Multimessenger study of neutrino-candidate blazar PKS 0735+178 using Korean VLBI Network multi-band observations

Kim, S., et al., in prep.

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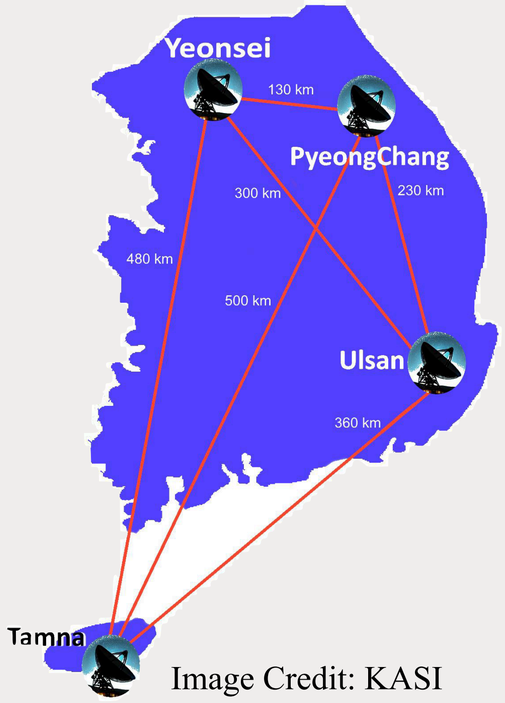
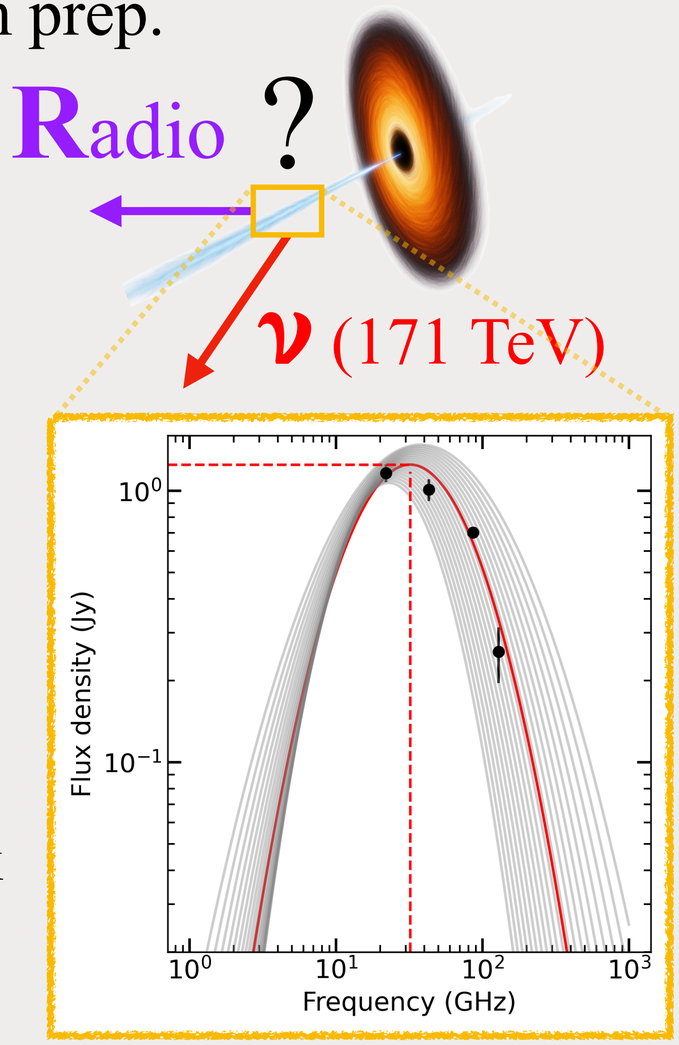


Image Credit: KASI

Korean VLBI Network (KVN) at 22–129 GHz



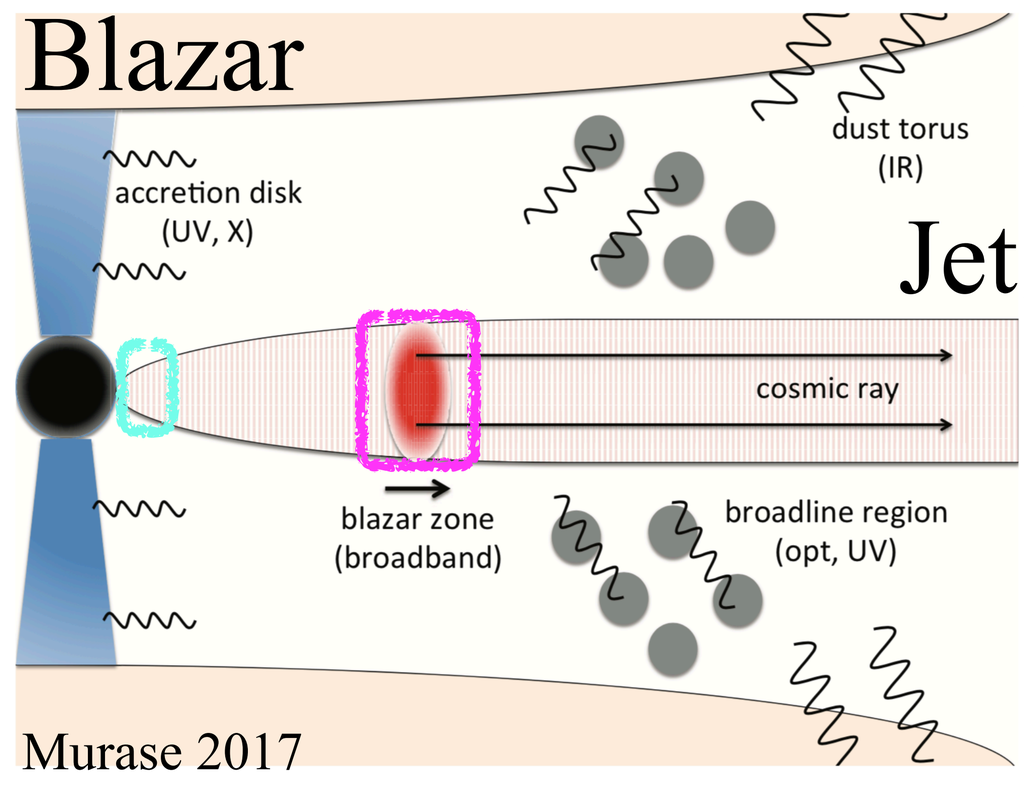
Towards high-performance mm-VLBI science operations with multi-band receivers

Area della Ricerca CNR, 29.10.2025

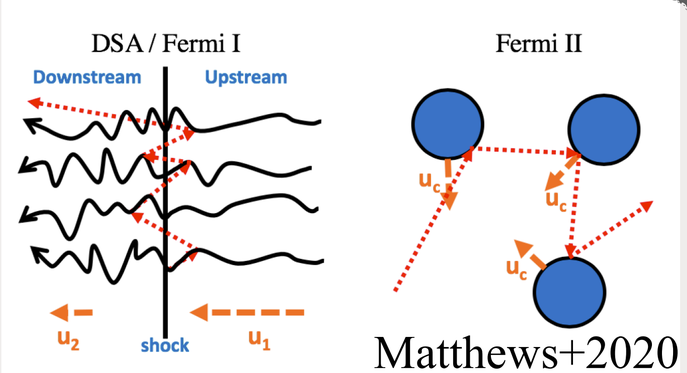
Korea Astronomy and Space Science Institute

Scientific goal

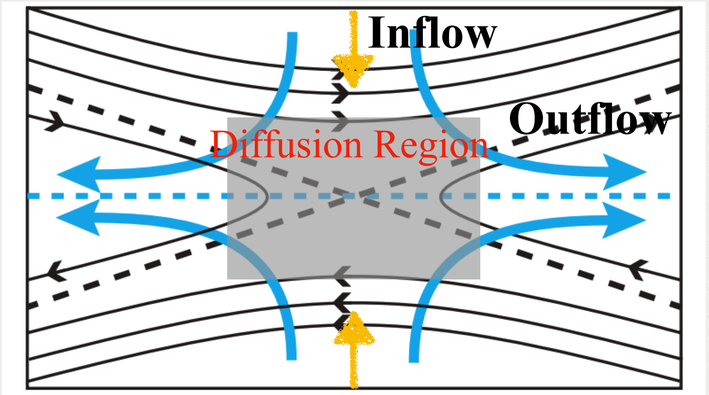
Do blazar jets produce high-energy neutrinos?



Shock

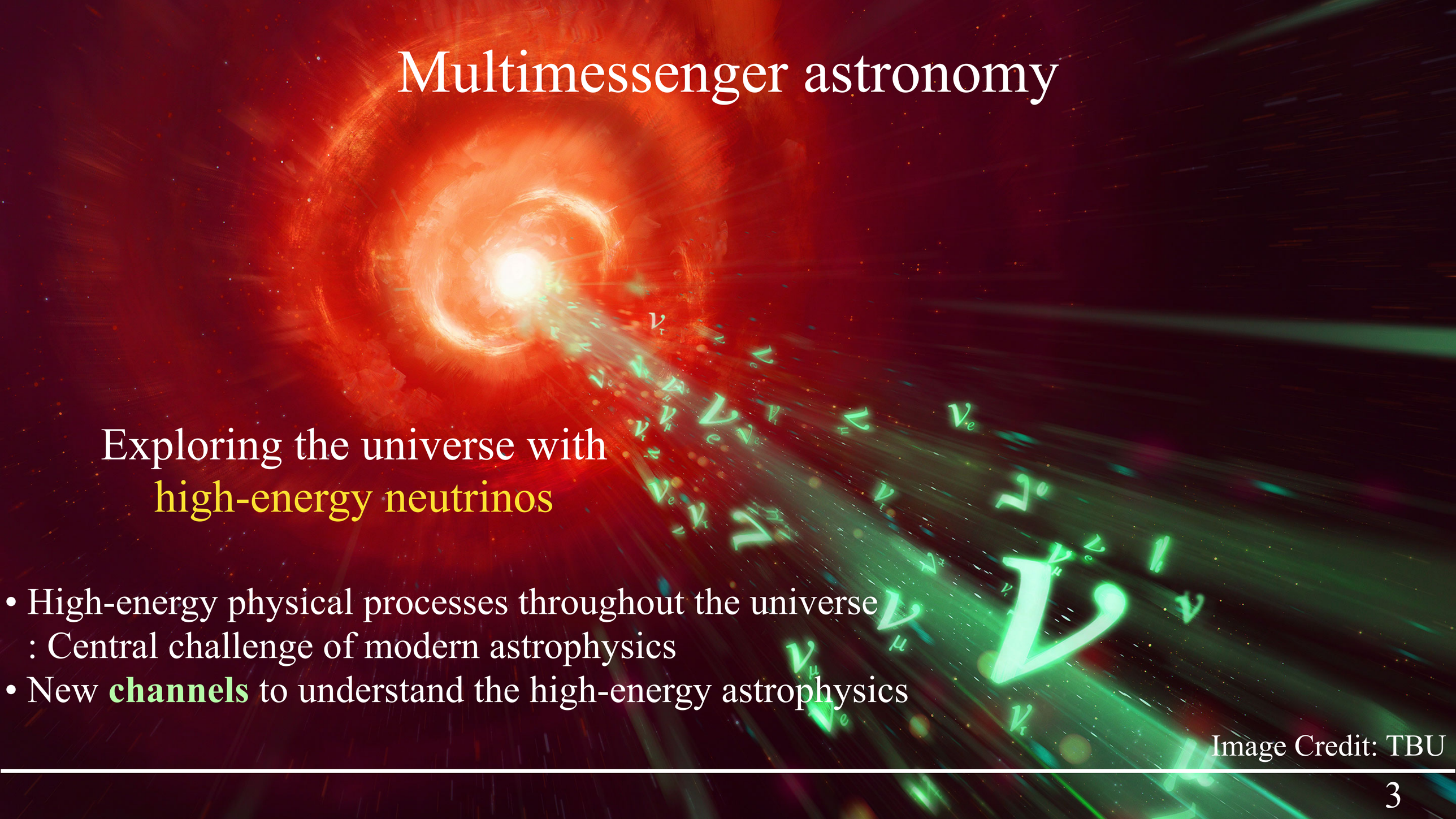


Magnetic Reconnection



- Where **neutrinos** are generated in blazars? **Jet** vs. **Near the black hole**?
- Where do **target photons** come from?
- How particles are produced? **Shock** acceleration or **magnetic reconnection**?

