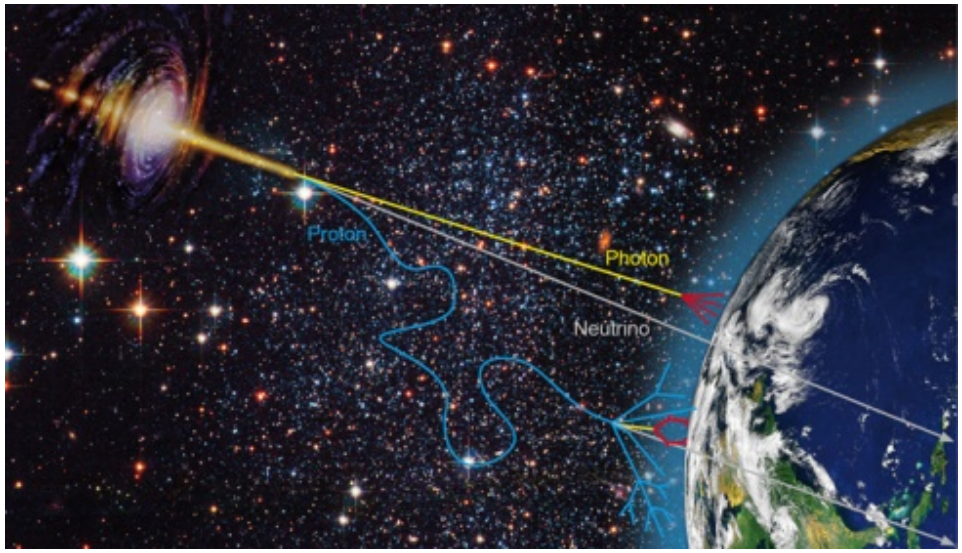


https://physics.ua.edu

The Impact of Southern-Hemisphere VLBI Blazar Observations on Neutrino Astronomy

Florian Rösch

M. Kadler, E.Ros, R. Ojha, P. Benke, F. Eppel, J. Heßdörfer,
on behalf of the TANAMI Team

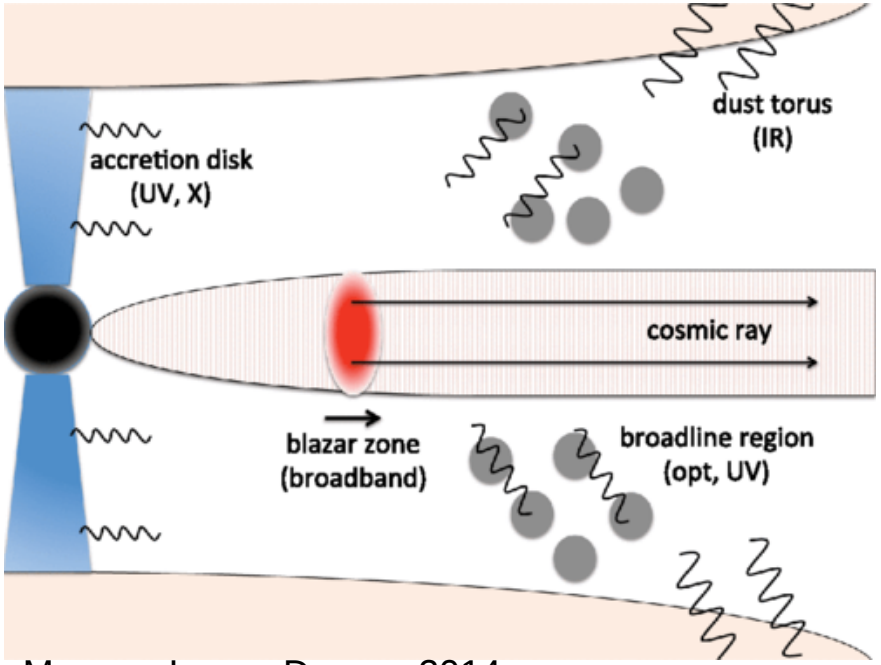
Bologna VLBI Conference, Bologna, May 22, 2023

Neutrino Production in Quasar Jets

- Relativistic protons in the jet interact with soft ambient photon field (Mannheim & Biermann 1989)

⇒ Pion production

⇒ Neutrinos and high-energy photons due to pion decay



Murase, Inoue, Dormer 2014

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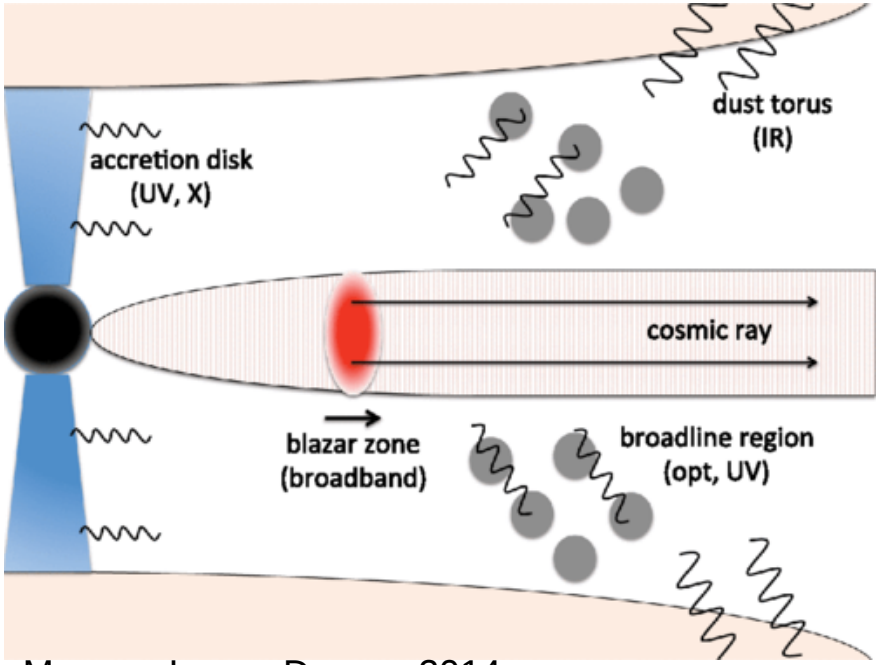
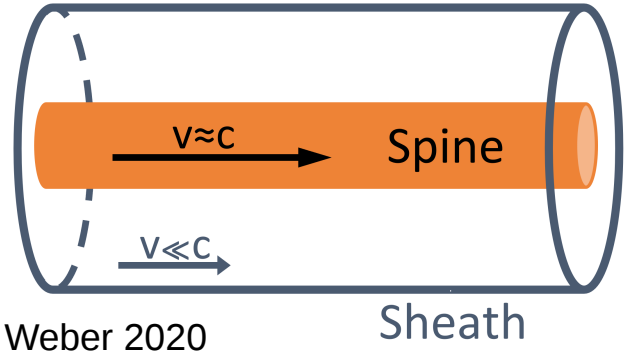


Murase, Inoue, Dormer 2014

Alternative:

- Spine – sheath model (Tavecchio et al. 2014, 2015)

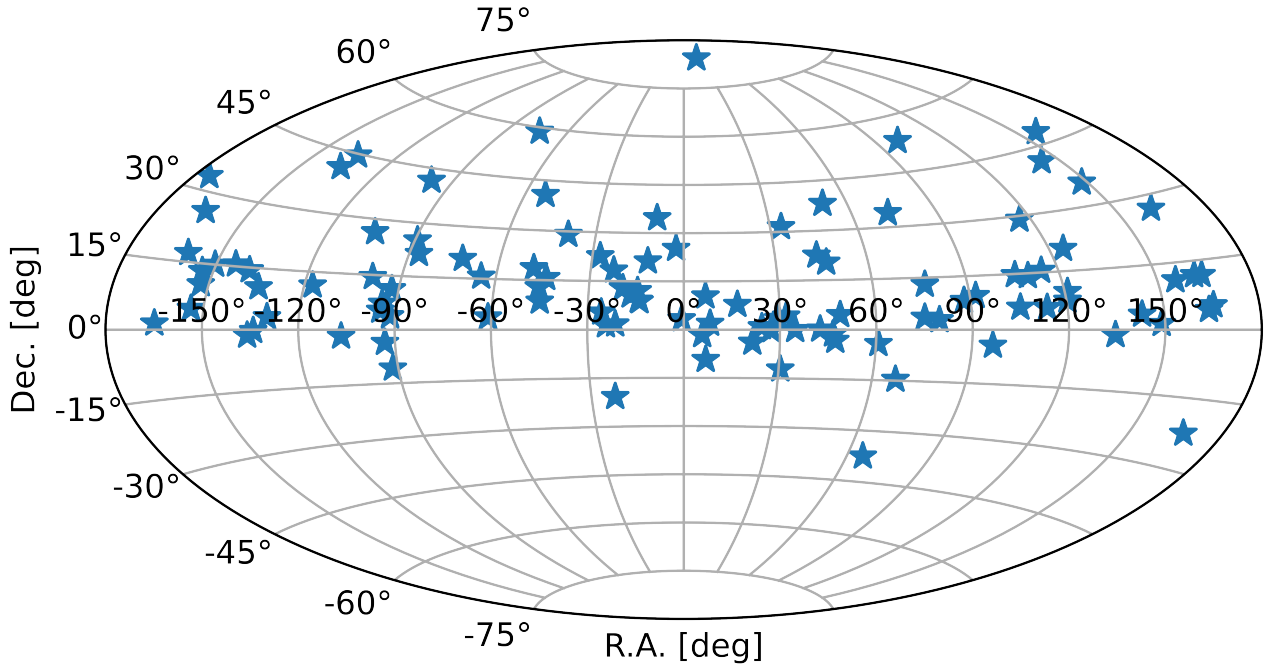
- Relativistic protons in the jet spine interact with soft photons of the slow sheath



