The ALMA contribution to the study of the blazar jets

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Outline

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

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 $\gamma$ 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
Jets emit from radio to $\gamma$ 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!

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

3C 279

Image courtesy NRAO/AUI

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AGILE 9th Scientific workshop

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Open questions

- How do jets form?
- What is the $\gamma$-ray emitting mechanism?
- Where is the region responsible for $\gamma$-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

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)

https://almascience.nrao.edu
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

Almost 2 orders of magnitude more sensitive!!!
Time delay of the flare at different $\lambda$

The peak of the flare in $\gamma$ rays and at mm/sub-mm is almost simultaneous.

Strong $\gamma$-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 $\gamma$-ray site of some flares off-nuclear?
The magnetic field

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

Distribution of the magnetic fields

TRANSVERSE/OBLIQUE SHOCK!
Jet base: 197x54 μas = 21x6 l.d. = 69x19 Rs
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
The location of the “jet-base”

Hada et al. 2012, Nature

M 87

To the Black Hole!!

ALMA/VLBI
Summary and outlook

- The ALMA sensitivity and operating wavelengths provide a unique opportunity to observe the region where $\gamma$ 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 $\mu$as 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