An Observational Perspective on the Drivers of Torus Evolution

Richard Davies
Max Planck Institute for Extraterrestrial Physics, Germany

- Torus must be a dynamical structure, the properties of which depend on the balance between inflow & outflow
- Outflow: implications of ionisation cone geometry
- Inflow: thick molecular disks on 50pc scales

NGC1365

NGC3081

NGC1068

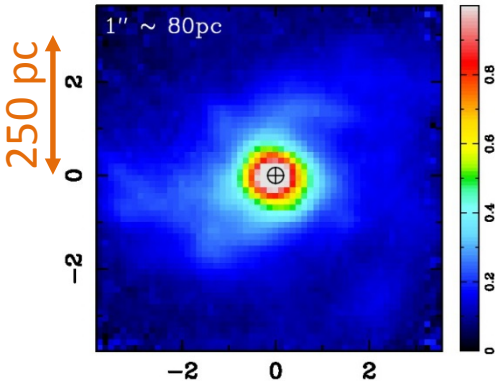
NGC4051

Nuclear inflow & outflow imply an evolving torus

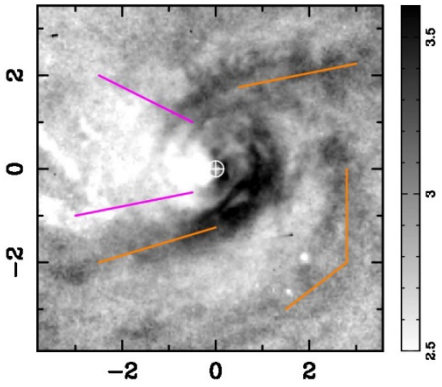
NGC 5643

Large scale bar stimulates circumnuclear spiral/ring which drives inflow;
Molecular outflow superimposed (ionized outflow is well known); see Davies+ 14

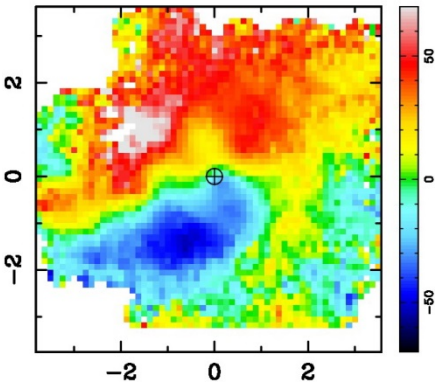
H_2 1-0S(1) flux



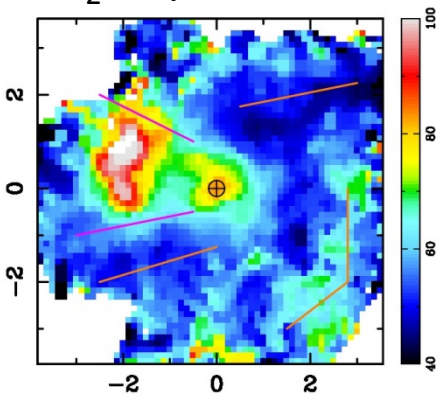
V-H dust structure



H_2 velocity

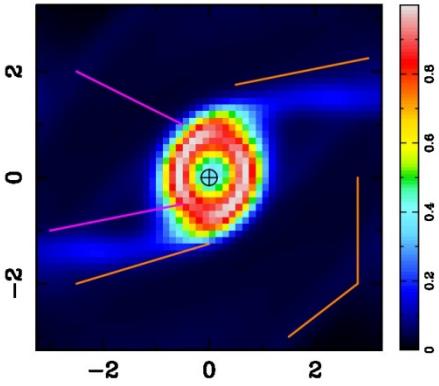


H_2 dispersion

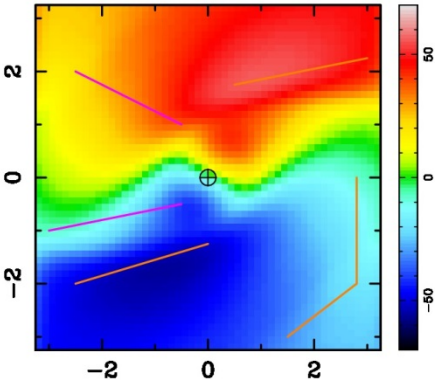


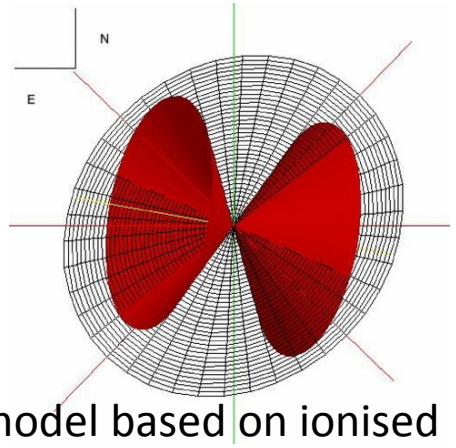
- Model S20 from Maciejewski 04.
- Bar & host geometry matched to NGC 5643.
- Scaling applied.