Weber 2020

IceCube Neutrino Alerts

- Located at the South Pole
- Mostly sensitive to neutrinos from the Northern Hemisphere
- Realtime automatic neutrino alerts
- Updated alert with improved positional reconstruction



Neutrino – Radio Associations

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

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However:
- IceCube Collaboration 2023:
  - No statistically significant correlation between RFC sources and neutrino emission
  - < 1% of AGN are neutrino emitters

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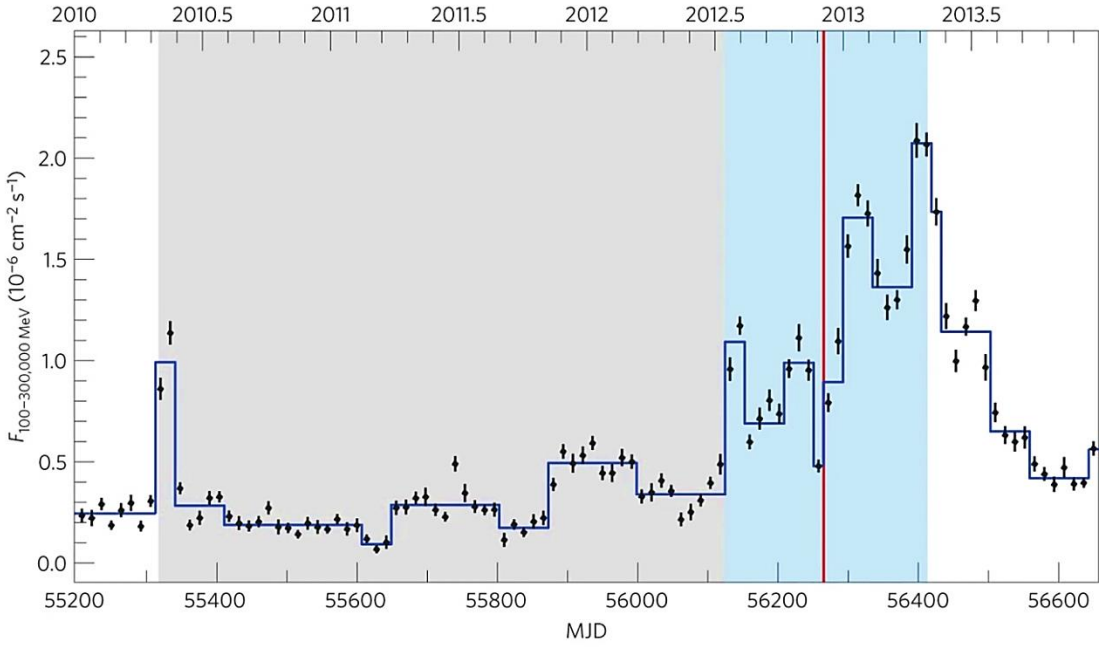
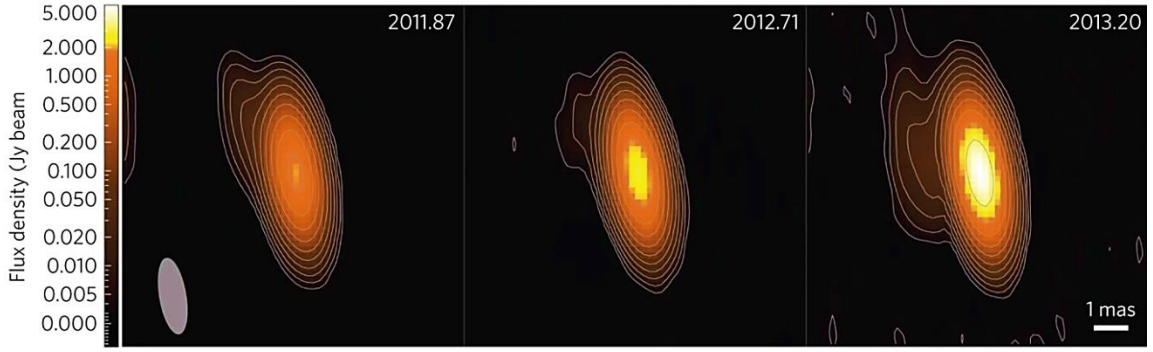
But: individual neutrino – AGN associations
- NGC 1068 (~4 sigma; IceCube Collaboration 2022)
- TXS 0506+056 (~3 sigma; IceCube Collaboration 2018; Talk by F. Eppel)

8.4 GHz VLBI Observations of PKS 1424-418

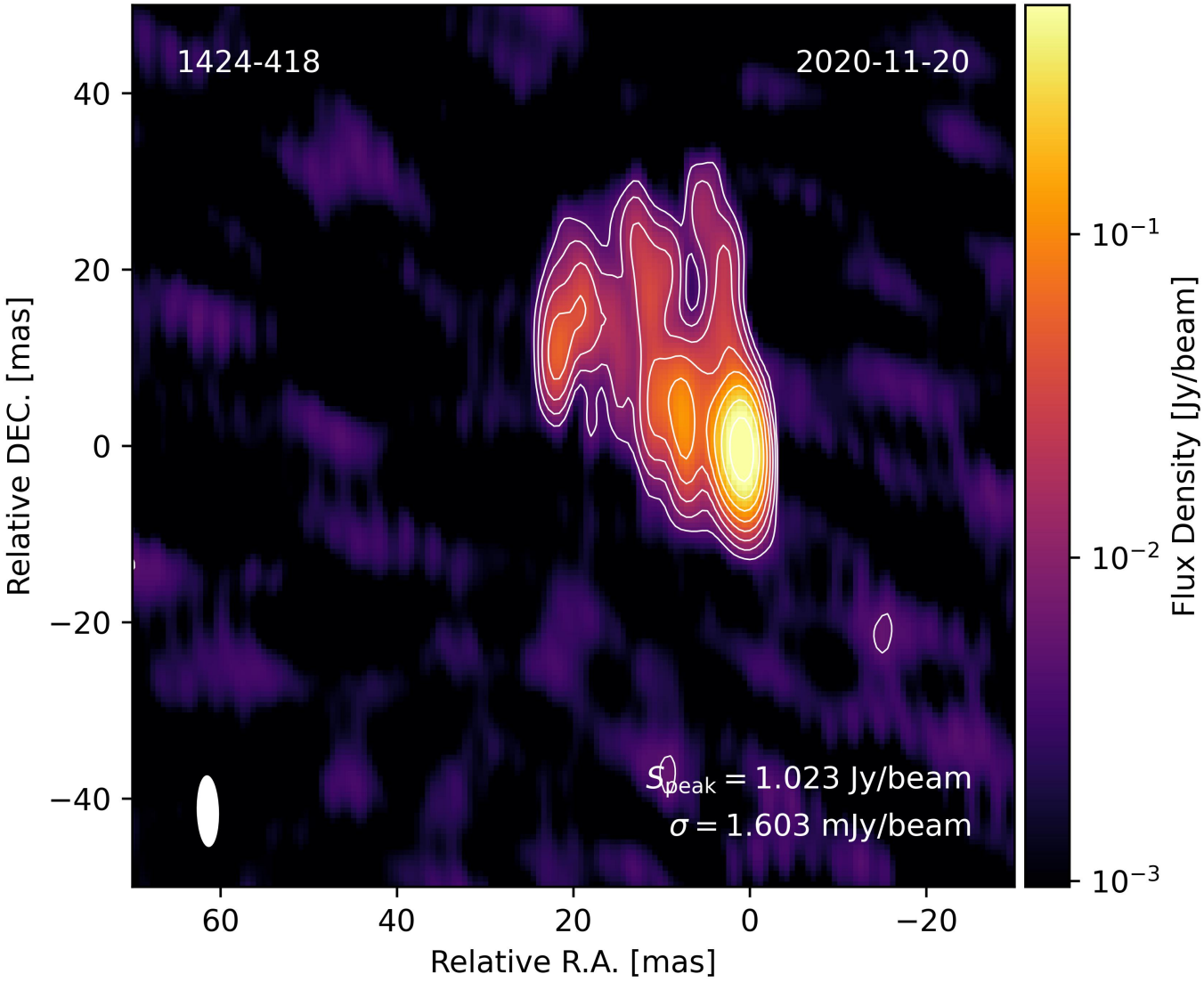




Kadler et al. 2016

- Associated at ~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 at 8.4 GHz

Preliminary 2.3 GHz Image of PKS 1424-418



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 with the LBA+
- Multiwavelength observations at higher energies (optical/UV, X-ray, γ-ray)

Credit: TANAMI homepage

TANAMI Observations

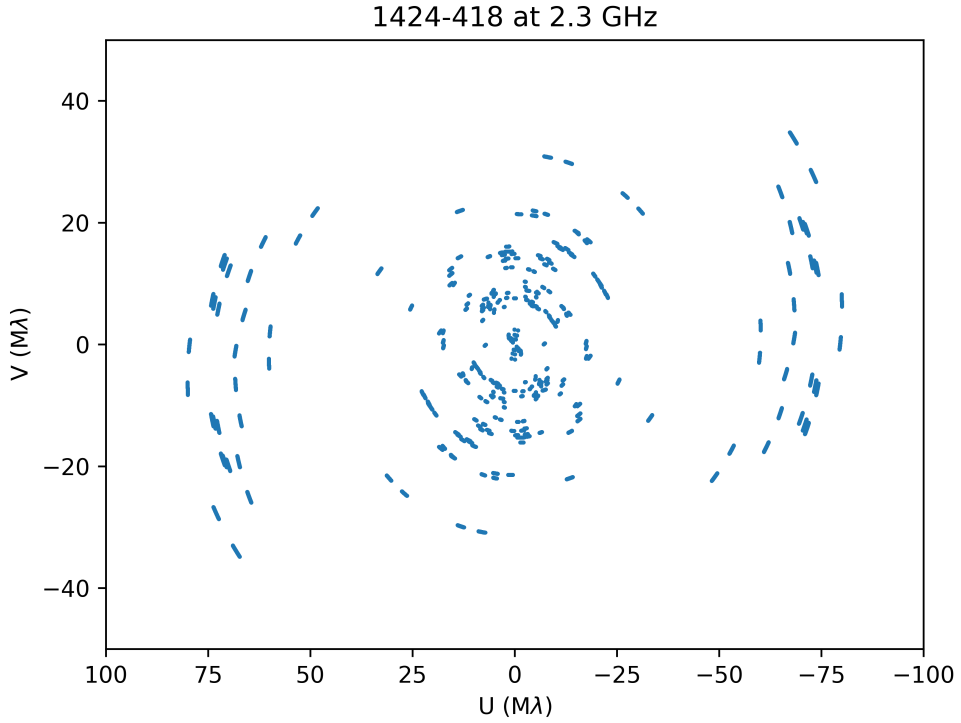
- 2007 – 2020: Observations at 8.4 GHz and 22.3 GHz
- Since 2020: Observations at 2.3 GHz and 8.4 GHz
- ~6 scans of ~10 min. spread over a few hours
  ➔ 1 hour per source

