Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Credit: TANAMI homepage

ASTRO WÜRZBURG

TANAMI
VLBI and Multiwavelength Observations of Blazars with Very-High-Energy Astroparticle Emissions

Florian Rösch

FRANCI, Erlangen, October 14, 2021

The TANAMI Team

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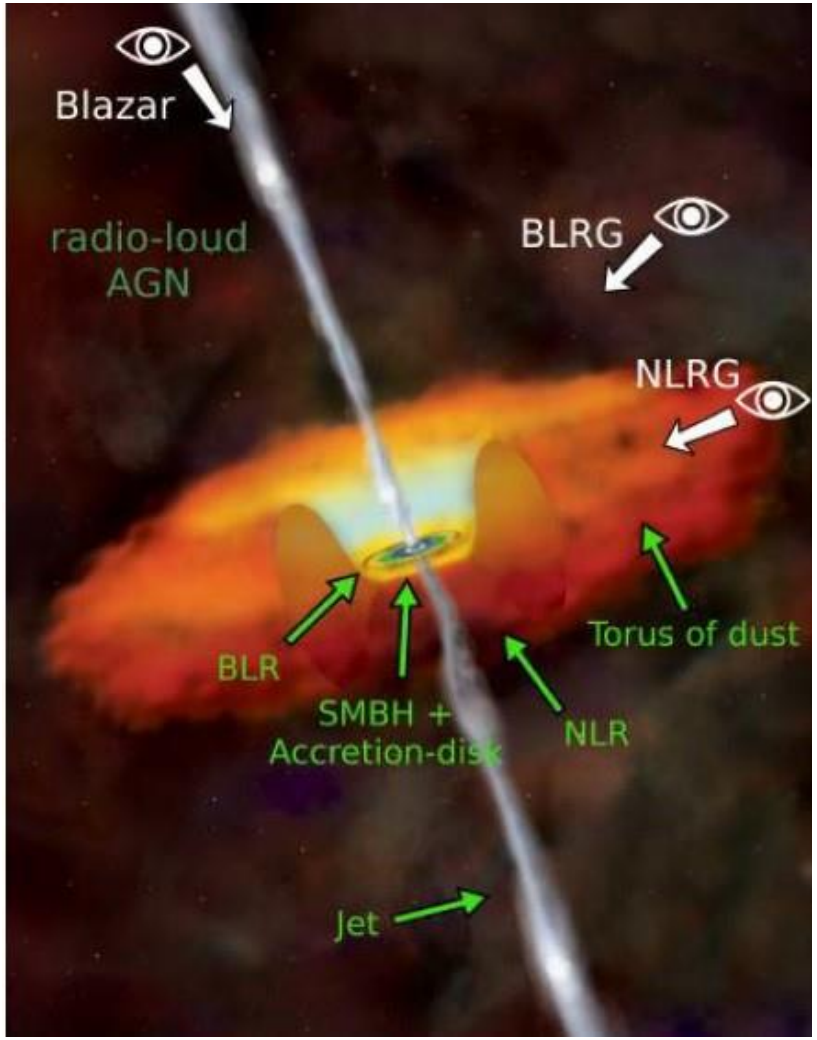
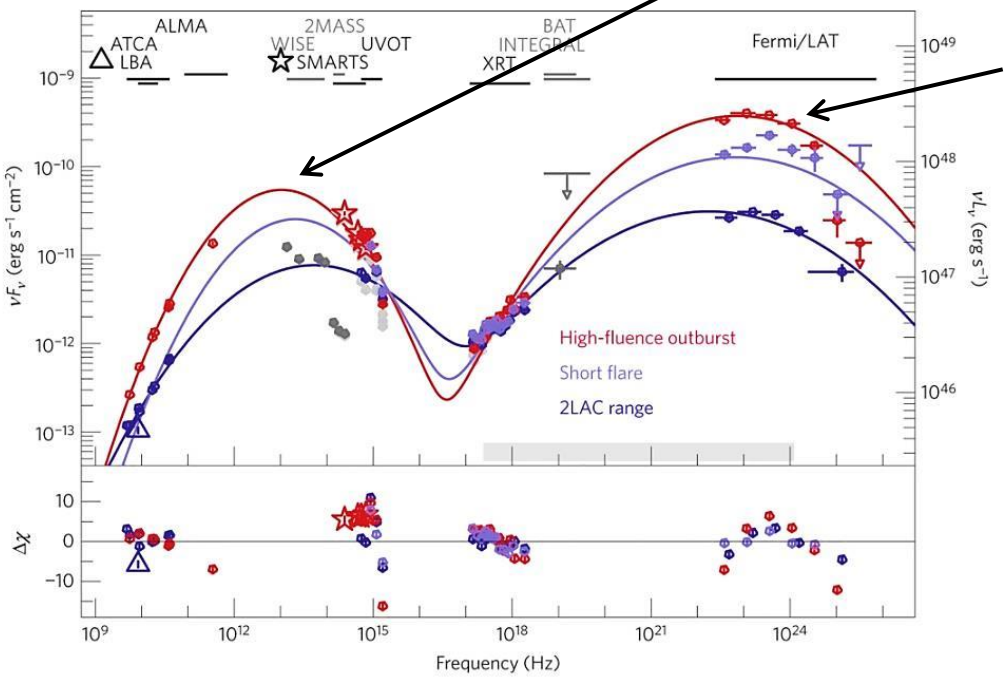
Active Galactic Nuclei (AGN)



