VLBI observations of HBLs

and a "special HBL" case...

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VLBI in the GLAST Era

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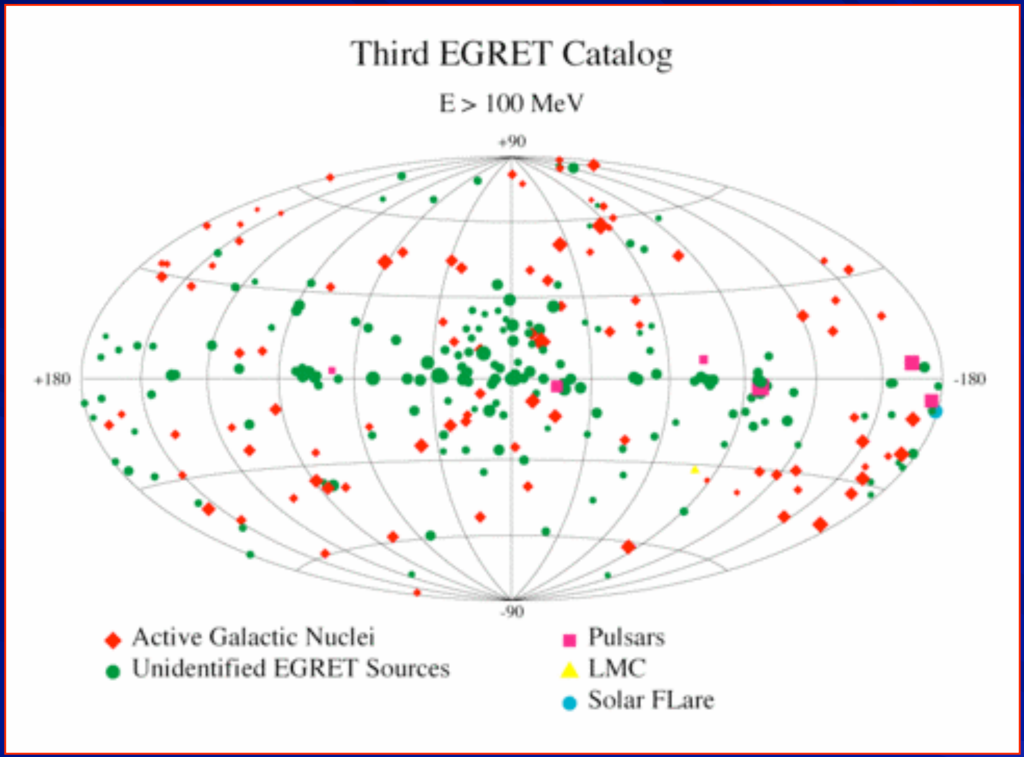
Part 1
GLAST/VLBI and HBLs

– basics
– a sample of nearby BL Lacs
– results...

Basics #1: EGRET results

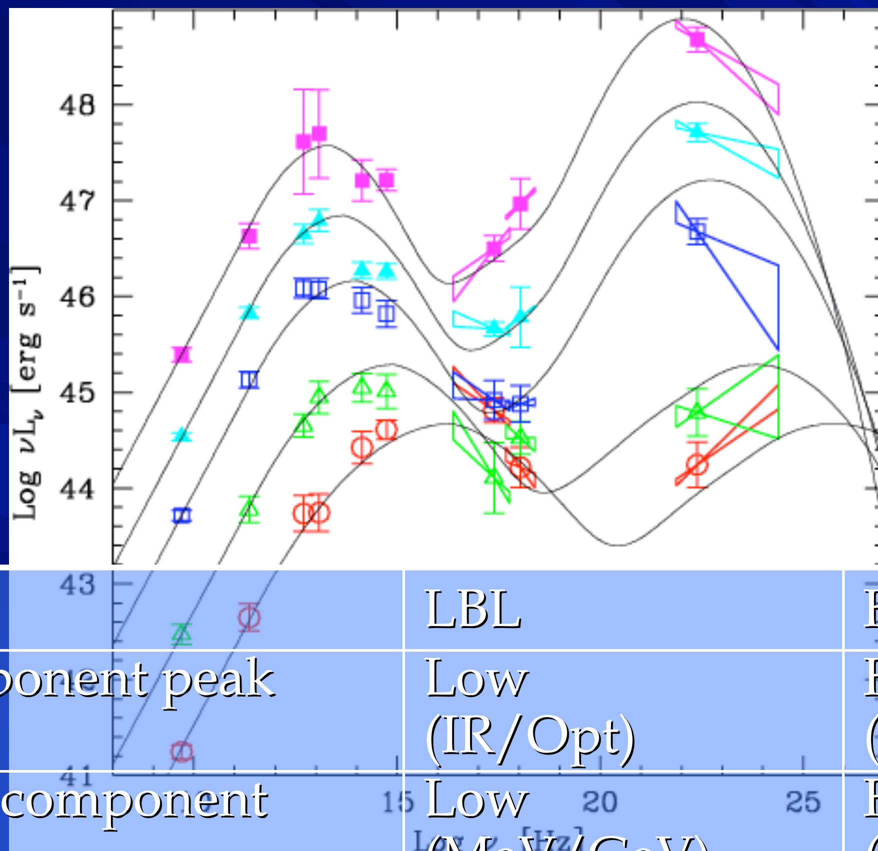


The Third EGRET Catalog consists of 271 sources, including 66 high-confidence and 27 possible blazar identifications

FSRQs >> LBLs >> HBLs

HBLs just 3% of high confidence blazars

Basics #2: the blazar sequence



(Donato et al. 2001 A&A)

	LBL	HBL
Synchrotron component peak frequency	Low (IR/Opt)	High (UV/keV)
Inverse Compton component peak frequency	Low (MeV/GeV)	High (GeV/TeV)
Compton dominance (L_C/L_S)	High (>>1)	Low (~ 1)
Inverse Compton photons	external (EC)	self (SSC)

total luminosity

Putting basics together...

- do the EGRET results make sense in the light of the blazar sequence?
  - EGRET energy range: 20 MeV to about 30 GeV.
  - Synchrotron component fades at lower energy
  - IC component strong only for high luminosity/low energy peaked sources
  - EGRET sensitivity
- Yes, they do! HBLs largely escape detection in that band
  - #1 What do/can we know of HBLs then?
  - #2 Will GLAST greater sensitivity detect many HBLs?
  - #3 What if the blazar sequence is an artifact?

What about HBLs

- HBLs strenghts:
  - traditionally X-ray selected (X-rays: synchrotron)
  - TeV sources!!! (95% of extragalactic detections)
- HBLs weaknesses:
  - radio: detected but “unexciting”
    - radio properties: best known for LBL/FSRQ
    - easy to understand why… (RBL, …)
  - Mev/Gev gamma rays: undetected
- GLAST/VLBI meeting: we're at a loss!
  - *...let me show you we can actually do something!*

