VLBI Observations of HI in Compact Symmetric Objects: the case of B2352+495

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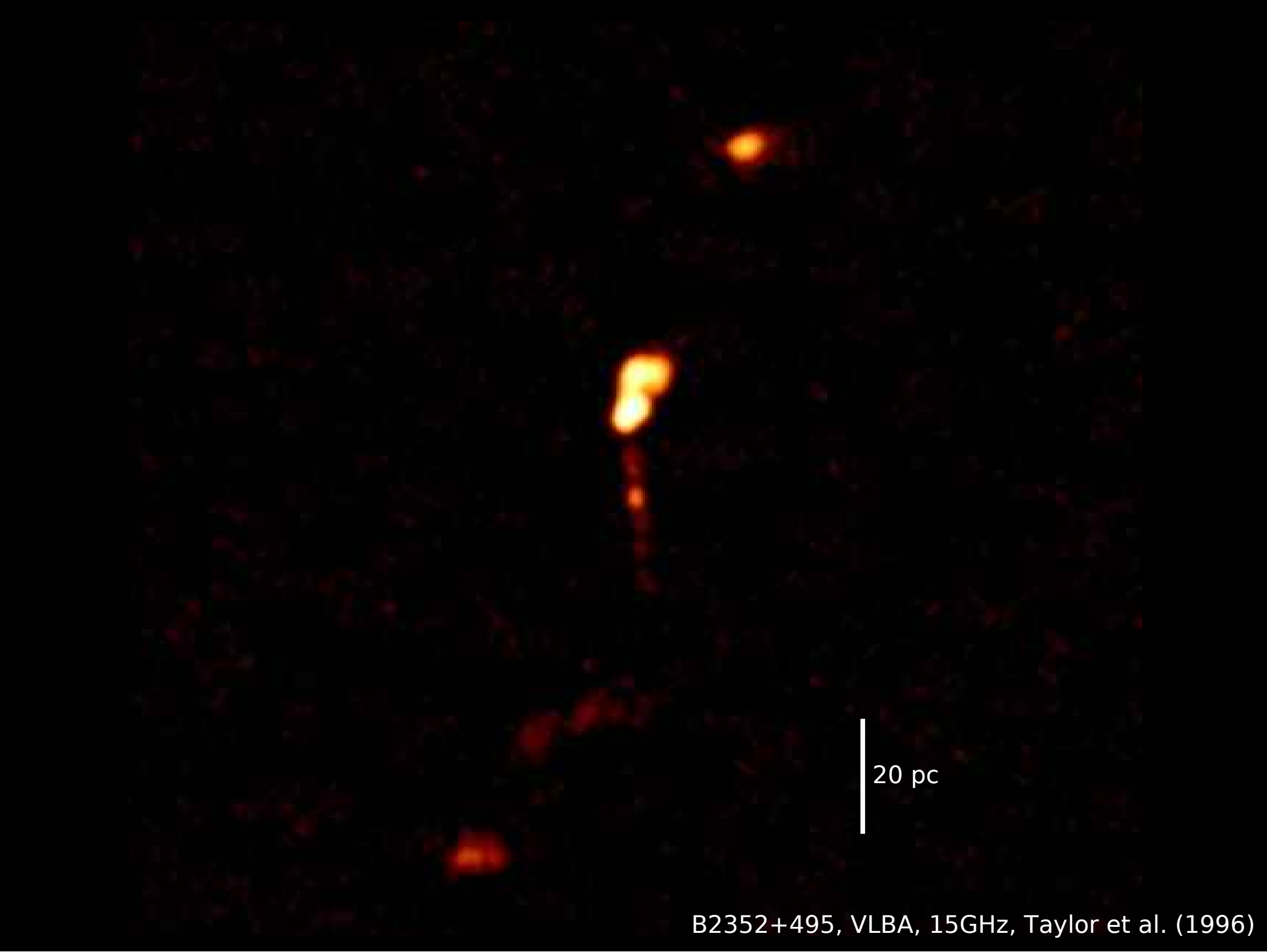
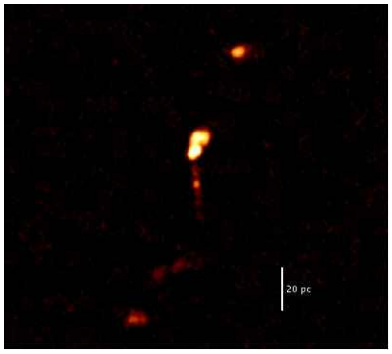
Cristina Rodriguez (UNM)
Steven Tremblay (UNM)
Rene Vermeulen (ASTRON)


20 pc
B2352+495, VLBA, 15GHz, Taylor et al. (1996)



Compact Symmetric Objects (CSOs)

- Compact (< 1kpc) radio emission

- S-shape morphology

- Radio lobes at both sides of a central engine

- Radio bright ($L_{5GHz} > 5 \times 10^{25}$ W Hz^{-1})

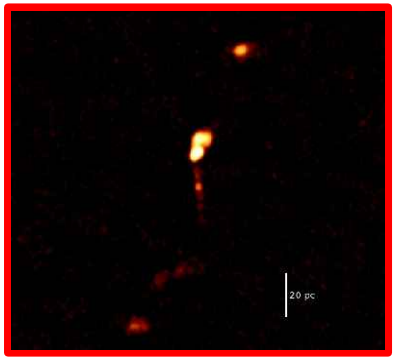
- GigaHertz Peak Spectrum (GPS)

- Elliptical galaxies (but also quasars and spiral galaxies!)

- Non-variable, low polarization

- No superluminal motions; dynamically young, ($<10^5$ yr)

Wilkinson et al. (1994)
Readhead et al. (1996)
Taylor et al. (1996)
Augusto et al. (2006)



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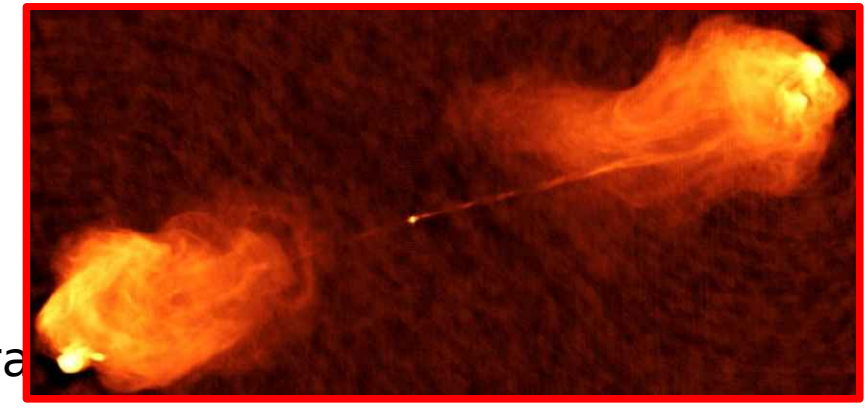

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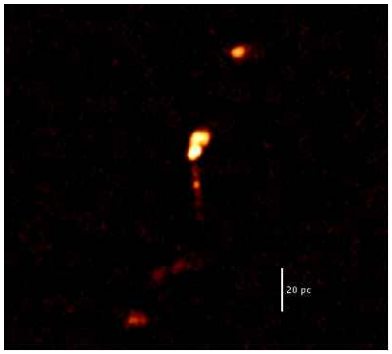

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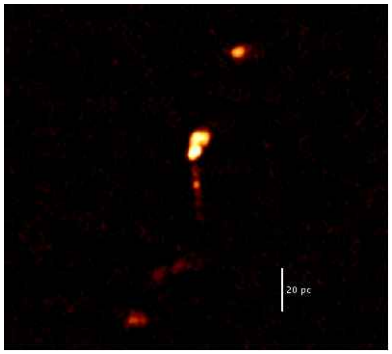

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VLBI HI Observations:

B1946+708

4C 31.04

4C 37.11

PKS 1413+135

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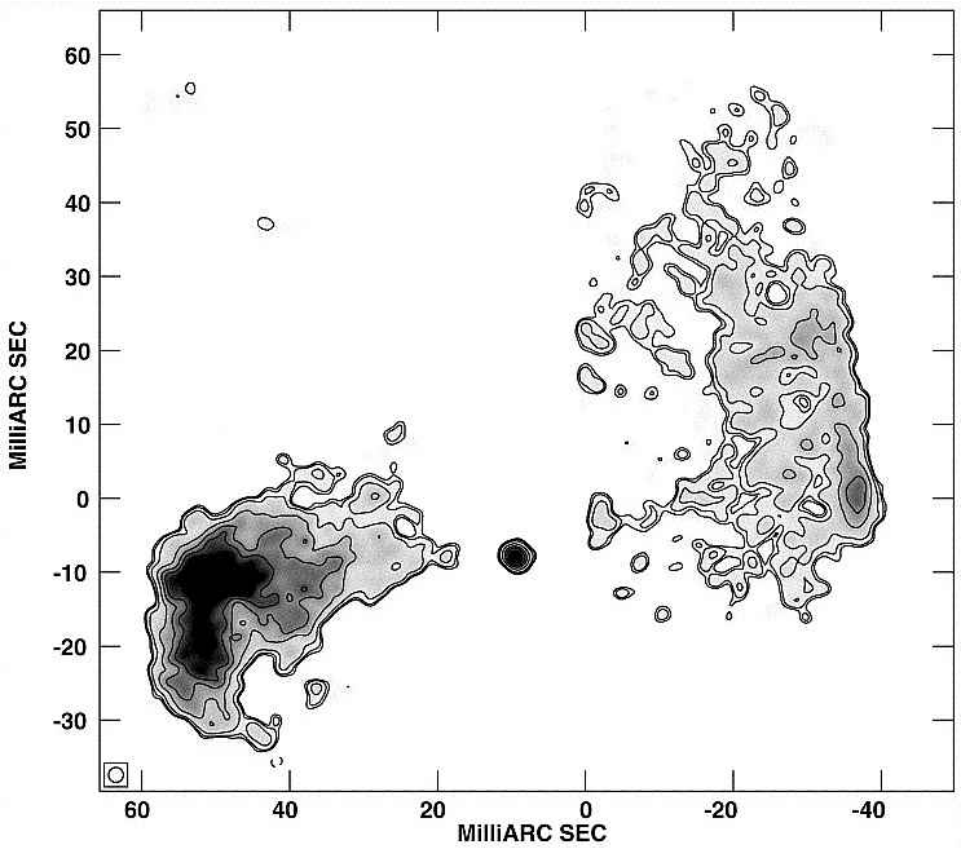

VLBA, 5GHz, I_ν = 20.6 mJy/b, Θ_{syn} = 2 mas, rms = 0.2 mJy/b
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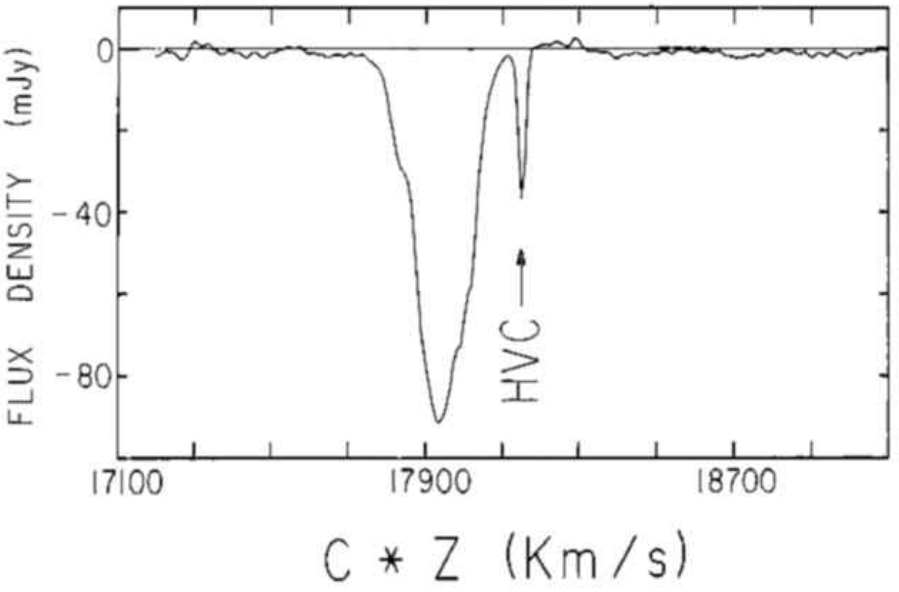
Arecibo, Mirabel (1990)



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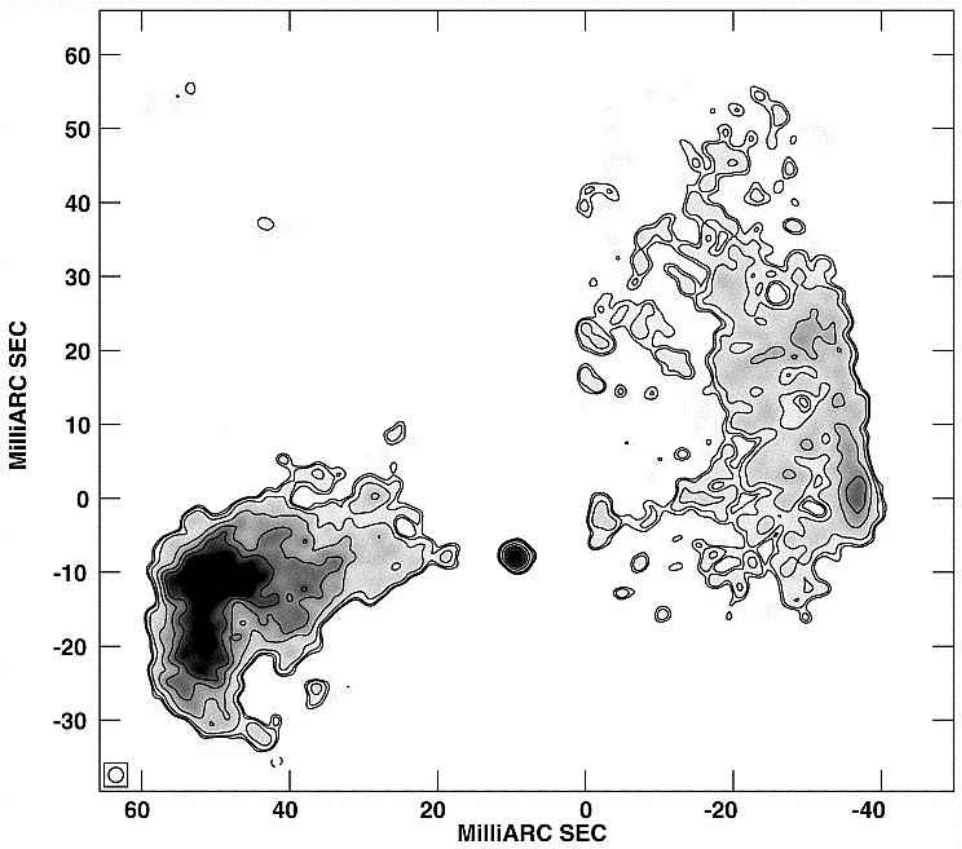

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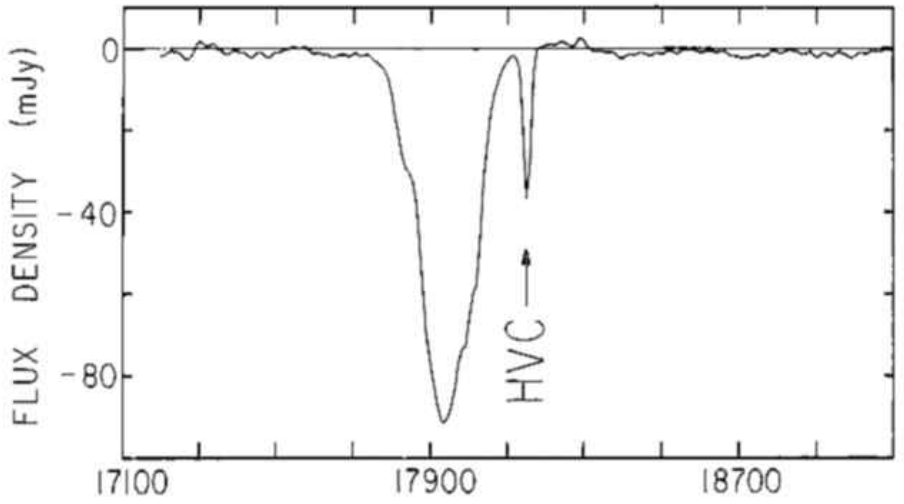
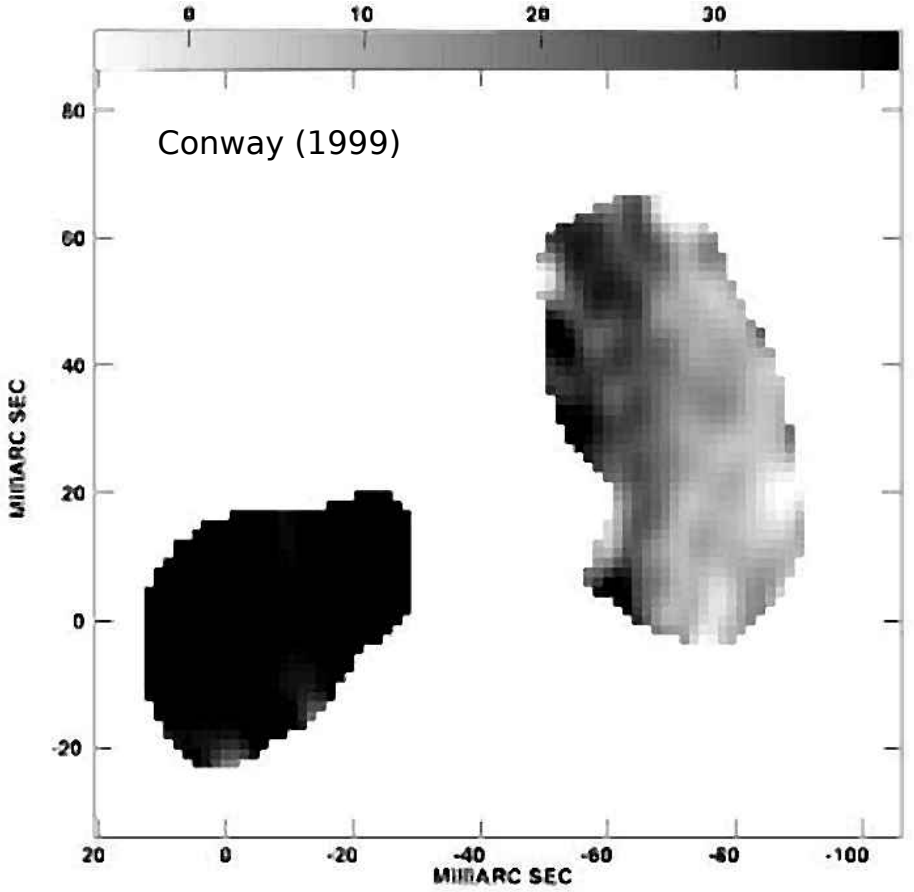
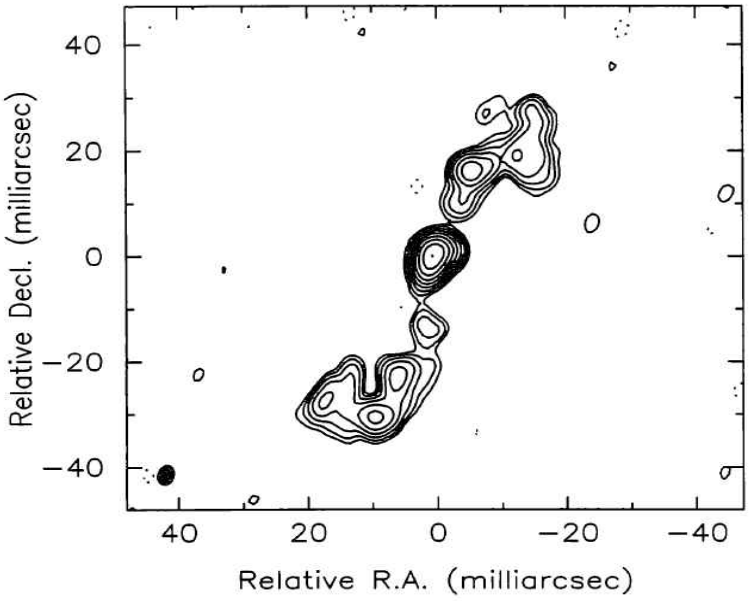


