The connection between millimeter and gamma-ray emission in AGNs

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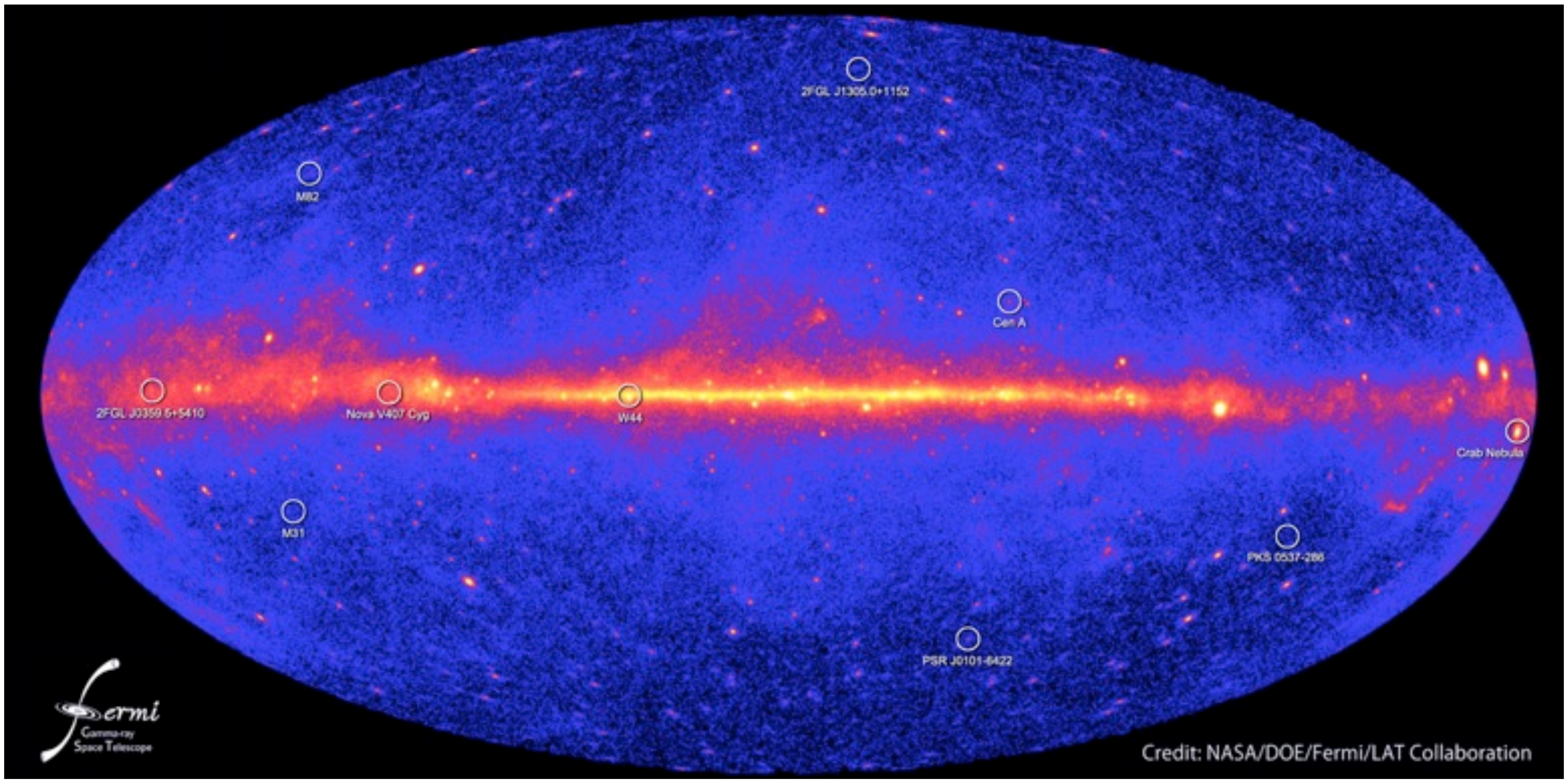
The Large Area Telescope (LAT) onboard Fermi

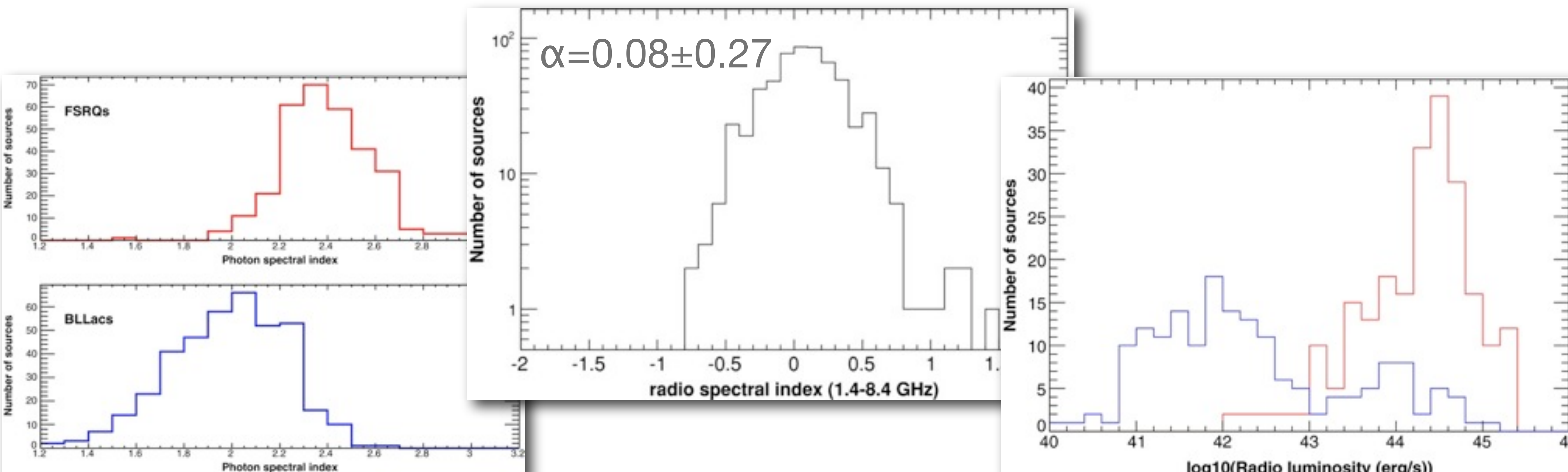


- Since 2008, Fermi-LAT is continuously monitoring the gamma-ray sky in the energy range ~100 MeV-100 GeV.

