



Max-Planck-Institut  
für Radioastronomie

IMPRS  
astronomy &  
astrophysics  
Bonn and Cologne



Roberto Angioni – 2016 Fermi Summer School

# VLBI and $\gamma$ -ray studies of TANAMI radio galaxies

*Advisors:*

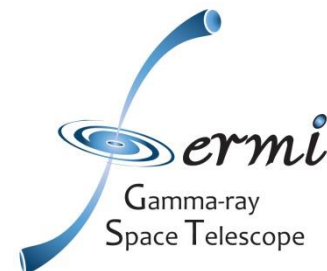
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*Supervisors:*

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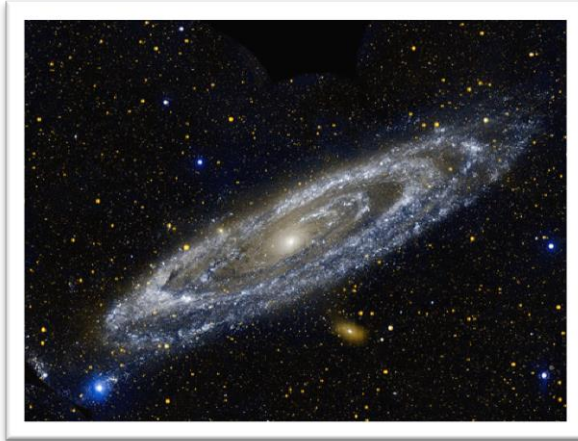
*Collaborators:*

Dr. C. Müller (Radboud U. Nijmegen), Ms. F. Krauß (Remeis obs. Bamberg/U. Erlangen),  
Dr. R. Ojha (NASA Goddard)



# Background: Active Galactic Nuclei

Normal galaxy



Accretion on  
central SMBH



+ Magnetic field?  
SMBH spin?

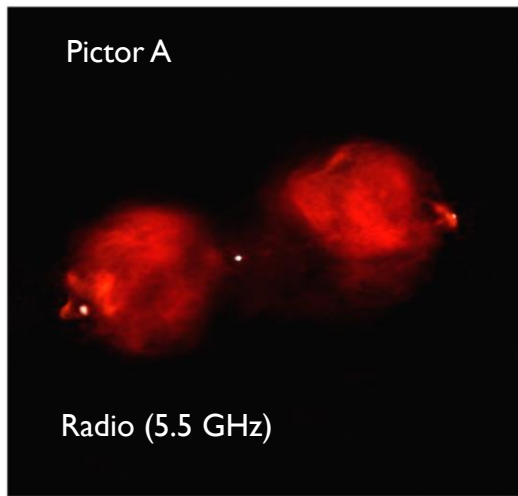


Radio-loud AGN

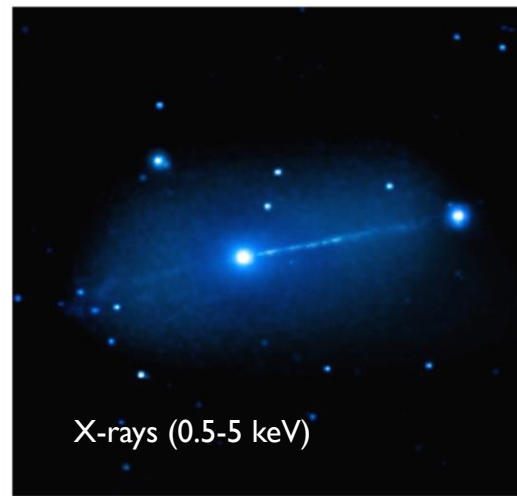
AGN



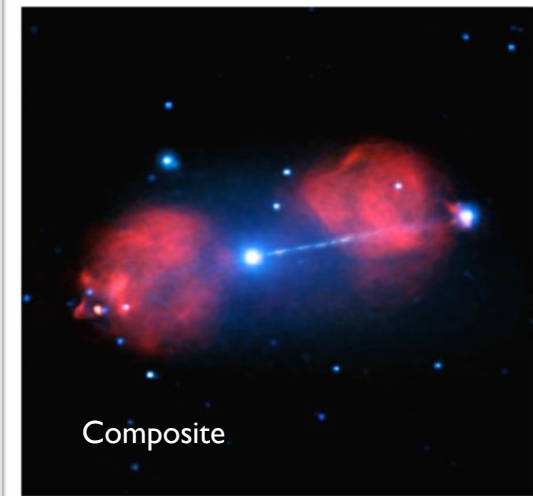
Pictor A



Radio (5.5 GHz)



X-rays (0.5-5 keV)