Multimessenger astronomy



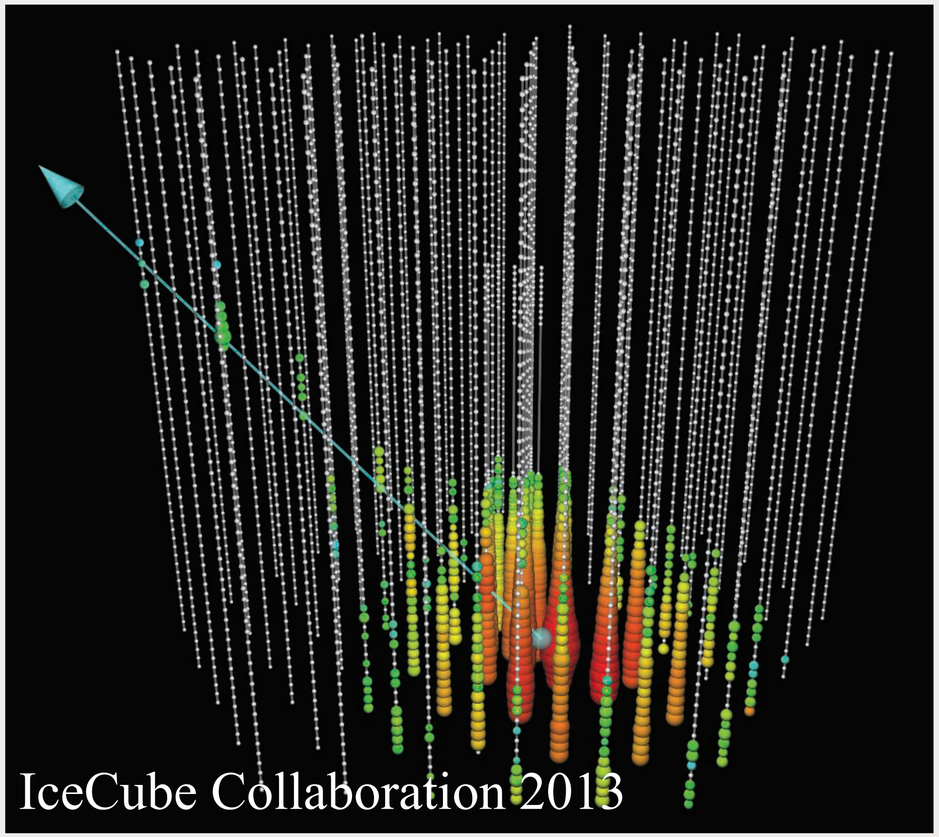
Exploring the universe with
high-energy neutrinos

- High-energy physical processes throughout the universe
  : Central challenge of modern astrophysics
- New **channels** to understand the high-energy astrophysics

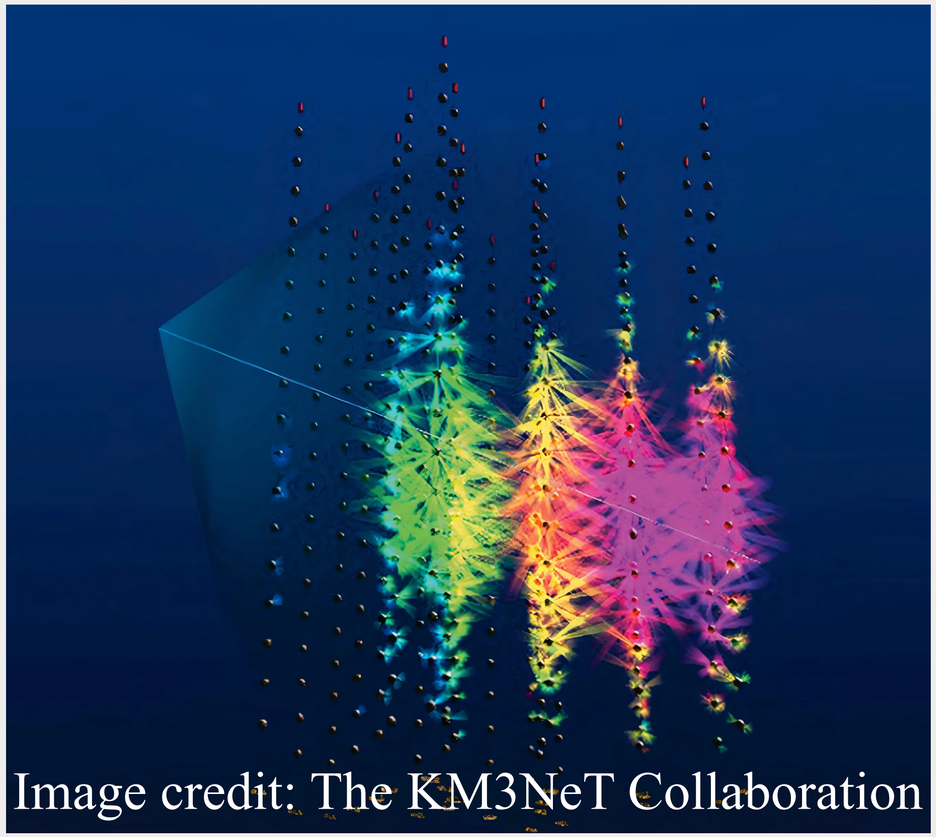
Image Credit: TBU

Astrophysical neutrinos above TeV energies

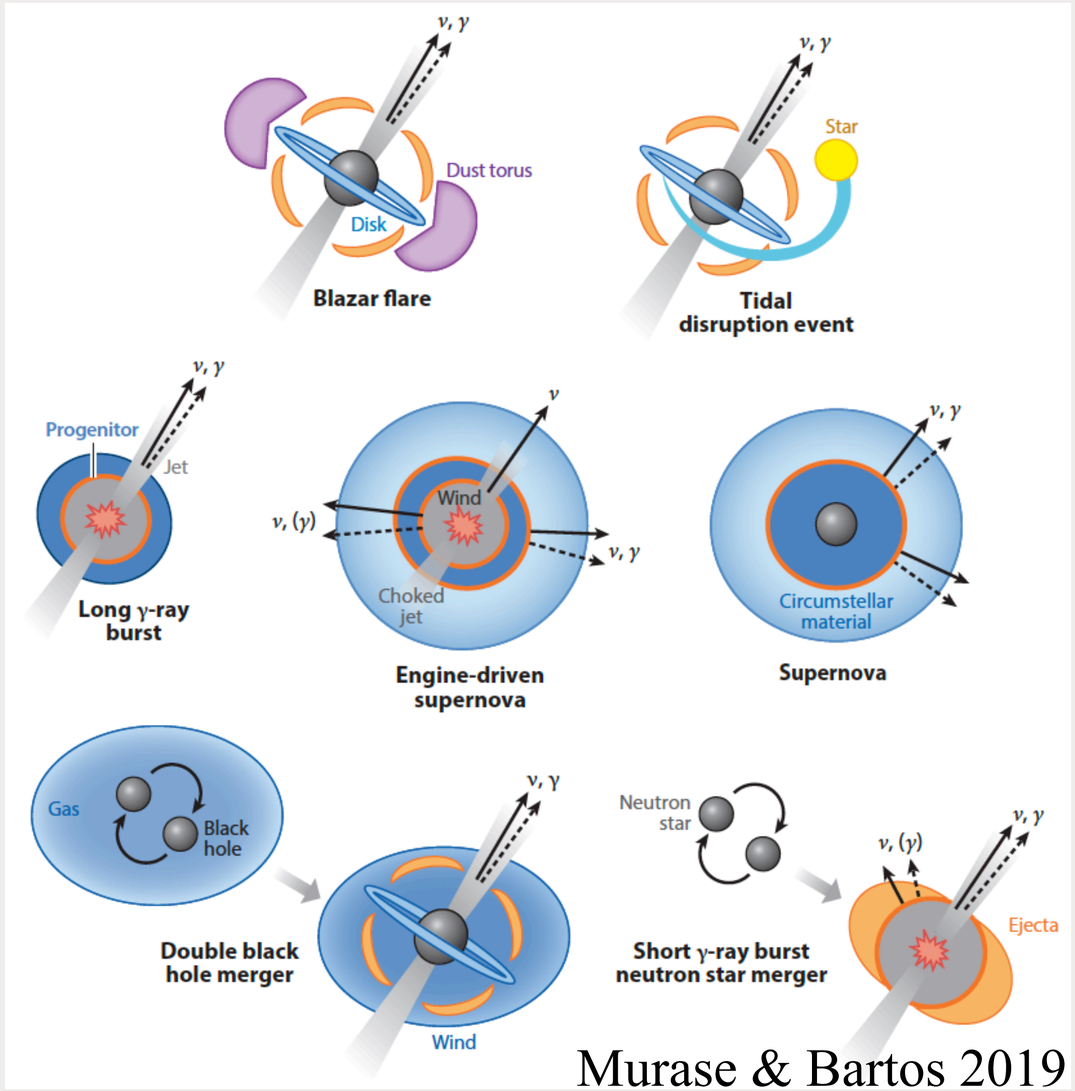
IceCube 250 TeV neutrino event



KM3NeT 220 PeV neutrino event



Multimessengers?