2.3 GHz observations:

- Once per year
- Bandwidth: 14.5 MHz

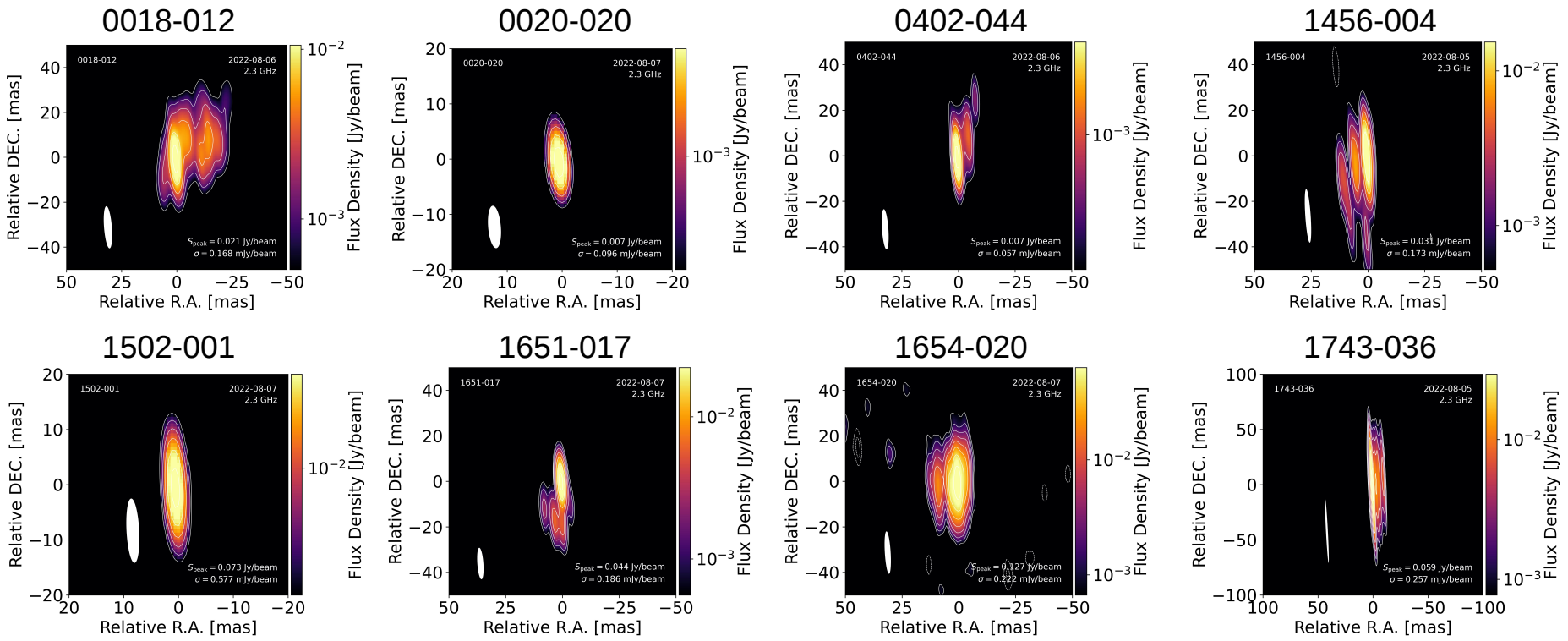
8.4 GHz observations:

- 3 times per year
- Bandwidth: 8 MHz

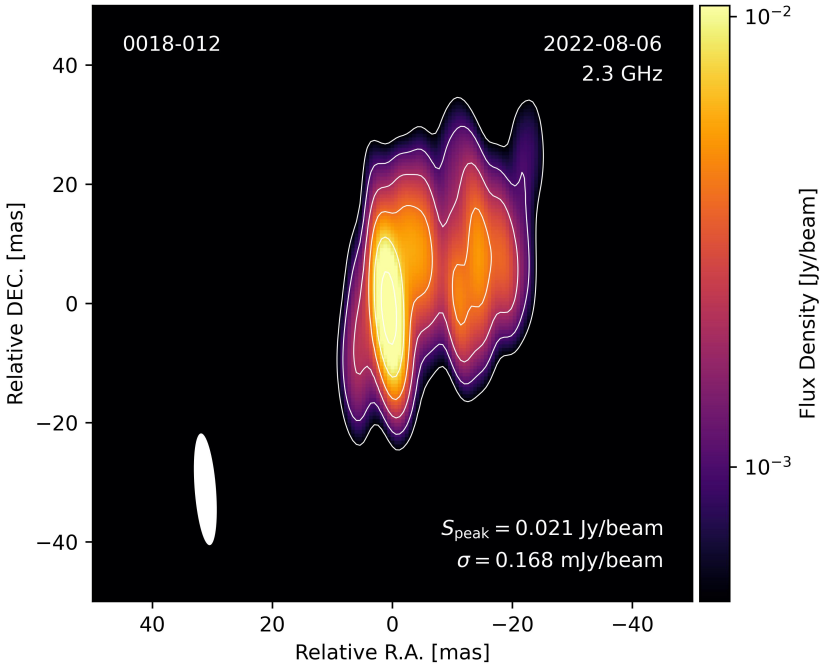


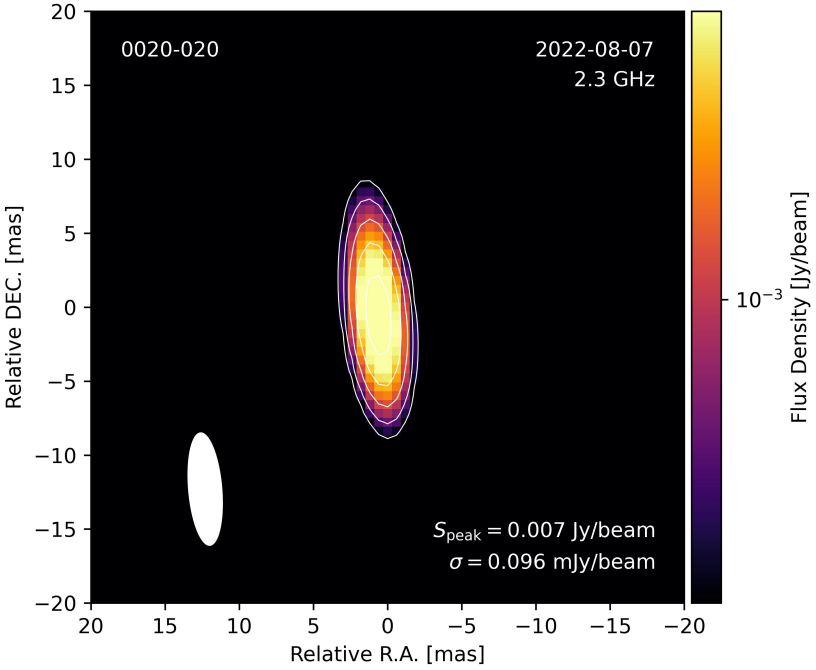
TANAMI 2.3 GHz Observations of AGN in IceCube Neutrino Fields

- AGN listed in 2021d RFC catalog located inside of Southern-Hemisphere IceCube neutrino fields
- Small IceCube neutrino fields
  - ➔ Not more than 2 AGN inside 90% localization region



