The connection between radio and gamma-rays in AGN: towards the SKA era

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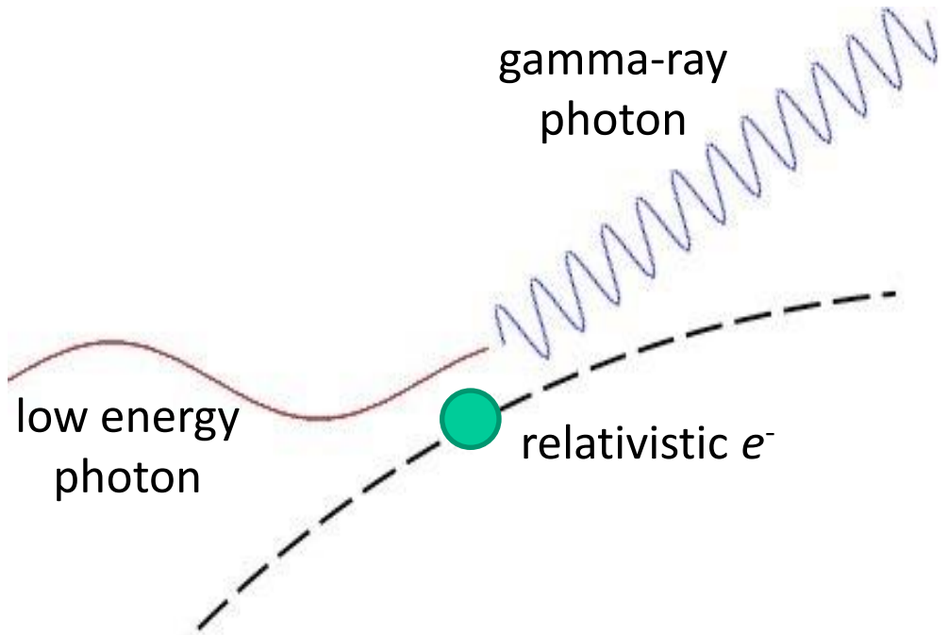
..and Marcello Giroletti, Monica Orienti, Gabriele Giovannini

Radio waves and gamma rays: an obvious couple

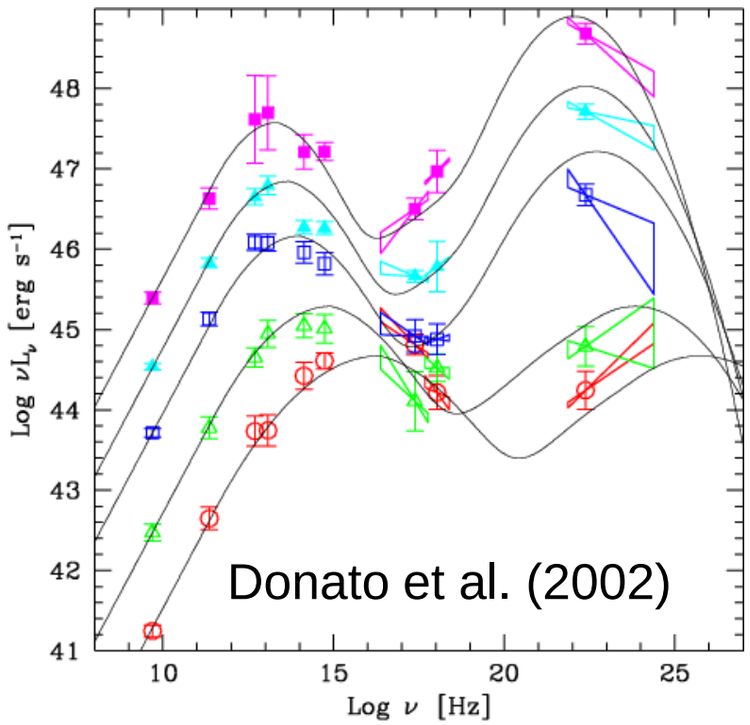
- synchrotron radio emission originates from relativistic electrons that can up-scatter photons to high energy:

  - leptonic models predict some connection between radio and gamma-ray emission



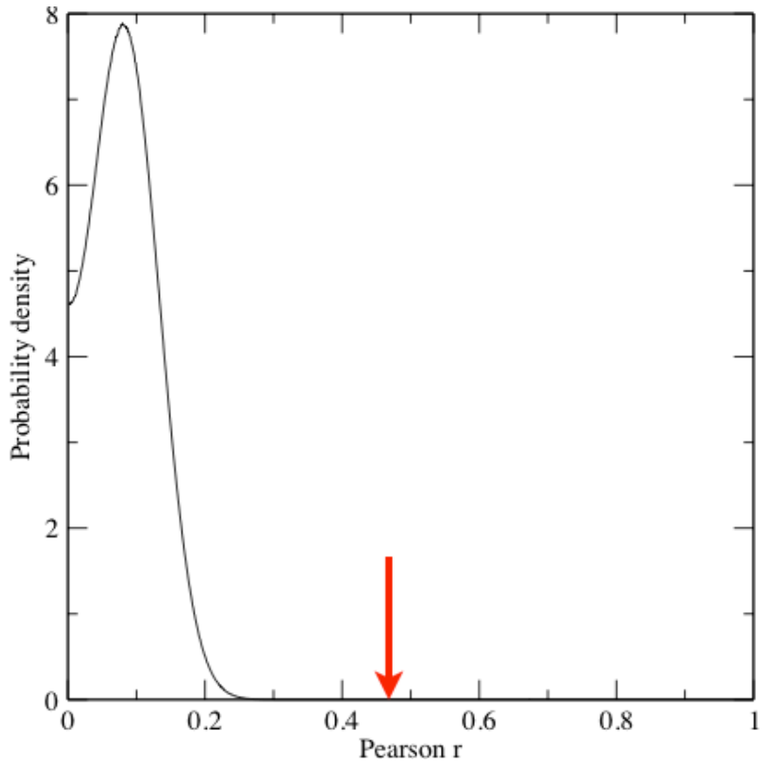
- the blazar sequence was originally devised on the basis of the radio luminosity