Selection

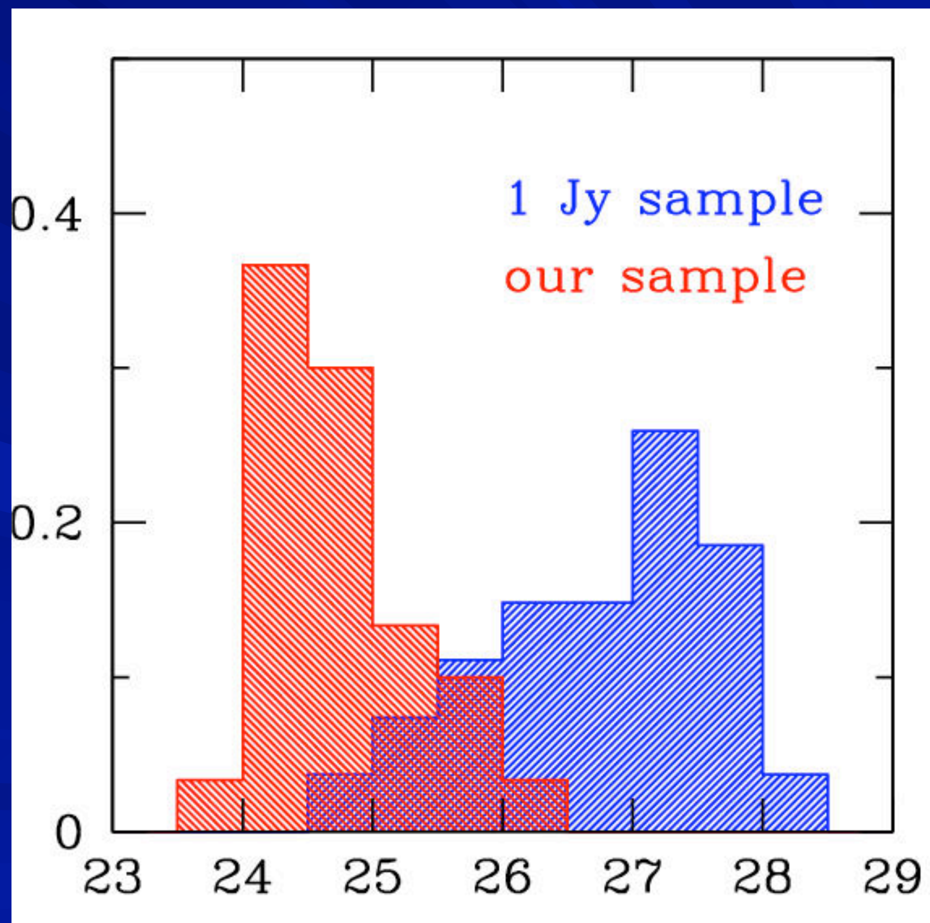
- All sources from the HST snapshot survey, at $z<0.2$
  - distance limited - *not complete though*
  - no (additional) selection on radio/X-rays flux density
  - subset of a collection of objects with random properties, e.g.:
    - 1 Jy: complete but with high flux limit
    - EMSS, Slew: X-ray selected, contain HBLs
  - 30 objects with z<0.2 (out of the 110 sample)
    - 1 outlier, 7 LBLs, **22 HBLs**

A comparison to the 1 Jy sample

$\langle \text{Log } P_{1.4\text{ GHz}} \rangle = 26.8 +/- 0.9$

$\langle \text{Log } P_{1.4\text{ GHz}} \rangle = 24.8 +/- 0.6$

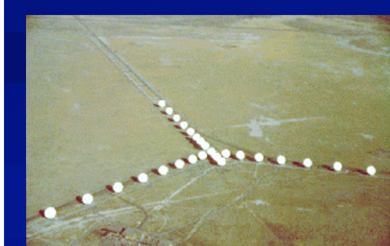
Few objects already known in radio (less than 50% had VLBI or VLA)

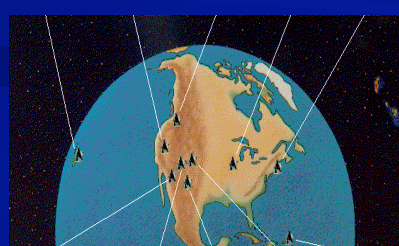


[Log $P_{tot,\ 1.4\text{ GHZ}}$]

Observations

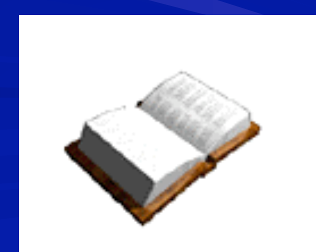
- Large scale and arcsecond core
  - VLA @1.4 GHz: A conf., 10 hrs/19 sources
  - VLA @1.4 GHz: C conf., 5 hrs/9 sources
- milliarcsecond structure
  - VLBA @5 GHz: 15 hrs/15 sources
  - EVN @1.6 GHz: 12 hrs/6 sources
- Intermediate scale peculiarities
  - EVN+MERLIN @5 GHz: 12 hrs/2 sources
- Well known sources
  - ADS, NED, VLA, EVN, MERLIN archives



