Radio-gamma ray connection

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The gamma-ray sky with ASTROGAM
Outline

• Background

• Future radio facilities

• The radio-gamma ray connection with ASTROGAM: better science & new science
  • blazars, young radio sources, pulsars, novae, clusters, etc.
Radio waves and gamma rays: an obvious couple

- synchrotron radio emission originates from relativistic electrons that can upscatter photons to high energy

- observationally, all EGRET AGNs are radio loud, differently from most X-ray QSOs

- the blazar sequence was originally devised on the basis of the radio luminosity
EGRET, AGILE, *Fermi* census

- Fraction of **radio loud sources** (radio pulsars, RL AGNs, SNR, …) in gamma-ray catalogues:
  - 3EG (Hartman et al. 2009) \(~37\%\) (but nearly all of the associated ones)
  - 1AGL(R) (Pittori et al. 2009, Verrecchia et al. 2013) \(~77\%\)
  - 3FGL (Acero et al. 2015) \(~60\%\)(\(~90\%\) of the associations)
Future instruments

- Radio astronomy is entering a *Golden Age*
- upgrade of existing instruments, new instrumentation, “new” technology
  - wider band
  - unprecedented computational power
- new windows: *polarisation and transients*
The Square Kilometre Array

- total collecting area of 1,000,000 m²: the largest radio telescope array ever constructed to be built in radio quiet locations in South Africa and Australia

- Key Science areas:
  - Galaxy evolution, **cosmology** and dark energy
  - Strong-field tests of **gravity**
  - The origin and evolution of **cosmic magnetism**
  - Probing the **Cosmic Dawn**
  - The cradle of **life**
  - Exploration of the **unknown**
Phase 1 - low+high

- **SKA1-low** (Australia)
  - Main driver: highly redshifted 21 cm HI line from the Epoch of Reionization
  - 50-350 MHz
  - ~250000 antennas
  - 1 km radius core, 45 km maximum baseline
  - 20 deg$^2$ field of view

- **SKA1-mid** (South Africa)
  - Pulsars, nearby to mid-z HI line, high sensitivity continuum sources
  - ~250 15m dishes (Meerkat+SKA1 dishes)
  - 0.35-3 GHz; ready for additional receivers
  - ~100 km maximum baseline
SKA pathfinders & precursors

- new parameter space
- low frequency (LOFAR, MWA)
- real time with long baselines (e-EVN, e-MERLIN, MeerKAT)
- fast survey capability (APERTIF, ASKAP)
- of interest for ASTROGAM science targets such as:
  - beamed and misaligned relativistic jets, galaxy clusters, pulsars, novae, etc.
blazar critical questions

• Where are the gamma rays produced?

• What is the velocity and magnetic field structure of the jet?

• What is the electron energy distribution?

• could be addressed through a combined approach based on total intensity and polarisation sensitive surveys and single dish and VLBI monitoring
population study

- 599 1LAC clean sources
- VLA/ATCA & *Fermi* data
- correlation coefficient: $r=0.47$
- chance probability $< 10^{-7}$

Ackermann et al. (2011)
population correlation in bands

- correlation dependence on energy band
- FSRQs & LSP blazars have strongest correlation using 100-300 MeV gamma rays
- only ASTROGAM can extend this to lower energies, important for luminous and high-z sources

Ackermann et al. (2011)
single dish monitoring projects

- single dish: more resources available, denser time+frequency sampling (e.g., F-GAMMA, GASP, OVRO); most practical for strongly beamed sources (little contamination from extended emission)

- Fuhrmann et al. (2014)
  
  - highly significant average radio lagging $\gamma$-rays correlation, with $\Delta t \sim v^{-1}$ (SSA)
  
  - bulk $\gamma$-ray production region within/upstream of the 3mm core region
  
  - mean distances between the region of $\gamma$-ray peak emission and the radio “core” $0.9 \pm 1.1$ pc (2 mm)
  
  - 3 mm/$\gamma$-ray correlations in 9 individual sources (vs 1 by chance)
VLBI monitoring projects

- **MOJAVE**: VLBA @15 GHz, 100’s sources; **BU**: VLBA @43 GHz, 10’s sources (sub-mas angular resolution); **GENJI**: VERA @22 GHz

- constrain epoch of component ejection and compare to gamma ray flares

- determine (range of) velocity in jet motions and infer kinematic, geometric parameters

- polarimetry: B, $n_e$
Data from a long dense monitoring with the eEVN reveal ejection of superluminal components within the jet knot. HST-1 is temporally associated to 2008, 2011 VHE events.

Giroletti et al. 2012

\( v = (4.1 \pm 0.1)c \)

\( \delta = 1.5 - 4.0 \)

3C120, Agudo et al. 2012

Recollimation shock? Polarization?
misaligned gamma-ray AGN: a limited population

• ~20 in 3LAC

• viewing angle is larger ($\theta > \sim 20^\circ$)

• gamma-ray spectra are generally very soft ($\Gamma \sim 2.5$)

• could become a substantial population with ASTROGAM

• jet velocity structure? one zone SSC vs spine-sheath, hadrons, ...
from rare to missing populations: young radio sources

- mini radio galaxies (pc vs kpc scale)
- generally on the plane of the sky
- evidence of young vs frustration from kinematic and spectral age studies
- inverse-Compton up-scattering of various surrounding photon fields by the lobes’ electrons
- yet, no γ rays so far! (but see McConville et al. 2011)
“missing”: galaxy clusters

- origin of ~100’s Mpc scale radio halos reacceleration or secondary electrons
  - LOFAR, SKA will clarify the radio properties and detect many more radio halos
- Fermi has so far provided limits, ASTRAGAM could reveal clusters
  - important for understanding of galaxy cluster physics, dark matter searches, etc.
novae

- Fermi has revealed the first symbiotic nova and a class of classical novae
- ASTROGAM will be important for the study of novae, e.g. discrimination between leptonic and hadronic models (Hernanz talk)
- Radio observations can constrain several parameters on the physical condition (e.g. density, mass, temperature of the ejecta and the medium), with light curve and spatially resolved proper motion

\[ v \approx 1500 \text{ km s}^{-1} \]
Take home notes

• Radio astronomy is entering a *Golden Age*

• *polarization and transients*

• ASTROGAM can be an ideal partner in this era

• synergy on novae, pulsars, (young) radio galaxies, blazars, clusters