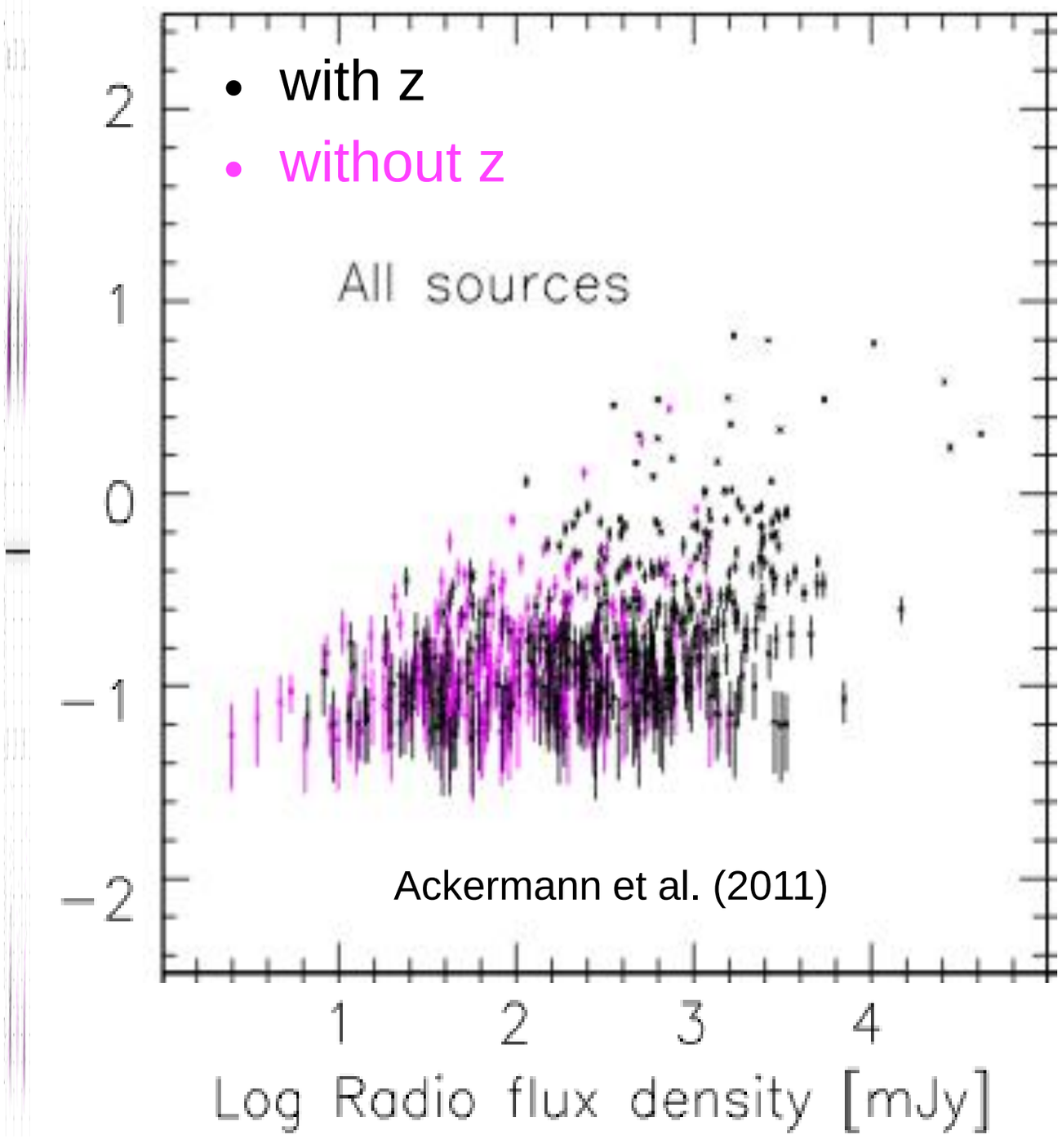
- evidence or not of flux-flux, Lum-Lum correlations is a debated issue (e.g. Padovani et al. 1993, Stecker et al. 1993, Mücke et al. 1997, Ghirlanda et al. 2010) due to bias, variability, number of sources, etc.



The radio-gamma connection

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





The radio-gamma connection

- Not all LAT energy bands correlate with radio with the same strength

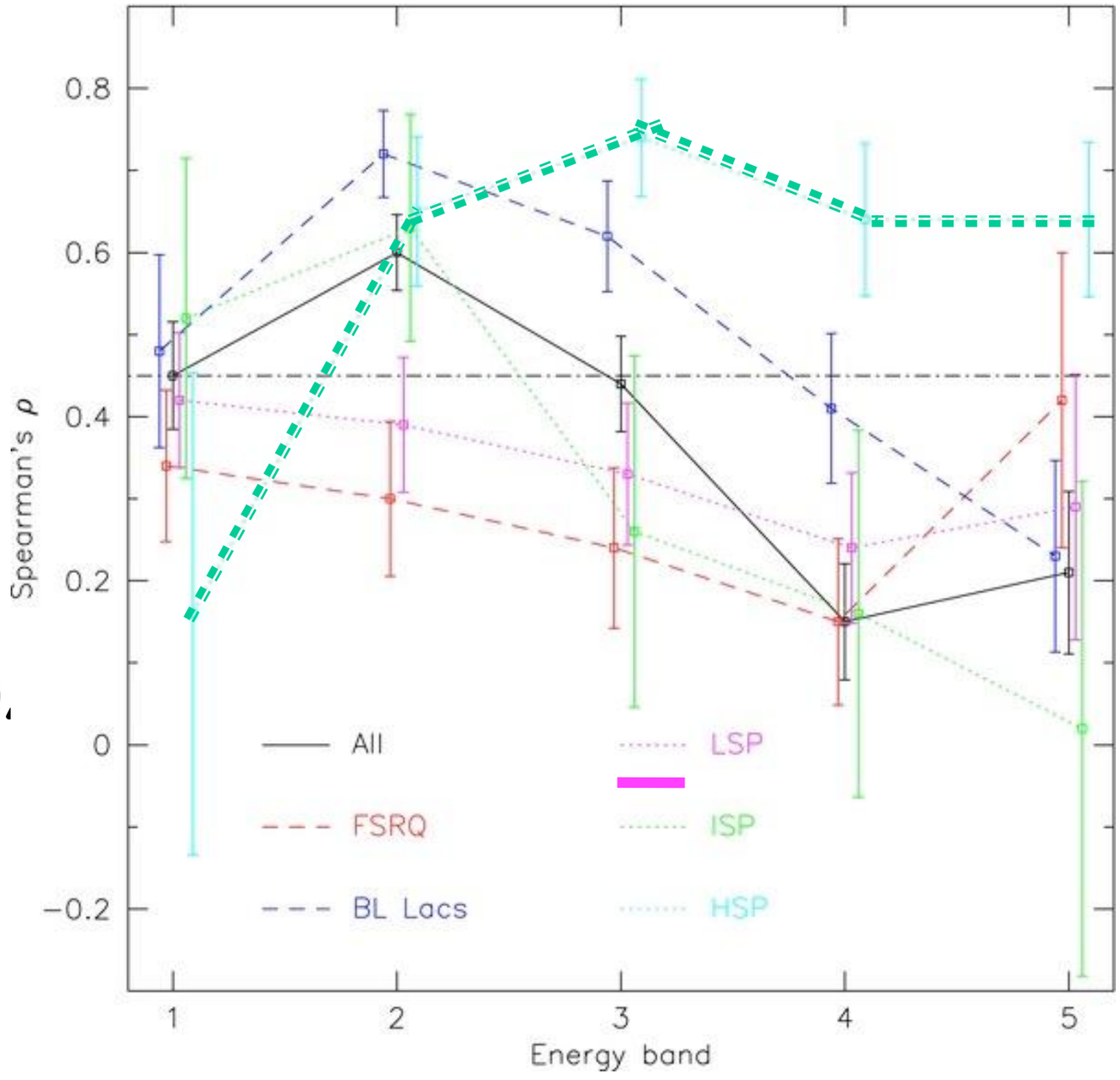
  - for the whole 1LAC, the strongest correlation is found using Band 2 (0.3-1 GeV)

