The ALMA contribution to the study of the blazar jets

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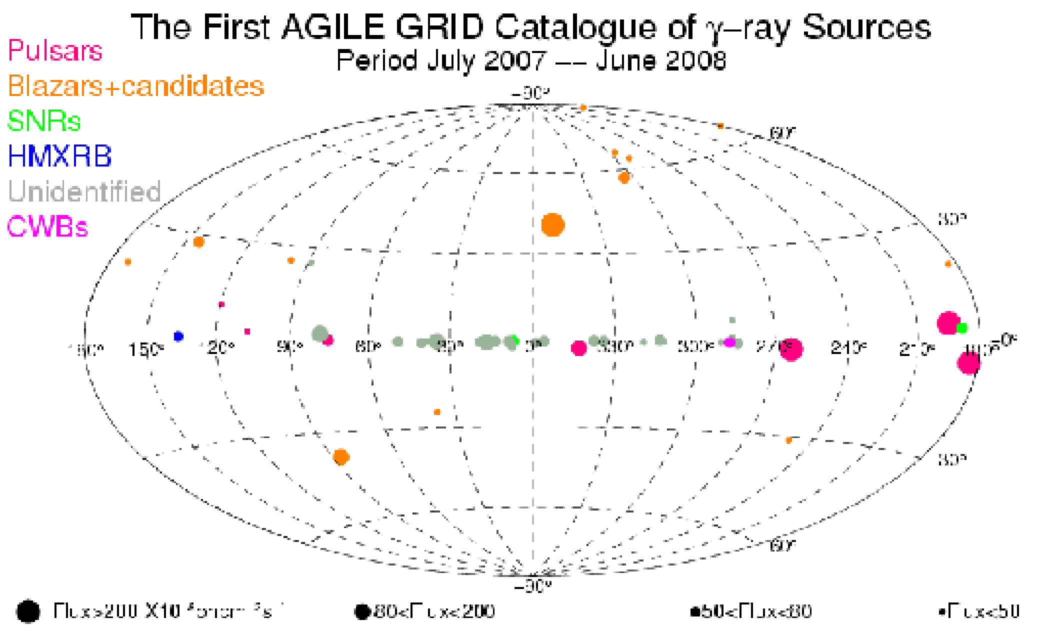
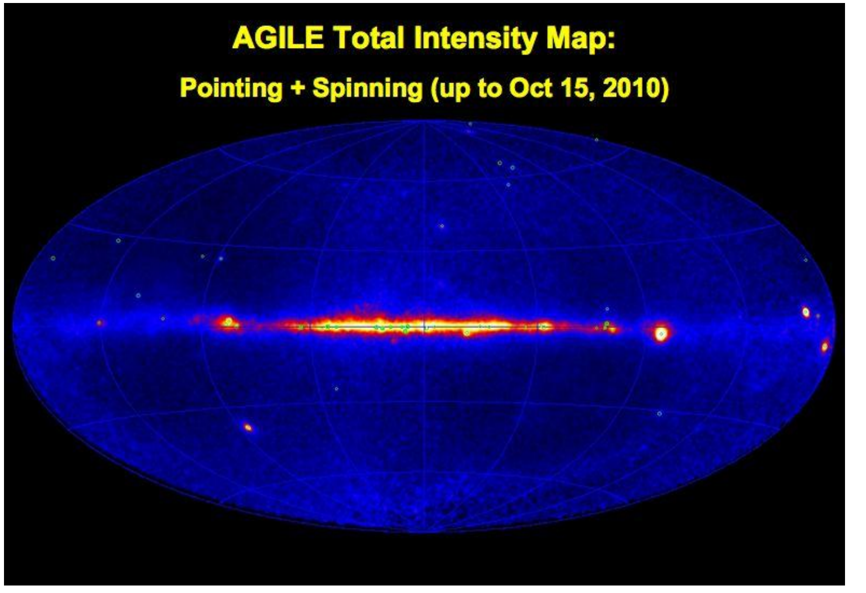
Outline

- The extragalactic γ-ray sky and relativistic jets
- The Atacama Large Millimeter Array
- Relativistic jets in the ALMA era
- ALMA and the VLBI Network

The extragalactic γ-ray sky





Pittori+09

In the First AGILE Catalogue all the extragalactic sources are blazars

In the 2LAC: 96% blazars

4% misaligned AGN (FRI and SSRQ)

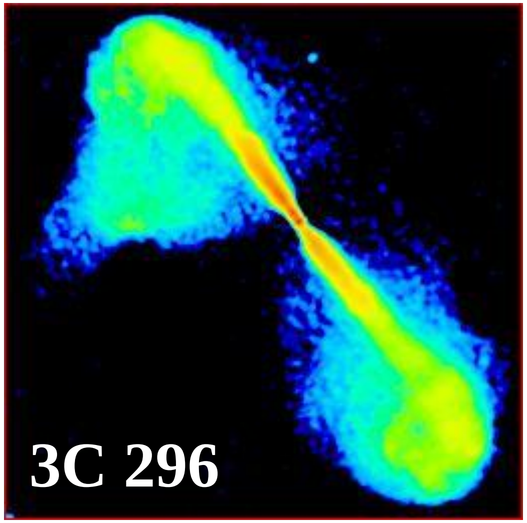
4 Seyferts and 2 starburst with γ rays from star formation

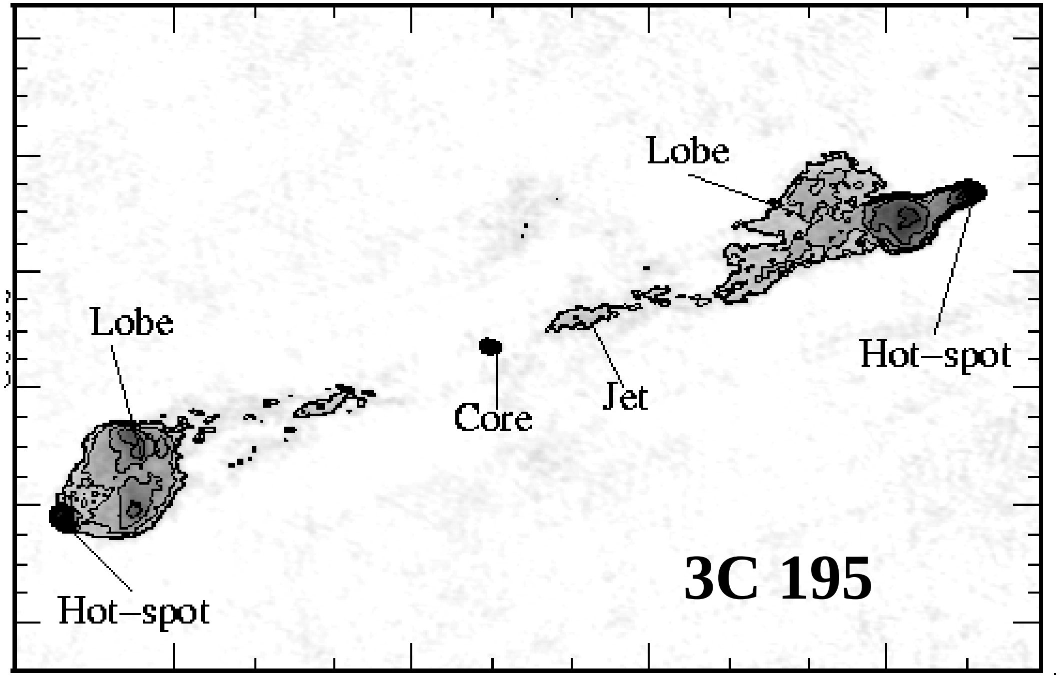
Dominated by radio-loud AGN

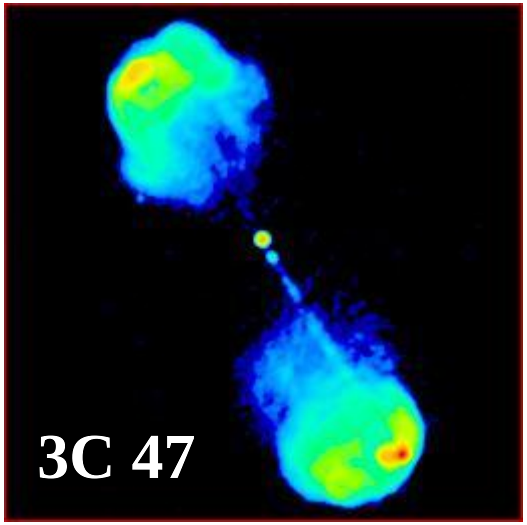
The relativistic jet

Only ~10% of the AGN population is radio-loud
Their radio emission is related to the presence of relativistic jets producing synchrotron radiation