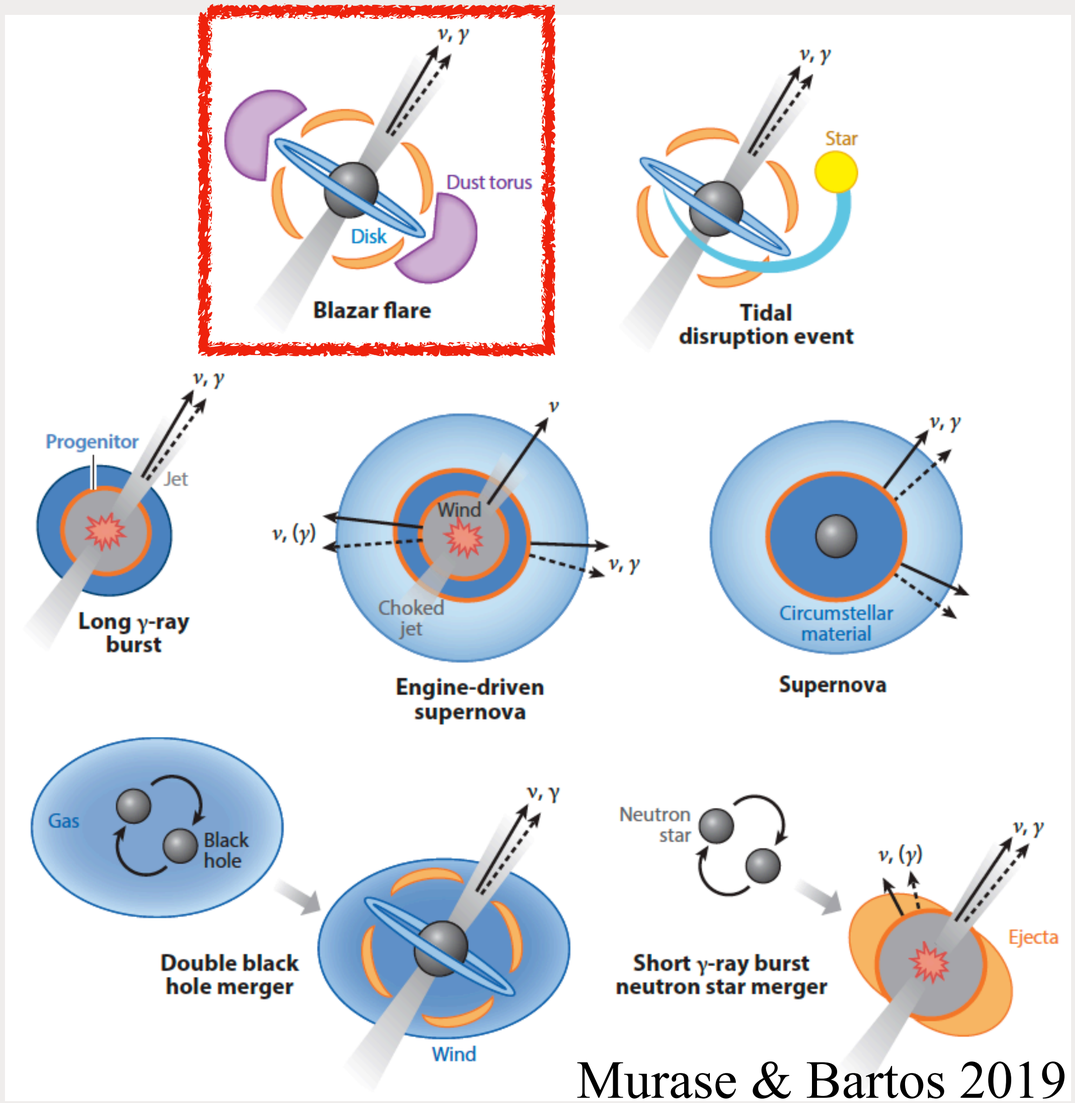


Murase & Bartos 2019

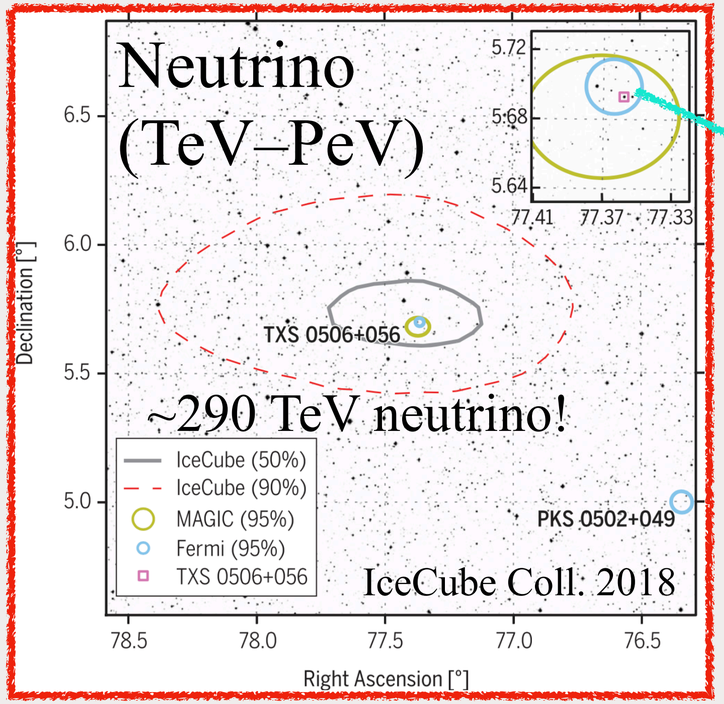
Black holes: Engines of multimessengers

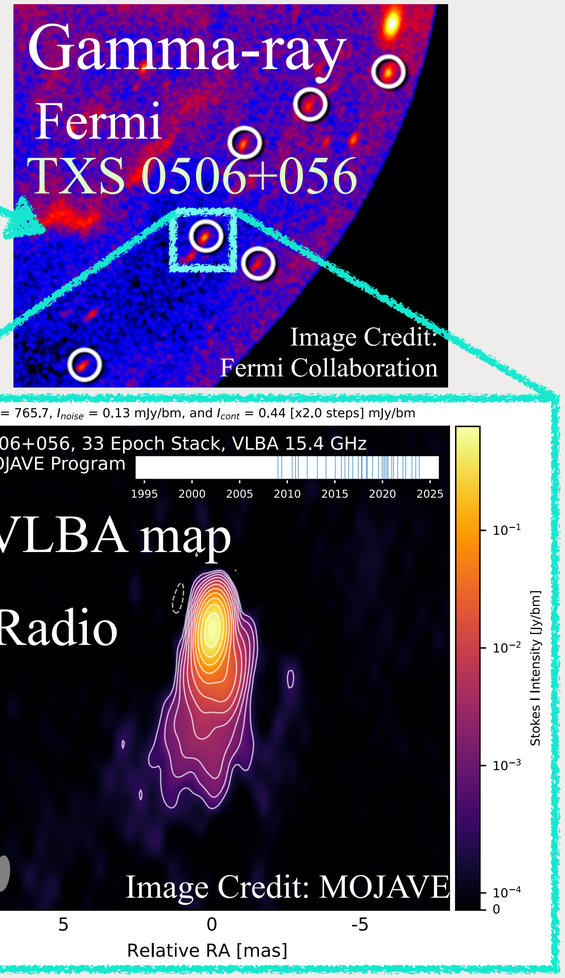
Multimessengers?

"Blazars!"



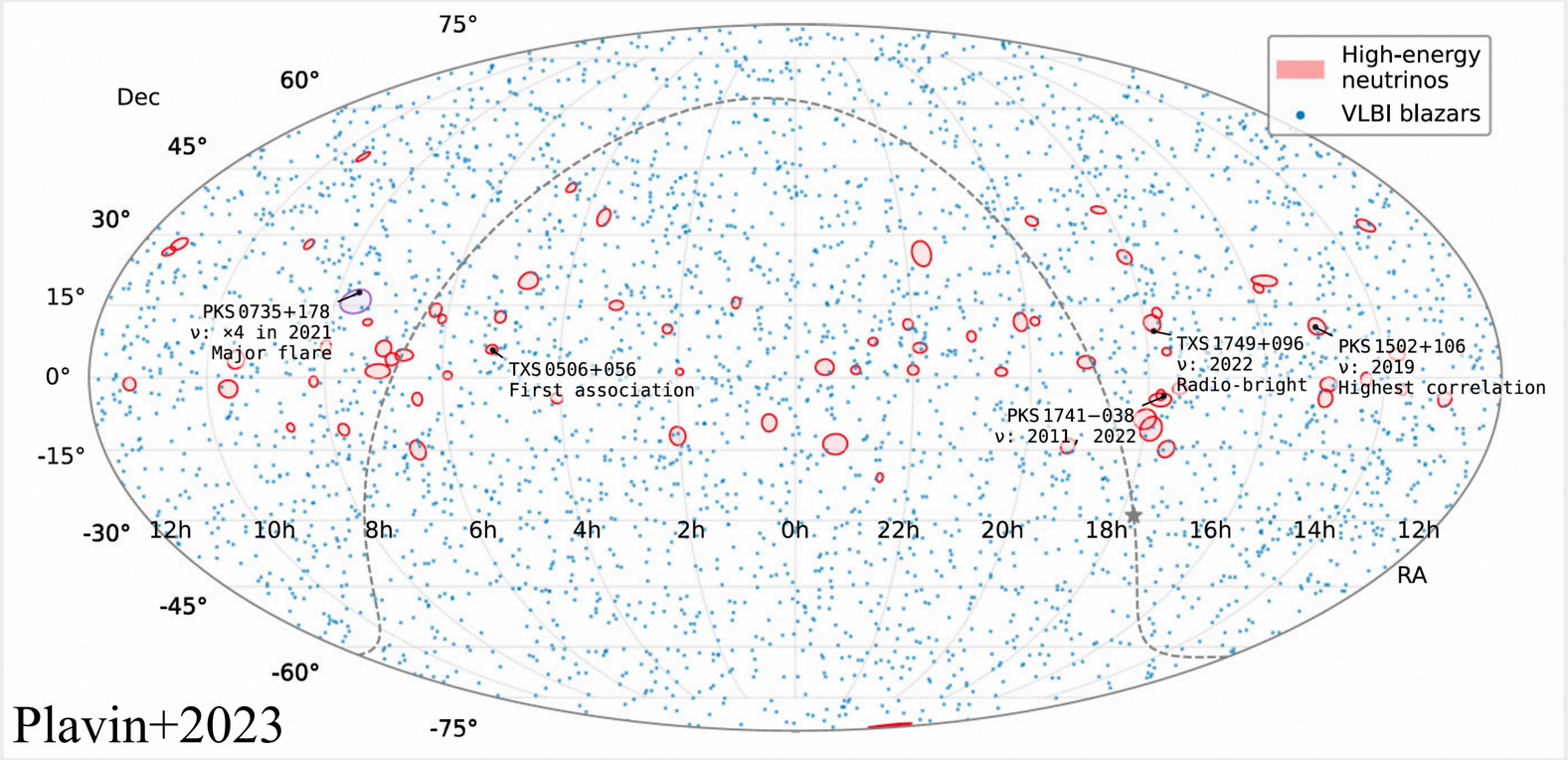
Murase & Bartos 2019



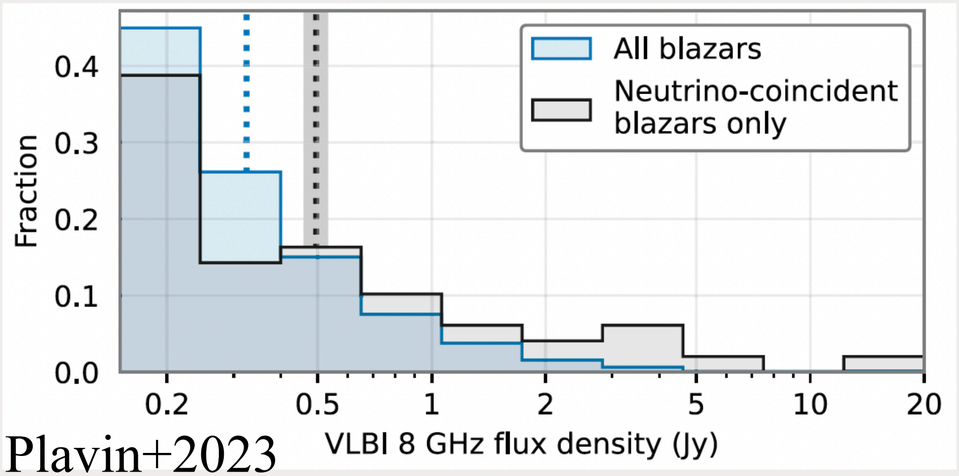


- Blazar TXS 0506+056: First identified IceCube neutrino source
- High-energy neutrino excess at 3-sigma level - mostly AGNs
- AGNs (especially **blazars**) are efficient particle accelerators!

High-energy neutrino–radio blazar connection



Plavin+2023



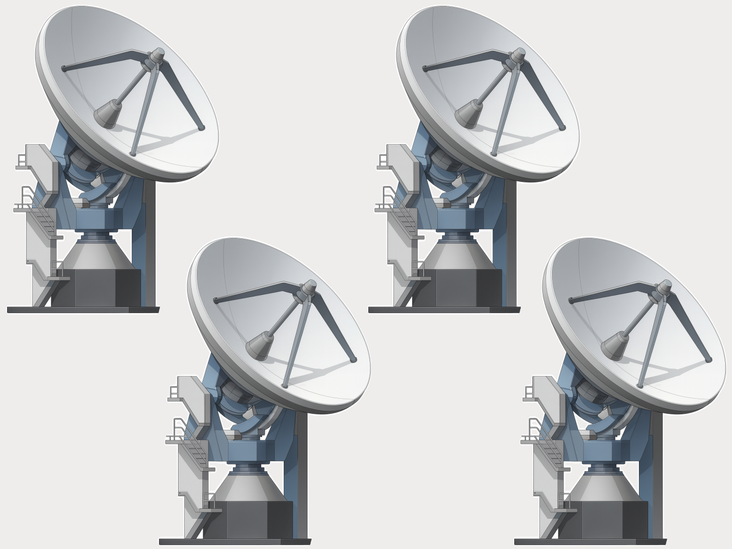
Plavin+2023

- VLBI-bright blazars are **spatially coincident** with high-energy neutrino events.
- Neutrino-associated blazars are **brighter** than non-associated blazars on average.

Why VLBI?