IC190922B, Signalness: 51%, 187 TeV, 2 RFC sources





$S_{tot} = 59\,mJy$

$SNR = 125$

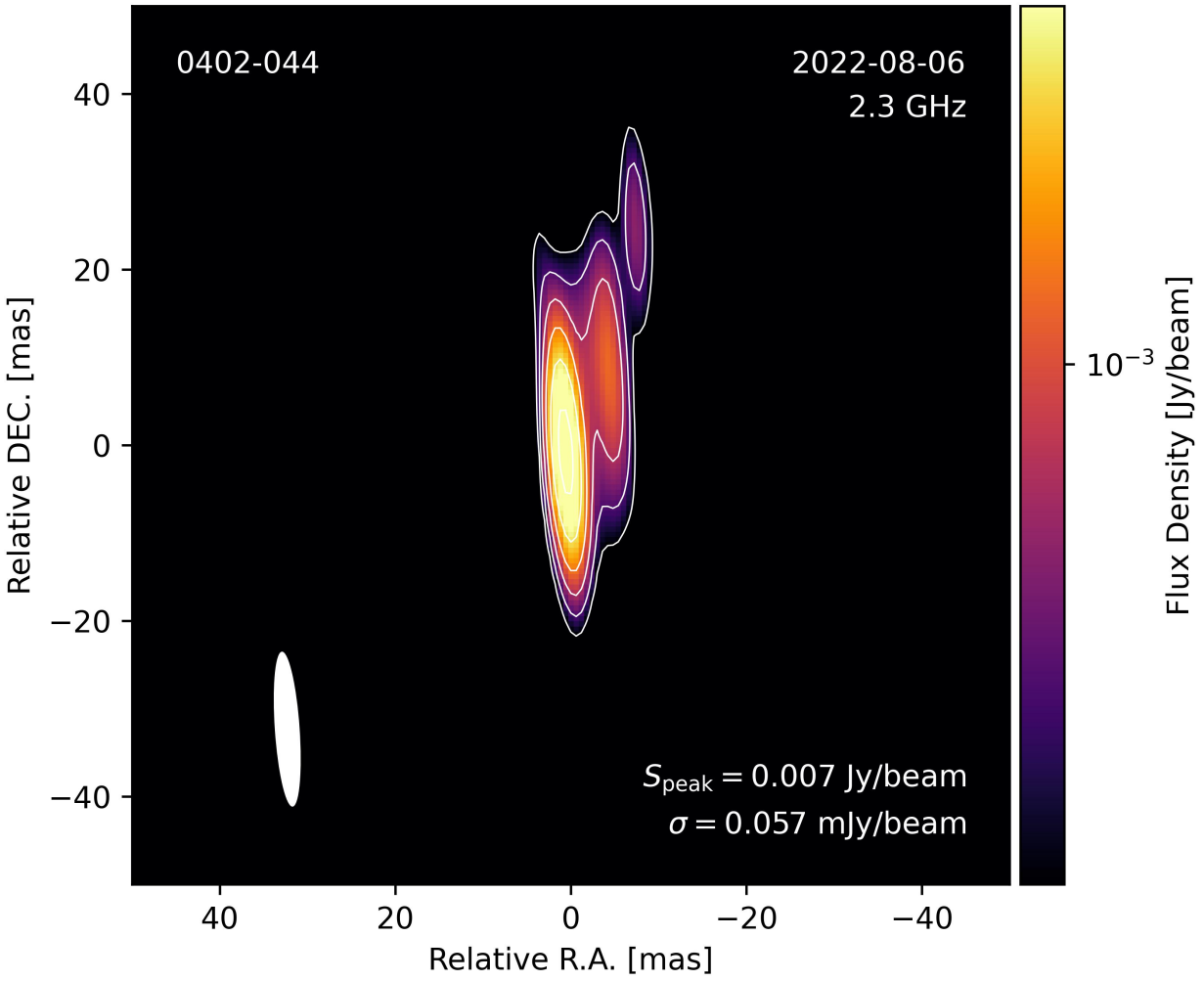
$T_{B,core} > 5.82 \cdot 10^{8}\,K$

$S_{tot} = 7\,mJy$

$SNR = 73$

$T_{B,core} > 9.70 \cdot 10^{9}\,K$

IC210922A, Signalness: 93%, 751 TeV, 1 RFC source

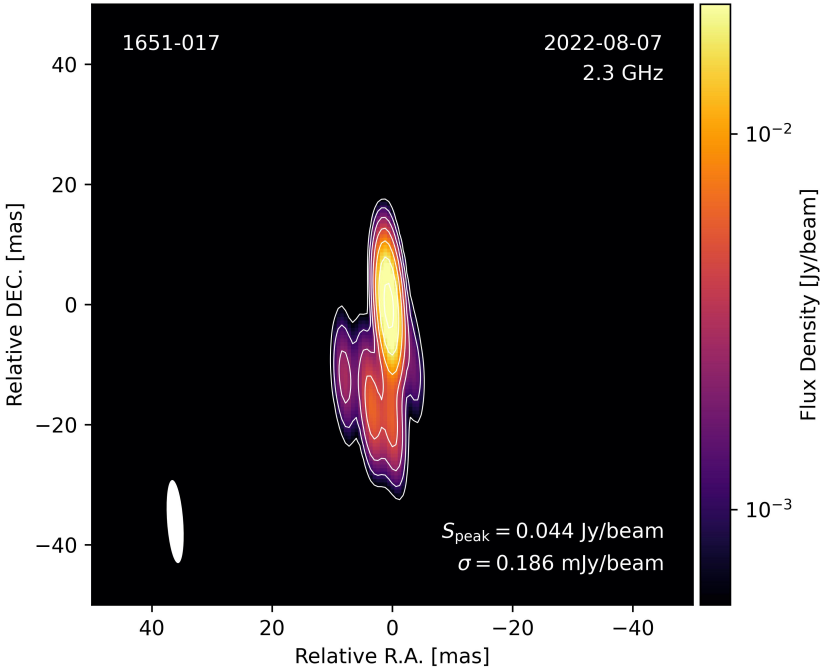


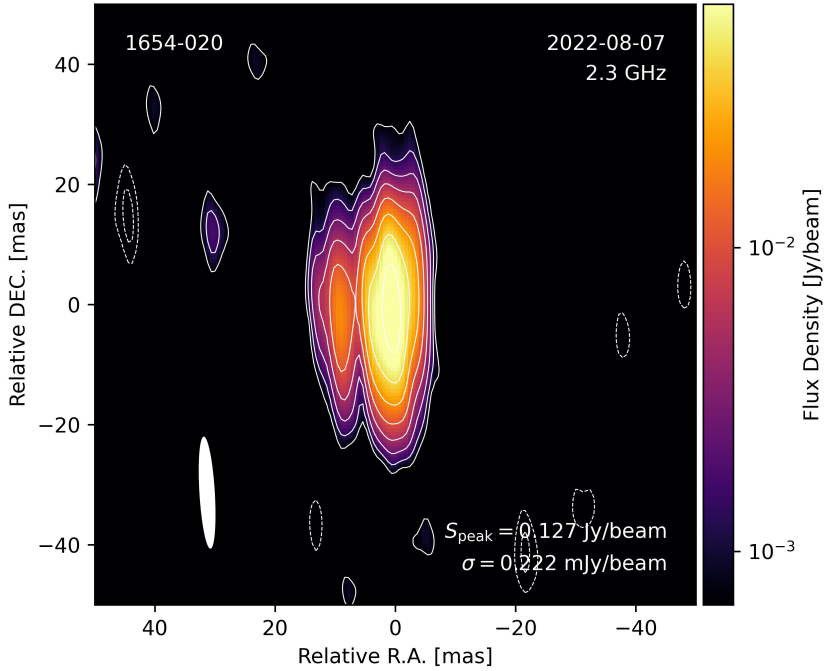
$S_{tot} = 9\,mJy$

$SNR = 123$

$T_{B,core} > 9.81 \cdot 10^{8}\,K$

IC211023A, Signalness: 33%, 121 TeV, 2 RFC sources





$S_{tot} = 63\,mJy$

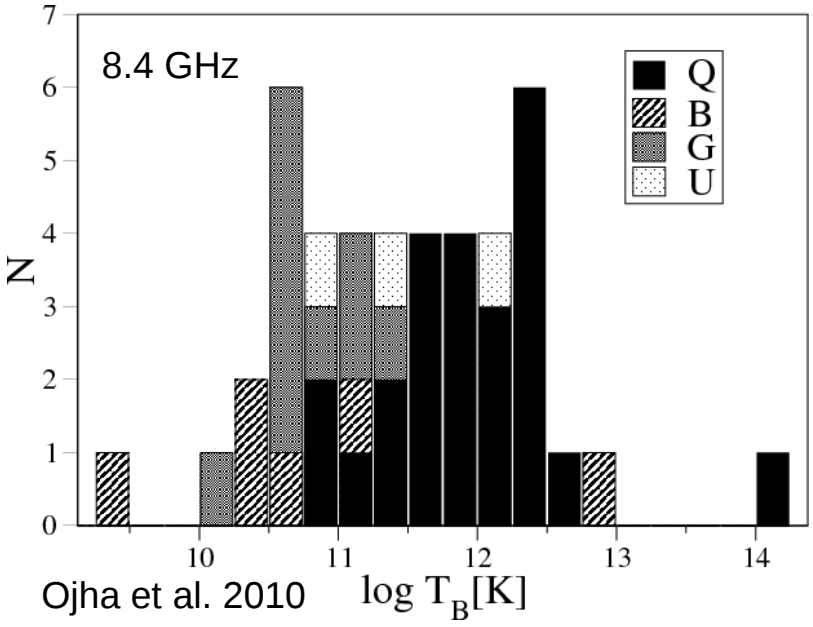
$SNR = 237$

$T_{B,core} > 1.39 \cdot 10^{10}\,K$

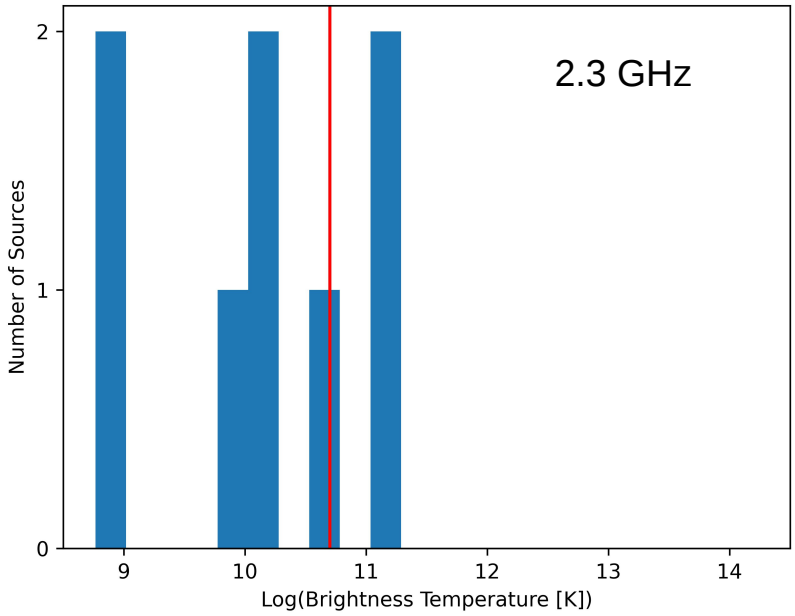
$S_{tot} = 301\,mJy$

$SNR = 572$

$T_{B,core} > 5.42 \cdot 10^{10}\,K$



Ojha et al. 2010

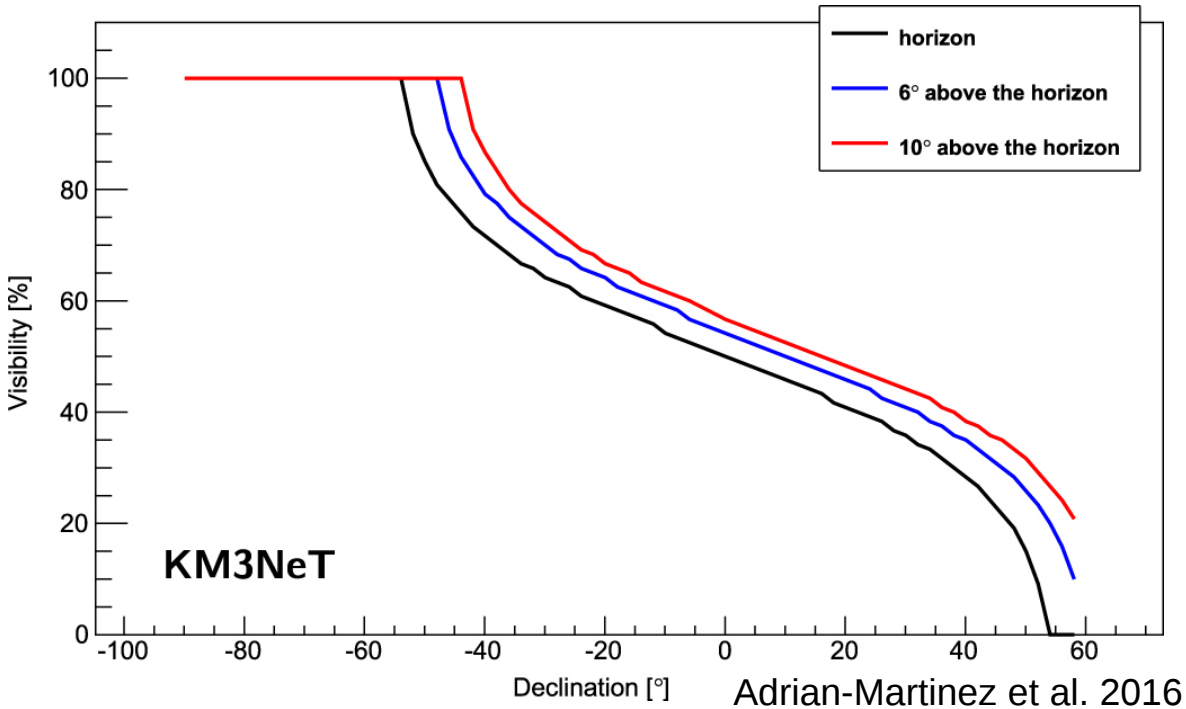


Brightness Temperature

- Lower brightness temperatures compared to 8.4 GHz TANAMI observations
- Consistent with brightness temperatures from 2.3 GHz TANAMI observations of TeV blazars
  ➔ Poster P6 by Petra Benke
- Spine-sheath neutrino production model
- More data are needed to confirm this
  ➔ 8.4 GHz TANAMI observations

The Future: KM3NeT