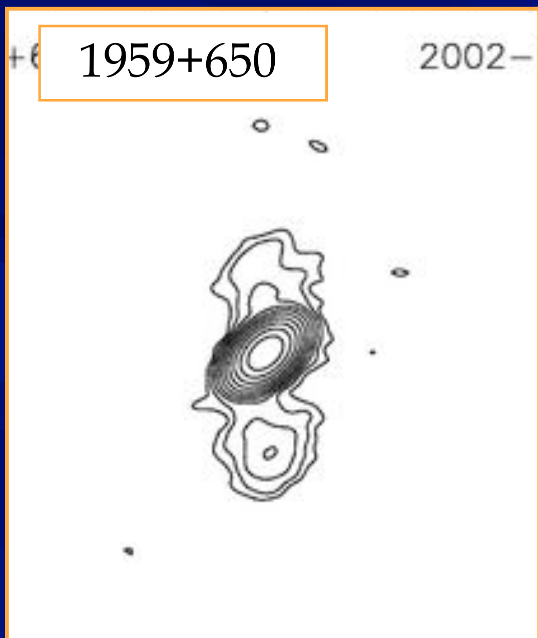


EUROPEAN vlbi NETWORK

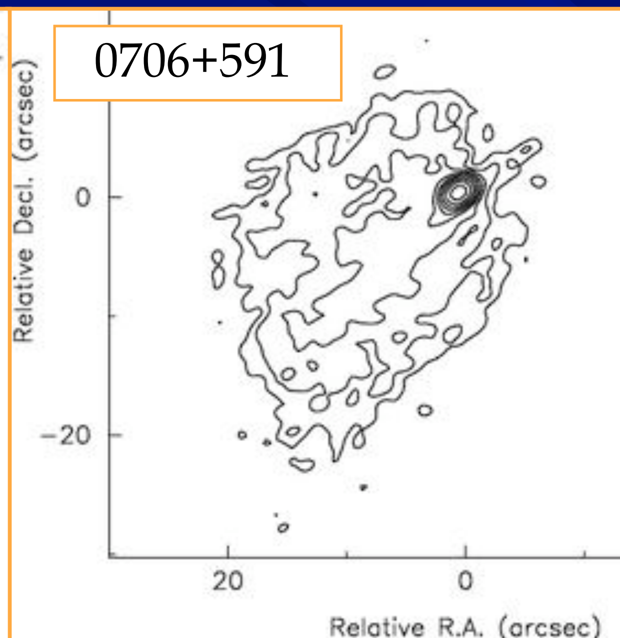
MERLIN



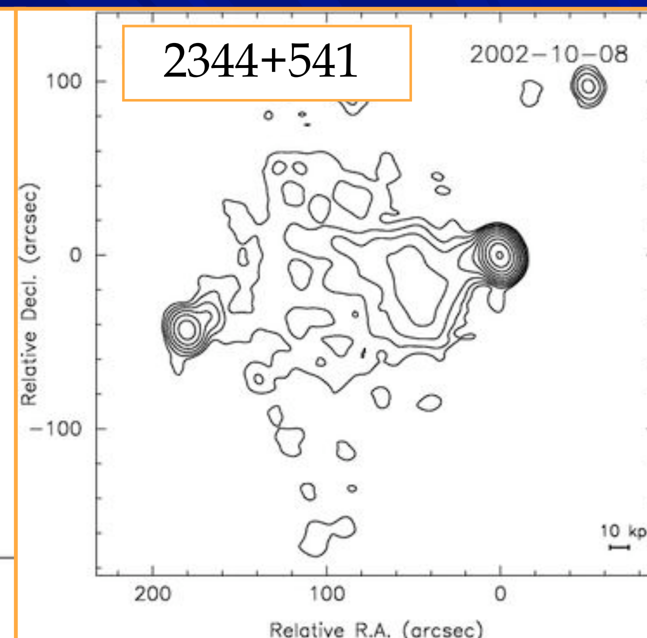
HBLs: low resolution images



Core-jet(s): 8



Core-halo: 2

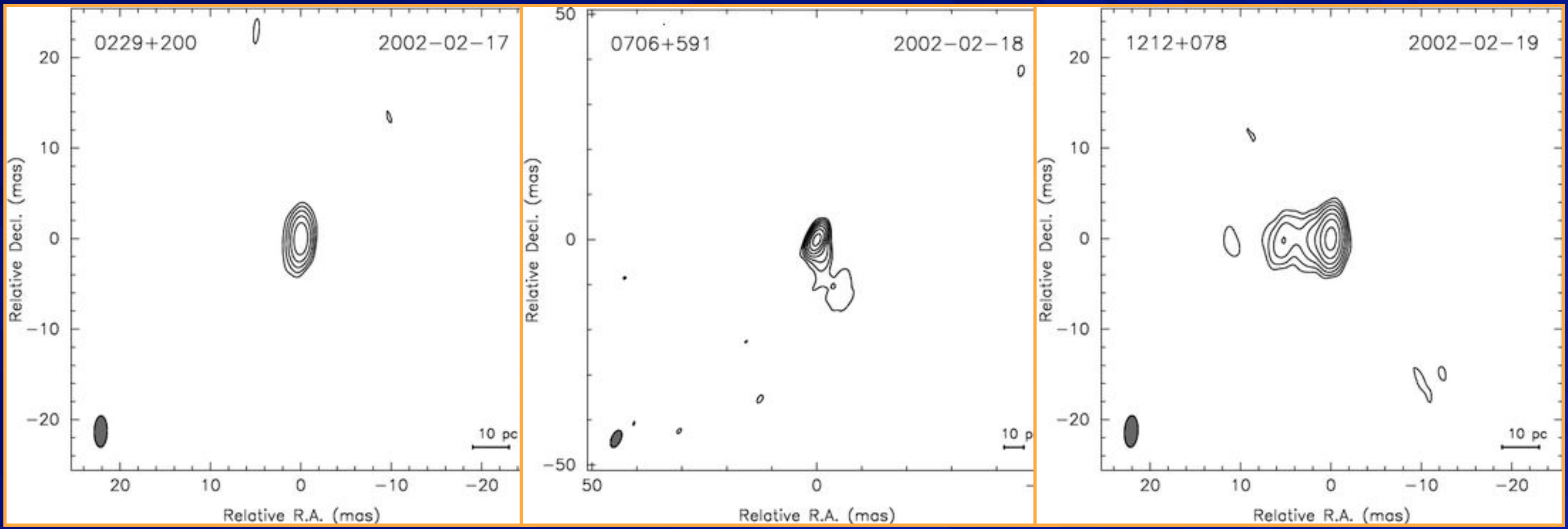


Complex: 5

plus 8 unexciting unresolved ones...

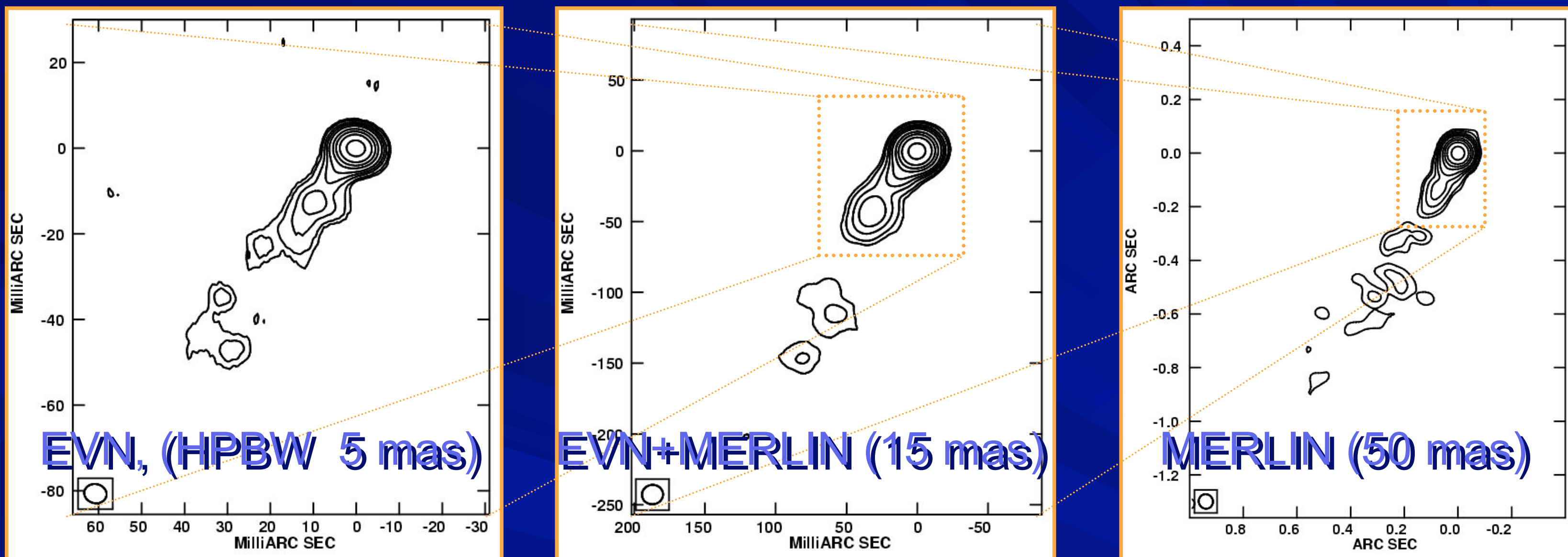
LBLs: 1 unres., 2 core/halo, 4 complex

HBLs: high resolution images

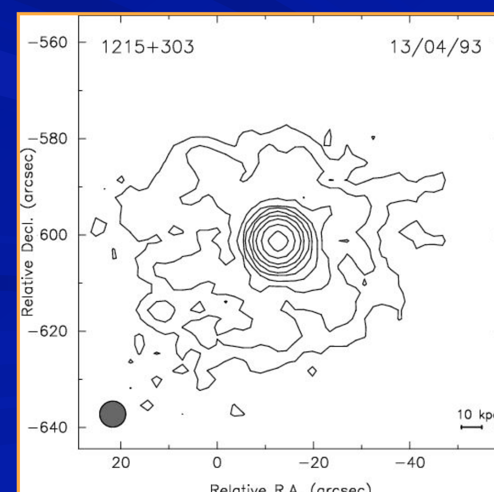


- All sources detected without phase ref. (yet highly desirable in some cases)
- cores between 3 and 300 mJy
- 7 unresolved
- 15 jets, both short and not so short!