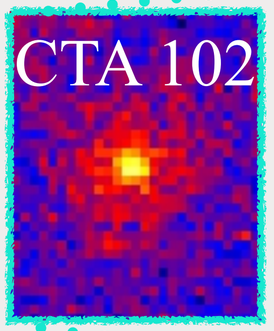
VLBI

: “Unique Facility” to unveil the nature of the High-energy emission



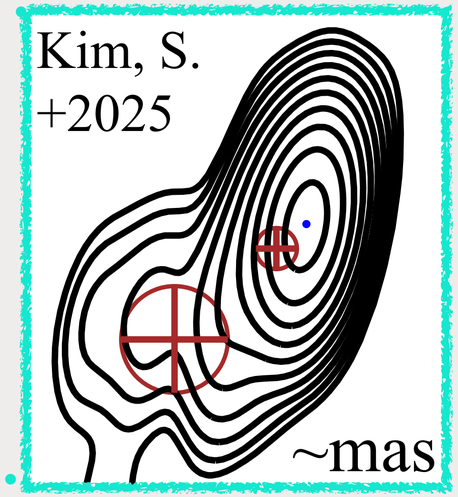
Very Long Baseline Interferometry

Gamma-ray

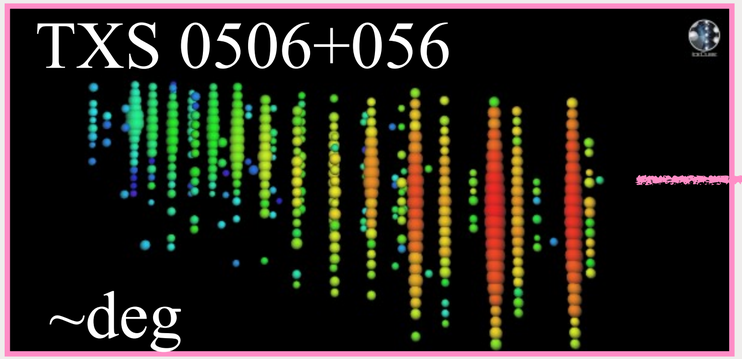


~deg

Radio

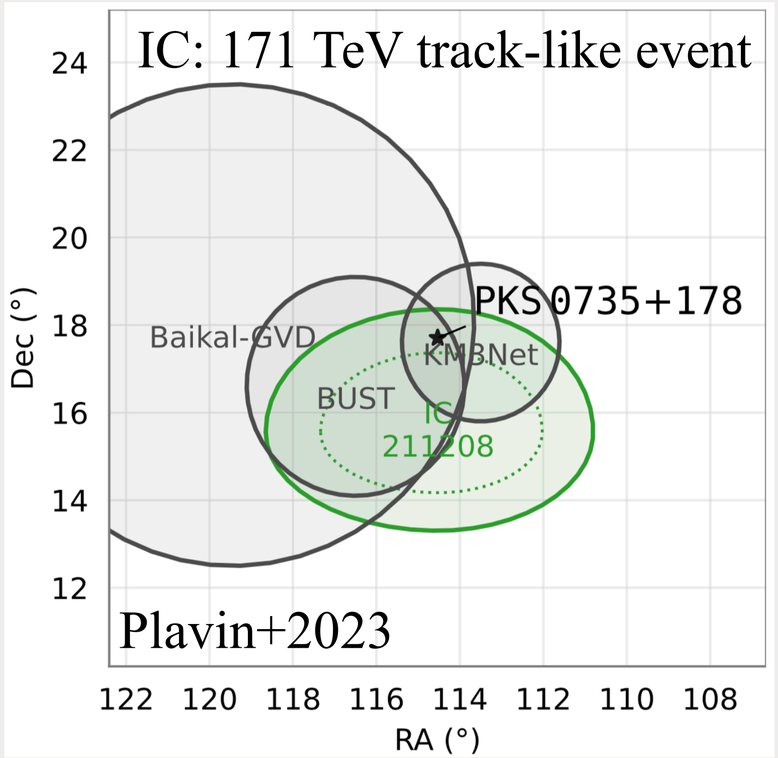


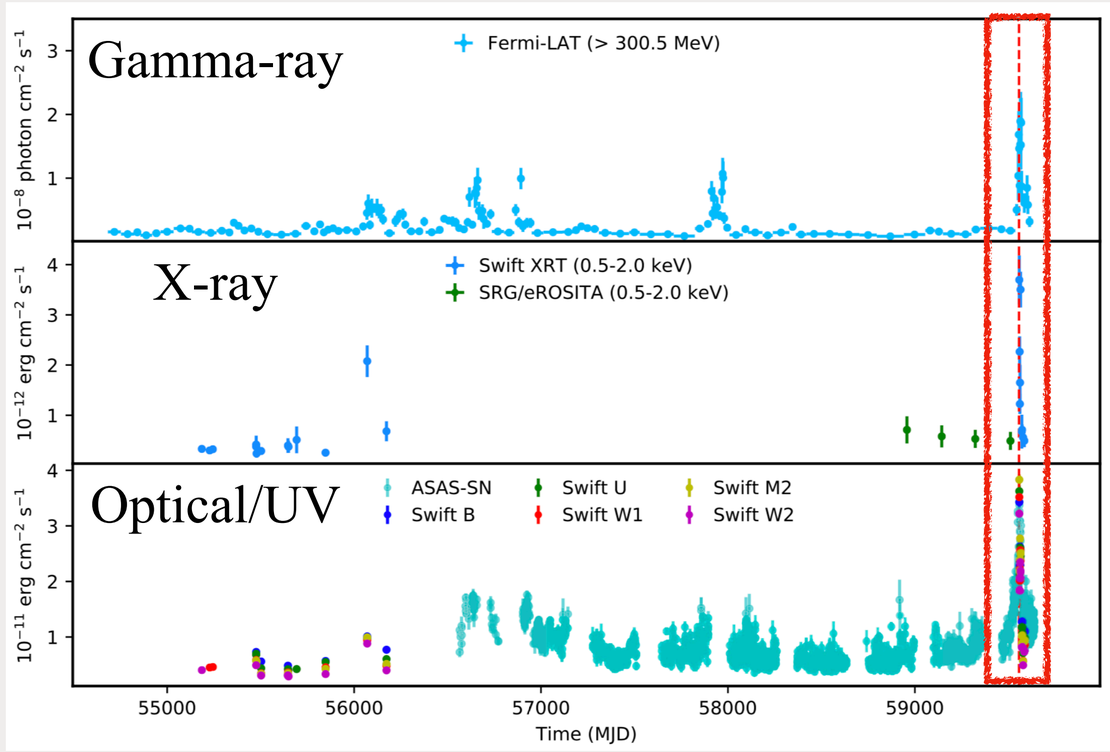
Neutrino



Target source: PKS 0735+178 (J0738+1742)

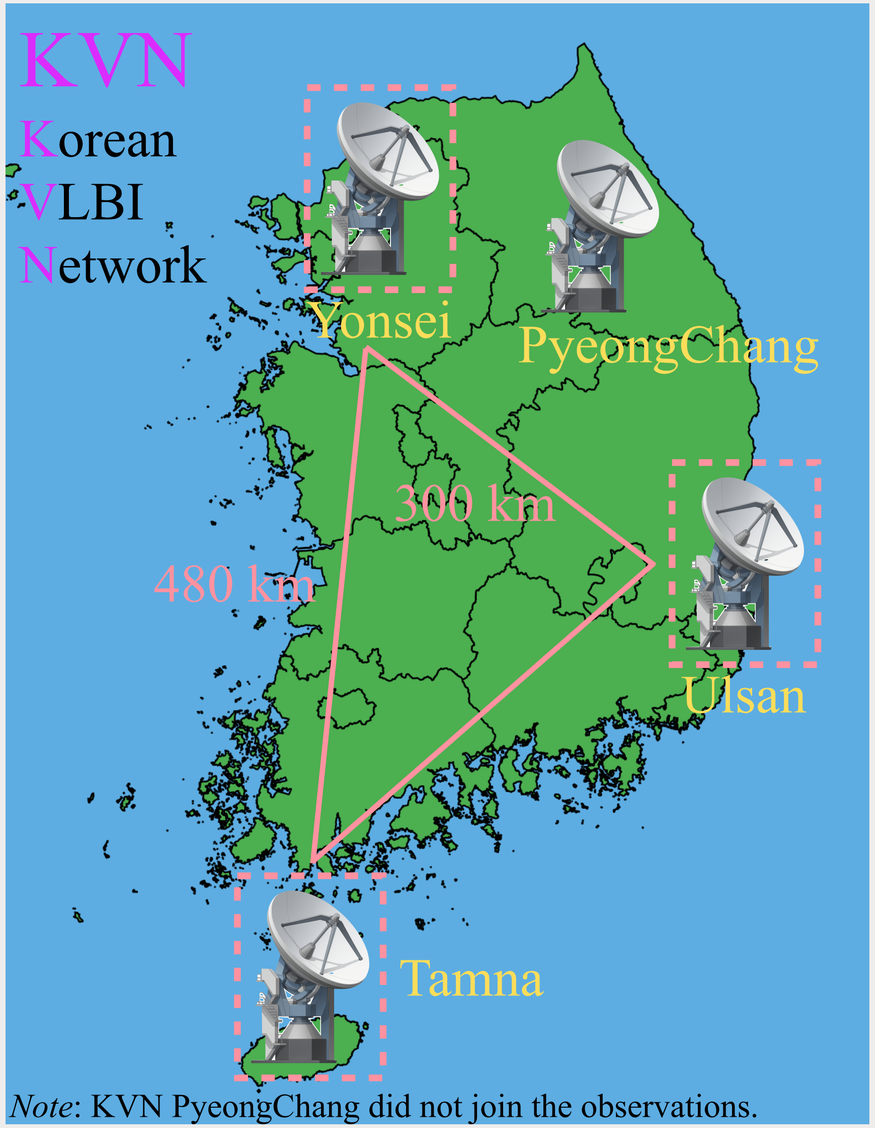
- High-energy "neutrino detection" on December 2021 (IceCube Collaboration 2021)
- Multiple neutrino events were detected (e.g., KM3NeT, Baikal-GVD, and BUST).
- Multi-wavelength flares (radio to gamma-rays) following the neutrino arrival time





Sahakyan+2023

Observations: Korean VLBI Network (KVN)

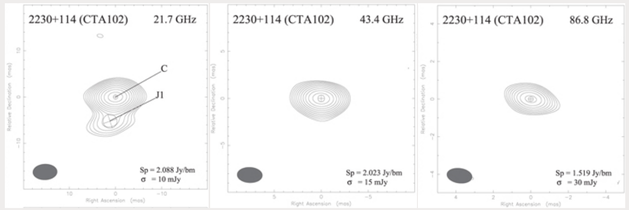


Note: KVN PyeongChang did not join the observations.

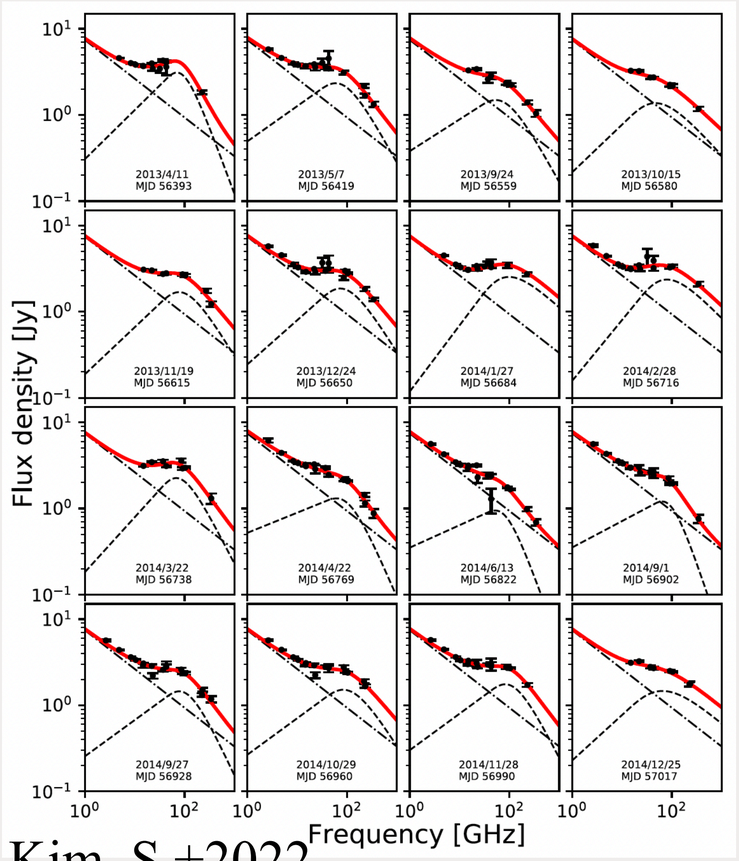
Why KVN?

- High spatial resolution on milliarcsecond scales
- Simultaneous multi-band VLBI observations
- ToO + Regular monitoring (PI: Sanghyun Kim)
- Observing bands: K/Q/W/D (22/43/86/129 GHz)
- Period: 2021.12.27 – 2023.11.19
- Calibration of the W and D-band data using the FPT (Frequency Phase Transfer; Rioja & Dodson 2011).