NASA/CXC/M.Weiss

- Blazars
  - High luminosity
  - High variability on all time scales
  - High polarisation
  - Largest population of extragalactic γ-ray sources
  - Candidates for high-energy extraterrestrial neutrinos
- Jets
  - Well-collimated plasma
  - Apparent superluminal motion

Spectral Energy Distribution (SED)



Kadler et al. 2016

Low-energy peak:

- Radio to infrared
- Synchrotron radiation

High-energy peak:

- Inverse Compton scattering
  - Synchrotron Self-Compton (e.g. Maraschi et al. 1992)
  - External Compton (e.g. Sikora et al. 1994)
- Hadronic Models (e.g. Mannheim 1993)
  - Pion production due to pγ interaction
  - Pion decay into photons and neutrinos

Very Long Baseline Interferometry (VLBI)

- Angular resolution of a single radio telescope is given by

$$\Theta = 1.22\frac{\lambda}{D}$$

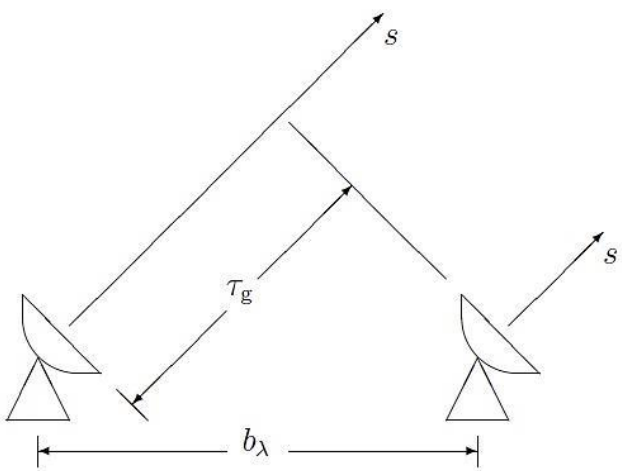
λ: wavelength of observation, D: diameter of the telescope

- Observation at a given wavelength

  $\Rightarrow$ diameter has to be increased to improve the angular resolution

- Synchronization of multiple radio telescopes

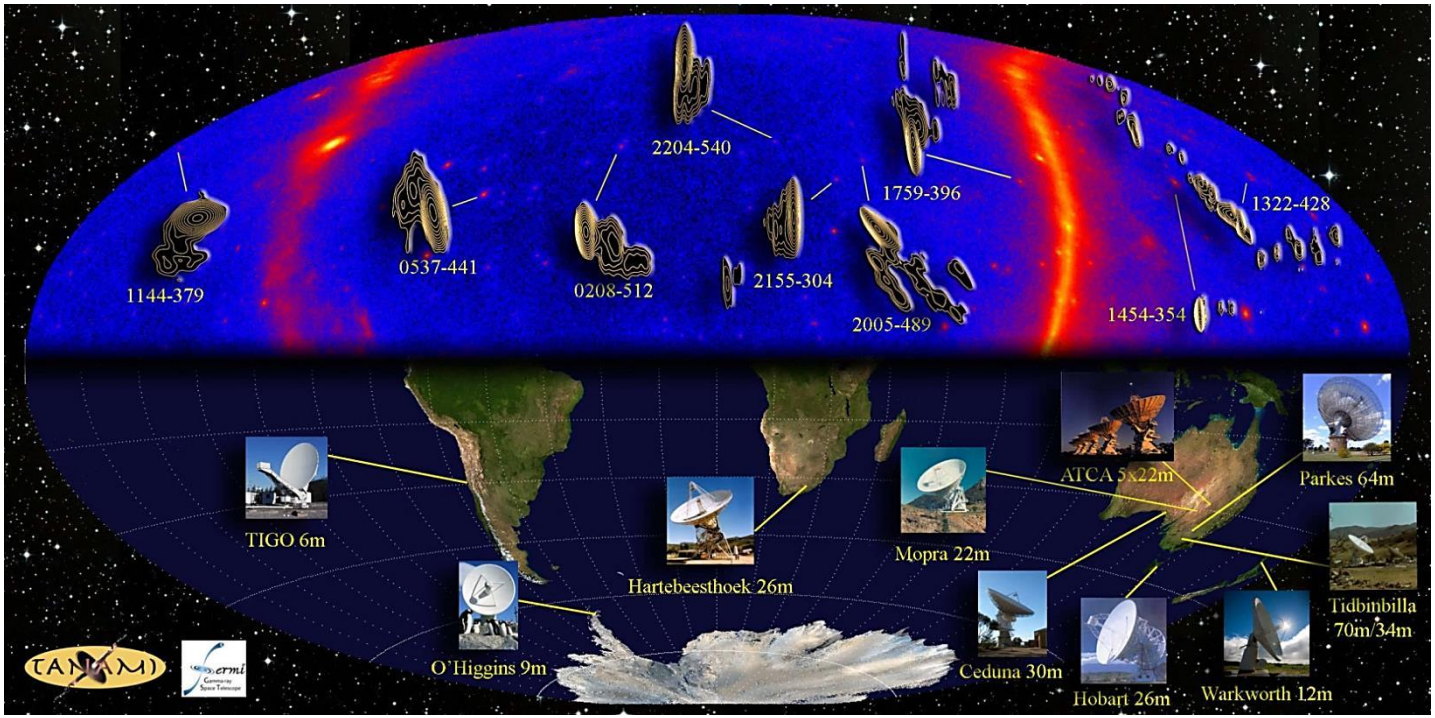
- Diameter is given by the largest baseline b_λ



