The multi-λ study of 2 unique & key RGs at low z : *Hercules A & 3C310*

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Why studying them? Both RGs have many essential similarities & many differences from usual morphology & characteristics of DRAGNs (double radio sources associated with AGN).

Current work: Multi-λ observations of both sources in order to:

- Interprete their morphology features & understand the physical mechanisms that take place
- Investigate in detail the 2 sources & their environments
- Look for differences and similarities in the FR classification
- Add information to complement UT?

Hercules A

Environment

Kpc-scale

(Gizani & Leahy)

pc-scale

(Gizani, Garrett & Leahy)

VLA radio data, 1''.4

- L-band (A+B+C confign)

1665, 1435, 1365 & 1295 MHz

- X-band (B+C+D confign)

8465 & 8415 MHz

- C-band (B+C+D confgn)

EVN + MERLIN
radio study of the core

L+C, X+C data at 1''.4 resolution >> DP-, RM-, α–map

Kpc-scale environment continued....

ROSAT X-ray PSPC & HRI data

- **Temperature of the intracluster gas,**

Assuming N_H, hydrogen column density,

- **n_o, central electron density,**
- **Radius of the X-ray core,**
- **Cooling flow cluster**

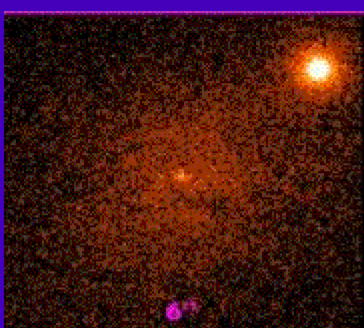
Radio + X-ray data > >

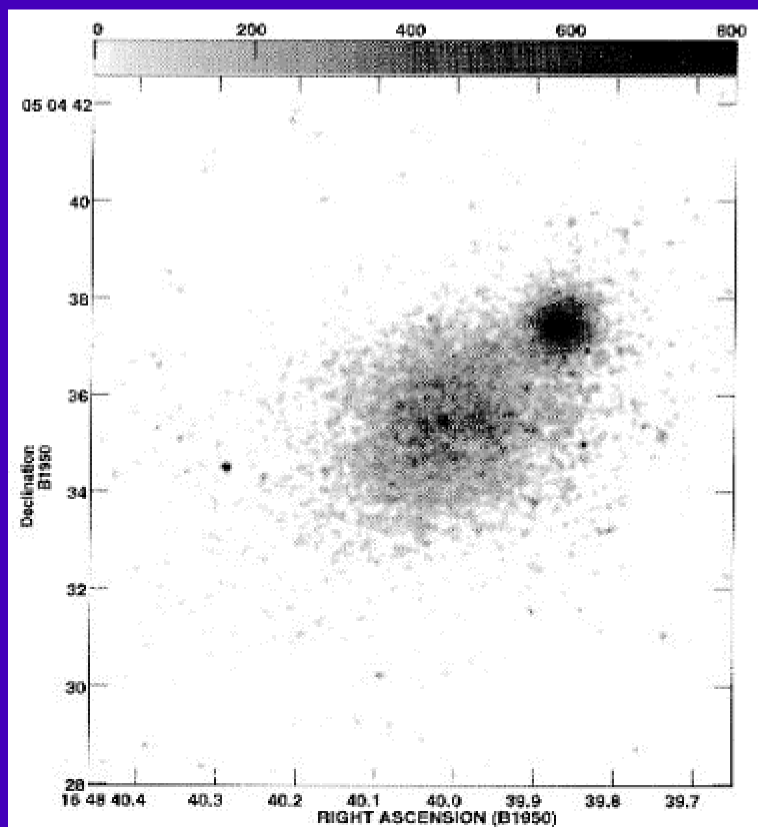
- ***External* B-field,**
- **Inclination of radio axis with axis along the l.o.s.**