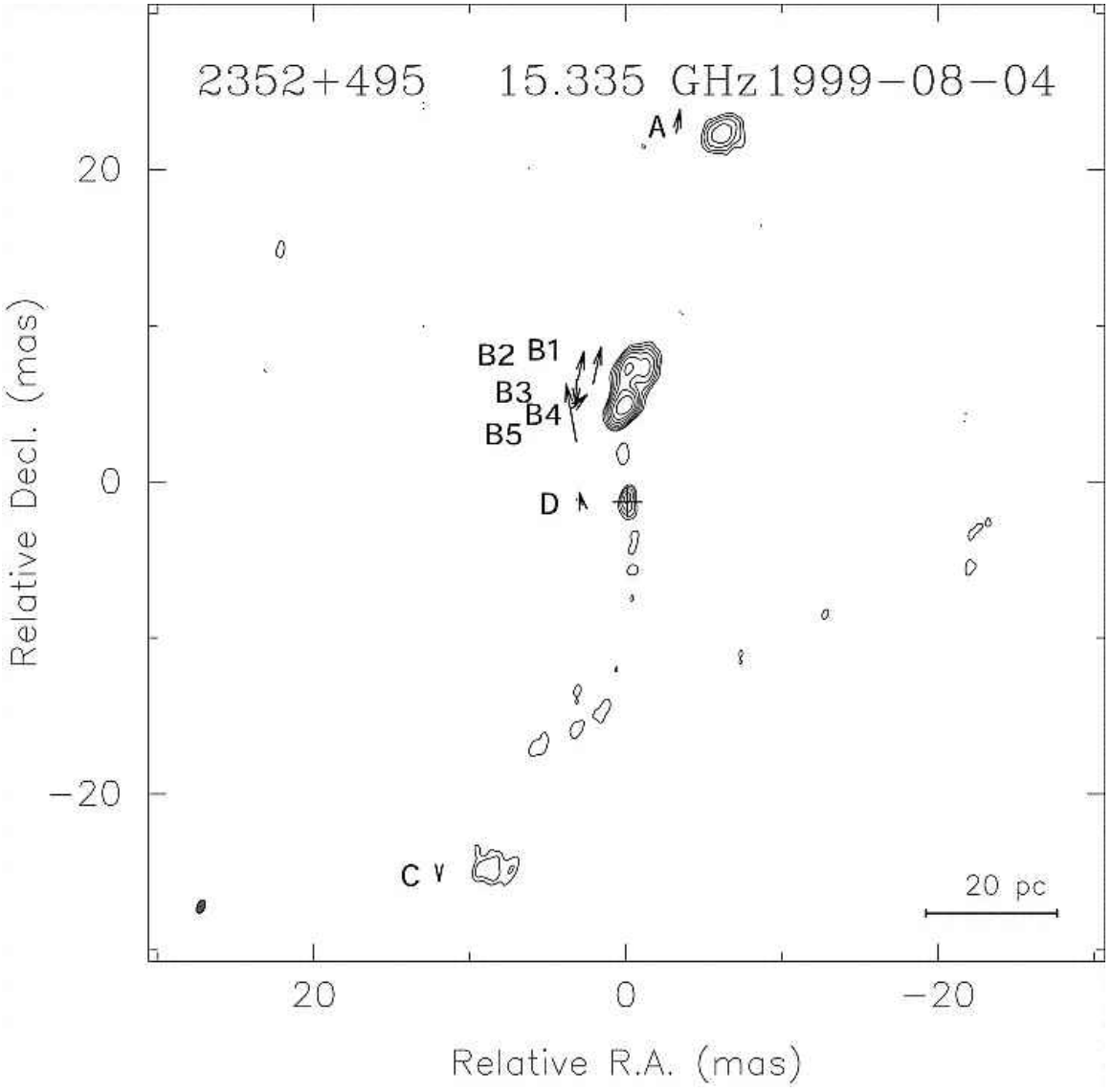


B2352+495

B2352+495: Radio Continuum



Wilkinson et al. (1994)
18cm, global VLBI



Taylor et al. (2000), VLBA

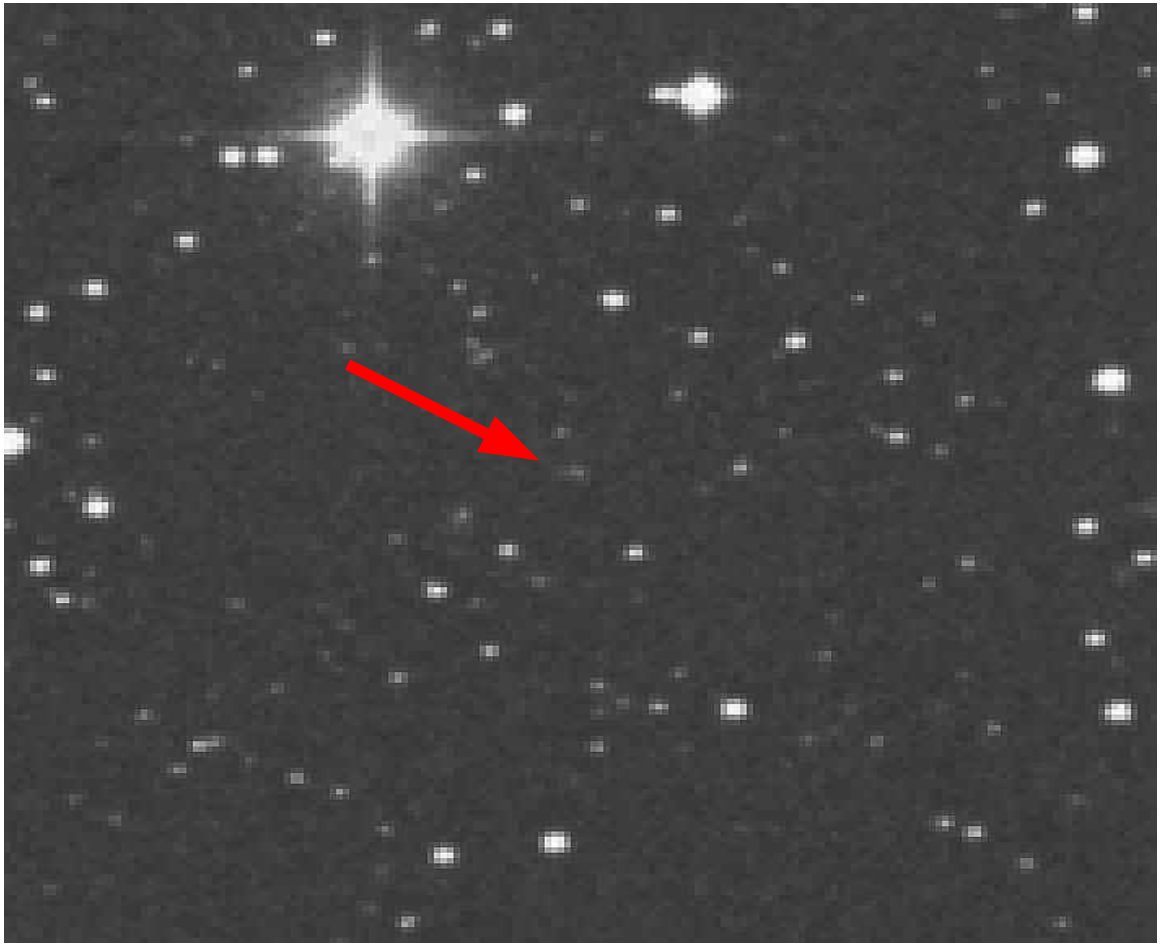
SED Peak: ~ 1 GHz

Modest Variability < 20%

$L_{5GHz} \sim 10^{26}\ h^{-2}\ W\ Hz^{-1}$

Dynamic age ~ 1000 yr

B2352+495: Other wavelengths



NED, Palomar, 6450A

Elliptical Galaxy

$z = 0.23790$

$\sigma = 201 \pm 17$ km/s

$M_v = -19.8$

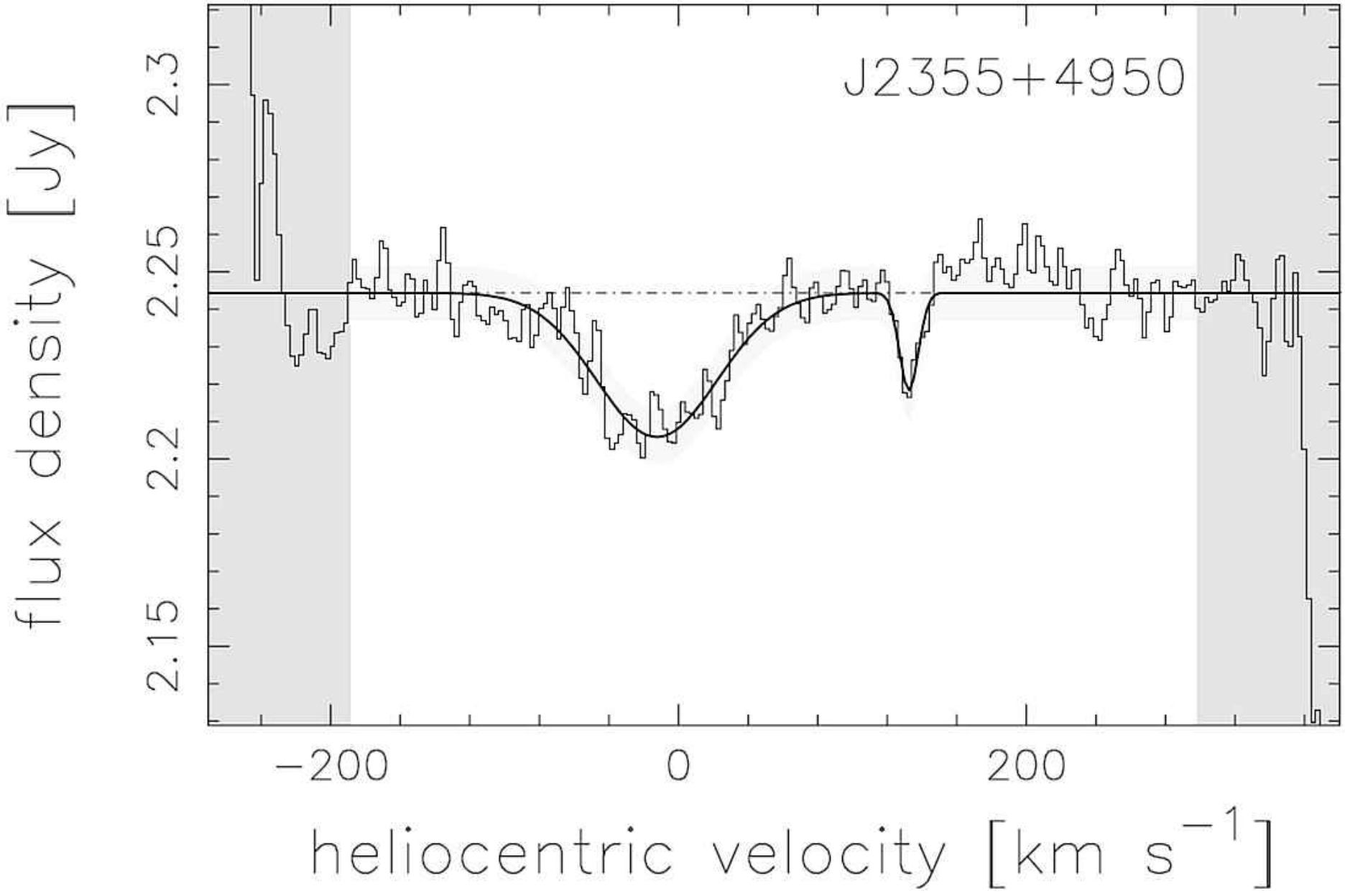
$m_v = 20.1$

No IRAS detection (at the Arp220 luminosity limit)

X-Ray detection:
$0.66 \pm 0.27 \times 10^{22}$ cm^{-2} absorption column density

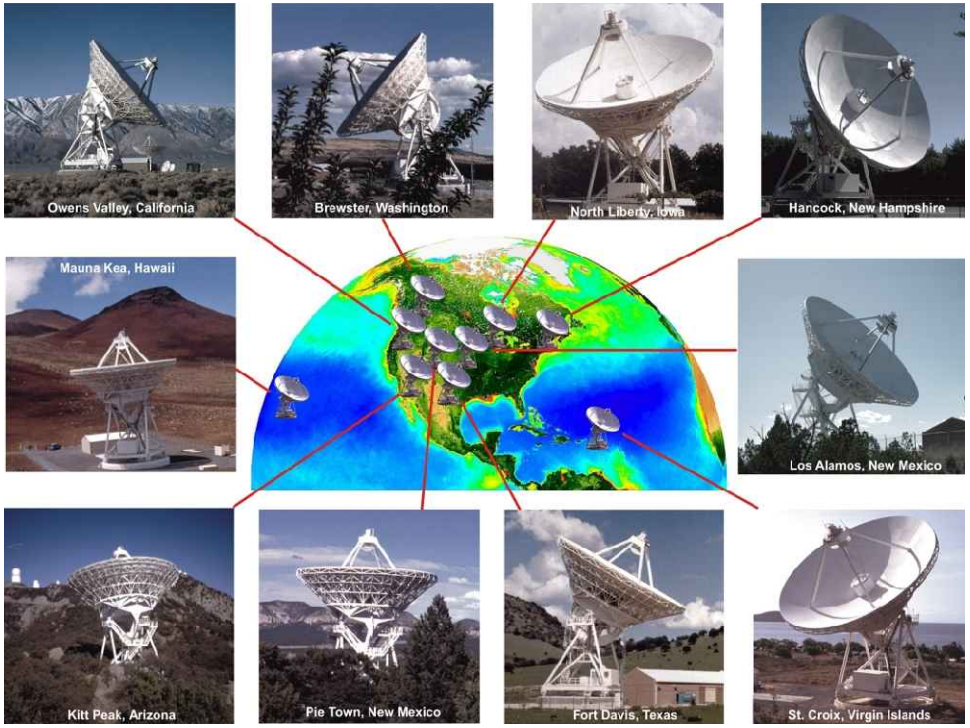
Readhead et al. (1996)
Snellen et al. (2003)
Vink et al. (2006)