Adapted from Burke & Graham-Smith (2010)

The TANAMI Program

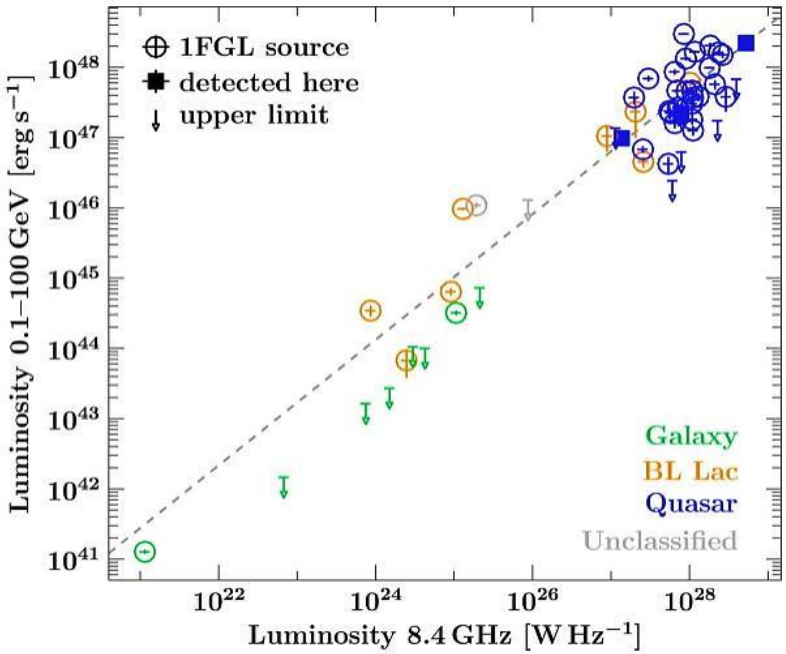
- Tracking Active Galactic Nuclei with Austral Milliarcsecond Interferometry
- Monitoring of AGN of Southern Sky
- VLBI core program to study parsec-scale structure of AGN jets
- VLBI observations at 2.3 GHz, 8.4 GHz, 22.3 GHz
- Multiwavelength observations at higher energies (e.g. optical/UV, X-ray, γ-ray)



Credit: TANAMI homepage

Radio – Gamma Connection (Böck et al. 2016)

- γ-ray data during the first 11 months of *Fermi*/LAT operation
- 75 AGN of TANAMI sample detected by *Fermi*/LAT



$p = 4.3 \times 10^{-3}$

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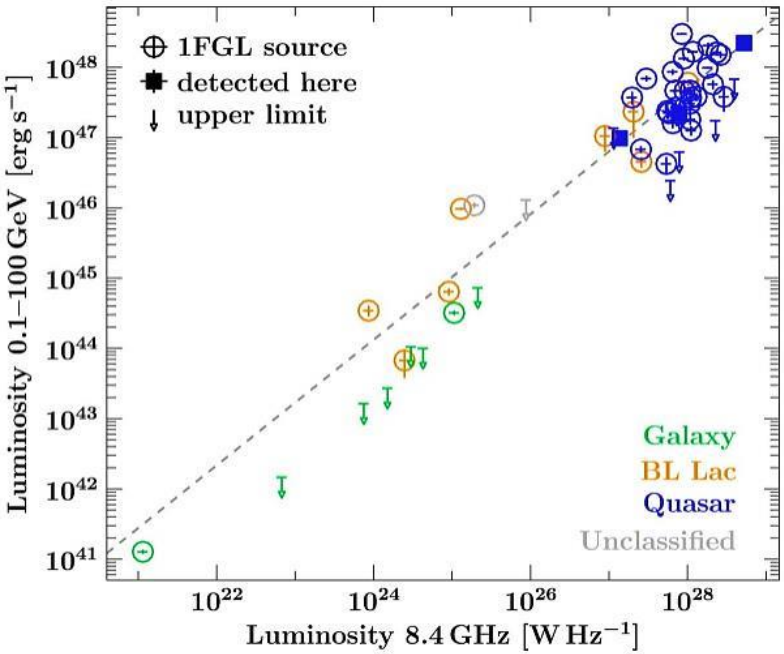