Model gas density



Model gas velocity





model based on ionised gas (Fischer+ 13)

Nuclear inflow & outflow imply an evolving torus

Many observations & measurements of inflow & outflow

Storchi-Bergmann+14 (see also Veilleux+ 05)

Seyferts: log L_{AGN} [erg/s] ~ 42-45

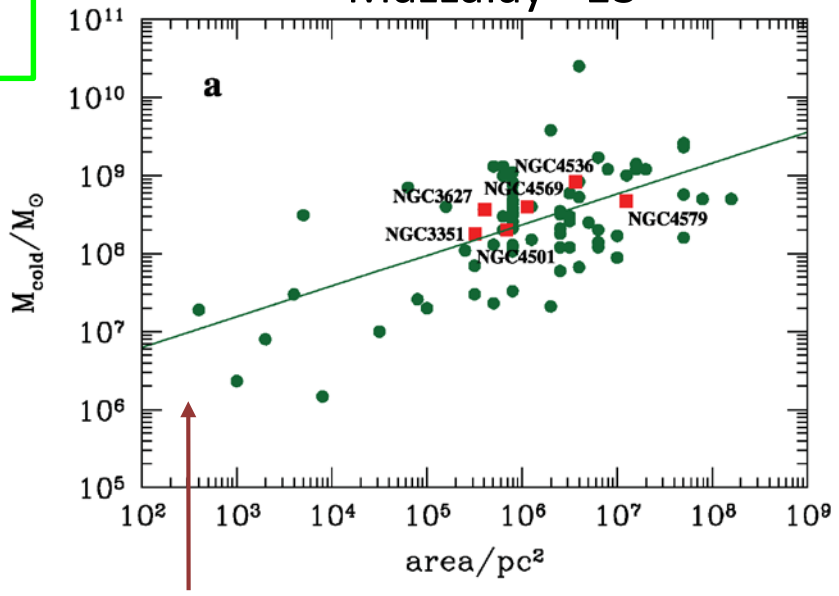
$\dot{M}_{BH}$ ~ 10^{-4} to 0.1 M_{sun}/yr

Inflow rates 0.1-1M_{sun}/yr

Outflow rates 0.5 to a few M_{sun}/yr

- Very little of the inflowing mass accretes onto the BH
- Most of the mass must pass through the torus
- Torus properties are determined by balance between gas inflow from large scales & AGN driven outflow

Mazzalay+ 13



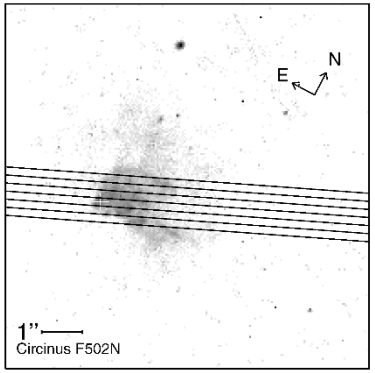
R=10pc

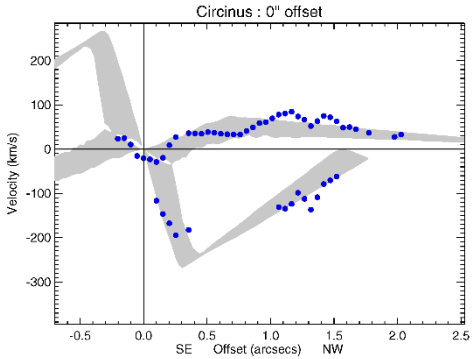
~10^7 M_{sun}

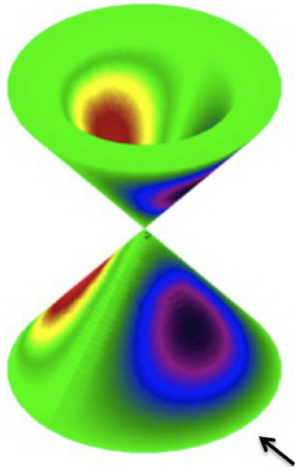
Ionised Outflows: modelling the 3D geometry

- model *kinematics* of coronal lines emission as outflow bicone + rotating disk
- outflow accelerates to few hundred pc, and then decelerates
  (Das et al. 06 – see also Matzner & McKee 99, Everett & Murray 07)
- Only possible in 1/3 of sample; others ambiguous, compact, complex (Fischer+ 13)