B2352+495: Prior HI Observations



Vermeulen et al. (2003)
WSRT

B2352+495: Observations



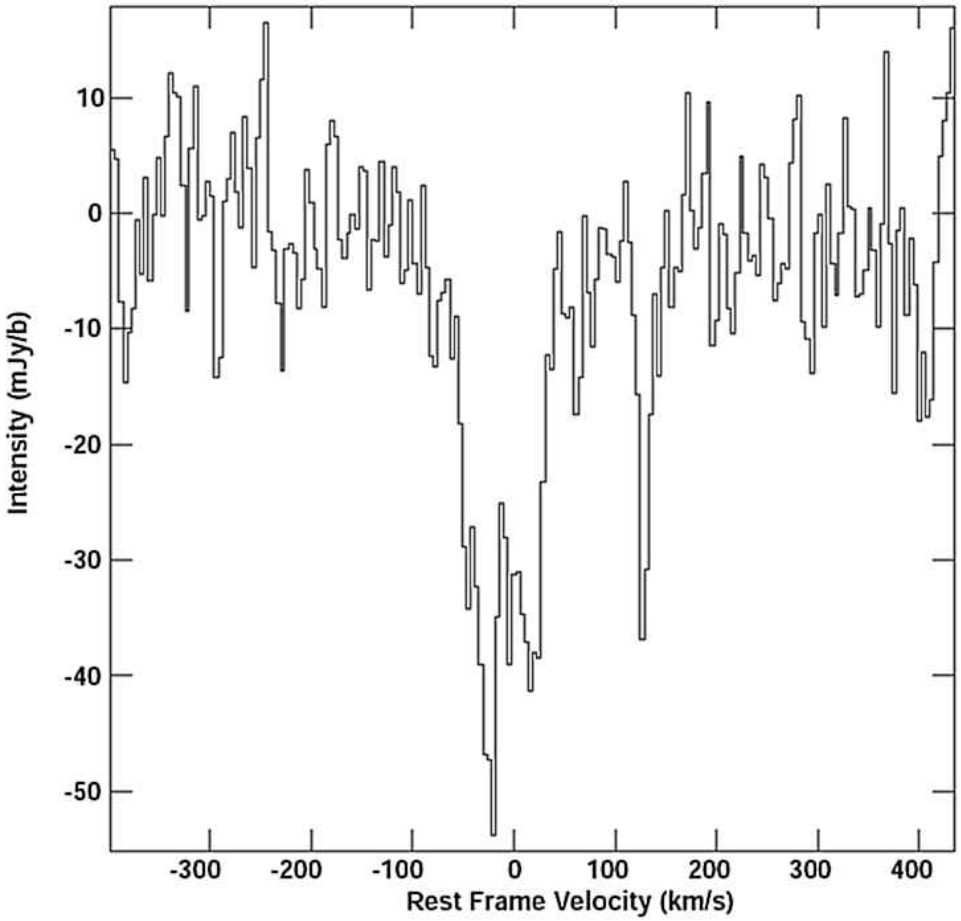
VLBA

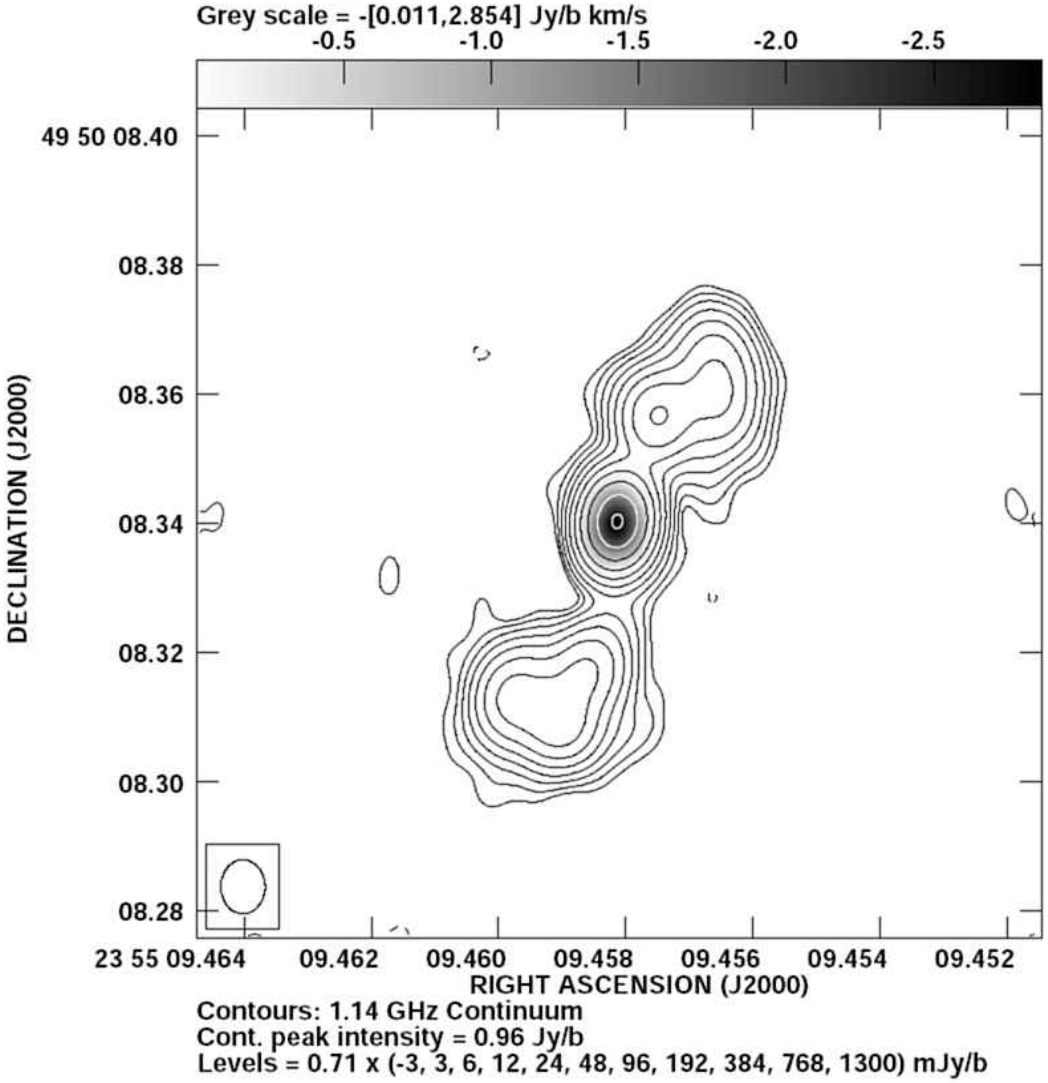
+

WSRT

- 2 days, ~17 h on source
- ν_{sky} = 1147.40 MHz
- BW = 8 MHz, 1024 channels
- Dual polarization
- Final spectral resolution = 15.6 kHz (4.1 km/s)
- Flux density calibration: 2.55 Jy at 1.14 GHz assumed.

B2352+495: Results

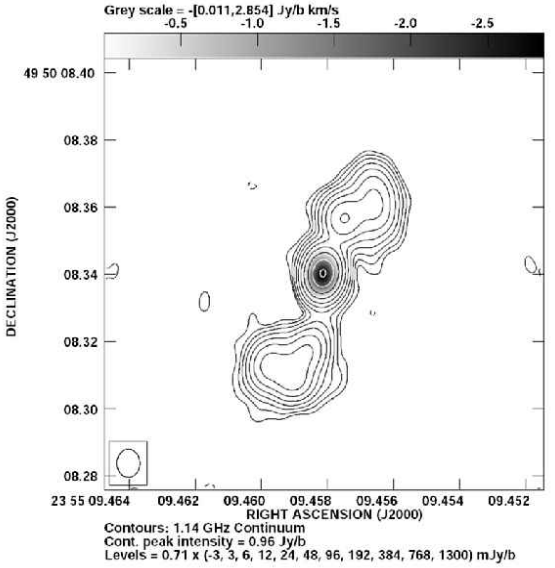


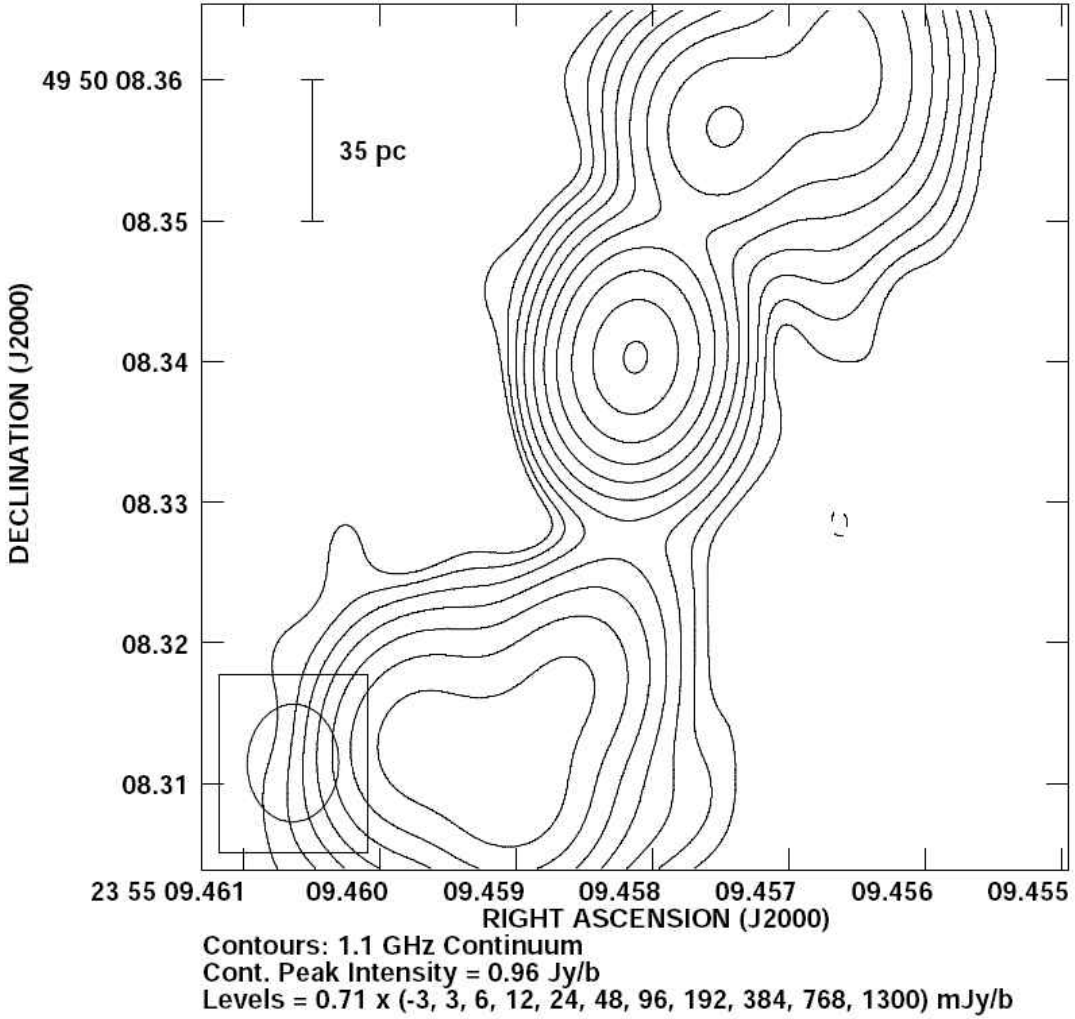


Narrow Line: FWHM = 13 ± 2 km/s, N_H = 7.3 ± 1.0 x 10^{21} cm^{-2}

Broad Line: FWHM = 85 ± 4 km/s, N_H = 5.2 ± 0.2 x 10^{22} cm^{-2}

B2352+495: Continuum Emission toward the HI Absorption





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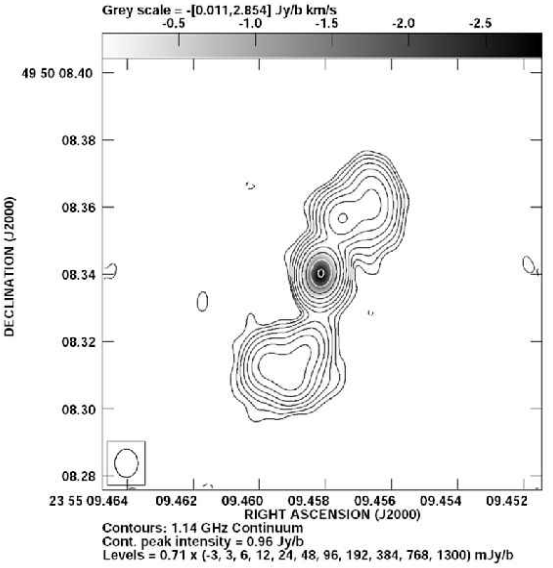
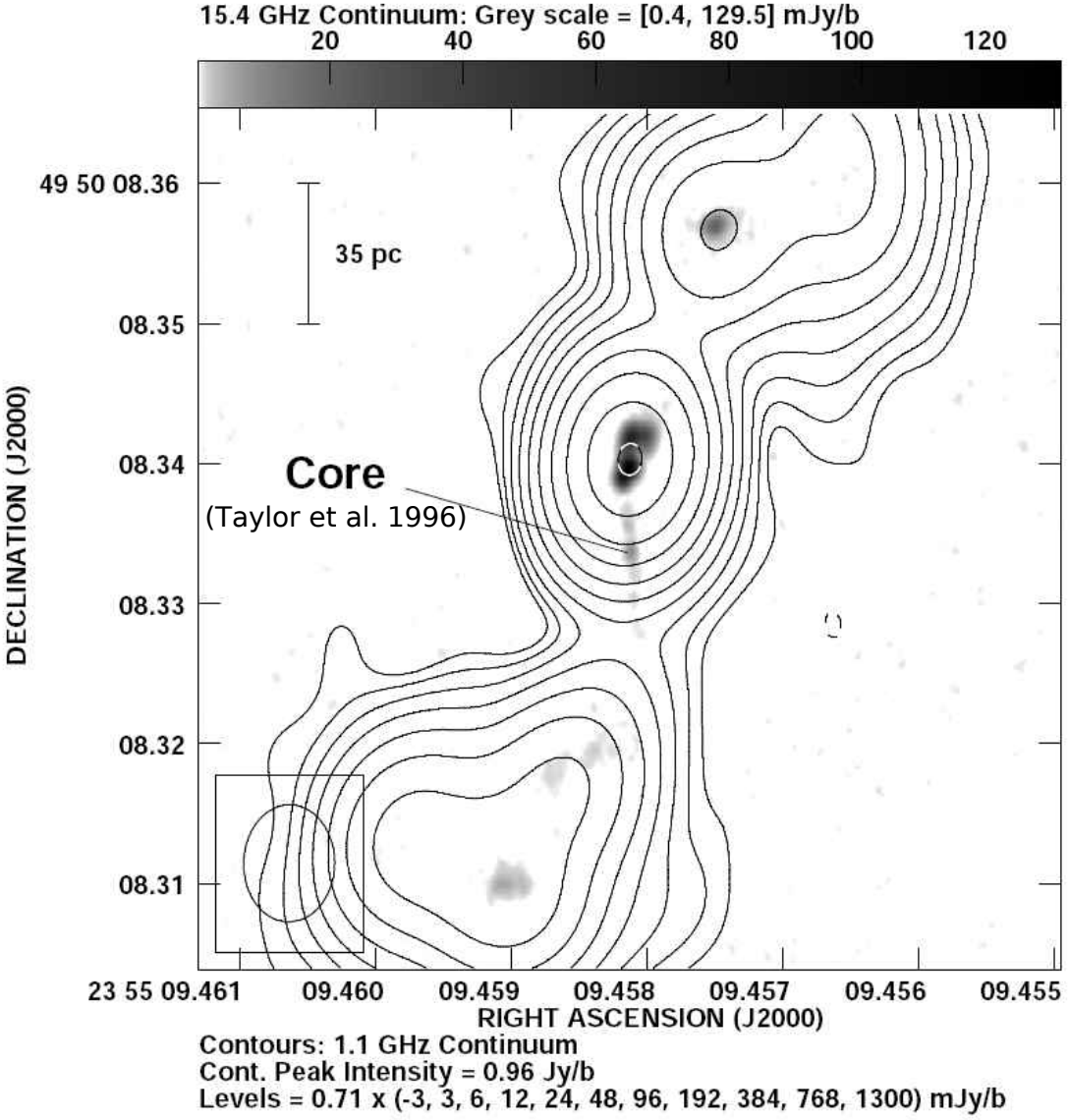
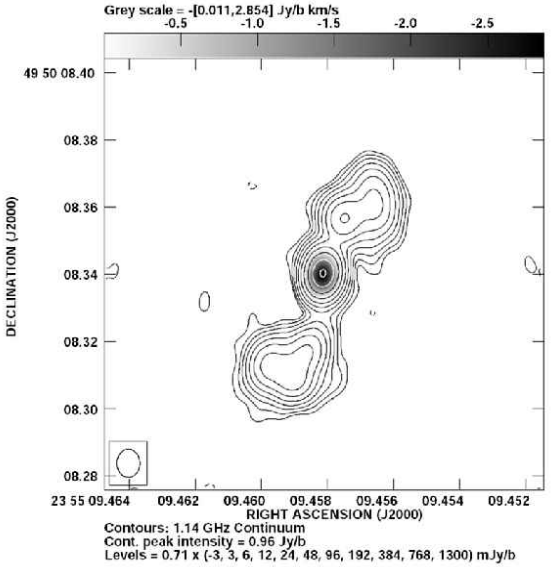
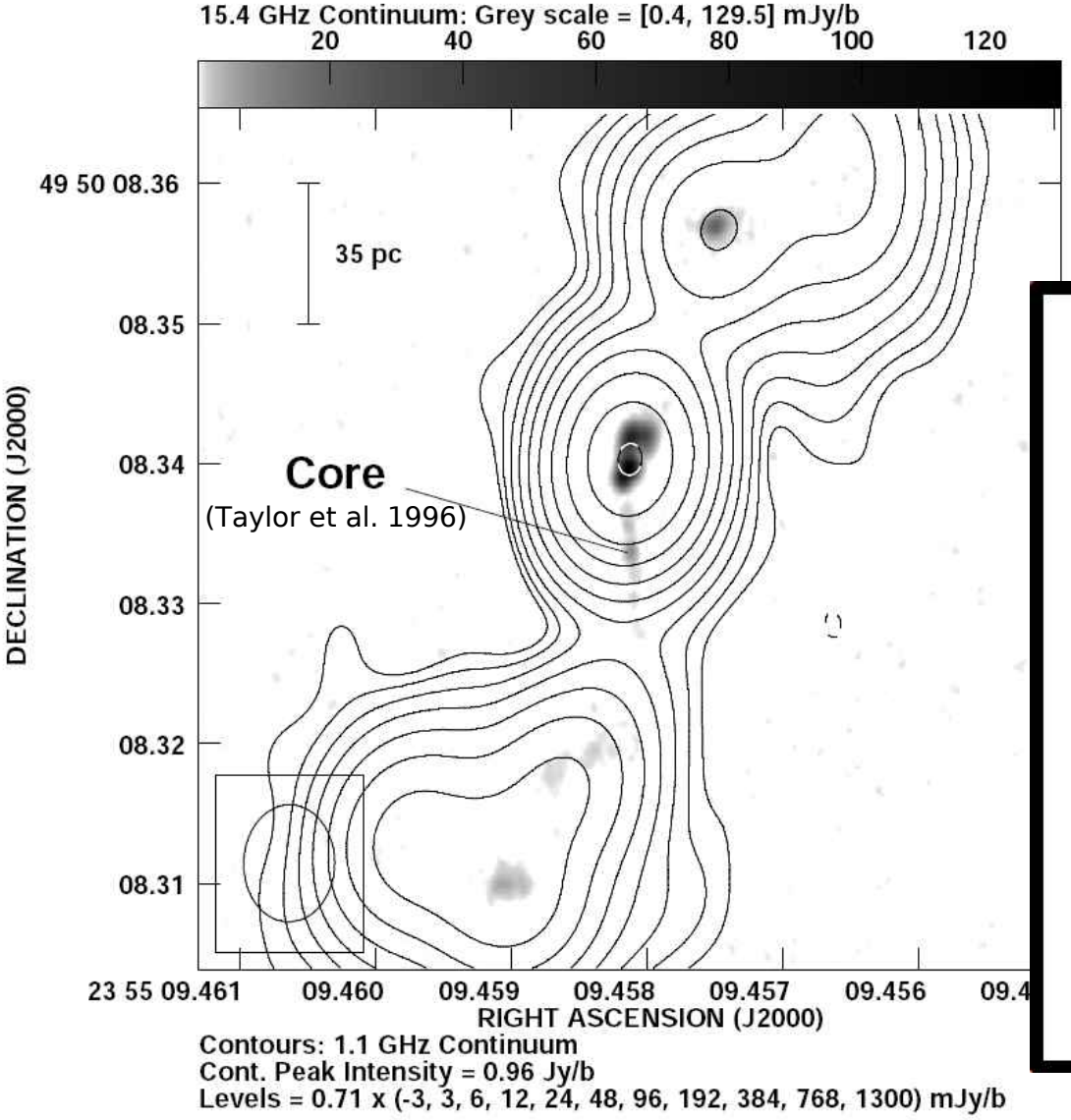
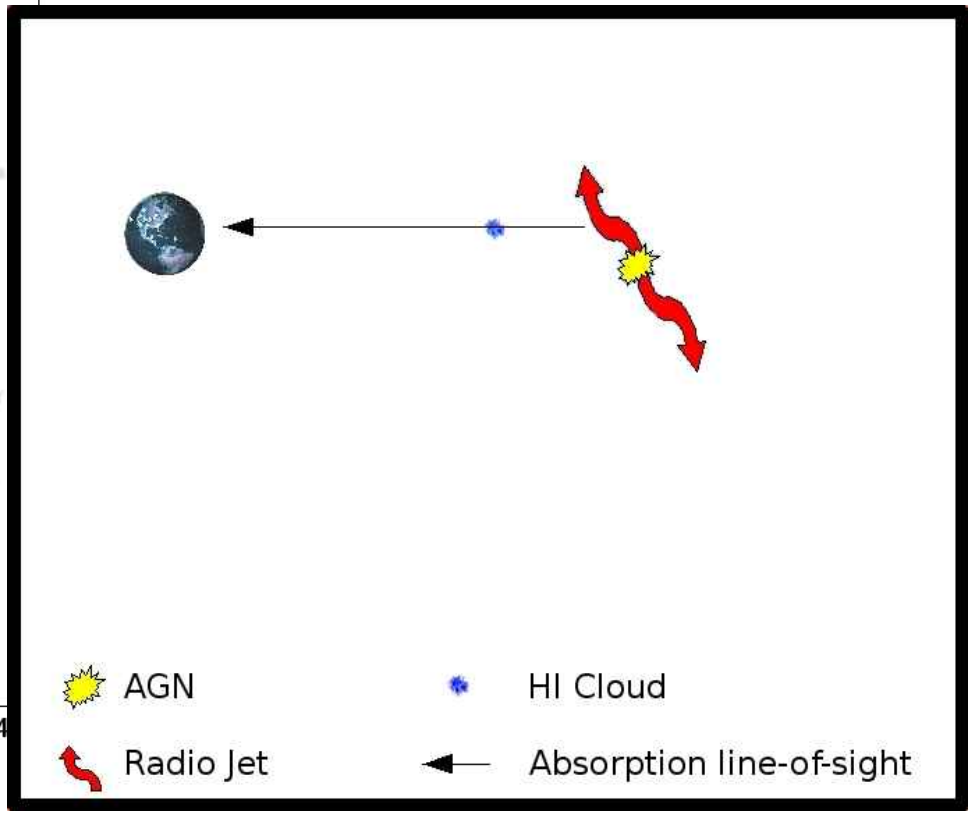




