Sub-arcsecond, decimetre absorption studies of Active Galaxies

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Also…
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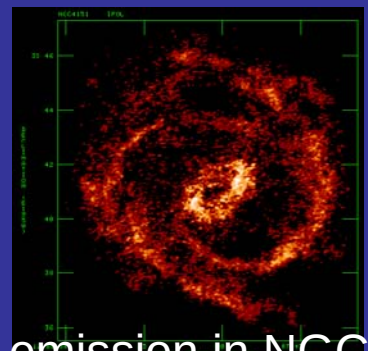
1. **Why use decimetre absorption?**
2. **Examples of Intermediate resolution statistical studies**
3. **High resolution case studies:**
   - **Seyfert Galaxies: NGC4151, NGC7674, NGC7469, NGC3079…. (+ NGC6240)**
   - **Radio Galaxies: 3C293, 3C305..**

Radio observations of HI at high resolution

- Small brightness temperature T_b~100K
- Small beam
- Large wavelength
- Narrow bandwidth (line width)
- Rayleigh-Jeans equation implies that

$$S = \frac{2 k T_b \Omega_b}{\lambda^2}$$

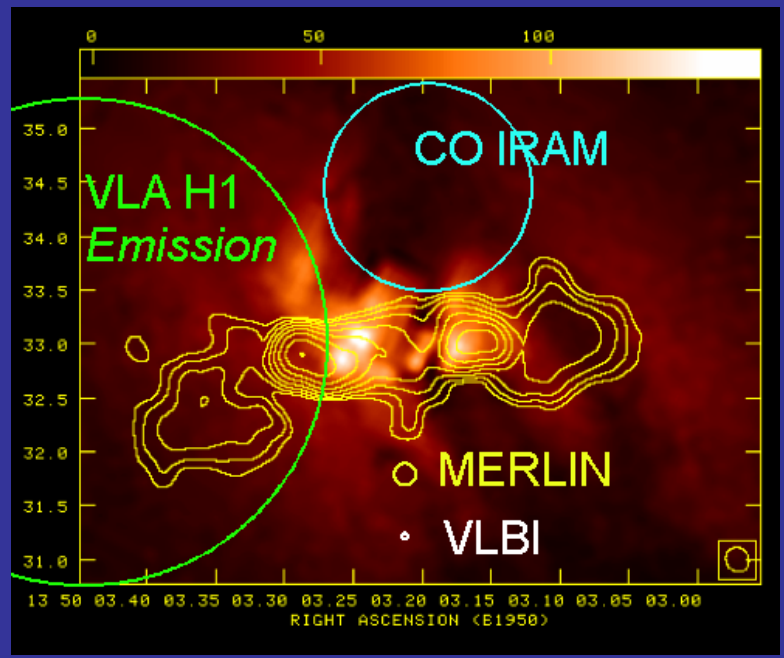
- **HI Emission studies are limited to resolutions ~few arcseconds at best.**



H1 emission in NGC4151 (Mundell et al 1999)

Observing neutral/molecular gas

- VLA emission –H1 gives ~**5 arcsec resolution**
- mm synthesis (CO) gives ~**1 arcsec resolution**
- MERLIN (& HST) ~**100mas**
- VLBI gives **<10mas**



Solutions (???)

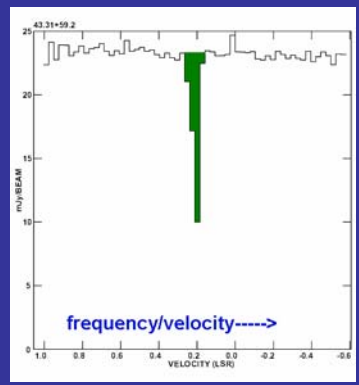
- More collecting area --- SKA (in the future)
- Shorter wavelength to get the resolution (study other lines, molecular etc) --- ALMA

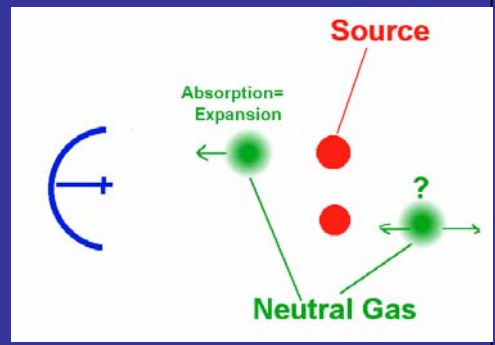
OR

- Observe the gas in absorption.. Where the line strength is determined by the background source (i.e. $T_b > 10^5$ K)

The advantages of *absorption* studies

- **Absorption line strength**
  - Determined by the brightness temperature of the background
  - Many Active Galaxies emit Synchrotron $T_b > 10^5$ K
    - (compare with **100K** excitation temperature)
- **Angular resolution**
  - arcsecs- few mas 100pc- <1pc
- **Geometry-** Absorber must be in front!
  - ie **Blueshift** must = expansion
  - & Redshift=infall





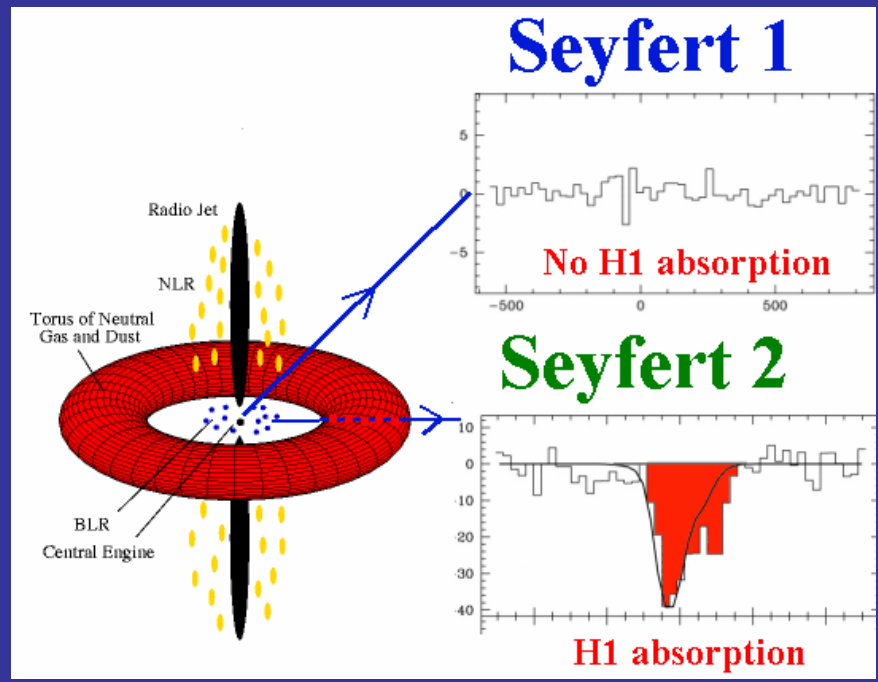
What can we get?

- Investigate the ‘dusty torus’ (obscuration)
- Measure velocity fields of gas
  - Circular motions =>enclosed masses…
  - Bars/fuelling mechanisms, Infall/Outflows etc
- Relationship between the neutral gas velocities and distribution to starbursts

(ALL AT SUB-ARCSEC ANGULAR RESOLUTIONS)

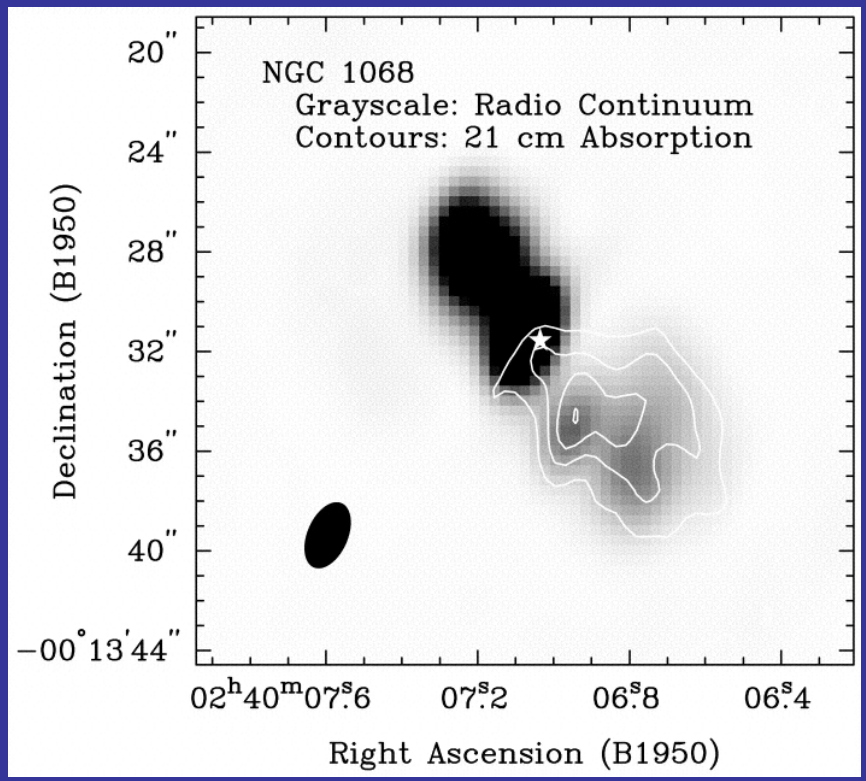
Simple test of dusty torus model

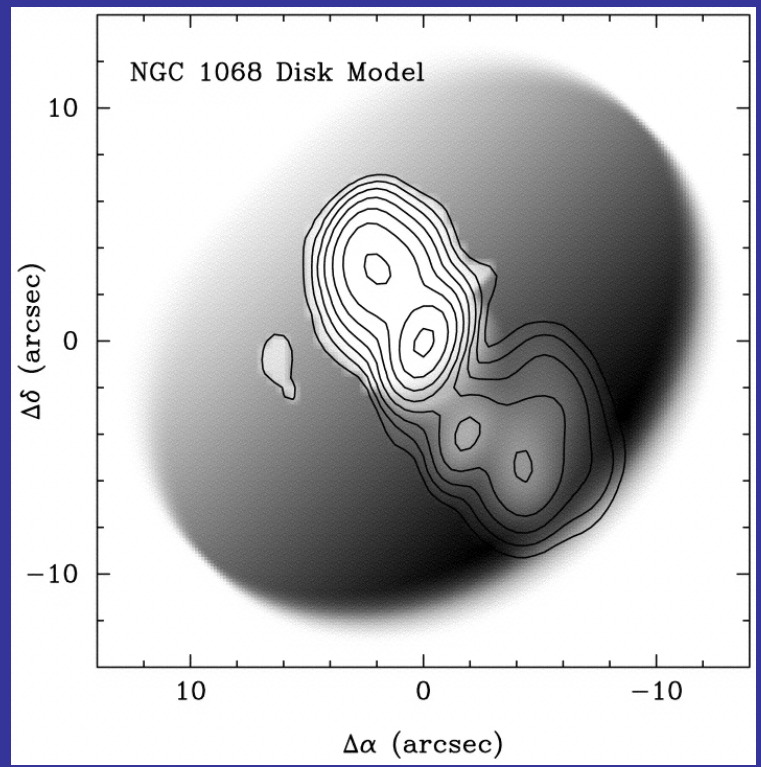
- Opposite of BLR lines
- Assume Torus contains H1
  - Column density >10^{19} atoms cm^{-2} T_s~100K
- Seyfert 2s (with radio emission) should show 21cm H1 absorption from Torus
  - But Seyfert 1s should not



Arcsecond resolution studies: H1 absorption not against nucleus

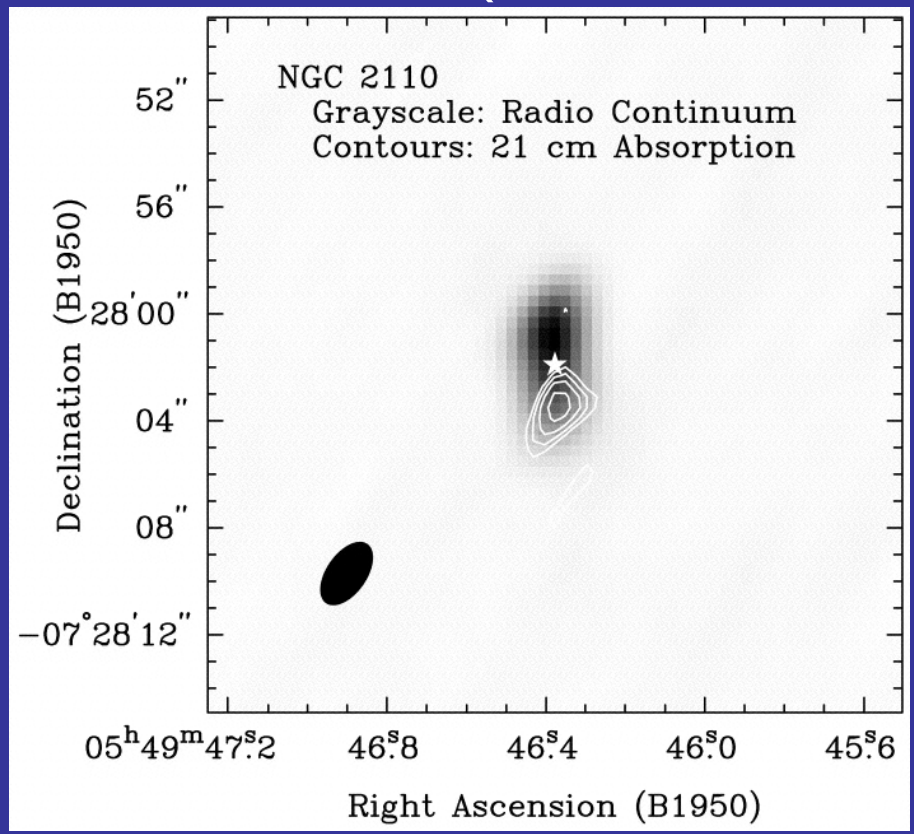
- NGC1068 (Gallimore et al 1999)