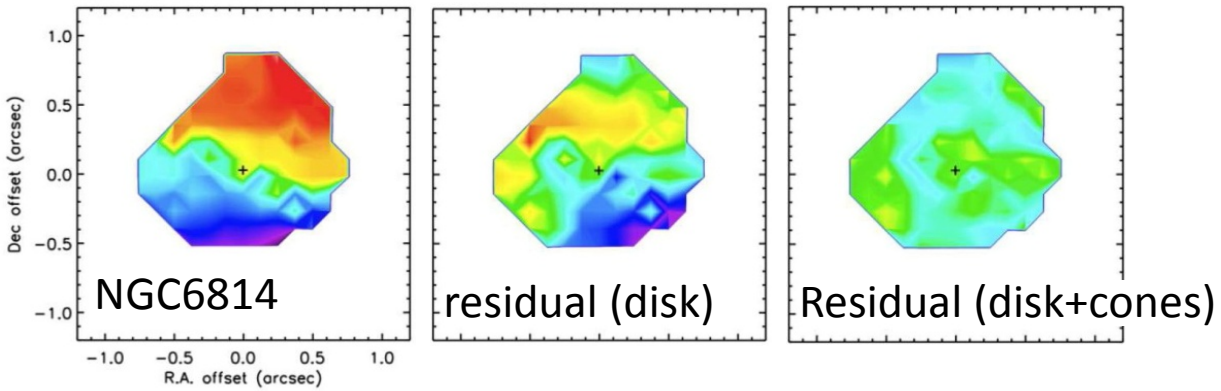
Fischer+13:
[OIII] in slits
from STIS

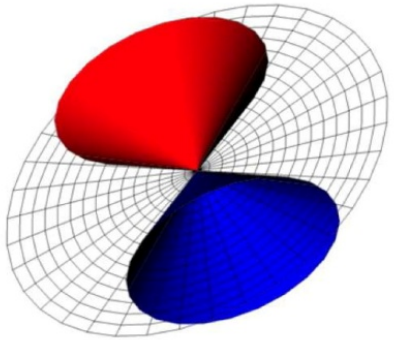






Müller Sánchez+ 11: [SiVI] & Brγ from SINFONI IFU



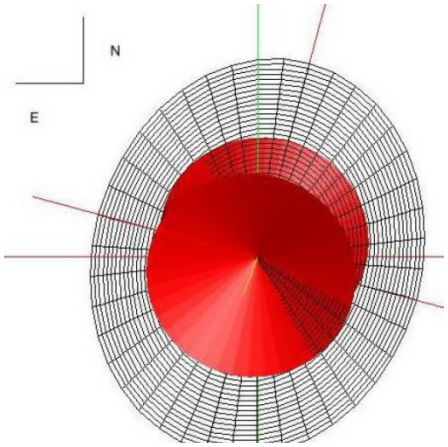


Ionised Outflows: 3D geometry & orientation

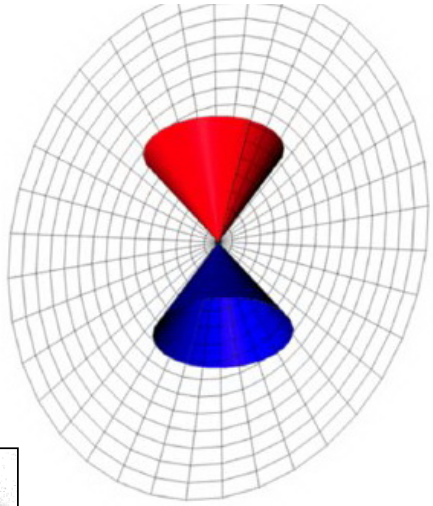
Spatially resolving the base of the outflow in nearby AGN

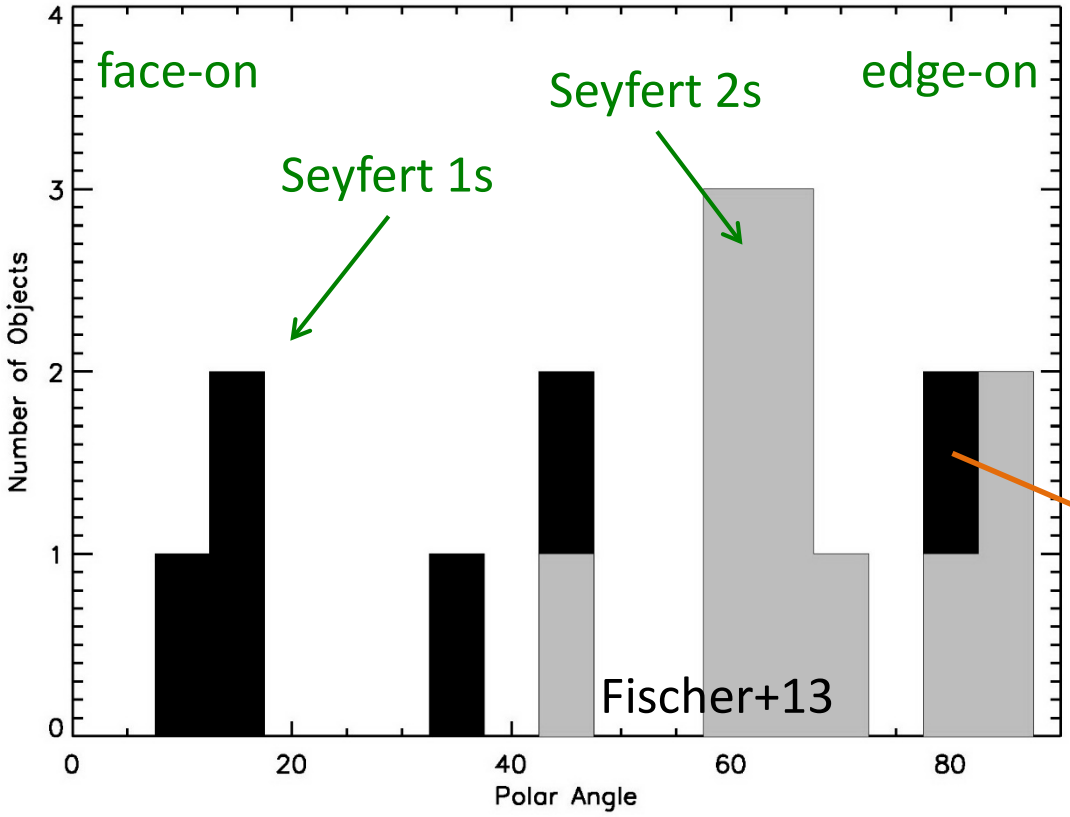
Crenshaw+ 11 [NLS1s], Müller Sánchez+ 11, Fischer+ 13:

