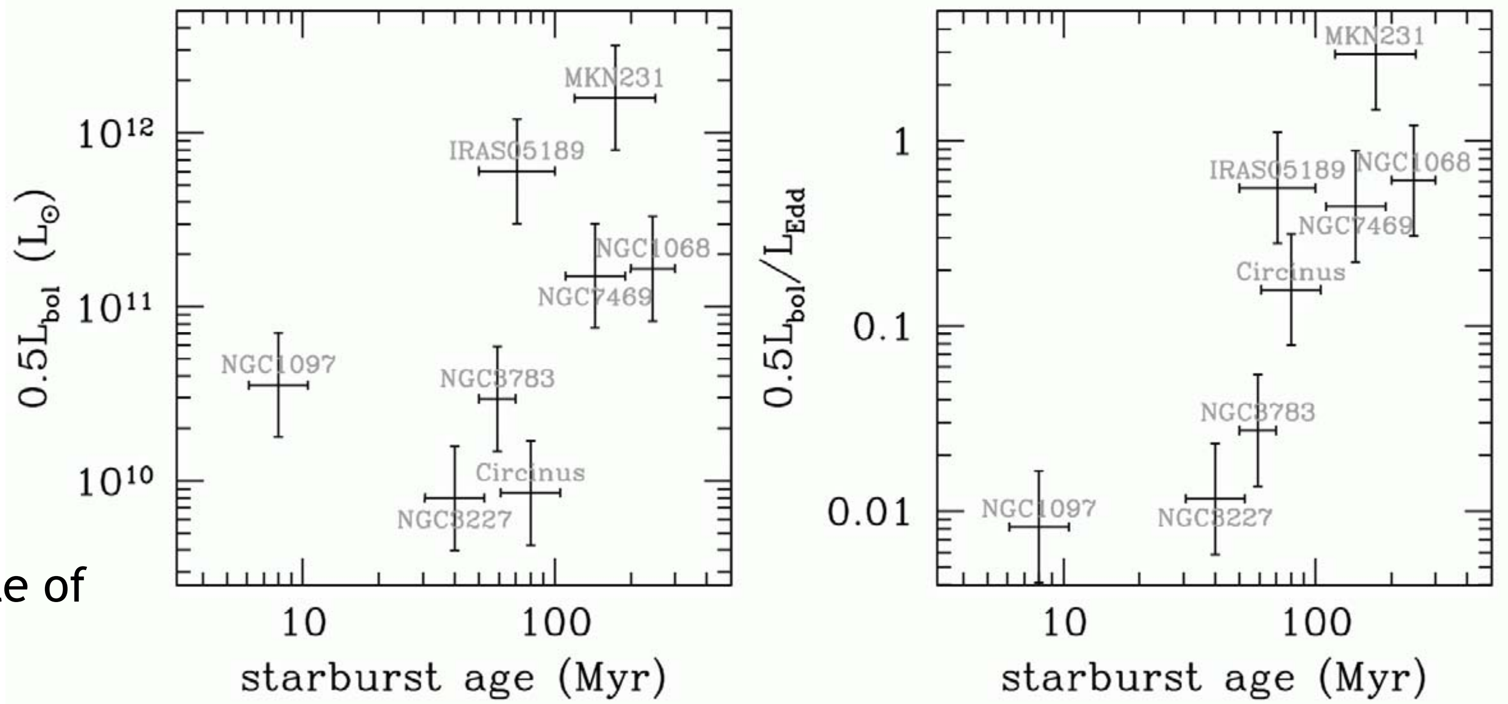
normalisation set by L_{bol} =2×10^9L_{sun} at 100Myr



Star formation around AGN

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

Davies+ 07



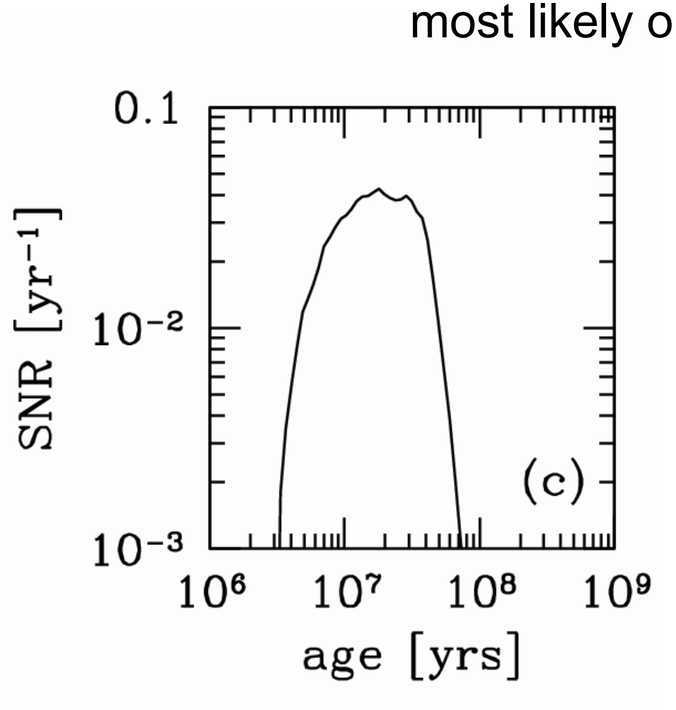
estimate of L_{AGN}

best estimate of time since most recent star forming episode began

Feeding the Monster: the role of stellar ejecta

OB stars — significant mass loss, but at speeds of ~1000km/s and only for a short time;
in Galactic Centre, winds are partially responsible for stopping accretion (Ozernoy+96,97, Cuadra+06,08)

supernovae — ~10^6 type II SNe, at 10-50Myr, each ~$5M_{sun}$ at ~5000km/s;
most likely outcome is a superwind rather than accretion