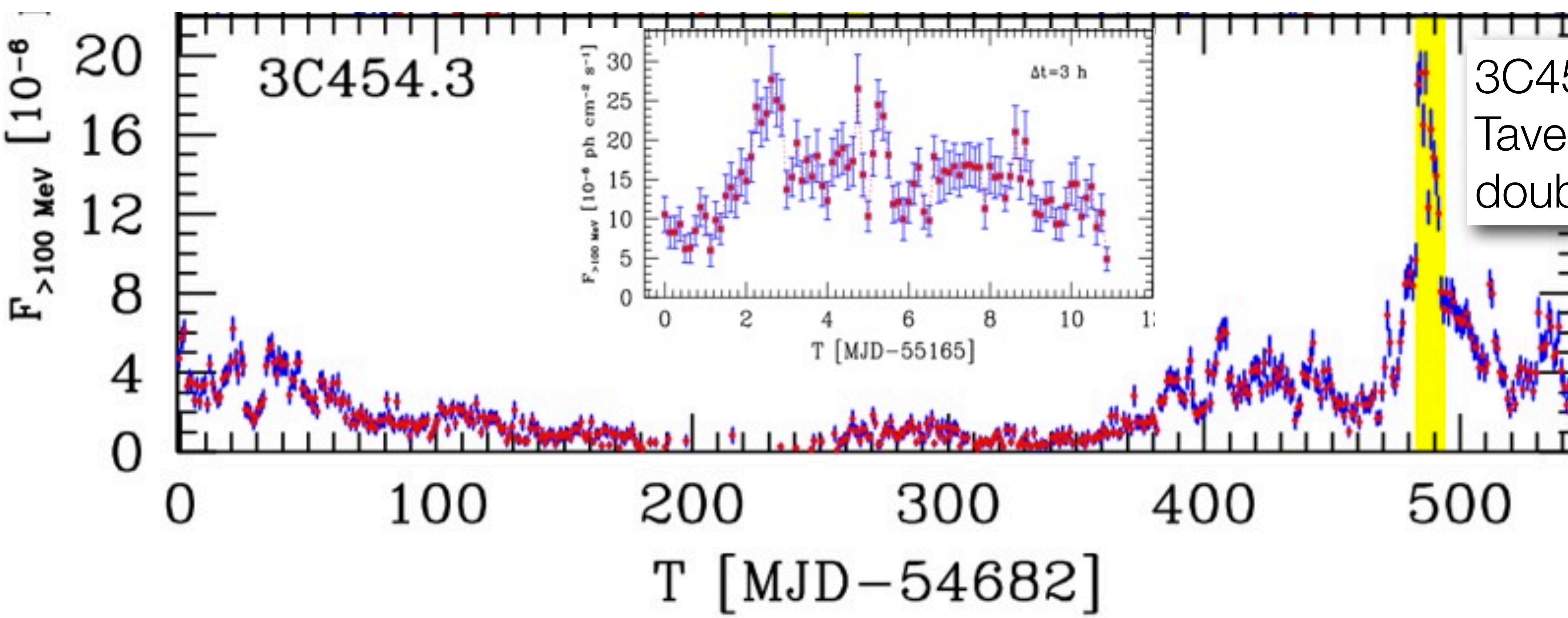
- After 2 years, Fermi has detected 1017 gamma-ray sources located at high galactic latitude that are associated statistically with AGNs (2LAC, Ackermann et al. 2011 ApJ 743)

2LAC

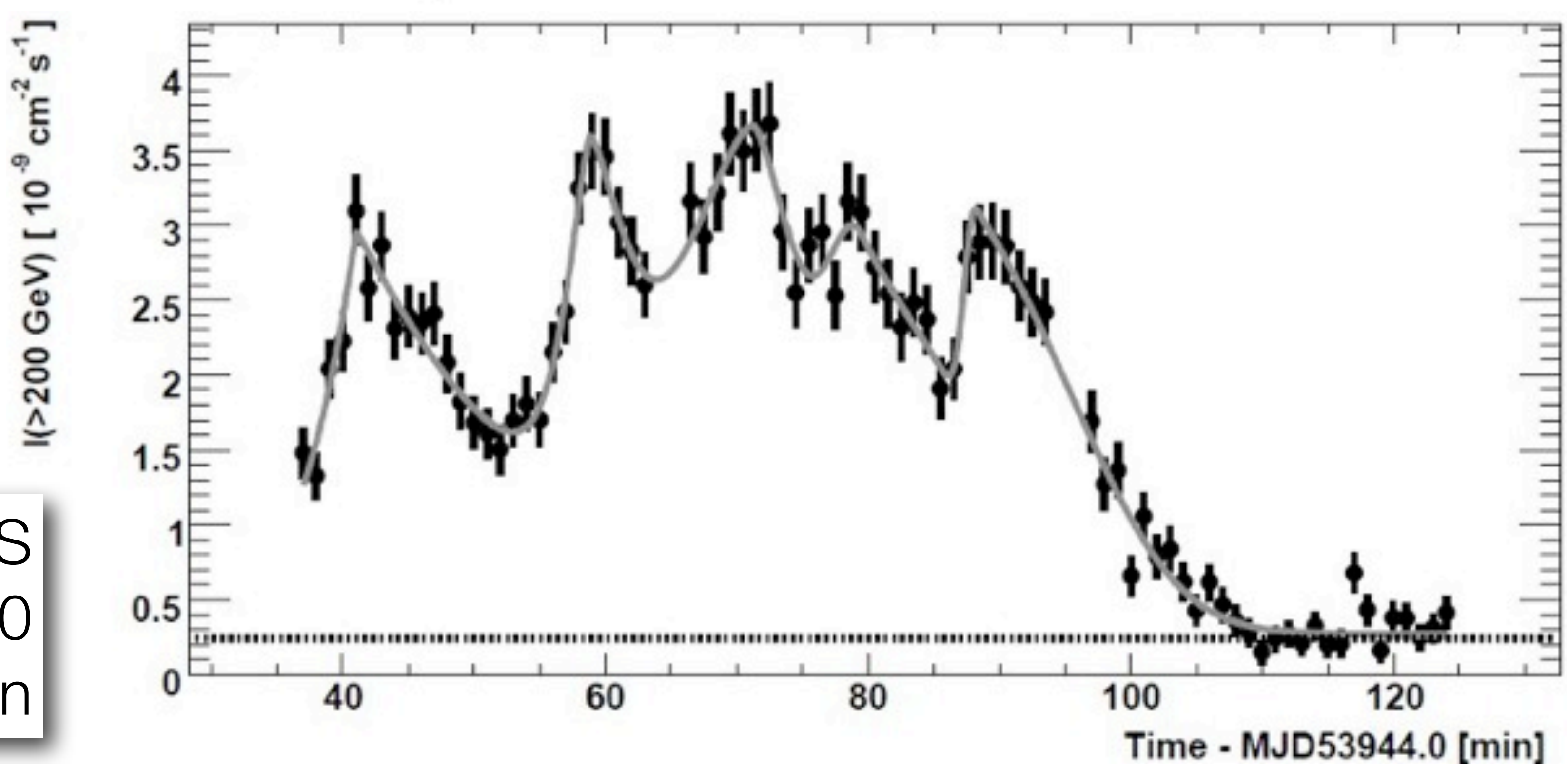
- A clean sub-sample of the 2LAC includes 395 BLL, 310 FSRQ, 157 unknown, 8 misaligned AGNs, 4 NLS1 (*very different from EGRET!*)
- The sources are characterized in 5 energy bands - BLL are harder than FSRQ
- Radio data are available for all sources - BLL are fainter and less powerful than FSRQ - for both classes, low frequency (1-8 GHz) spectral index is typically flat