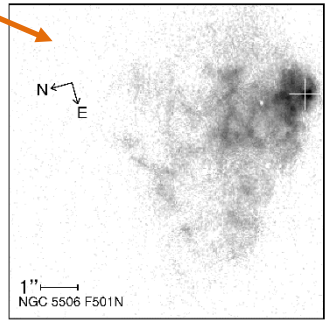
- Some overlap, mostly consistent results
- 10 Seyfert 2
- 10 Seyfert 1



NGC 3783







NGC 5506

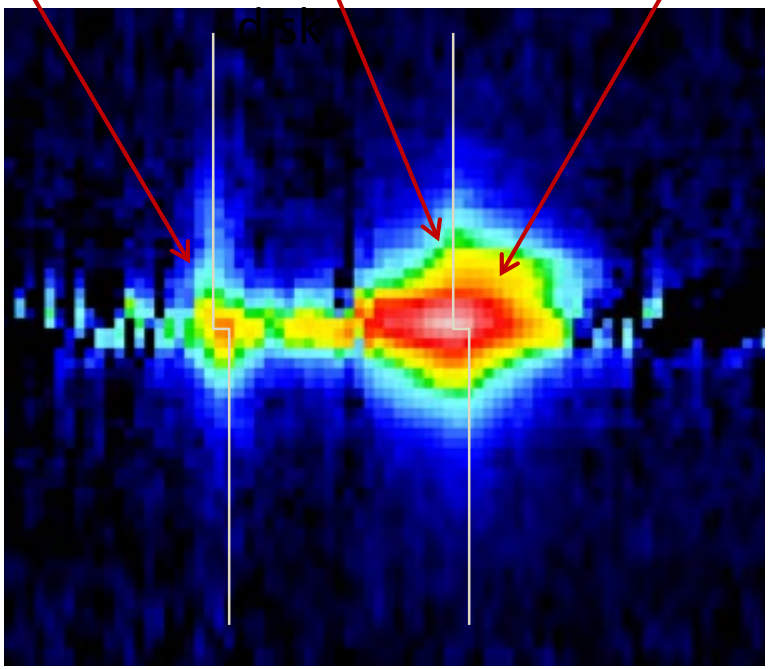
Ionised Outflow Geometry: NGC3783

PV diagram (continuum subtracted line emission) at PA -5deg

H_2 1-0S(3) in rotating disk

[Si VI] narrow cpt in rotating disk

[Si VI] broad cpt in outflow

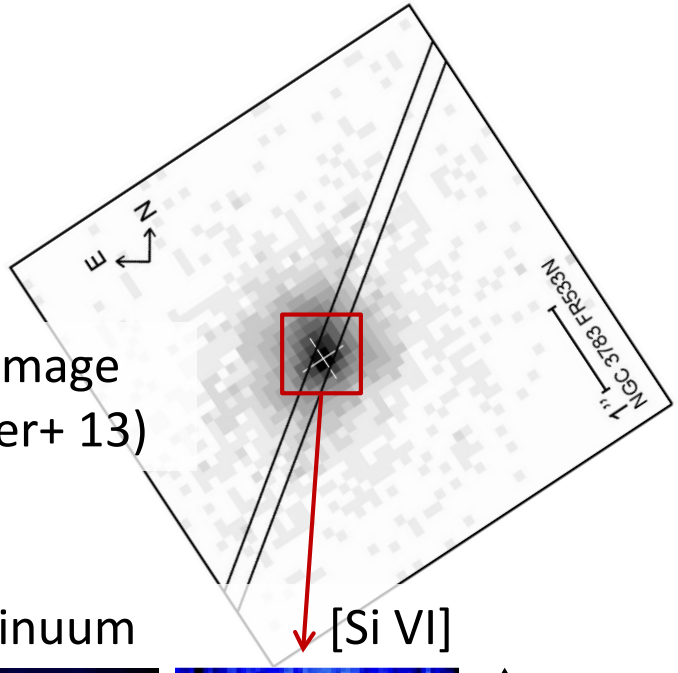


north

south

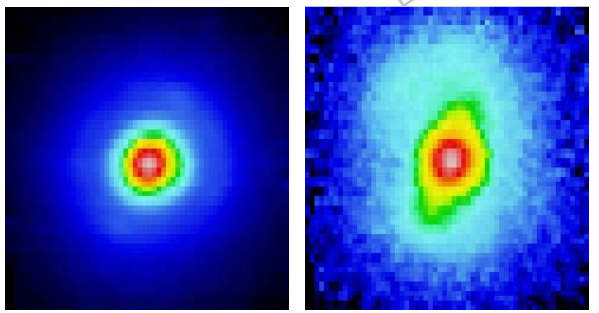
velocity

[OIII] image (Fischer+ 13)