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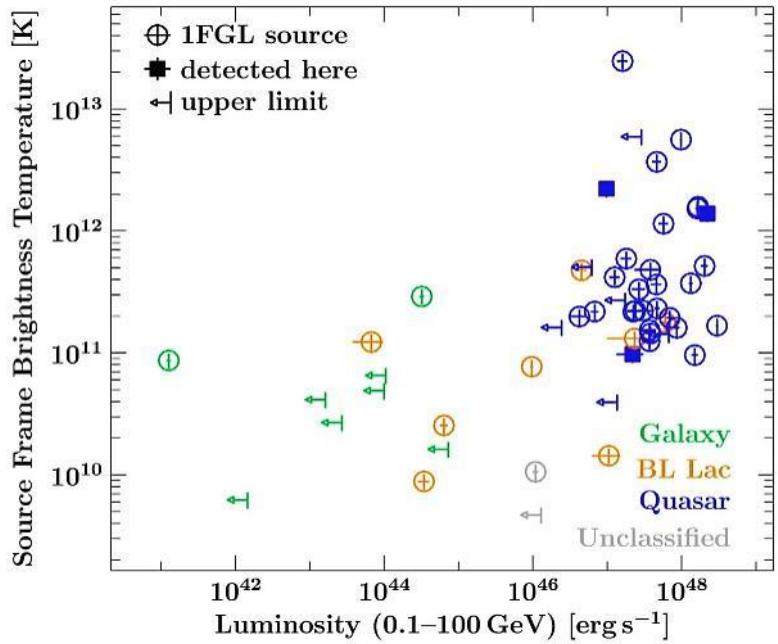

$p = 1.8 \times 10^{-3}$

$T_B > 10^{12}$ K

⇒ Doppler boosting

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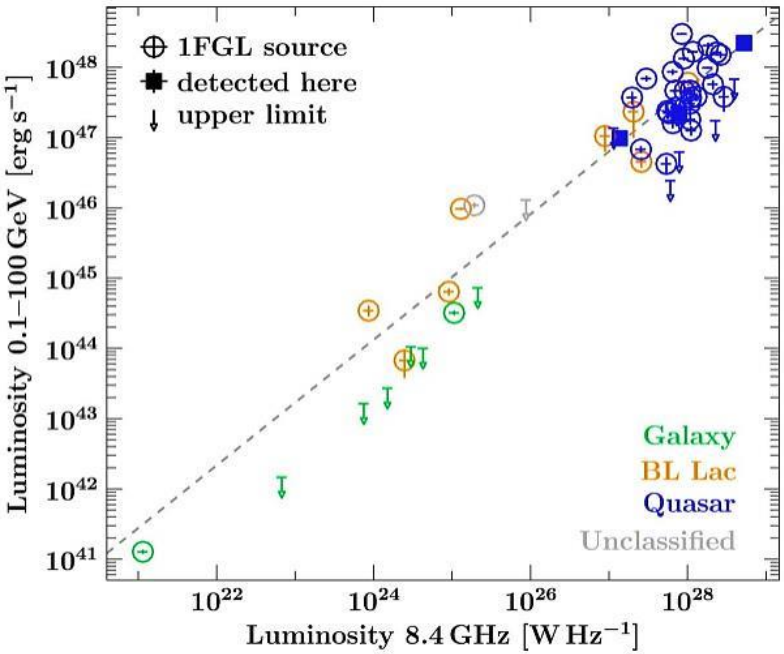

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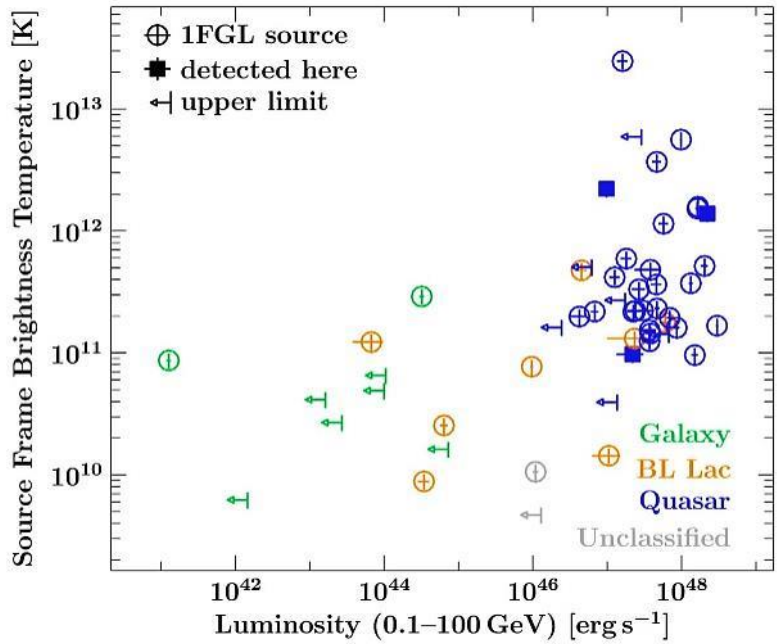