HST image

Baum et al., 1996

Chiaberge et al., 1999



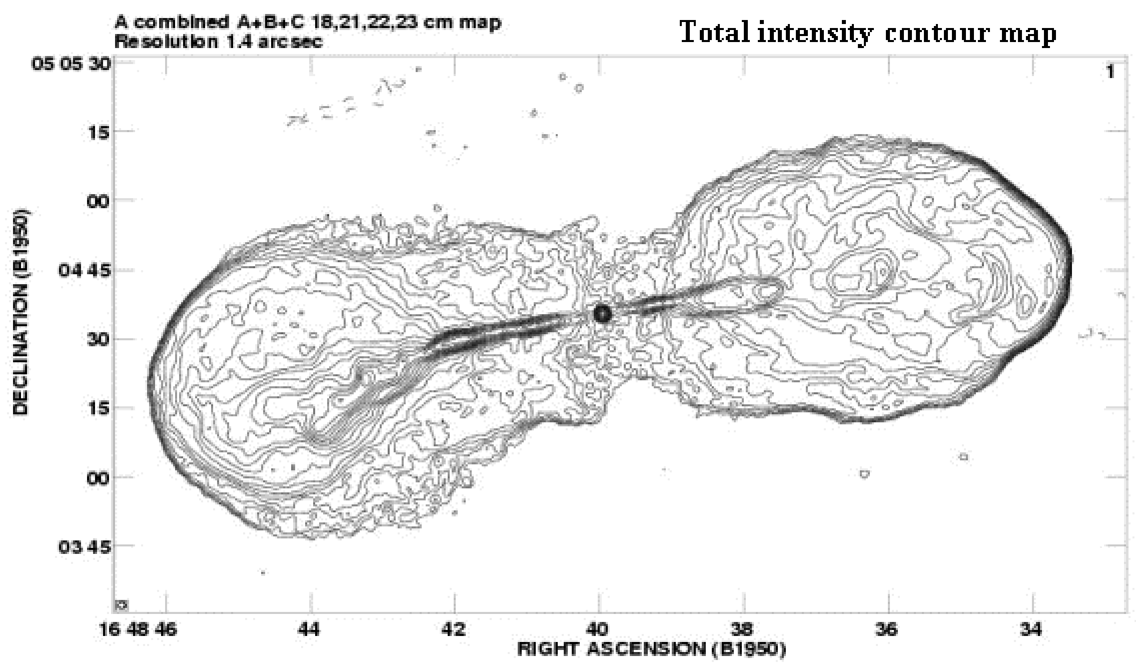


M_R **= -23.75**

HST/WFPC2
snapshot (280 s)
F702 W red filter
0.05 arcsec

4

Very elongated cD galaxy with double nucleus and a tail



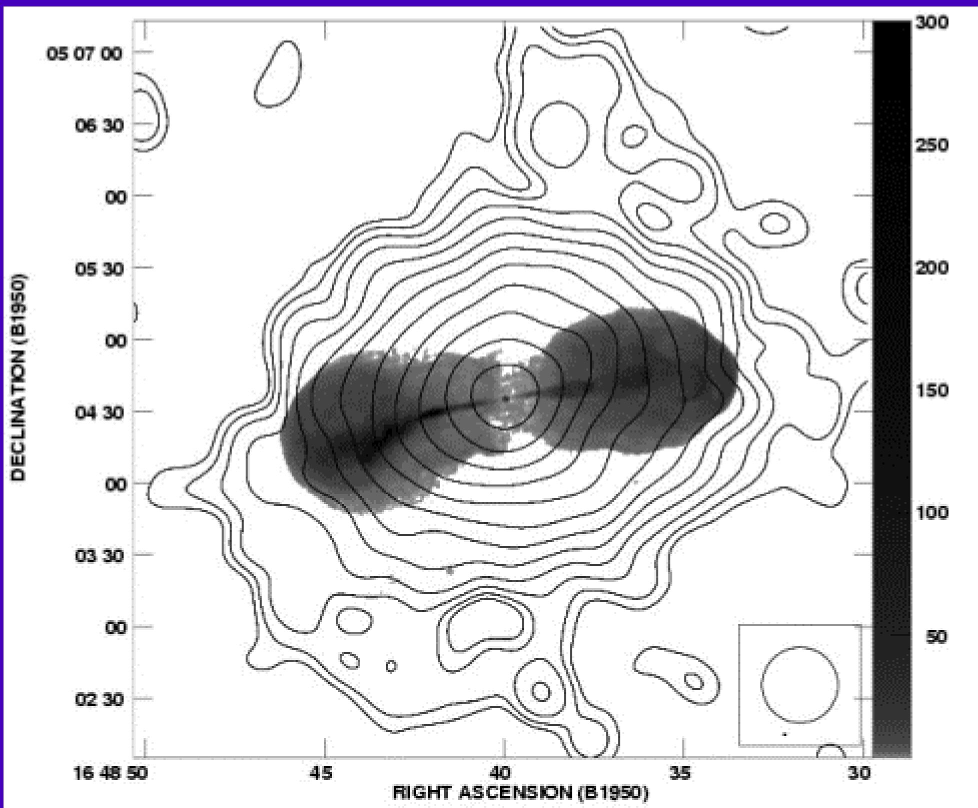
Logarithmic Contours separated by factors √2,
1st non-negative contour ≅ 0.16 mJy/beam