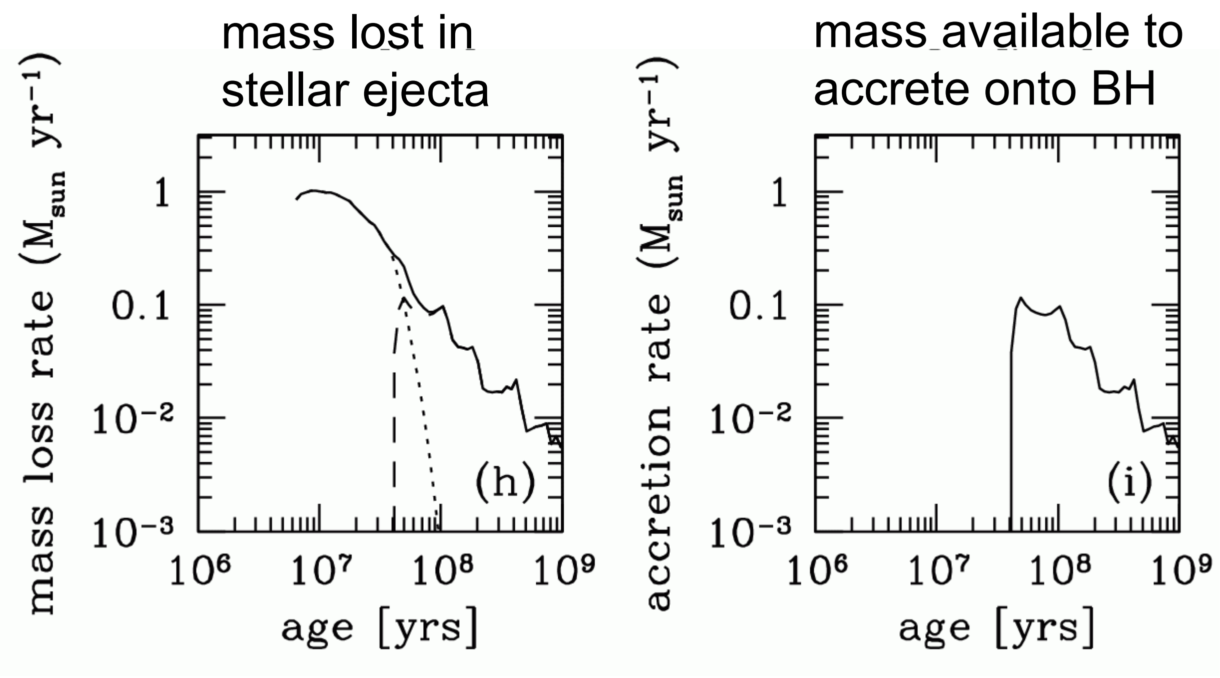
STARS stellar cluster model


M82 starburst wind (Subaru telescope)

Feeding the Monster: the role of stellar ejecta

AGB stars

stars of 1-8M_{sun} reach AGB phase after ~50Myr;
wind speeds of 10-30km/s
wind remains bound & is available for accretion onto BH;
mass available >0.02M_{sun}/yr over timescale of 50-200Myr;



STARS stellar cluster model

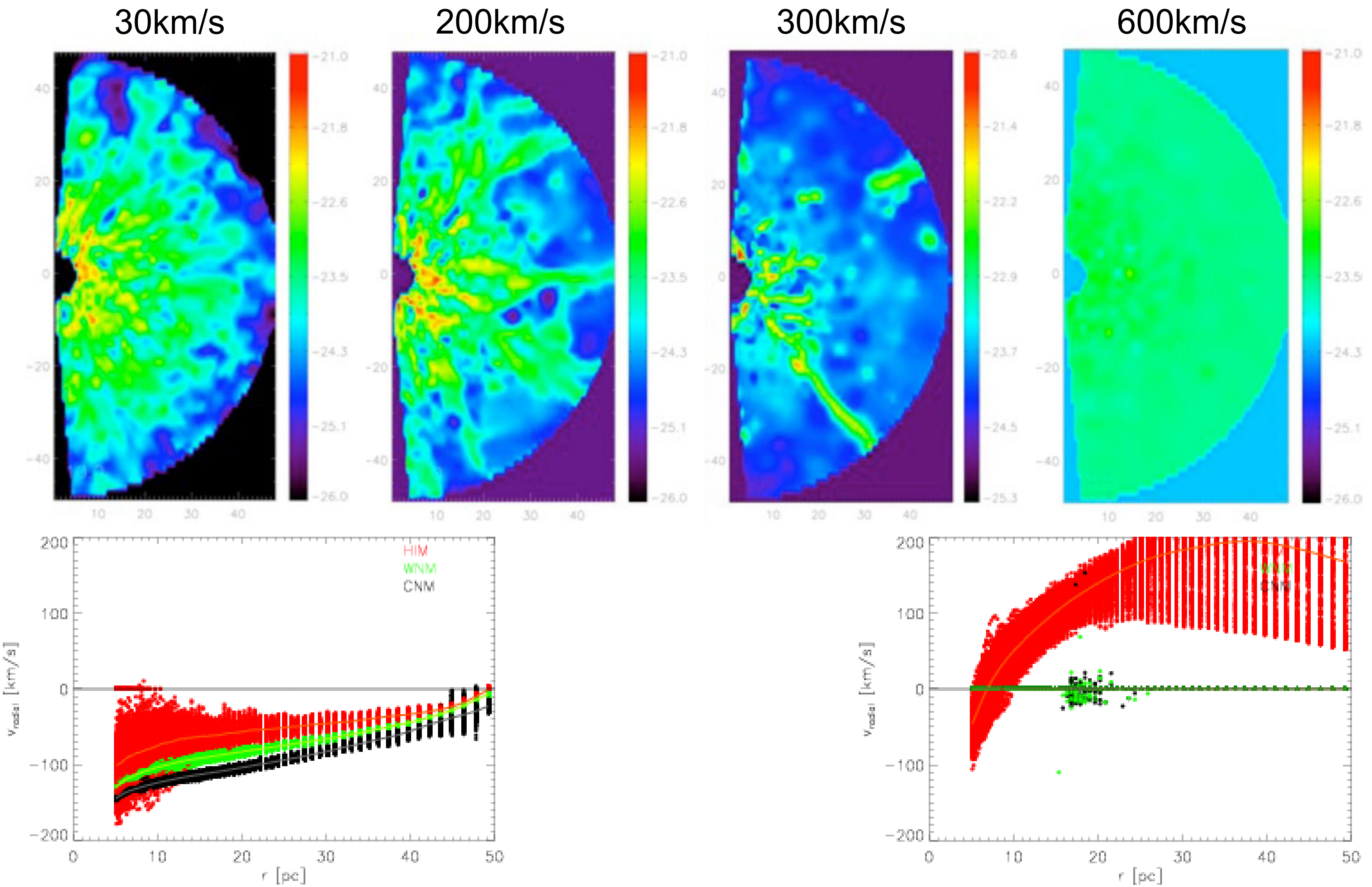
Hydrodynamical simulations

Schartmann (2007, PhD thesis);
Schartmann+ 09, & in prep.

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

M_{BH}	$\sim 10^7\ M_{sun}$
M_{stars}	$\sim 2\times10^8\ M_{sun}$
R_{core}	$\sim$25 pc
σ_*	$\sim$100 km/s
Mass loss	$\sim 6\times10^{-10}\ M_{sun}/yr/M_{sun} \sim 0.1\ M_{sun}/yr$

Hydrodynamical simulations

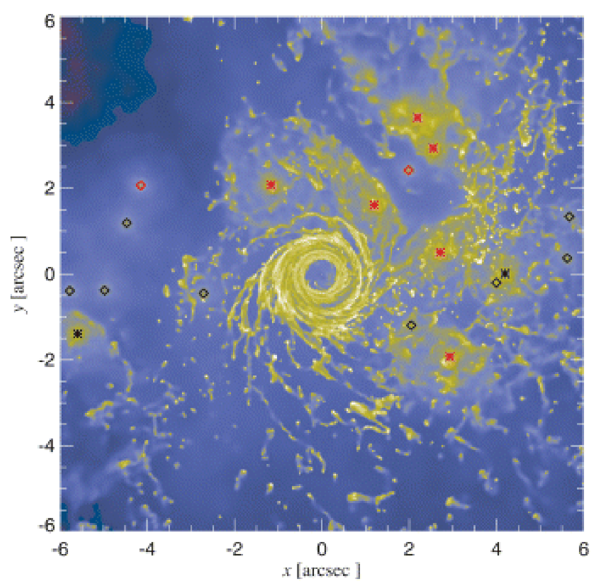


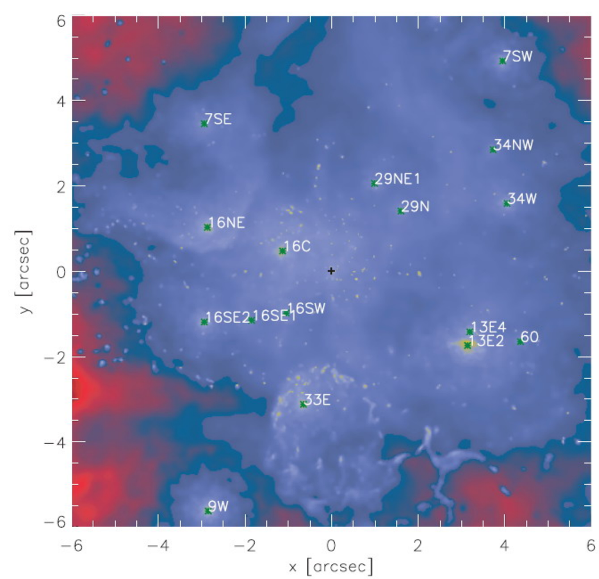
The Galactic Centre: stellar winds & a quiescent AGN