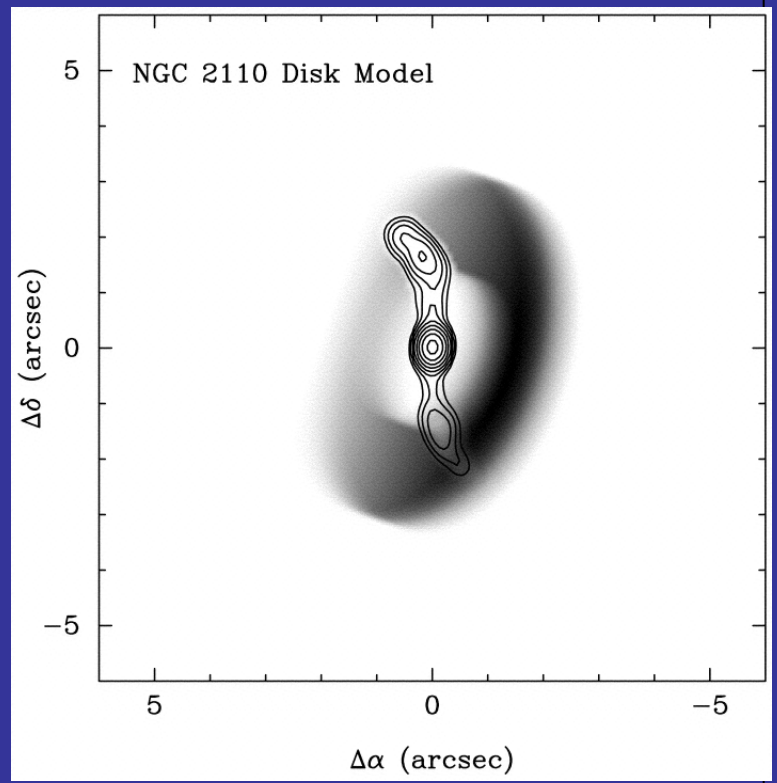




H1 absorption not against nucleus

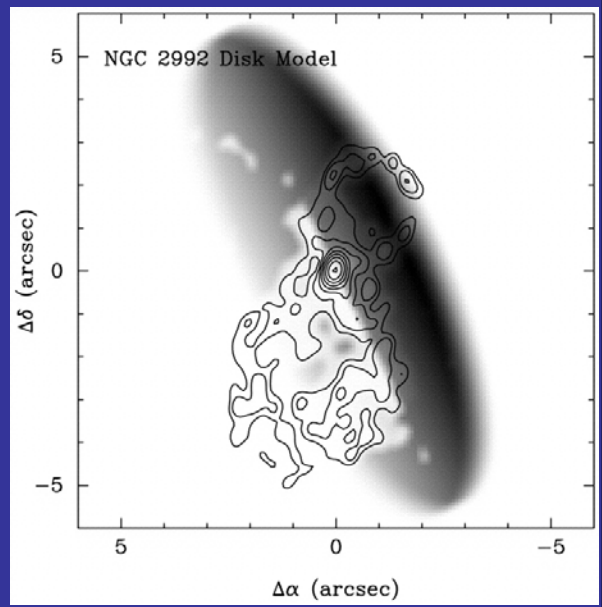
- NGC2110 (Gallimore et al 1999)





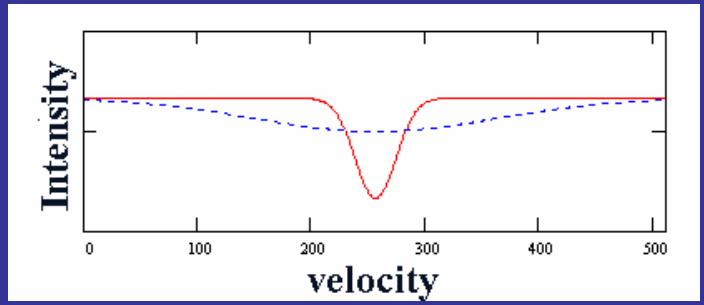
H1 disks

- Gallimore et al detected disks/rings
  - Column densities ~10^{21} atoms cm^{-2}
  - Typical sizes 500-1000pc
- Too large for ‘Dusty Torus’
  - (Hides NLR as well as BLR)



Why no H1 absorption by Torus

- Kinematic Line Broadening?

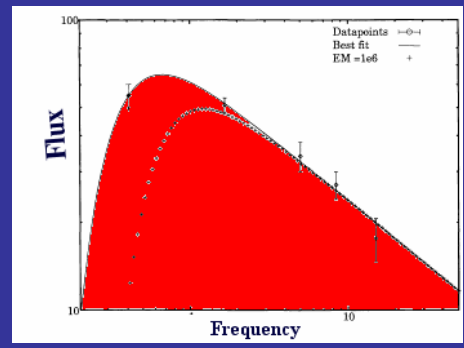


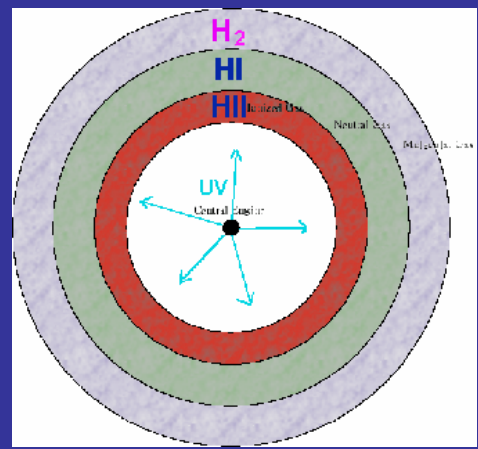
- Raising spin temperature
  - Intrinsic T_s >>100K
    - L_α pumping
    - Absorption of 21cm continuum

$$\int \tau . dv = \frac{5.49 \times 10^{-21} . N_{H1}}{T_s / 100}$$

Why no H1 absorption by Torus

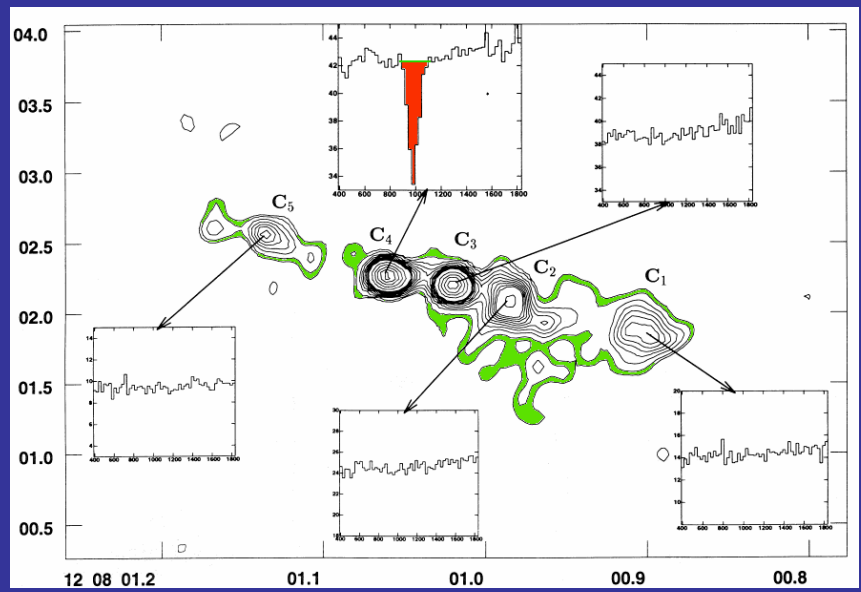
- Suppression of 20cm continuum
  - Free-Free absorption
  - Synchrotron self absorption
  - May apply to NGC1068
- Narrow dissociation front
  - H mostly HII & H_2?



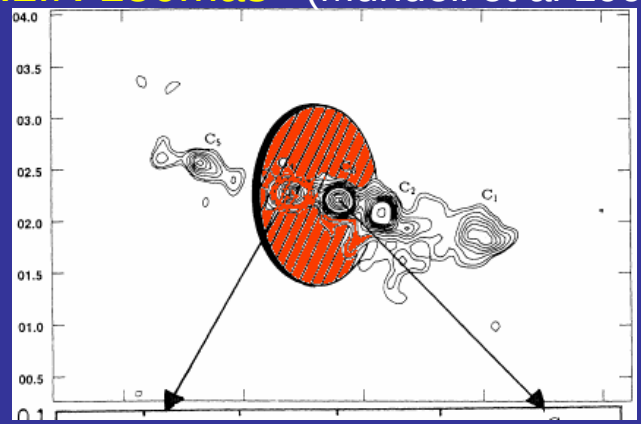


NGC4151 H1 absorption Possible HI Torus ..Seyfert 1!

- Absorption against knot in jet
- Inferred size ~ 60pc
- Column density
  - ~4x10^{21} atoms cm^{-2}
- VLBI Continuum

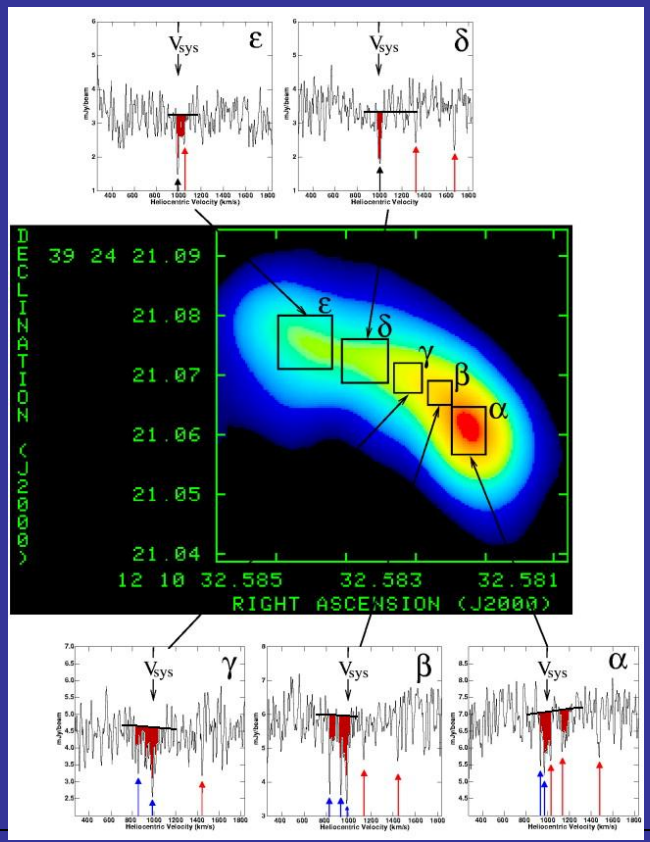


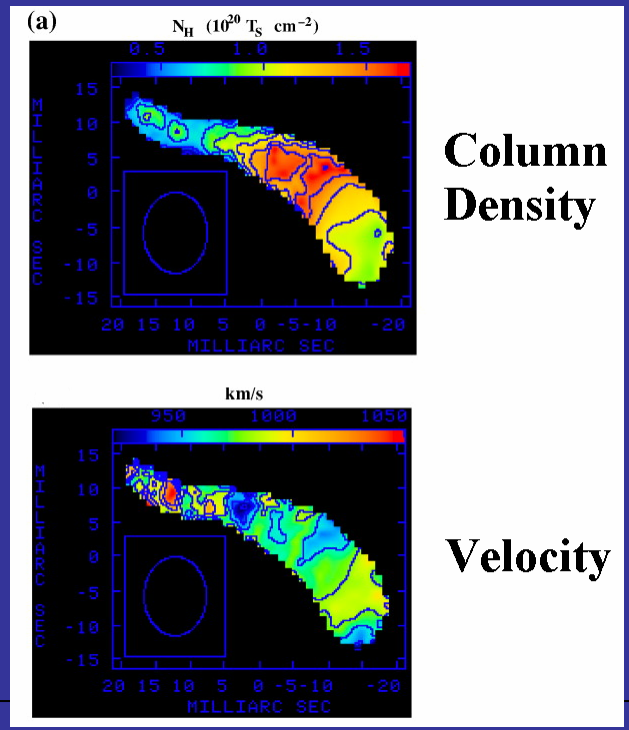
MERLIN 150mas (Mundell et al 1995)