Intermediate resolution images

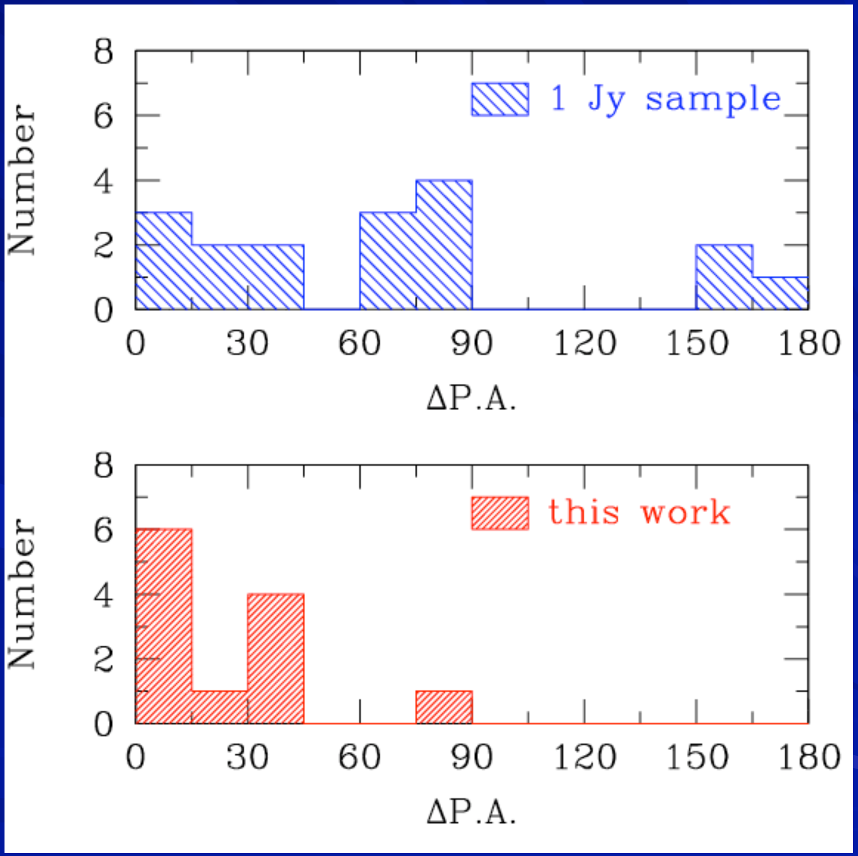


- 1215+303, *z = 0.130*
  - EVN+MERLIN image, 5 GHz
    - peak = 294 mJy/beam
    - total = 350 mJy
    - PA = 150°
  - VLA image, from FIRST survey (1.4 GHz)
    - peak = 377 mJy/beam
    - total = 590 mJy
    - PA = ???



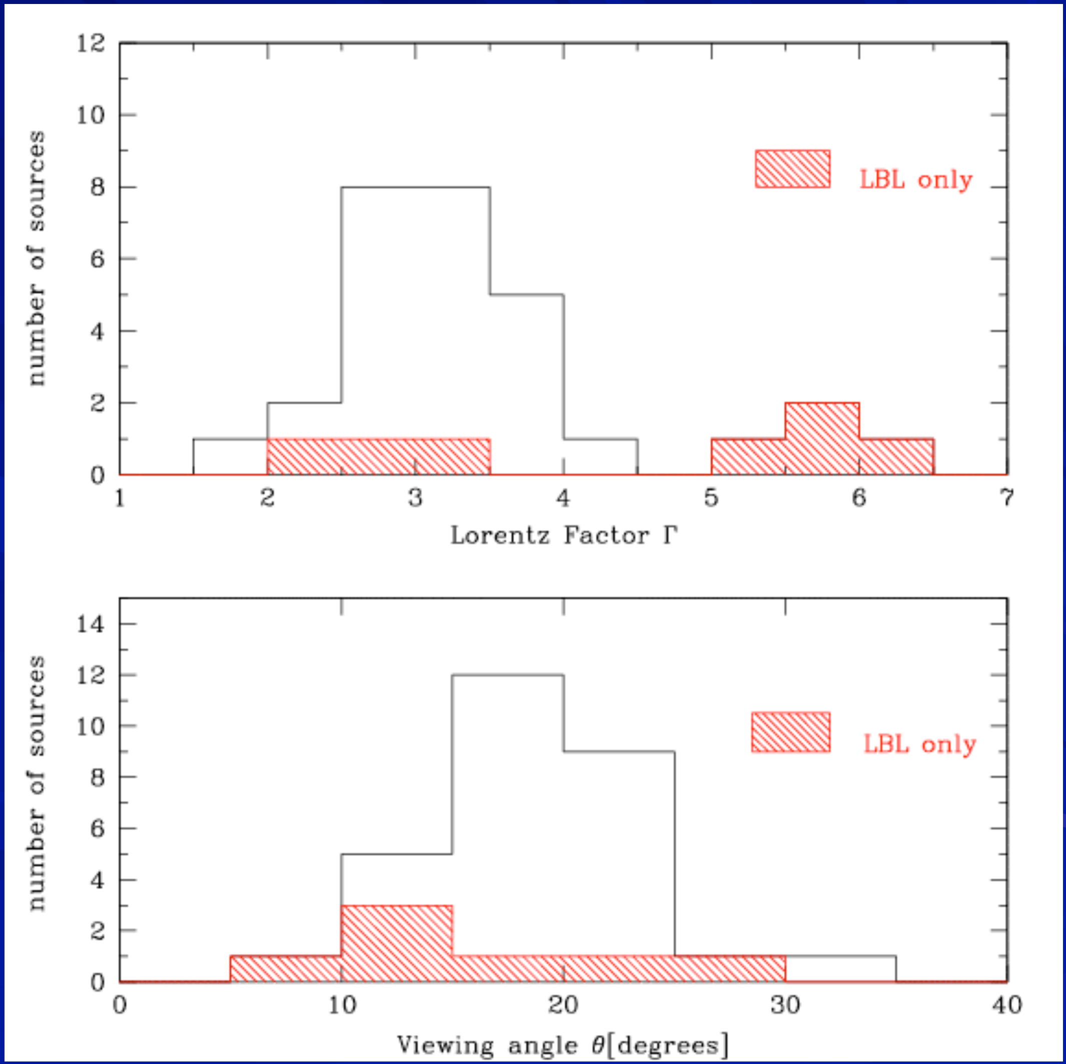
LBL/HBL & bending

- ΔP.A. = |P.A.$_{asec}$-P.A.$_{mas}$|
- Large ΔP.A. are less common in our sample than in the 1 Jy
  - HBL jets are intrinsically straighter
  - bending is less amplified in HBLs: smaller θ and δ
  - limits in image sensitivity?