- Neutrino telescope located in the Mediterranean sea
- Mostly sensitive to neutrino emission from the Southern Sky
- Will increase the importance of Southern-Hemisphere radio monitoring programs like TANAMI



Adrian-Martinez et al. 2016

Conclusion

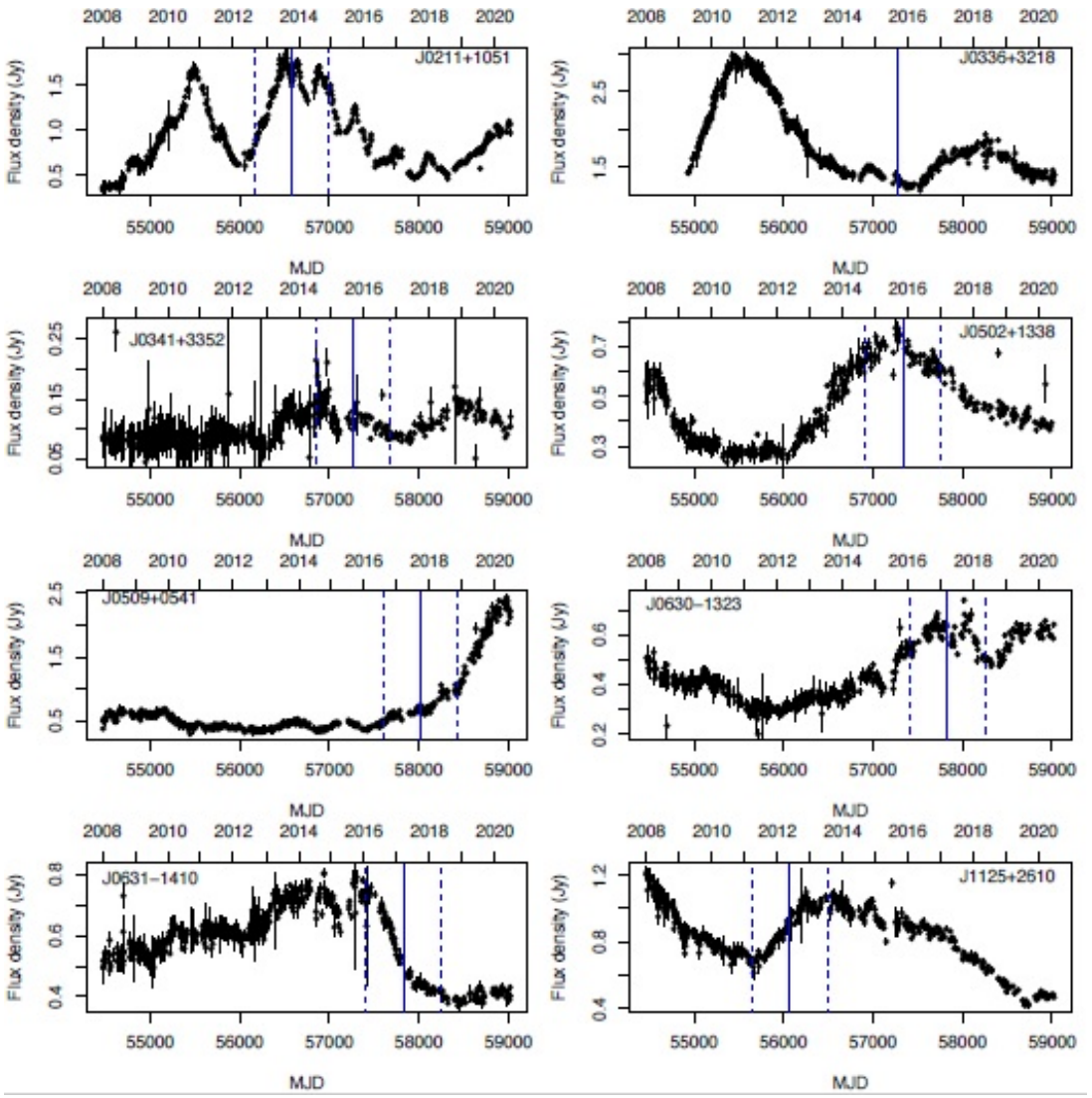
- 2.3 GHz TANAMI observations of RFC radio sources located in IceCube neutrino fields
- Mostly faint sources with flux densities below 100 mJy
- Lower brightness temperatures compared to TANAMI quasars observed at 8.4 GHz
- Brightness temperatures similar to TANAMI TeV blazars observed at 2.3 GHz
  - ➔ Spine-sheath neutrino production model
- Rapidly growing KM3NeT will increase the importance of Southern-Hemisphere radio monitoring programs like TANAMI

Backup

Neutrino – Radio Connection

Hovatta et al. 2021:

- Association of IceCube neutrinos with radio sources
- Half of the sources not detected at γ-rays
- Radio variability and Doppler factors similar to γ-ray detected sources
- Number of strongly flaring sources is unlikely to be a random coincidence

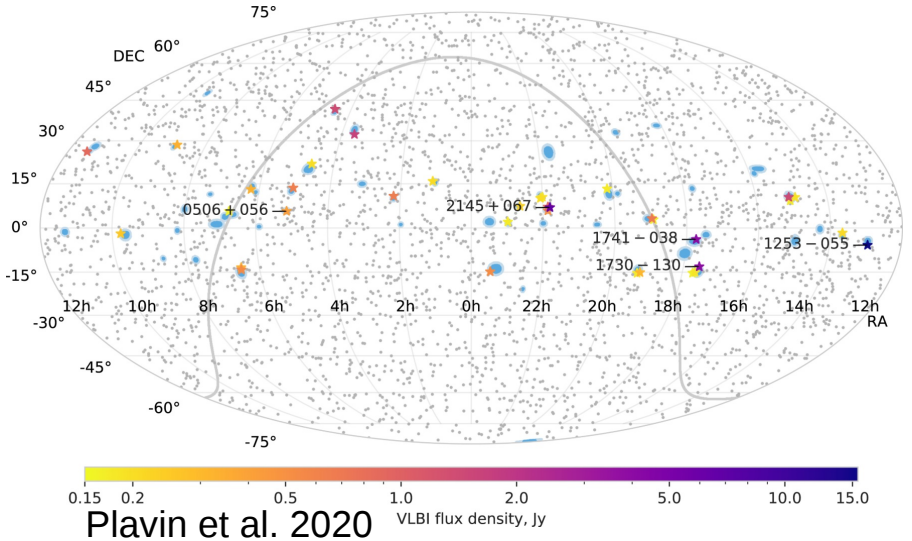


Hovatta et al. 2021

Catalog Correlation Analysis

Plavin et al. 2020, 2021, 2022:

- Complete VLBI flux density-limited sample of AGNs from Astrogeo RFC Catalog
- Neutrino-associated AGNs have stronger parsec-scale cores
- Increase of radio emission at frequencies above 10 GHz around neutrino arrival time



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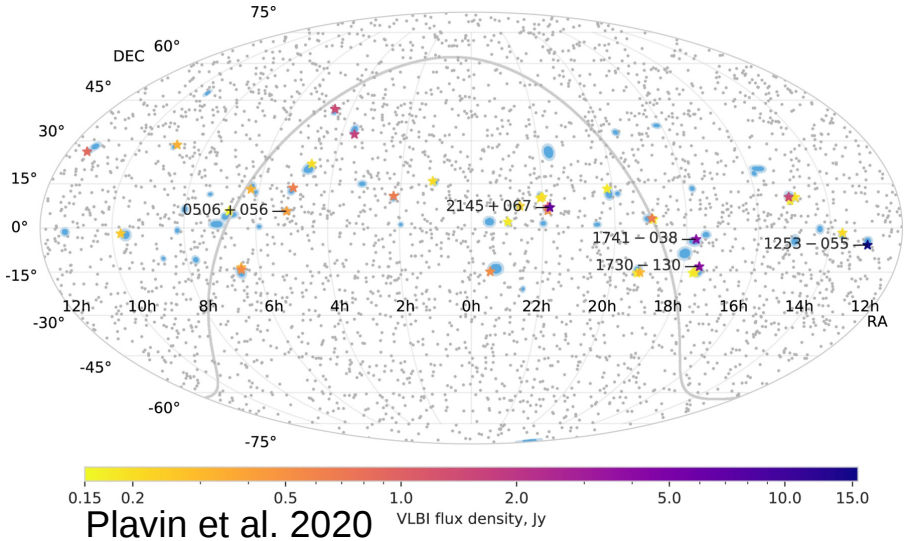
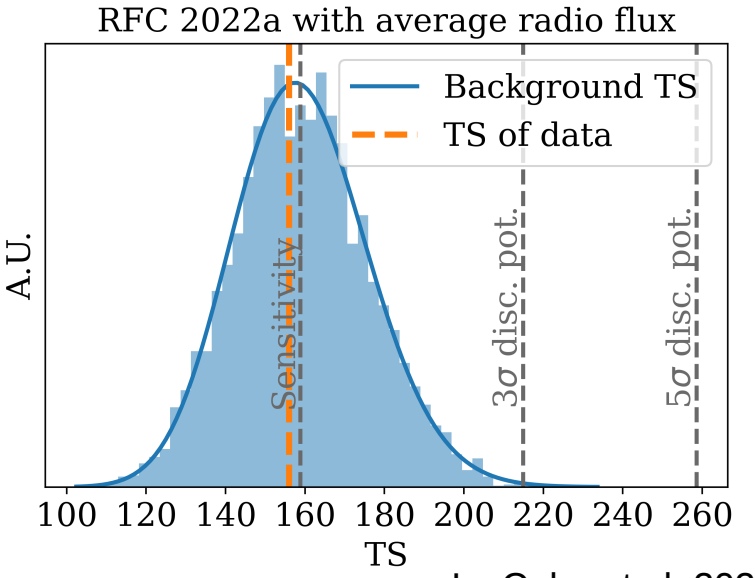


Plavin et al. 2020

IceCube Collaboration 2023:

- No statistically significant correlation between RFC sources and neutrino emission
- < 1% of AGN are neutrino emitters
- Result is compatible with background



IceCube et al. 2023

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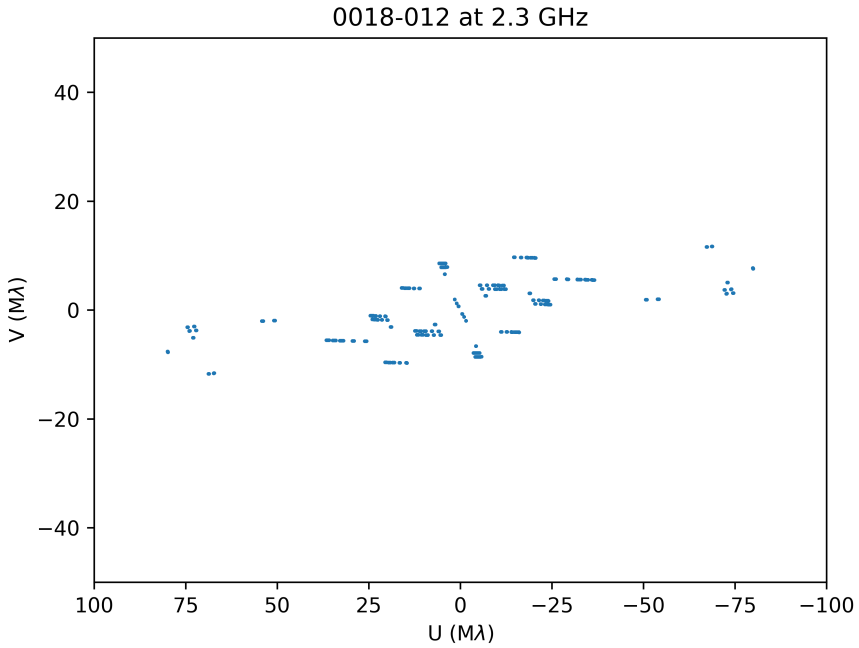