- HSP blazars are the subclass with the largest correlation coefficient in every band

  - expect for Band 1 (0.1-0.3 GeV), where there are very few of them

- *Gamma-ray data correlate better with concurrent radio data rather than with archival data*

Ackermann et al. (2011)



Single-dish monitoring projects

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

Fuhrmann et al. (2014) analyzed 11cm to 0.8 cm (2.64 to 345 GHz) radio light curve and 3.5 years of *Fermi*-LAT data of 54 blazars:

- highly significant average radio lagging γ-rays correlation, with $\Delta t \sim \nu^{-1}$ (SSA)
- bulk γ-ray production region within/upstream of the 3mm (86 GHz) core region ($\Delta t = 12 \pm 8$) days
- mean distances between the region of γ-ray peak emission and the radio "core" is (0.9 ± 1.1) pc (142 GHz)

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 motion and infer kinematic, geometric parameters

- polarimetry: B, n_e

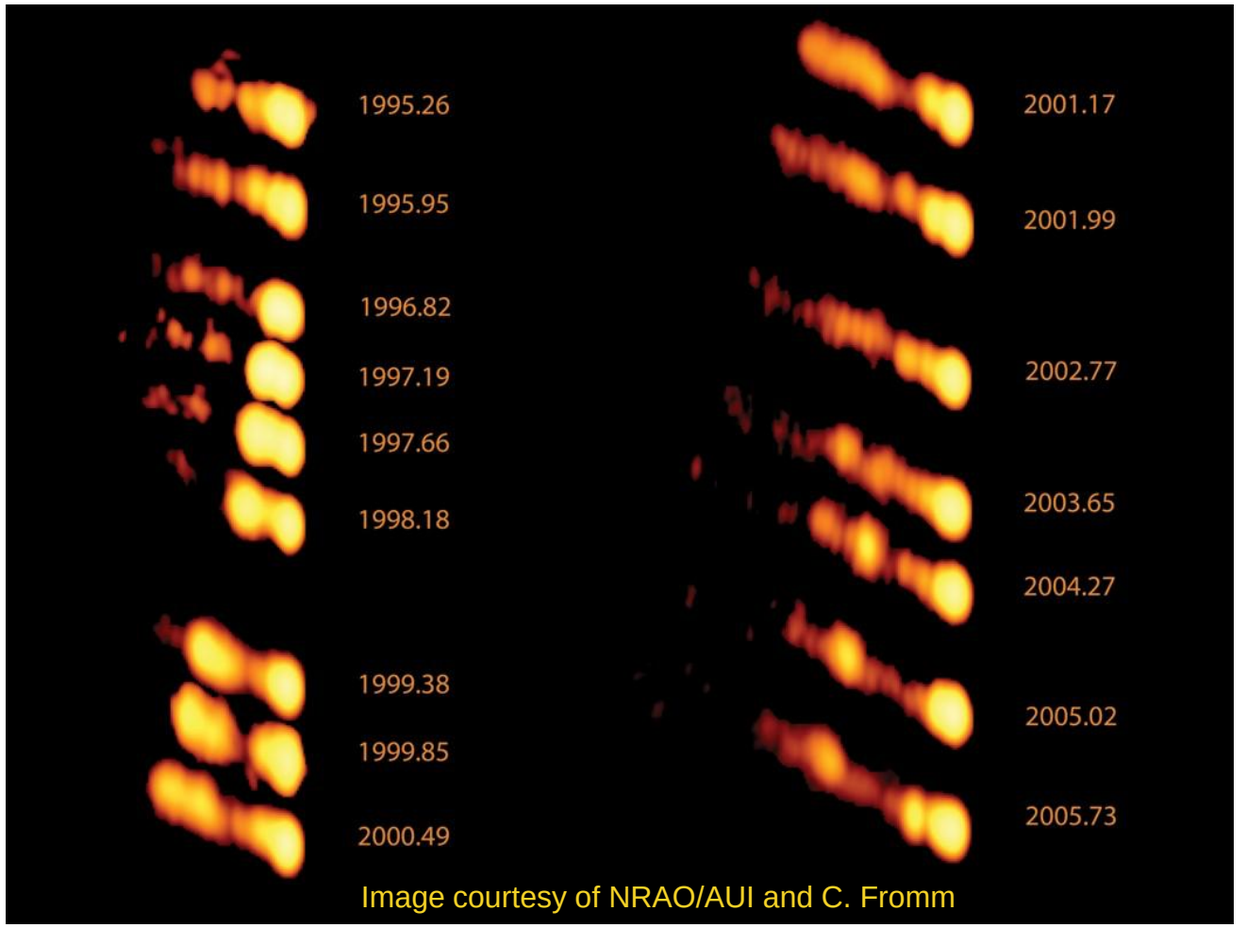
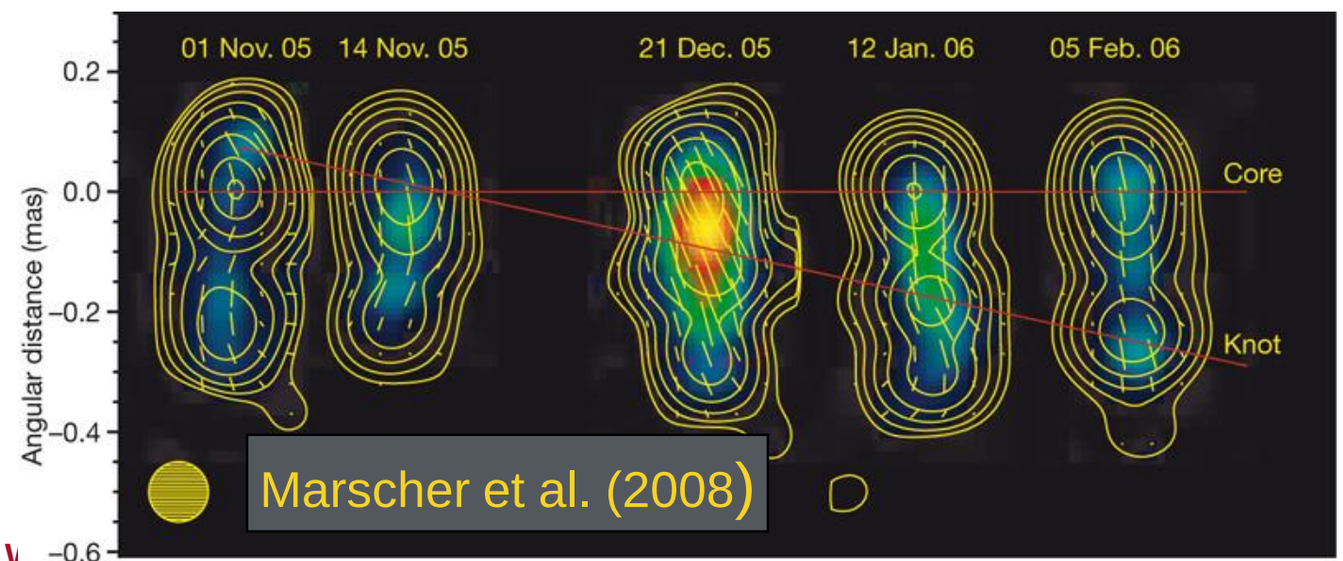
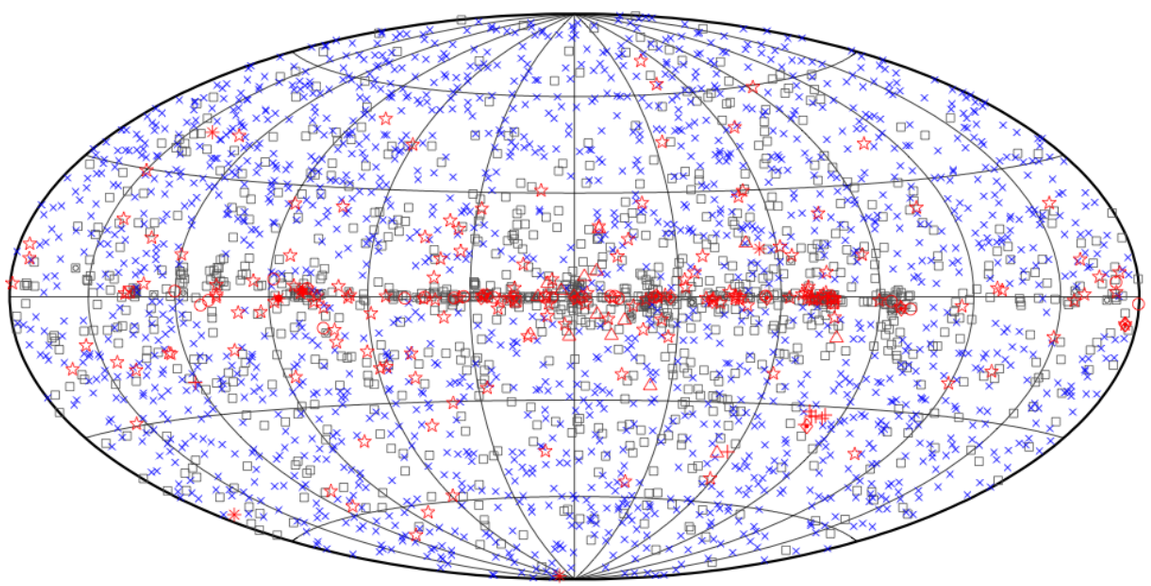
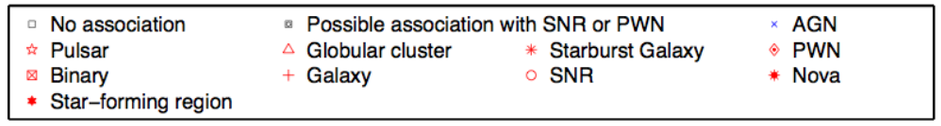


Image courtesy of NRAO/AUI and C. Fromm



Unassociated gamma-ray sources





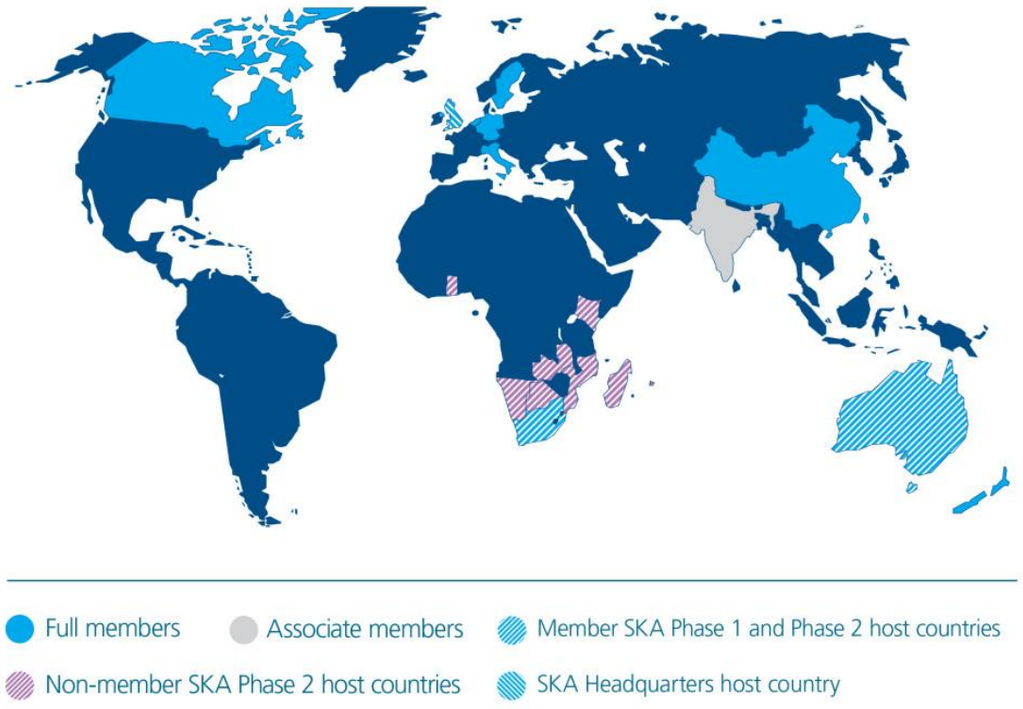
- Overall, about 30% of the Fermi sources lack a high-confidence low-frequency counterpart. Are they blazars in disguise?