Multi-band KVN data from iMOGABA program



Lee+2016

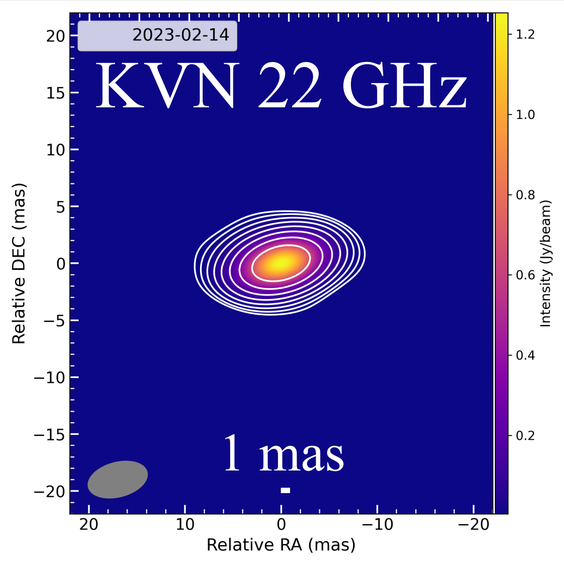


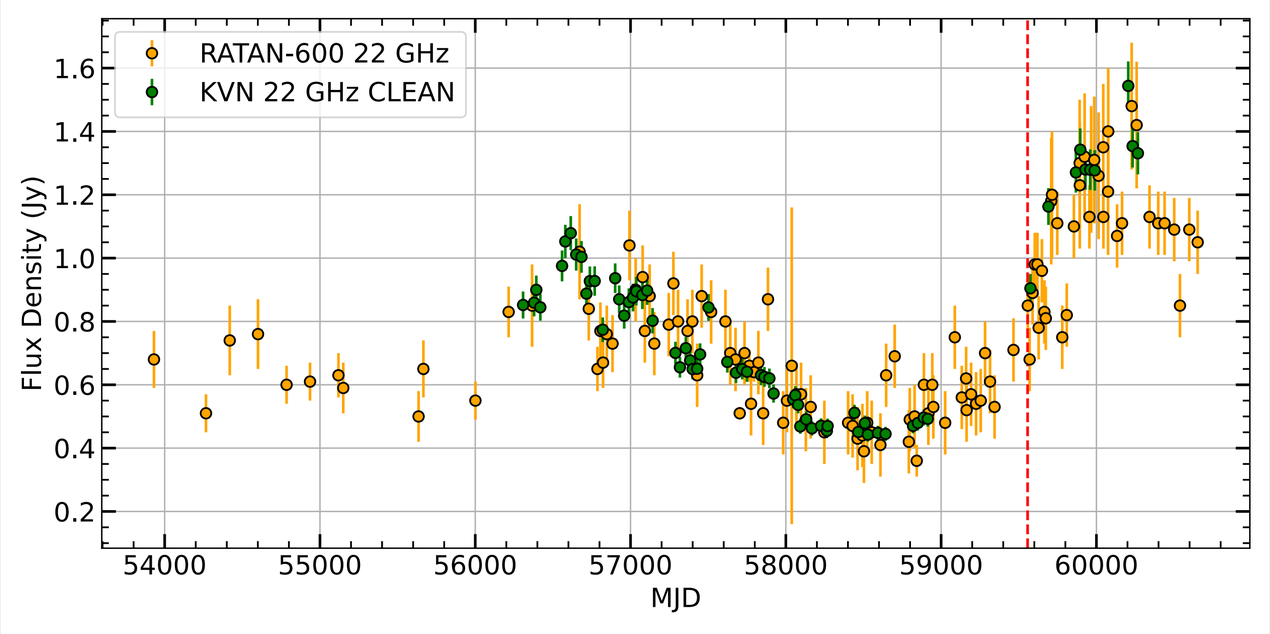
Kim, S.+2022

iMOGABA (**i**nterferometric **mo**nitoring of **ga**mma-ray **b**right **A**GNs)

- KVN key science program (2012–2020)
- Project leader: Prof. Sang-Sung Lee at KASI/UST
- Multi-frequency radio spectral studies on gamma-ray flaring blazars (see, e.g., Kang+2021; Kim, S.+2022; Jeong+2023; Nam+2023; Cheong+2024; Li+2024)

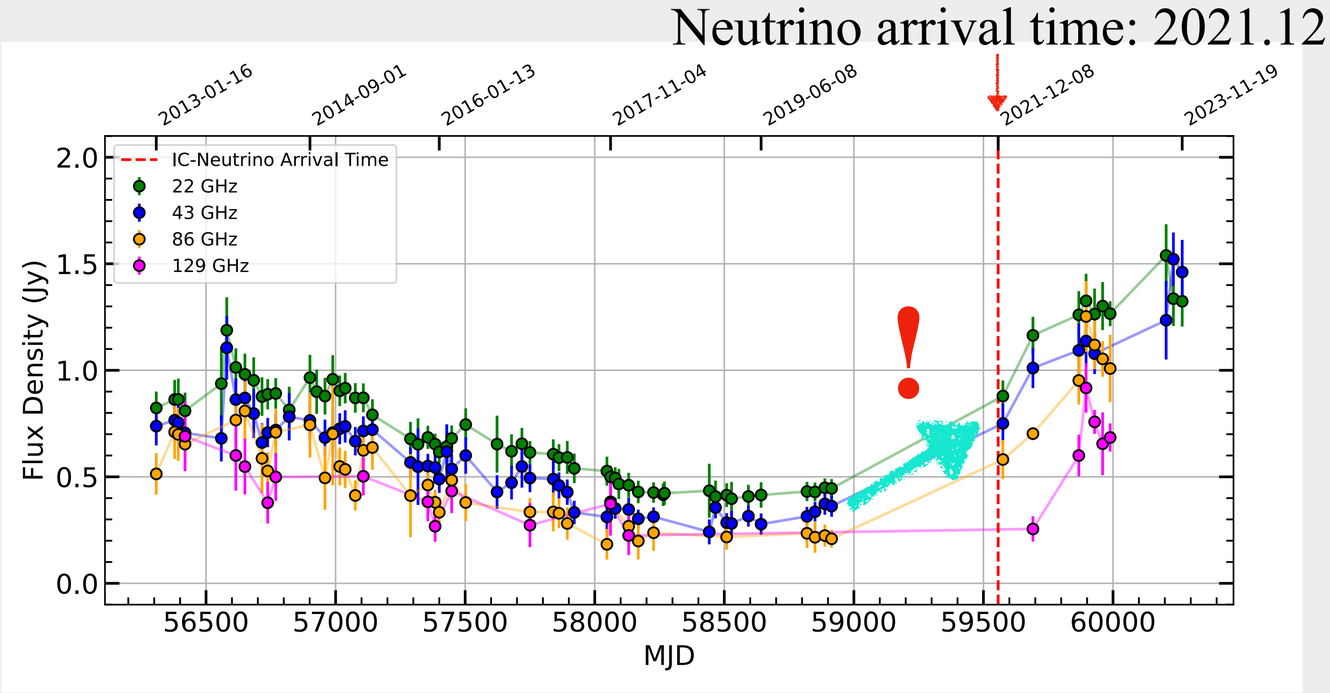
Core-dominated radio emission

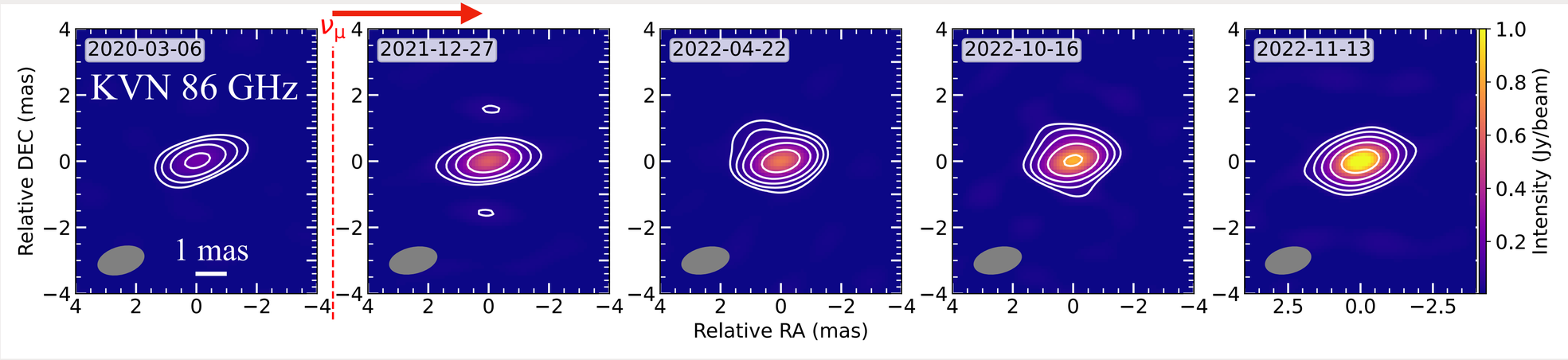




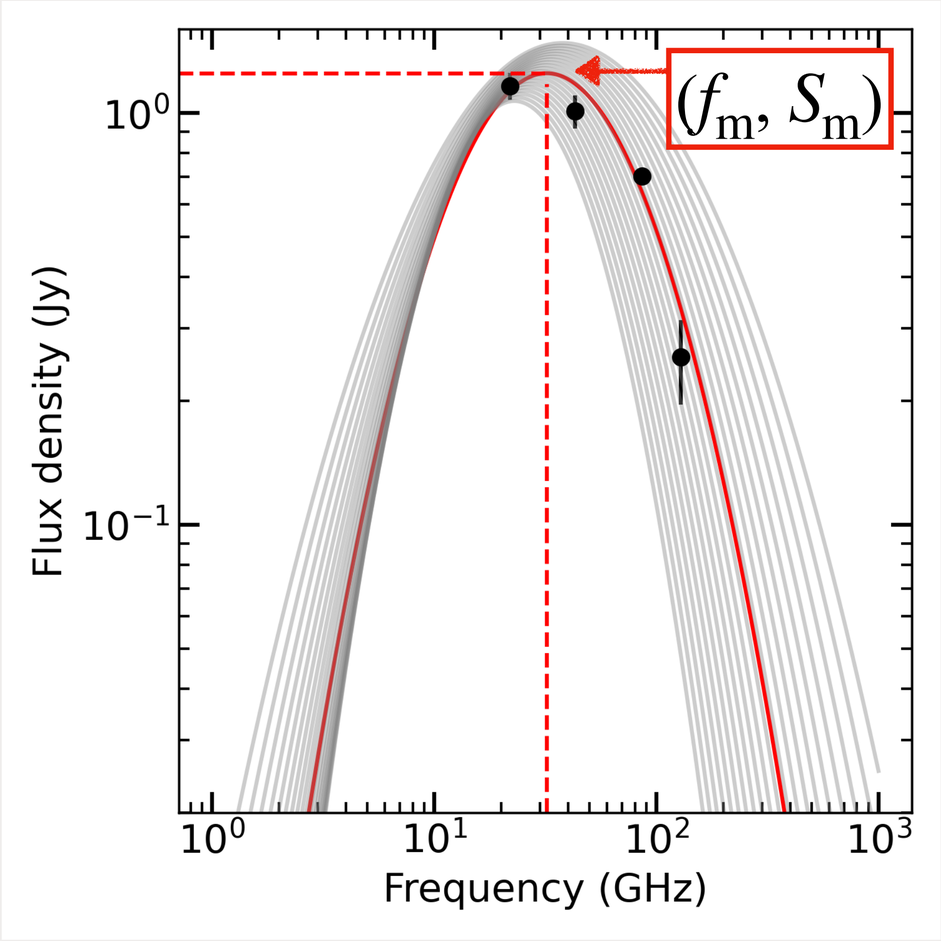
- Imaging: CLEAN algorithm (Högbom 1974) using the DIFMAP software (Shepherd 1997)
- Model-fitting: 2D circular Gaussian models
- Radio flux density is dominated by the core
  - Compactness of the core (e.g., Lee+2008): $S_{\rm Core}/S_{\rm CLEAN} > \sim 97\%$
  - Core-dominance: Single-dish flux density is comparable to the CLEAN flux density.

Radio jet activity following the neutrino event!