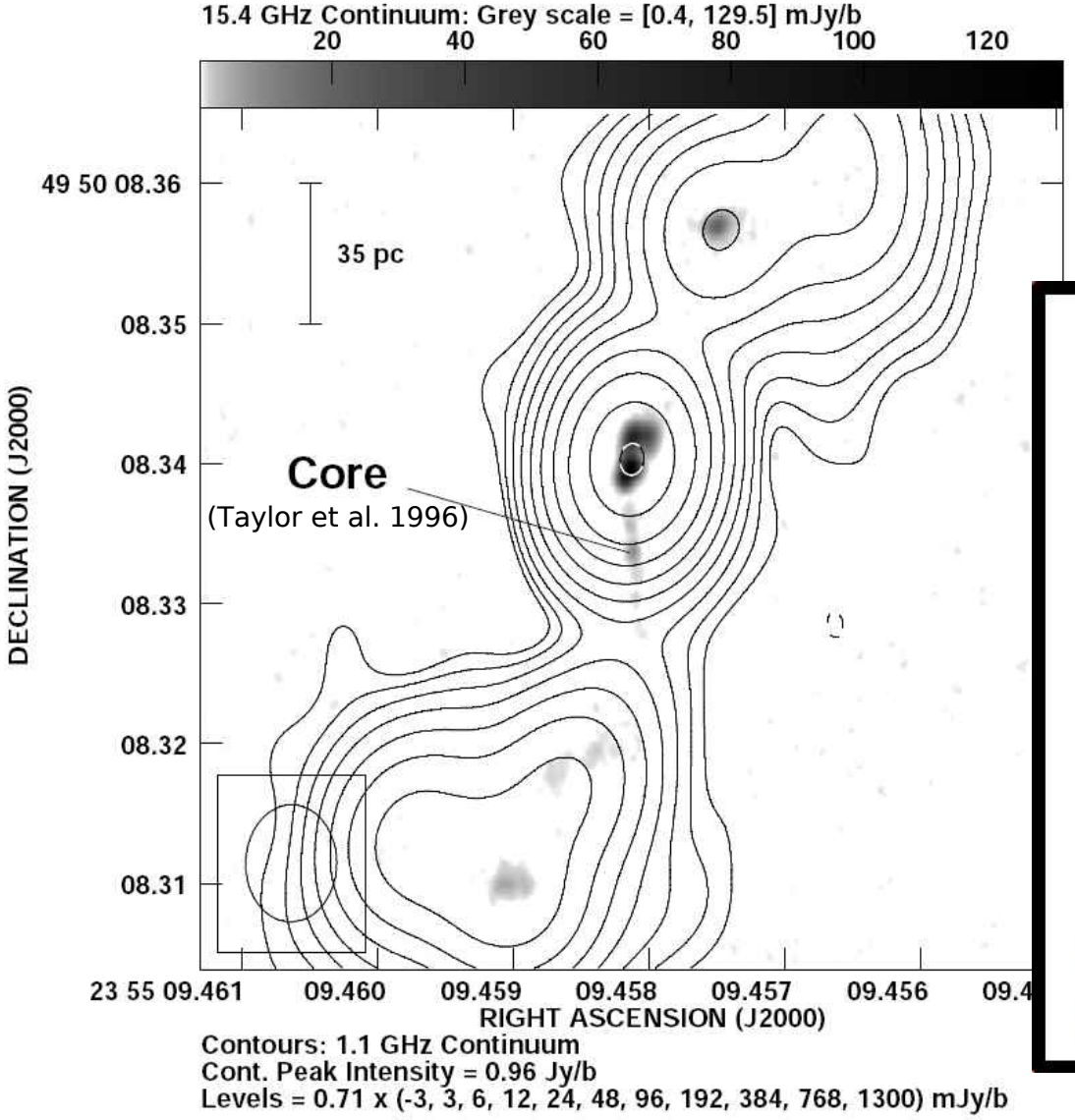
B2352+495: Radio Continuum toward the HI Absorption

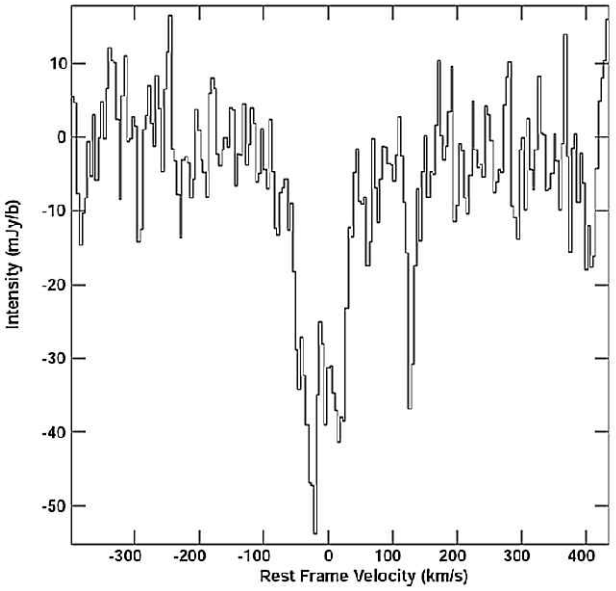


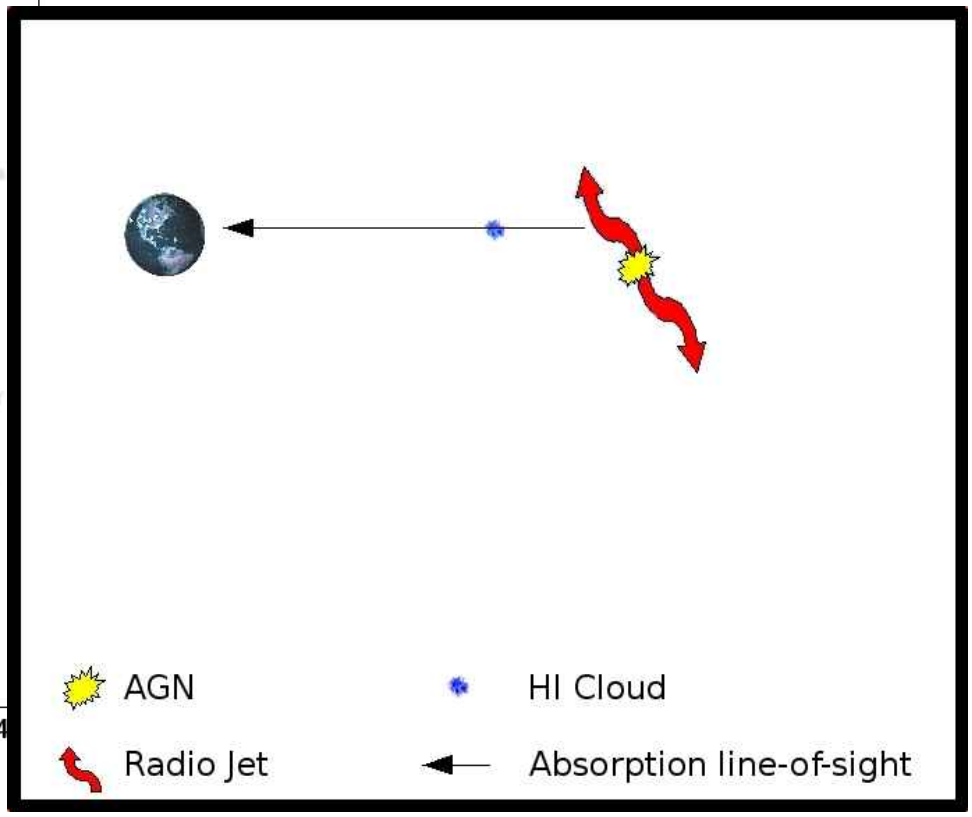




B2352+495: Nature of the HI Absorption







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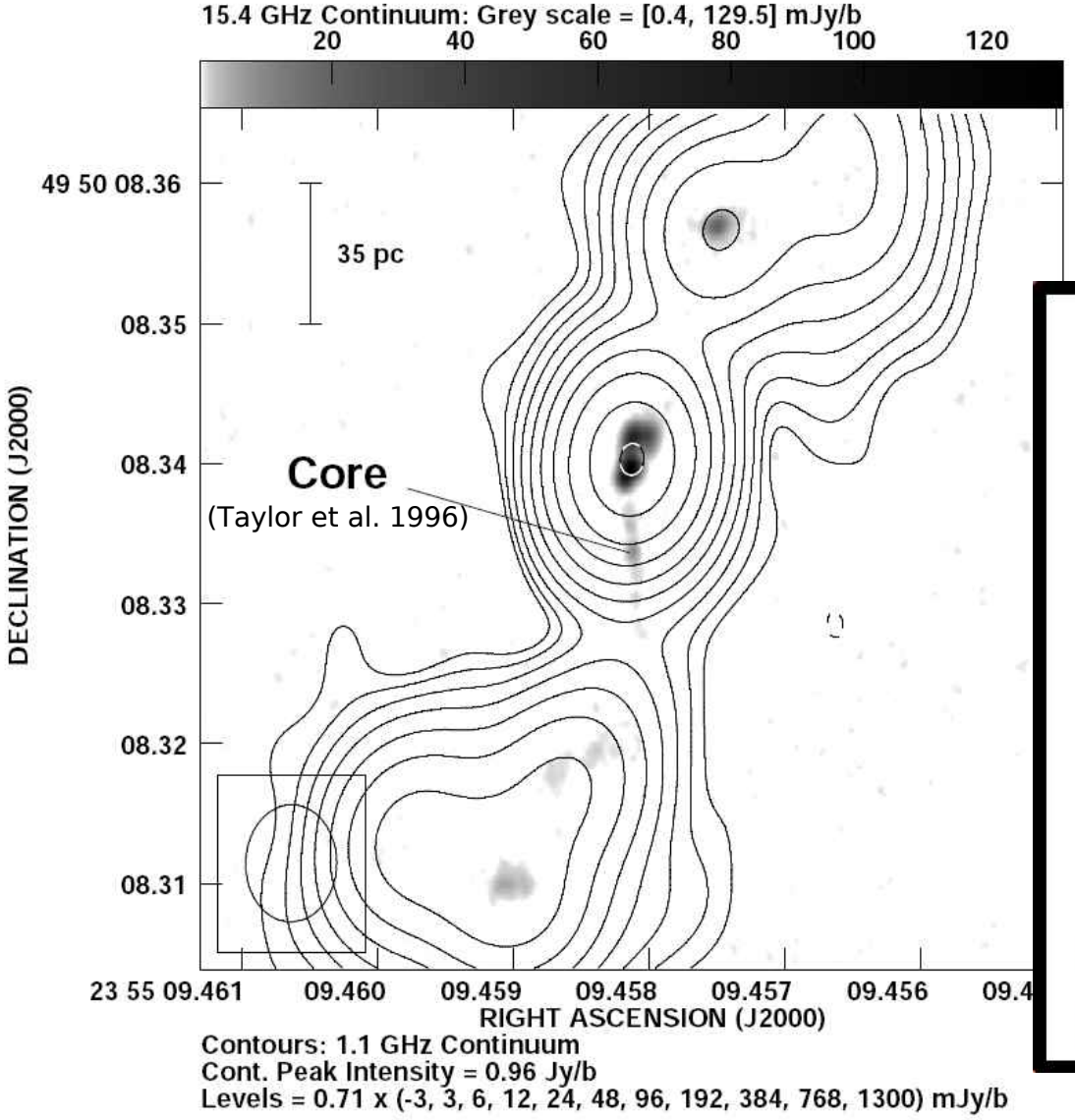
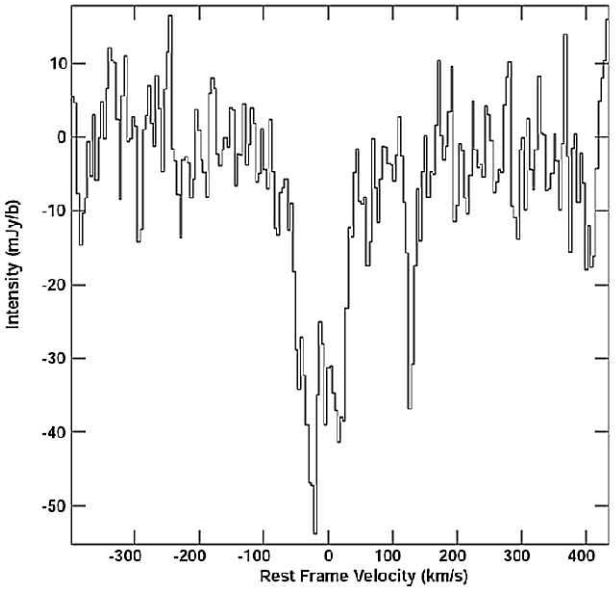
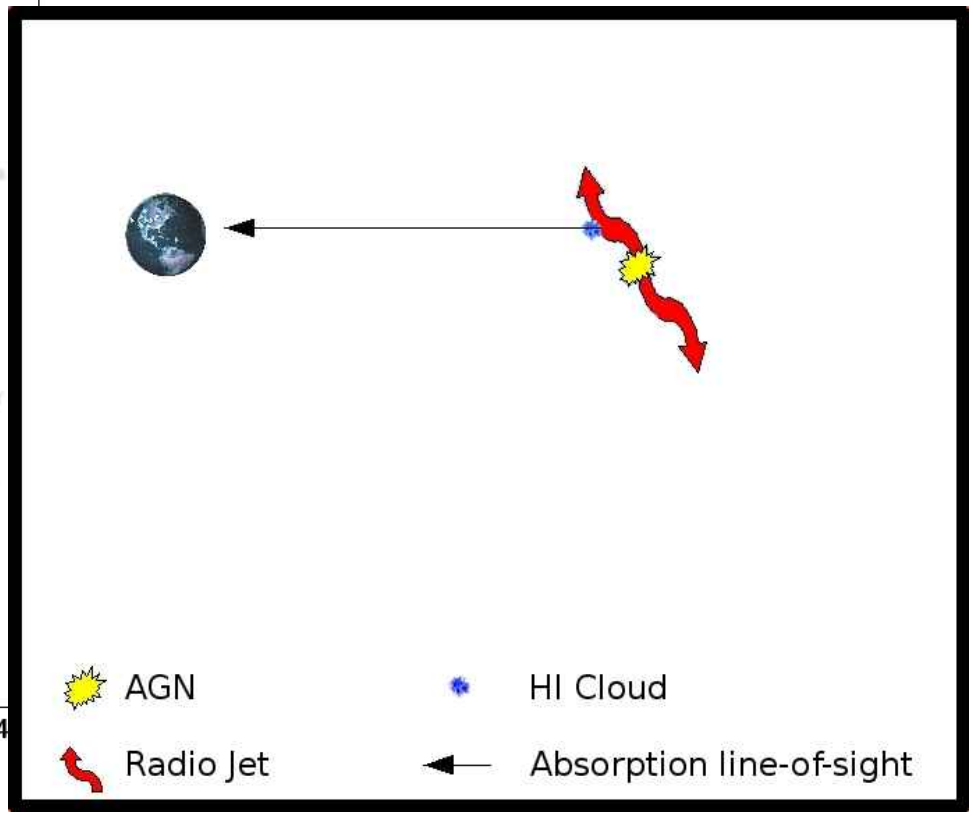
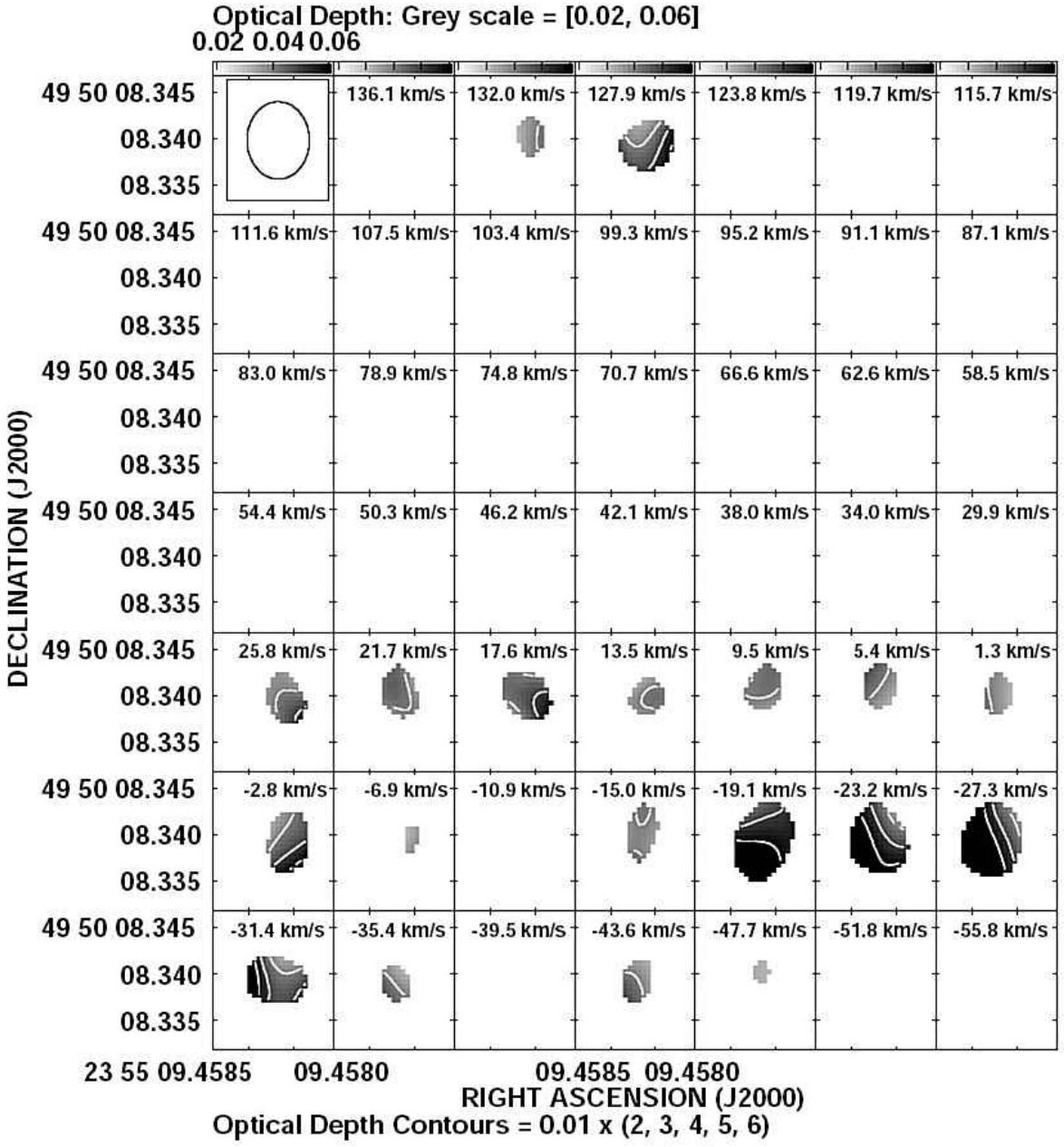
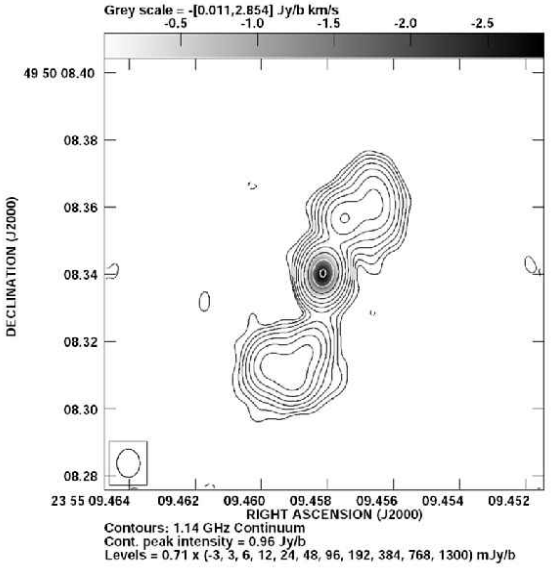