Cuadra+ 06, 08:

- fast 700km/s young stellar winds; slow 200km/s winds; total mass loss $\sim 8\times10^{-4} M_{sun} yr^{-1}$; orbital motion of stars
- gas has 2-phase structure: hot X-ray emitting gas & cold filaments, which settle into a disk; slow winds create cold gas clumps that introduce the variability
- the same processes operate in the GC on small scales as in Seyferts on larger scales: accretion of slow stellar winds, hindered by angular momentum

box is 12” (0.5pc) on a side





Star formation around AGN

2. Although the star formation has ceased, the H_2 dispersion is still high

Hicks+ 09

- Radiation pressure from stars (Thompson+ 05):
  only while star formation is active

- Type II Supernovae (Wada & Norman 02):
  but need a high SN rate & active star formation

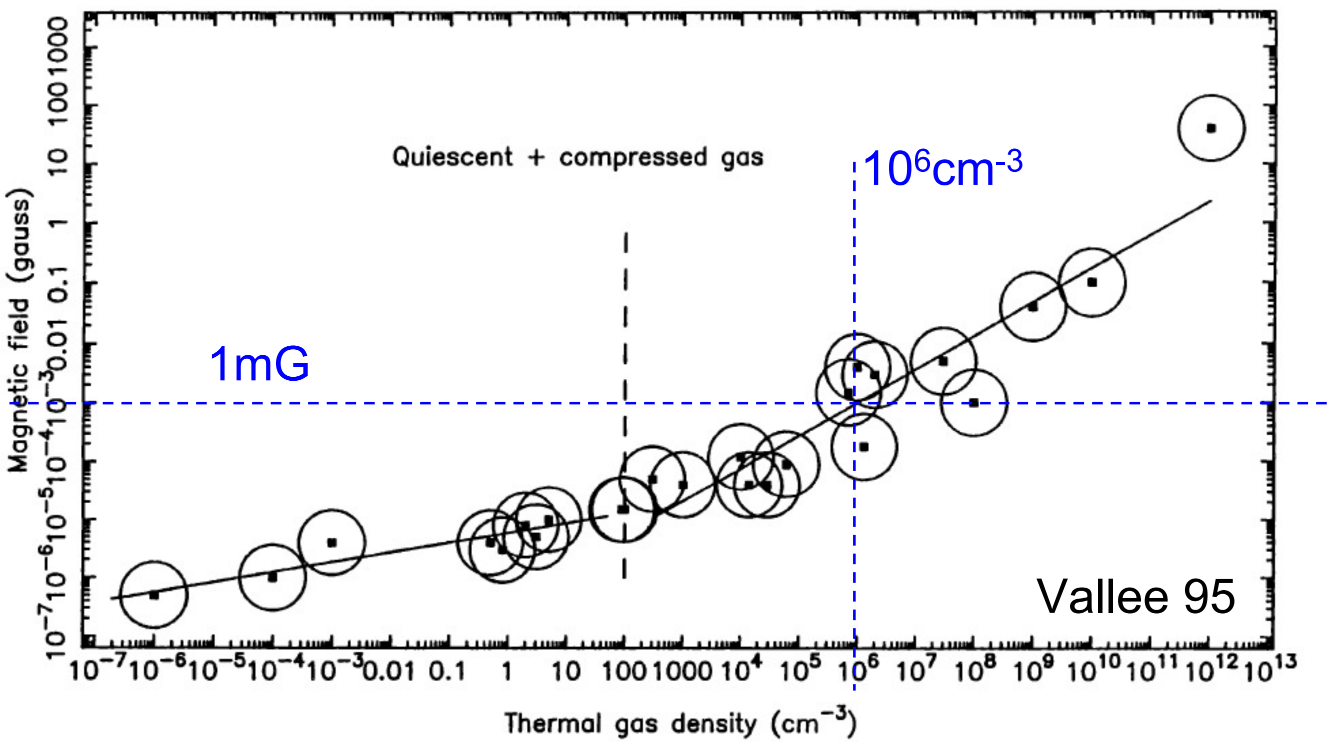
- Radiation pressure from AGN (Krolik 07):
  most effective at small radii

- Gas accretion into central region (Krolik & Begelman 88, Vollmer+ 08):
  might work if clouds are sufficiently magnetised

Magnetic Fields in Dense Gas

- relation due to magnetic flux & mass conservation during cloud contraction; magnetic fields also amplified by turbulence
- Relation for dense gas is: $B = 0.4\times10^{-6}\ n^{0.56}$ (close to expectation for magnetically supported clouds) so that $n \sim 10^6 cm^{-3}$ gives ~1mG
- Galactic Center is consistent with this relation:

  $n \sim 10^7$ (e.g. Christopher+ 05); B ~ 0.5-3mG (e.g. Yusef-Zadeh+ 96, Plante+ 05)



Evolutionary scenario for the nuclear region

Phase I

(obs. input is estimate of initial SFR)

initial massive gas infall forms a turbulent Q~1 star forming disk. Once SNe explode, ISM is blown out leaving only small dense clouds in a collisional disk