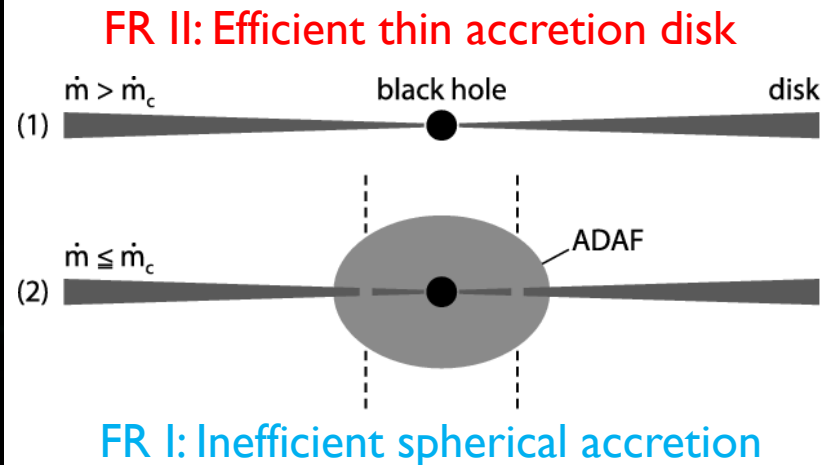
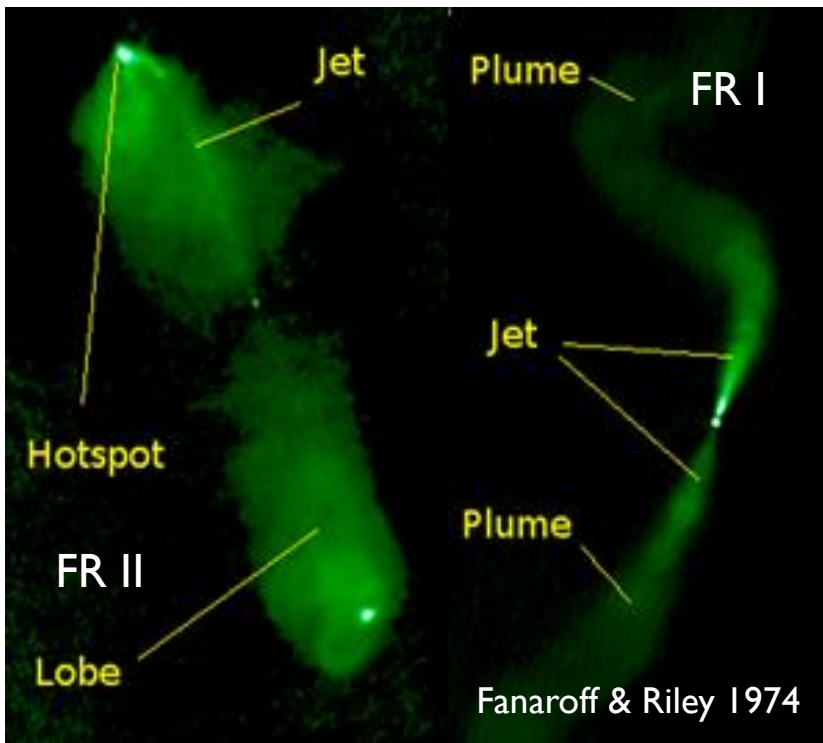


Composite

# Background: radio galaxies

FR I  
Edge-darkened  
Bright jet  
Slower/disturbed jet

FR II  
Edge-brightened  
Weak jet  
Faster/collimated jet



# Background: orientation effect

FR I and FR II radio galaxies are considered to be the **misaligned parent population** of blazar subclasses BL Lacs and FSRQs, respectively (Urry & Padovani 1995)