- The fraction of unassociated sources becomes larger for faint gamma-ray sources (larger error ellipse), associated with low flux density radio sources, whose space density is larger

- Large and deep high-frequency surveys are the best valuable resource to solve this issue (e.g. Australia Telescope 20 GHz survey, Murphy et al. 2010).

SKA: the Square Kilometer Array

- total collecting area of 1,000,000 m^2: the largest radio telescope array ever constructed
- conceived in the 1990's, will become operational in 2020+
- members from 10+1 countries representing >40% of world population
- HQ in UK, instrument split between South Africa and Australia
- Italy is one of the founding members of the SKA organization

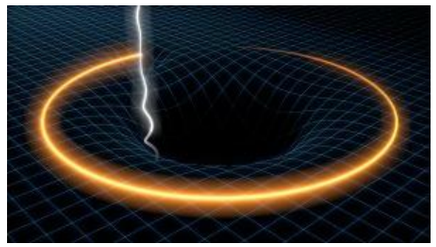


SKA Key Science Projects

- Galaxy evolution, cosmology and dark energy

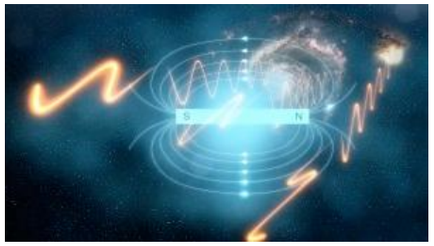
How do galaxies evolve? What is dark energy?

- Strong-field tests of gravity



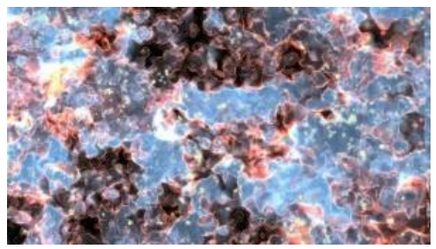
Was Einstein right about gravity?

- The origin and evolution of cosmic magnetism



What generates giant magnetic fields in space?

- Probing the Cosmic Dawn



How were the first black holes and stars formed?

- The cradle of life

Are we alone?

- Exploration of the unknown

SKA Design

- 2 phases
  - SKA1: construction 2018-2023
  - SKA2: detailed design >2018

- SKA1: dual site, dual scope (frequency & design)
  - SKA1-low (Australia)
  - SKA1-mid (South Africa)

SKA1-low

- Australia
- Main driver: highly redshifted 21 cm HI line from the Epoch of Reionization and earlier
  - pulsars, magnetized plasma, extrasolar planets
- ~250000 antennas
- 50-350 MHz
- 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)
  - 0.35-14 GHz; ready for additional receivers
  - ~100 km maximum baseline, but it can be included in the VLBI network

SKA2 – early view

- Increase total collecting area
  - 1,000,000 m^2

- Improve angular resolution (longer baselines) at lower frequencies
  - ~1 mas

- Extend frequency coverage (additional receivers)
  - 20 GHz

SKA pathfinder and precursors

- new parameter space
  - low frequency window (LOFAR, MWA)
  - real time with long baselines (e-EVN, e-MERLIN, MeerKAT)
  - fast survey capability (APERTIF, ASKAP)

- of interest for AGILE, *Fermi*, eASTROGAM, CTA science targets such as:
  - beamed and misaligned relativistic jets, galaxy clusters, pulsars, novae, etc.

SKA science

AGN keywords: *sensitivity, polarization, variability*

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 polarization sensitive surveys and single dish and VLBI monitoring***