Total radio luminosity ~ 6.2×10^{37} W, H_o = 65 km/s, $q_o = 0$

linear size ~ 194" (540 kpc), width ~ 250 kpc

power density $P_{178\ MHz} = 2.3\times10^{27}\ WHz^{-1}sr^{-1}$

Contour map: Summed PSPC & HRI image in 0.5-2 keV band at 32 arcsec



Grey-scale: 20cm radio map in log display at 1''.4

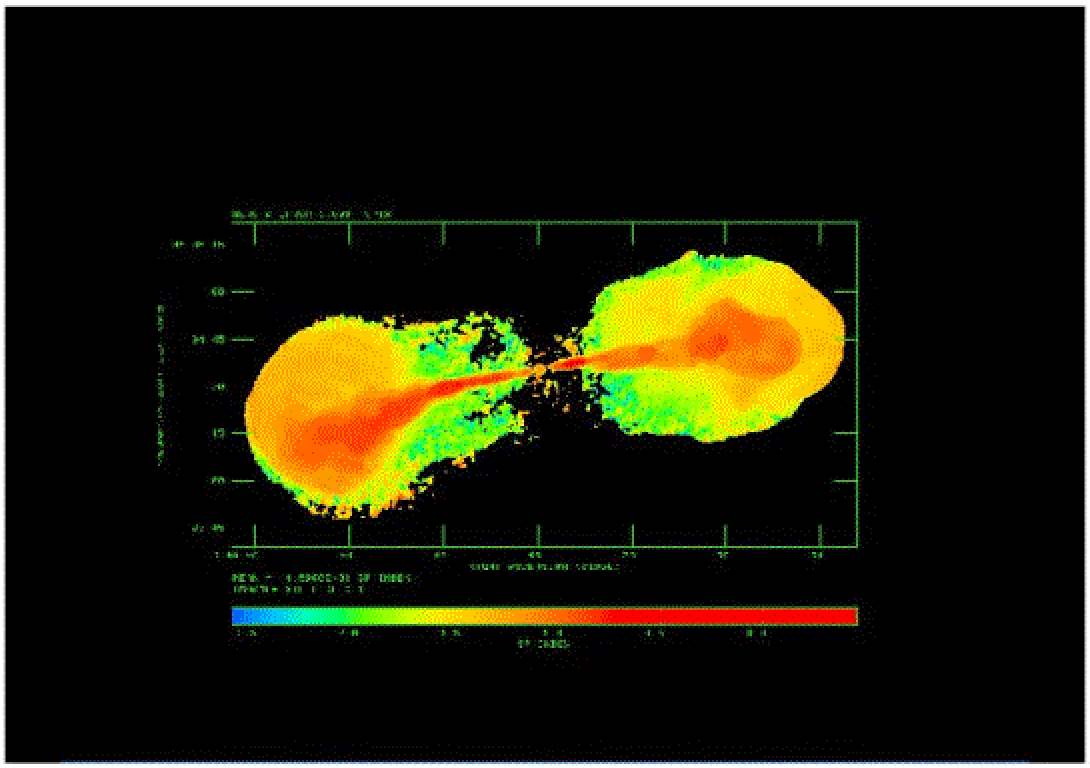
X-ray luminosity ≈ 3.16×10^{37} W; of point source ≈ 2×10^{36} W

kT ≈ 2.45 keV for $N_H \approx 6.2\times10^{20}$ cm^{-2} (BeppoSax: $3 \leq kT$ (keV) ≤ 5, Trussoni et al., 2001, ASCA: kT ≈ 4.25 keV, Siebert & Brinkmann, 1999)