B2352+495: Possible Velocity Gradient





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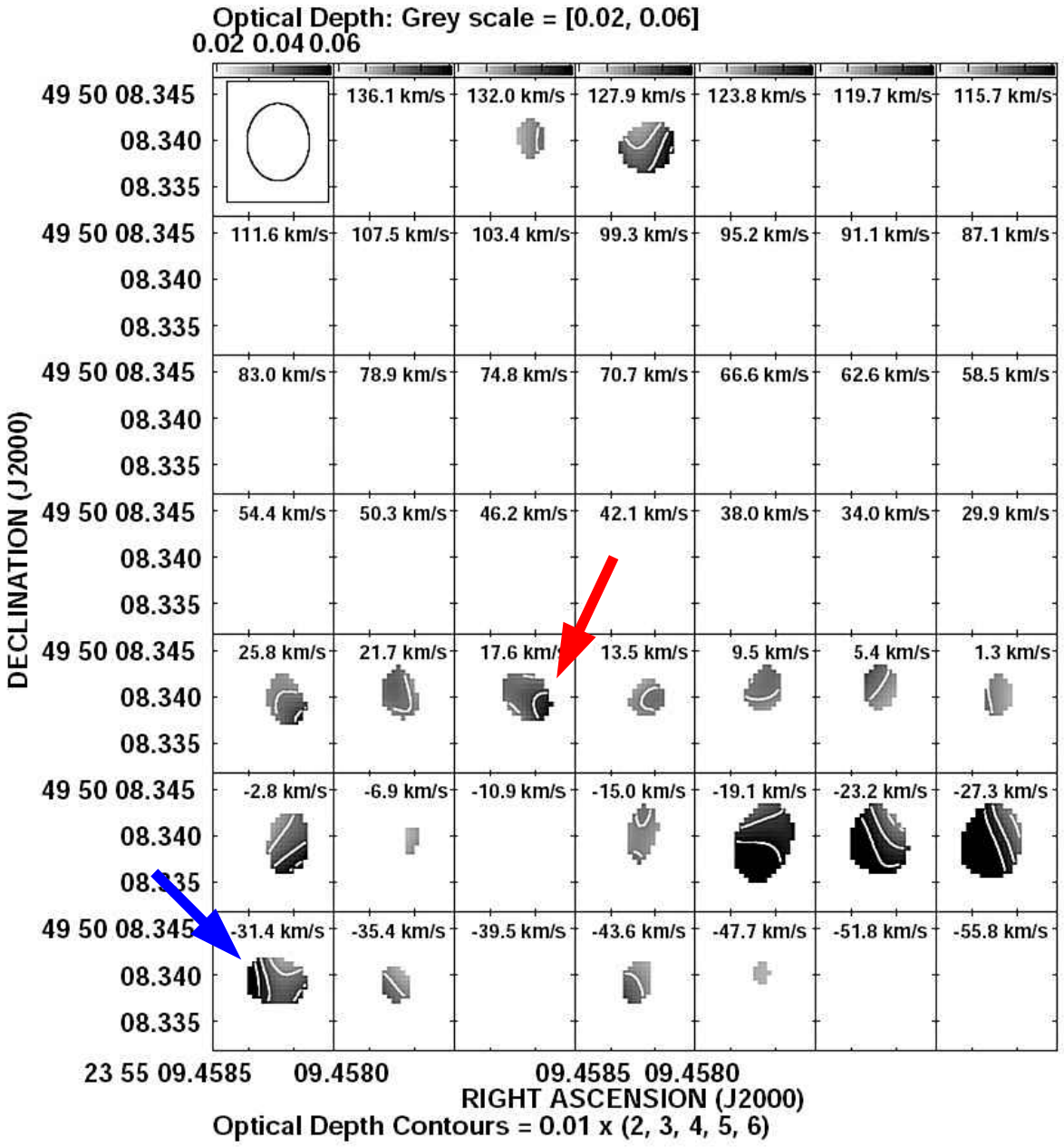

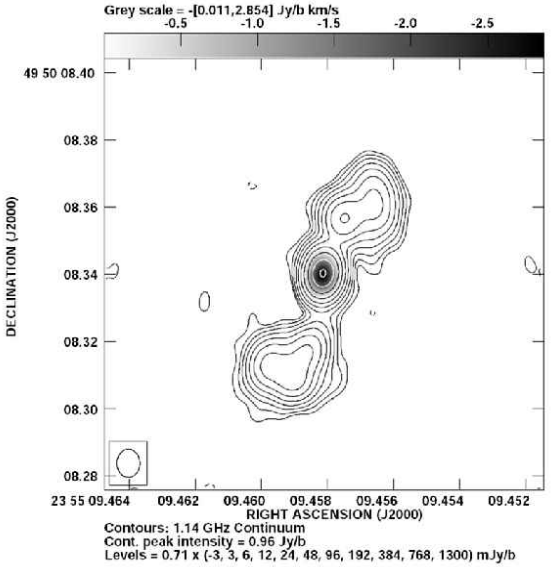

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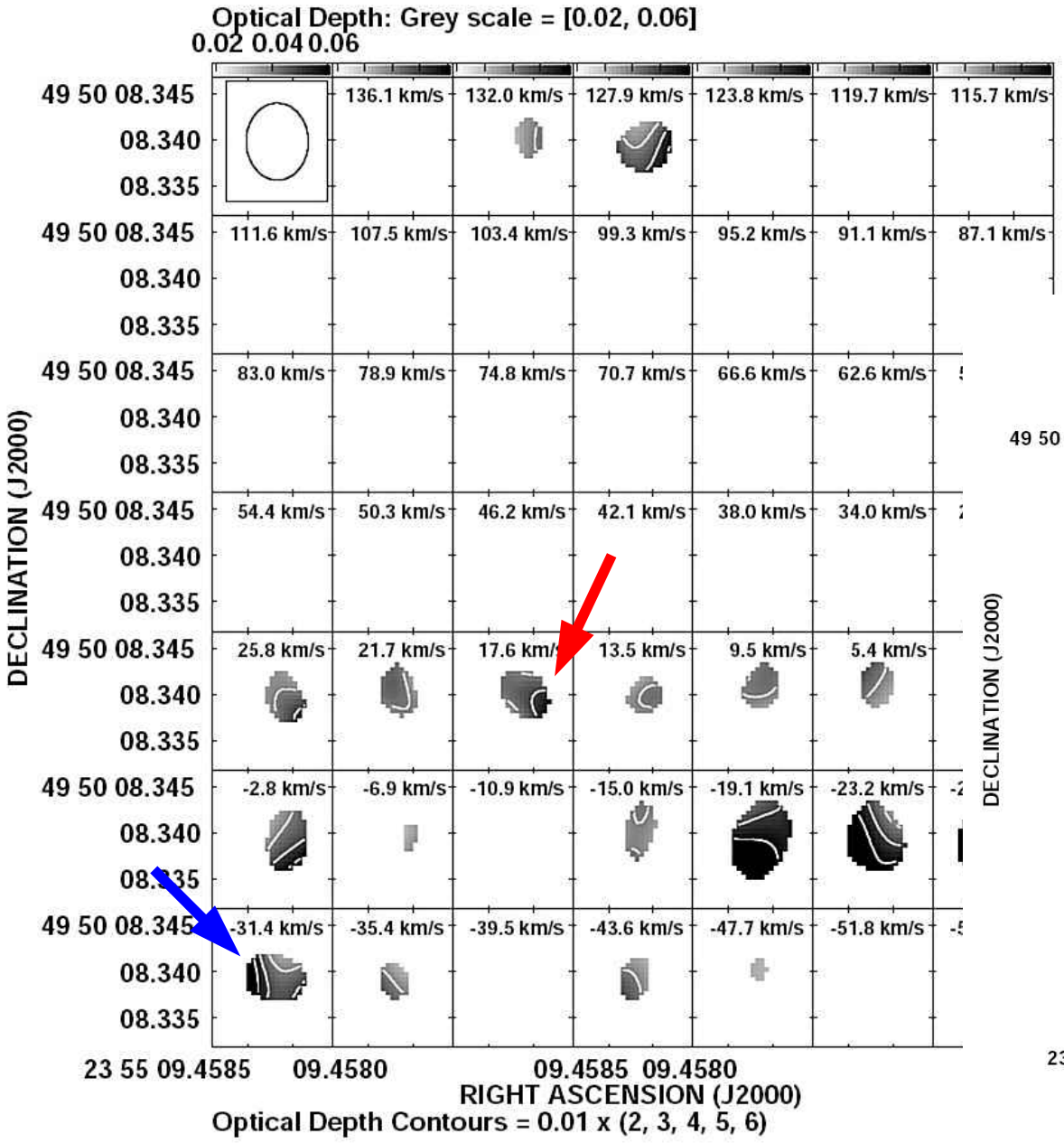
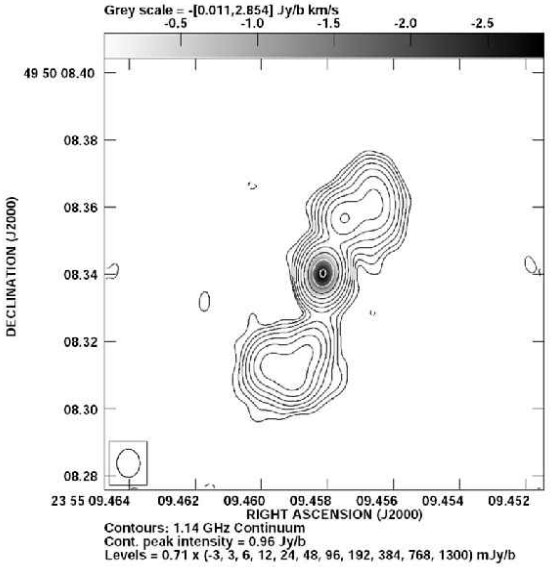
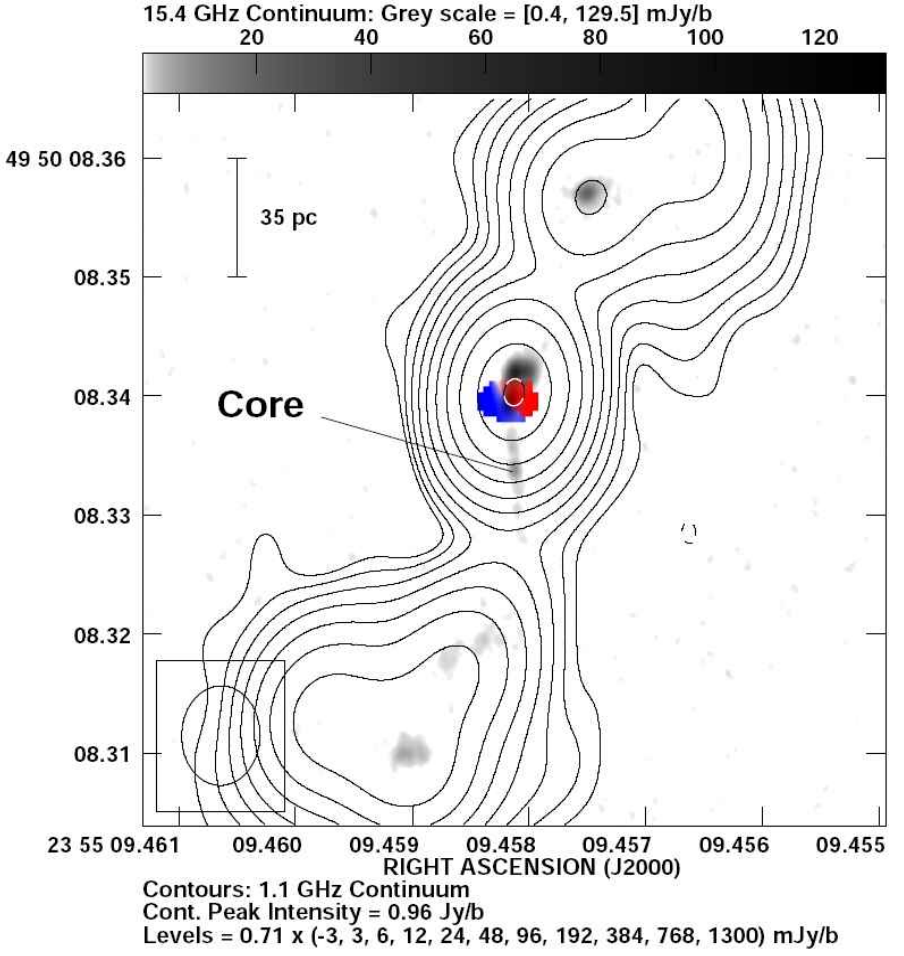
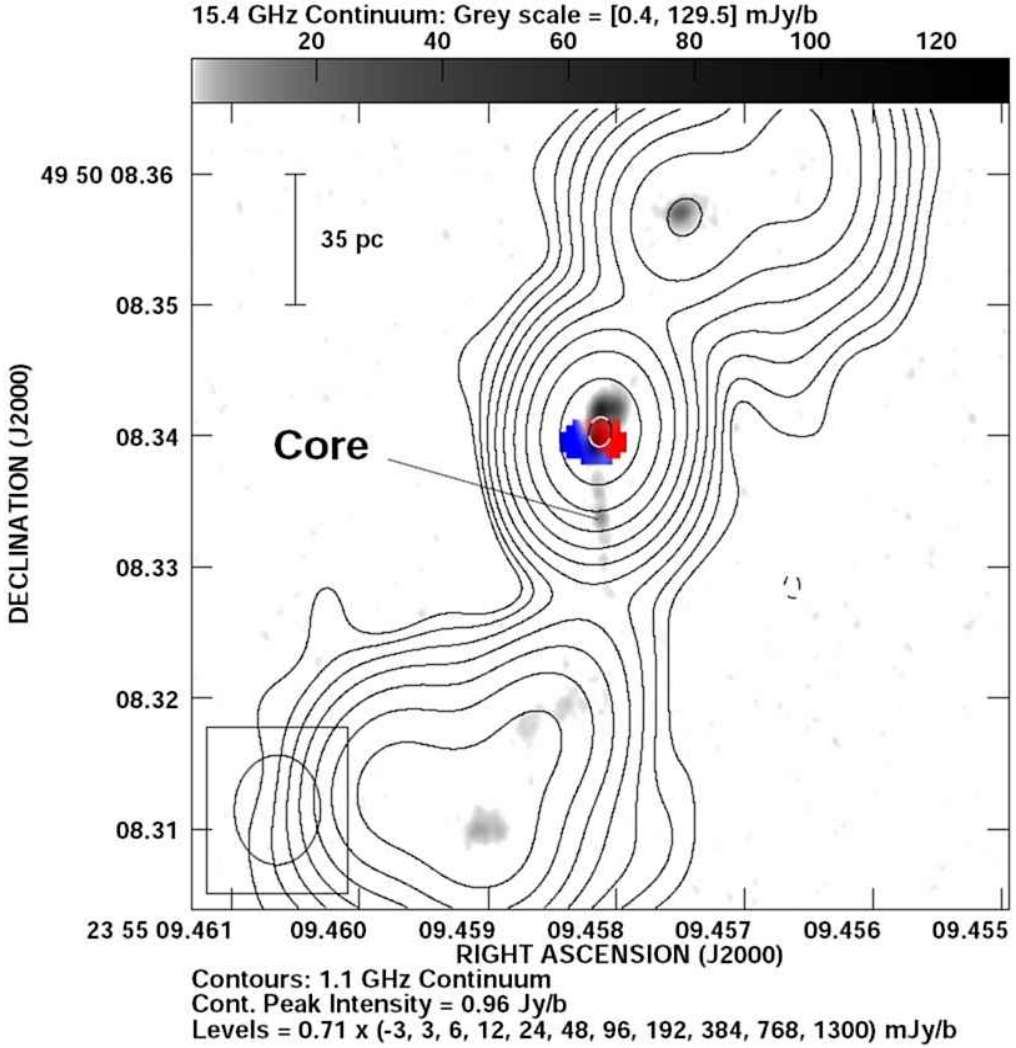