NGC4151 H1 absorption -VLBA

- 10mas =0.6pc

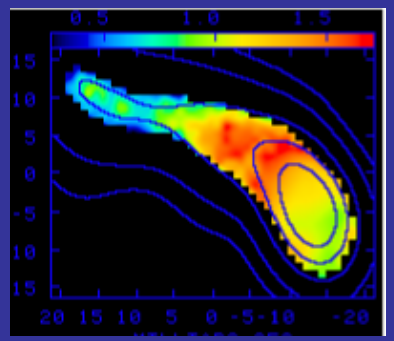


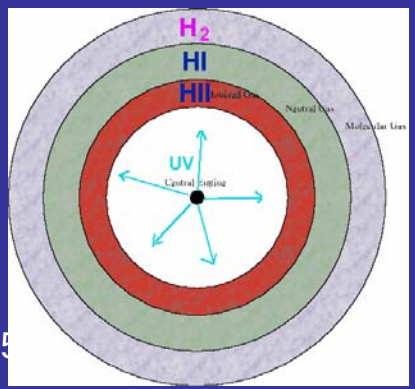


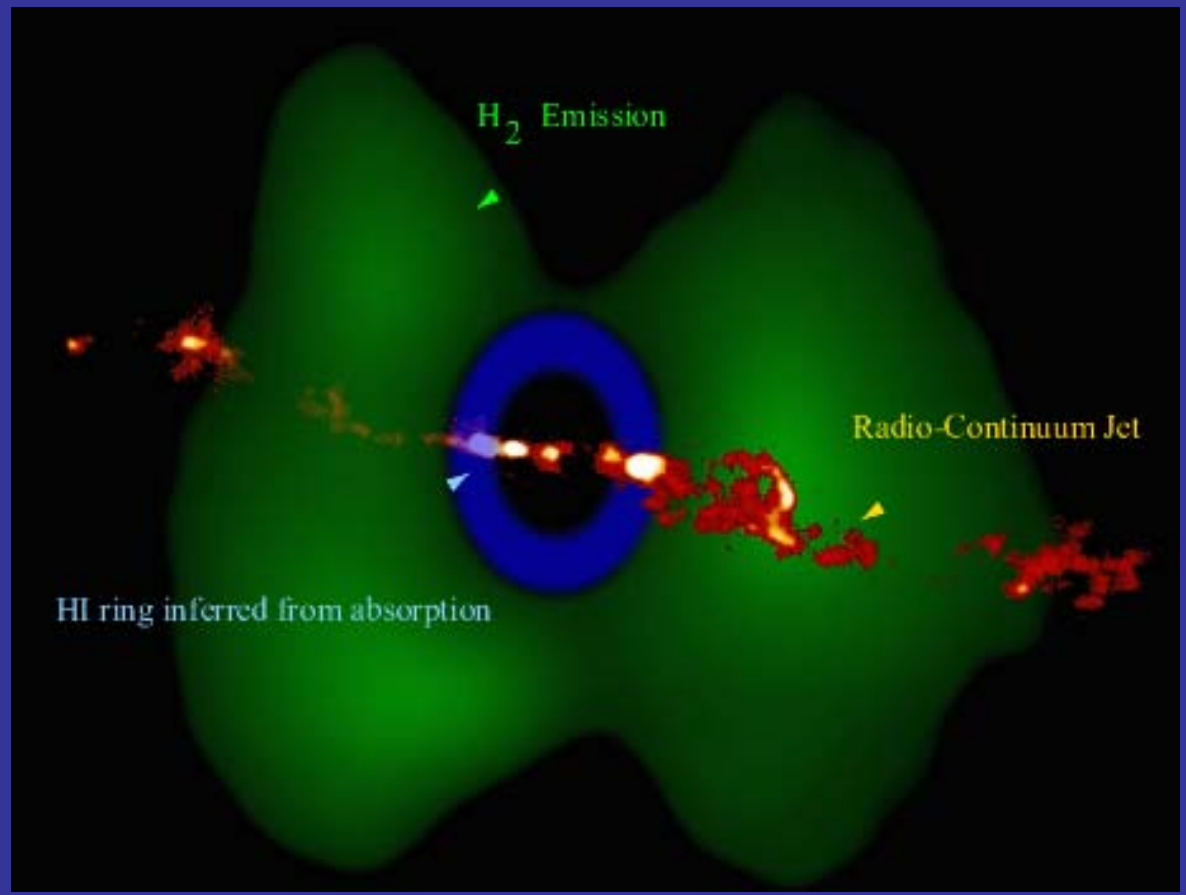
(Mundell et al 2003)

Clumpy H1 in NGC4151 - a torus?

- 5mas(0.3pc)
  - Clumpy
  - Variability?





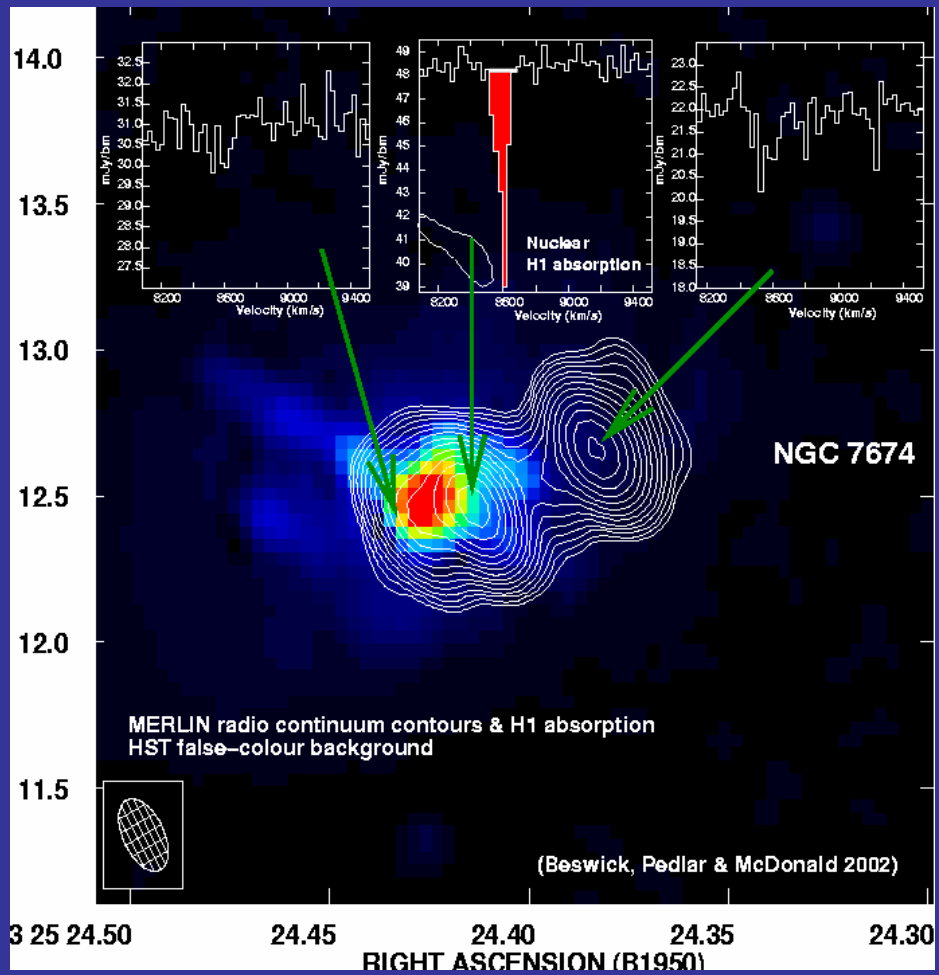


(Mundell, Wrobel, Pedlar, Gallimore ApJ 2003)

NGC7674 Seyfert 2 (possible H1 torus)

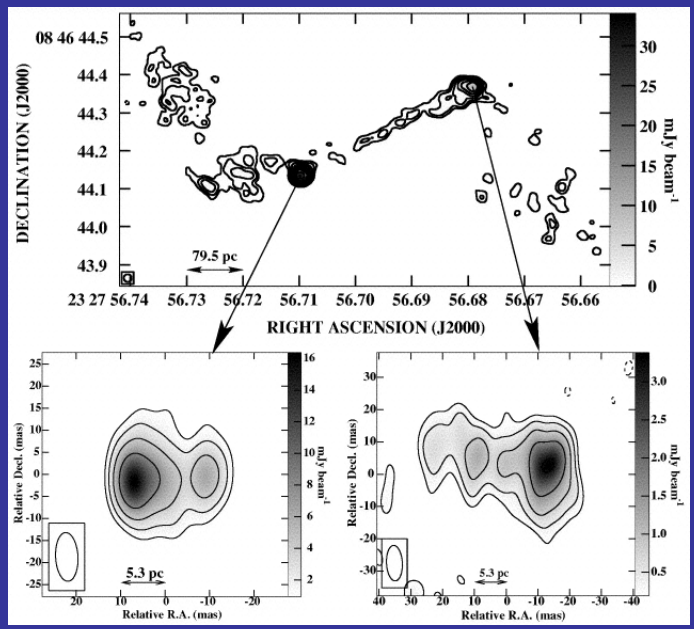
- Size <100pc
- N_H~ 5x10^{21} cm^{-2}
- Seyfert 2
- Similar H1 absorption geometry to NGC4151

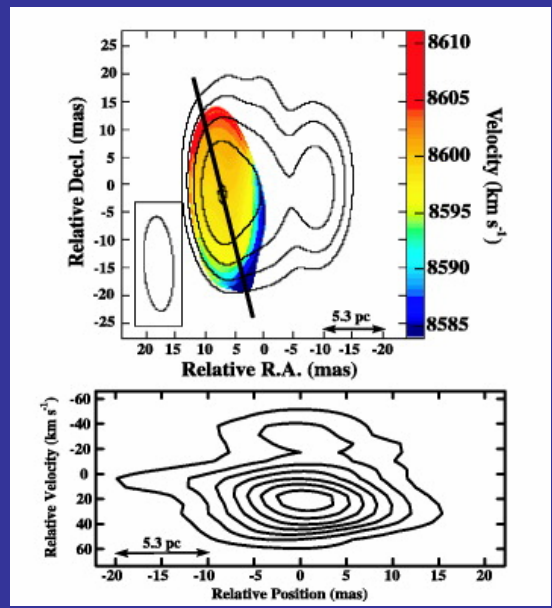
(Beswick et al 2002b)



At high mas resolution: NGC7674 – H1 torus

- VLBA + GBT & Arecibo results
- ~10mas beam → size ~15pc
- Enclosed mass ~7X10^7 M_o



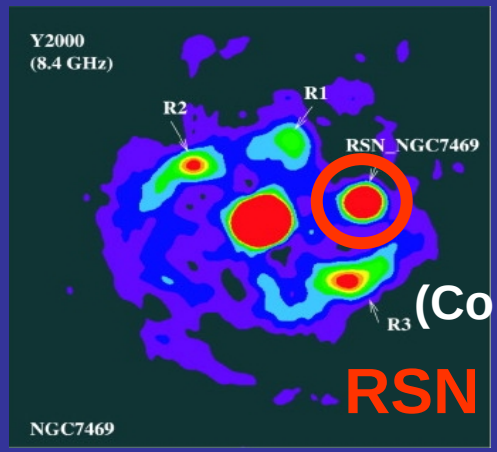


(Momjian et al 2003)

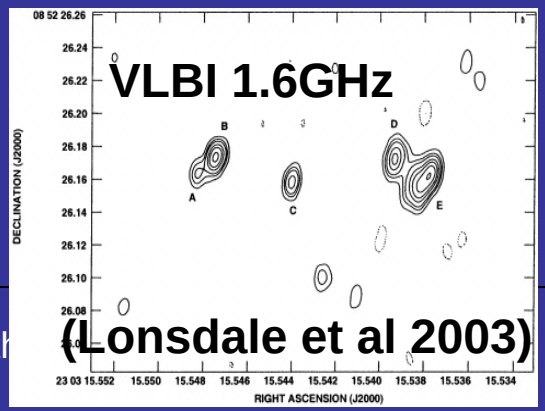
NGC7469 –Seyfert 1

(+ starburst ring)

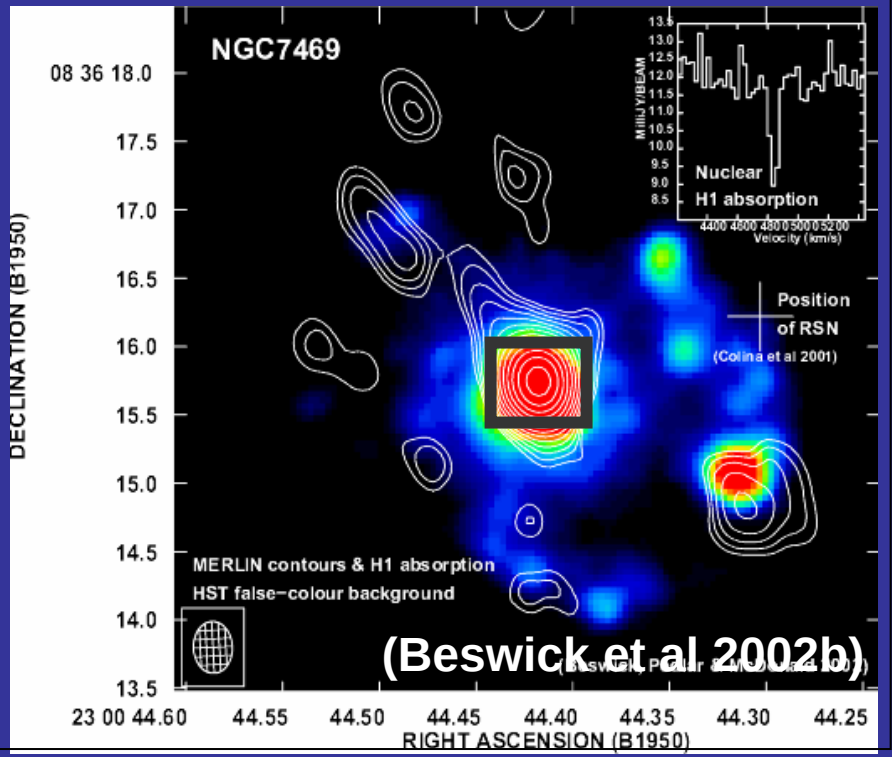
- In some cases the AGN & starburst are clearly separated
  - eg NGC7469 – lots of gas
    - Could be absorption from intervening material



(Colina et al 2001)



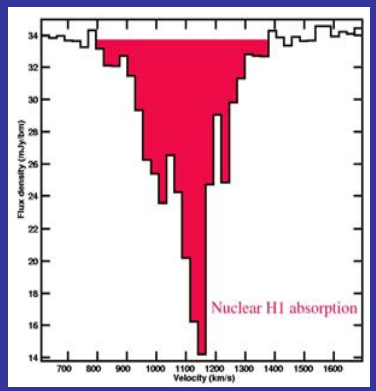
(Lonsdale et al 2003)