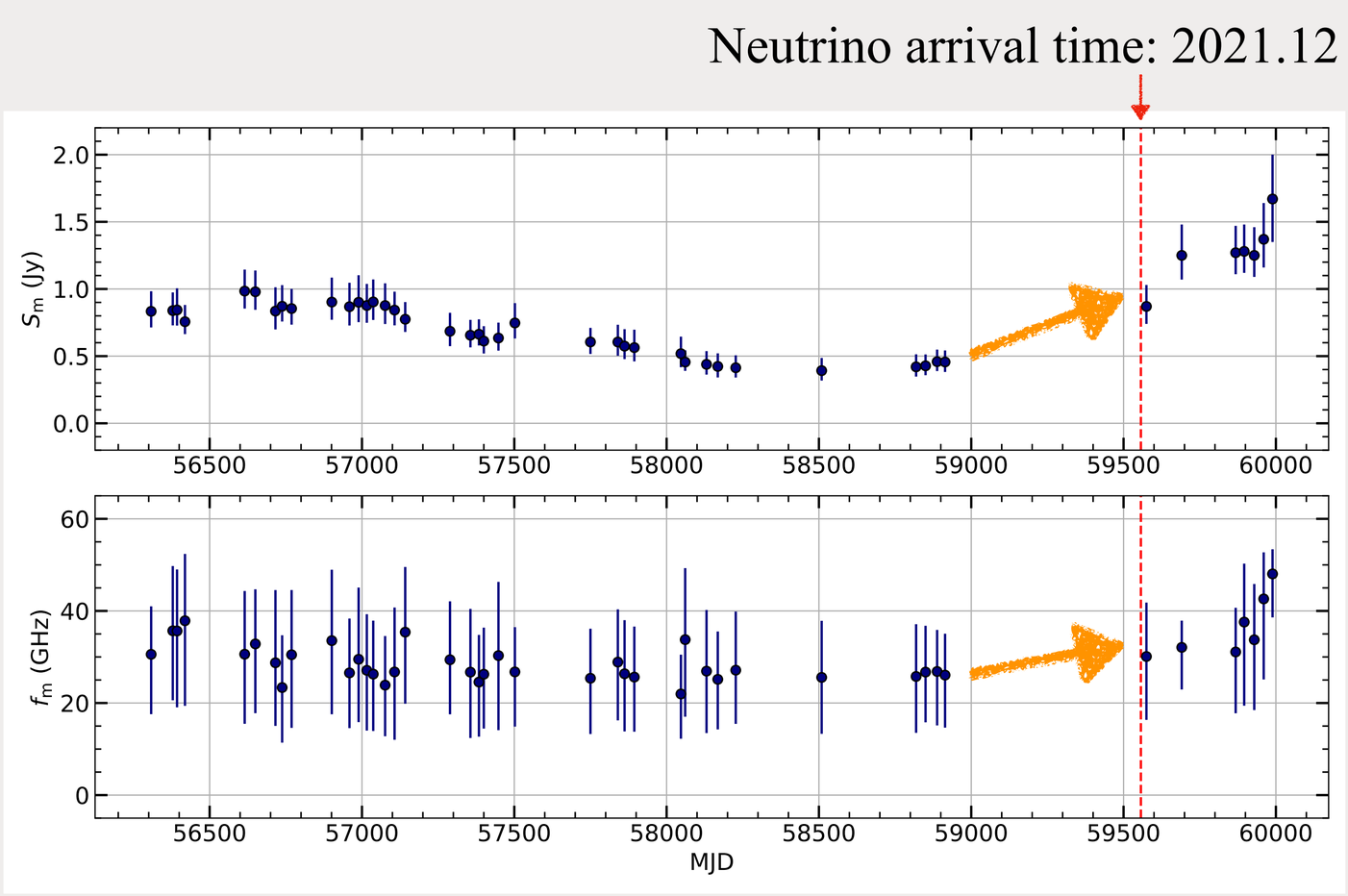


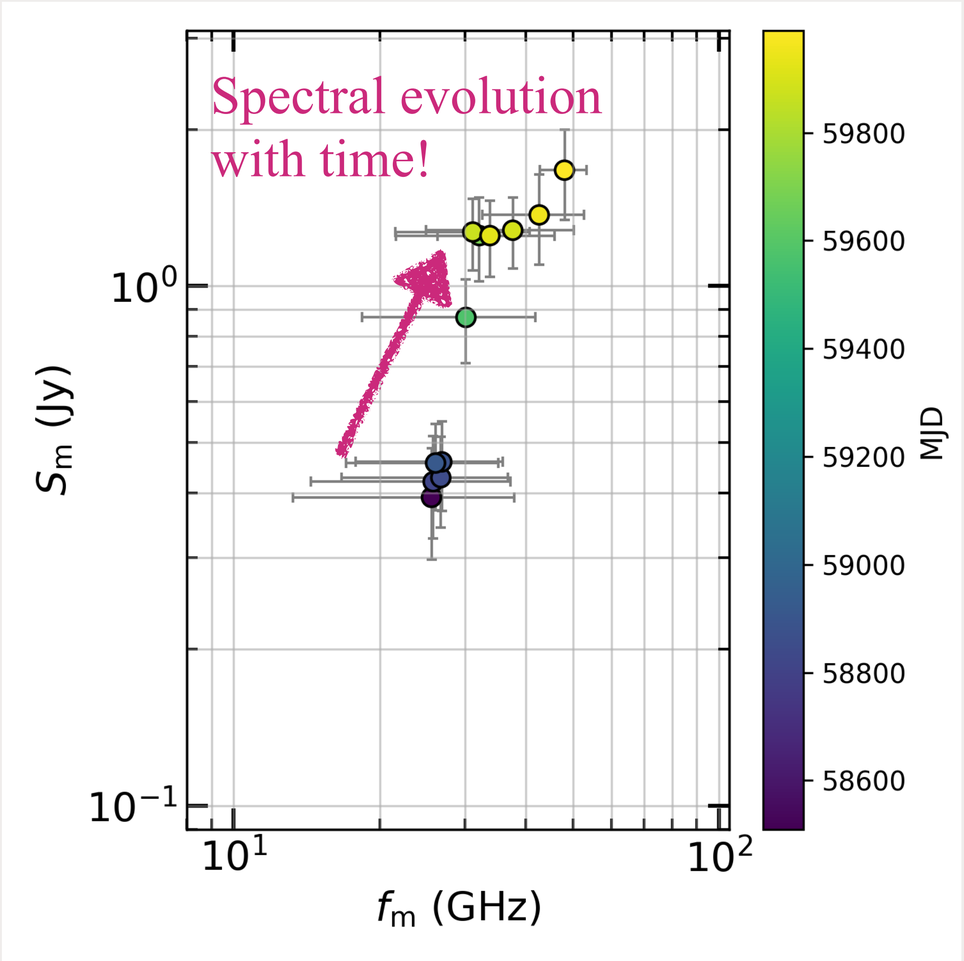
Synchrotron self-absorption (SSA) spectrum



- KVN core flux density → Radio spectrum
- Curved power-law spectrum
  (e.g., Massaro+2004; Lee+2016)
  - f_m: Turnover frequency (GHz)
  - S_m: Peak flux density (Jy)
  - β: Curvature index

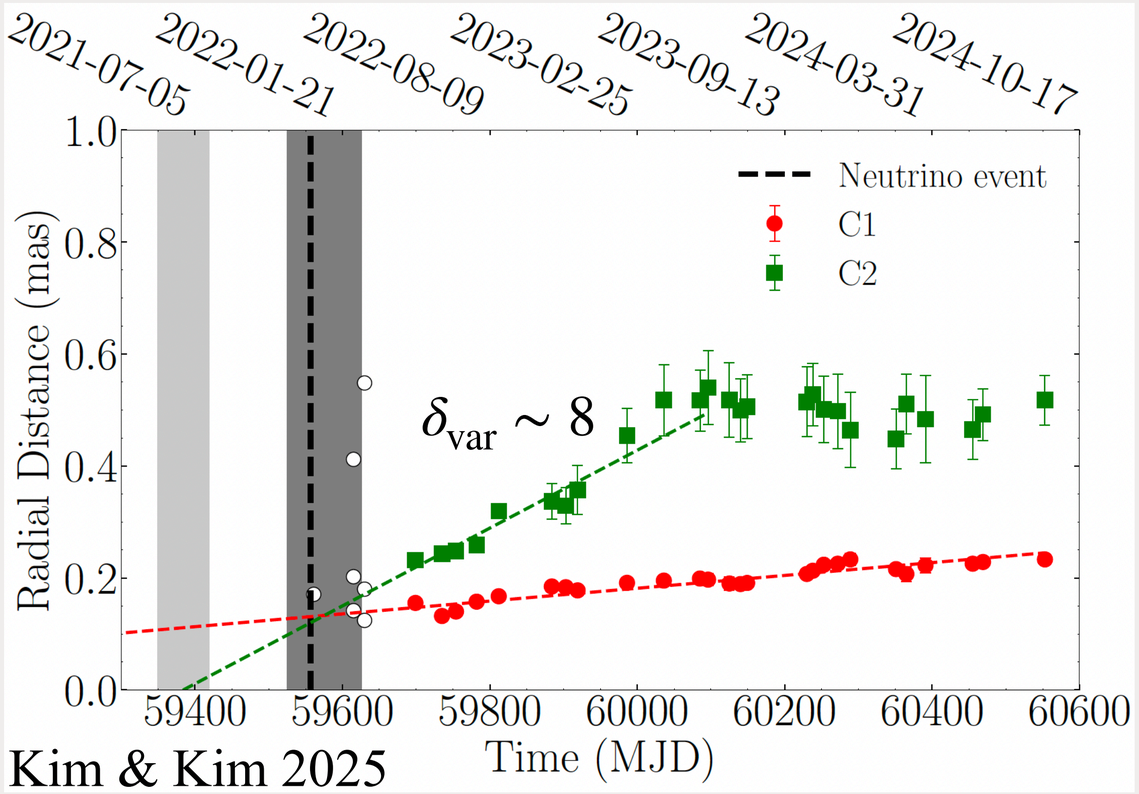
Spectral evolution: signature of shock formation?

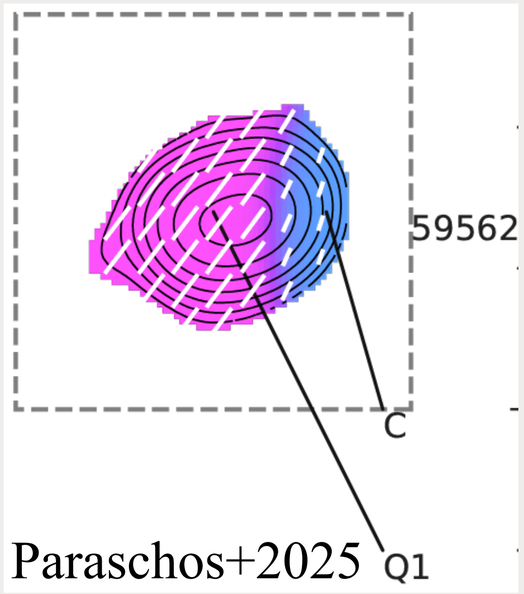




Increase in f_m & S_m: Interpreted as increased plasma density and shock acceleration due to the formation of a newly ejected shock (e.g., Lobanov & Census 1999)

Alignment with other VLBI studies

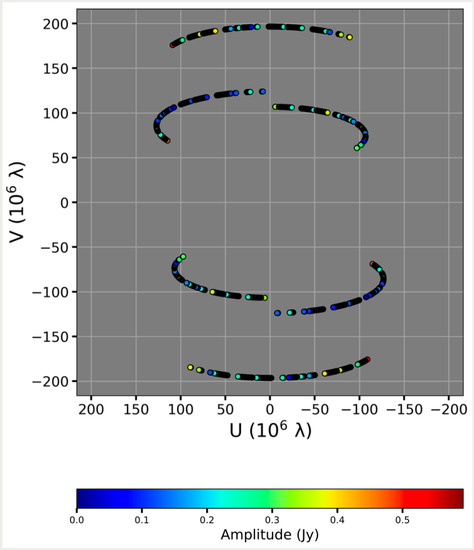




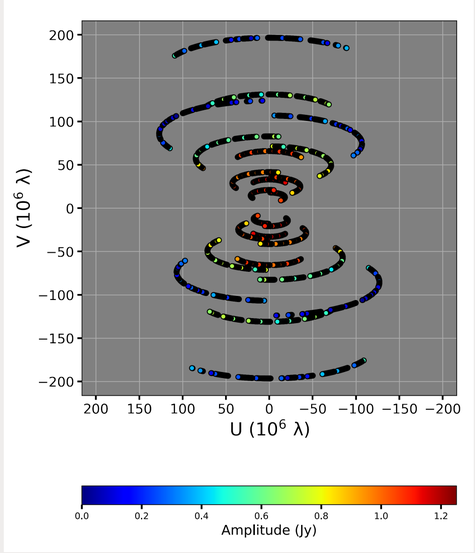
- Radio activity following the high-energy neutrino events
  - Emergence of a new disturbance from the radio core (Kim & Kim 2025)
  - Increase in the linear fractional polarization ~8% (Paraschos+2025)
- The shock-shock interaction is likely to be linked to the spectral evolution.