Luminosity ~ $10^{49} – 10^{50}$ erg/s
Linear size ~ from pc to Mpc scales







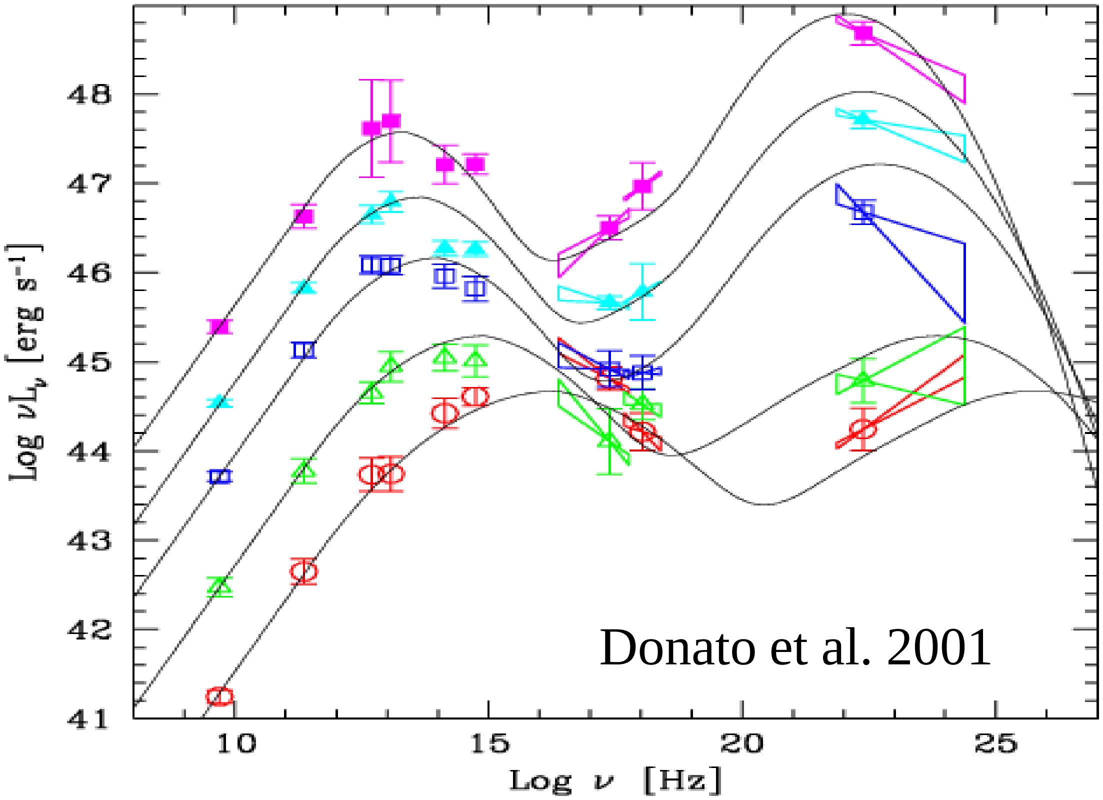
The blazar sequence

Jets emit from radio to γ rays

- Low energy: synchrotron
- High energy: inverse Compton

IC produced by the relativistic electrons that scatter:

- their own synchrotron photons (Synchrotron-self Compton)
- external photons from torus, disk, BLR... (External Compton)

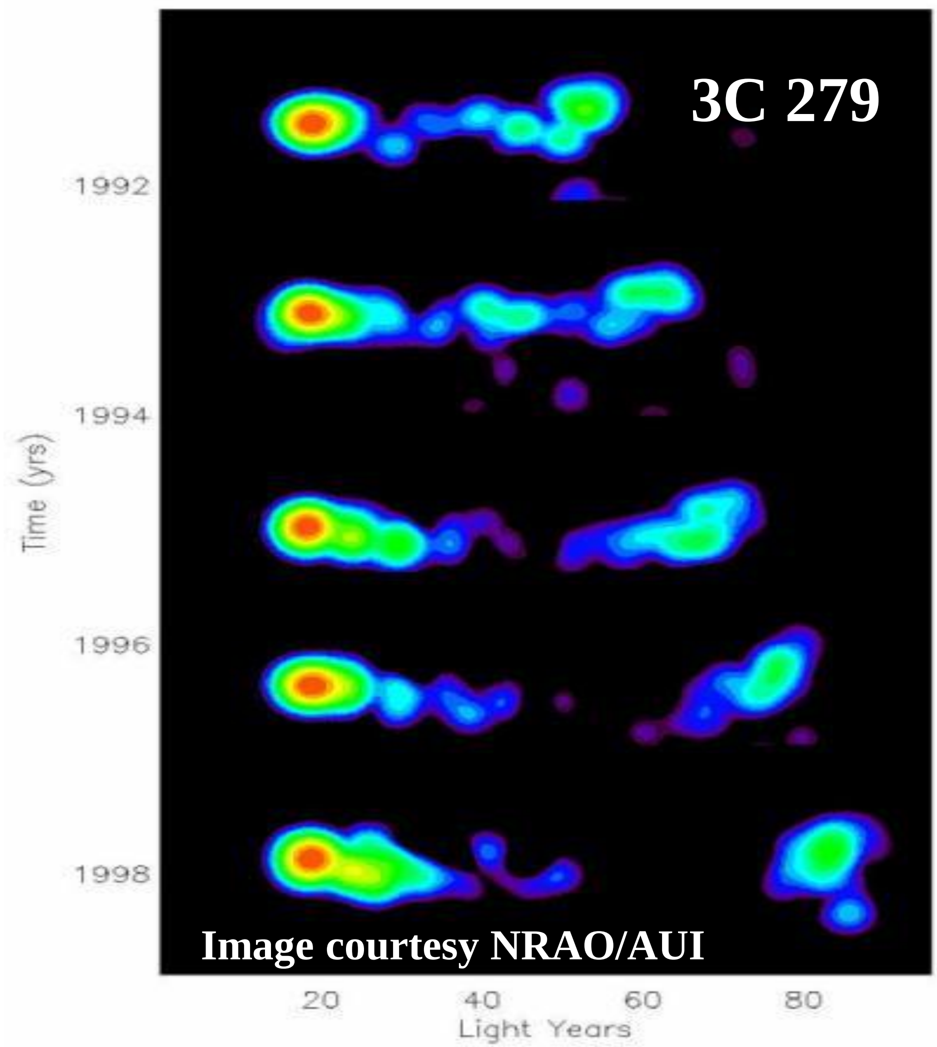


Derived from radio selected blazars by Fossati et al. (1998)

Jets on parsec scale

- Usually one-sided
- Compact components with T_B exceeding the Compton catastrophe limit (10^{12} K)
- Superluminal motion

Severe Boosting effects!

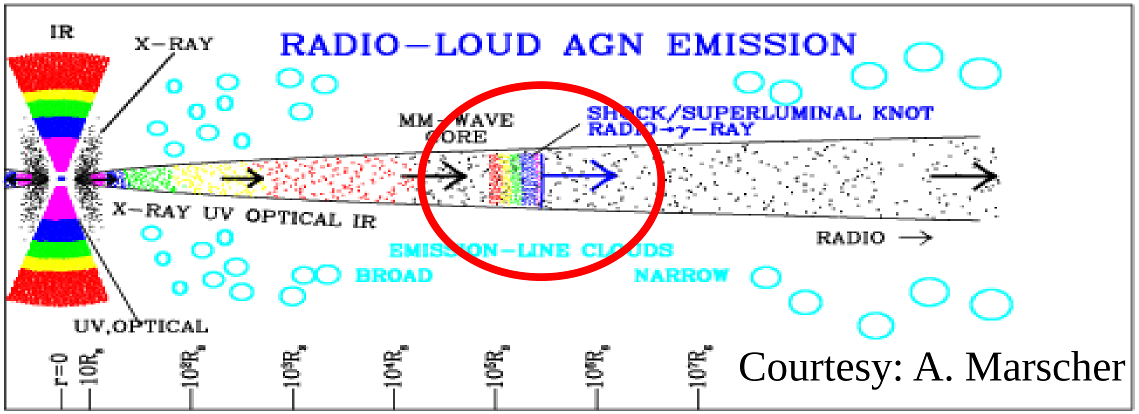


$\beta_{app} \sim 25$!!