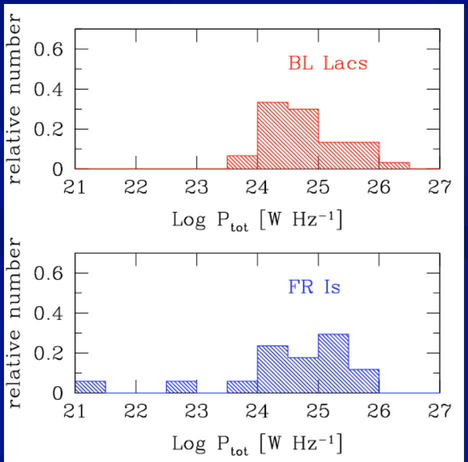
Radio jet parameters

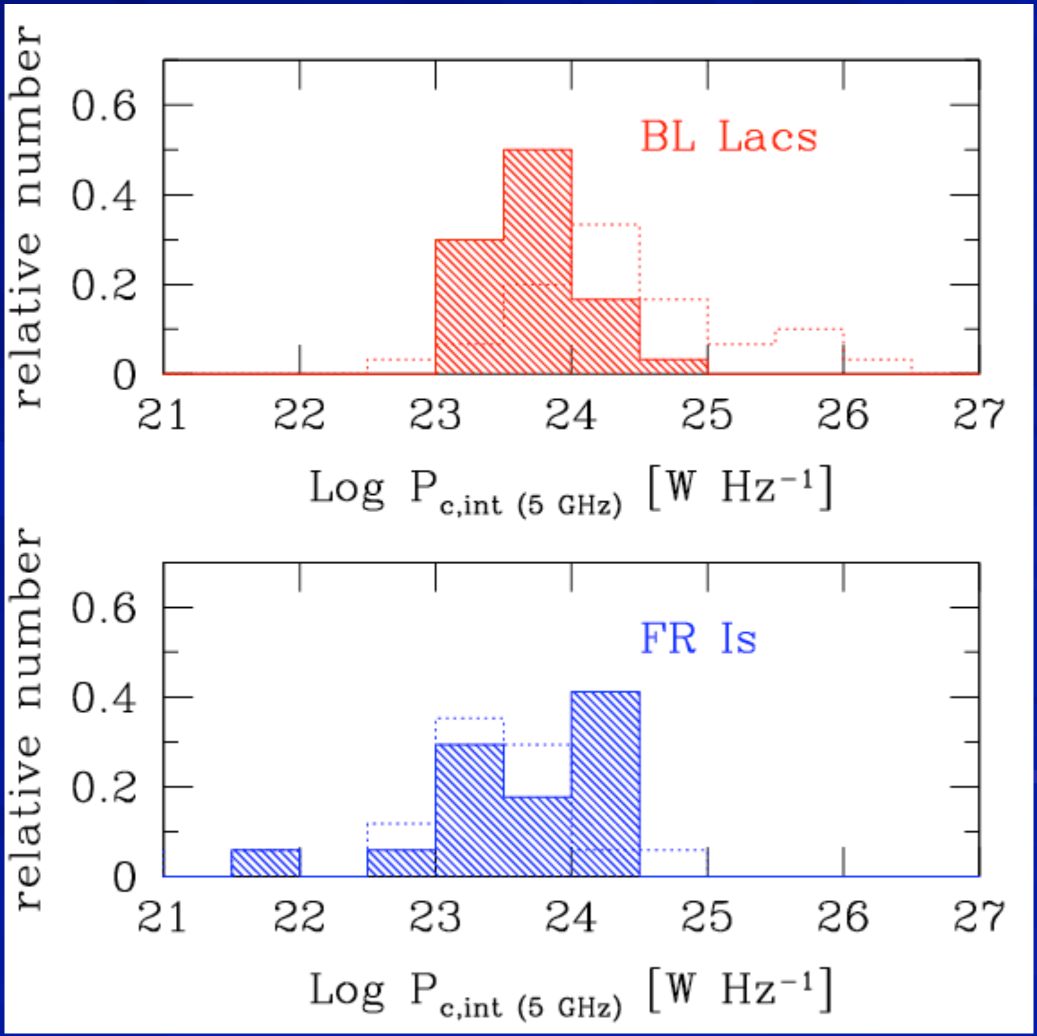
- From:
  - core dominance
  - SSC
  - jet/counterjet
  - assumptions...
- Results
  - $10° < \theta < 25°$
  - Γ_{HBL} 2~4
  - $1 < \delta < 10$



Parent Population (1)

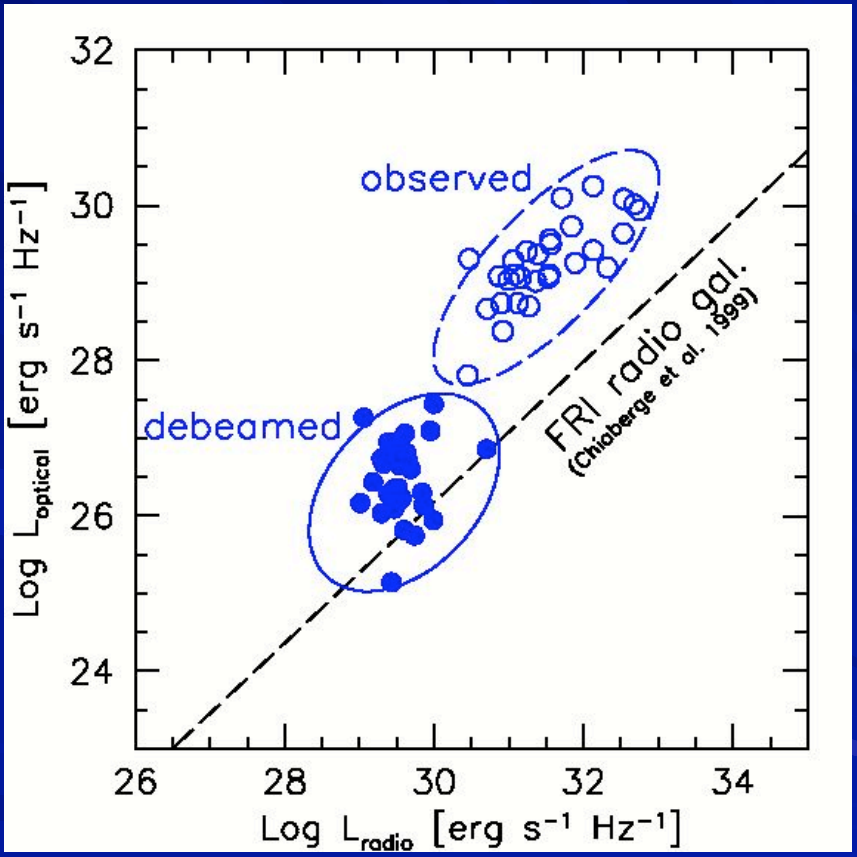
Comparing to FR I studied by Giovannini et al. (2001), both extended and nuclear radio power overlap





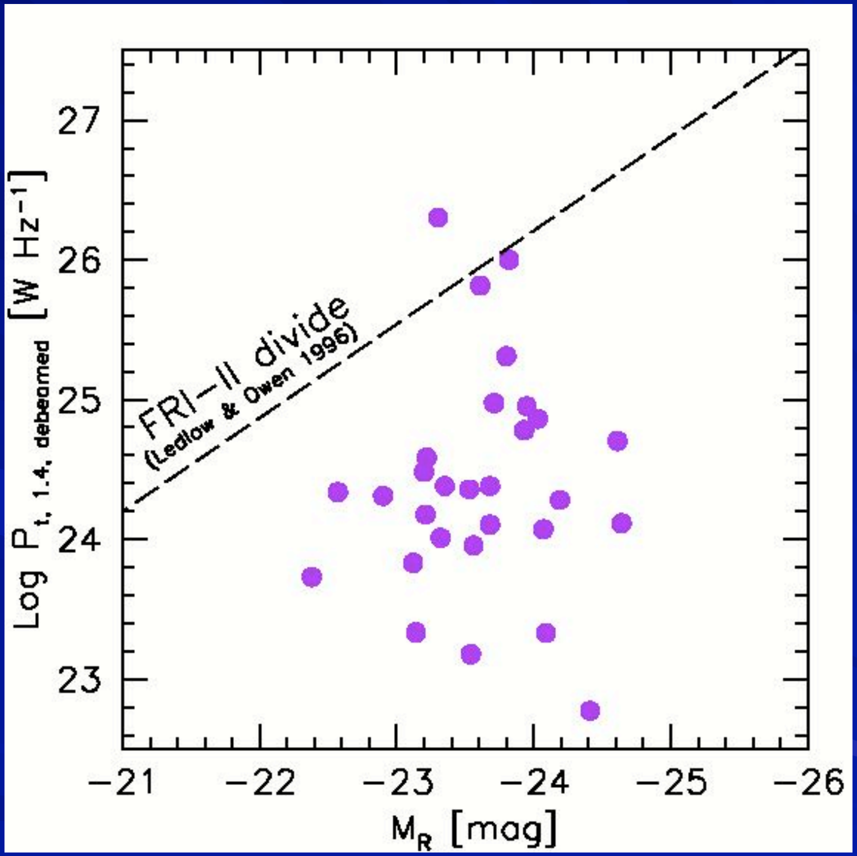
Parent Population (2)

- HST and radio data for FRIs (Chiaberge+ 99):
  - radio and optical core luminosities are correlated
  - same emission mechanism? synchrotron!
- HST and radio data for BL Lacs (Giroletti+ 06)
  - radio and optical core luminosities (and fluxes) correlate
  - observed L are offset w.r.t. FRIs
  - debeamed L fall on FRI correlation!