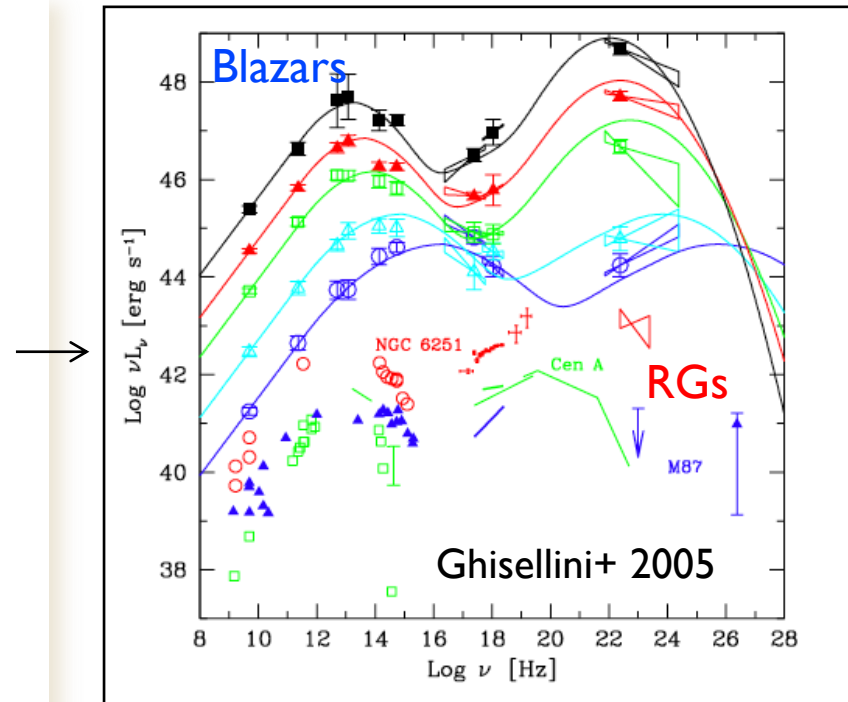
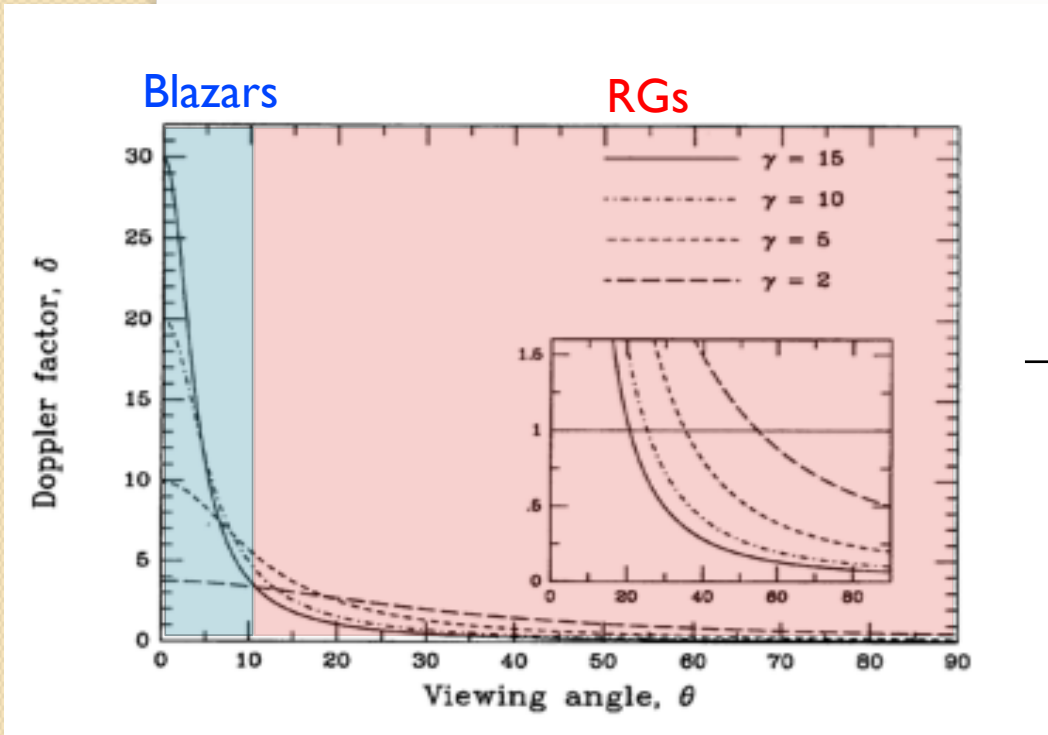
Doppler boosting:

$$F_{obs} = \delta^n F_{intr}$$

where

$$\delta = [\Gamma(1 - \beta \cos\theta)]^{-1} \quad \longrightarrow \quad (\Gamma = \text{jet Lorentz factor}, \beta = v/c, \theta = \text{viewing angle})$$

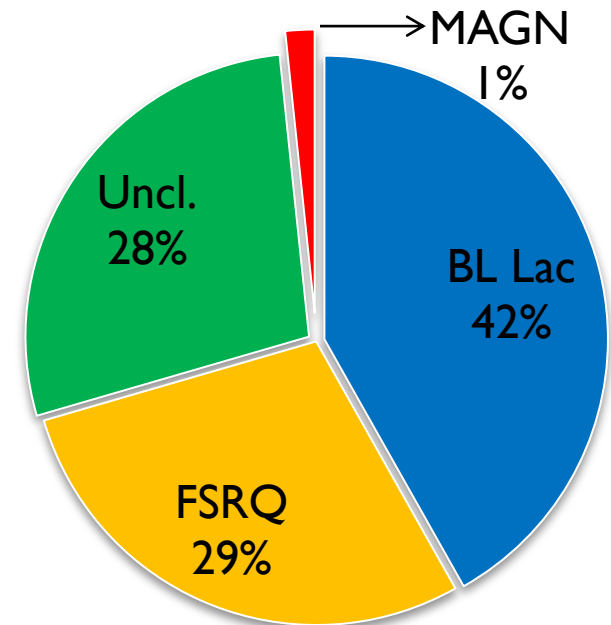
—————> Larger  $\theta$   $\rightarrow$  smaller  $\delta$   $\rightarrow$  weaker source



# Background: radio galaxies in $\gamma$ -rays

- Investigate **jet structure** and **particle content** through SED modeling (Böttcher+ 2013)
- Investigate **acceleration processes** in the jet and in diffuse structures (radio lobes)
- Test **unified models** by comparison with blazars
- GeV **detection rate** much higher for FR Is w.r.t. FR IIs (Grandi+ 2012) : different jet structure?
- $\gamma$ -ray emission from **lobes** (Cen A, Abdo+2012): efficient particle transport or *in situ* acceleration?