Open questions

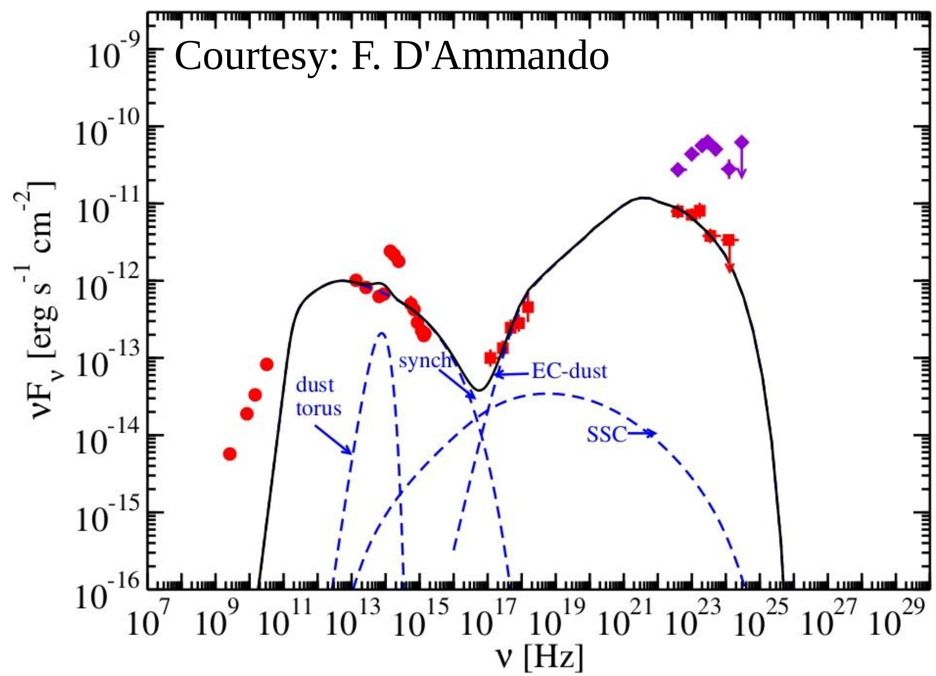
- How do jets form?
- What is the γ-ray emitting mechanism?
- Where is the region responsible for γ-ray emission?
- What is the “jet-base”?
- .....

Why mm/sub-mm observations?



- Radio band highly self-absorbed
- Discriminate the emission models at low energy

- Quasi-simultaneous mm/sub-mm and γ-ray flares due to less opacity
- Possibility to study the various stages of the shock along the jet, i.e. formation, plateau, decaying
- Determining the distribution and strength of the magnetic field



The Atacama Large Millimeter Array

https://almascience.nrao.edu
/

Located at Chajnantor, North Chile, in the Atacama desert

- From 86 to 720 GHz
 i.e. 3mm to 450 μm

- Many configurations:
 compact: 160 m
 extended: ~16 km

- Spectral resolution:
 3.8 kHz – 2 GHz per channel
 (@110 GHz 1 km/s=370kHz)

- **FULL POLARIZATION!**

- 50 12-m antennas (main ALMA array)
- 12 7-m antennas (ACA)
- 4 12-m antennas (Total Power)

The Atacama Large Millimeter Array

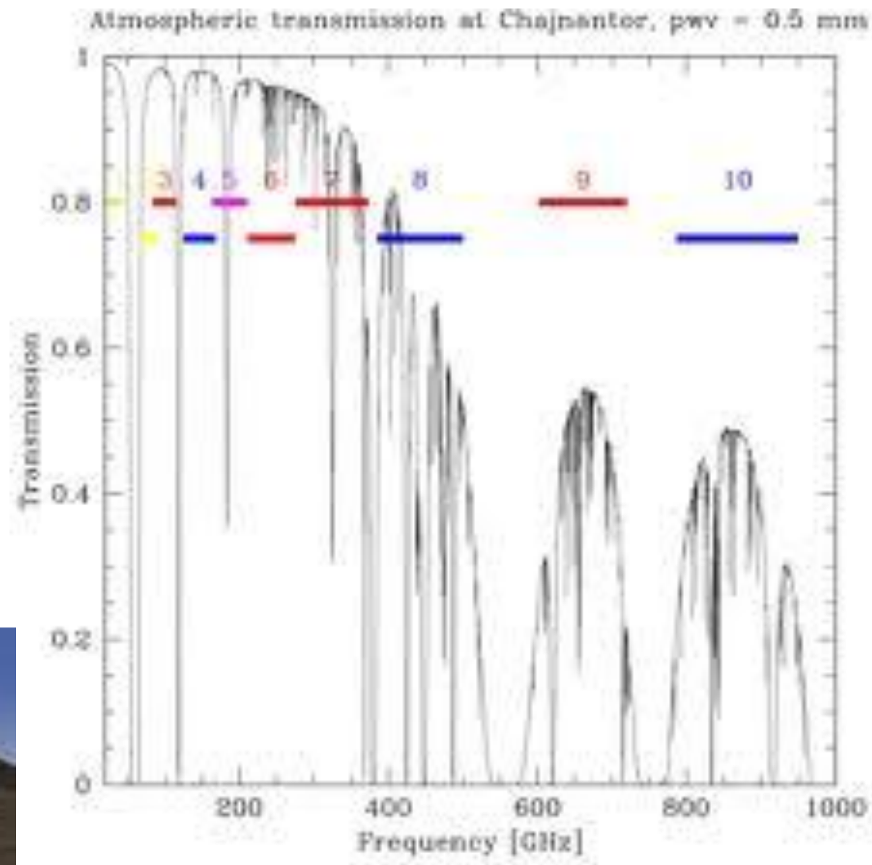
Spatial resolution:

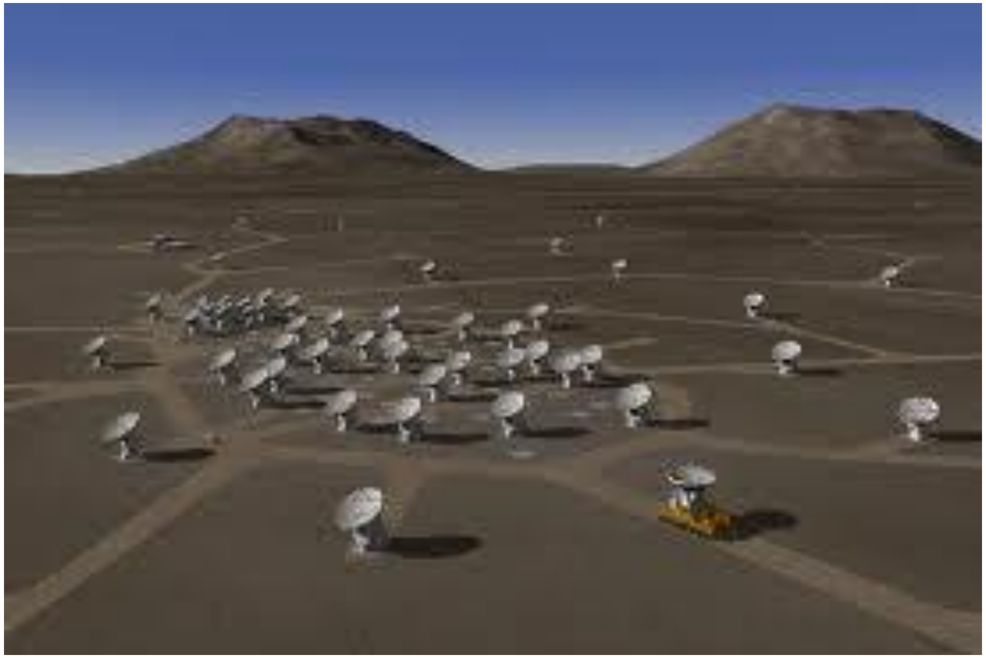
3" - 40 mas @ 110 GHz

1.3" - 20 mas @ 230 GHz

0.9" - 12 mas @ 345 GHz

0.4" - 6 mas @ 675 GHz

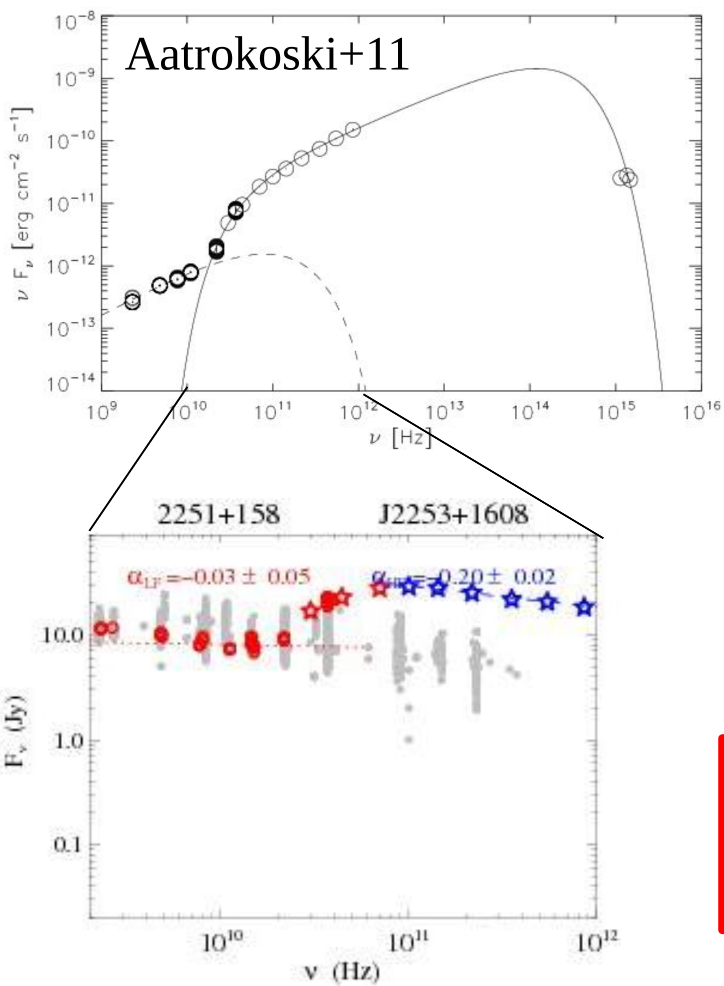


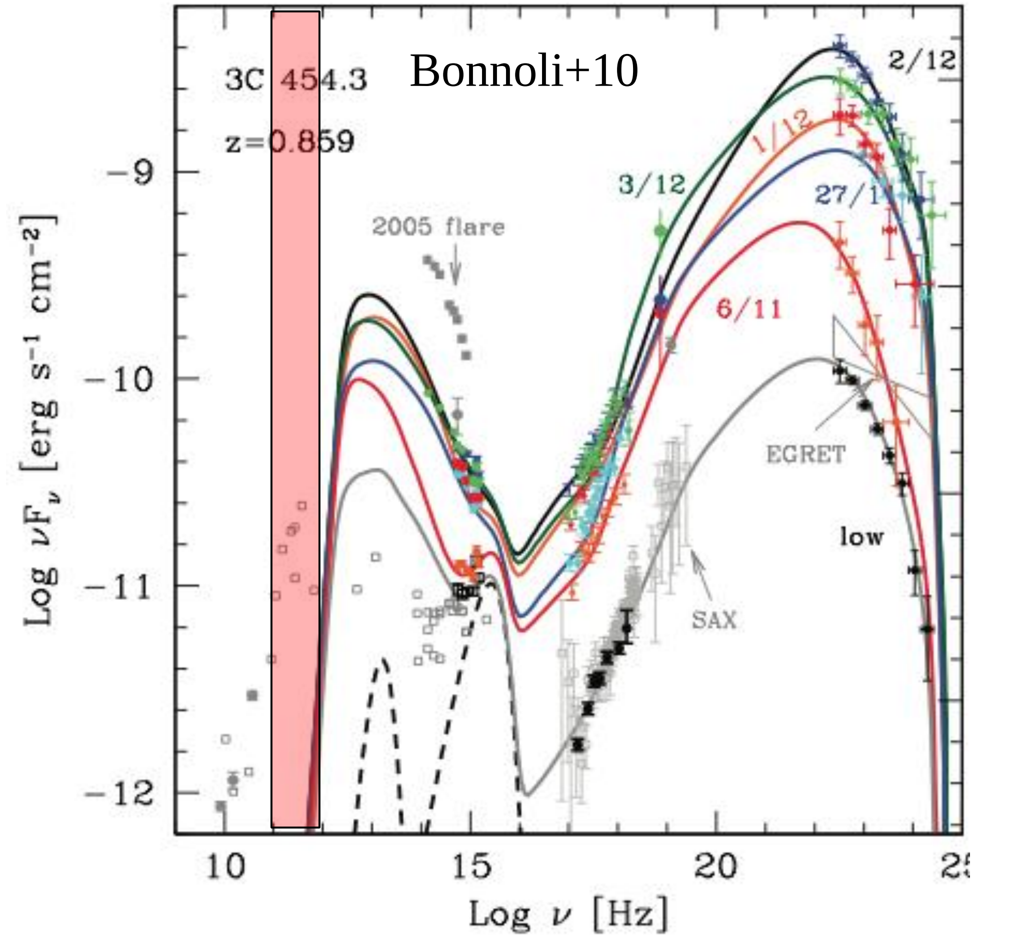


The dry conditions at the site allow observations up to 720 GHz

Different emitting models

Planck observations from 30 to 857 GHz allow to disentangle the jet emission from the "core" in 3C454.3





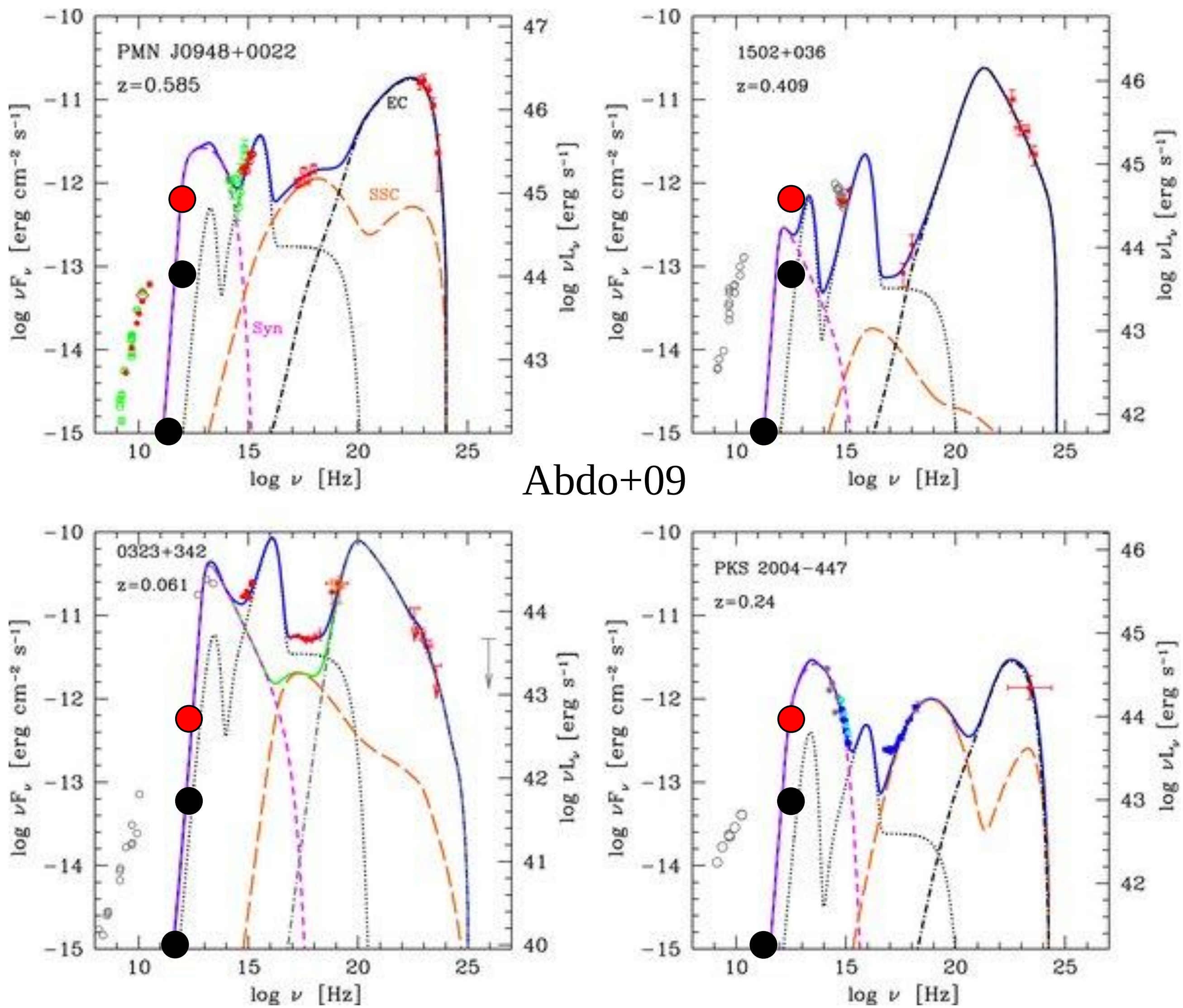
WHY ALMA?