B2352+495: Disk/Torus Interpretation



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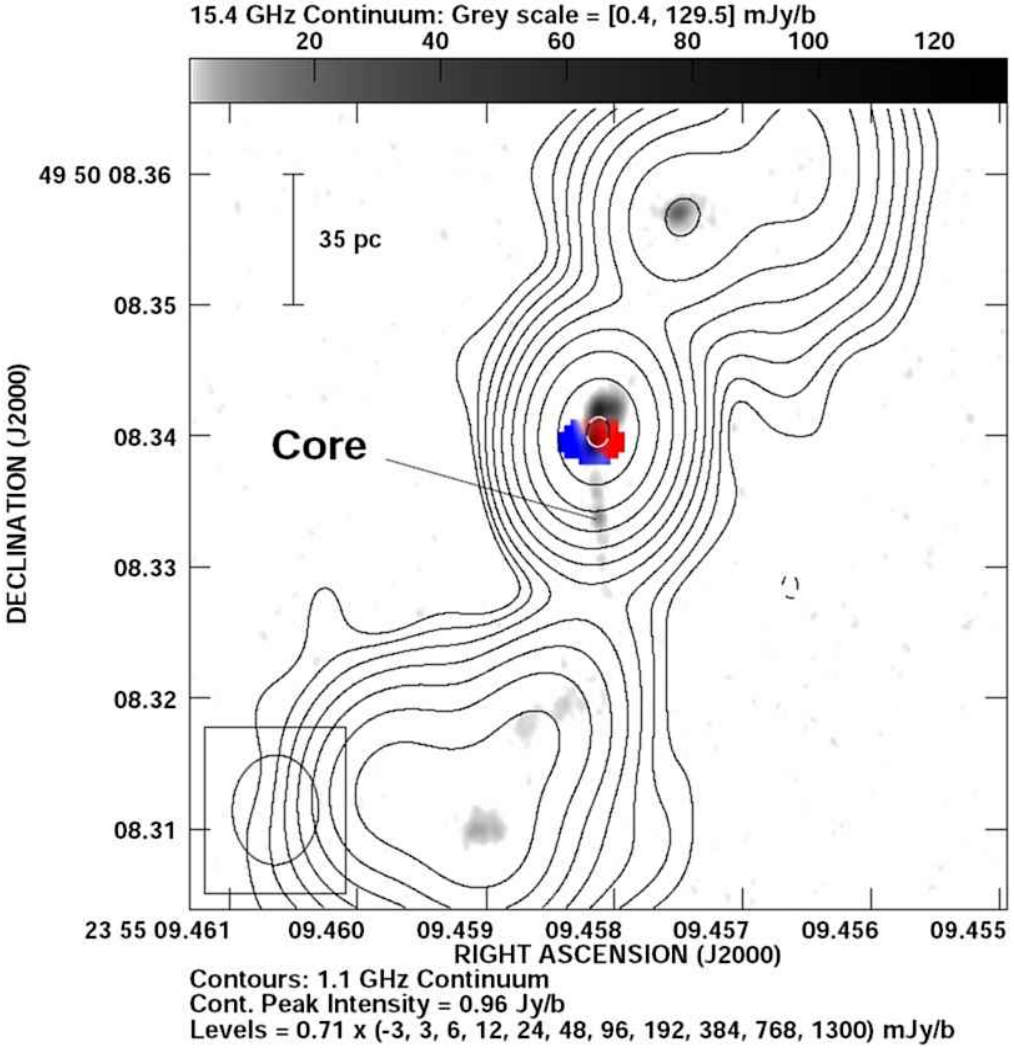
Physically Reasonable: $M_{BH} \sim 10^8 M_\odot$



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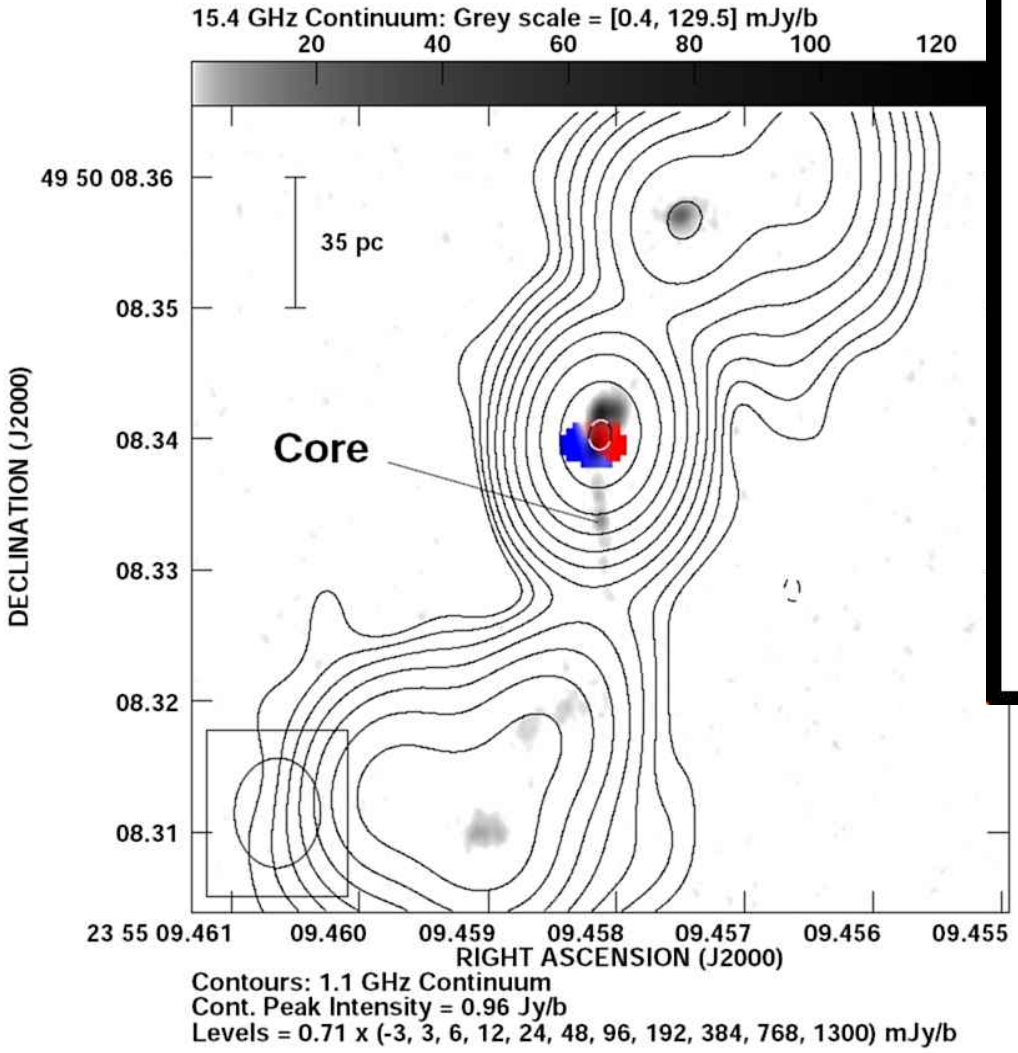

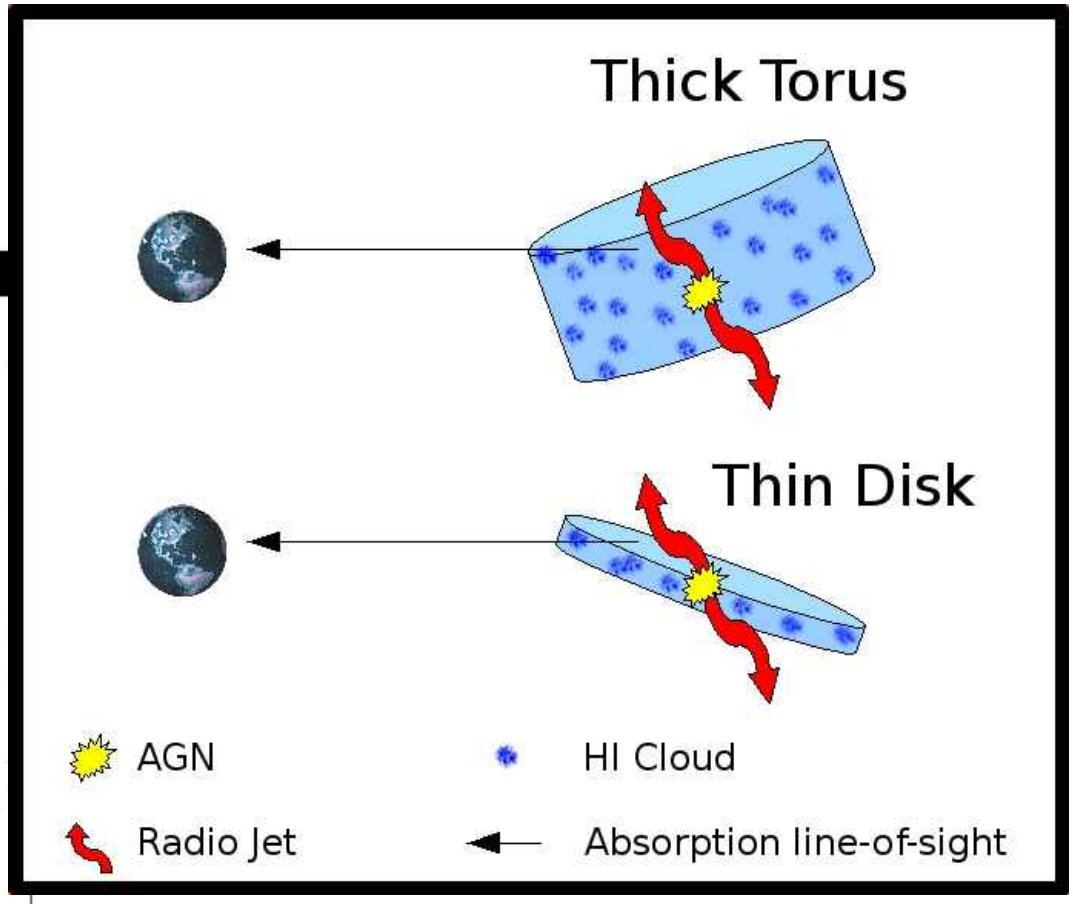

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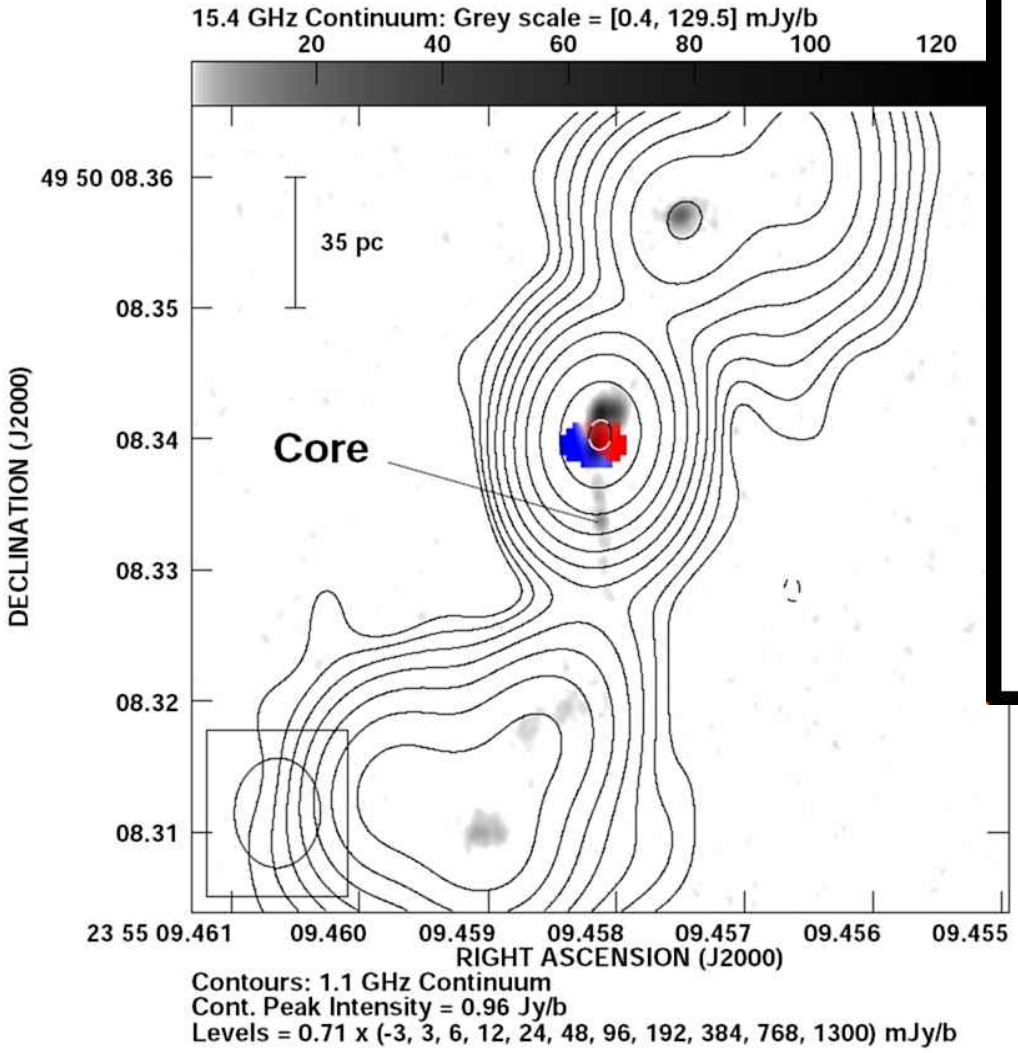