Towards SKA science: M87

Istituto di Radioastronomia

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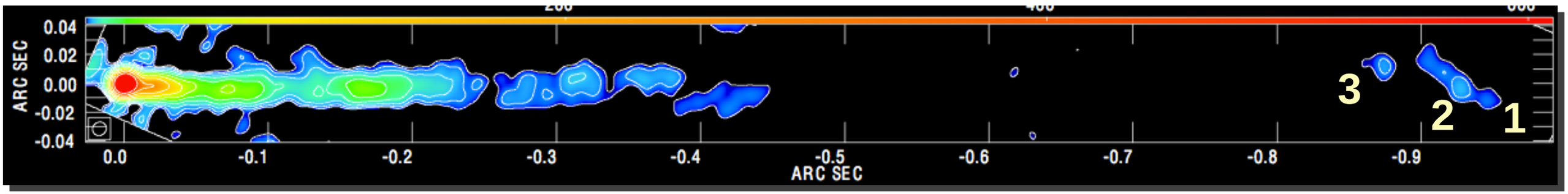
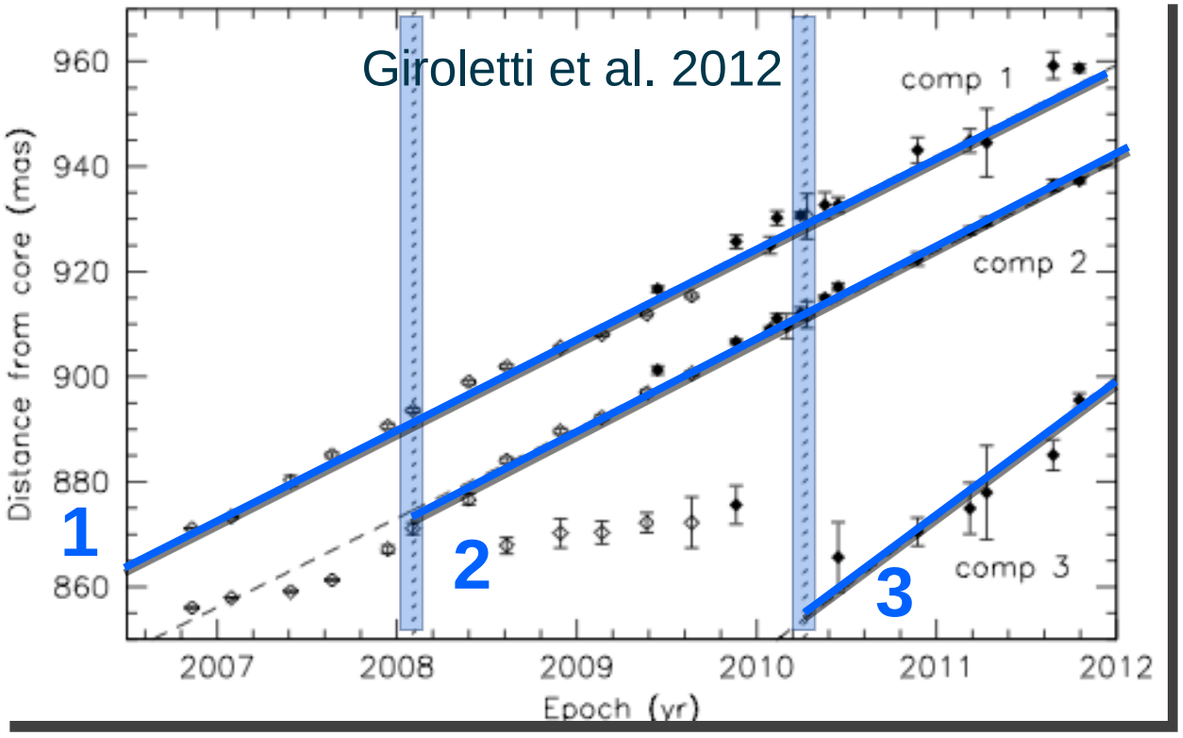
Data from a long & dense monitoring with the e-EVN reveal ejection of superluminal components within the jet knot HST-1 is temporally associated to 2008, 2011 VHE events.





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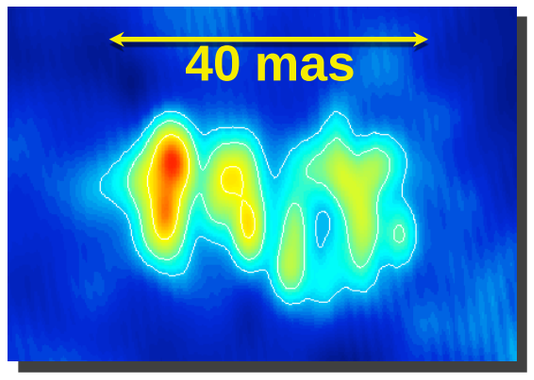
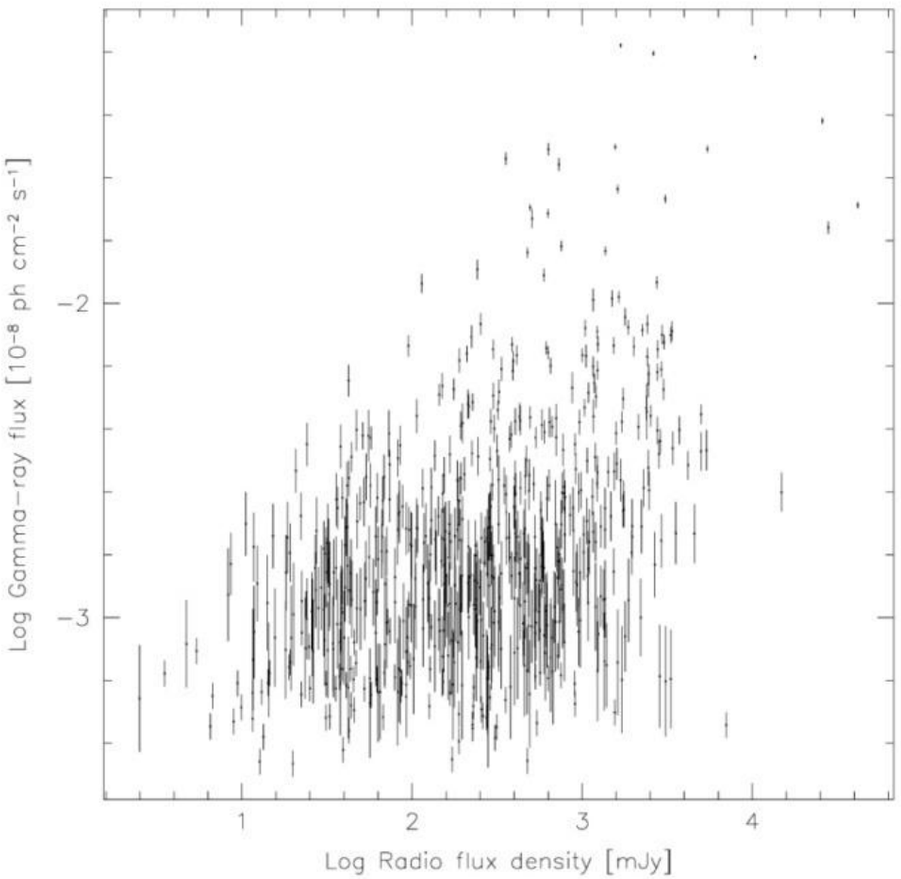
δ=1.5-4.0



High resolution, time resolved, sensitive, polarimetric observations of several individual sources will become possible with SKA