β–model fitting: $\beta \cong 0.74$, $r_c \cong 121$ kpc

$n_o \approx 7.8\times10^{3}$ m^{-3}, quite dense environment

Hercules A: steep spectrum, $\alpha \cong -1.5$; young jets, rings $\alpha \cong -.7$; older lobes $\alpha \cong -1.5$; faint material $-2.5 \leq \alpha \leq -1.5$



AIPS User 1020 A MAP AT 1.4 ARCS, X,C,L

$S_\nu \propto \nu^\alpha$, $\alpha < 0$

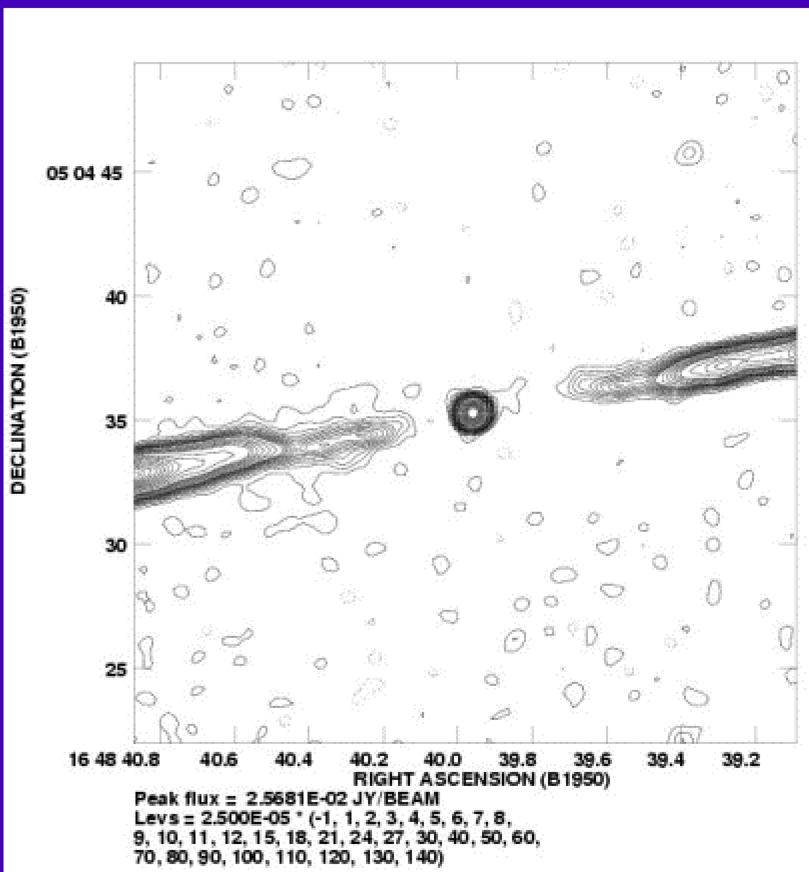
$\alpha_{core} \approx -1.3$, steep spectrum, optically thin

Conclusions of the kpc-scale study

- VLA Radio data: Hercules A exhibits a *strong* Laing-Garrington effect (Laing, 1988; Garrington et al., 1988). The depolarization asymmetry maybe explained in terms of the relativistic beaming model as a simple geometric effect:
Hercules A is embedded in a centrally condensed medium at an angle of ≅ 50° to the l.o.s. The stronger jet is on the near side of the source (eastern side) and hense it is seen through less depolarized gas.
- A steep spectrum extended radio emission is revealed surrounding the jets of Hercules A. The more depolarized western side has a steeper spectrum than the less depolarised eastern side. Jets, rings (especially in the western lobe) have a much less steep spectrum than the lobe material:
We maybe witnessing a renewed outburst from the active nucleus .
- ROSAT PSPC & HRI X-ray data: Extended X-ray emission elongated along the radio axis, on roughly the same scales & a weak nuclear component. The Hercules A cluster is quite dense with a significant