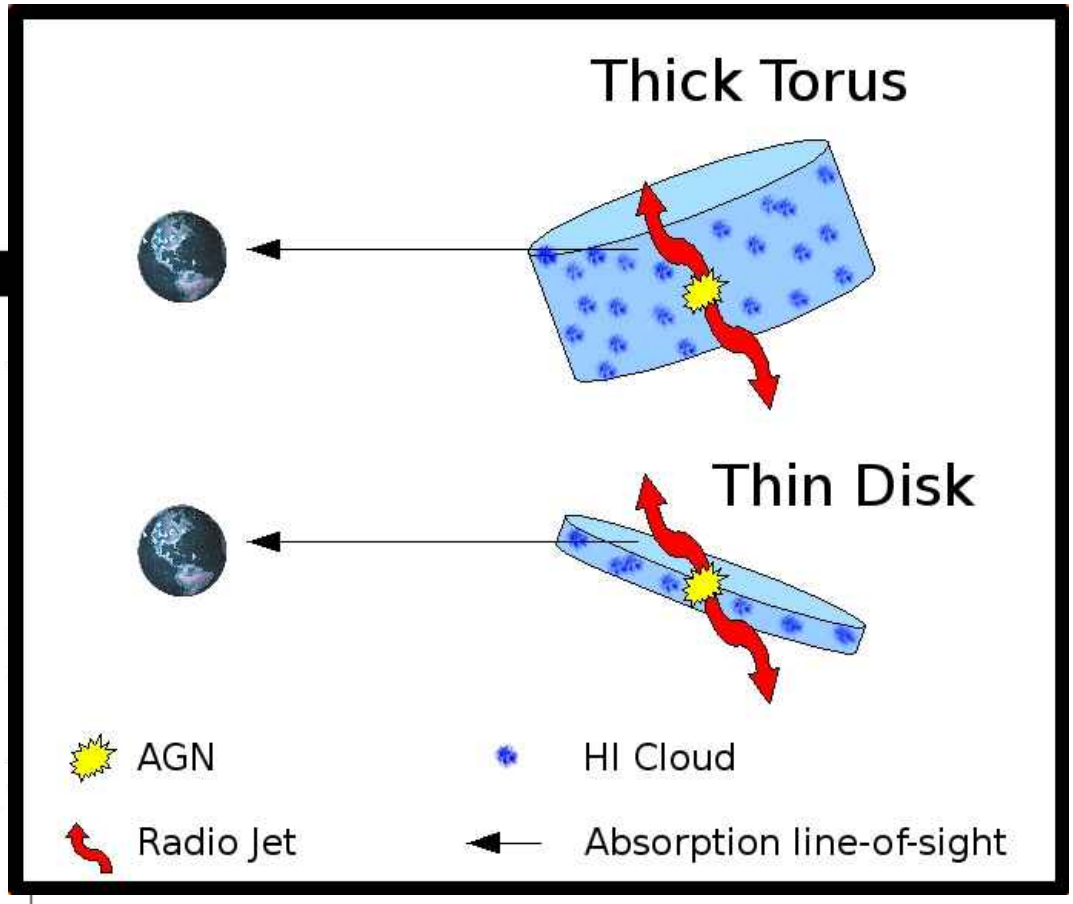

- HI Distribution

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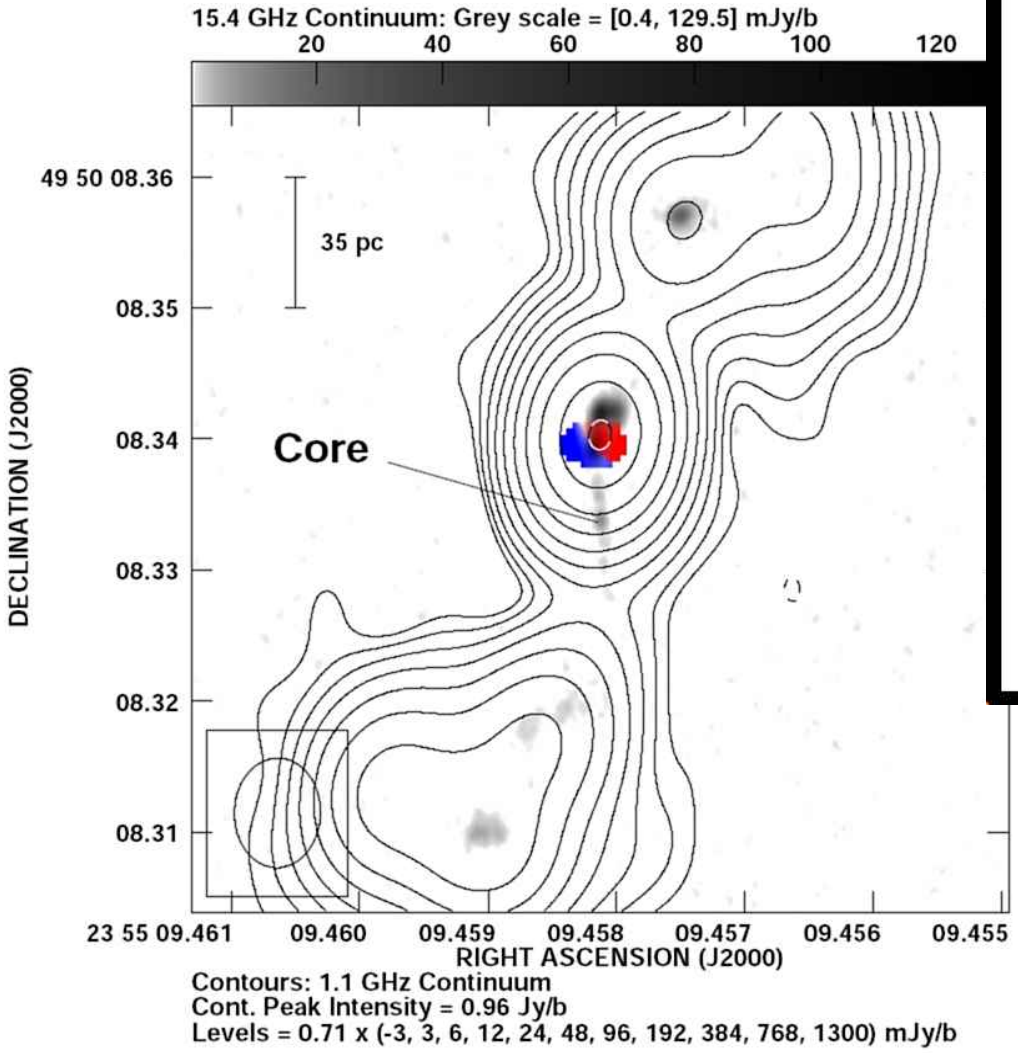
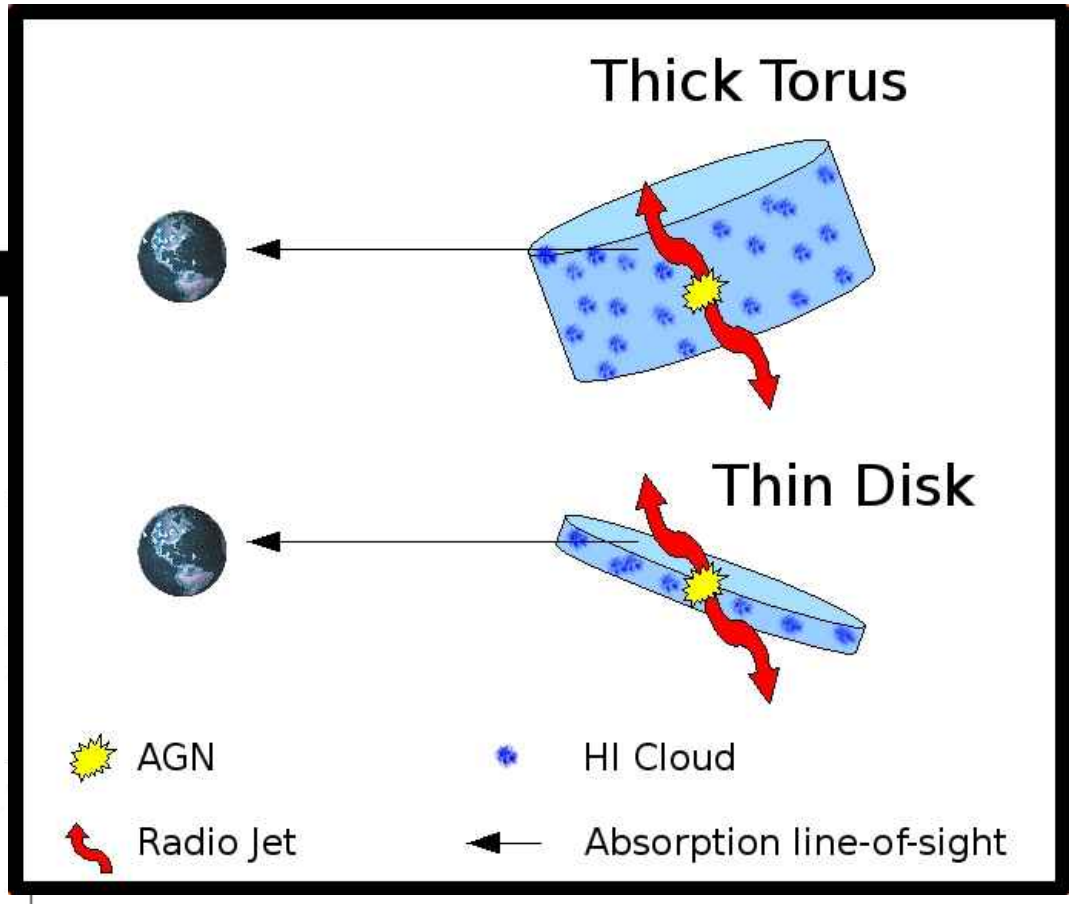
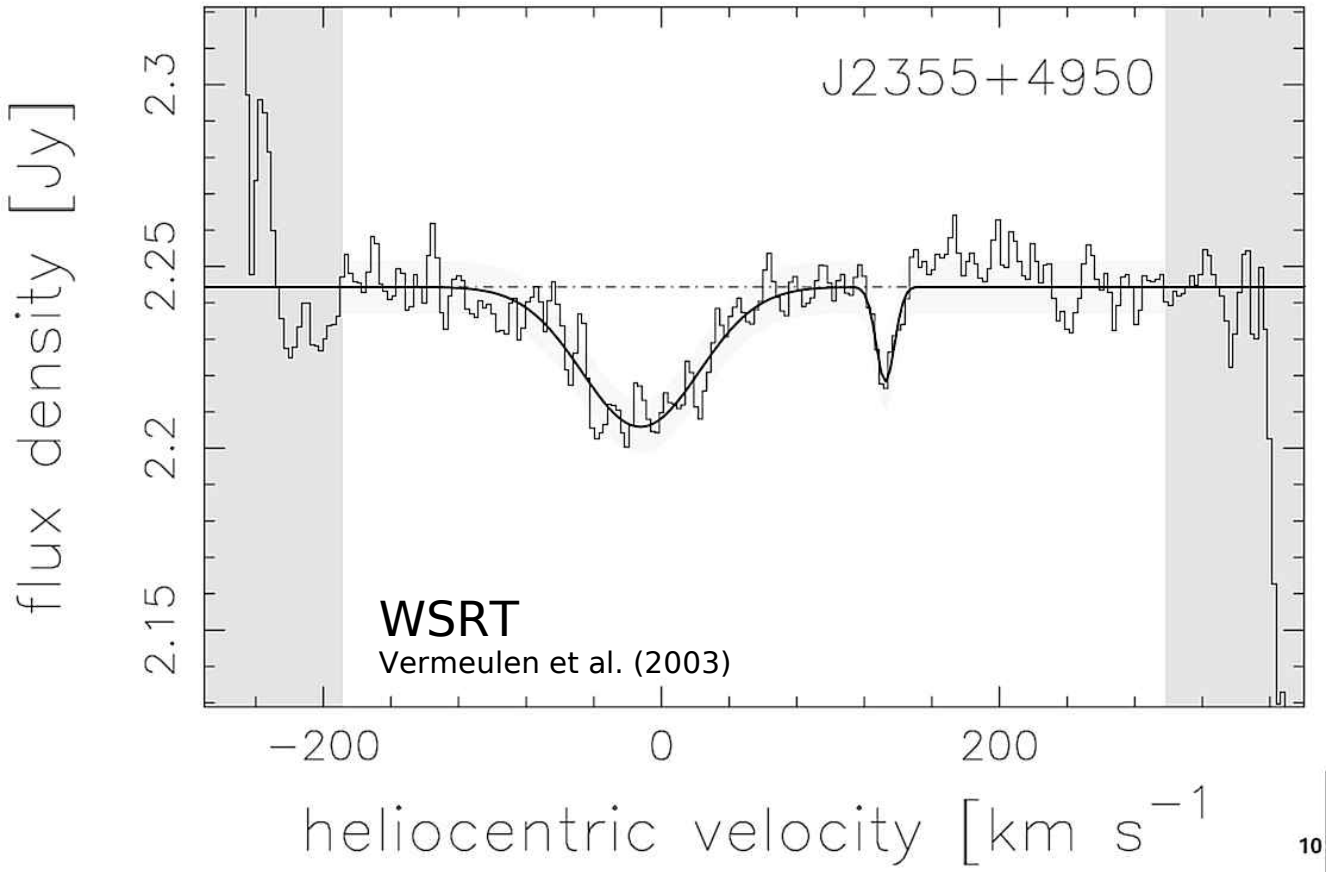
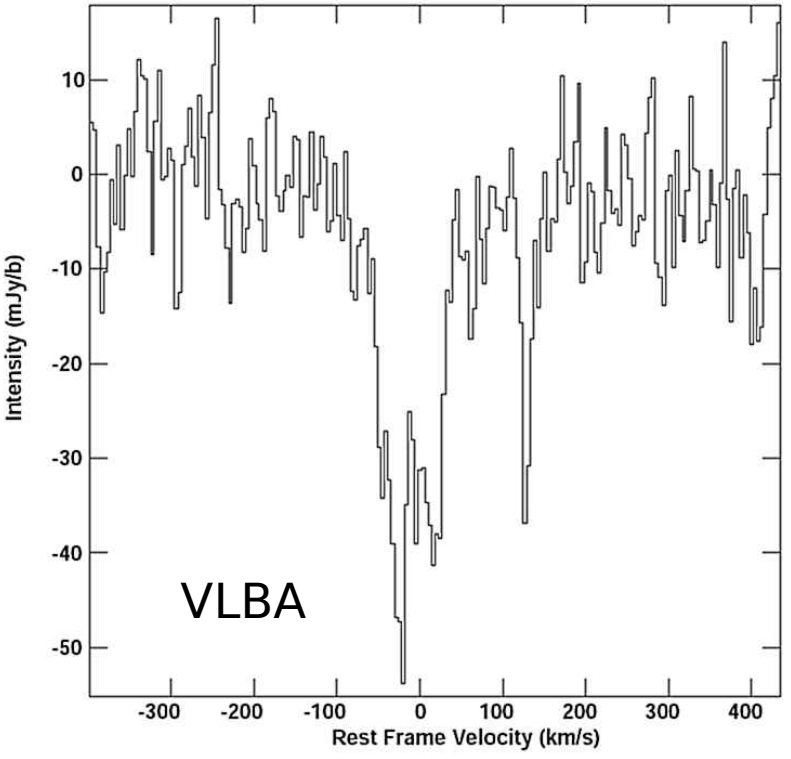




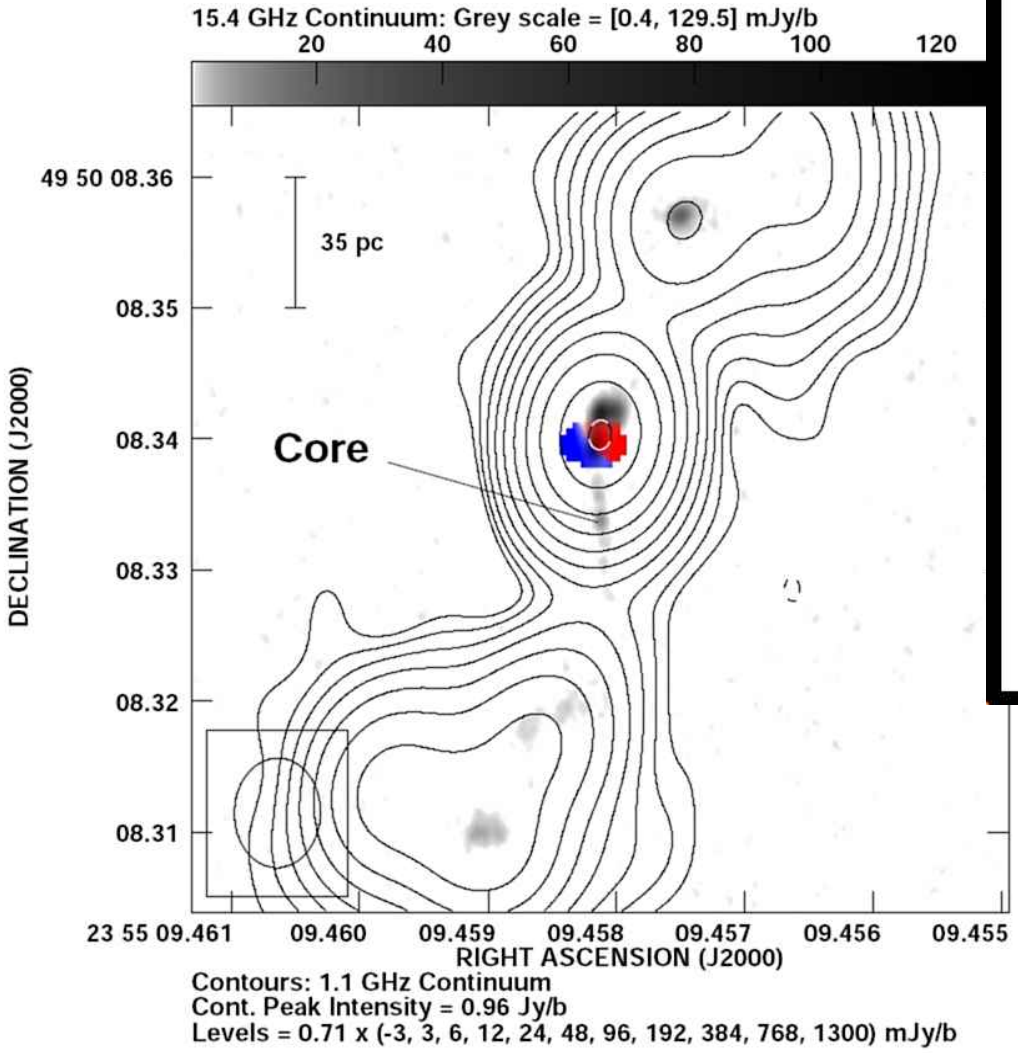
- HI Distribution
- VLBA vs WSTR flux density

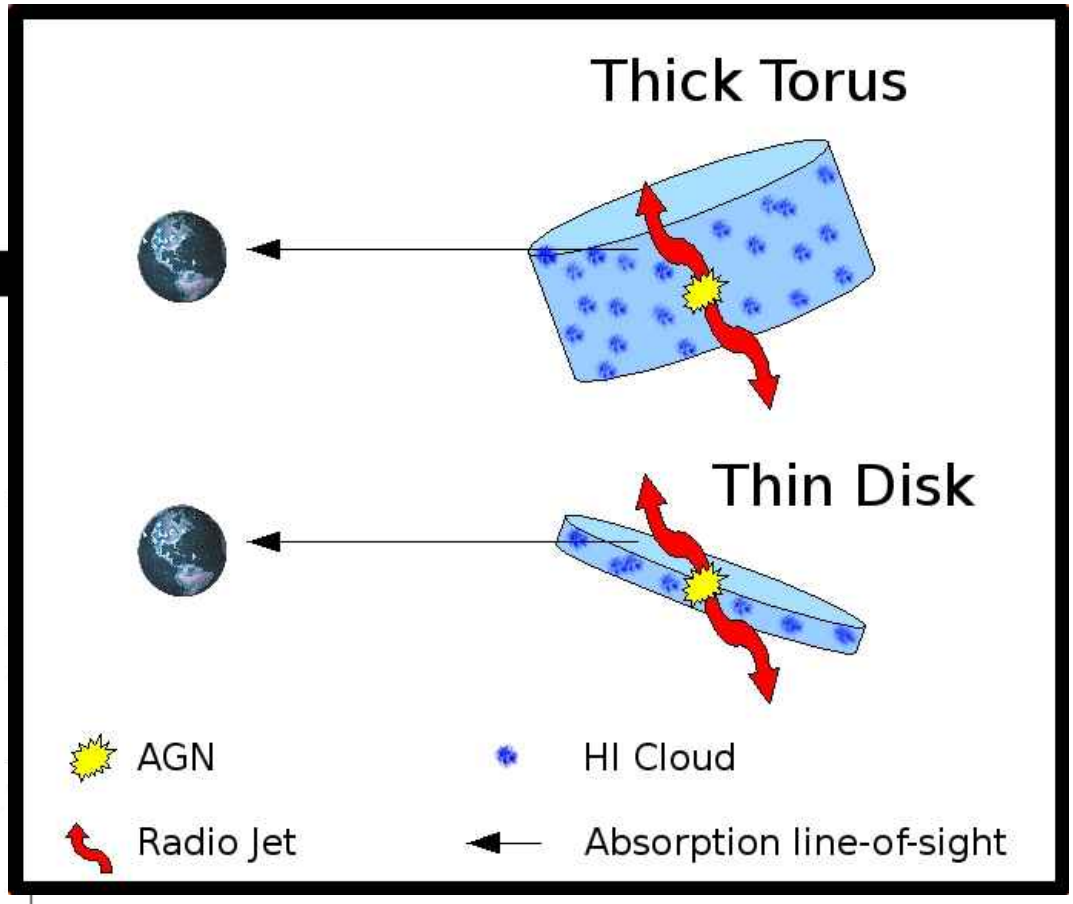

J2355+4950
flux density [Jy]
2.3
2.25
2.2
2.15
−200
0
200
heliocentric velocity [km s^{-1}]
WSRT
Vermeulen et al. (2003)


Intensity (mJy/b)
10
0
-10
-20
-30
-40
-50
-300
-200
-100
0
100
200
300
400
Rest Frame Velocity (km/s)
VLBA

B2352+495: Disk/Torus Interpretation

Physically Reasonable: $M_{BH} \sim 10^8 M_\odot$





- HI Distribution
- VLBA vs WSTR flux density

B2352+495 results versus other VLBI HI studies

Galaxy	HI Detection	Line Profile	HI Location
1. Compact Symmetric Objects			
4C 31.04, B0116+319, J0119+3210	Both lobes	N, B, M	AGN torus + infalling HVC
4C 37.11, B0402+379, J0405+3803	One lobe	B, M	AGN torus
OQ +122, PKS 1413+135, J1415+1320	One lobe	N	GMC in kpc disk
B1946+708, J1945+7055	Both lobes	N, B, M	AGN torus
B2352+495, J2355+4950	One lobe	N, B, M	AGN disk + infalling cloud

CSO

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2. Non-CSO Radio Sources: Double Jet/Lobe Systems as Imaged by VLBI			
3C 49, B0138+136, J0141+1353	One lobe	N, M	Cloud/jet interaction
NGC 1052, B0238−084, J0241−0815	Both radio jets	N, M	Nuclear and/or galactic?
Mrk 6, IRAS 06457+7429, J0652+7425	One side of jet	N	kpc disk
Hydra A, 3C 218, B0915−118, J0918−1205	Both jets+core	N, M	AGN disk
3C 236, B1003+351, J1006+3454	One lobe	B	Tip of radio jet
NGC 3894, B1146+596, J1148+5924	Lobes + core	N, M	AGN torus
3C 268.3, B1203+6430, J1206+6413	One lobe	N, M?	Cloud/jet interaction
NGC 4151, B1208+396, J1210+394	One radio jet	B, M	AGN torus
NGC 4261, B1216+061, J1219+0549	Counterjet	N, M	AGN disk
Mrk 231, IRAS 12540+5708, J1256+5652	Both lobes	B	∼ 100 pc disk
4C 12.50, IRAS 13451+1232, J1347+1217†	Counterjet	B	Cloud/jet interaction
3C 293, B1350+3141, J1352+3126	Both radio jets	B, N, M	Outer (8 kpc) and < 500 pc disk
NGC 5793, IRAS 14566−1629, J1459−1641	Both lobes	N, M	1 kpc disk
NGC 5929, B1524+4151, J1526+4140	One lobe	N	130 pc ring, or bar?
PKS 1814−63, J1820−6343	Both lobes	M, N	AGN disk + cloud/jet interaction?
IC 5063, B2048−572, J2052−5704	One lobe	B, M	Cloud/jet interaction
TXS 2226−184, IRAS 22265−1826, J2229−1810	Radio jet	B	Cloud/jet interaction (∼ 100 pc)
NGC 7469, B2300+0836, J2303+0852	Radio core	N	Nuclear or galactic?
PKS 2322−123, J2325-1207	One jet + core	B, M	AGN disk + infall (Scale height < 20 pc)
NGC 7674, IRAS 23254+0830, J2327+0846	One jet	B, N, M	AGN disk/torus