High sensitivity observations

Planck 10σ is 0.25–1.0 Jy depending on the band. Only the brightest objects can be observed

The majority of the radio sources is much fainter!!!

ALMA rms in 1 min: **0.2, 0.3, 0.6, 5.3 mJy beam^{-1}** at 100, 230, 345, and 675 GHz



Abdo+09

Almost 2 orders of magnitude more sensitive!!!

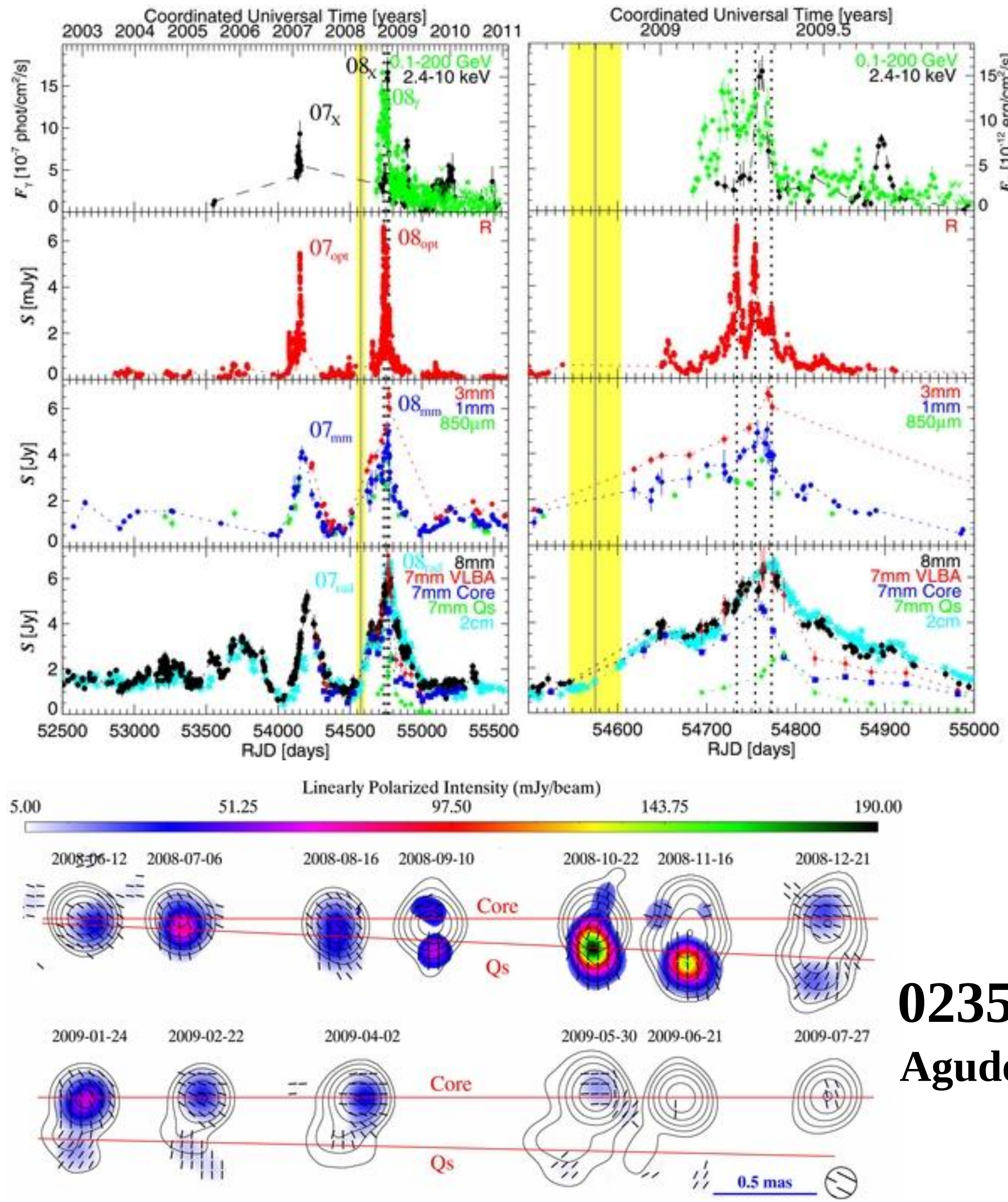
Time delay of the flare at different λ

The peak of the flare in γ rays and at mm/sub-mm is almost simultaneous

Strong γ-ray flares take place **AFTER** the rise of the mm flux density

Strong mm flares seem to be related to the ejection of a superluminal plasmoid in the jet, i.e. a shock

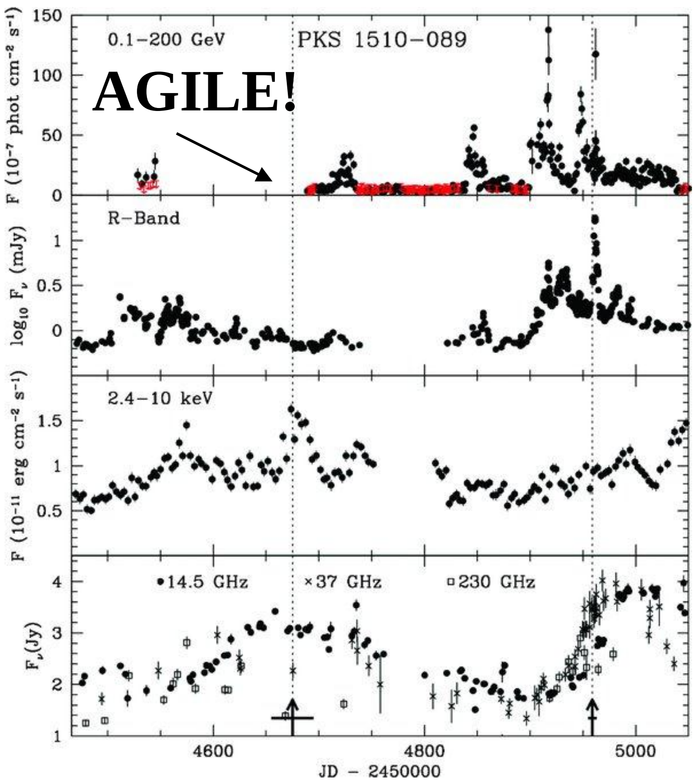
Is the γ-ray site of some flares off-nuclear?