- concentration of gas towards the center ($n_o \cong 7.8\times 10^3\ m^{-3}$) , most probably a cooling flow cluster.
- RM-, DP-maps + model fitting & b-model fitting >> estimate of the central value of the external B-field strength $3 \leq B_o(mG) \leq 9$. There is a radial dependence of the magnetic field and the electron density and the density of the gas.

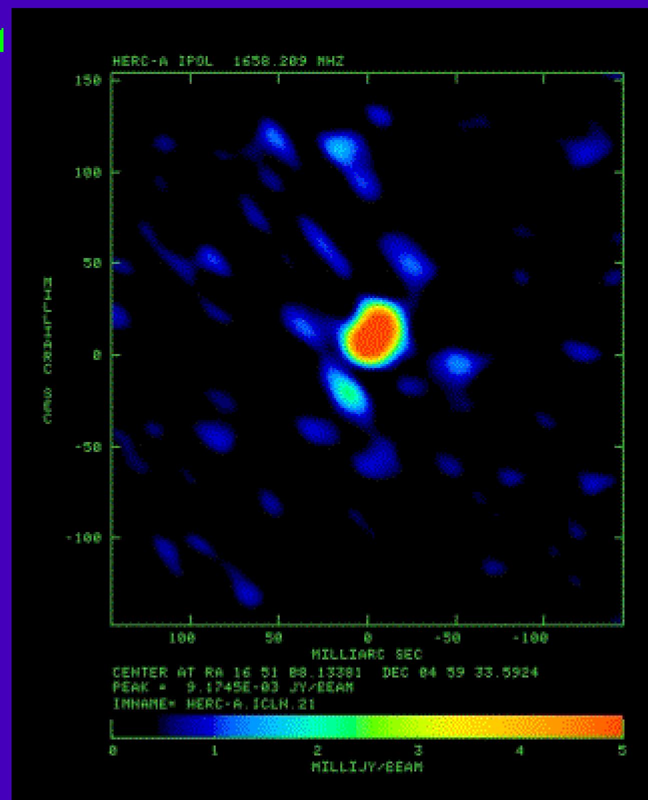
The study of the pc-scale environment



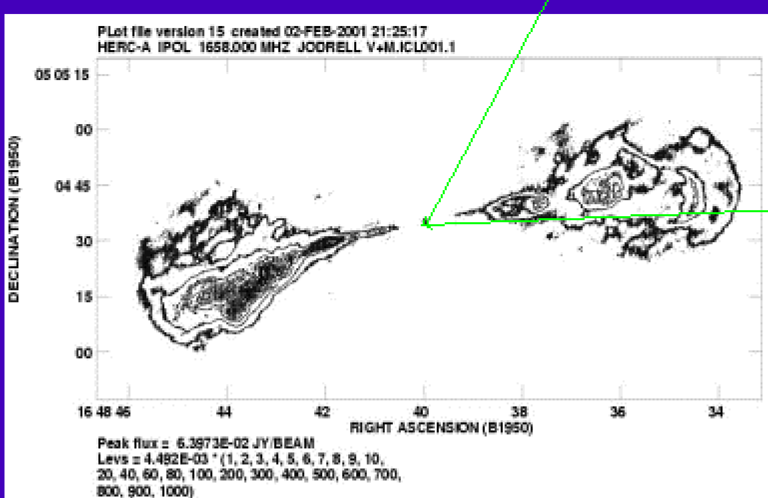
A VLA B+C+D contour map of the core region at 3.6 cm, at 0.74 arcsec.
Noise of the map: 11 μJy
Contours just over 2σ apart

Core flux:
6.0 mJy at 3.6 cm (X-band)
44 mJy at 20 cm (L-band)

EVN+MERLIN Observations of the core of Hercules A at 18 cm with phase referencing