18 RGs observed at HE (0.1-100 GeV) by **Fermi-LAT** 3LAC (Ackermann+ 2015):

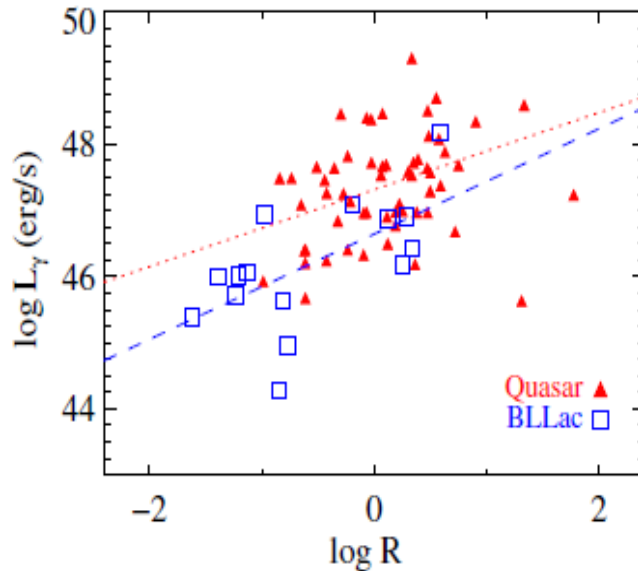


$\gamma$ -ray RGs provide crucial information, but we have only few sources, and no robust detection of young sources (possible news soon...)

New detections with Pass8 analysis?

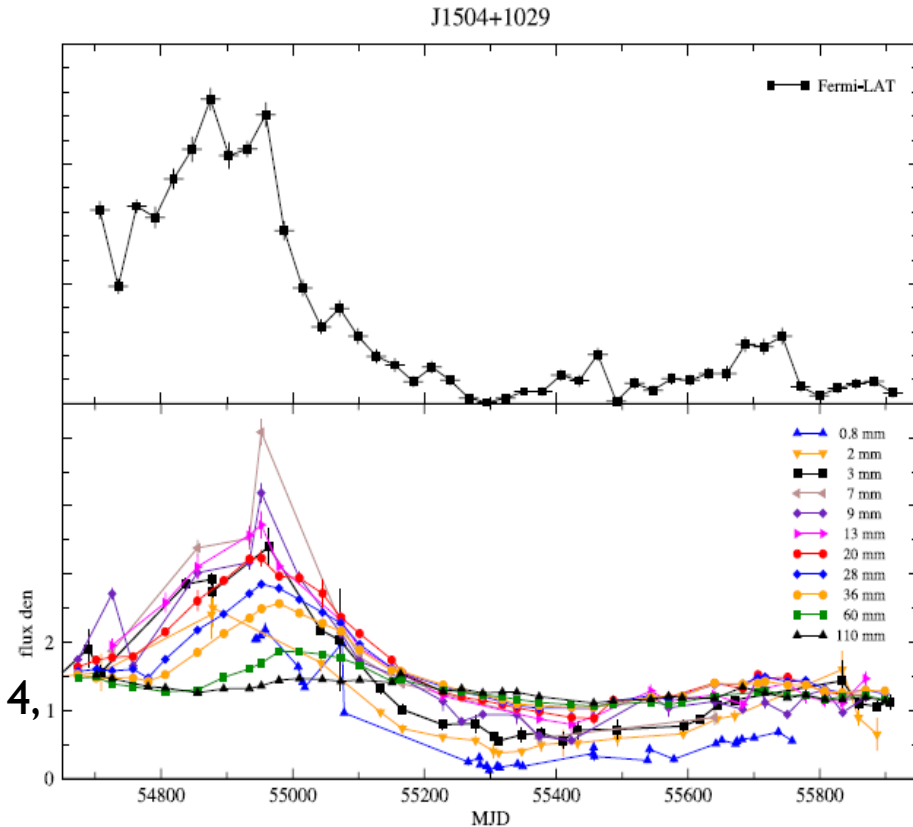
# Background: radio- $\gamma$ -ray connection

There is a strong connection between radio and  $\gamma$ -ray emission in radio-loud AGN...



Correlations (Arshakian+ 2012)

Variability behavior (e.g. Fuhrmann+ 2014, Casadio+ 2015, Rani+ 2014, 2015, Karamanavis+ 2015, 2016)



...but there are bright radio-loud sources without a  $\gamma$ -ray detection (Lister+ 2015)

Lower SED peak?

Doppler factor?

# The project: TANAMI



- ~90 extragalactic jets below  $-30^\circ$  Dec (Ojha+2010)
- Southern VLBI array: LBA + South Africa, New Zealand, Antarctica, Chile
- Extensive dual-frequency VLBI and multi-wavelength data set
- ~75% detected by *Fermi*-LAT (Böck+2016)