Short gamma-ray variability time scales



3C454.3, Fermi-LAT
Tavecchio et al. 2010
doubling timescale ~6hr

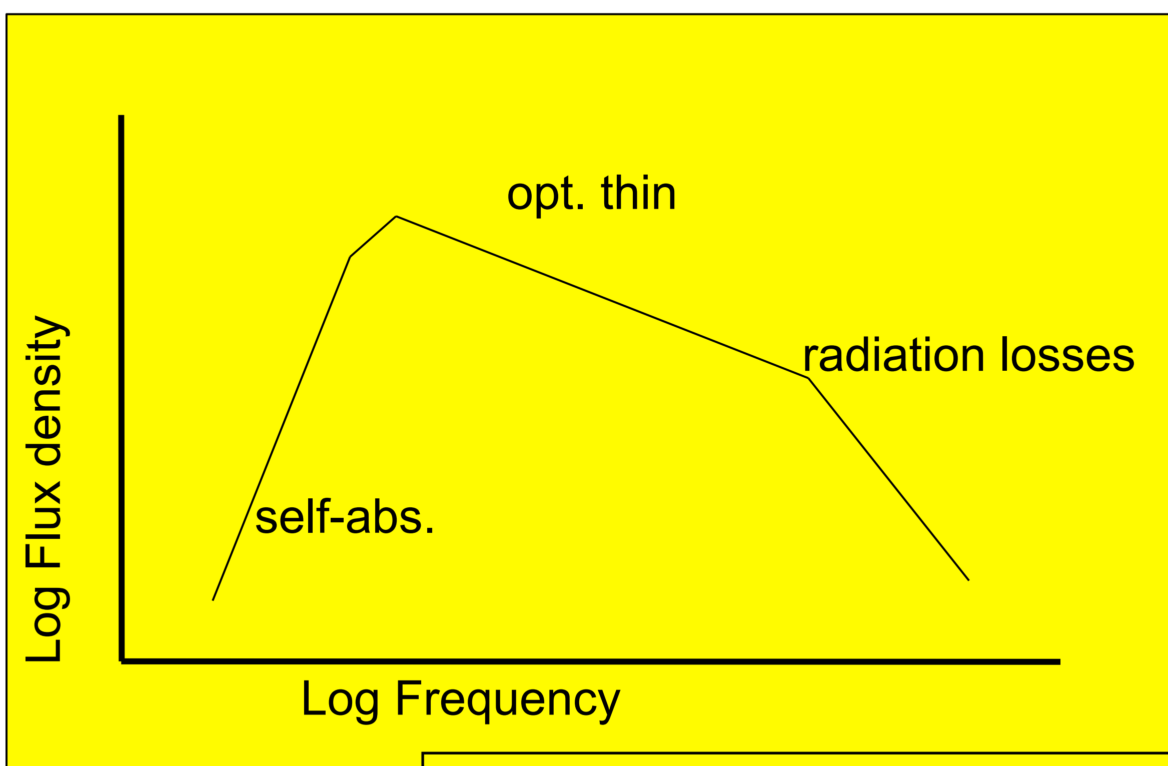


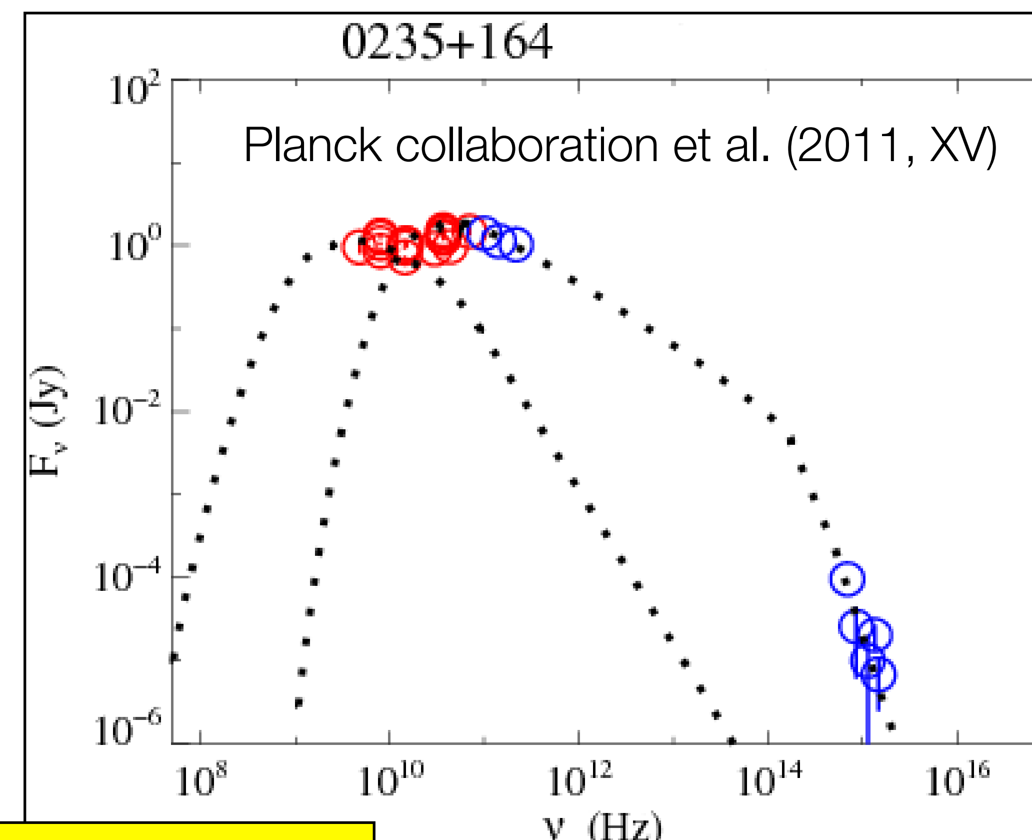
2155-304, HESS
Abramowski et al. 2010
TeV, doubling timescale ~2min

From gamma-rays to mm-wavelength

- Gamma-ray variability implies compactness, compactness implies low frequency self-absorption

- Fermi sources call for millimeter observations. Indeed, some interesting results were obtained by Planck, but due to sensitivity limitations we are far from a clear understanding of radio spectra and broad-band SED