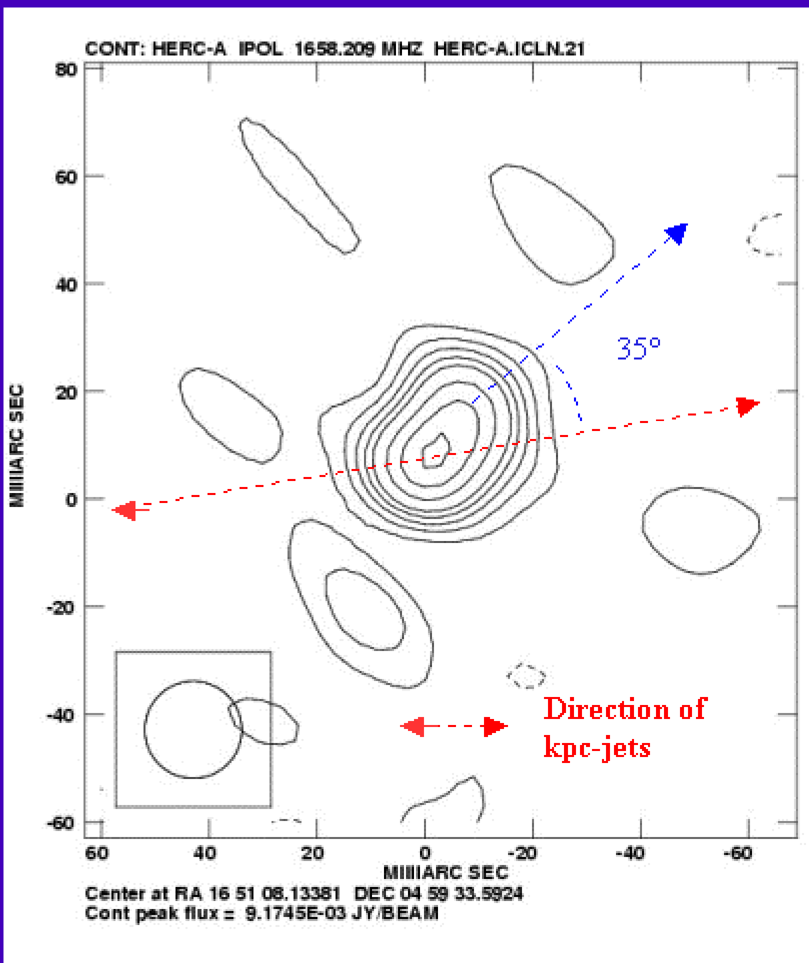


The VLA+MERLIN detection at 18 cm, 0.51 arcsec. The diffuse emission not well mapped by MERLIN



The EVN detection at 18 cm, at 0.018 arcsec: ~30% of the flux of the core detected with the VLA is detected with EVN

EVN map at 18 cm, at 0.018 arcsec; rms ≈ 0.45 mJy/beam; contours at -1,1,2,3,4,5,6,7,9,11,13. 1st non-neg. At 0.8 mJy/beam



Core flux ≅ 14.6 mJy,
size: 18.2×7 mas, posn angle 139°
$T_b \cong 2 \times 10^7$ K

Hercules A asymmetric on pc-scales: NW-SE emission probably from the eastern pc-scale jet due to Doppler boosting >>

Misalignment of 35° between pc- and kpc-scale jets

Conclusions on the pc-scale study

EVN data at 18 cm, 18 mas: The radio core, still unresolved.
The core is very weak! Phase referencing did not work.
NW-SE emission, probably from the eastern pc-scale jet
>> *The detected asymmetry in the mas-scale, while there is symmetry on kpc-scales should be due to the Doppler Beaming: The mas scale jet is always on the same side as the kpc-scale jet, which is the brightest with respect to the core.*

MERLIN got confused by Hercules A's extended structure >> VLA+MERLIN map, but...

Further observations at 6 cm could confirm the detected misalignment.