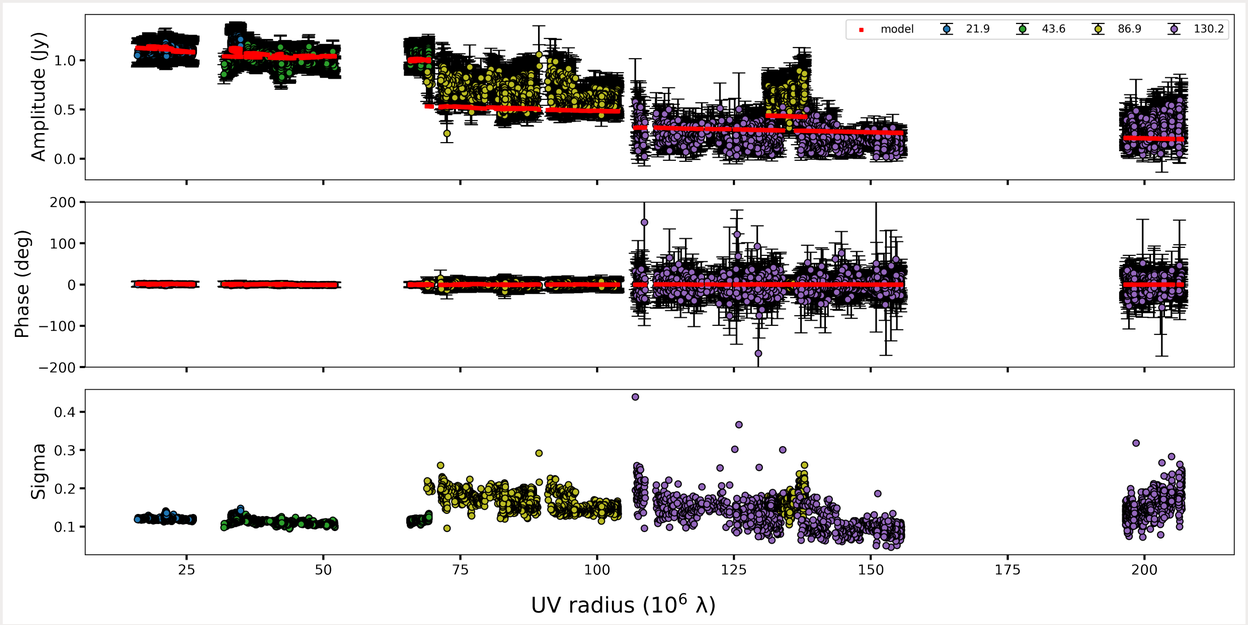
GaMVAs: synthesizing multi-band VLBI data for spectral modeling

D-band



Four bands (K/Q/W/D)

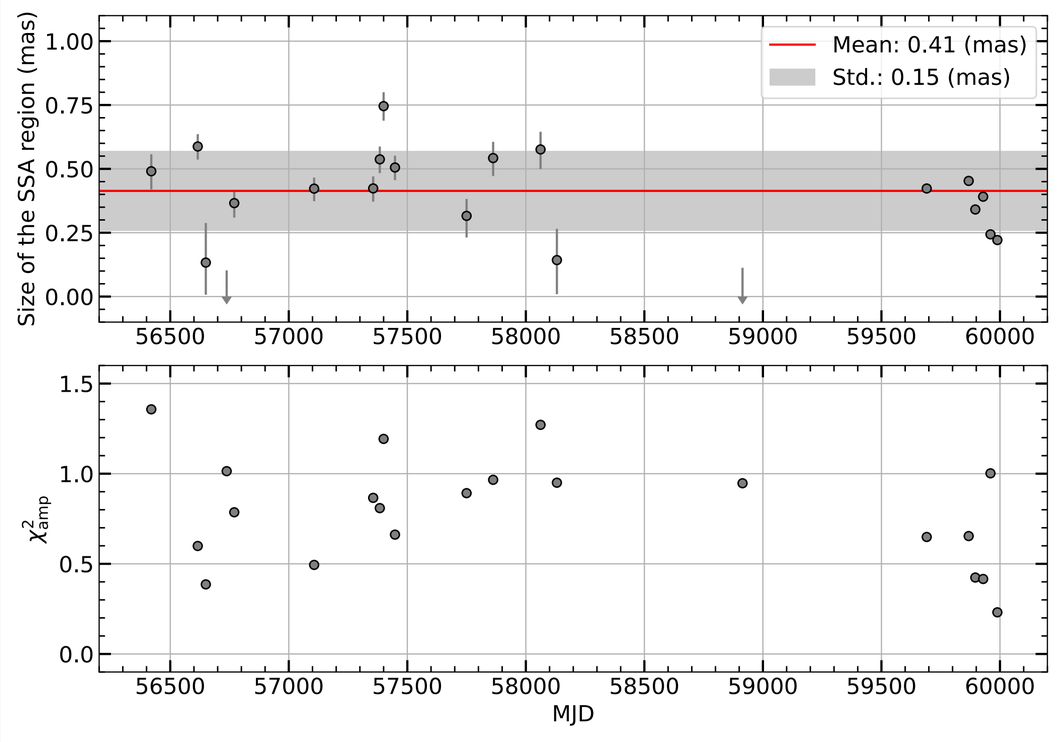




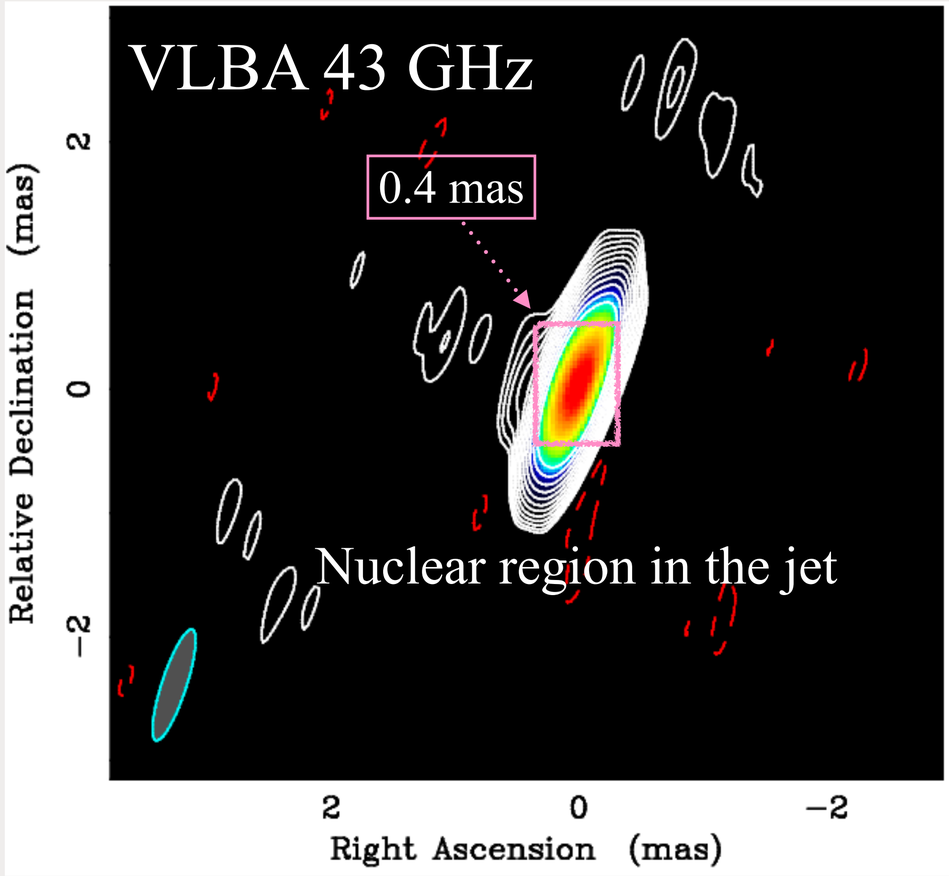
- New script: **Ga**ussian **m**ulti-frequency **V**LBI **a**nalyse**s** (**GaMVAs**; *Jeong, H.-W.*, in prep.)
- Direct SSA model fit to the multi-band VLBI data → Improvement of (*u*, *v*)-coverage
- Assumptions:
  - Common position of the Gaussian model components across the observing frequencies
  - Marginal core-shift effects on the multi-band KVN data
- For more details, please refer to Hyeon-Woo Jeong's talk

SSA spectral results using the GaMVAs analysis

Size of the SSA region



Consistency!

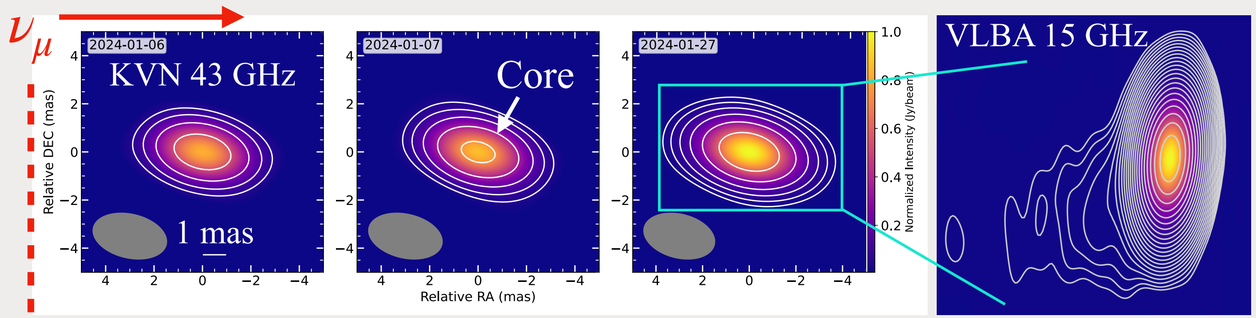


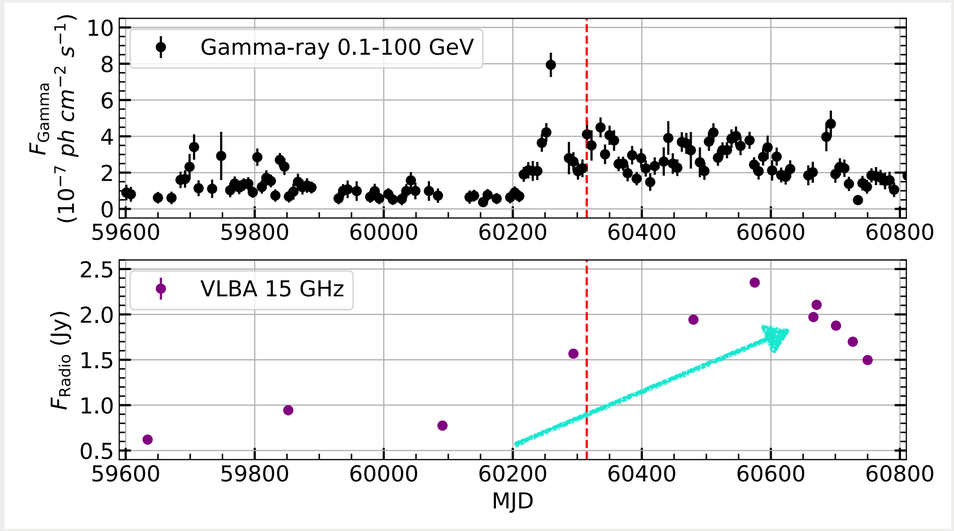
Note: Turnover parameters (f_m & S_m) are **consistent** with modeling results using KVN core flux density.

Kim & Kim 2025

Comparison with the neutrino blazar PKS 0446+11

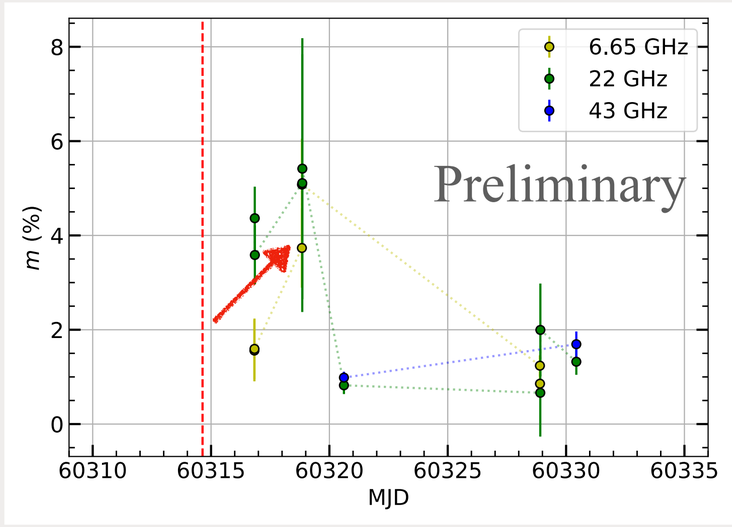
Kim, S., et al., in prep.