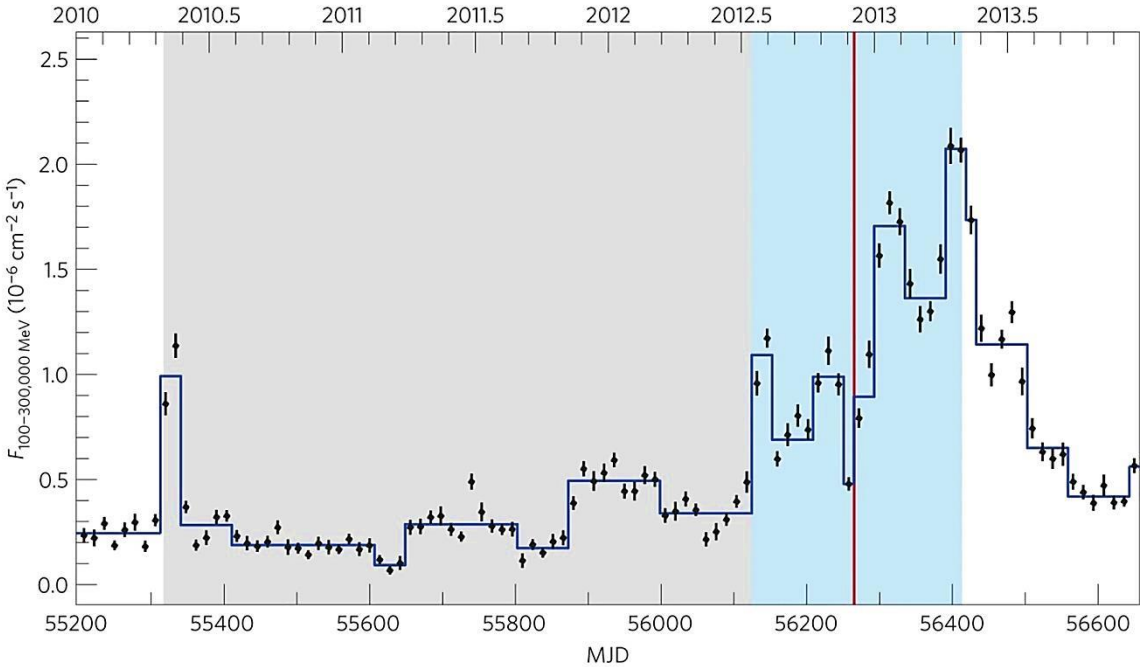
$p = 1.8 \times 10^{-3}$

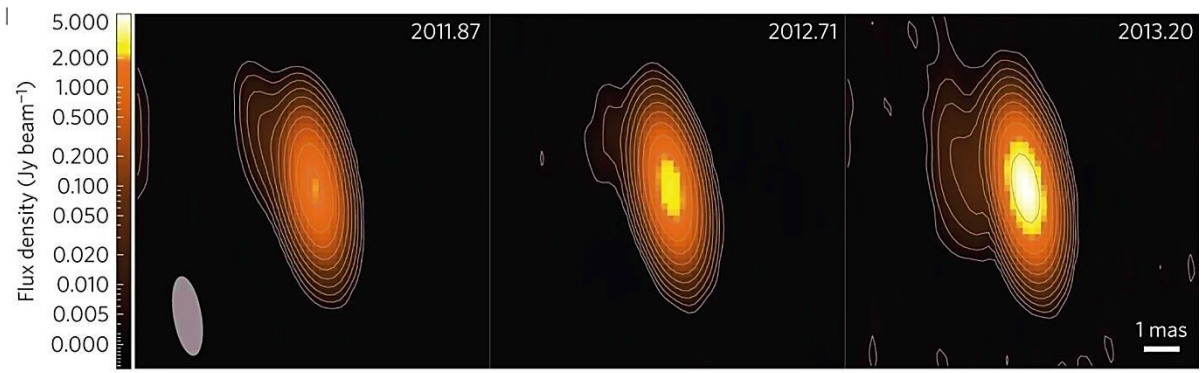
$T_B > 10^{12}$ K

⇒ Doppler boosting

⇒ Significant correlation between γ-ray and VLBI core properties

Neutrino – Blazar Association (Kadler et al. 2016)





- PKS 1424-418 associated at $\sim 2\sigma$ with the ~ 2 PeV IceCube neutrino event IC 35 (aka „BigBird“) in December 2012
- Bright γ-ray outburst
- Increase of VLBI core flux density

Neutrino – Radio Associations

- Plavin et al. 2020:
  - Association of neutrinos with radio-bright AGN using VLBI and RATAN-600 data
  - AGN positionally associated with IceCube events have stronger parsec-scale cores

- Hovatta et al. 2021:
  - Neutrino – blazar association using OVRO and Metsähovi data
  - Connection between largest radio flares and neutrino arrival times

Main PhD Project

Analysis of TANAMI data that have been observed since June 2013 (data observed between Nov 2007 and Mar 2013 are already analyzed)

Broadband follow-up studies of individual TANAMI neutrino-candidate blazars

- Is there enhanced activity in the radio band?
  - Component ejections
  - Flares in flux density of VLBI core