# The project: TANAMI RGs

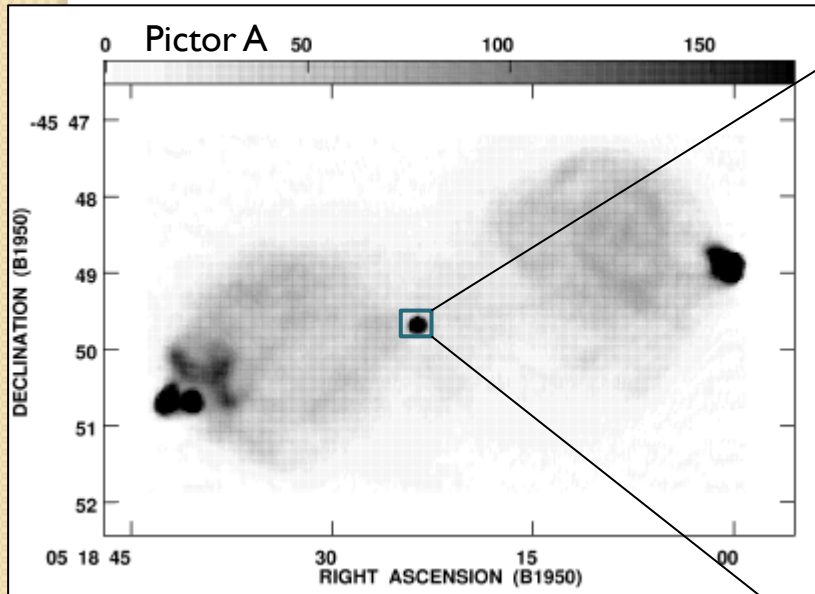
| Name     | Cat. name      | RA     | Dec    | Class   | z     | $\gamma$ -ray det. |
|----------|----------------|--------|--------|---------|-------|--------------------|
| 0518-458 | Pictor A       | 79.96  | -45.78 | FR II   | 0.035 | Y                  |
| 0521-365 | PKS 0521-36    | 80.74  | -36.46 | RG/SSRQ | 0.057 | Y                  |
| 0625-354 | PKS 0625-35    | 96.78  | -35.49 | FRI/BLL | 0.055 | Y                  |
| 0903-573 | PKS 0903-57    | 136.18 | -35.24 | BCU     | 0.695 | Y                  |
| 1121-640 | PMN J1123-6417 | 170.83 | -64.30 | BCU     | -     | Y                  |
| 1258-321 | PKS 1258-321   | 195.25 | -32.44 | FR I    | 0.017 | Cand.              |
| 1333-337 | IC 4296        | 204.16 | -33.97 | FR I    | 0.013 | N                  |
| 1343-601 | Centaurus B    | 206.70 | -60.41 | FR I    | 0.013 | Y                  |
| 1549-790 | PKS 1549-79    | 239.25 | -79.23 | RG/CSO  | 0.15  | N                  |
| 1718-649 | NGC 6328       | 260.92 | -65.01 | GPS/CSO | 0.014 | Y                  |
| 1733-565 | PKS 1733-56    | 264.40 | -56.57 | FR II   | 0.099 | N                  |
| 1814-637 | PKS 1814-63    | 274.90 | -63.76 | CSS/CSO | 0.065 | N                  |
| 1934-638 | PKS 1934-63    | 294.85 | -63.71 | GPS     | 0.18  | N                  |
| 2027-308 | PKS 2027-308   | 307.41 | -30.66 | RG      | 0.54  | N                  |
| 2152-699 | PKS 2153-69    | 329.28 | -69.69 | FR II   | 0.028 | Cand.              |



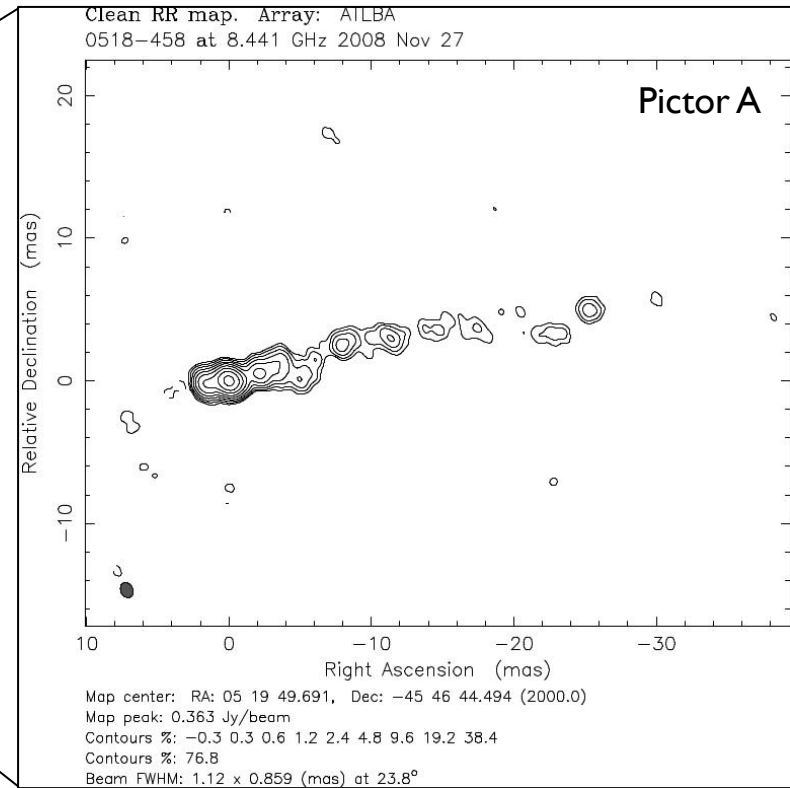
# The project: radio

VLBI imaging of southern hemisphere radio galaxies (FR I, FR II, compact objects) at 3.6 cm and 1.3 cm