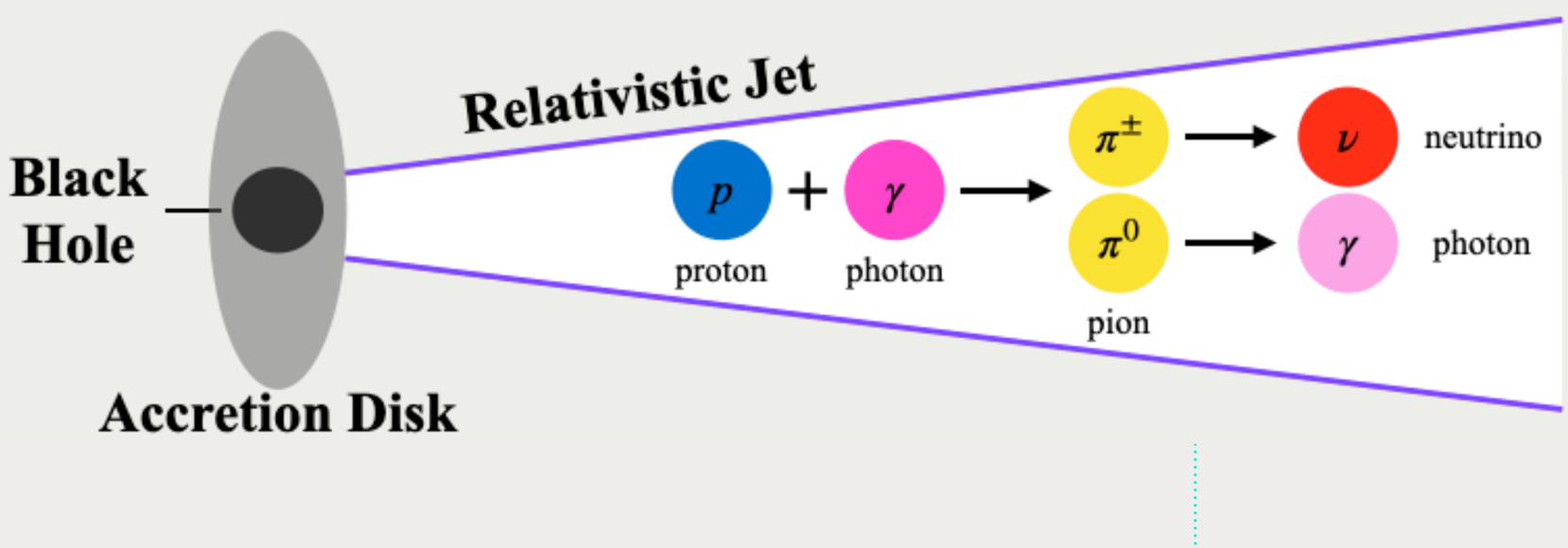


These neutrino blazars exhibit “similar” features!

- Both sources are classified as FSRQs*: High-power blazars.
  **Note*: PKS 0735+178 has been suggested as a masquerading BL Lac (Sahakyan+2023).
- Following the neutrino events,
  - Radio flares at 22–129 GHz
  - Increase in the linear fractional polarization



Jet-based scenario for the neutrino production?



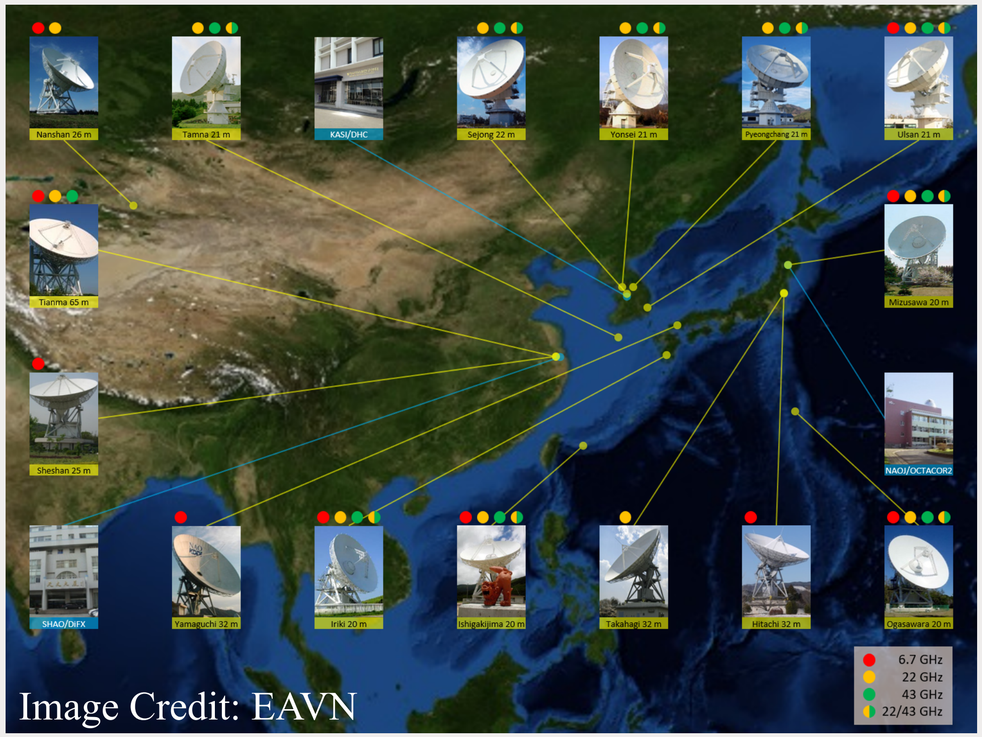
High-energy neutrino (~10^2 TeV) production via the $p\gamma$ interaction

→ Protons (p ~ 2–3 PeV) & Target Photons (γ ~ 20–60 keV)

Plan

Future Work 1: VLBI polarimetric monitoring

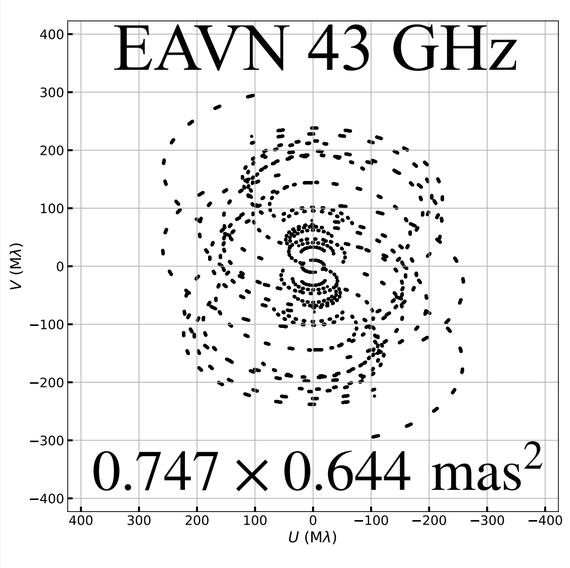
- **Neutrino production mechanism**?
  - "Magnetic reconnection" → Strong **B**-field!
  - "Shock" → EVPA rotation, polarization degree variation, etc.
- International collaboration: South Korea + Germany + Italy

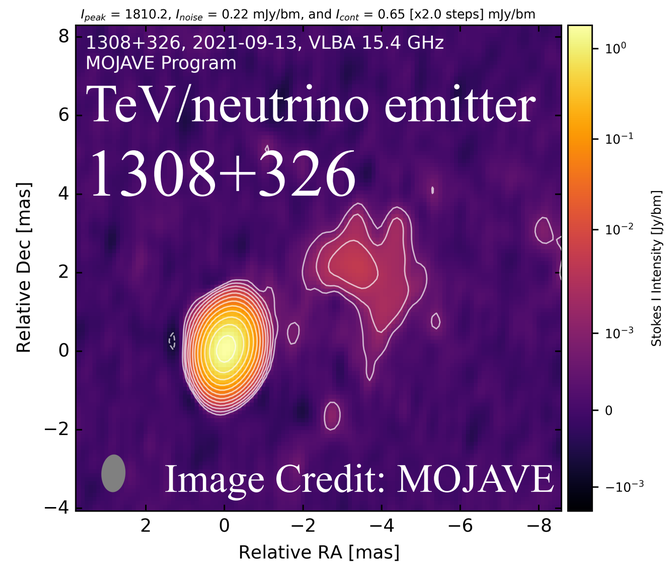


2025B EAVN OBSERVING PROPOSAL COVER SHEET

**Note: Please use the latest version of the format and fill information properly; older version and incorrect usage of each item will be subject to reject your proposal.*

1. Title of proposal: HIGH-RESOLUTION VLBI PROBES OF PARSEC-SCALE JETS IN TEV BLAZARS





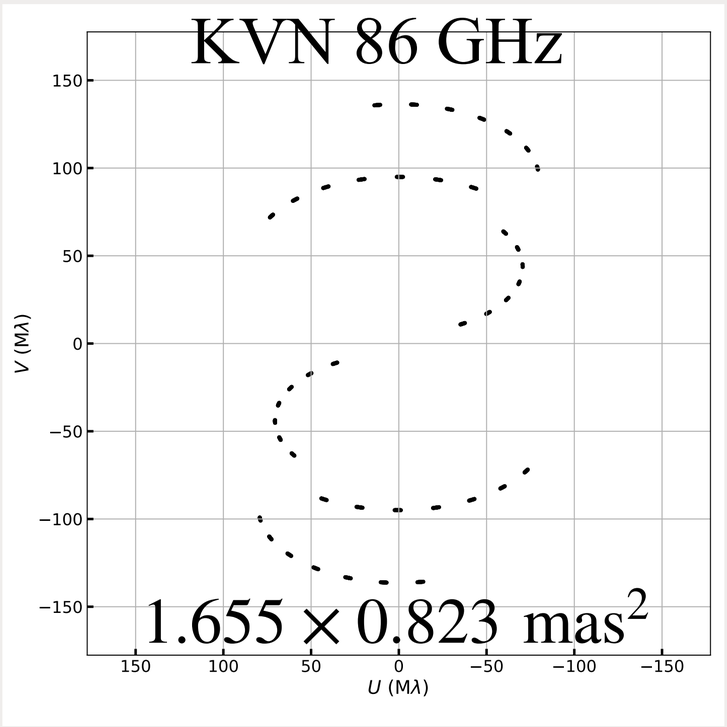
Plan

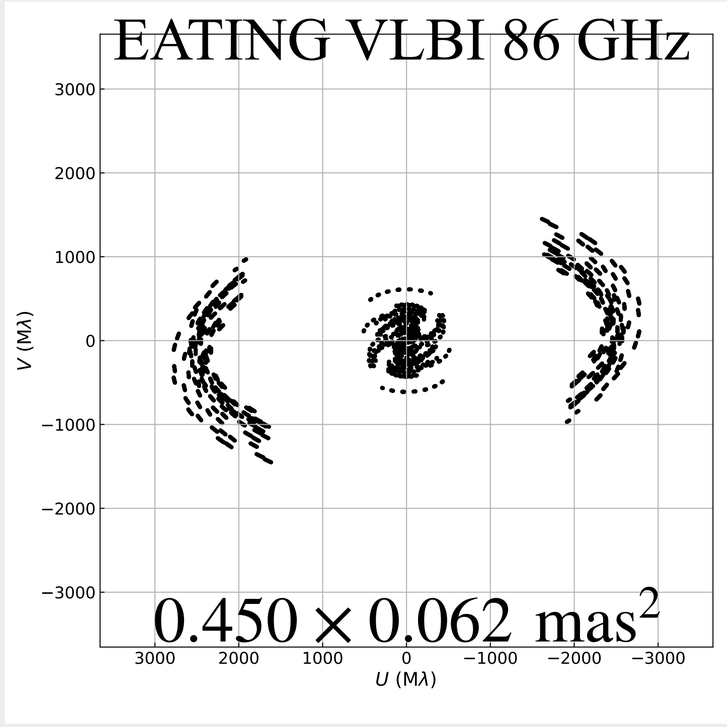
Future Work 2: Spectral study with EATING VLBI

- With the **new CTR** in Italian telescopes → Simultaneous multi-band observations
- Comparison with KVN: Much improvement of spatial resolution!
  → Better constraint on the size of the emission region
- Statistical study - Comparison between neutrino-associated and non-associated AGNs

EAVN +

INAF radio telescopes





Summary

- We observed radio flares in the blazar PKS 0735+178 following the high-energy neutrino events.
- The KVN multi-band spectrum suggests shock formation.
- Spectral evolution implies that shock acceleration may have triggered the high-energy neutrino events.
- High spatial resolution and VLBI polarimetric monitoring is necessary to more clearly understand the physics of promising neutrino-emitting blazars.