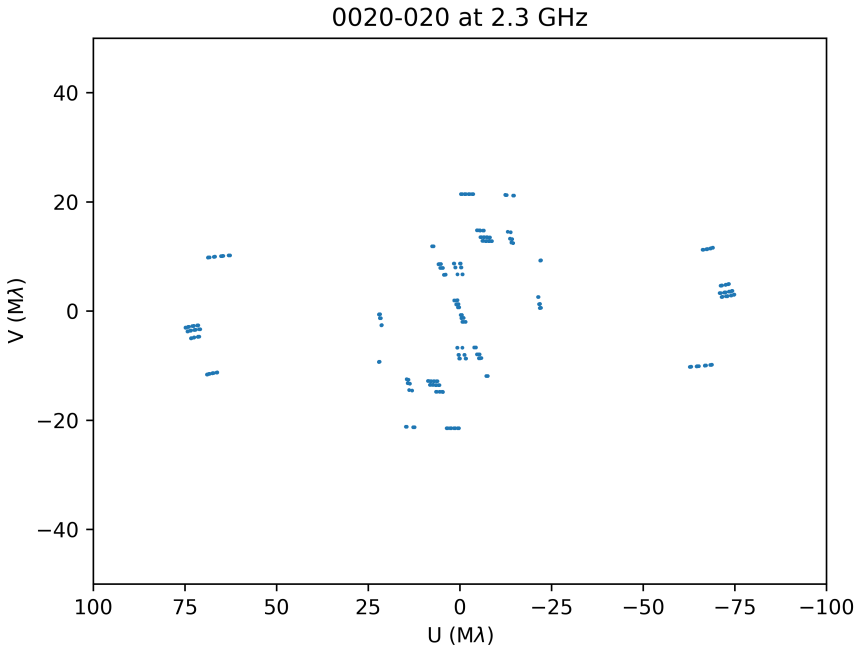

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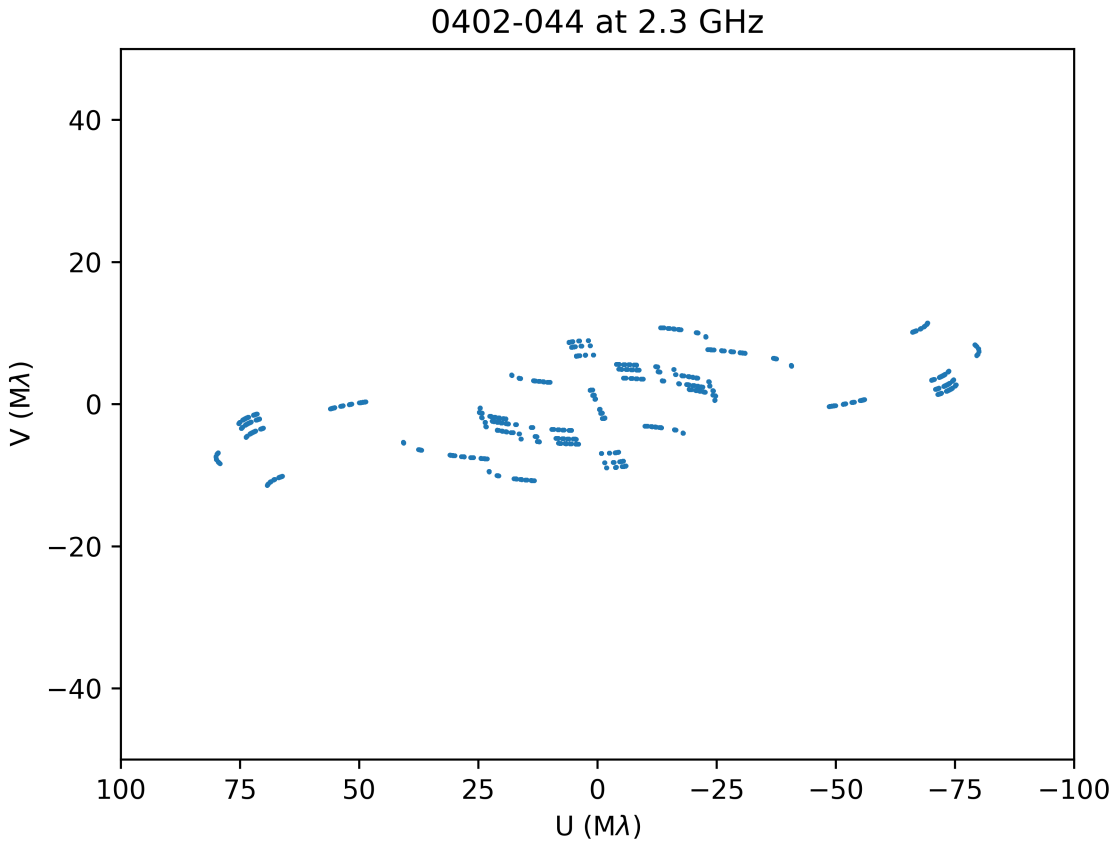
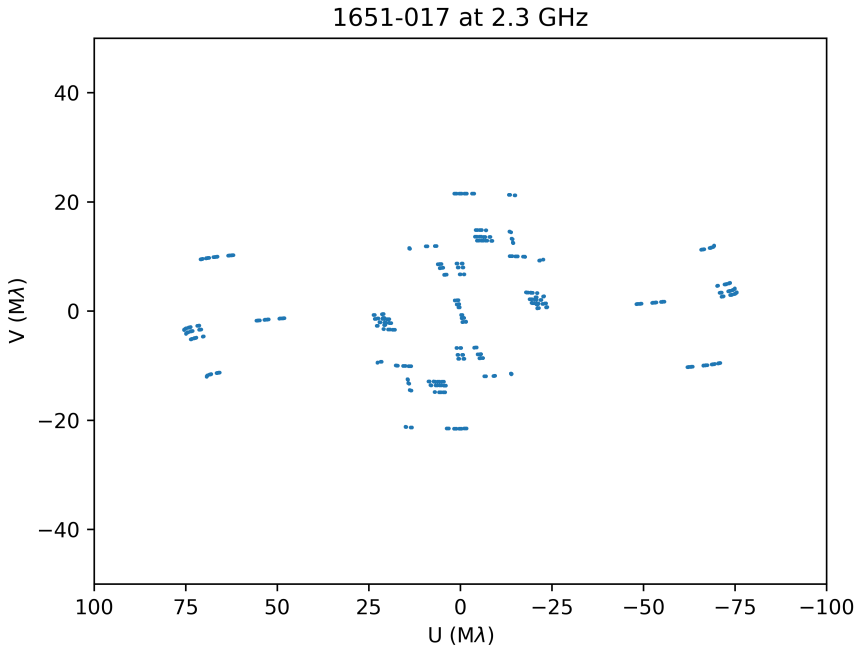
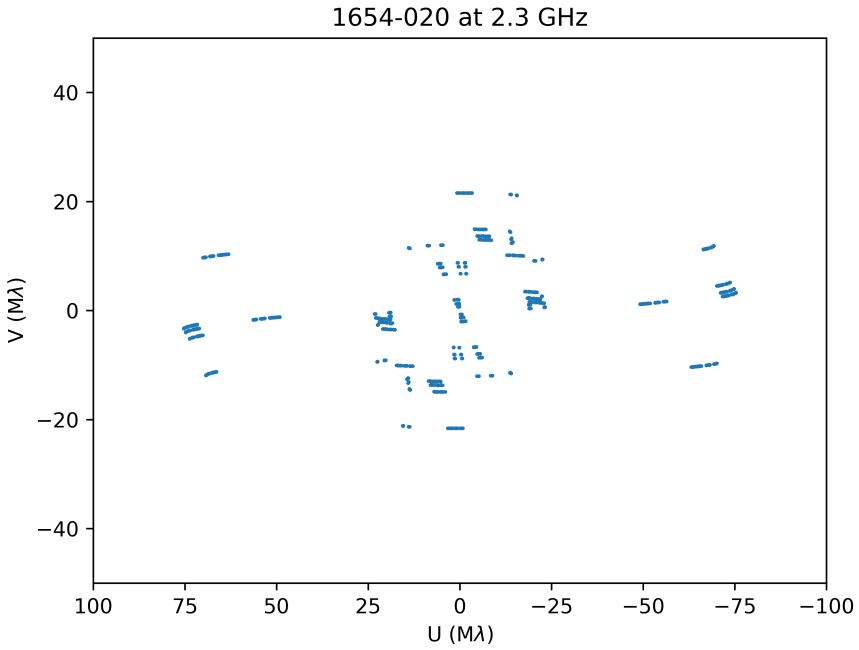
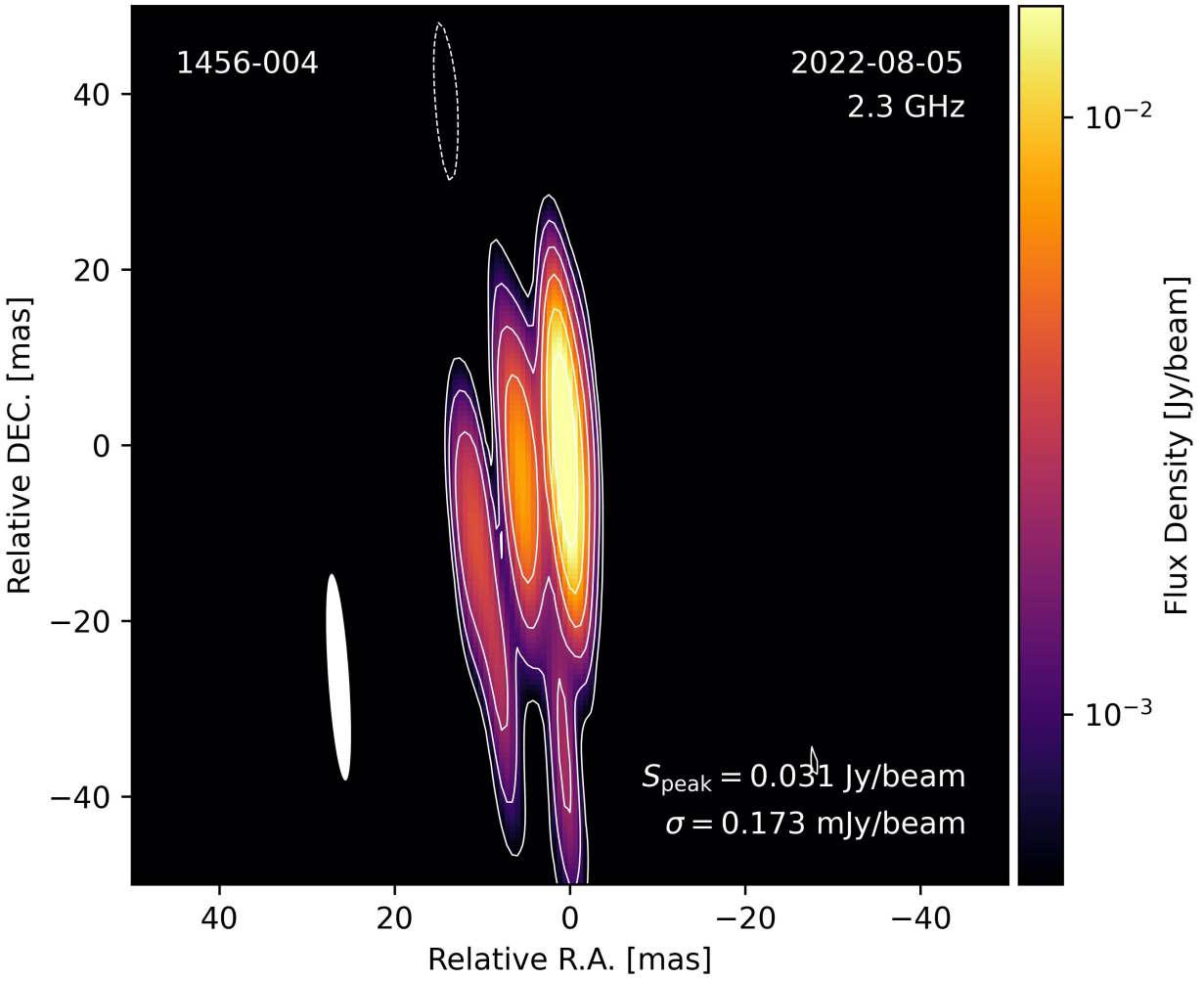