3C310

▫ **Optical:** HST snapshot observations (Chiaberge et al., 1999): elliptical galaxy, double nucleus (+ elliptical galaxy ≈ 15 arcsec west), absolute magnitude -23.2, R-band >> striking linear correlation of the optical flux of the central compact core with the radio core of non-thermal origin.
Z=0.054

▫ **Radio:** VLA total intensity and poln observations at 6, 21 cm at 4", Wb array observns (van Breugel and co-authors).
$P_{178\ MHz} \sim 3.57 \times 10^{25}$ WHz^{-1}.
Steep spectrum α = -1.38, linear size 173 kpc, FR1.5.
Core coincident with center of western nucleus of the bright pair.
$P^{core}_{6\ cm} \sim 7.25 \times 10^{23}$ Whz^{-1}

? **X-ray:** At center of Z1500.6+2559, $L_x \sim 9.8 \times 10^{35}$ W in 1-3 keV (Einstein data at 64", Burns et al., 1981).
ROSAT pointed obsns (Hardcastle & Worrall, 1999)

Similarities

- Double optical nuclei, with similar absolute magnitude in R-band
- Hosts of clusters, similar gas temperature, contribution from point source
- Sharply bounded double lobes, FR1.5
- Lobe asymmetry with respect to brightness, depolarization and spectral index
- No compact hotspots, presence of rings and other high-brightness structure with much flatter spectra than the surrounding diffuse lobes >> *Renewed outburst from the active nucleus?*
- Projected B-field followes the edges of rings
- Steep spectum ($\alpha \sim 1.4$)
- The thermal pressure at the distance of the radio lobes is larger than the lobe minimum pressure

Differences

- 3C310 smaller, less powerful than Hercules A in the radio, lower X-ray luminosity

- Her A has weaker radio core

- 3C310's core: Flat spectrum
  Her A's core: *Steep spectrum*

- X-ray emission of 3C310 ambiguous.

X-ray emission of Her A centered on radio core. The central electron density of the Hercules A cluster is greater than for the 3C310 cluster

- The thermal pressure of the Hercules A cluster is larger $\Rightarrow$ the confinement of its lobes by the intracluster medium is greater

HST/WFPC2, F702W filter

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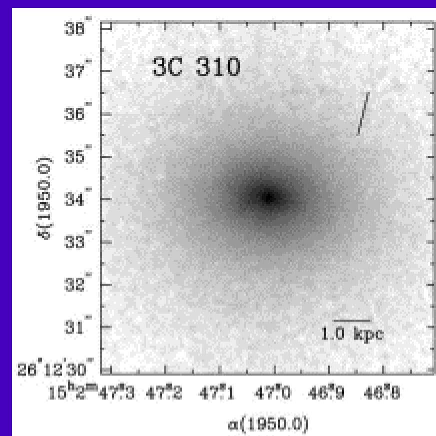
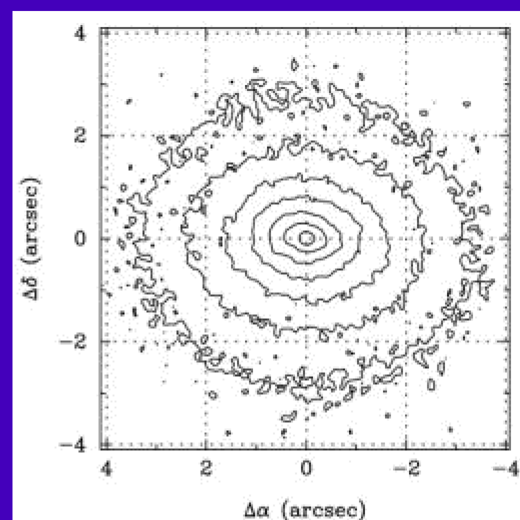