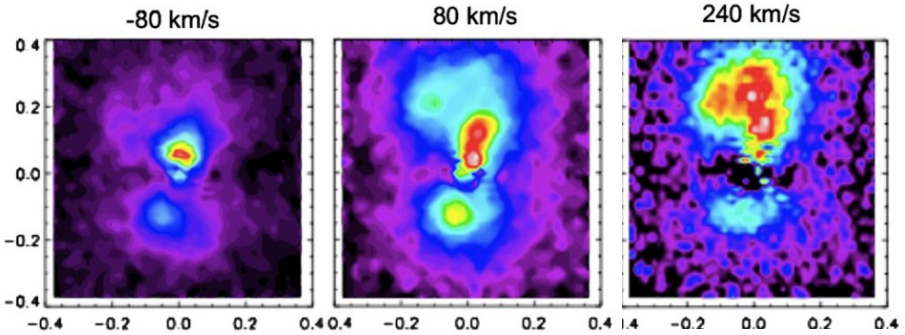


Continuum

[Si VI]



0.8”



Ionised Outflows: 3D geometry & orientation

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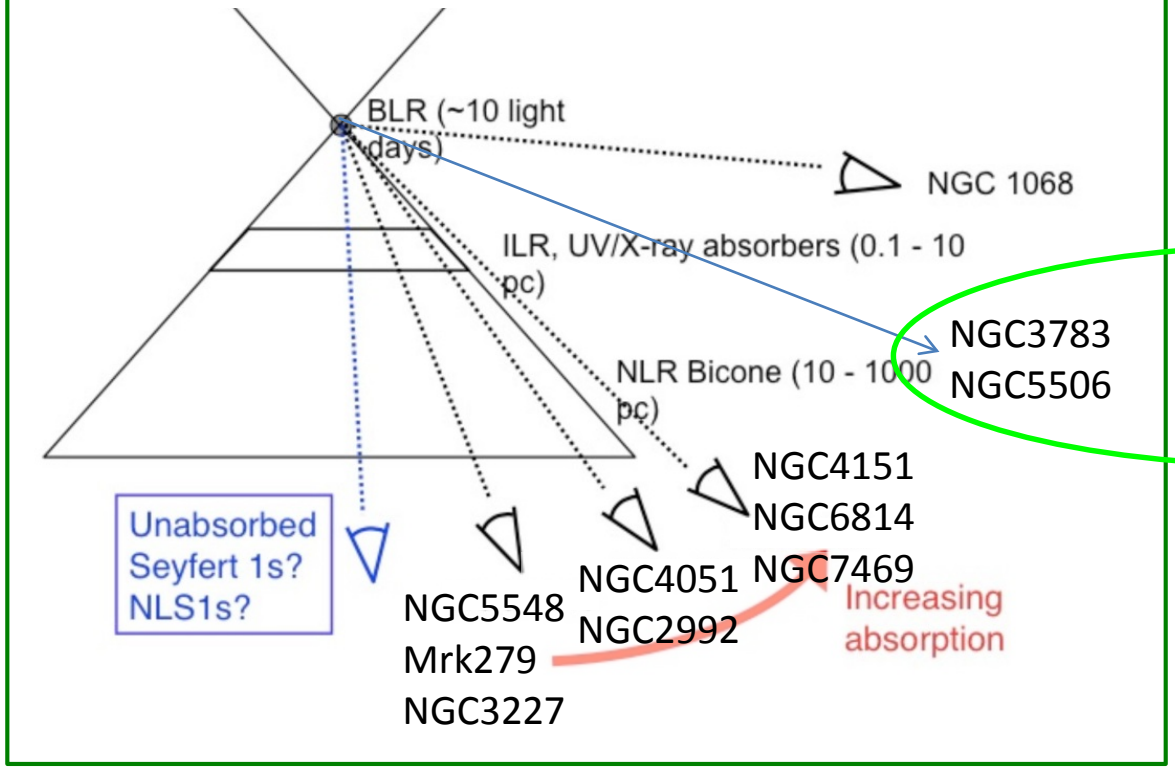
- Some overlap, mostly consistent results
- 10 Seyfert 2
- 10 Seyfert 1 : 3 face-on, *5 close to cone edge, 2 side-on.*

Schematic AGN model (adapted from Crenshaw+11)



2 of 10 Seyfert 1s are edge-on.

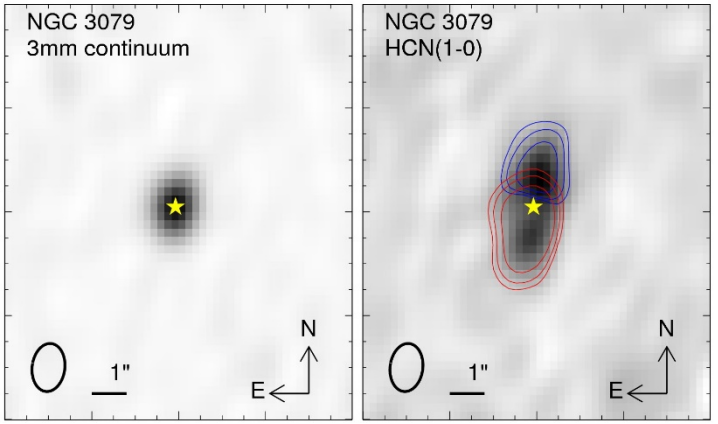
Thick Molecular Gas Disks on ~50pc scales