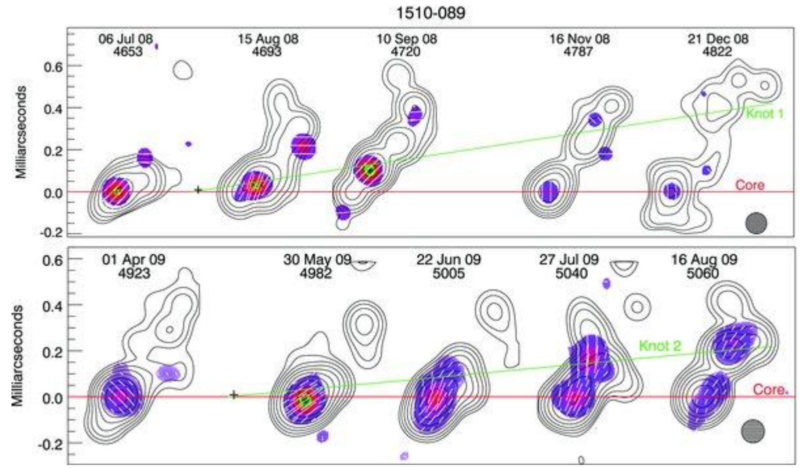
0235+164

Agudo+11

The magnetic field

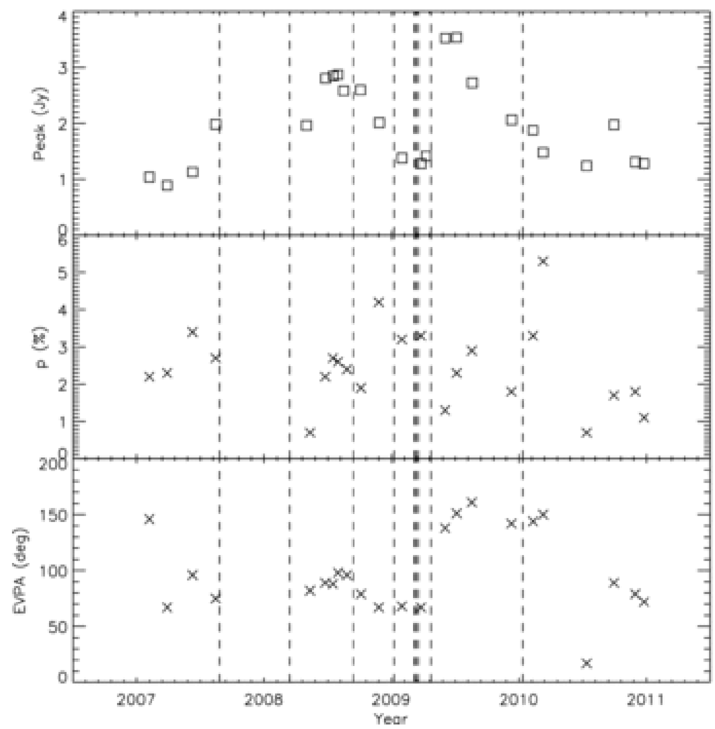


Marscher+10



PKS 1510-089

Orienti+11

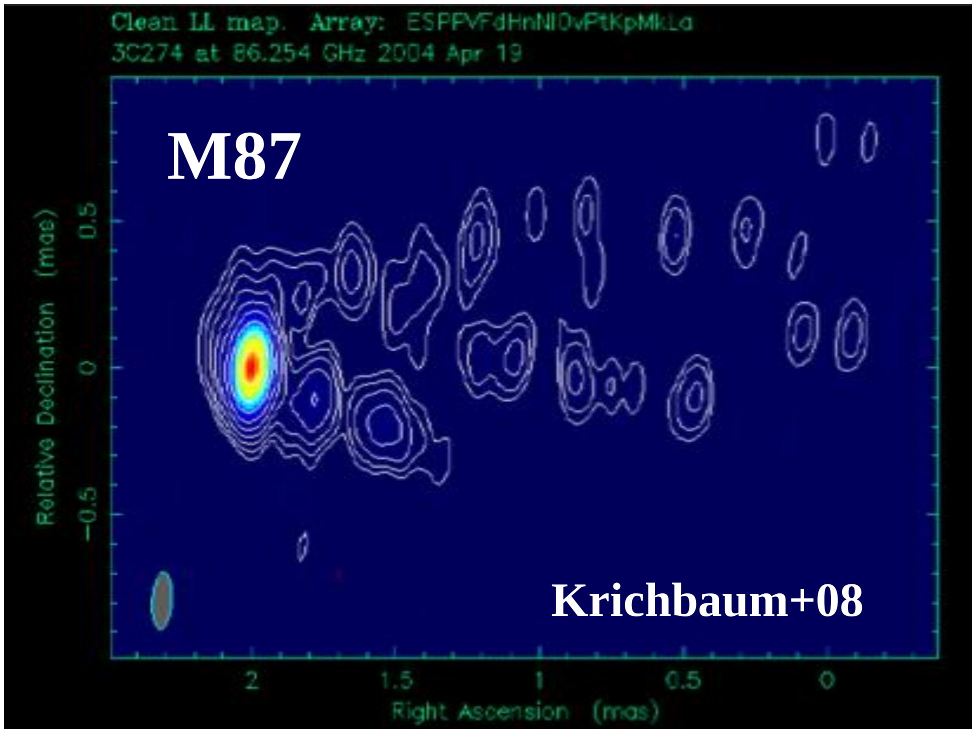


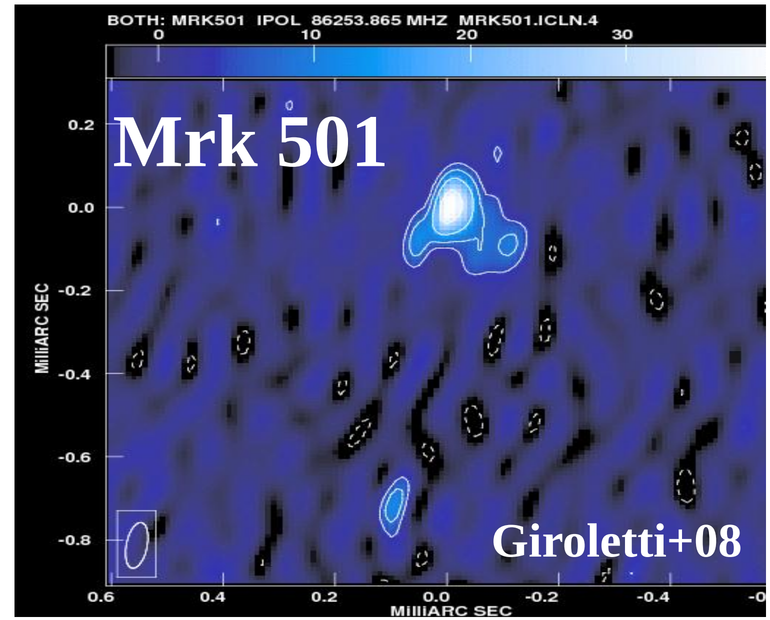
A flip of 90 degrees of the polarization angle in optical and radio after strong γ-ray flares.

Distribution of the magnetic fields

TRANSVERSE/OBLIQUE SHOCK!

Spatial resolution: mm-VLBI





Jet base: 197x54 μas = 21x6 l.d. = **69x19 R_s**
transverse width of jet at 0.5 mas: ~174 Rs
clear transverse structure, counter-jet feature?