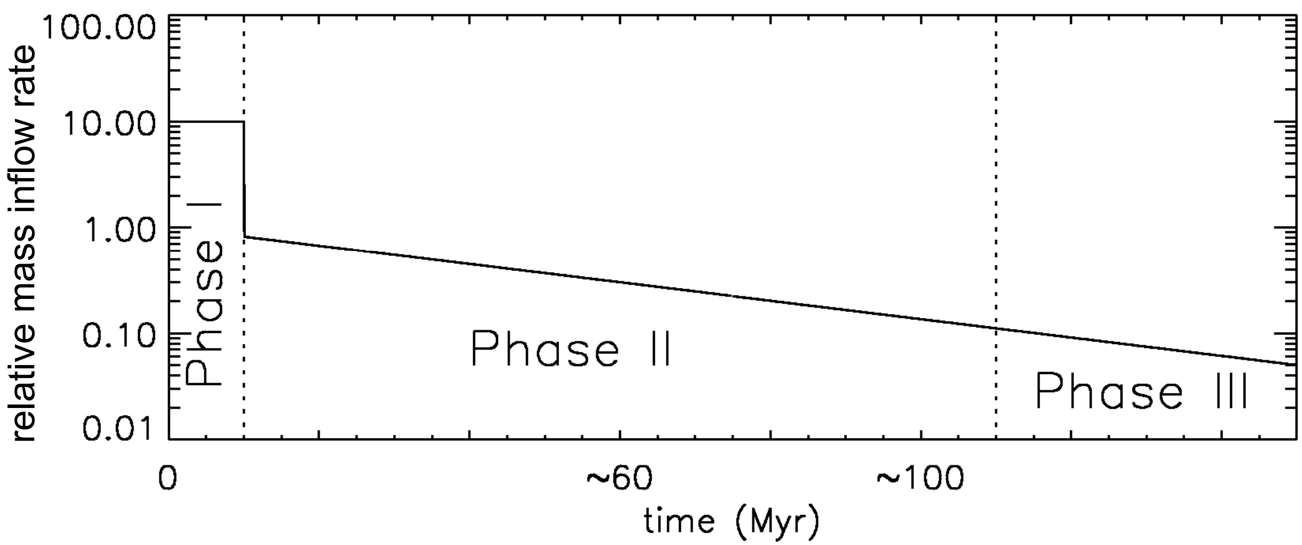
Phase II

(obs. input is V, σ, M_{gas} since the galaxies observed are all in this phase)

mass accretion rate remains high, although decreasing slowly. Model shows that disk thickness remains constant.

Phase III

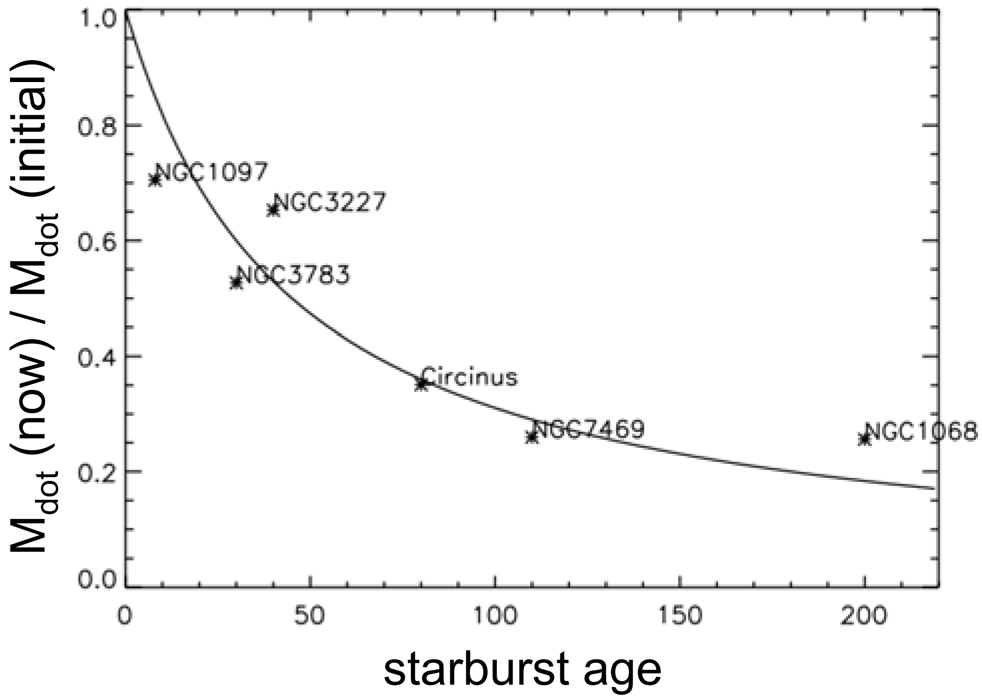
mass accretion rate is now much less. Model shows that disk thickness decreases.



Vollmer, Beckert, & Davies 2008

Application to Observations

Phase II & evolution of mass accretion rate



input:
observations of
V, σ, M_{gas}

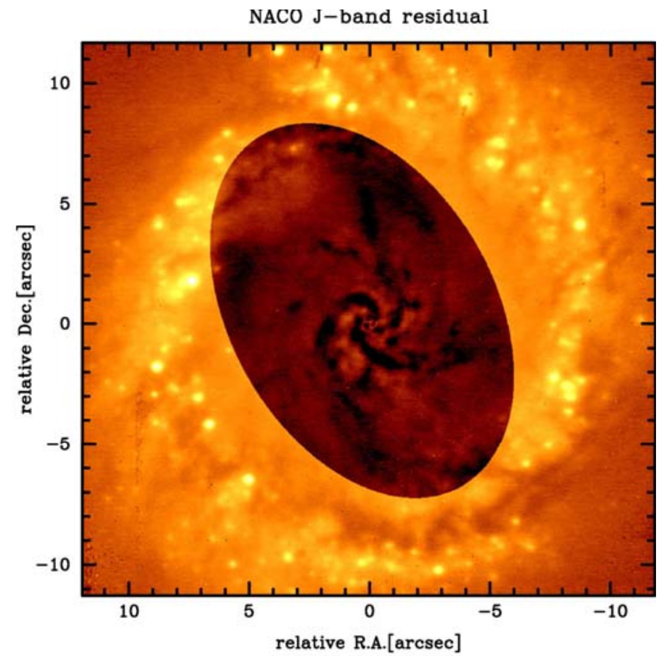
	current collisional disk	
	M_{dot}	Q
Circinus	0.8	5.7
NGC3227	4.3	5.5
NGC1068	**3.5**	5.4
NGC1097	**0.6**	4.8
NGC7469	0.7	5.1
NGC3783	0.1	4.1

- Phase II can last at least ~200Myr
- M_{dot} decreases by a factor ~4
- $\dot{M}_* / \dot{M} \sim 0.04$

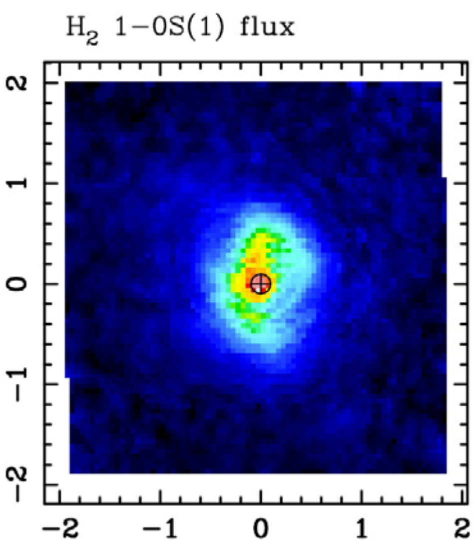
Mass Accretion rate in NGC1097

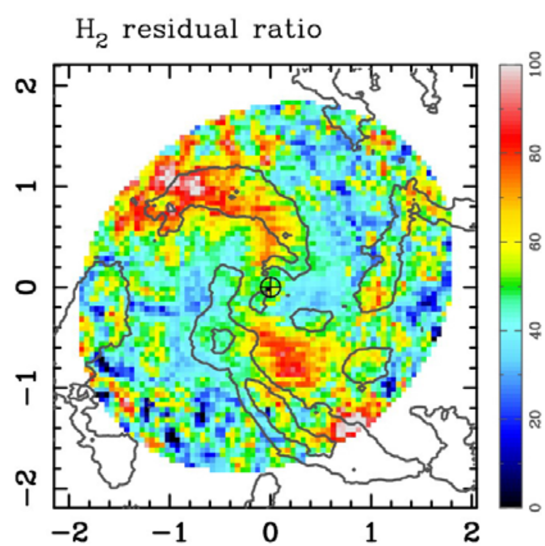
Davies, Maciejewski, et al 09:

- gas flow along spiral arms
- residual velocity ~60km/s
- net inflow rate 0.05-0.5M_{sun}/yr
- gas driven in to ~20pc where it fuels a starburst

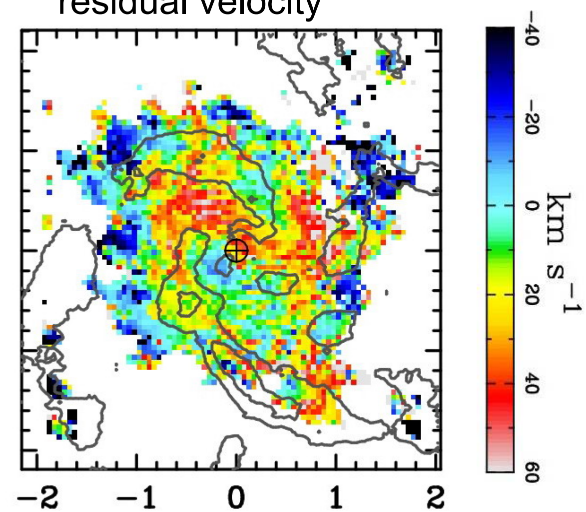


Prieto+05

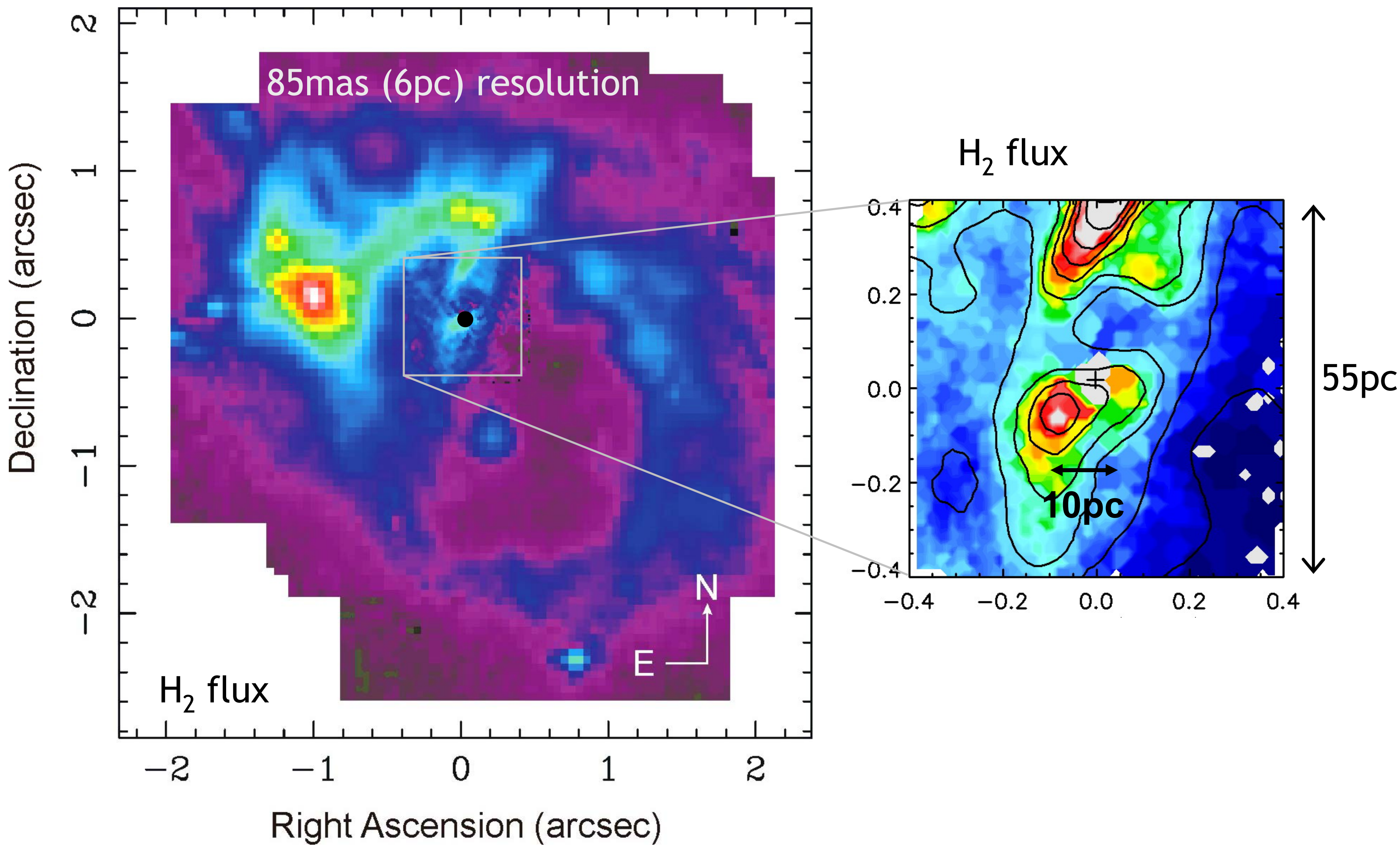




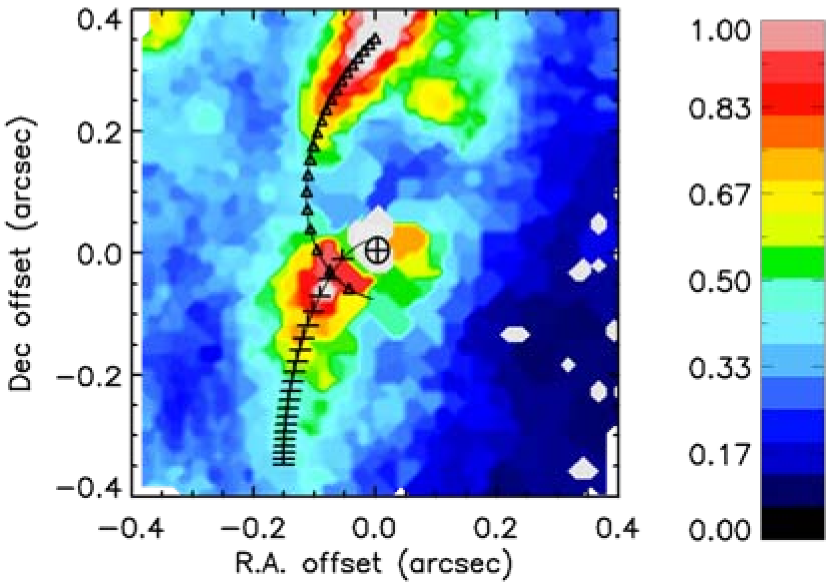