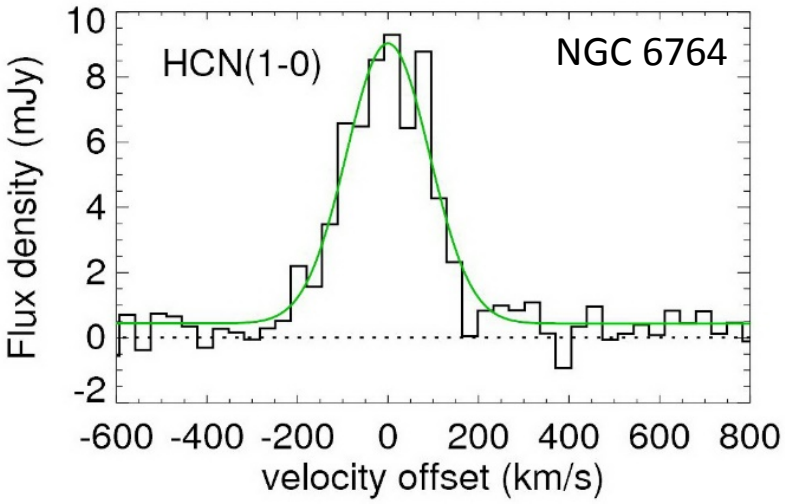
Sani, RD, + 12
Lin, RD, + submitted

- HCN observations probe dense >3×10^{4}cm^{-3} gas
- ~1” resolution from PdBI for 8 Seyferts
- Velocity gradient is spatially resolved
  & lies along galaxy major axis

Directly observable constraints:

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





Thick Molecular Gas Disks on ~50pc scales

- Model as inclined disk with finite thickness
- Elliptical beam (beam smearing is a key input to dynamical models)

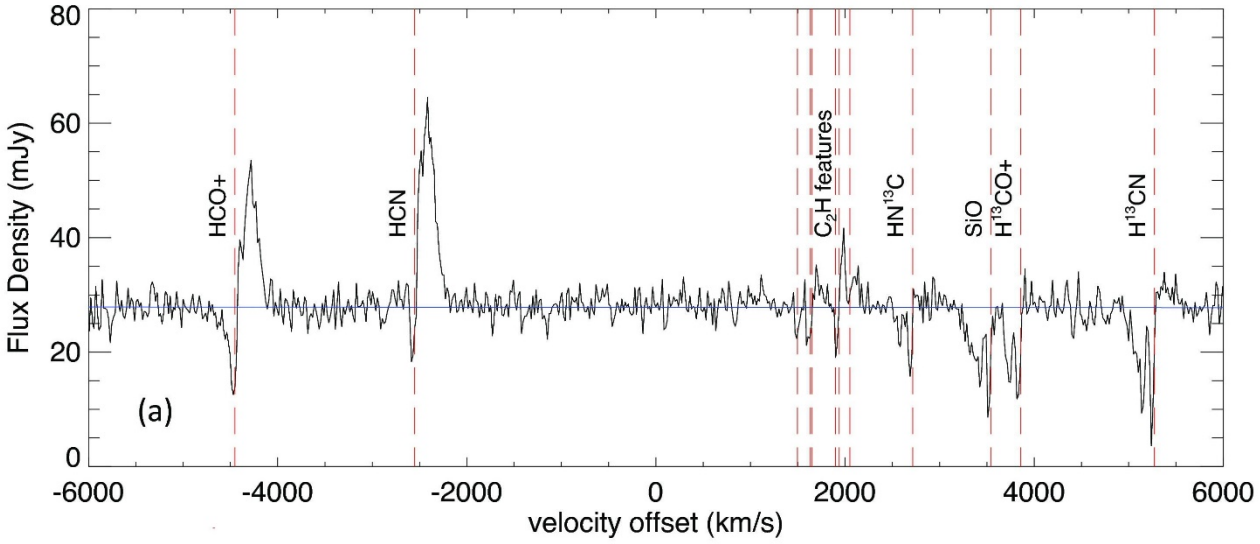
- thick disk reproduces all characteristics in 7 of 8 Seyferts
- dispersion due to a combination of beam smearing of velocity gradient as well as $v/\sigma \sim 3$
- intrinsic dispersion is 25-50 km/s for HCN & HCO^+
- about half that of 1-0S(1) reported by Hicks+ 09

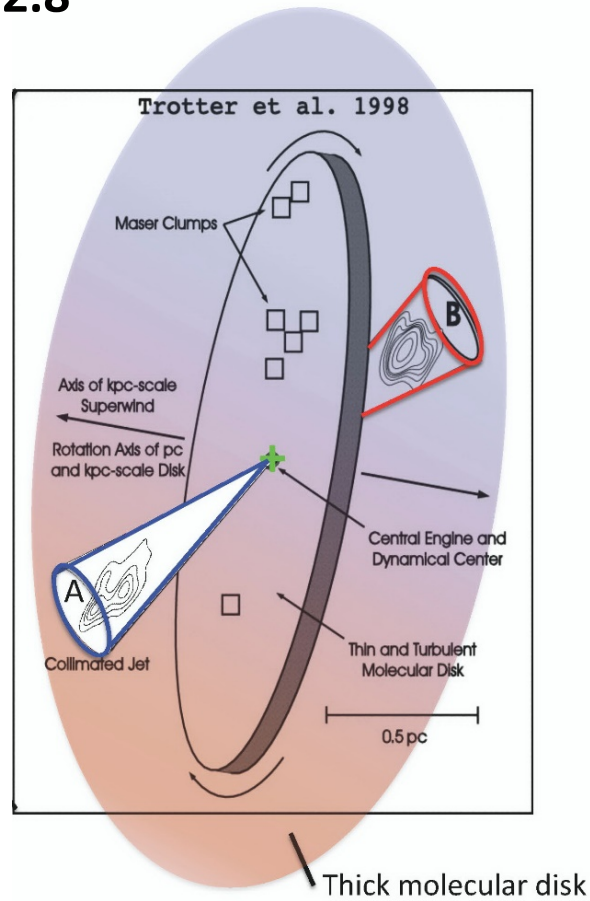
ΔV_{FWHM}=60-120km/s,
cf 27km/s for HCN in GC