Chiaberge et al., 1999

280 sec

0.05 arcsec

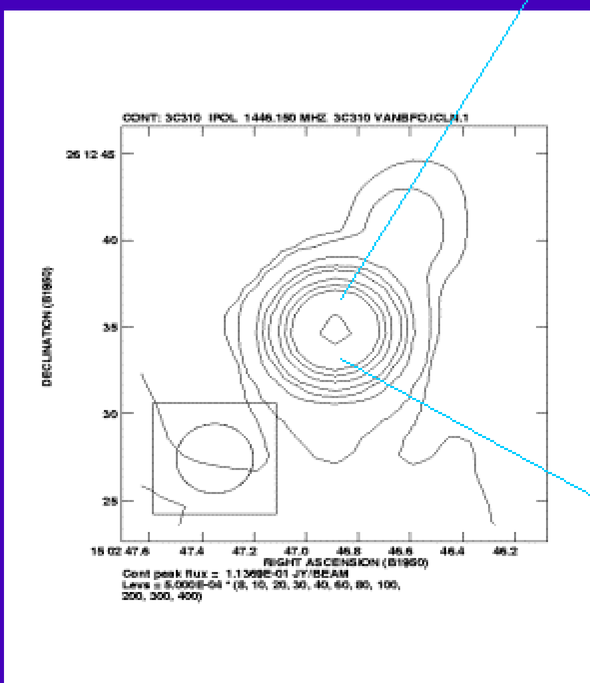
central kpc emission ~⊥ radio jet axis, Martel et al., 1999

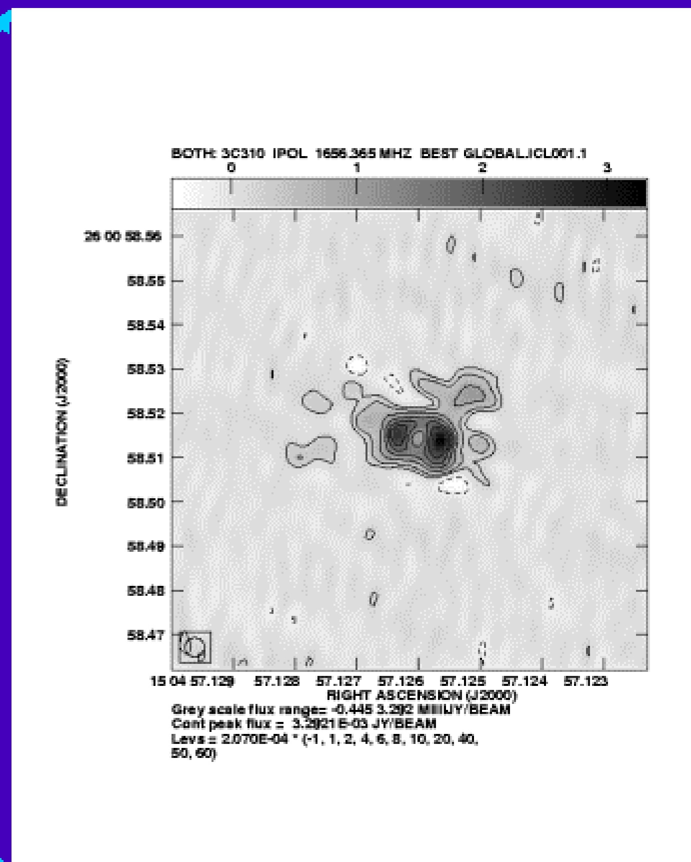
VLA total intensity distribution at 21cm, 4" resolution

Ring-like features & an unresolved core apparent.

Van Breugel & Fomalont, 1984

The VLA map of the reagion of the nucleus of 3C310 at 4 arcsec resolution, 21 cm. Flux ~ 130 mJy





The Global VLBI map of the core region at 18 cm. Flux ~22 mJy. Resolution 4 marcsec. Position of the core unknown.

Future multi-λ Work (Hercules A, 3C310)

Apart from planned new VLA obsrvns on 3C310 ....

HI observations of each galaxy with emphasis on their nuclear region *(with Wb array (Morganti, Gizani & Garrett); Not sure about the detection of HI absorption. More observations needed.)*

Infrared observations of the ring-like and helical-structures of the radio emission; Near IR polarimetric observations *(Spring-Autumn 2002; Gizani & Gonzalez-Serrano),* observations with the VLTI MIDI if possible.

X-ray follow-ups, where possible. Chandra Observations for 3C310

HST observations of 3C310; V, R, I-band observations, obtain Ha map of the nuclear region, spectroscopy. VLTI obs for both RGs

OAL

UV observations, to use together with other wavelength observations, as diagnostic of the ISM; Study the UV emission from nuclear region