—————> 15 sources in total

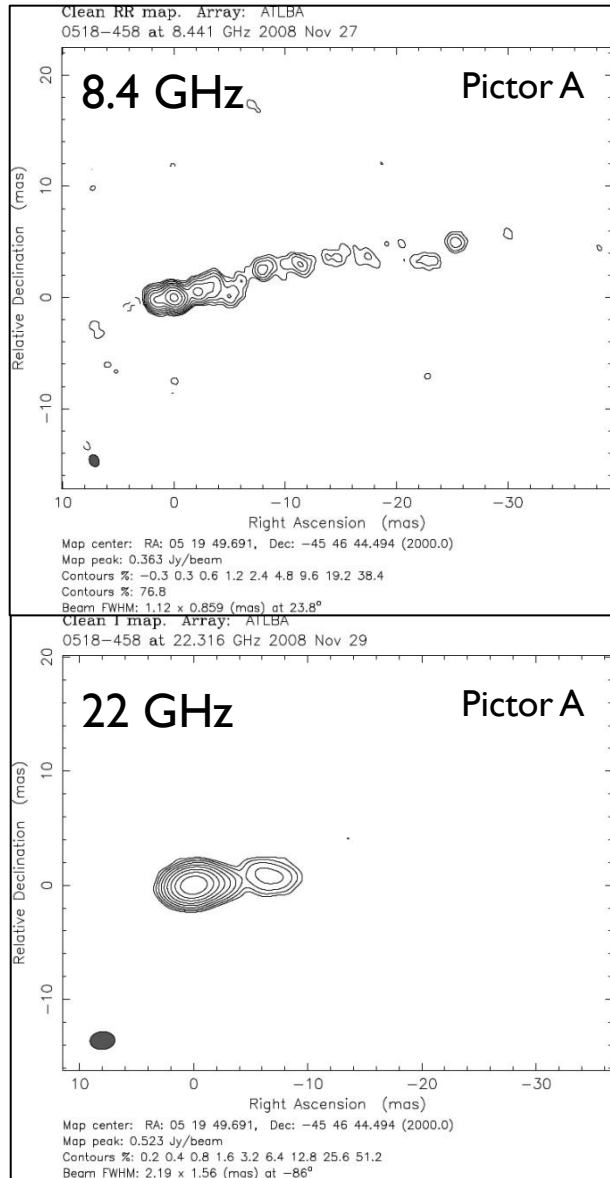


Perley+ 1997, VLA 1.4 GHz

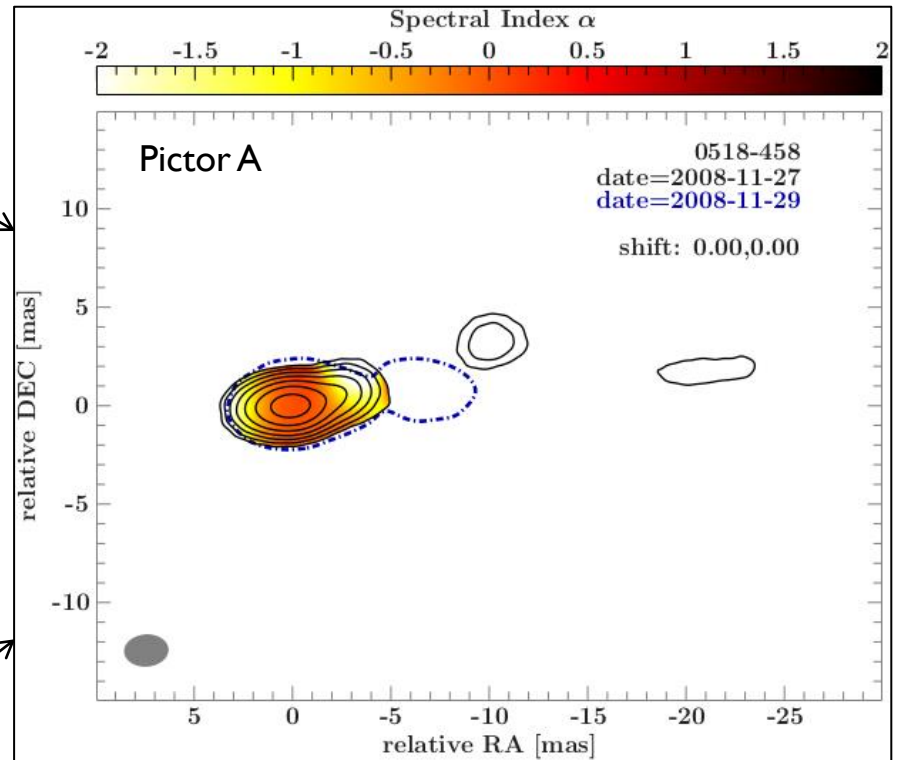


Angioni+ in prep., TANAMI 8.4 GHz