Parent Population (3)

- Host galaxy magnitude and total radio power divide FRI/II (Ledlow&Owen 1996)
  - all HBLs fall into FRI region
  - if M_R~BH mass and P_r~Mdot:, HBL are sub-Eddington



Summary (focus VLBI)

- HBLs are detected with VLBI 100%
- with jets 70%
  - less misaligned than LBLs
  - less fast than LBLs
  - no motions (cfr. Piner+ and next slides…)
  - some interesting target…

Part 2

A special HBL and mm-VLBI

– object ID

– from kpc to sub-pc scale

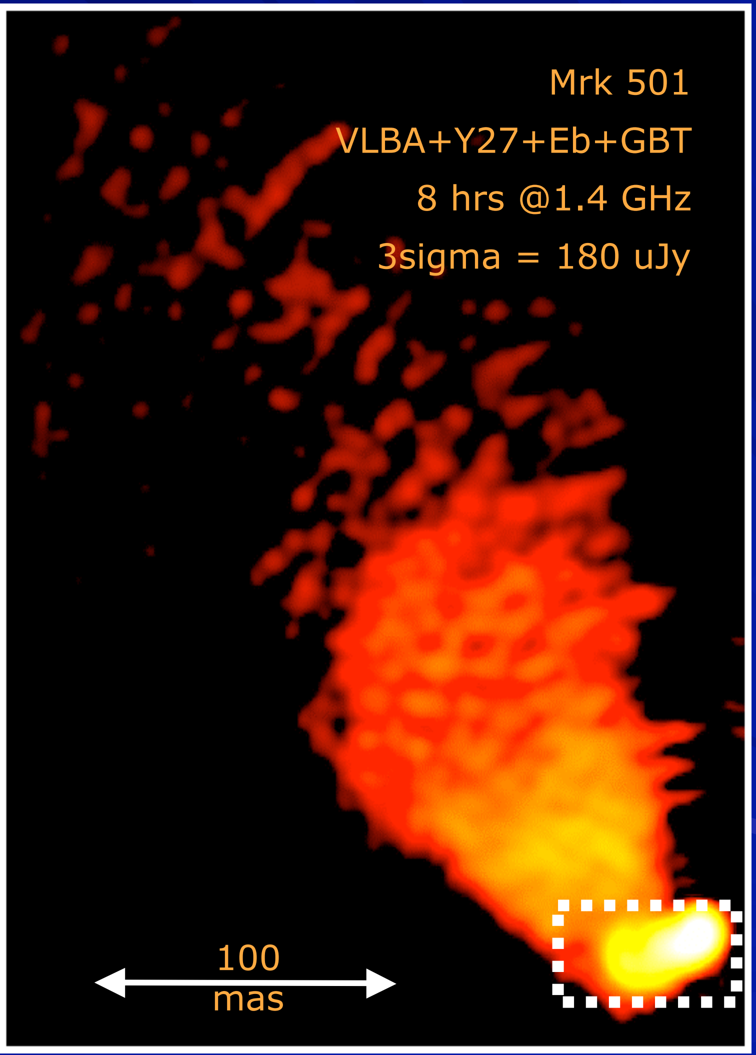
– results…

Markarian 501

- $z=0.0337$: 1 mas = 0.7 pc, 1 $R_S=10^{-3}$ pc
- $S_{NVSS}=1.6$ Jy - the brightest HBL
- $P_{1.4\,GHz}=4.7\times10^{24}$ W/Hz
- activity and extreme variability detected in X and TeV
- EGRET: not in 3EG
- Thanks to its proximity and brightness, the source is an ideal laboratory for experiments using advanced VLBI techniques at all frequencies.

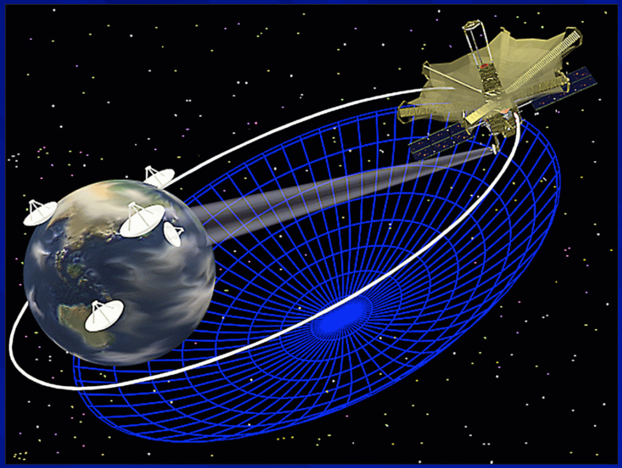
High Sensitivity Array observations

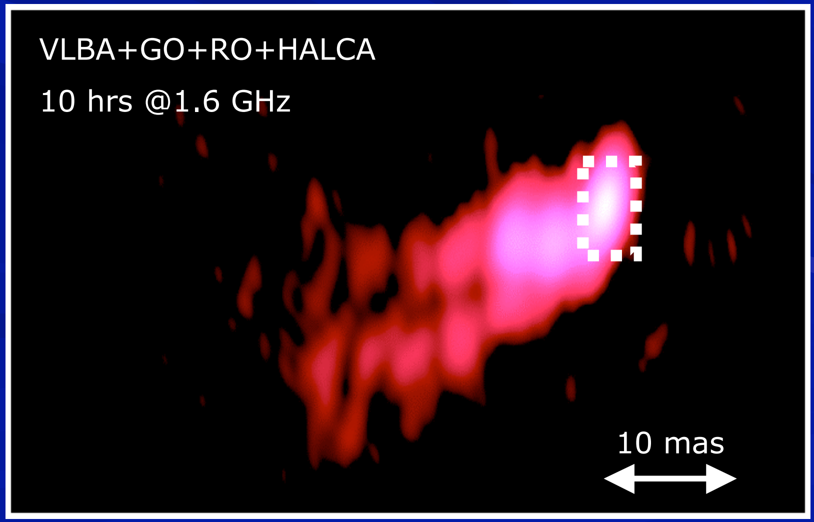
- We observed Mrk 501 with the HSA on 26 Nov 2004
- High jet/counterjet ratio:
  - R>2860 near the core
  - R>20 at 120 mas
- fit to the trend of the jet brightness and FWHM:
  - not in agreement with a parallel magnetic field adiabatic model since it predicts a jet velocity decrease at ~80 mas from the core, in contrast with measured R
  - On the contrary a perpendicular magnetic field model predicts a large jet velocity in agreement with the non detection of a cj and a jet velocity decrease far from the core (arcsecond scale, VLA).