- ➢ Dense gas is turbulent
- ➢ Column densities: log N_H [cm^{-2}] ~ 22.5 - 23
- ➢ Since $v/\sigma \sim 3$ this structure already obscures AGN from 30% of viewing angles
- ➢ Is this the outer part of what, at smaller radii, becomes the torus?

NGC 3079: absorption measures disk column density

- Well known starburst driven superwind (Cecil+ 01)
- 20-100keV: compton thick AGN, $L_{2\text{-}10keV} > 10^{42}$ erg/s (Iyomoto+ 01)
- PdBI: HCN & HCO^+ emission as well as HCN, HCO^+, SiO, HNC absorption
- Absorption depth -> column density, **log N_H [cm^{-3}] ~ 22.8**



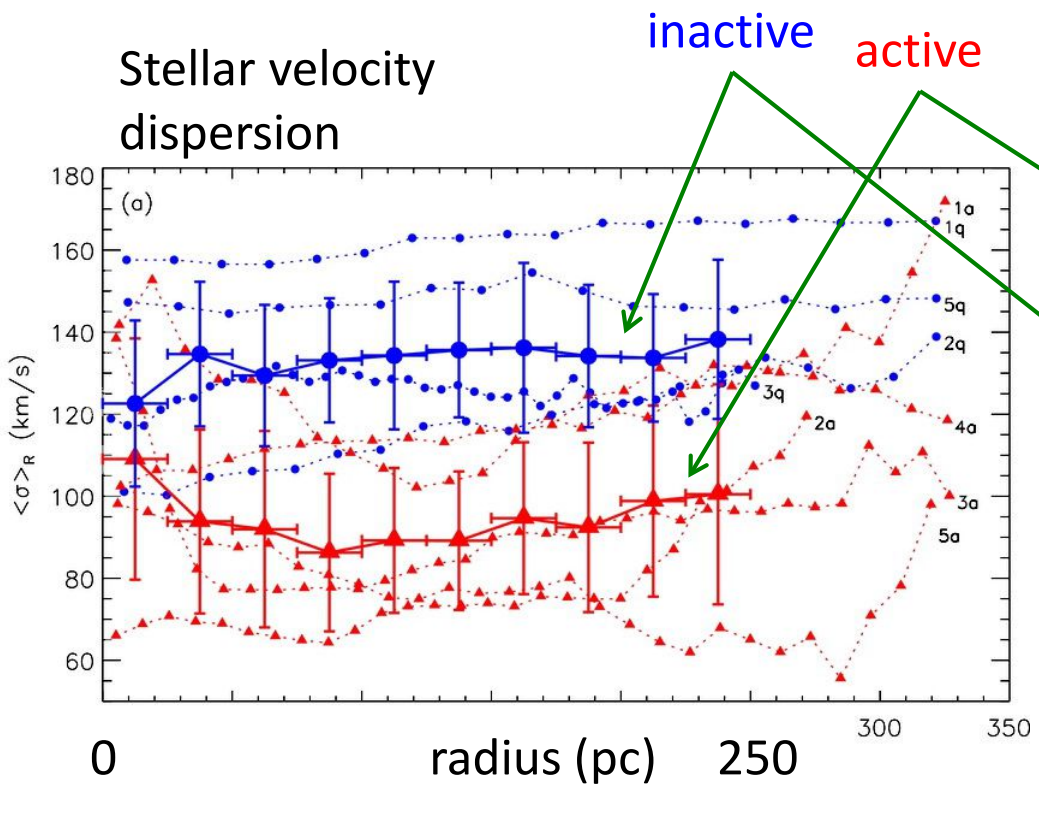


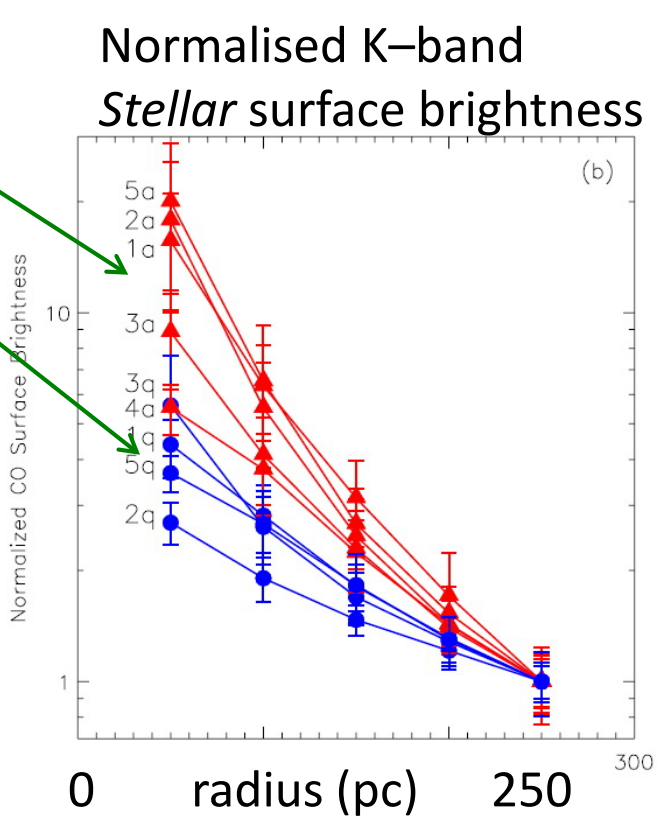
Lin, RD, + submitted

Are there signs of star formation on ~50pc scales?

Hicks+ 13, Davies+ 14

- Systematic differences between active & inactive galaxies
- Seyferts have kinematically distinct population of young stars