Resolution: 110x40 μas
Size < 0.03 pc: ~ 300 RS

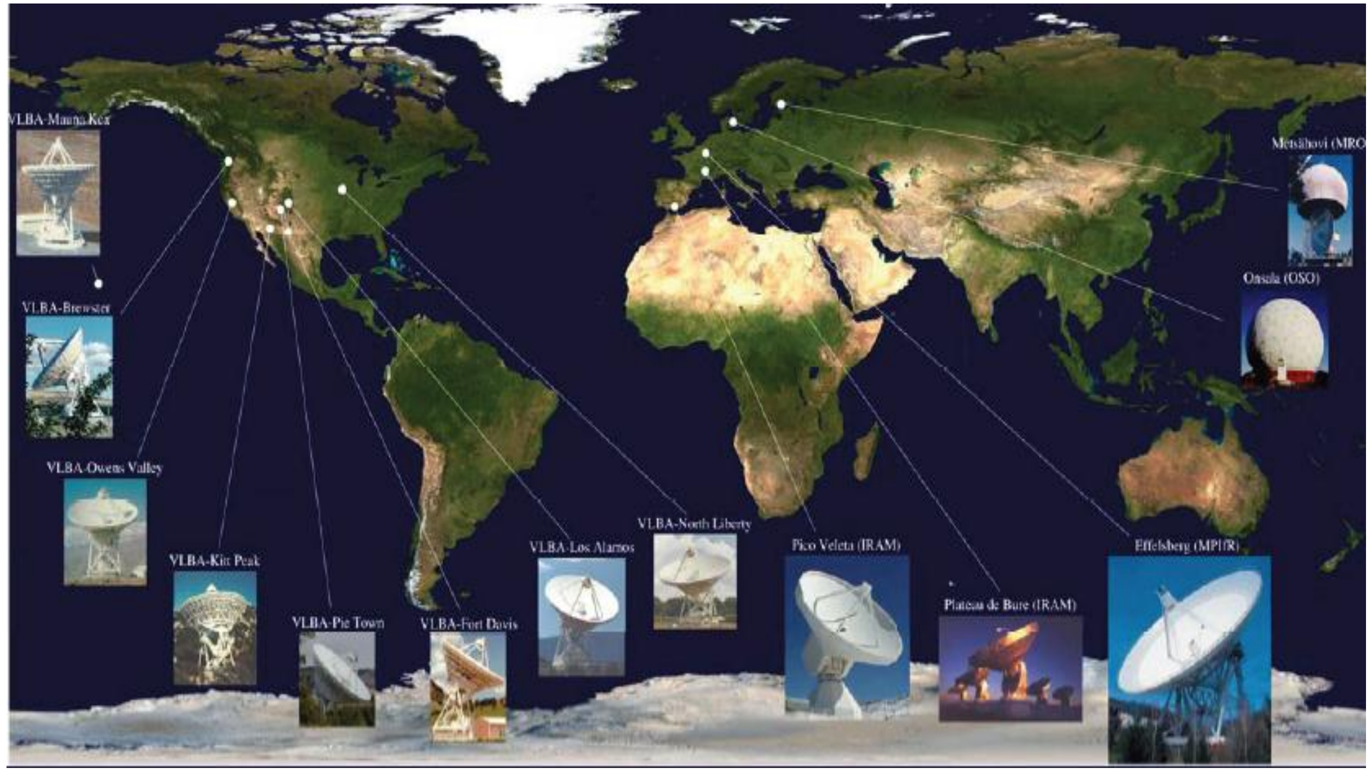
But ALMA cannot go further than 5 mas!!

Actual situation: GMVA

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

Capabilities (12hr):

3mm (86 GHz)
Resolution= 45 μas
Bas. rms=50–350 mJy
rms = 1 – 5 mJy



VLBA + Effelsberg+IRAM-30m+PdB+Metsähovi+Yebes+Onsala

A step forward
The Event Horizon Telescope

http://eventhorizontelescope.org/index.htm
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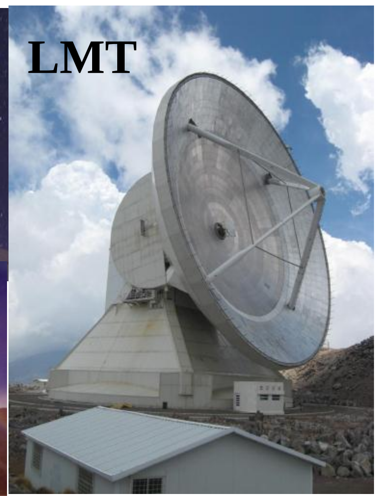
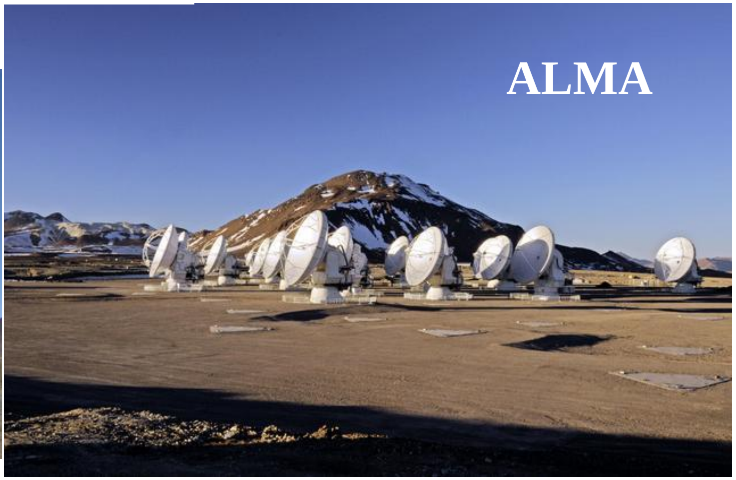




The location of the "jet-base"

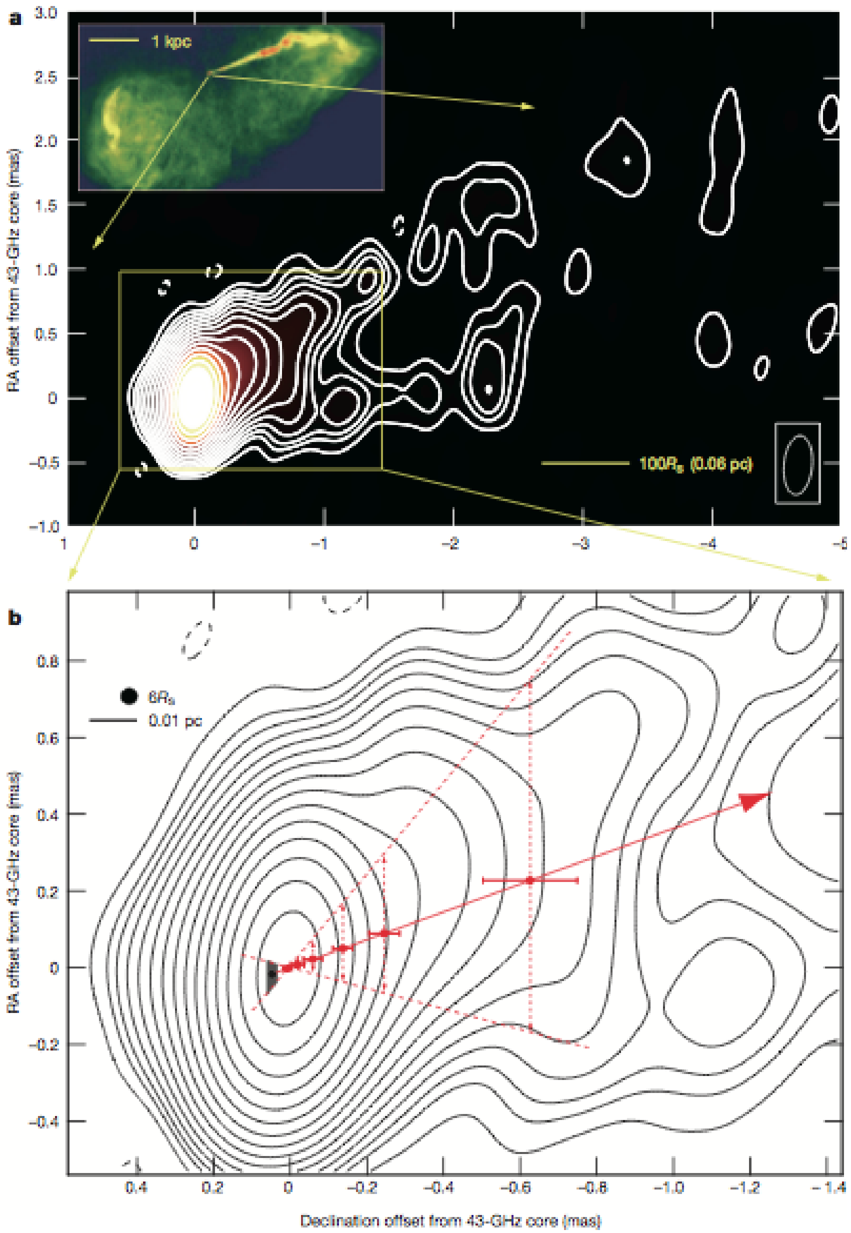
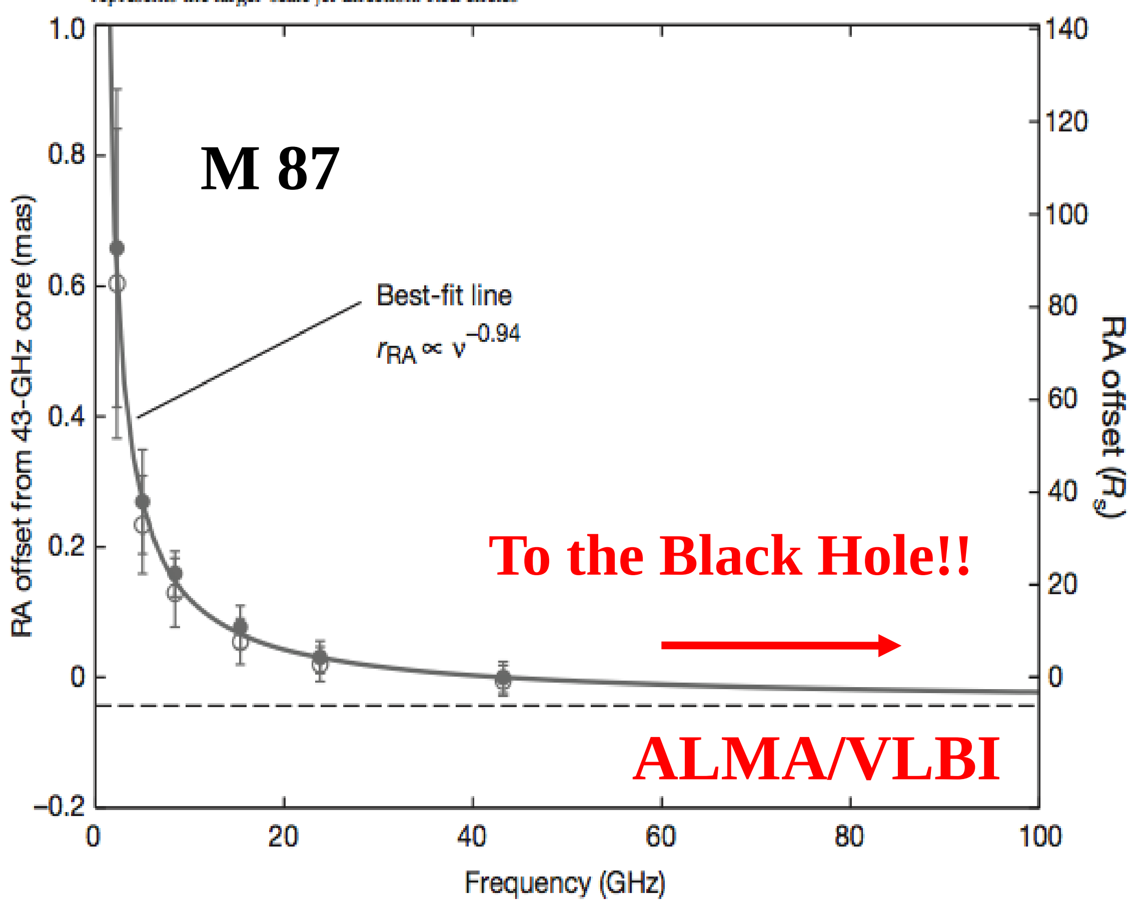