VSOP observations

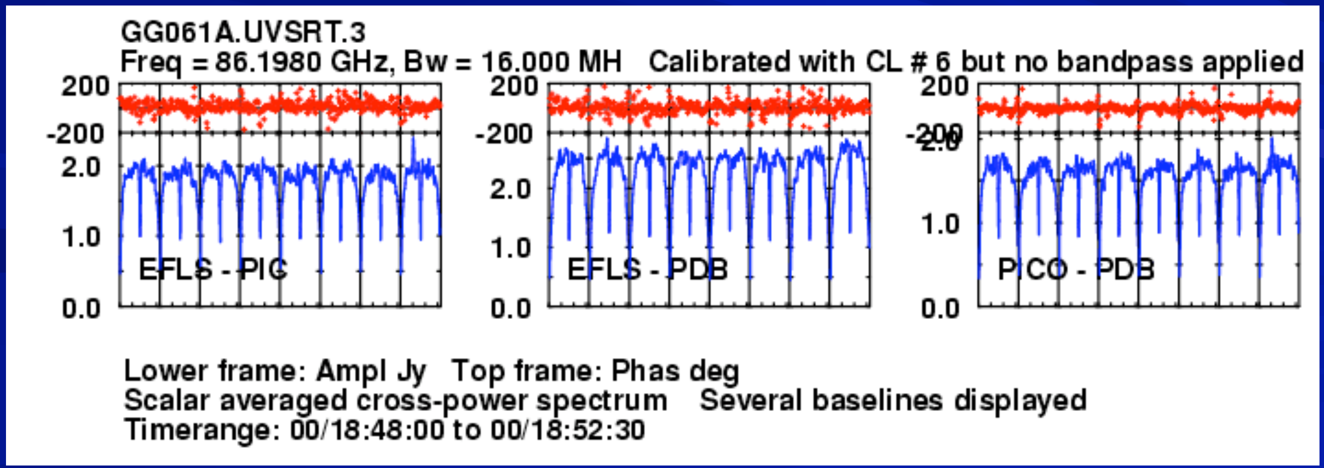
- The best resolution @1.6 GHz is provided by Space VLBI (obs. 4 Apr 1998)
- The image reveals an evident limb-brightened structure in the very inner jet and visible for several parsecs:
  - evidence of a velocity structure starting near to the core (inner fast spine, slower external layer)
  - visible also in ground VLBI @22 GHz
  - No proper motion found comparing 9 different epochs (cfr. Piner&Edwards)





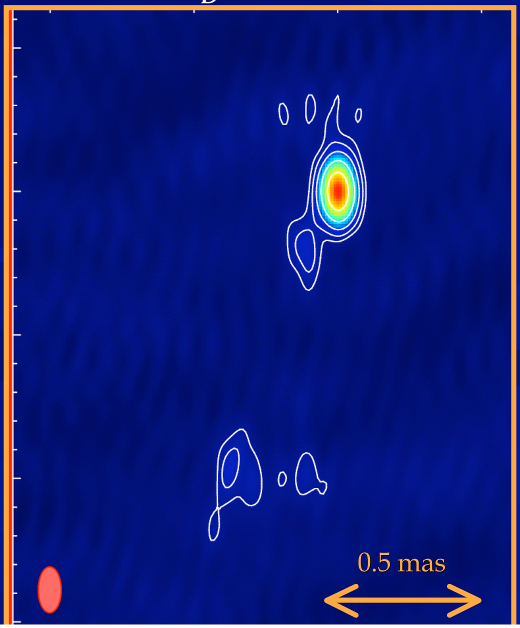
Global mm-VLBI observations

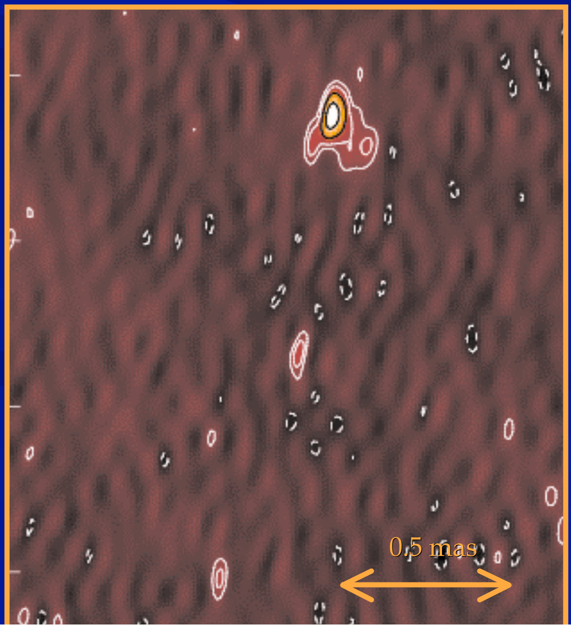
- We observed Mrk 501 with the Global mm-VLBI Array [see T. Krichbaum's talk + `http://www.mpifr-bonn.mpg.de/div/vlbi/globalmm/`]
- Standard frequency is 86.453 GHz
- Participating telescopes: Effelsberg, Pico Veleta, Plateau de Bure, Onsala, Metsahovi, and 8 VLBA stations
- European telescopes ~9 hours, American ones ~6
- Experiment to the array sensitivity limits, since Mrk 501 is expected to be only a few 100's mJy at 3mm...
- **with success!!!**

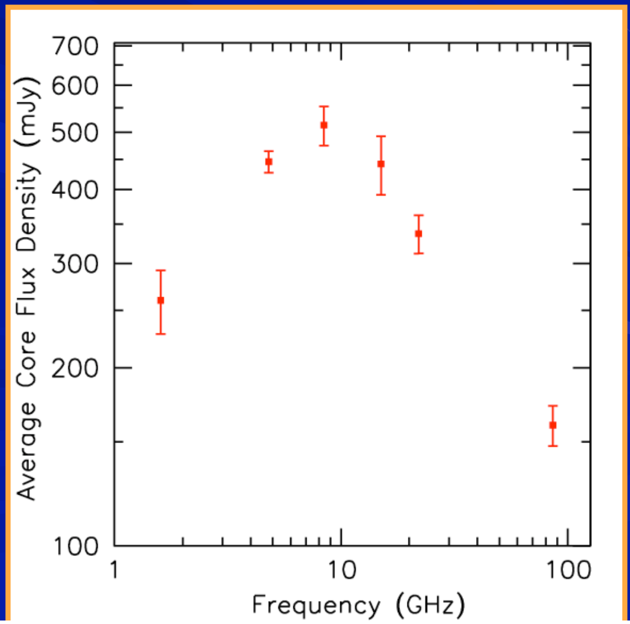


GMVA results (preliminary)

- The resolution is 0.16 x 0.08 mas, i.e. ~560 R_S. At this resolution:
  - Compact core: OK!!
  - Diffuse emission: difficult to clean/model; tentative jet P.A. ~170˚, OK with 22 GHz images, still different w.r.t. >2 and >20 mas
- encouraging result for current mm-VLBI and promising about upgrades
- Preliminary scientific applications:
  - core spectrum; flux density at 86 GHz follows the lower frequency optically thin part
  - $T_B > 10^9$ K

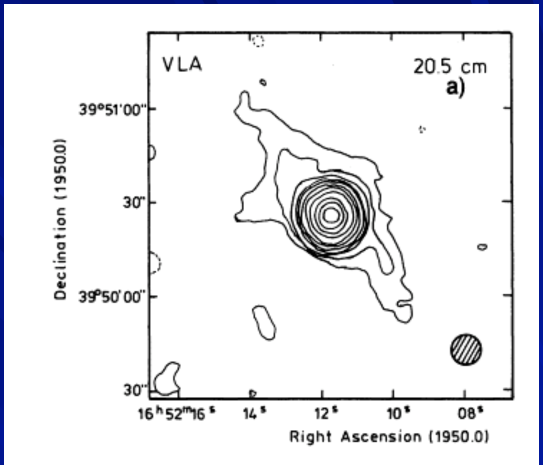


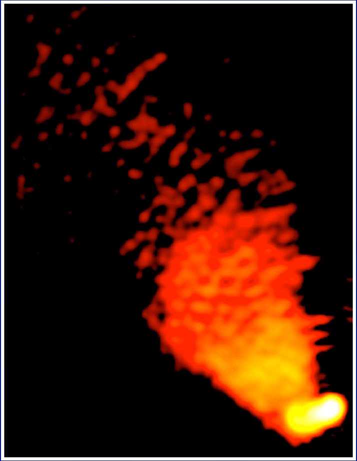


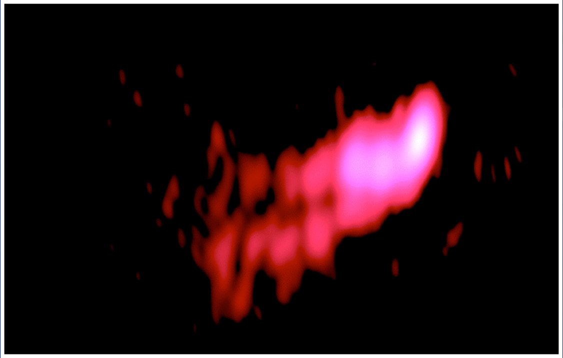


Mrk501, VLBI summary

- Strong core and a bright one-sided jet.
- Large jet/counterjet ratio
- The jet exhibits multiple bends before undergoing a last turn, followed by rapid expansion in the direction of the symmetric non relativistic kpc scale structure
- Well defined limb brightened structure is visible from ~1 mas up to ~30 mas
- There is no indication of proper motion of components
- Magnetic field
  - core region (0.03 to 0.15 pc) = 0.03 gauss (self-absorption)
  - Jet region = 0.015 – 0.010 gauss (equipartition)