Radio-gamma connection in the SKA era

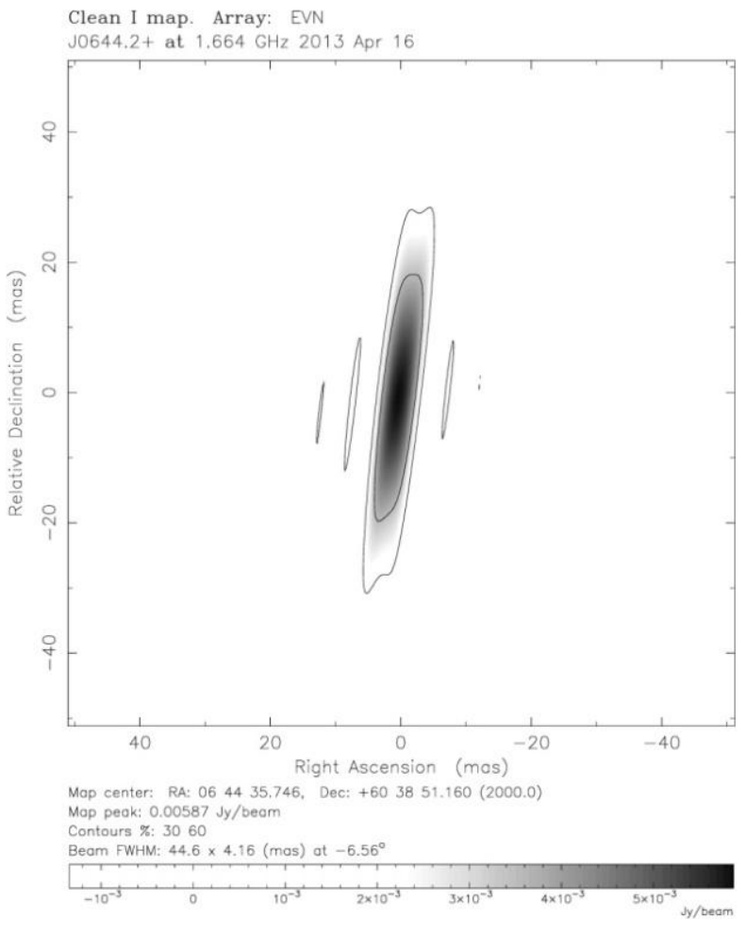


Giroletti, Orienti, D'Ammando, et al. 2015

- Simultaneous radio (SKA1-MID) and γ-ray (*Fermi* and CTA) observations will reveal how much on the scatter in the radio-gamma correlation is due to non-simultaneity, providing insights on the size and the relative distance between radio and gamma-ray emitting regions

- Not only the radio flux but also the spectral index and the polarization percentage can be compared to the gamma-ray properties, tracing the compactness, core dominance, and magnetic field configuration of the gamma-ray emitting region

Unassociated γ-ray sources in the SKA era



Giroletti, Orienti, D'Ammando, et al. 2015

- SKA1 characteristics (wide field, polarimetry, band width, timing) will be essential for a characterization of the unassociated gamma-ray sources

- A first step will be the build up of a complete and deep blazar catalog by means of sky survey (e.g. EMU with ASKAP and VLASS with VLA)

- Dedicated multi-frequency, multi-epoch SKA1-MID observations will provide a better characterization of their spectral, variability, structural, and polarization properties

Summary

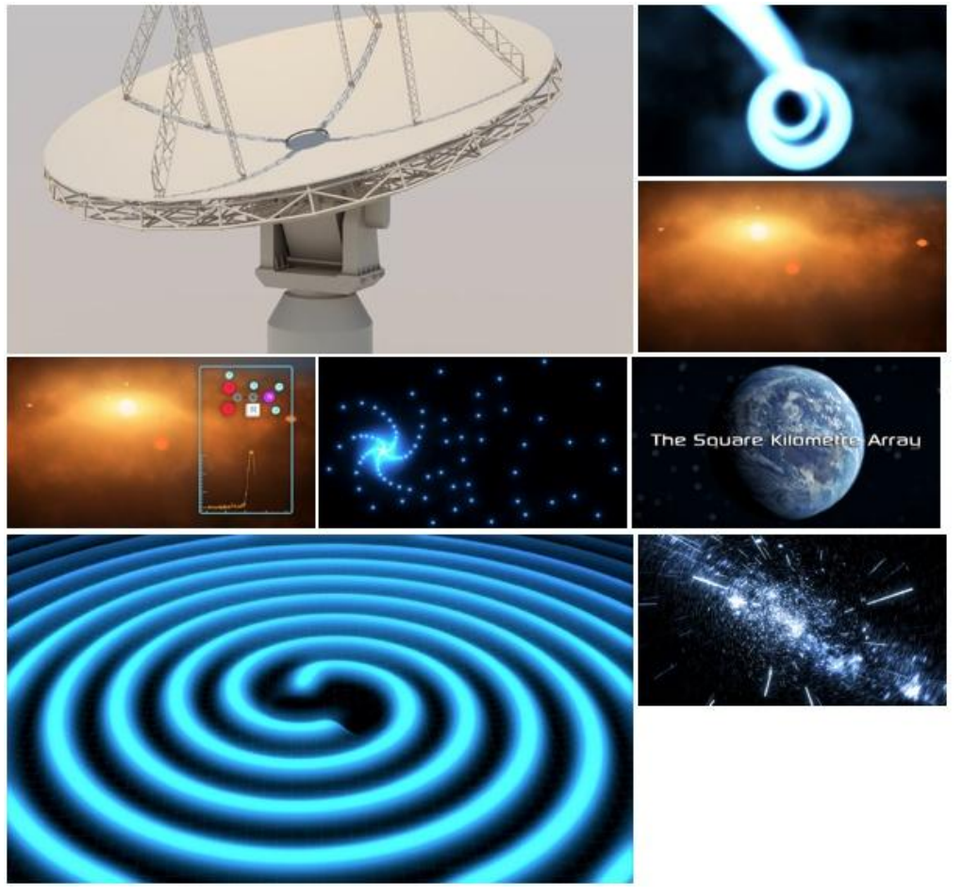
Radio Astronomy is entering a *Golden Age*