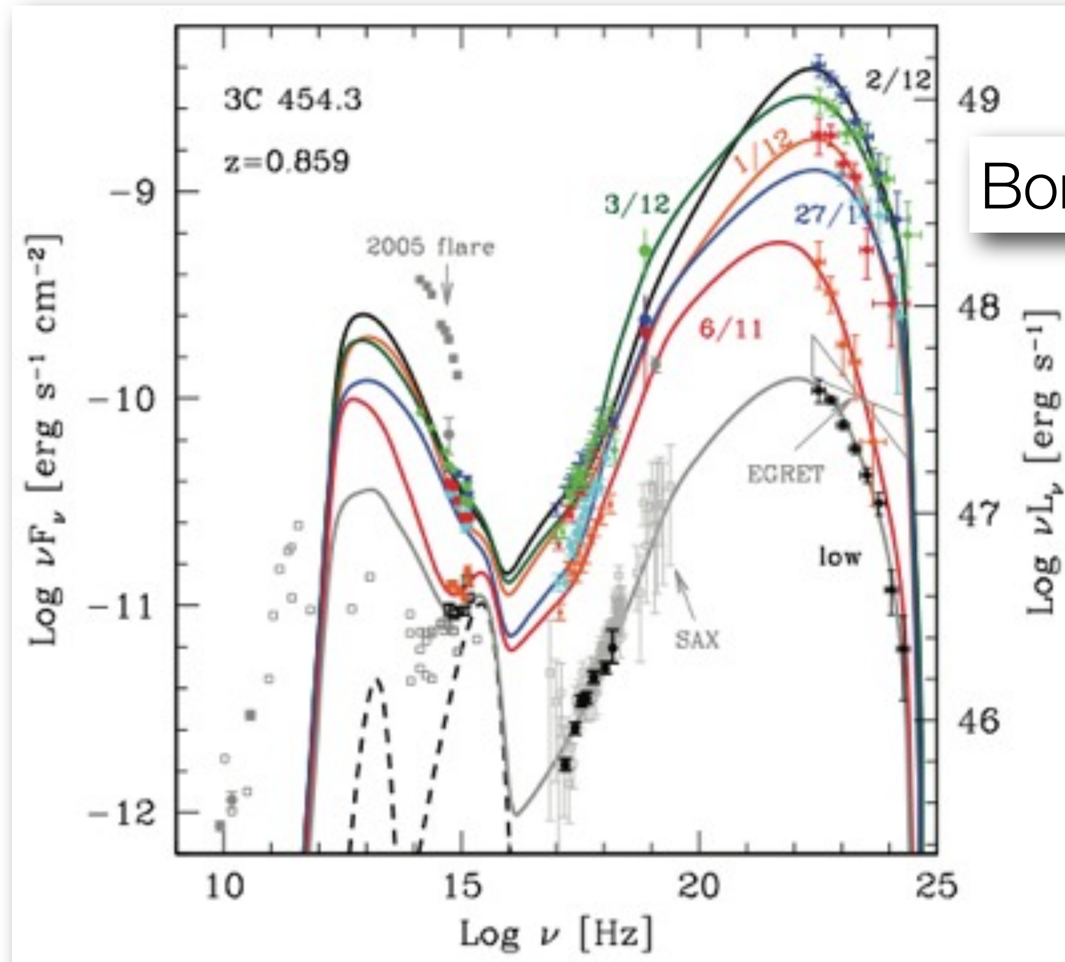




$$\nu_{max} = e(\alpha)\, H^{1/5}\, \theta^{-4/5}\, S_{max}^{2/5} (1+z)^{1/5}$$

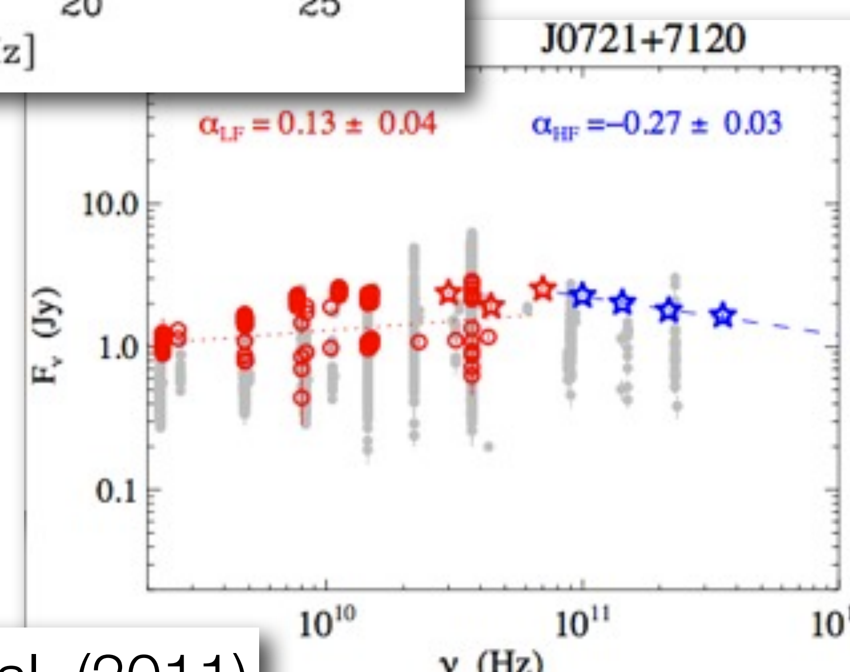
ALMA sensitivity for Fermi sources

- 1min ALMA rms about 0.2, 0.3, 0.6, 5.3 mJy beam^{-1} at 100, 230, 345, and 675 GHz
- let's assume $\alpha = 0.5$ ($S \propto \nu^{-\alpha}$), this correspond to high significance detections for tens of Fermi blazars - note that the most intriguing sources have even flatter observed spectra
- still, no structural information
- need VLBI for that...



Bonnoli et al. (2010)