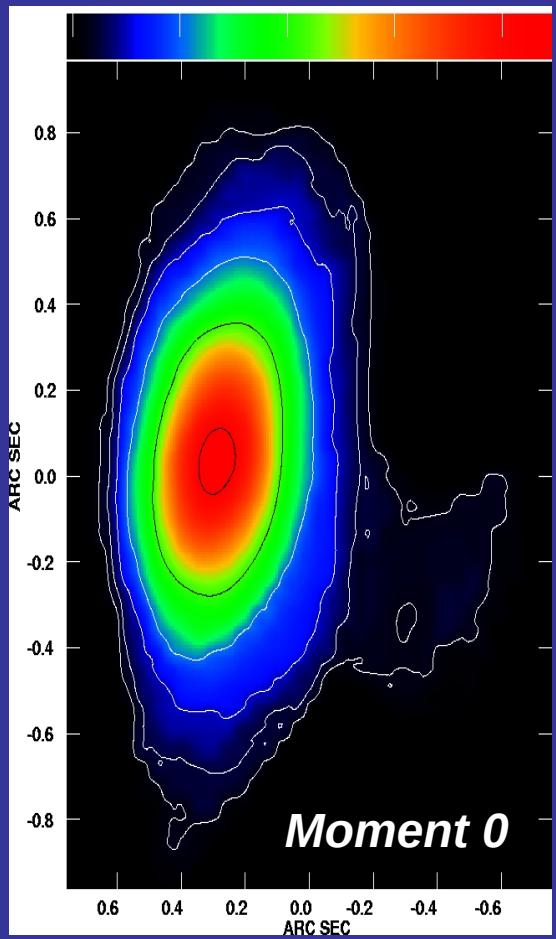


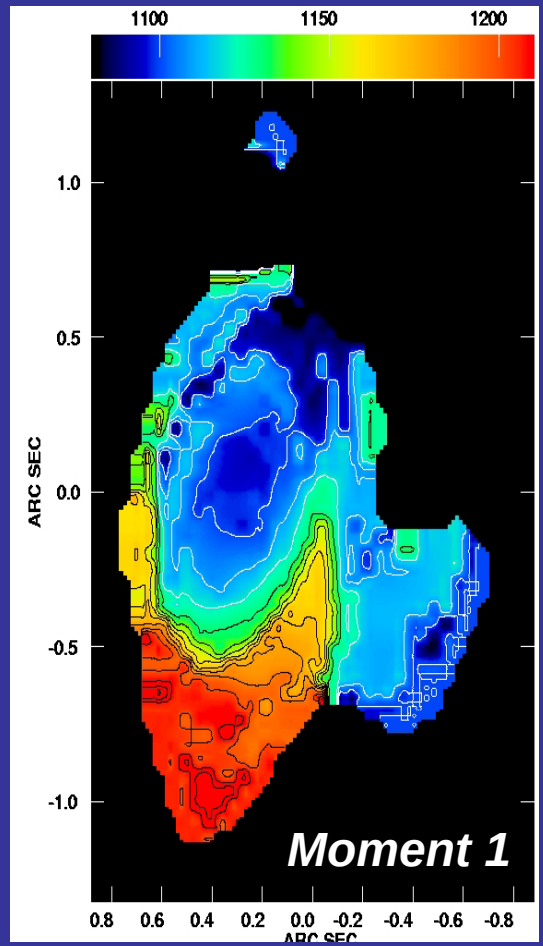
(Beswick et al 2002b)

NGC3079 (Sy2): MERLIN H1 absorption

- Tracing kpc scale gas
- Two absorption components
  - narrow (across the whole of the continuum)
  - broad (concentrated in the nucleus)

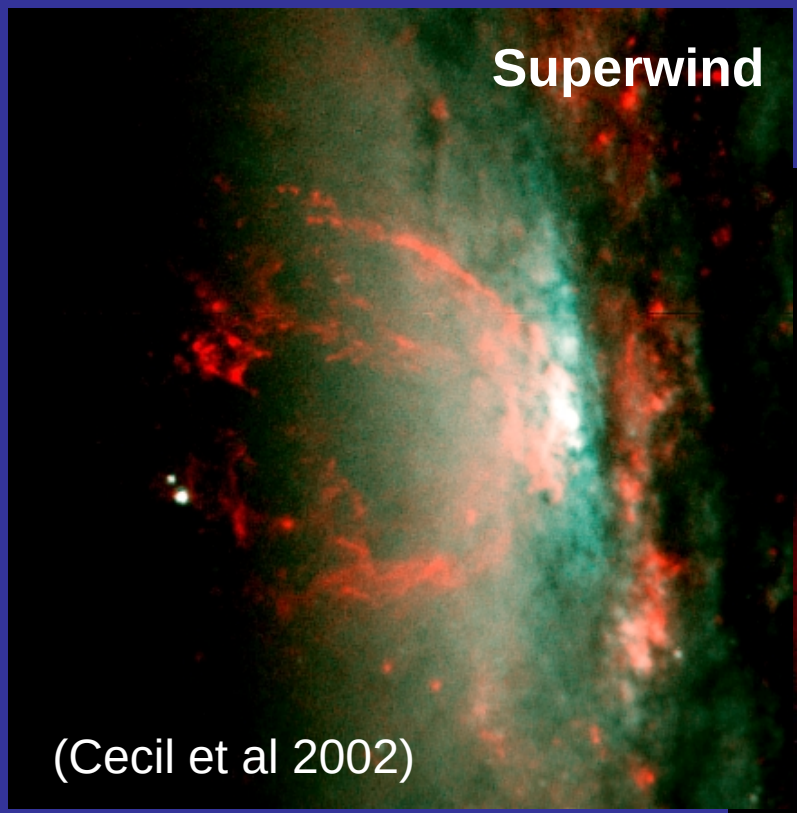


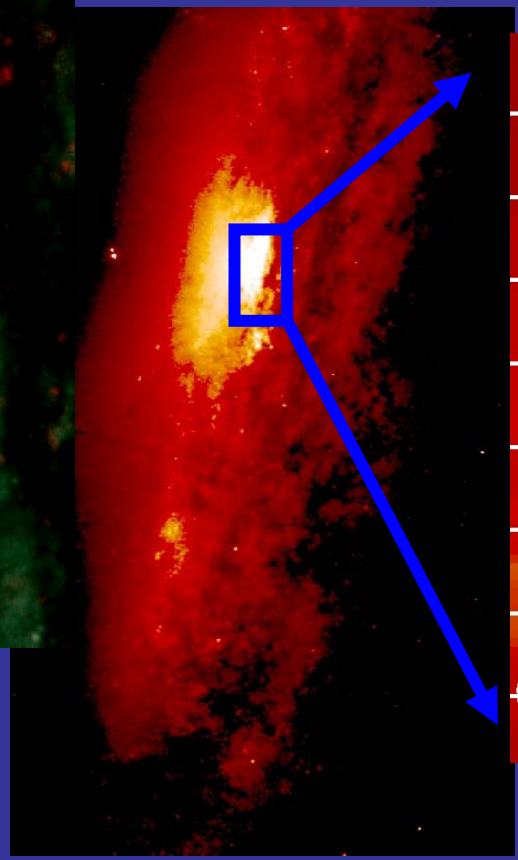


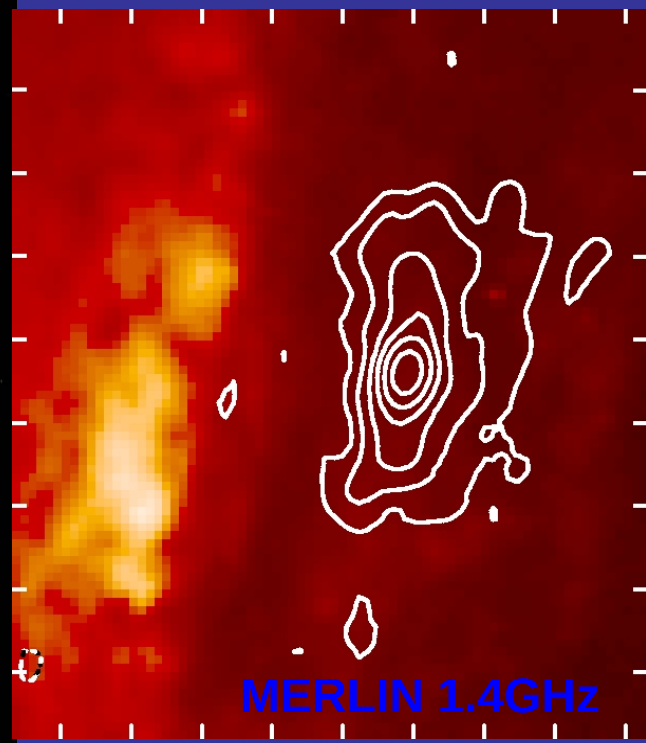


(Strong et al. in Prep)

NGC3079 – Seyfert 2 +(nuclear starburst?)







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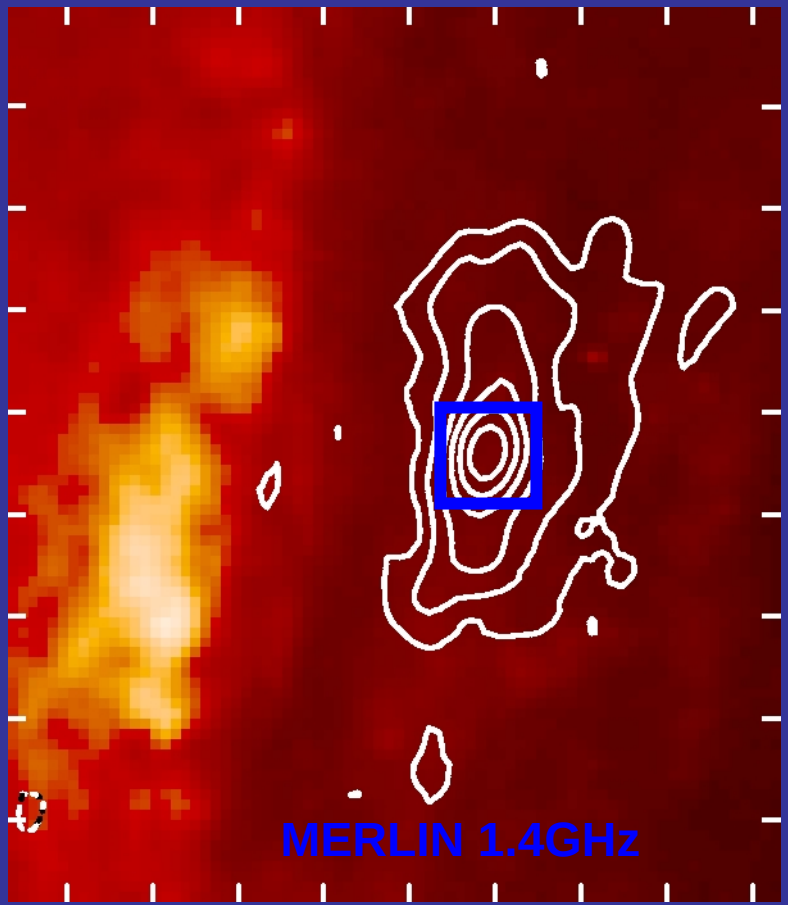
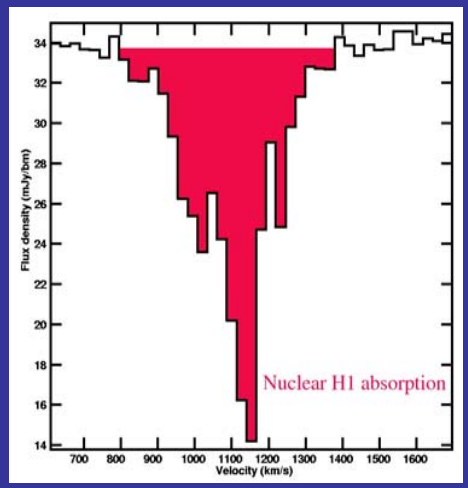
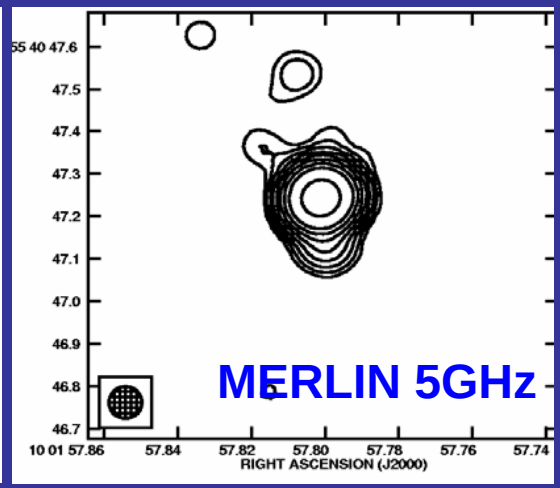
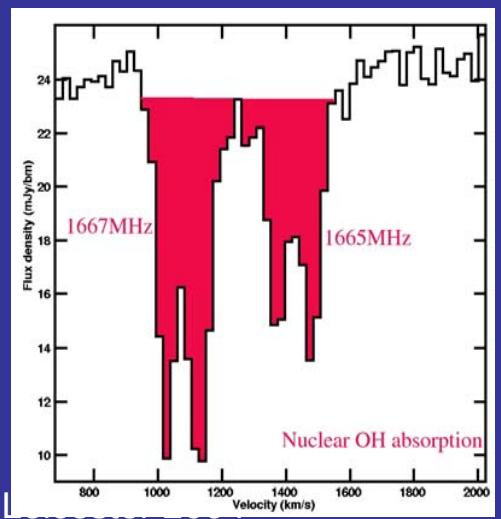
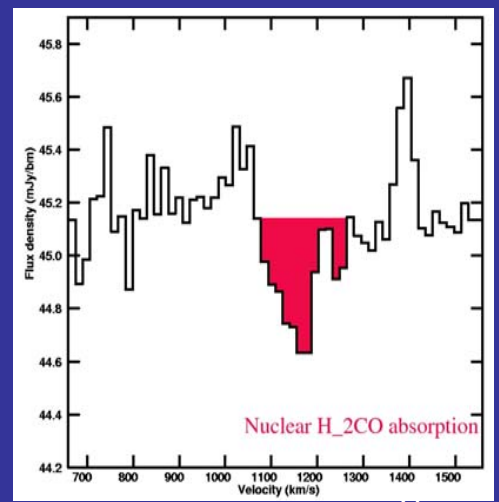