- Comparison with *Fermi*/LAT γ-ray data

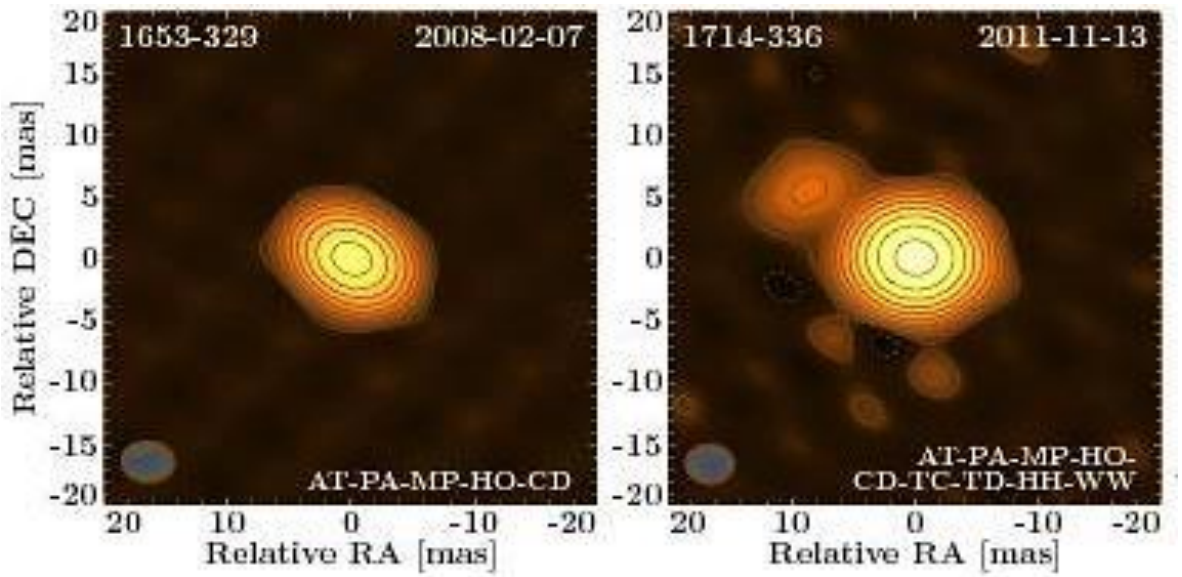
- SED modeling together with other multiwavelength data
  - Testing time-dependent lepto-hadronic emission models

TANAMI Neutrino-Candidate Blazars

Swift J1656.3-3302 and PMN J1717-3342:

- Highest potential neutrino flux in the field of the ∼ 1 PeV IceCube neutrino event IC 14 (aka „Bert“, Krauß et al. 2014)
- Constrained by ANTARES (ANTARES Collaboration & TANAMI Collaboration 2015)

Swift J1656.3-3302 PMN J1717-3342

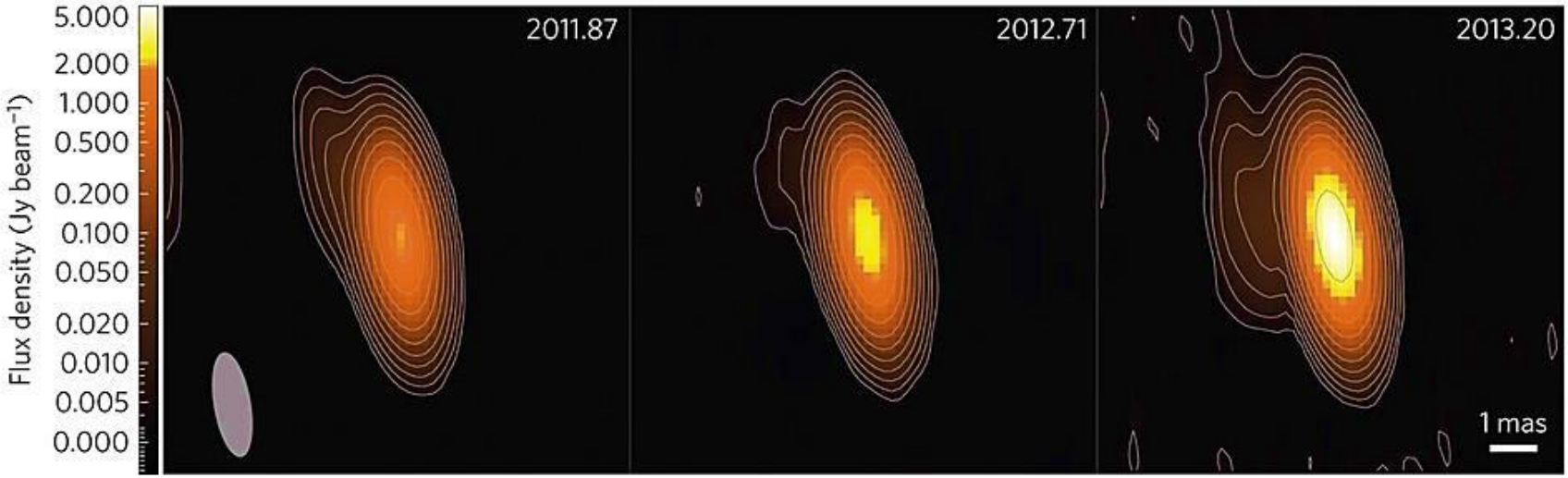


Krauß et al. 2014

TANAMI Neutrino-Candidate Blazars

PKS 1424-418:

- Associated with the ~ 2 PeV IceCube neutrino event IC 35 (aka „BigBird“, Kadler et al. 2016)
- 10 alternative possible associations within the „BigBird“ field