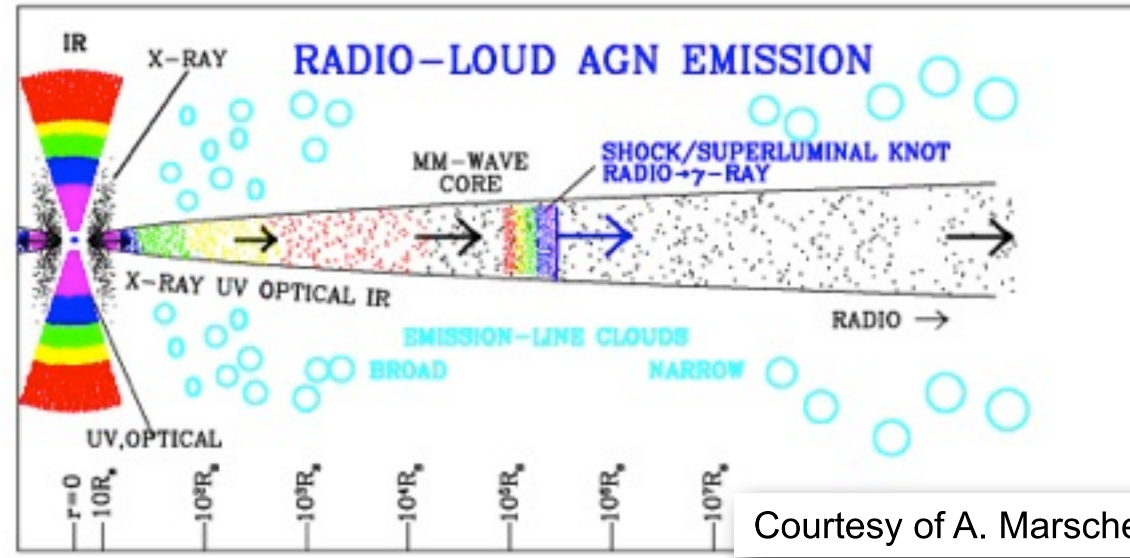
ALMA



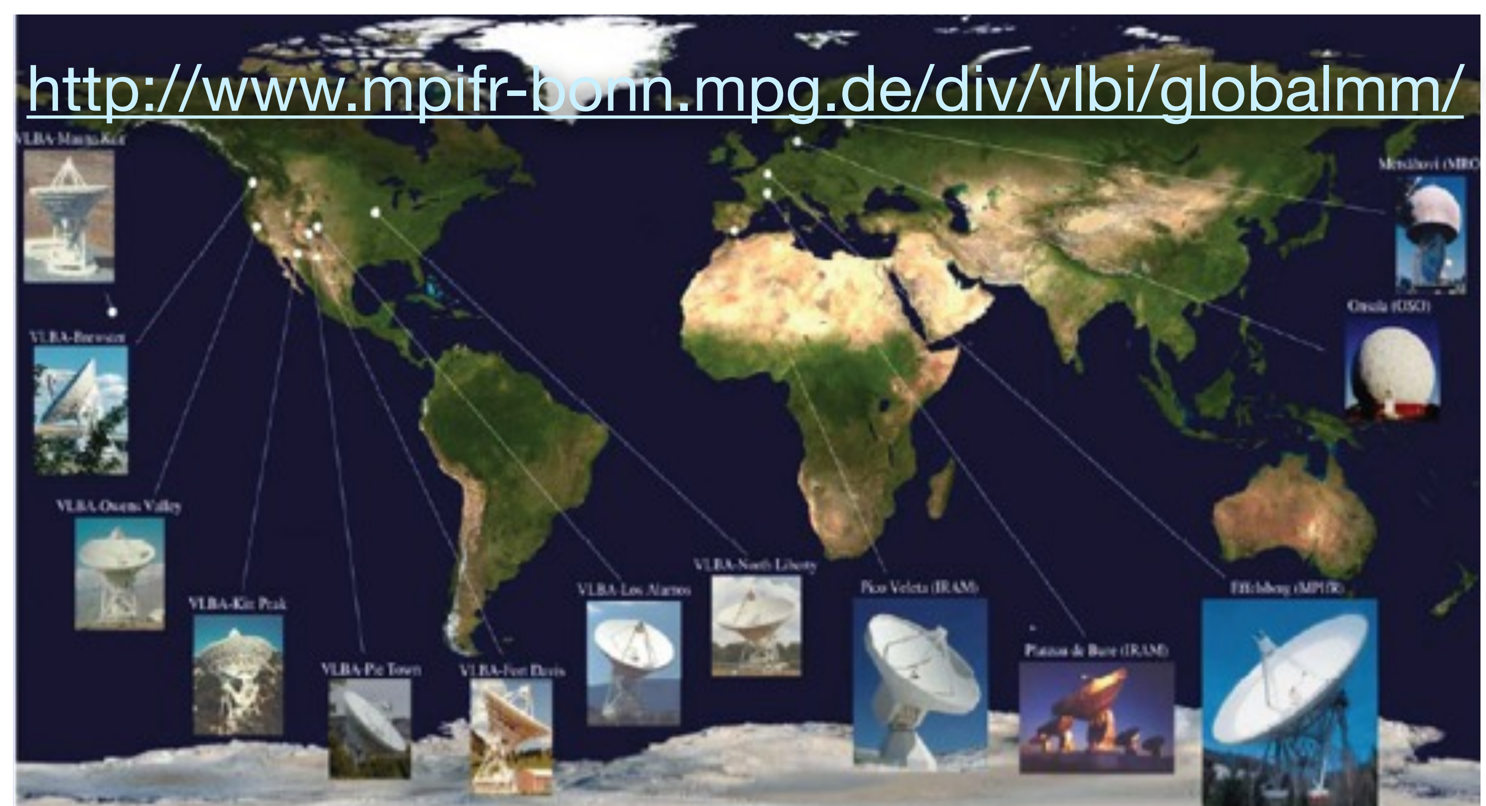
Planck collaboration et al. (2011)

VLBI with ALMA?

- At present, Global Millimeter VLBI Array (GMVA)
  - ~14 participating telescopes (6 Europe, 8 VLBA) - Noto, SRT in the future(?)
  - 2 sessions per year
  - Baseline sensitivity 50-350 mJy
  - Angular resolution 40 µas



Courtesy of A. Marscher



http://www.mpifr-bonn.mpg.de/div/vlbi/globalmm/

mm-VLBI	current	with ALMA
sensitivity	100 mJy	10 mJy
resolution	50 µas	10 µas

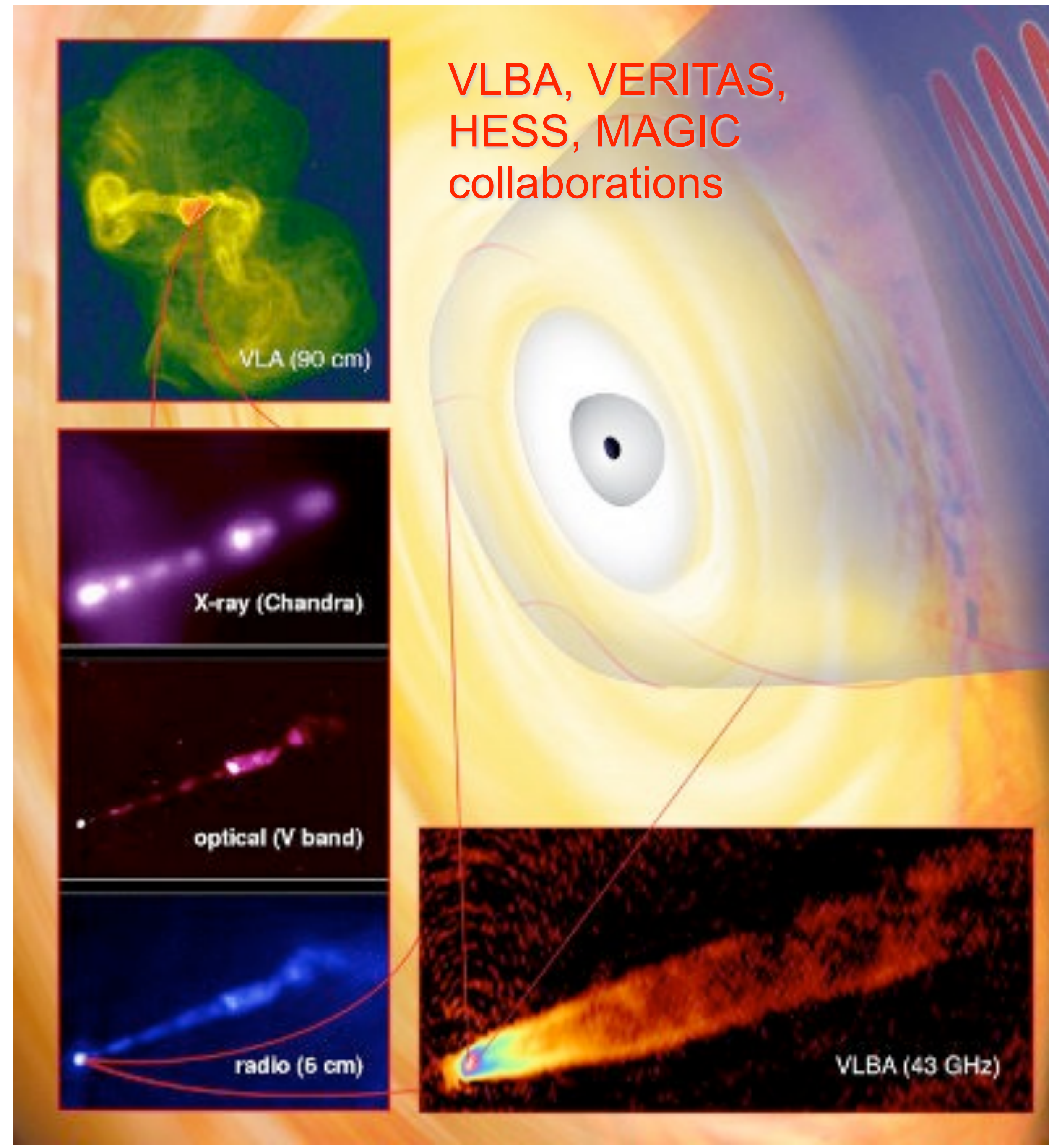
Angular and spatial resolution of mm-VLBI