- Low Brγ equivalent width rules out OB stars -> young post-starbursts



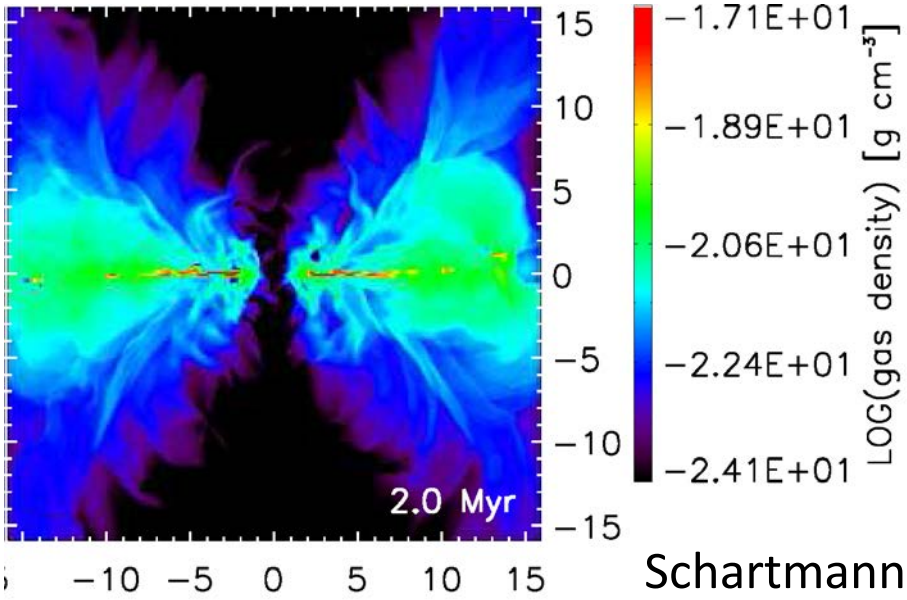


Are there signs of star formation on ~50pc scales?

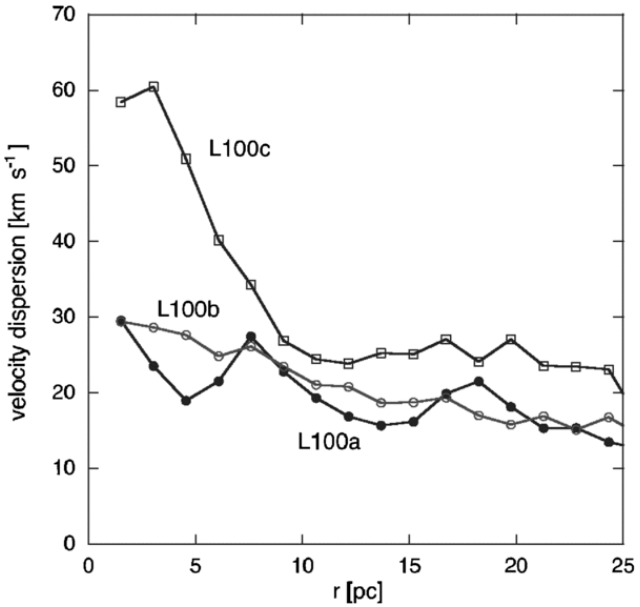
3D Hydrodynamical simulations
Wada+ 09, 12, 15 & Schartmann+ 14

(but see also Schartmann+ 09, 10)

- Stars & supernovae in thin disk
- Supernovae create thick gas disk & drive inflow (turbulent viscosity)
- σ ~ 20km/s
- In these simulations, the puffed-up star forming disk *is* the torus (see Wada 15)



Schartmann+ 14



Wada+ 09

Conclusions

- Torus must be a dynamical structure, the properties of which are determined by balance between gas inflow from large scales & AGN driven outflow

- 3D geometry of ionisation cones

  Ionisation cones in 2 of 10 Seyfert1s are seen edge-on: covering factor, rather than just orientation, is important.

- Thick gas disks on 50-100pc scales

  These structures are the outer part of the torus