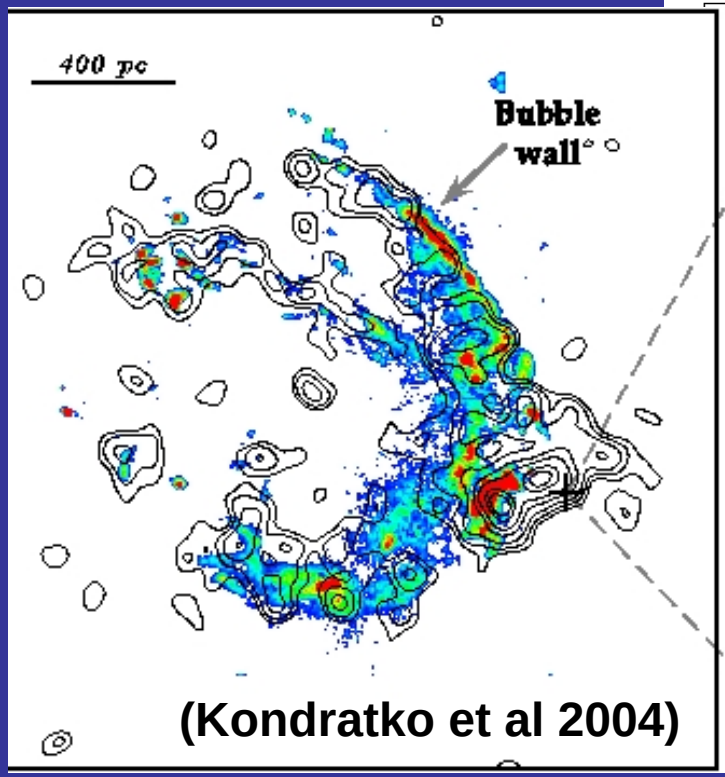


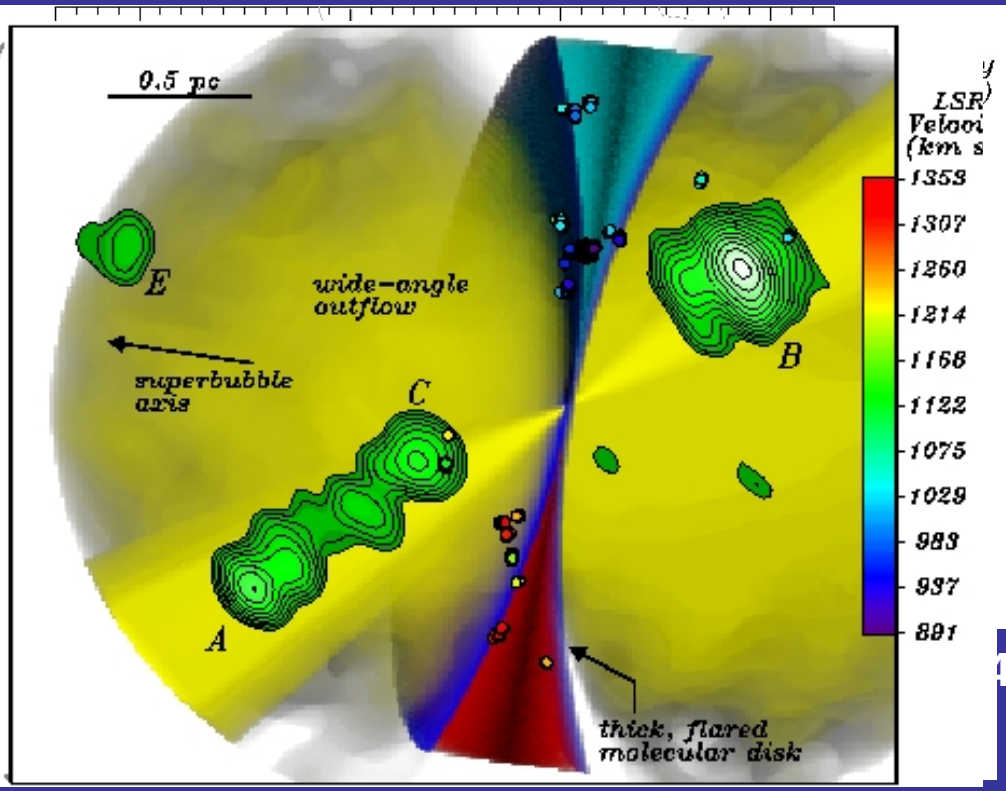






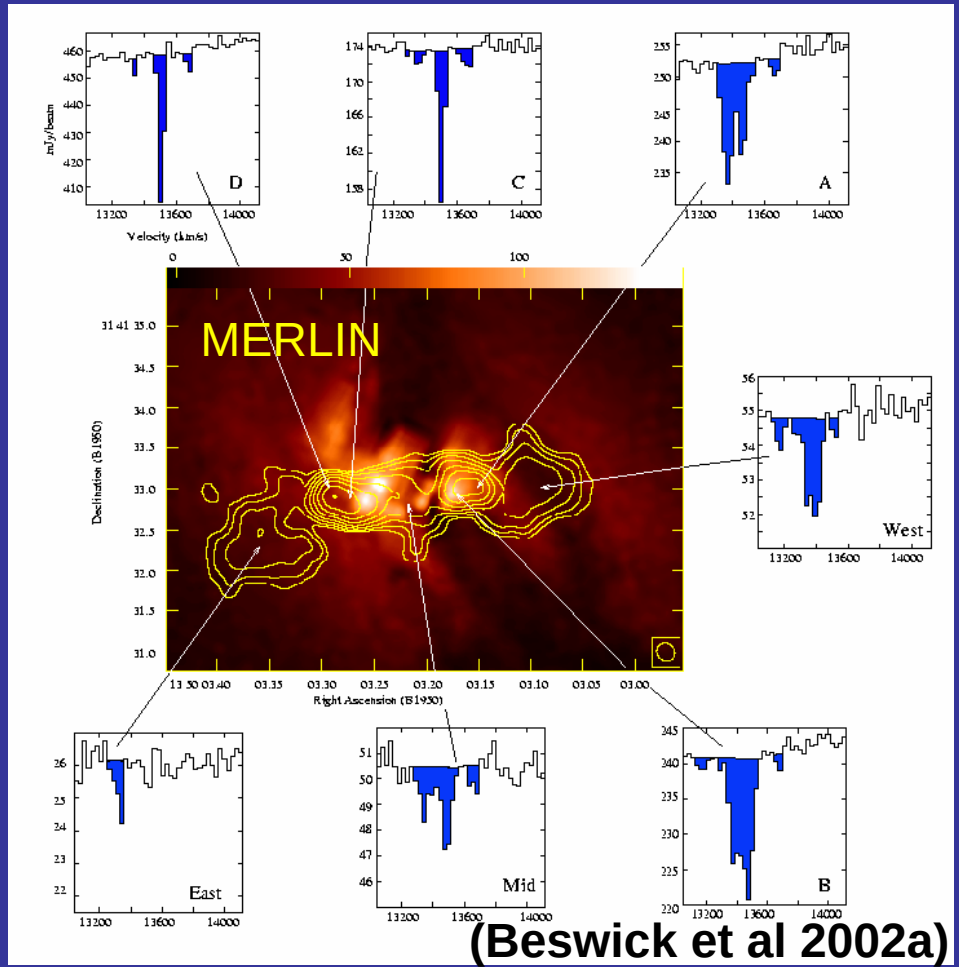
The core of NGC3079





Radio Galaxies: 3C293 multi-scale HI Absorption

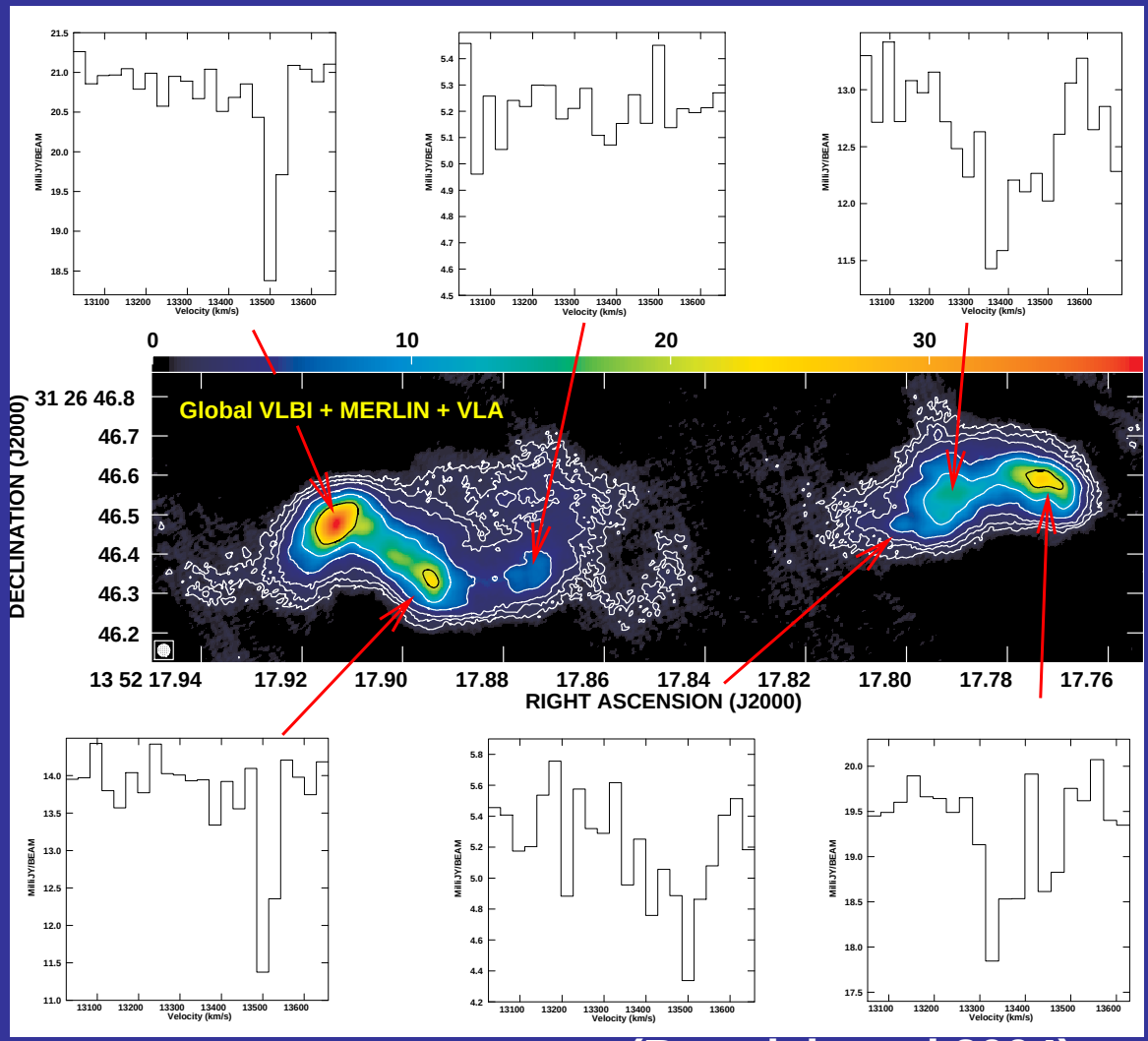
- Extensive MERLIN HI absorption
- Eastern side :- Narrow absorption
  - Coincident with nuclear dust lane
- Western side :- broad(er) absorption
  - Multi component (0.5 kpc ring/disk?)
  - Implies central mass $<10^9 M_{sun}$ (r<few hundred parsecs)
- Opacities ~0.01-> 0.2
- N_H ~10^{21} atoms^{-1}cm^{-2}



(Beswick et al 2002a)

Radio Galaxies: 3C293 multi-scale HI Absorption (VLBI)

Global VLBI provides a milliarcsecond angular resolution view of the absorbing gas



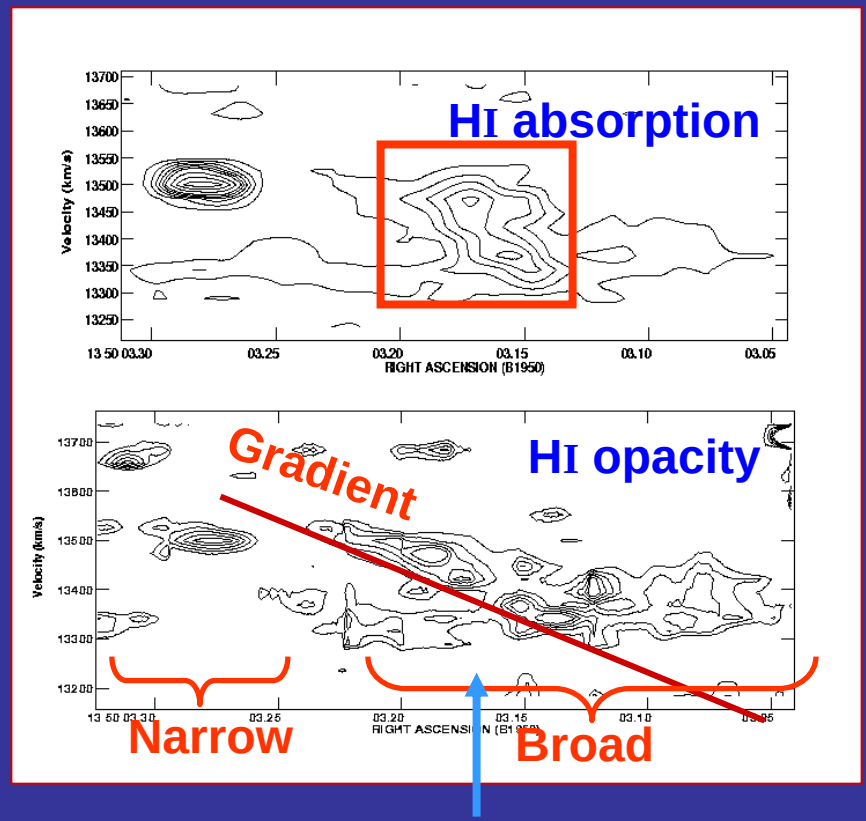
(Beswick et al 2004)

3C293 H1 rotating gas ring??

- On ~200mas angular scales. Velocity gradient centred upon the core(?)
  - Multi component (0.5 kpc ring/disk?)

- However stepping up the resolution the absorption breaks up many composite components.
- Lack of illuminating background continuum.