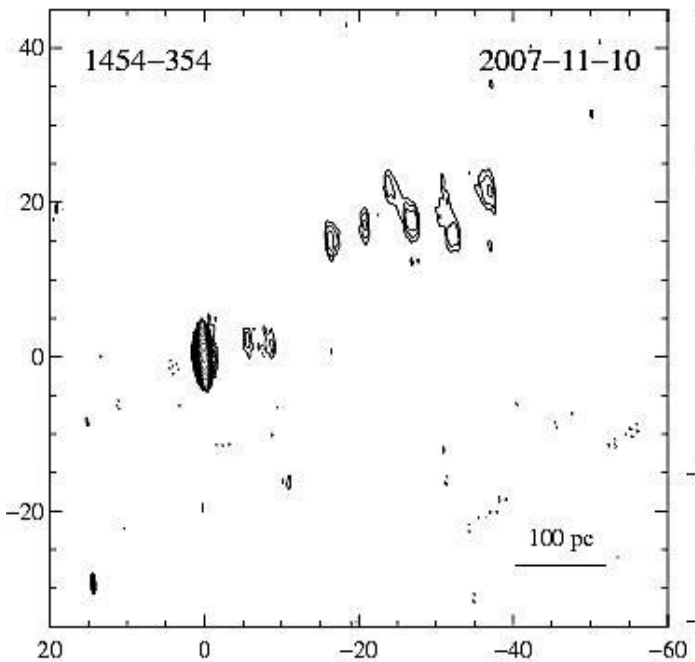
Kadler et al. 2016

TANAMI Neutrino-Candidate Blazars

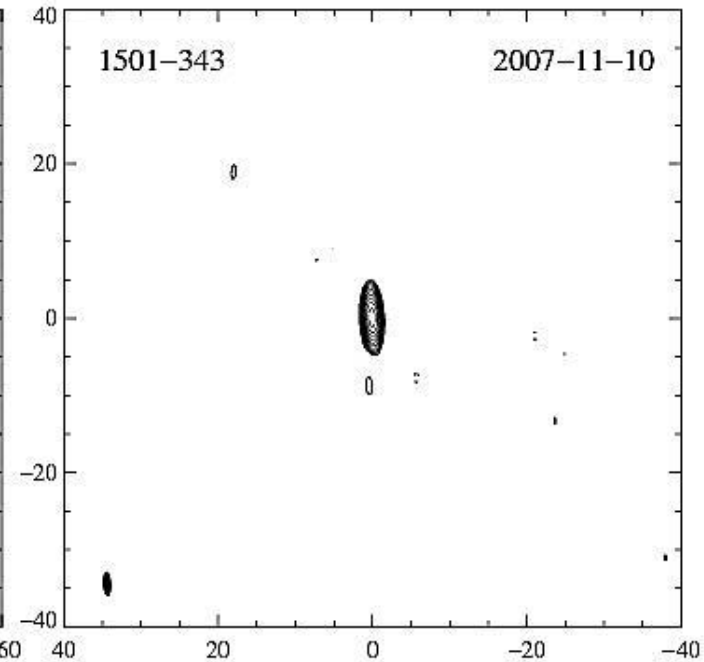
PKS 1454-354 and PMN J1505-3432:

- Public IceCube GCN alert IC 181014A
- Bright γ-ray sources

PKS 1454-354



PMN J1505-3432



Ojha et al. 2010

Summary

- TANAMI:
  - Multiwavelength monitoring program of AGN of Southern Sky
  - VLBI observations at 2.3 GHz, 8.4 GHz, 22.3 GHz
  - Data observed between Nov 2007 and Mar 2013 are already analyzed
  - Correlation between γ-ray and VLBI core properties
  - Neutrino – blazar associations

- Main PhD project:
  - Analysis of TANAMI data that have been observed since June 2013
  - Analysis of individual TANAMI neutrino-candidate blazars
    - 5 neutrino – blazar associations
    - 10 additional sources in „BigBird“ field

backup

Radio – Gamma Connection (Böck et al. 2016)