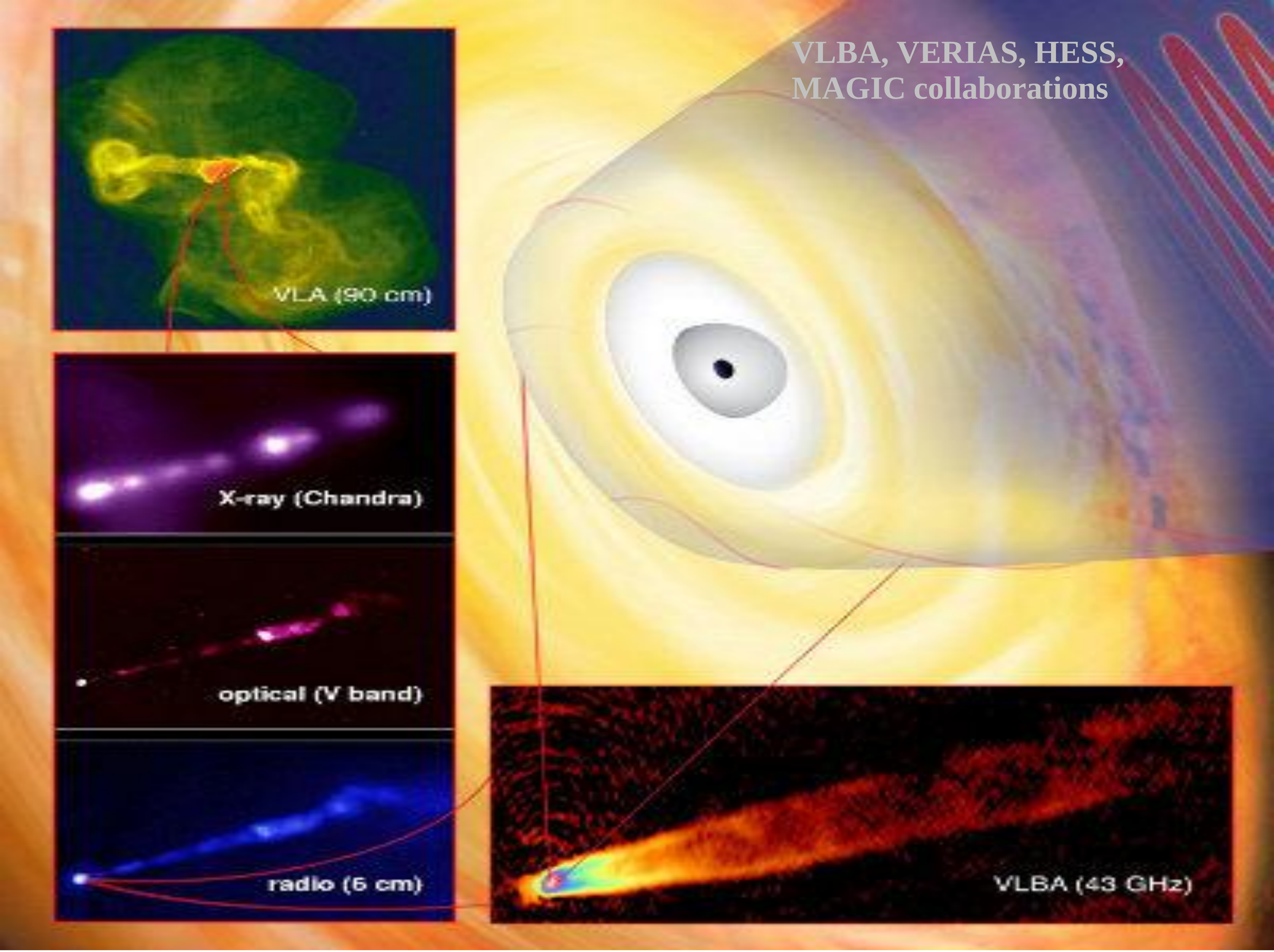
Figure 3 | VLBA image of M87 at 43 GHz superimposed on the measured core-shift positions. **a**, Global view of the radio jet on a subparsec scale. **b**, Close-up view of the region enclosed by the rectangle in **a**. The synthesized beam of the VLBA is 0.22 mas × 0.46 mas at −5° (bottom right in the 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 centred on the 43.2-GHz core. A solid red arrow represents the larger-scale jet direction. Red circles

Hada et al. 2012, Nature



Summary and outlook

- The ALMA sensitivity and operating wavelengths provide a unique opportunity to observe the region where γ rays are produced
- The availability of polarization observations will be crucial to constrain the characteristics of the magnetic fields in the very first part of the jet, and to derive their evolution as a shock passes through
- With its unprecedented resolution and sensitivity ALMA in a VLBI network (10 μas and 10 mJy/b) will shed a light on the event horizon and the region where jet forms and collimates


VLBA, VERIAS, HESS,
MAGIC collaborations
VLA (90 cm)
X-ray (Chandra)
optical (V band)
radio (6 cm)
VLBA (43 GHz)