MERLIN – 200mas angular resolution



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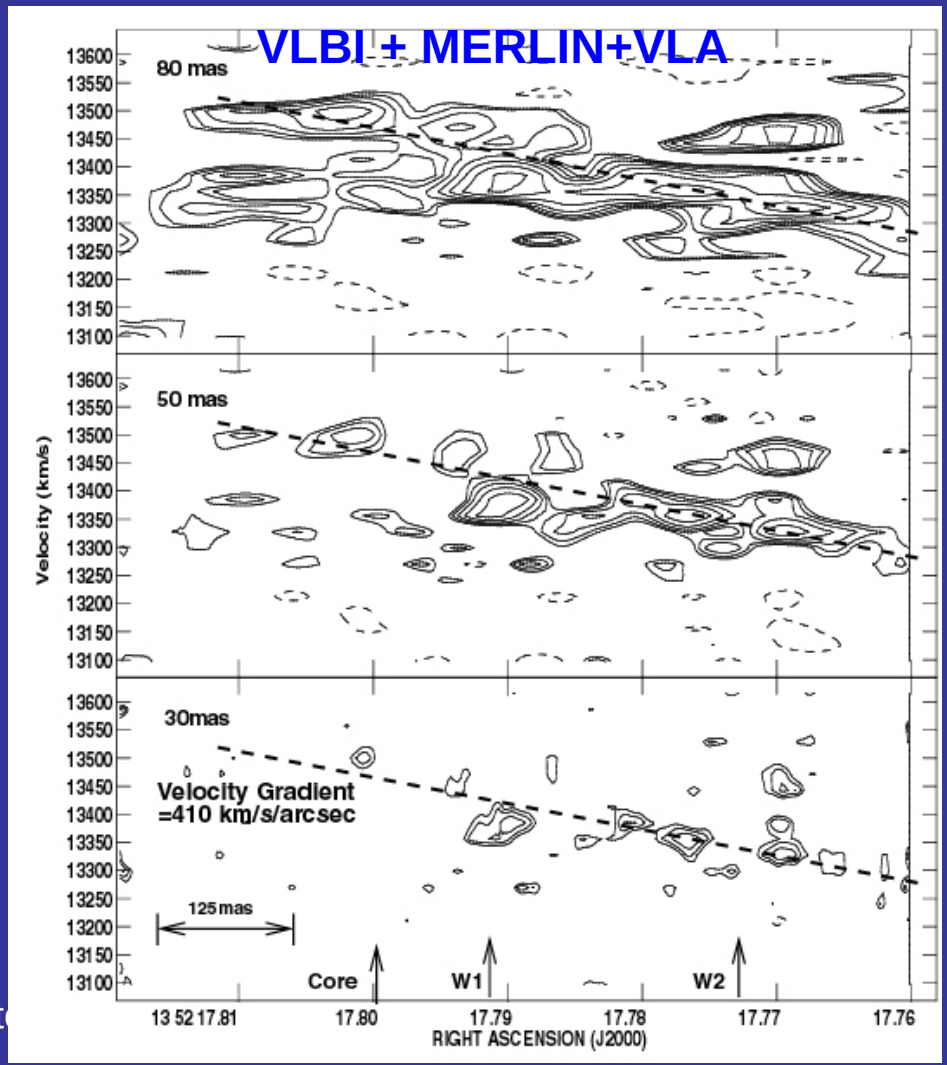
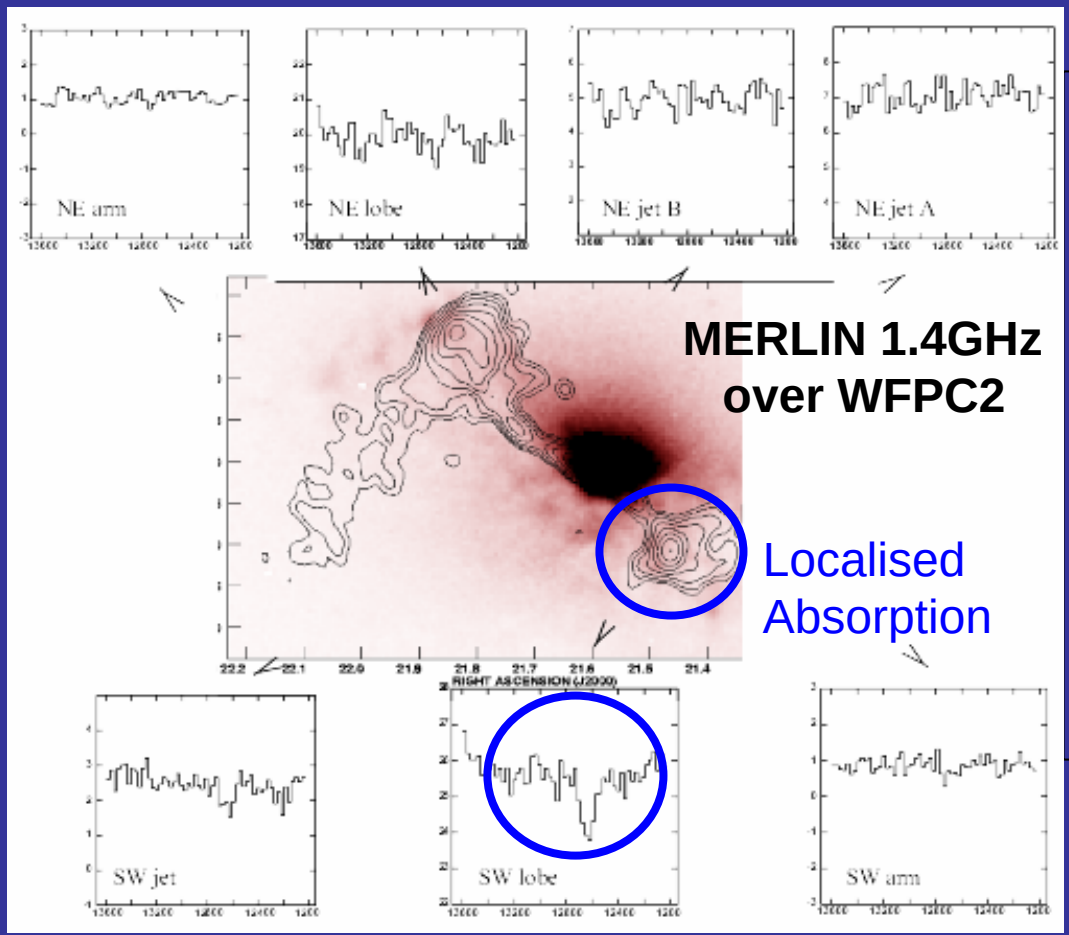


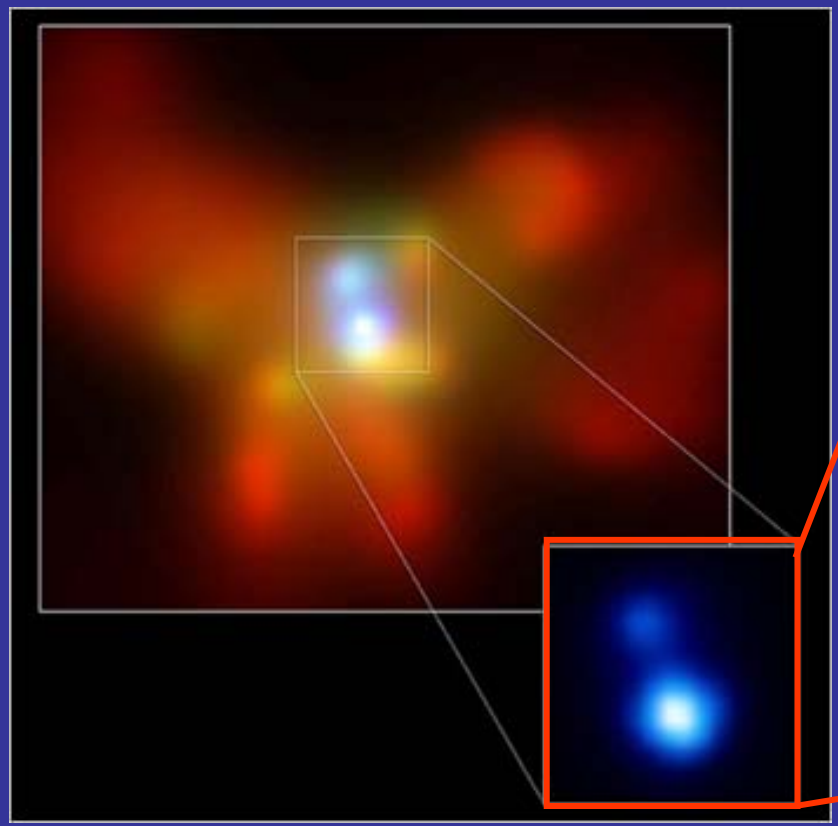
3C305: Off nuclear H1 absorption



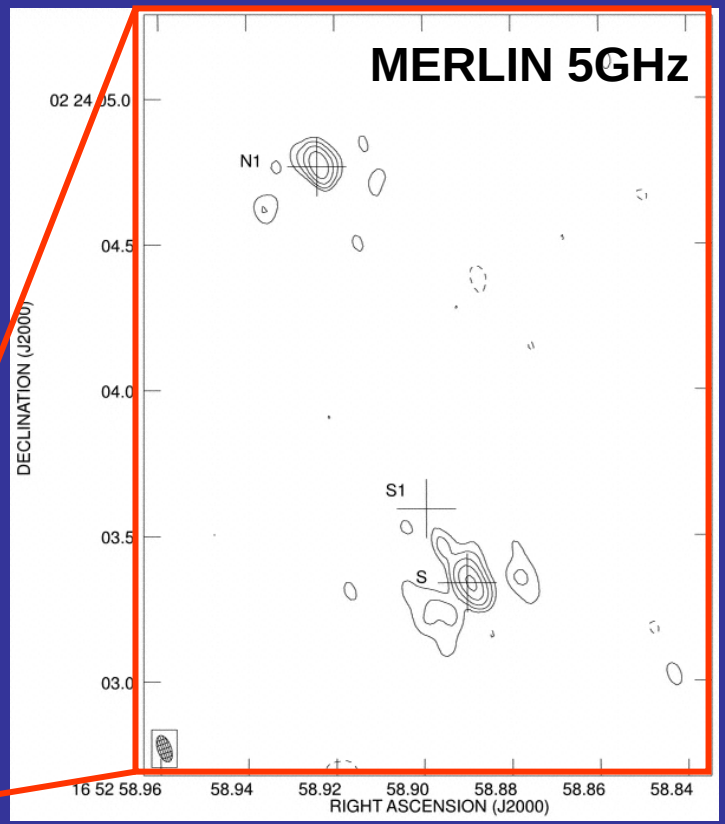
- **MERLIN H1 observations.**
- **Free-free absorbed core**
- **Weak H1 absorption only observed against SW jet emission.**
- **H1 absorption coincident with the cross nuclear dust lane.**

(Jackson et al 2003)

NGC6240 2 AGN
–confirmed by in the radio & X-rays



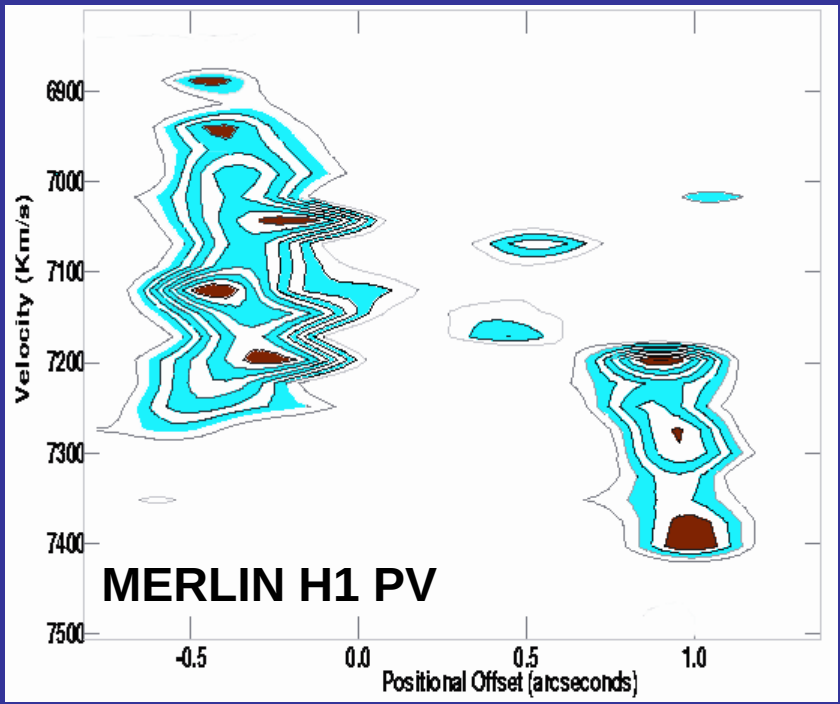
(Komossa et al 2003)