IC211023A, Signalness: 33%, 121 TeV, 2 RFC sources





IC220513A, Signalness: 56%, 208 TeV, 1 RFC source

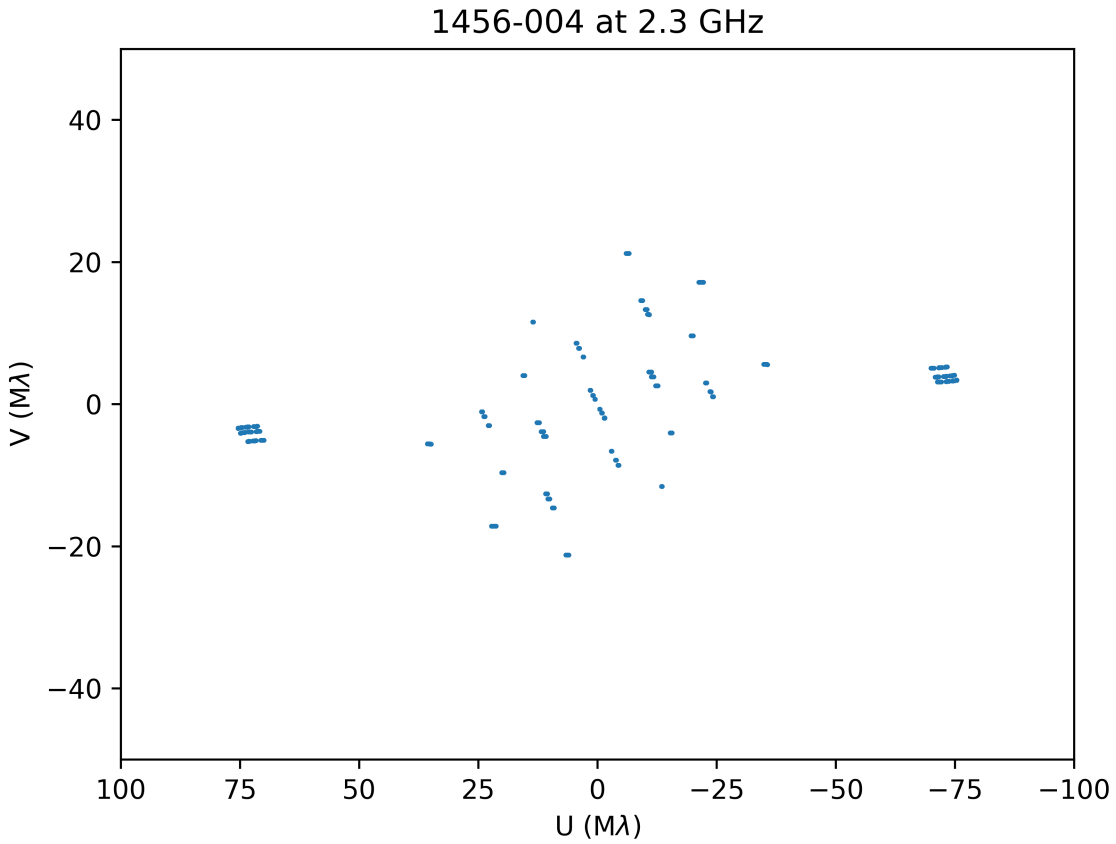


$S_{tot} = 59\,mJy$

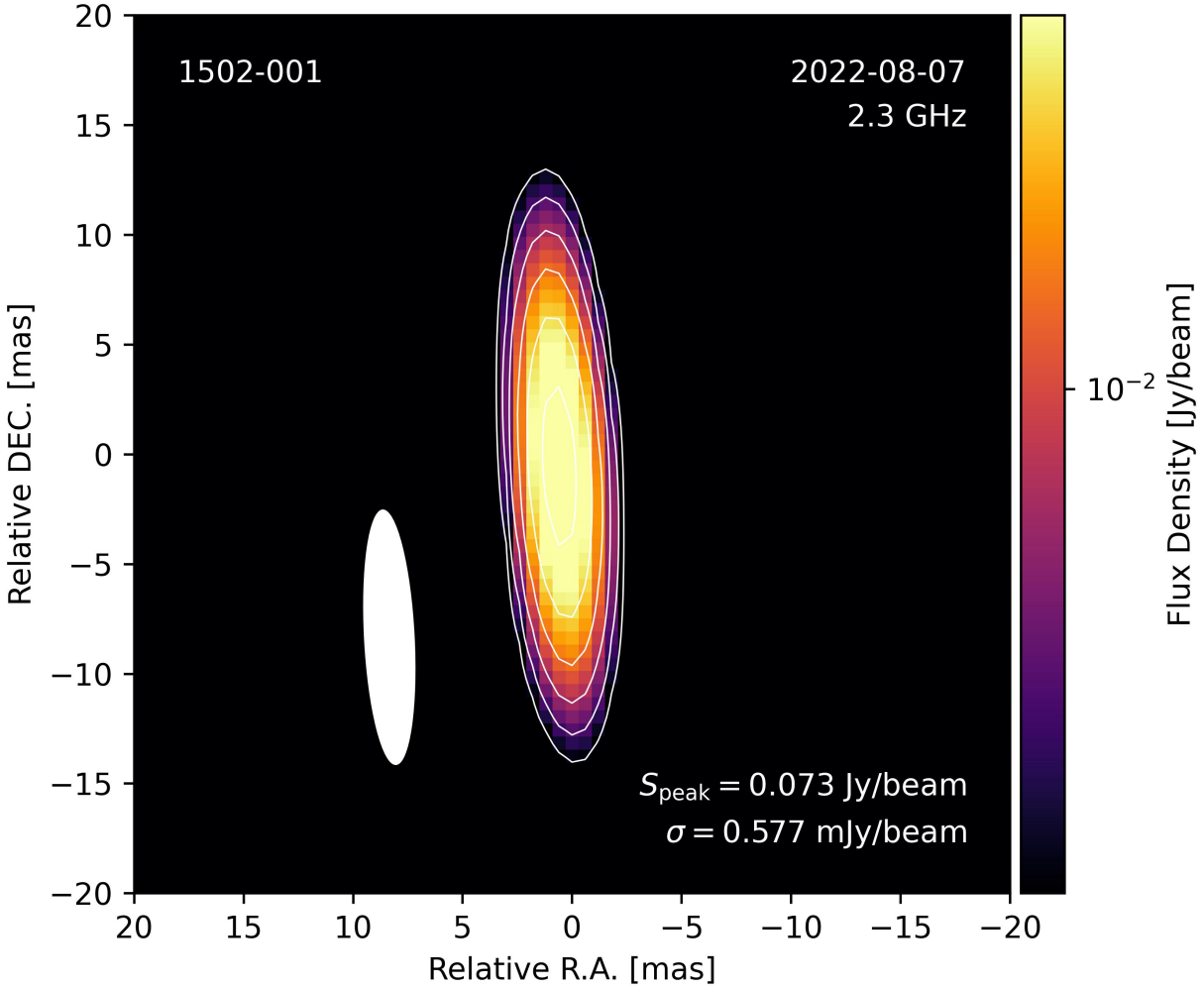
$SNR = 179$

$T_{B,core} > 1.18 \cdot 10^{10}\,K$

IC220513A, Signalness: 56%, 208 TeV, 1 RFC source



IC211117A, Signalness: 53%, 195 TeV, 1 RFC source



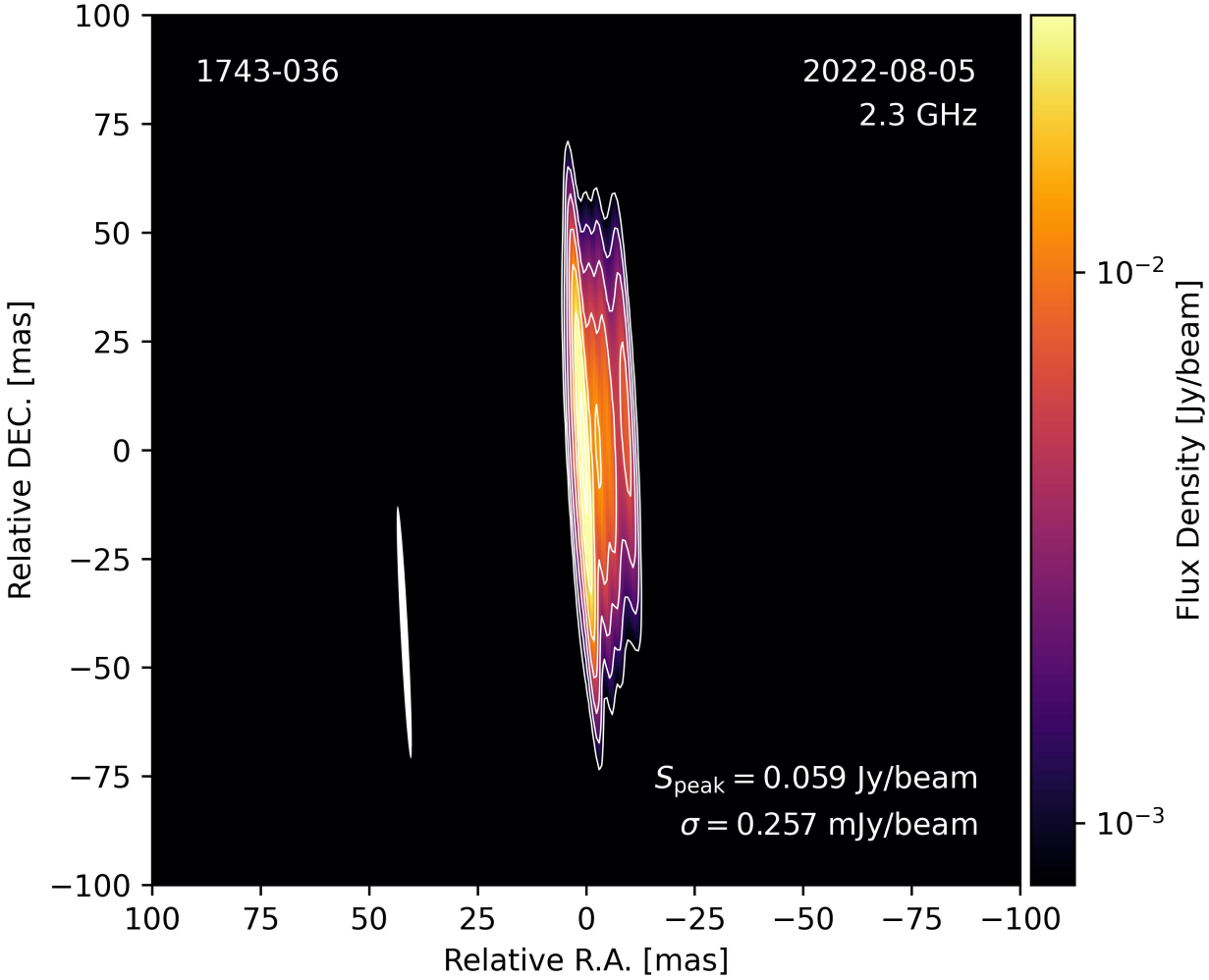
$S_{tot} = 79\,mJy$

$SNR = 127$

$T_{B,core} > 1.94 \cdot 10^{11}\,K$

IC211117A, Signalness: 53%, 195 TeV, 1 RFC source

IC220205B, Signalness: 59%, 216 TeV, 1 RFC source



$S_{tot} = 119\,mJy$

$SNR = 230$

$T_{B,core} > 1.14 \cdot 10^{11}\,K$

IC220205B, Signalness: 59%, 216 TeV, 1 RFC source