# The project: radio

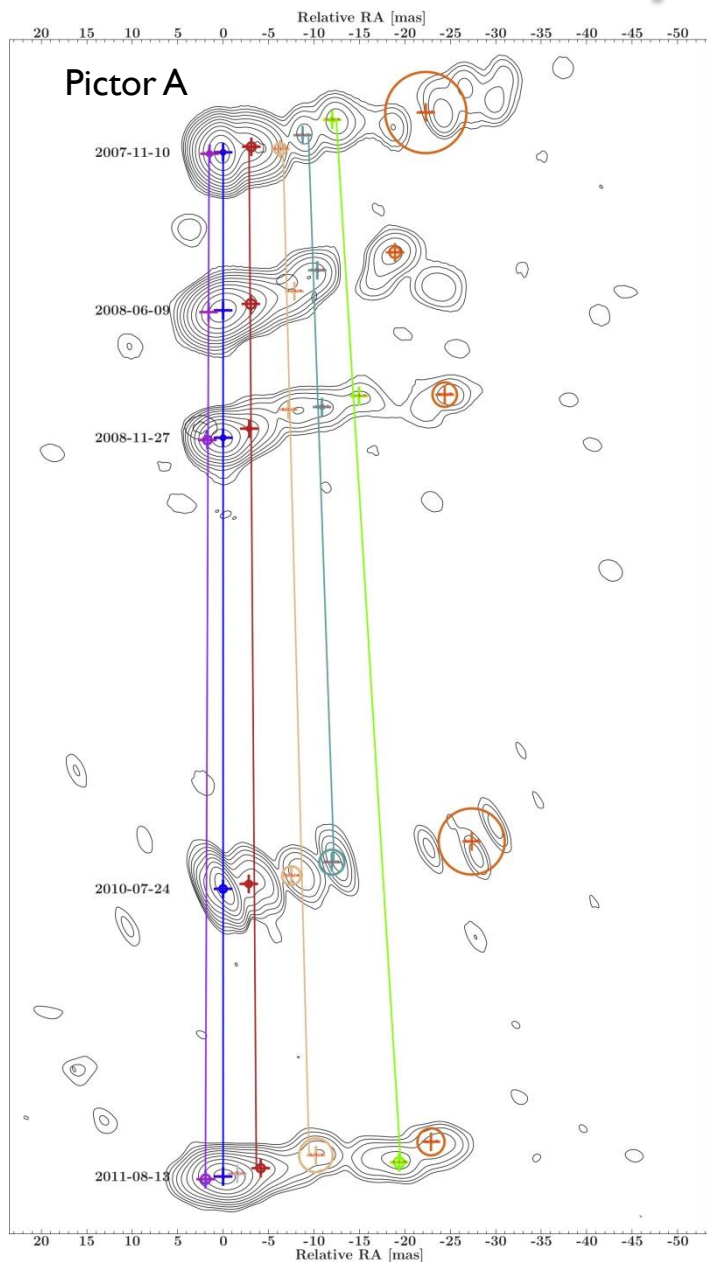


Spectral index mapping  $\rightarrow F_\nu \propto \nu^\alpha$

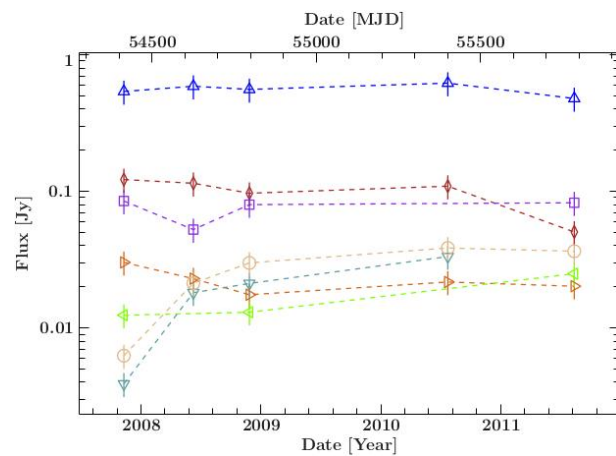
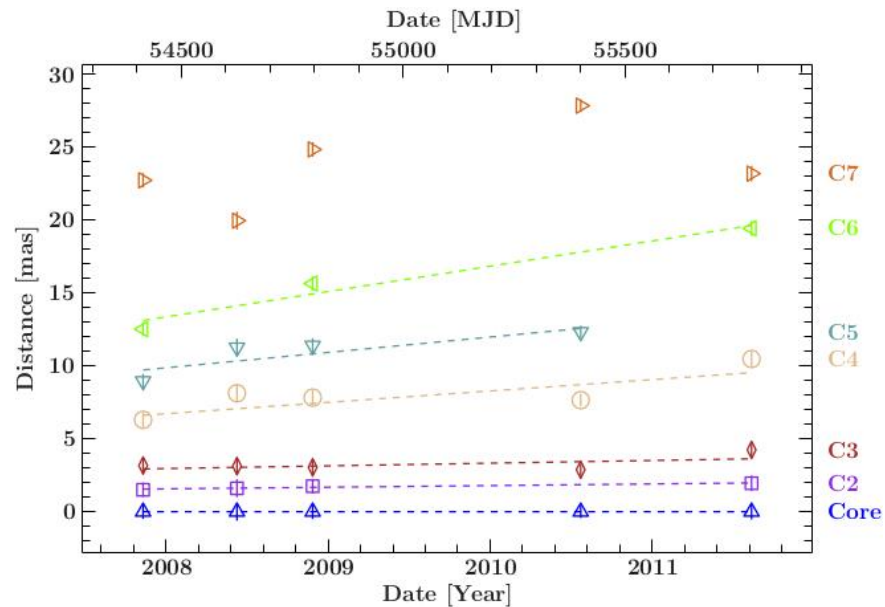


Angioni+ in prep.