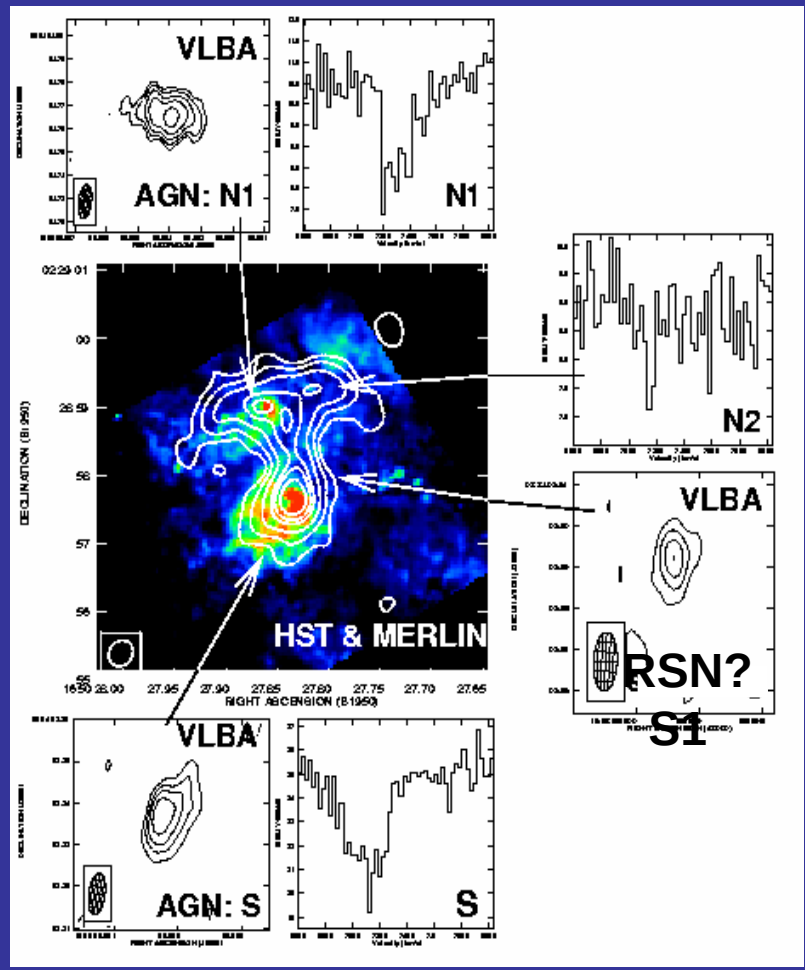


(Beswick et al 2001 & Gallimore & Beswick 2004)

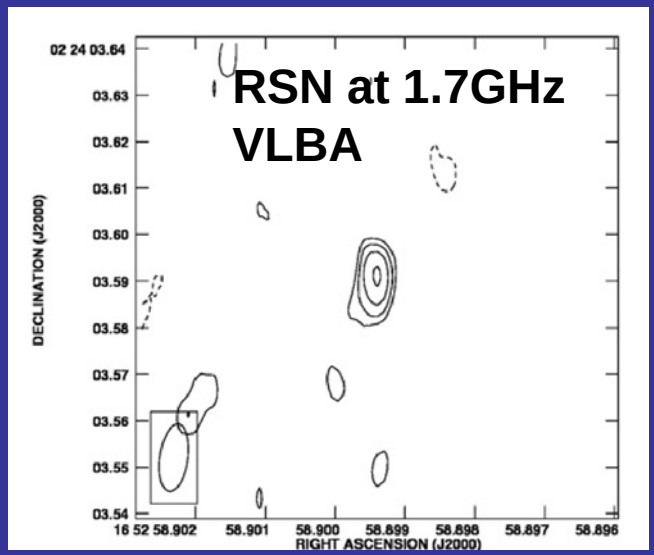
NGC6240
2 AGN + 1 RSN

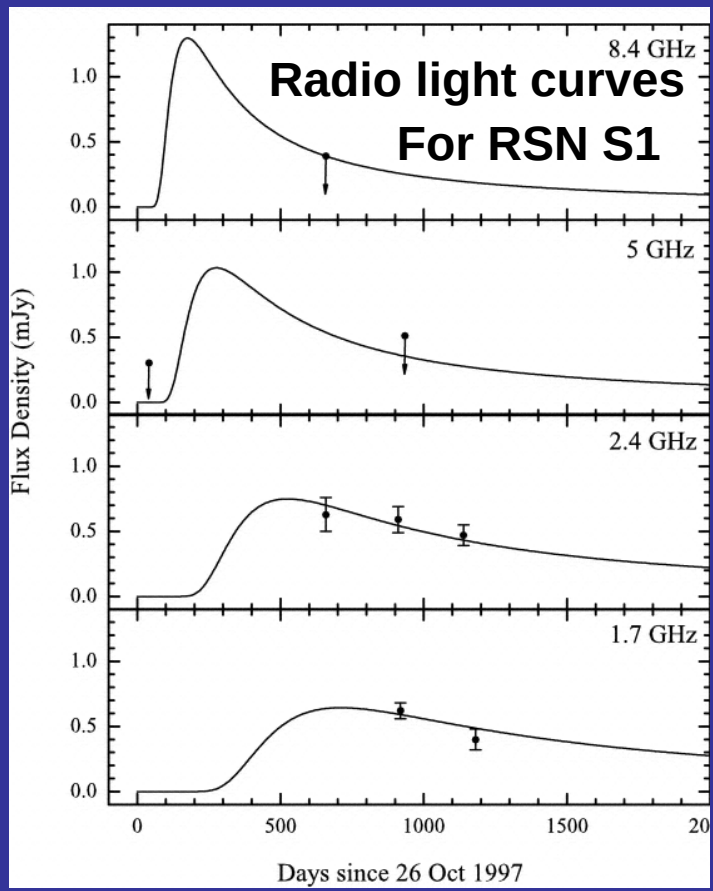
- (Beswick et al 2001;
  Gallimore & Beswick 2004)



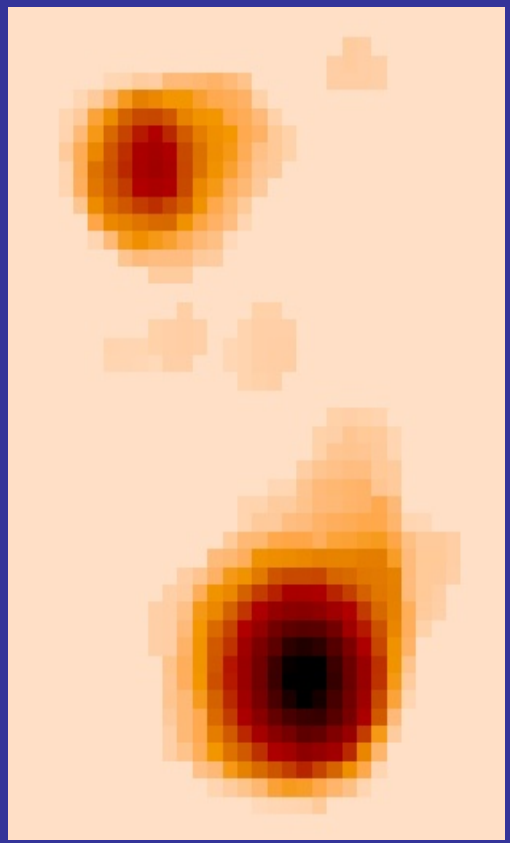


RSN in NGC6240

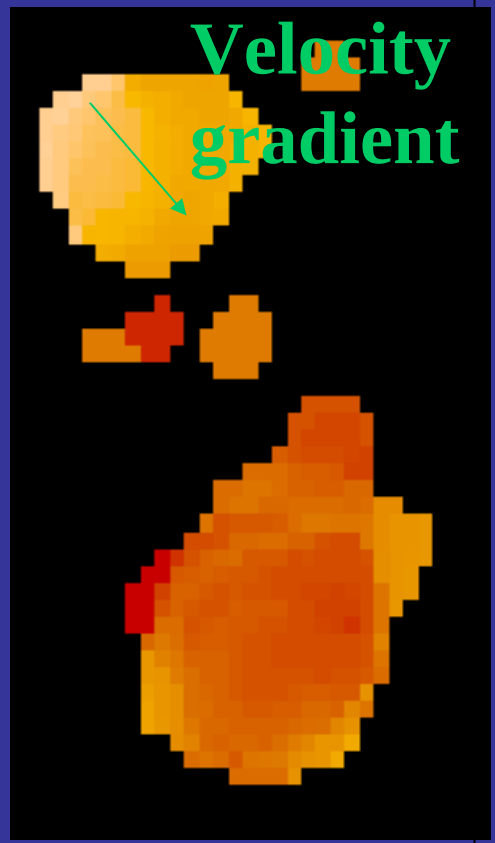




NGC 6240 (3)



Moment 0



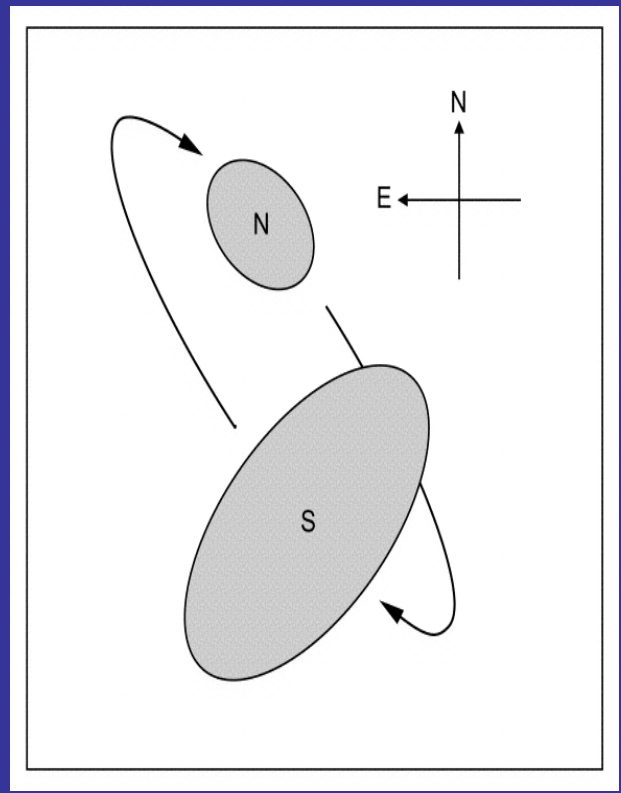
Moment 1

Moment 0 map shows the strong HI absorption against the 2 compact cores.

Moment 1 map shows that some velocity gradients are present.

Gas Dynamics in NGC 6240

HI absorption results show a velocity difference,in the dominant broad absorption component, of **150 kms^{-1}** between **N** and **S**, consistent with stellar dynamical results.



(Tecza et al., 2000)

Summary

- **Many Seyfert galaxies appear to show H1 absorption but on kpc scales**
  - Kiloparsec scale H1 disks rather than 'tori'
  - **Some apparent exceptions**
    - Eg NGC4151?, NGC7674….. With nuclear absorption.. (nuclear disks/rings?)
- **Radio galaxies:**
  - **Again show kpc scale H1 disks/rings**
    - Often the H1 is associated with the dust…..
- **Merger systems**
  - **Gas dynamics more confused**

Future…..

- **H1 & Molecular absorption gives**
  - **Subarcsecond resolution**
    - ~10s of parsec
    - Complementary with ALMA
  - **Unique Milliarcsecond resolution**
  - **Searches for more H1 absorption**
    - more homogenous samples

- -- that last slide was the end…..

Future……

- H1 & Molecular absorption gives
  - Subarcsecond resolution
    - ~10s of parsec
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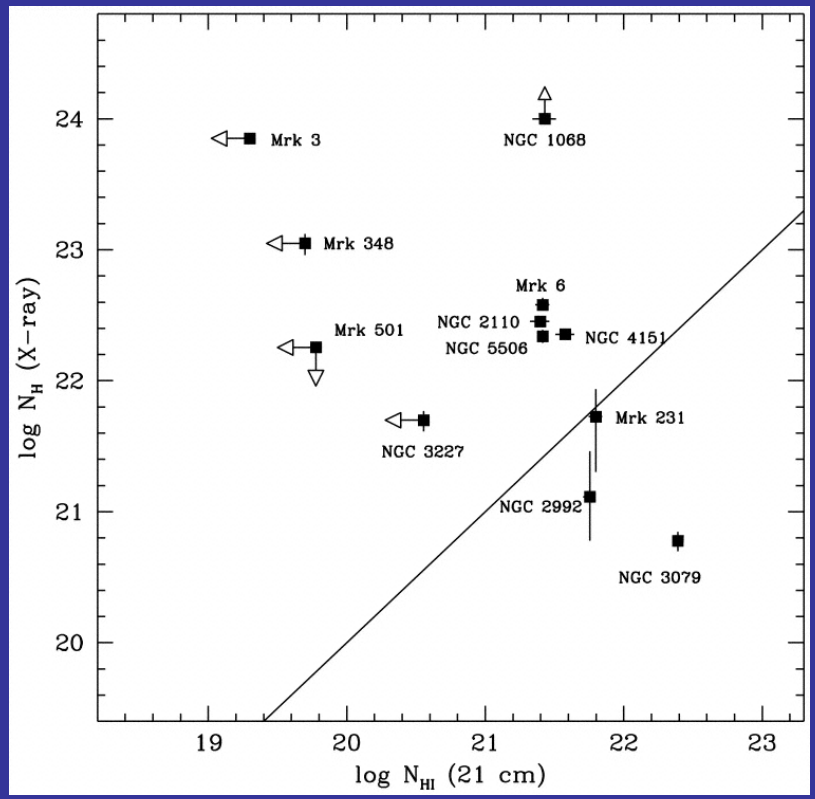
  - Searches for more H1 absorption
    - – more homogenous samples

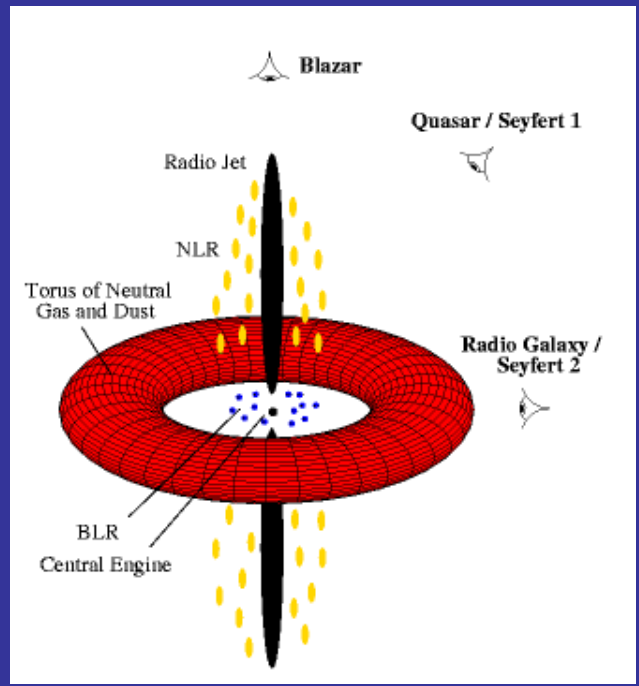
Why no H1 absorption by Torus?