residual velocity

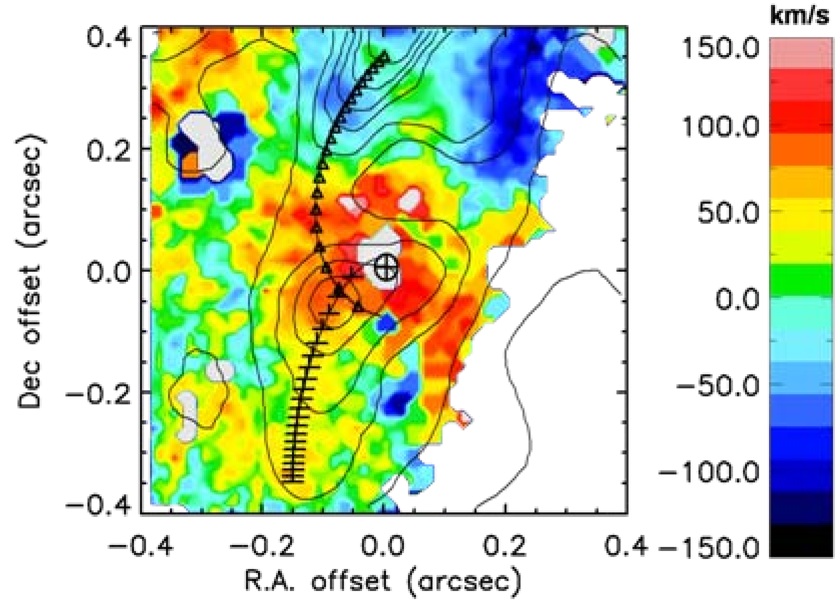


Mass Accretion rate in NGC1068



Mass Accretion rate in NGC1068

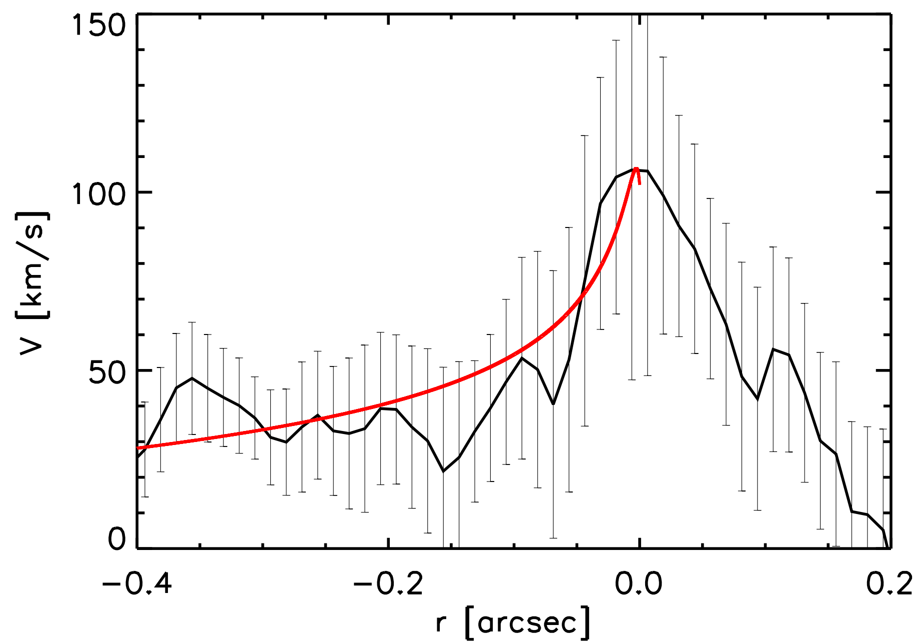




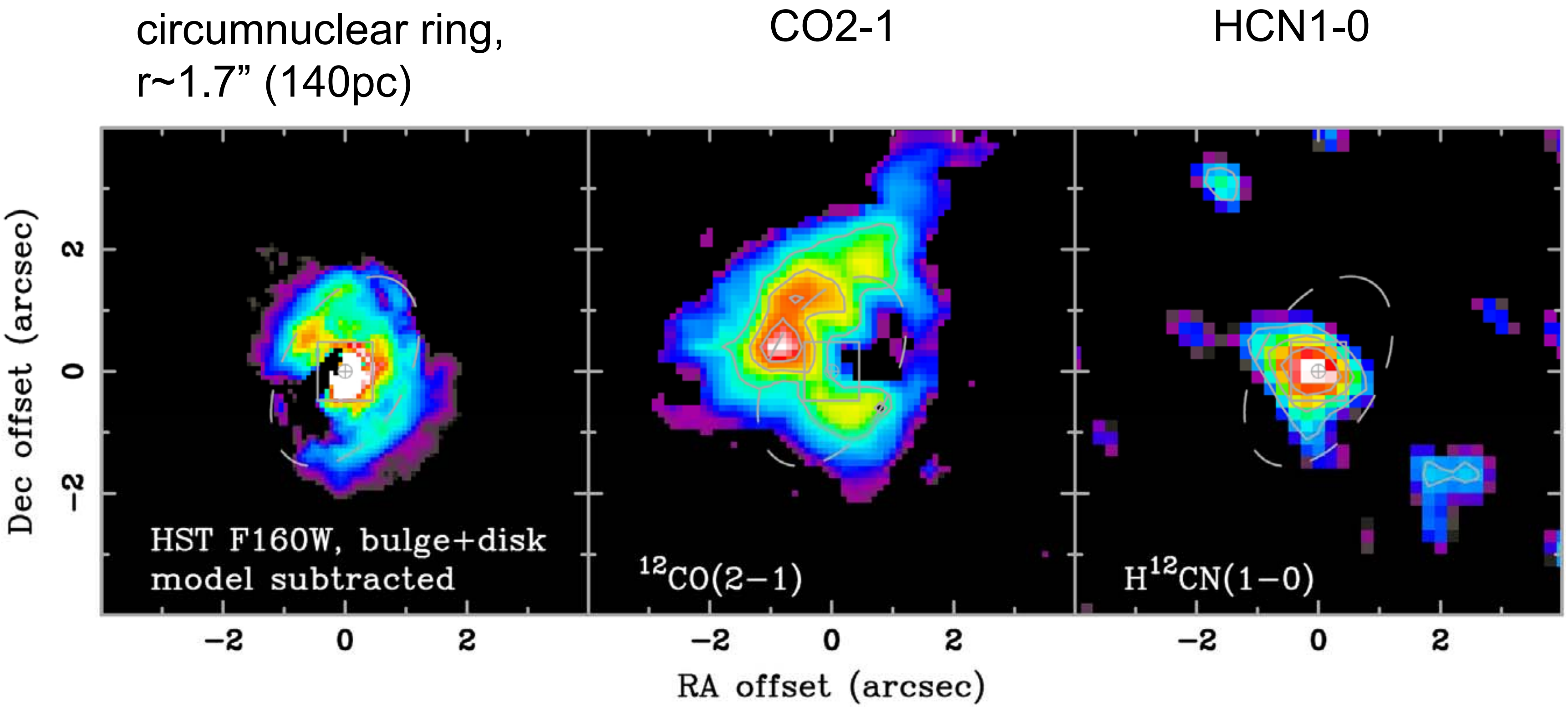
M_{clump} ~ 2 ×10^7 M_{sun}
infall timescale ~ 1.3 Myr
dM/dt (to a few pc) ~ 15 M_{sun}/yr