λ	ν	θ	z=1	z=0.01	d= 8 kpc
3 mm	86 GHz	45 μas	0.36 pc	9.1 mpc	1.75 μpc
2 mm	150 GHz	26 μas	0.21 pc	5.3 mpc	1.01 μpc
1.3 mm	230 GHz	17 μas	0.13 pc	3.4 mpc	0.66 μpc

- for nearby sources, these scales correspond to 1–100 Schwarzschild radii, depending on distance and black hole mass!
- linear size: $10^3 R_s$ (log M_{BH}=9), 30-100 R_s (log M_{BH}=9), 1-5 R_s (log M_{BH}=6)
- mm-VLBI is able to directly image the vicinity of SMBHs!
- best candidates: Sgr A*, M87

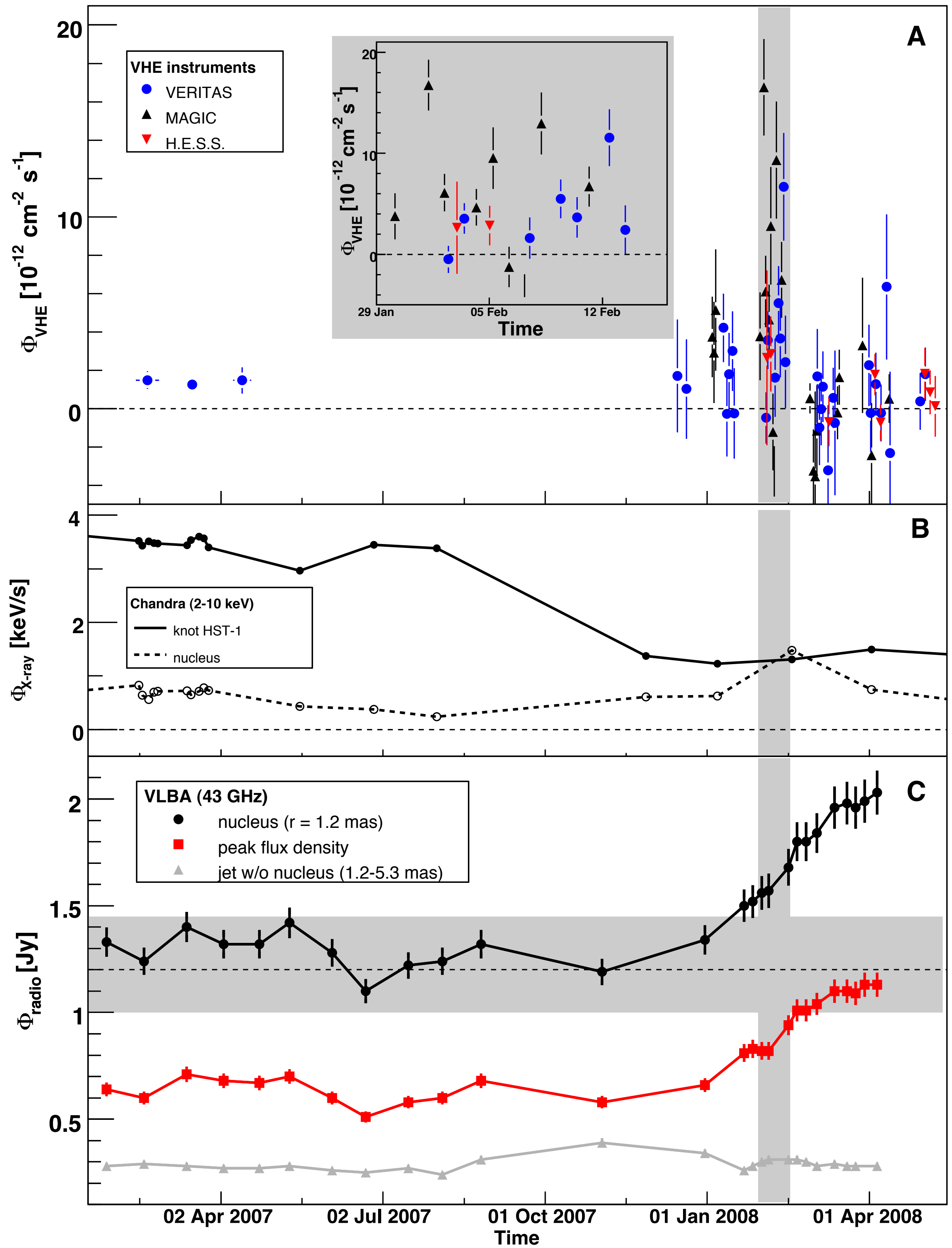
A near candidate for BH horizon: the radio galaxy M87

- d=16 Mpc
- low power but bright FR1 radio galaxy
- most massive black hole in nearby universe: $M_{BH}=10^9\ M_{sun}$
- Schwarzschild radius $R_S=3.7\ \mu as$
- optical and X-ray jet with superluminal motions
- source detected at GeV/TeV energy