# The project: radio

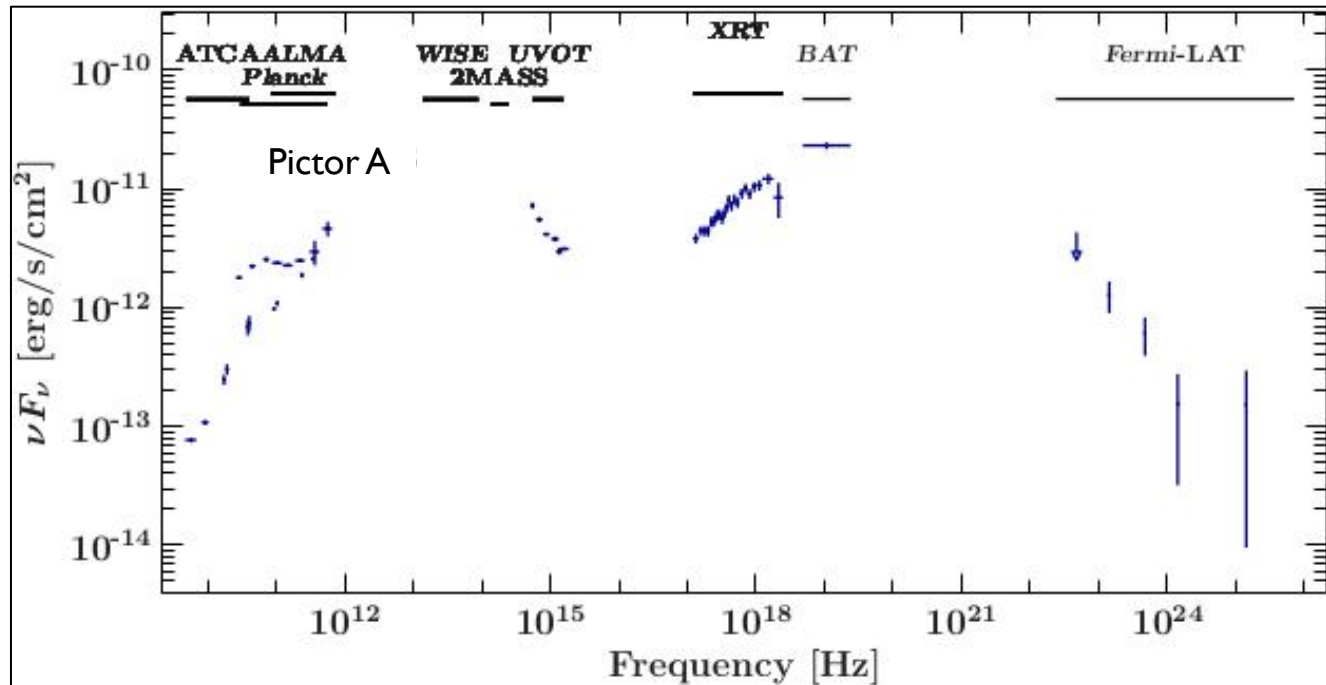
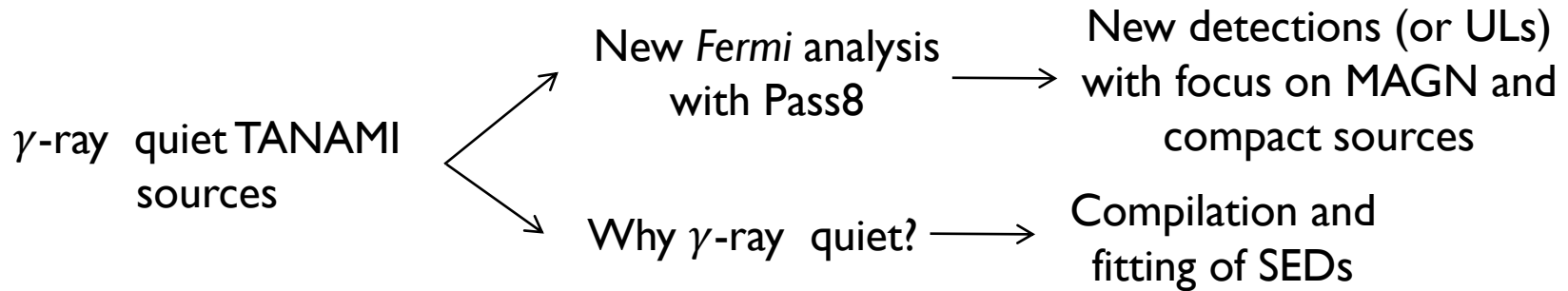


## Component fitting and kinematics



Angioni+  
in prep.

# The project: MWL and *Fermi*



Angioni+ in prep.

**Thank you for your  
attention!**