VLBI/γ-rays

- Radio results seem in disagreement with constraints derived from the high energy emission.
- To reconcile radio and γ-rays results we need:
  - a deceleration of the radio jet (*but still relativistic up to 1 kpc*)
  - an increase in viewing angle

Jet Velocity Structure - Parallel Magnetic Field

R_{core} pc	θ °	Γ_{spine}	δ_{spine}	Γ_{layer}	δ_{layer}	Notes
0.0001 – <0.03	4	15	15	?	?	γ-ray region
0.03 – 0.15	10	15	4	10	5	Radio core
0.15 – 7	15	15	2	3	5	First jet region
7 – 20	15–20	15	2–1	3	4–3	Before of large bending
20–30	25	10–3	1–2	2	2.5	After the large bending
50	25	1.25	1.8	1.1	1.5	Final VLBI jet region

Notes: R_{core} = projected distance from the core

TABLE 6b

Jet Velocity Structure - Perpendicular Magnetic Field

R_{core} pc	θ °	Γ_{spine}	δ_{spine}	Γ_{layer}	δ_{layer}	Notes
0.0001 – <0.03	4	15	15	?	?	γ-ray region
0.03 – 0.15	10	15	4	10	5	Radio core
0.15 – 7	15	15	2	3	5	First jet region
7 – 20	15	15	2	3	4	Before of large bending
20–30	15	10	2.5	3	4	After the large bending
50	15	10	2.5	3	4	Final VLBI jet region

Notes: R_{core} = projected distance from the core

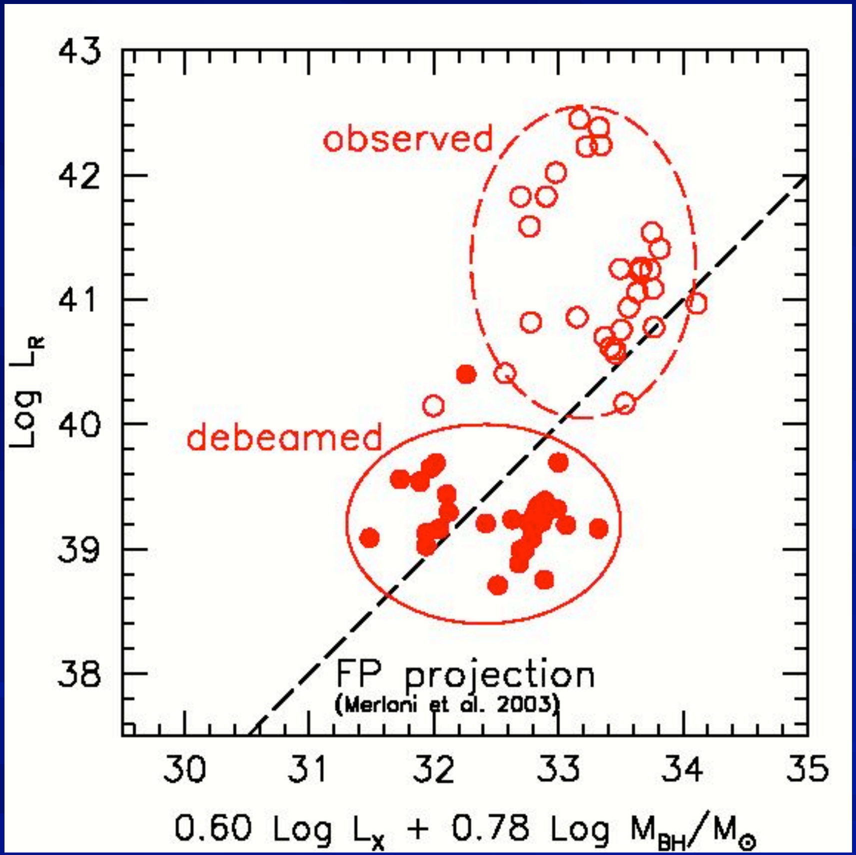
Mrk 501: Summary

- bright and well-known HBL... not detected by EGRET!
  - **will GLAST detect it?**
    - **YES!**
  - will GLAST detect other HBLs?
    - Yes, but how many?!
  - what is VLBI telling us about it?
    - Lots (structure, velocity, motion, ...)
  - what could VLBI tell us about other GLAST HBLs?
    - need to discover!

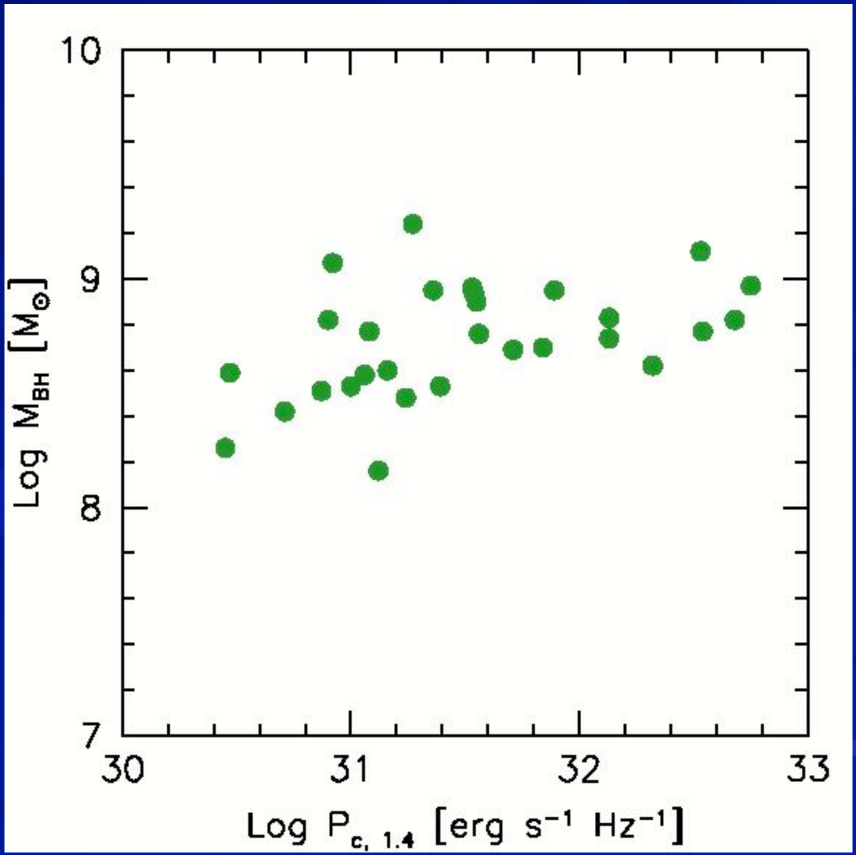
The End

Thank you!

More plots...



observed
debeamed
FP projection
(Merloni et al. 2003)
Log L_R
0.60 Log L_X + 0.78 Log M_BH/M_⊙
43
42
41
40
39
38
30
31
32
33
34
35



Log M_BH [M_⊙]
Log P_c, 1.4 [erg s^-1 Hz^-1]
10
9
8
7
30
31
32
33