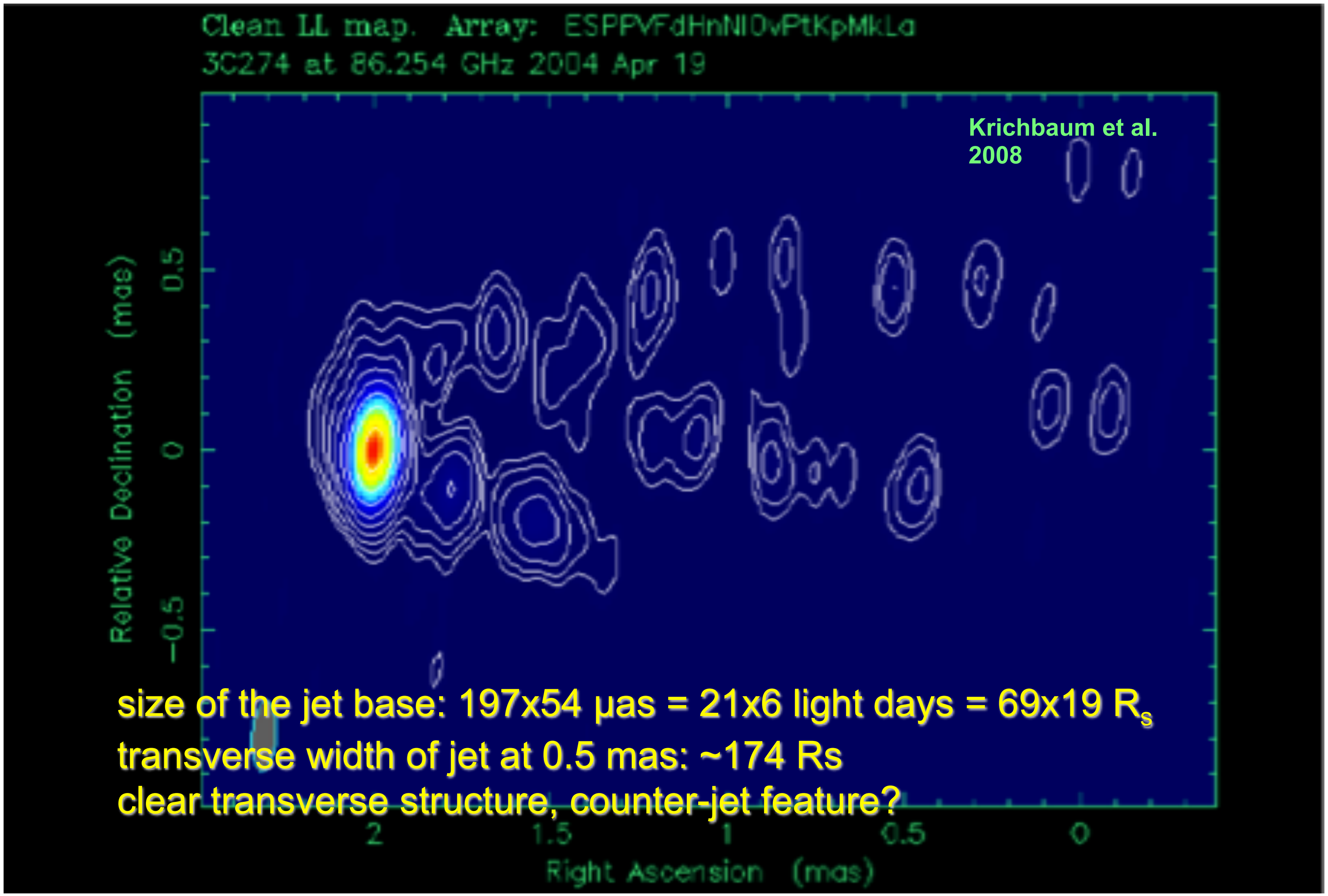


Coordinated VHE and MWL variability

- 2008: bright, fast TeV flare detected from all TeV telescopes (Acciari et al. 2009)
- VLBA 43 GHz radio core flux density increase
- (...but other TeV event show different MWL/radio characteristic, e.g. Harris et al. 2006, Giroletti et al. 2012)



M87 with present mm-VLBI



Locating the black hole in M87

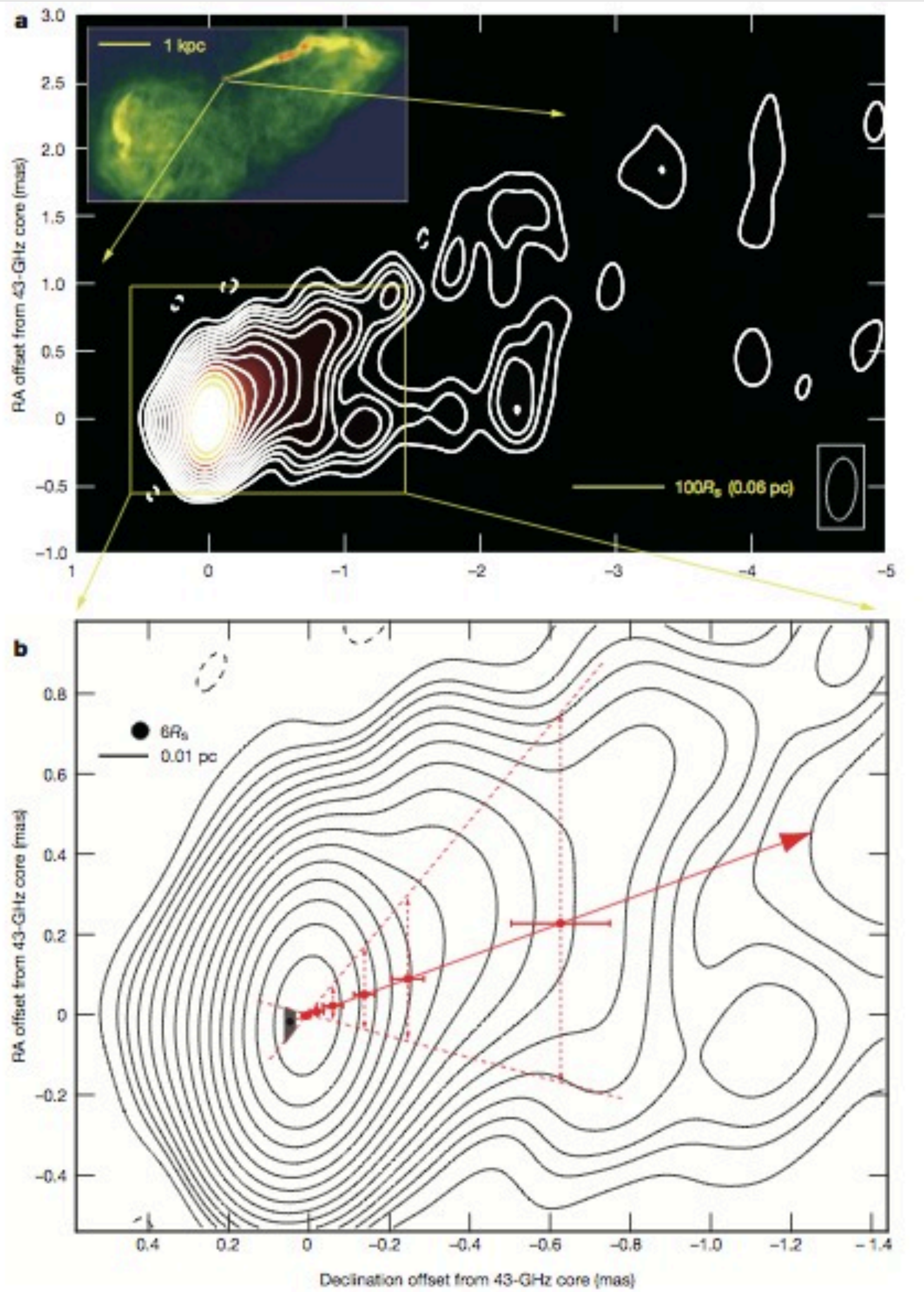
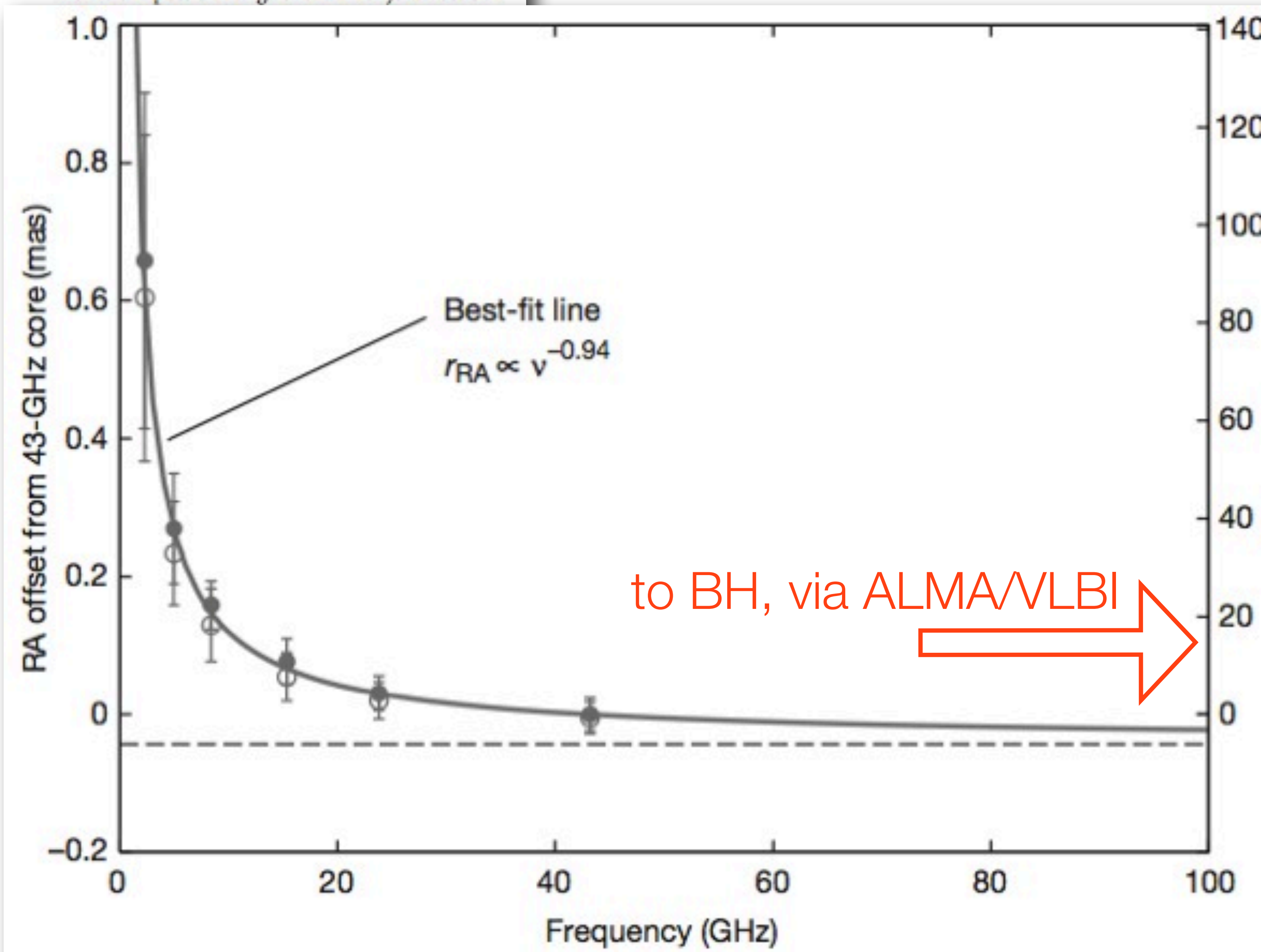