L_{AGN} ~ 10^{45} erg/s
dM/dt (to BH) ~ 0.03-0.09 M_{sun}/yr

Mueller Sanchez+ 2009



NGC3227: HCN as a probe of dense (>3×10^{4}cm^{-3}) gas

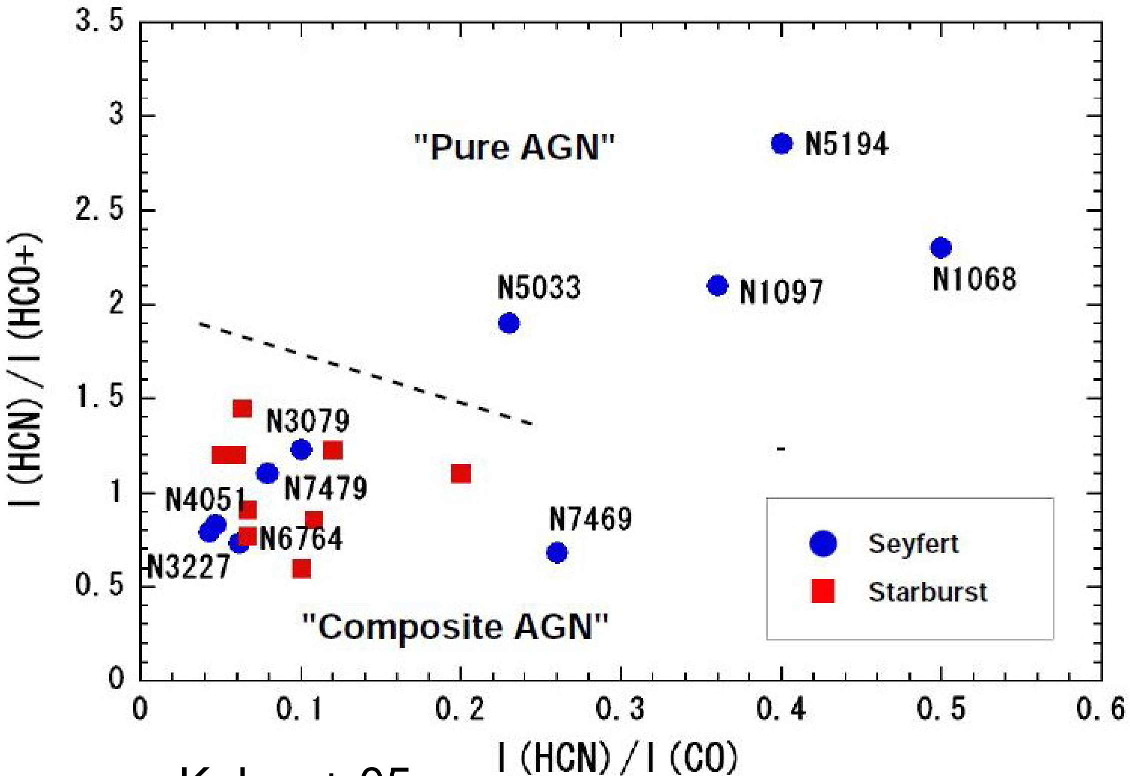


HCN/CO intensity ratio: ~0.01 in the ring
~0.14 in the nucleus

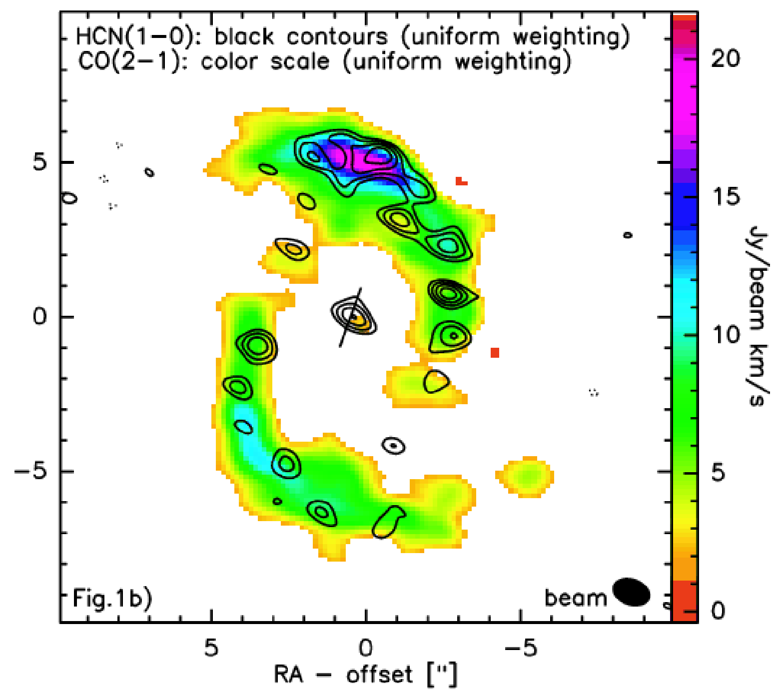
HCN abundance enhancement

Is the HCN enhancement due to XDR associated with the AGN?

- HCN/CO & HCN/HCO+ ratios in central 5” are normal (Kohno+ 05)
- but our nuclear HCN/CO ratio puts NGC3227 with other AGN
- similar to NGC6951 (Krips+ 07): 0.03 in ring & >0.4 in nucleus