- Huge breakthrough for data, technology, and science

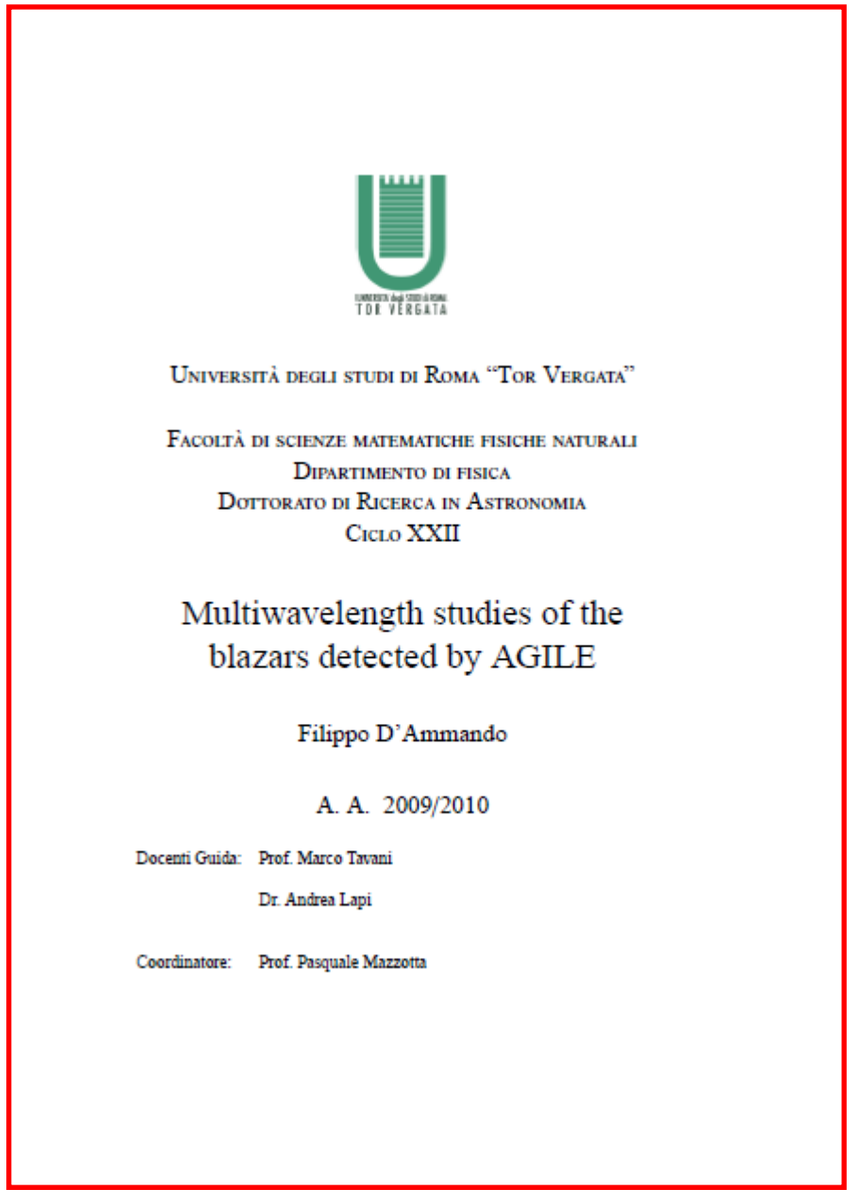
- Upgrade of existing instruments, new instrumentation, "new" technology (wider band, unprecedented computational power)

- New windows: *polarization* and *transients*

- and wait for SKA2!



Synergy with current (AGILE and Fermi) and future (CTA and e-ASTROGAM) gamma-ray satellies and facilities will be fundamental on several topics including AGN physics



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DOTTORATO DI RICERCA IN ASTRONOMIA
CICLO XXII

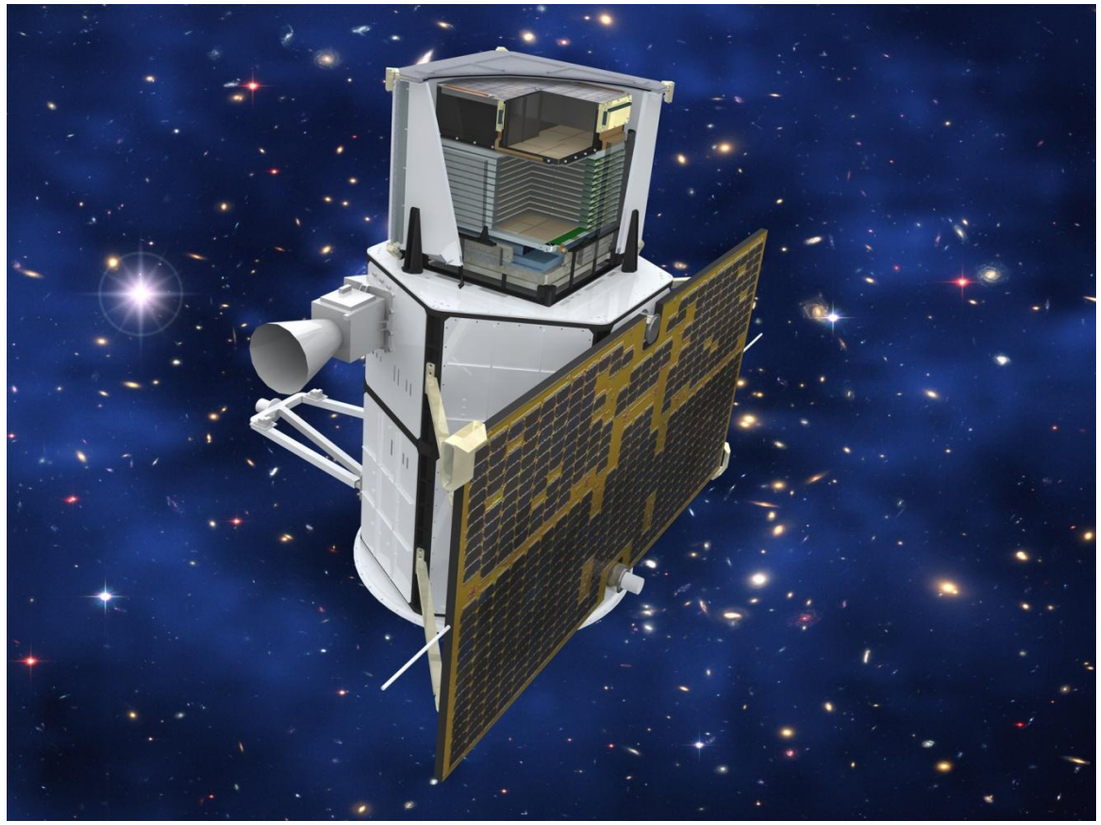
Multiwavelength studies of the blazars detected by AGILE

Filippo D'Ammando

A. A. 2009/2010

Docenti Guida: Prof. Marco Tavani
Dr. Andrea Lapi

Coordinatore: Prof. Pasquale Mazzotta



Happy Birthday AGILE!