- X-ray columns $10^{23\text{-}24}$ cm^{-2} to AGN
- H1 columns $<10^{21\text{-}22}$ (T_s=100K)
- If 1% H1 we should detect 21cm absorption



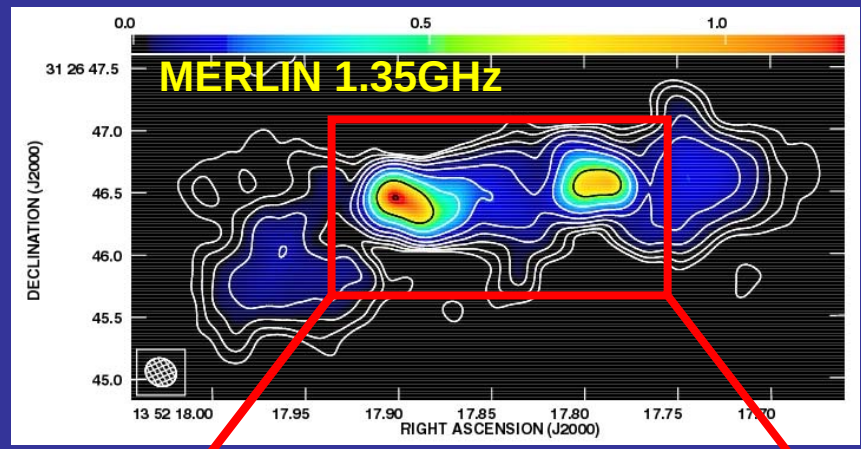
Seyferts:- the Dusty Torus model

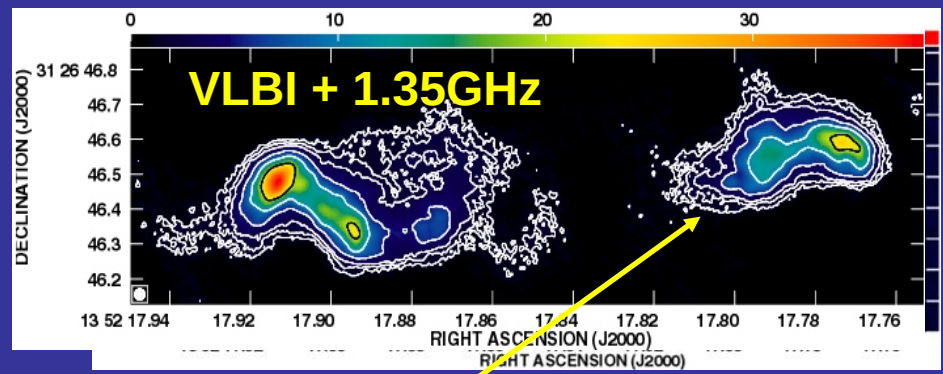
- Ratio of Seyfert1-> Seyfert 2 numbers
- For model to work
  - Torus hides BLR
  - But **not** NLR
- ∴ Torus size< NLR size
- ∴ For most Seyfert nuclei
  - <100pc → <1 arcsec



The inner jet of 3C293

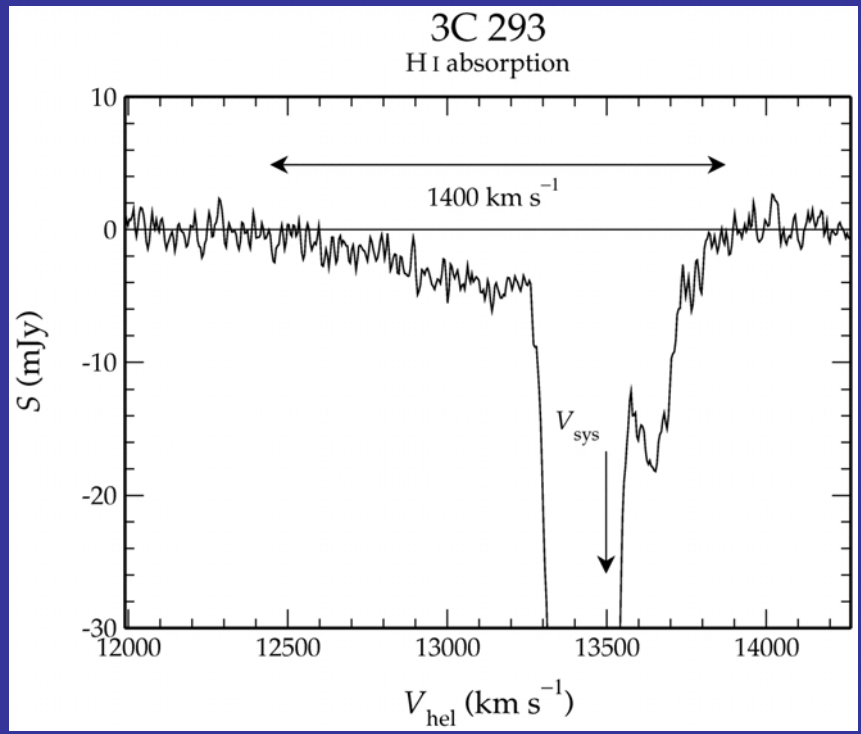
- At sub-arcsec angular resolutions the inner central few kiloparsec radio jet breaks into multiple components along an east-west orientation.
  - Steeply inverted spectrum of core
  - $\alpha \sim -1$ (Akujor et al 1996)
  - Fitted core size <17pc





Broad HI absorption in 3C293

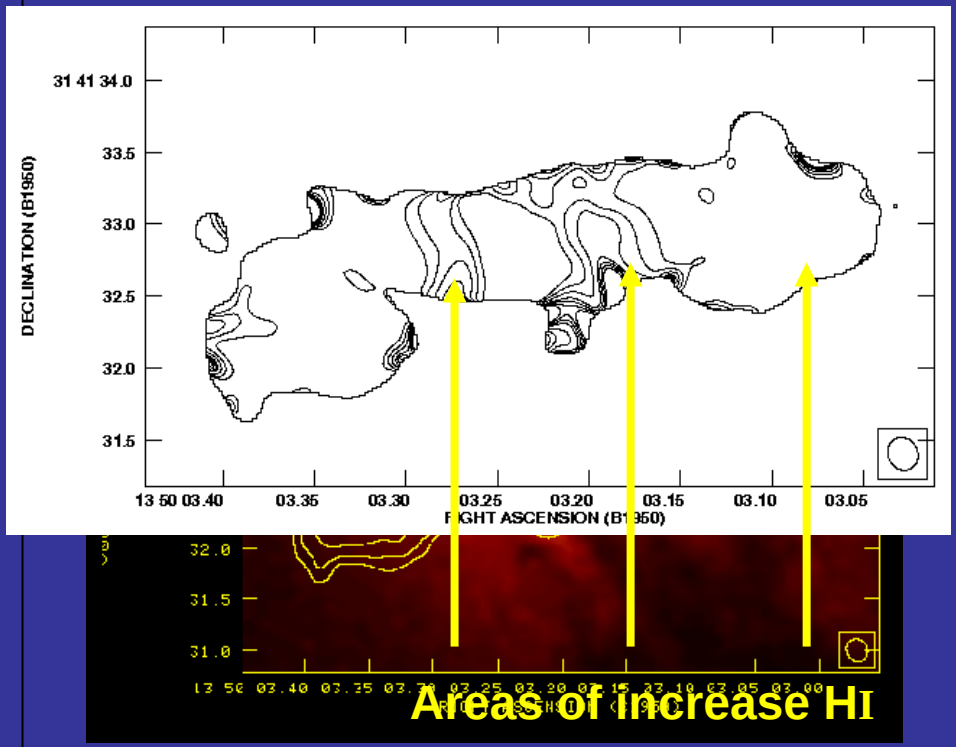
- Very broad & deep HI absorption seen in sensitive WSRT observations.
- Outflows Jet-ISM interactions…. Toward the inner eastern jet??



Morganti et al 2003 ApJ 593, L69

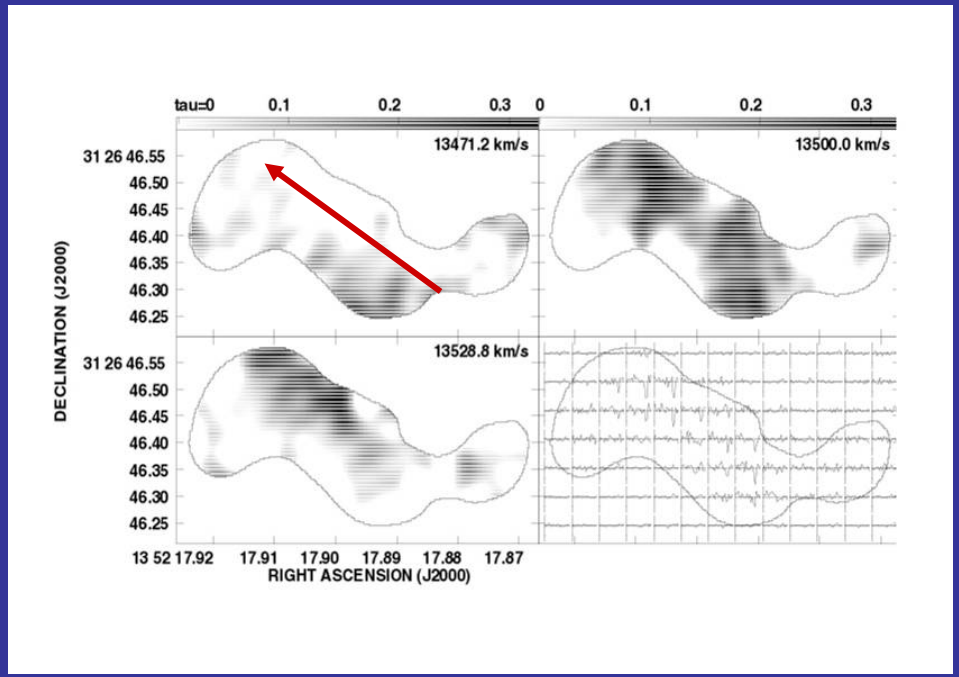
Gas & dust distribution

- The dust distribution is strongly correlated with areas of increased HI opacity.
  - Dust and Neutral gas spatially related
  - In particular the narrow HI absorption traces the dust lanes

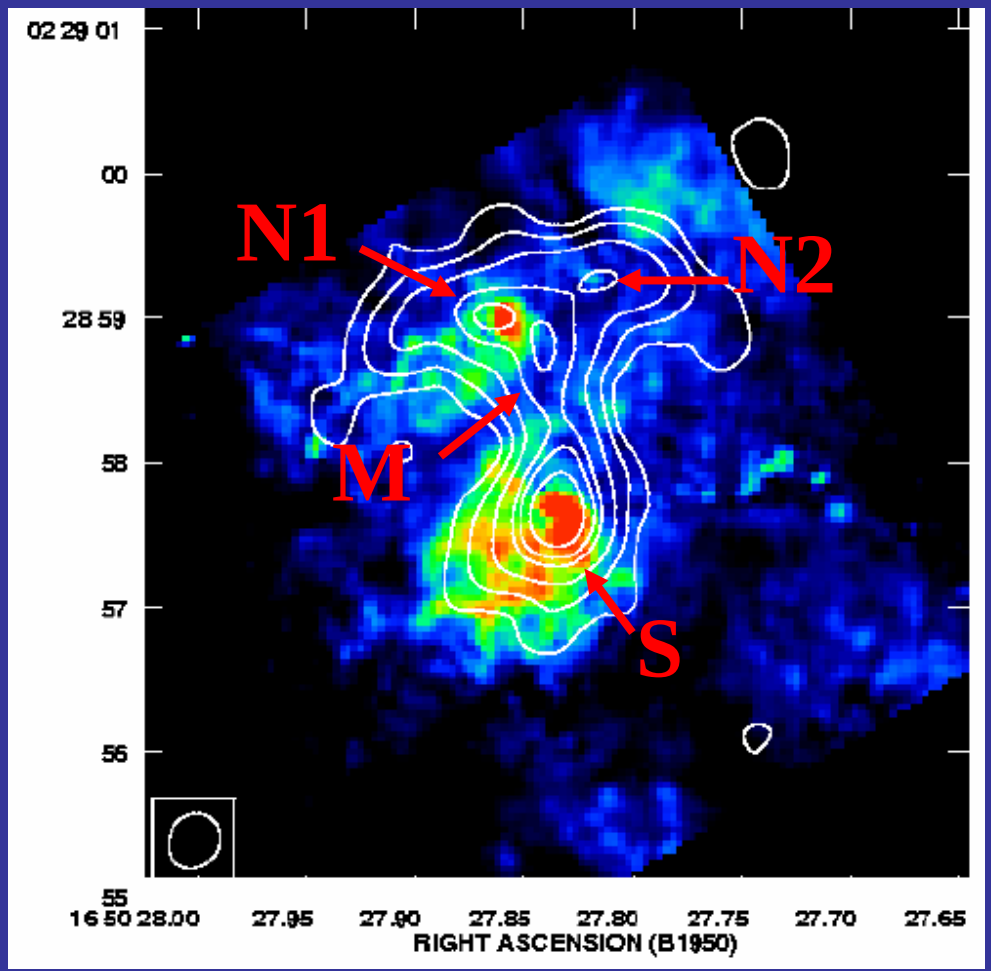


Narrow absorption

- At mas angular resolution the velocity structure of the narrow component is resolved against the eastern jet.
  - Small velocity gradient
    - Gas and dust rotating in the out reaches of the source.
    - VG ~ 50kms^{-1}arcsec^{-1}



NGC6240 Radio continuum



- 1.4GHz MERLIN image made from spectral line data set.
- Resolution ~0.3”
- 4 peaks in continuum flux are visible with the two strongest coincident with peaks on optical & IR emission.

HI Absorption in NGC 6240