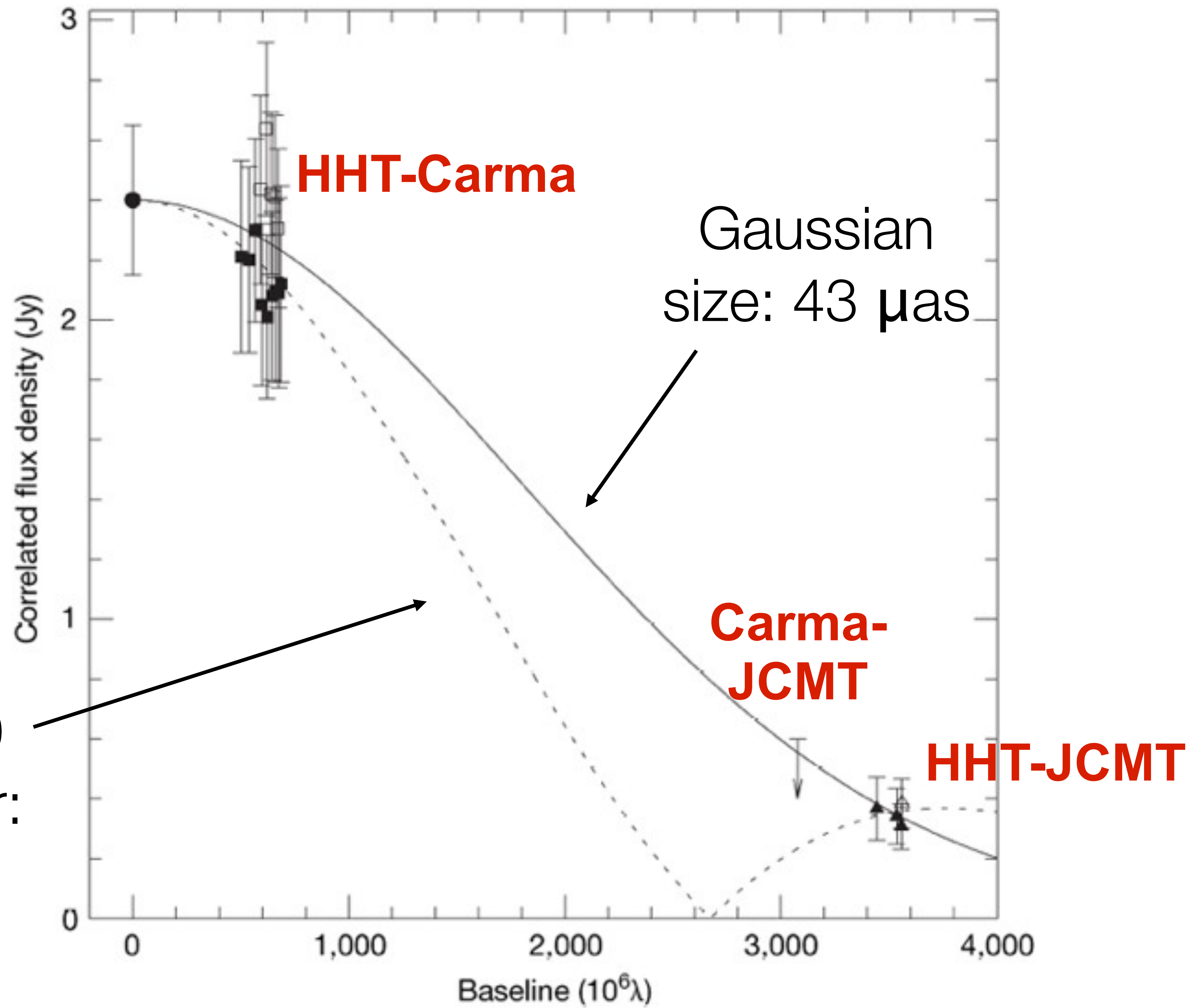
Figure 3 | VLBA image of M87 at 43 GHz superimposed on the measured core-shift positions. **a**, Global view of the radio jet on a subparsec scale. **b**, Close-up view of the region enclosed by the rectangle in **a**. The synthesized beam of the VLBA is 0.22 mas × 0.46 mas at −5° (bottom right in the upper image). The peak brightness and 1σ noise level are 724 mJy and 1.1 mJy per beam, respectively. Contours are (−1, 1, 2, 2.8 and 4) × 3.3 mJy per beam and thereafter increase by factors of $2^{1/2}$. Two broken red lines represent the maximum possible range of the inner jet direction

Hada et al. 2012, Nature




CREATING A BLACK HOLE TELESCOPE
230 GHz VLBI of Sgr A*
Doeleman et al. (2008)
10 & 11 April 2007 @3.84 Gbit/s
2: Combined Array for Research in Millimeter wave Astronomy – California
3: Arizona Radio Observatory
1. Submillimeter Array and James Clerk Maxwell Telescope – Hawaii
1
2
3
km230
4630 km

Fitting and resolving the size of Sgr A* with 1.3 mm VLBI



Ring ("doughnut") outer diameter: 80 μas, inner diameter: 35 μas

Doeleman et al. (2008)

Summary and outlook

- ALMA sensitivity and operating wavelength are ideal to access regions were gamma rays are most likely produced in AGNs

- As an element of a mm-VLBI array, ALMA will allow us to directly image the SMBH vicinity