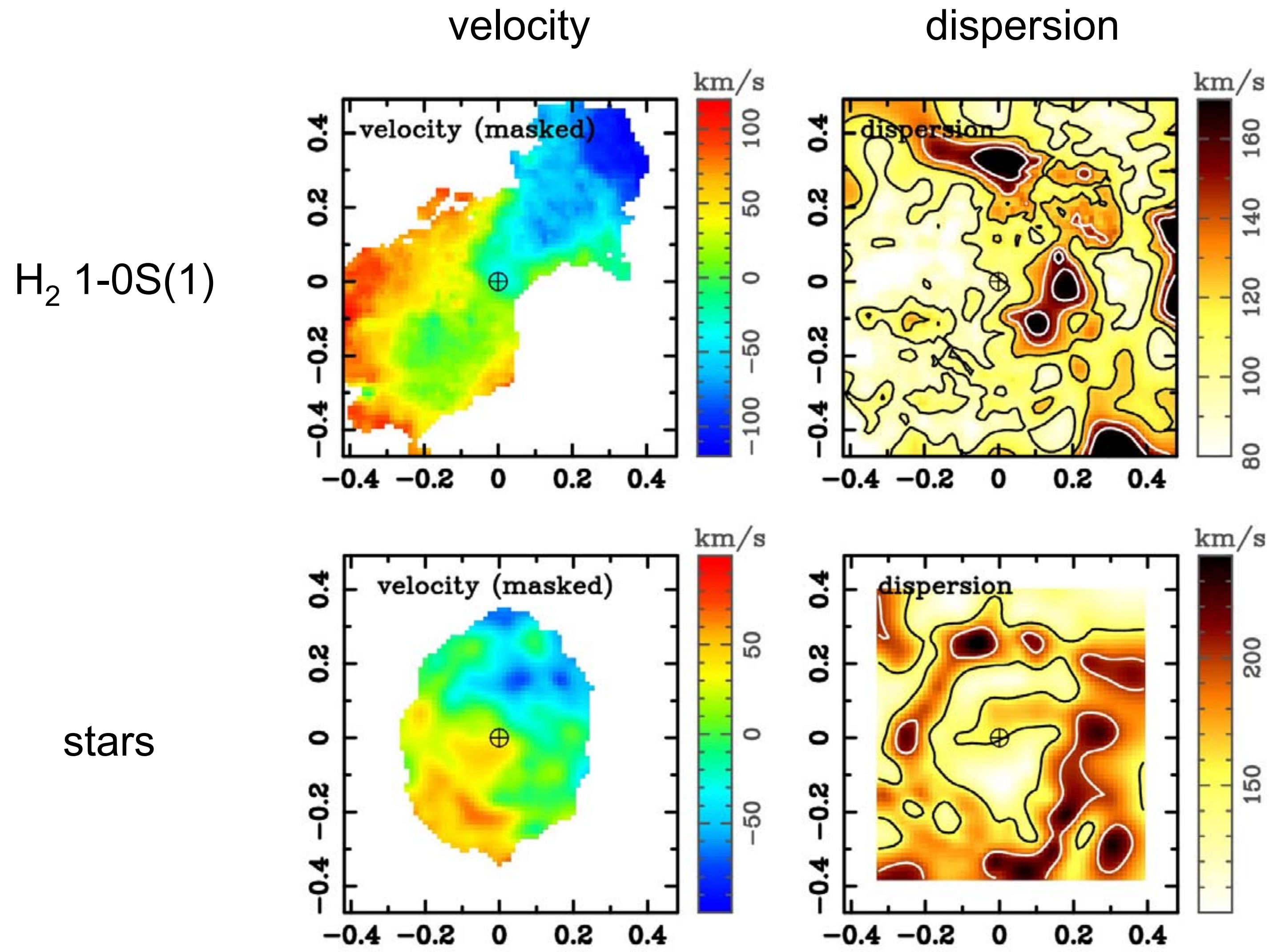


Kohno+ 05



Krips+ 07

Recall SINFONI data for stars & gas

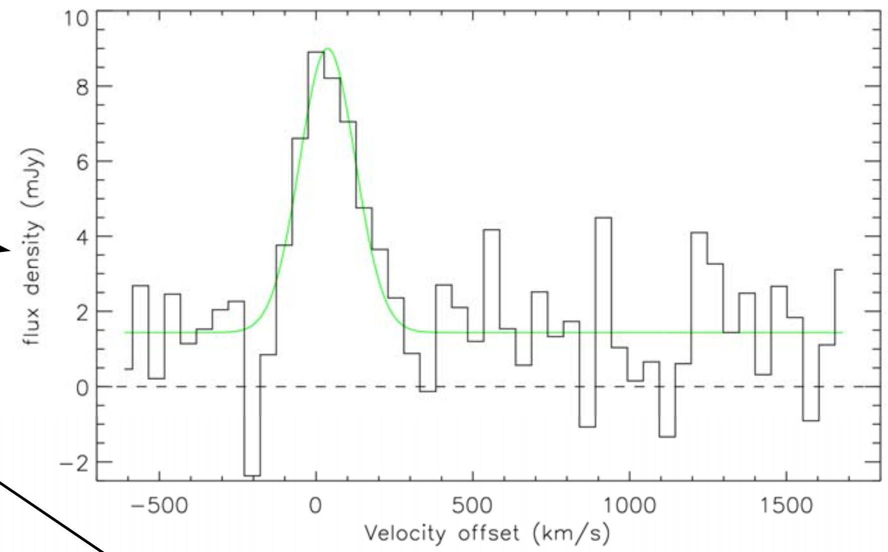


Davies et al. 2006

Observed HCN kinematics

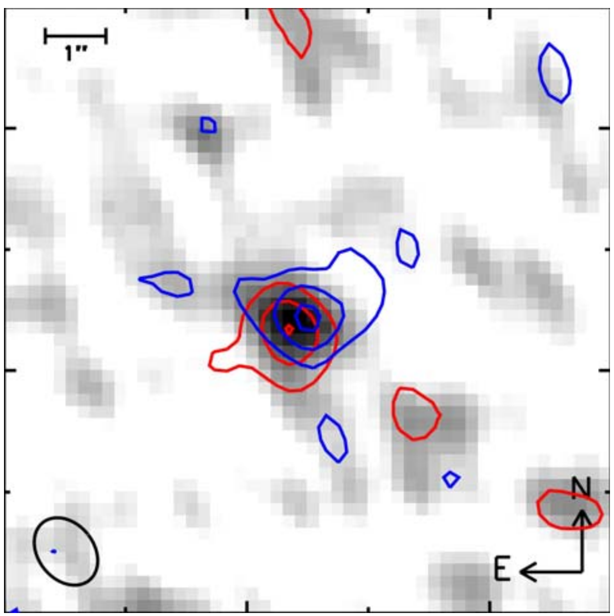
Directly observable constraints

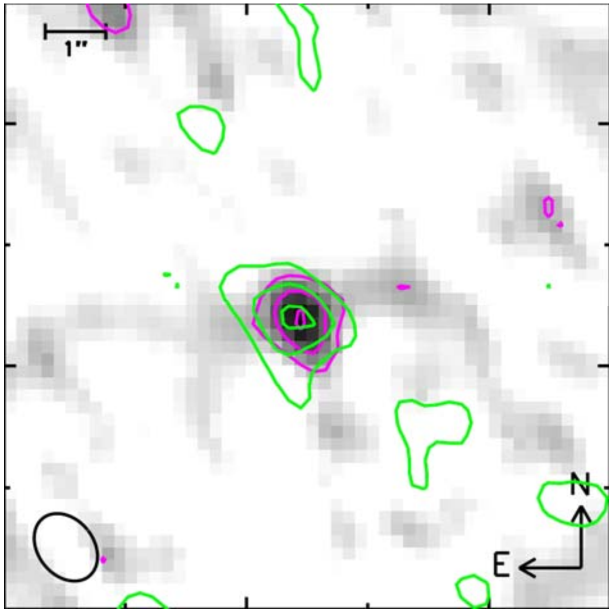
1. integrated line width has σ=95km/s
2. size is 1.2-1.3”
3. axis ratio is 1.4-1.5 (oriented perpendicular to velocity gradient)
4. separation of red/blue channels (+/- 25-250km/s) is 0.36”



Dynamical model

beam smearing plays an important role in what is observed, and is included in the dynamical models





Dynamical Models of HCN

- inclined disk – inclination and position angle from stars & 1-0S(1)
- rotation curve as measured from 1-0S(1)
- elliptical beam

thin disk

- Gaussian & uniform distributions yield similar results
- fails to explain axis ratio
- requires a large additional dispersion to increase linewidth from 45km/s to 95km/s

thin, fast rotating disk

- dispersion is entirely due to beam smearing of velocity gradient
- separation of red/blue velocity channels is too high

thick disk

- dispersion given by $V/\sigma=R/H$
- reproduces all characteristics reasonably well
- even dense clouds are scattered to a significant (~30pc) height

Conclusions

- Intense starbursts occur in the central 10s of pc around AGN, and are probably inevitable

- Stellar outflows play an important role:
  - OB winds & supernovae blow out intercloud medium & delay accretion
  - slow winds are able to stream down to smaller scales

- We propose an evolutionary scenario:
  - starburst → thick collisional disk → thin disk
  - everything depends on time evolution of external mass accretion rate
  - predictions of collisional disk & accretion rates are supported observationally