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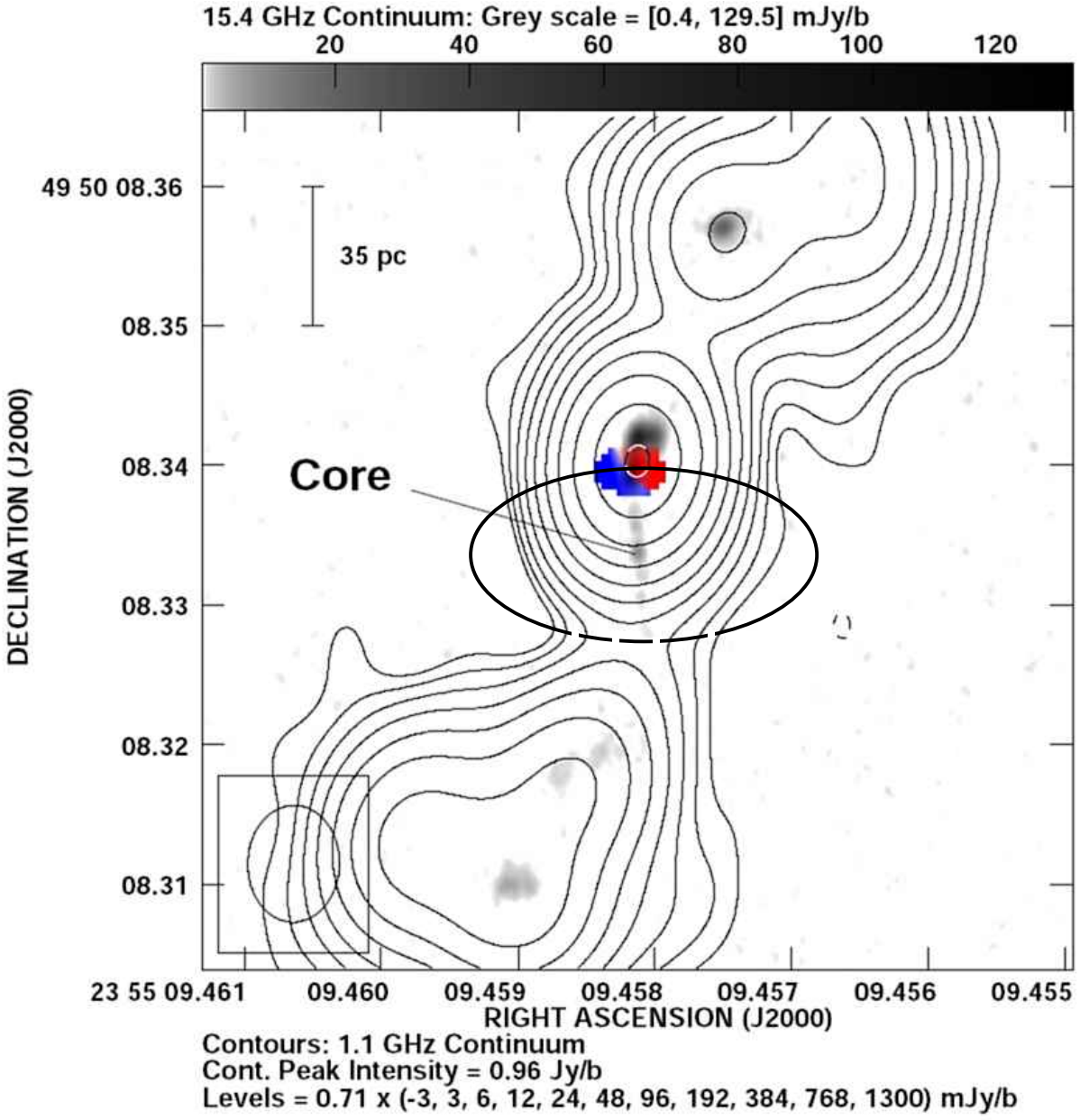
Implications for the Study of the M_{BH} - σ_* Relation



M_{BH} from VLBA HI Observations:

$\sim 10^8\ M_\odot$

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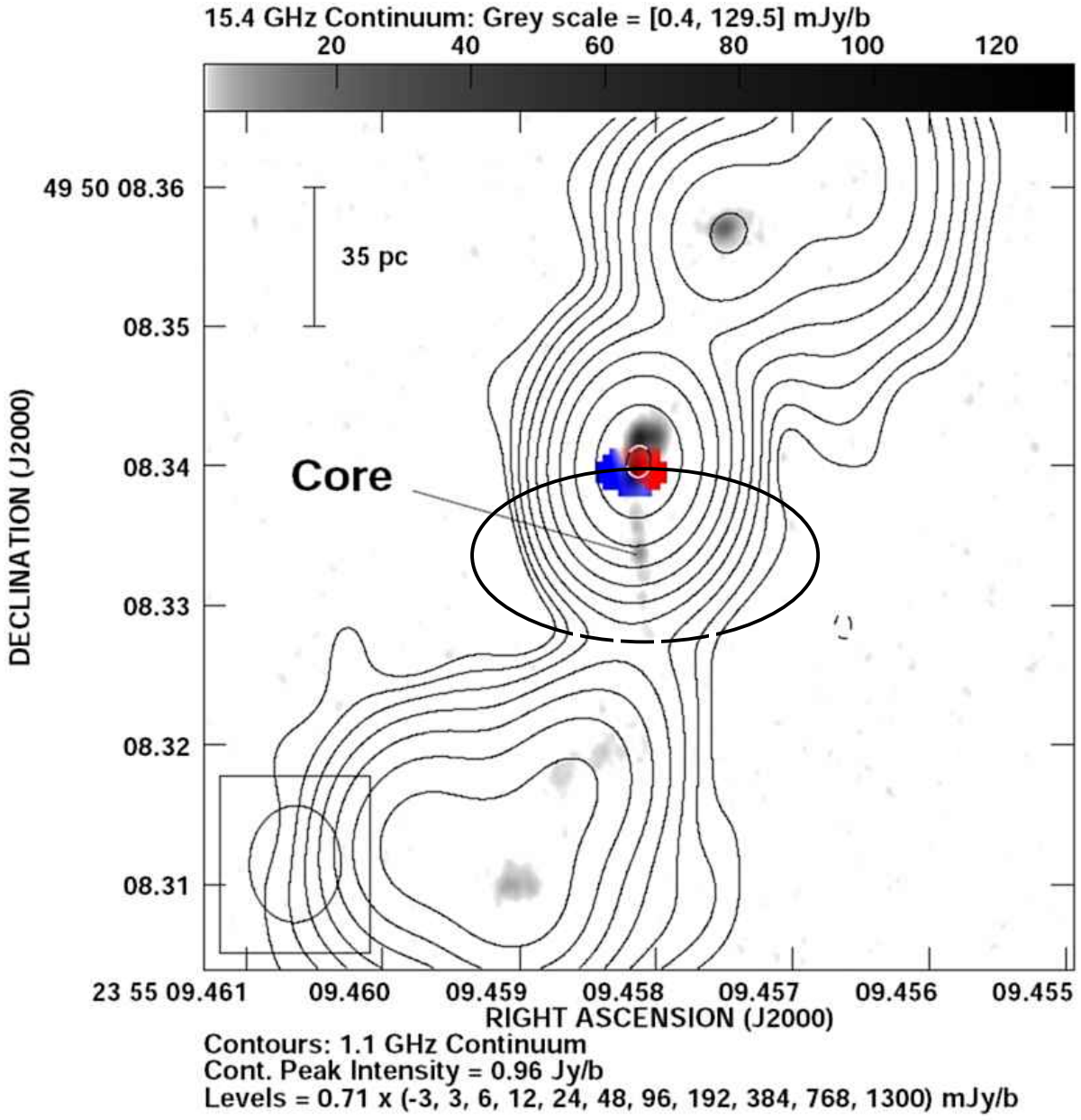

M_{BH} from VLBA HI Observations:

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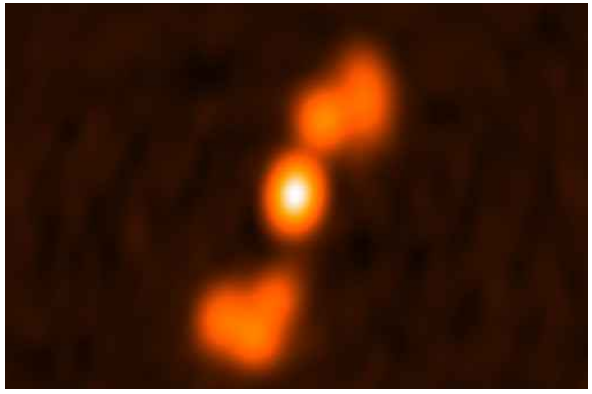
M_{BH} from M_{BH} - σ_* Relation:

$1.2 \times 10^8 M_\odot$

Summary

1. Compact Symmetric Objects may be the precursors of bright radio galaxies.



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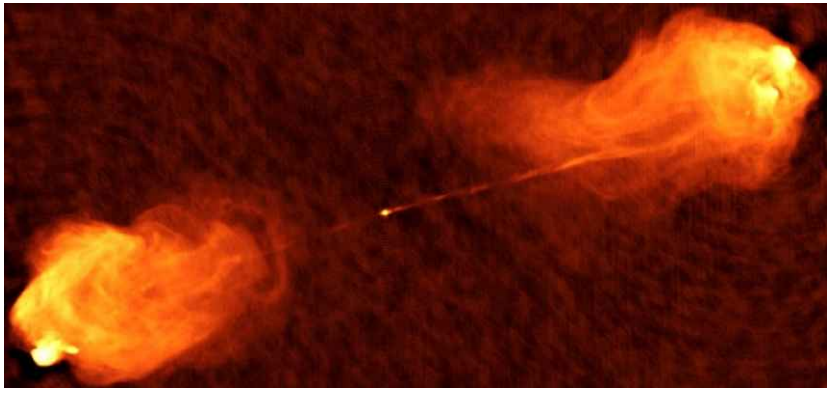
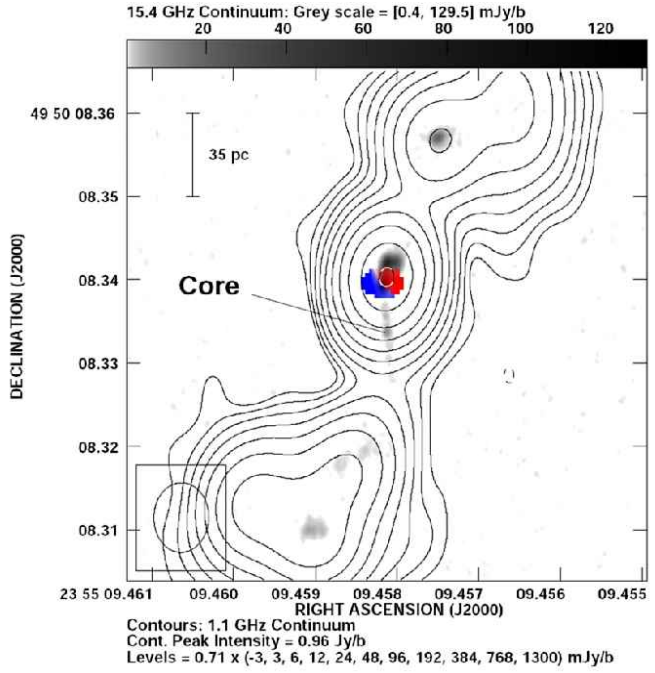
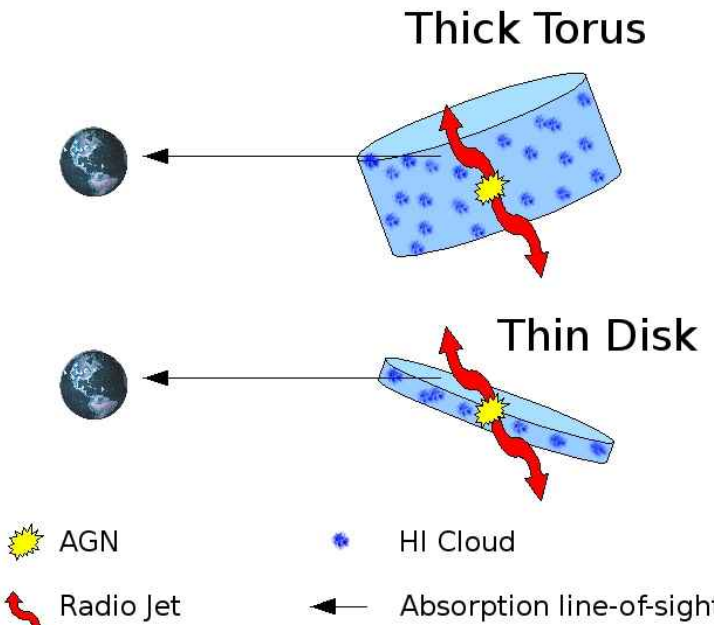


Summary

1. Compact Symmetric Objects may be the precursors of bright radio galaxies.

2. Broad HI absorption in B2352+495 is likely associated with a disk/torus.



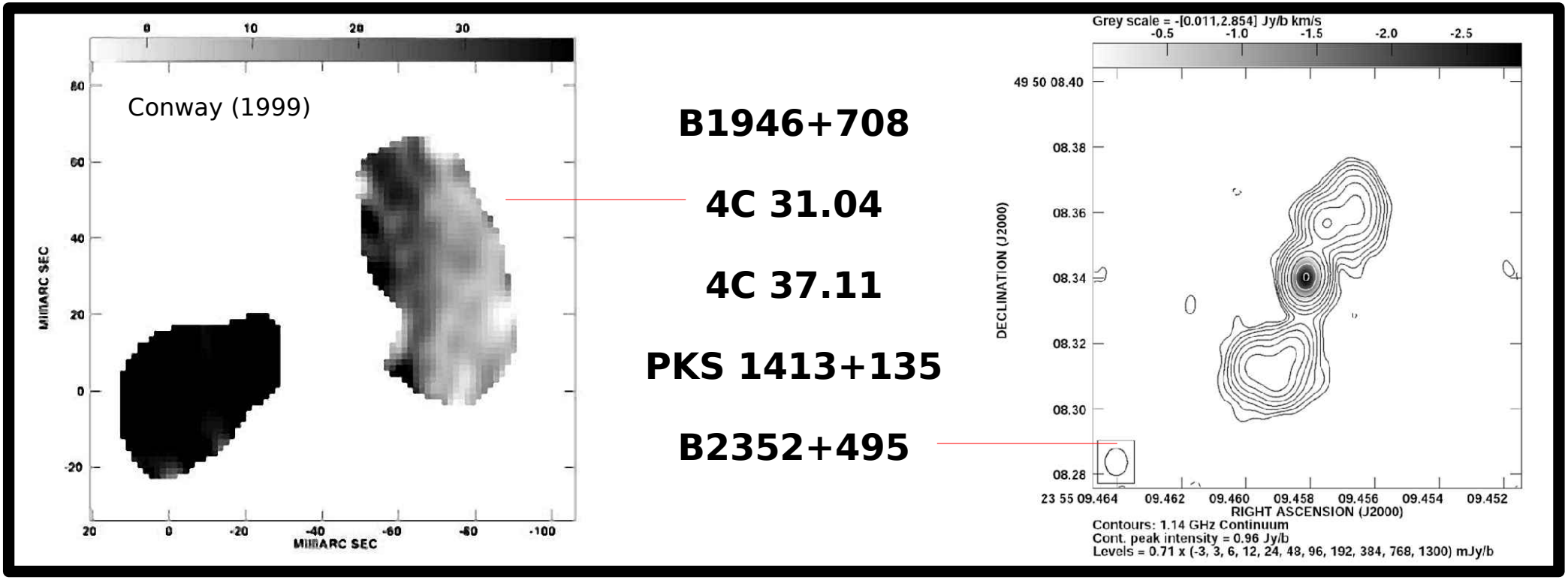


Summary

1. Compact Symmetric Objects may be the precursors of bright radio galaxies.

2. Broad HI absorption in B2352+495 is likely associated with a disk/torus.

3. Five CSOs have been imaged in HI at high angular resolution.



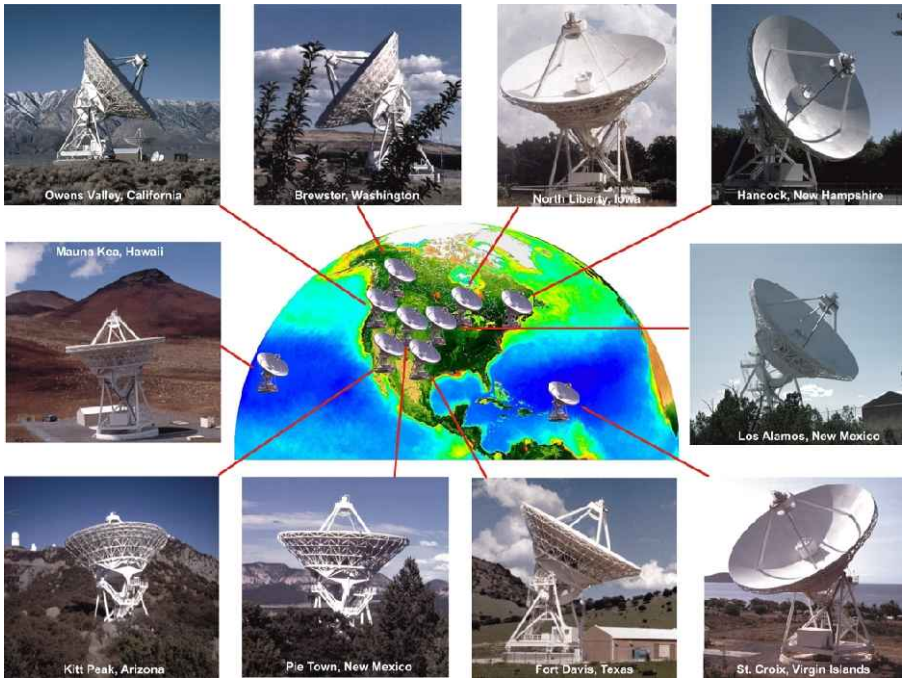
Summary

1. Compact Symmetric Objects may be the precursors of bright radio galaxies.

2. Broad HI absorption in B2352+495 is likely associated with a disk/torus.

3. Five CSOs have been imaged in HI at high angular resolution.

4. VLBI observations of CSOs may become a powerful tool to investigate the $M_{BH} - \sigma_*$ relation.



$\Leftrightarrow$ $M_{BH} - \sigma_*$