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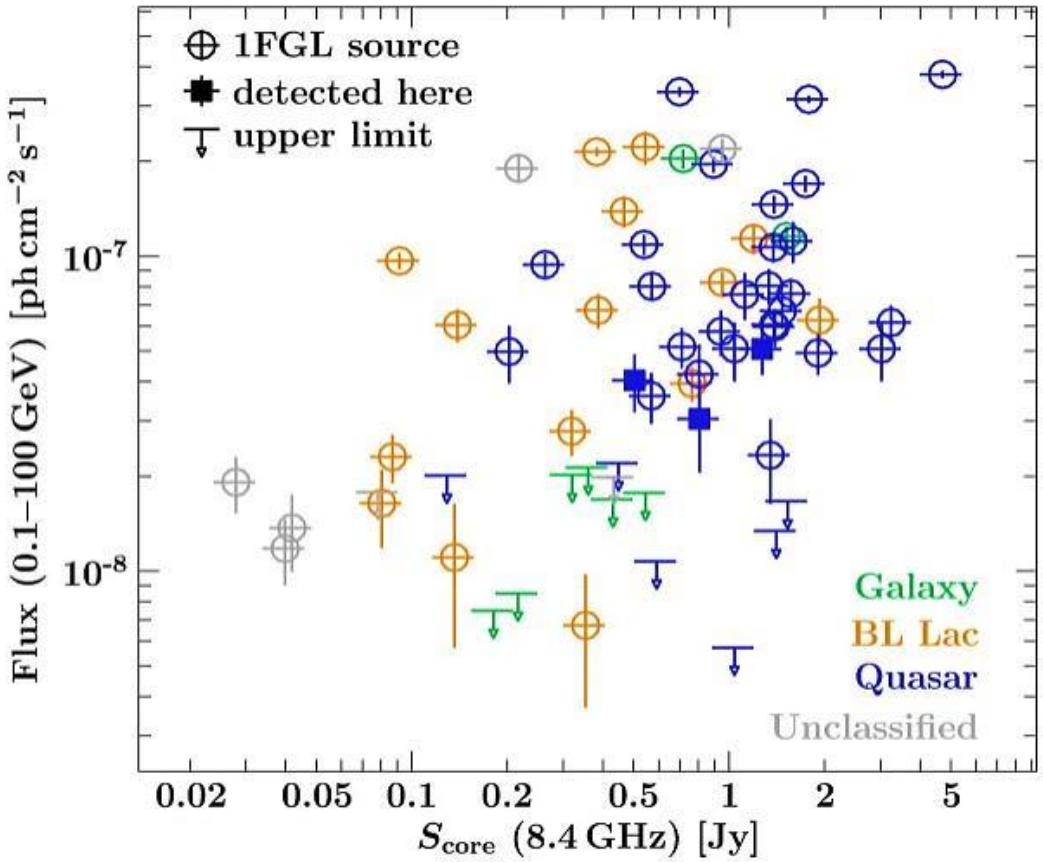

$p = 3.2 \times 10^{-5}$

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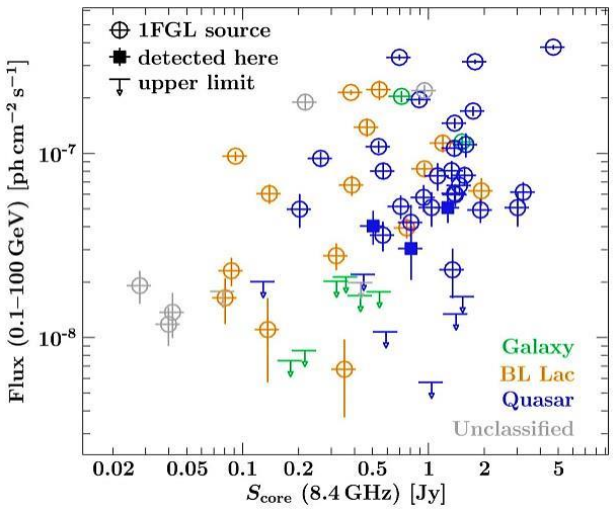

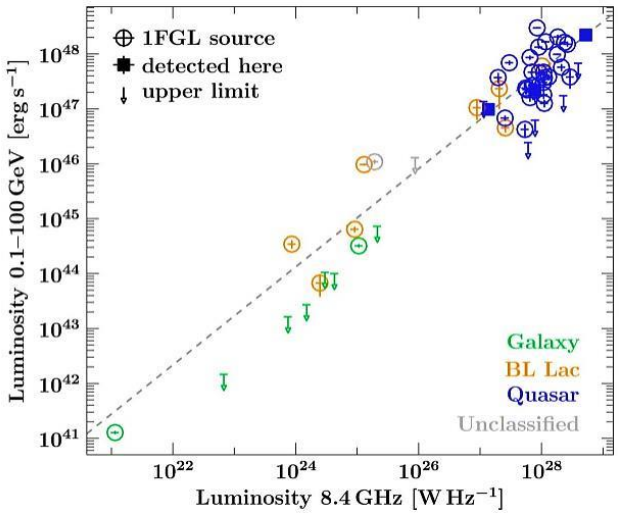

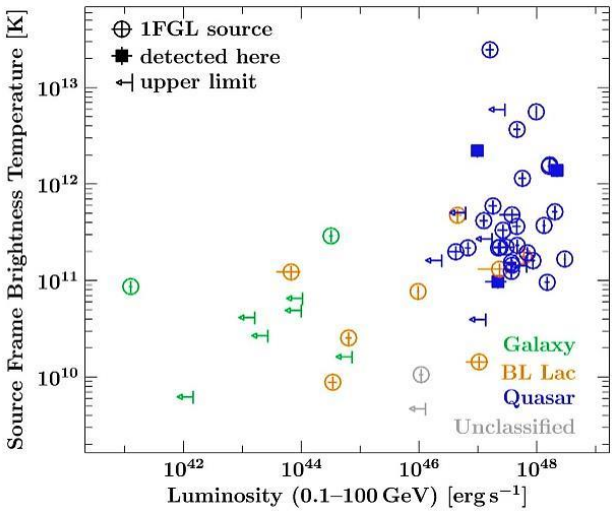

Kendall's τ = 0.29
p = 3.2×10^{-5}

Kendall's τ = 0.30
p = 4.3×10^{-3}

Kendall's τ = 0.25
p = 1.8×10^{-3}
$T_B > 10^{12}$ K
⇒ Doppler boosting

⇒ Significant correlation between γ-ray and VLBI core properties