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Ministero
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Italiadomani
PIANO NAZIONALE
DI RIPRESA E RESILIENZA



Radio counterparts of High Energy Neutrinos

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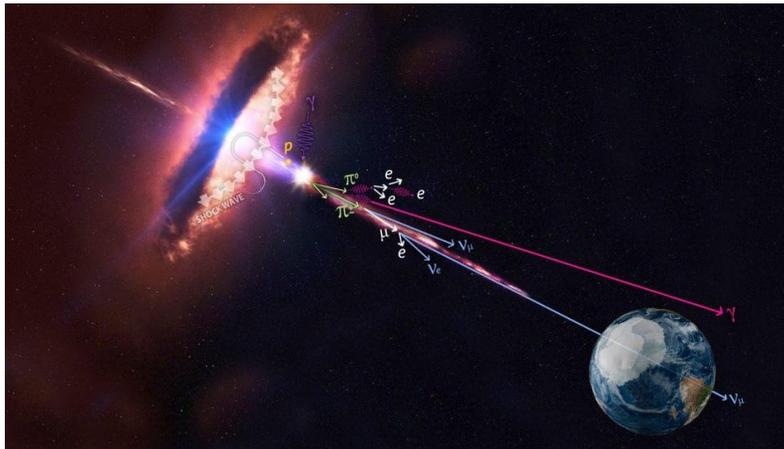
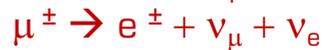


High Energy Neutrino Sources:

Collisions of high energy CRs with matter produces pions.



than, in turn, produces electrons, photons, neutrinos:



Flux of neutrinos is expected $\propto \gamma$ rays

However, γ rays suffer of absorption with environment

Radio emission travels free

From nuclear reactions (low energy):

- Sun
- Supernovae

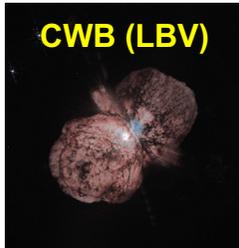
From VHE CRs interaction with matter:

- **Active Galactic Nuclei (AGN)**
- **Blazars**
- **Micro Quasars**
- **Gamma-Ray Busts (GRB), Kilonovae**
- **Colliding Wind Binaries (CWB)**
- **Magnetars (FRB?)**
- **Novae**
- **Supernovae Remnant (SNR)**
- **Pulsar Wind Nebulae**
- **Pulsar**

High Energy Neutrino Sources:



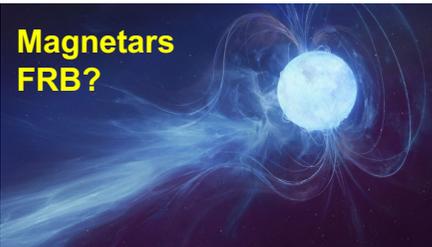
Focus on transient sources



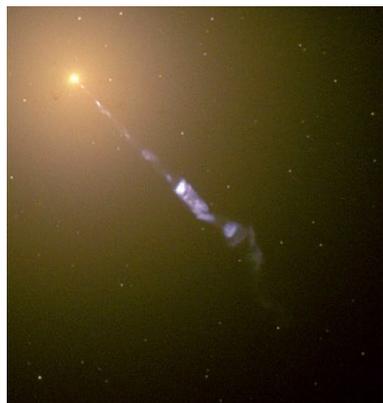
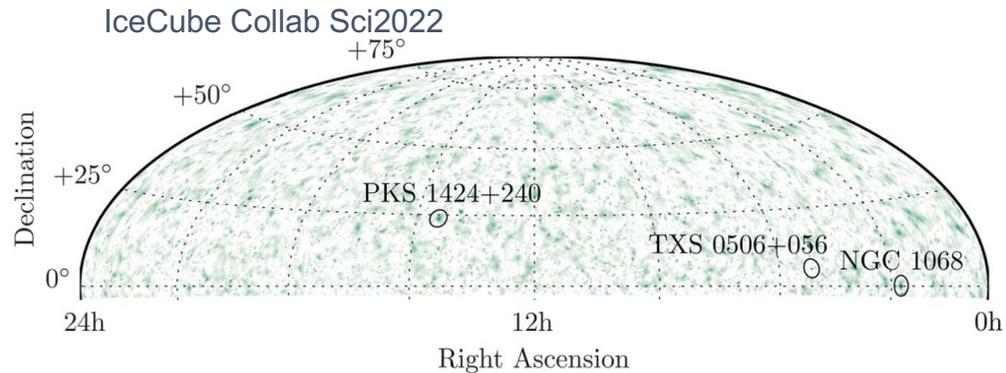
Most probable sources

As AGN and Blazars
Probable, no detection
Probable, to be investigated
Below the sensitivity NeT

- From VHE CRs interaction with matter:
- Active Galactic Nuclei (AGN)
 - Blazars
 - Micro Quasars
 - Gamma-Ray Busts (GRB), Kilonovae
 - Colliding Wind Binaries (CWB)
 - Magnetars (FRB?)
 - Novae



Main results from IceCube

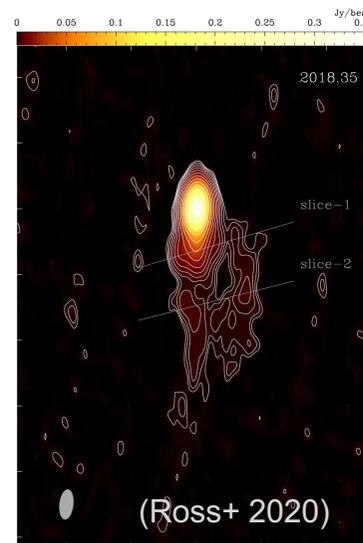


2 Blazars:

TXS0506+036
3.5 σ significance

PKS 1424+240
3.7 σ significance

TXS0506+036 in VLBI
2 months after neutrino
event (290 TeV)
in Sep 2017
(IceCube Collab 2018)

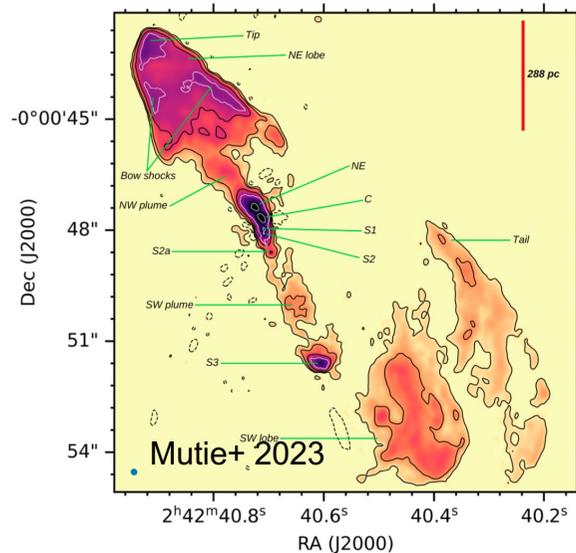


NGC 1068 (M77)
Seyfert-2 galaxy at
14.4 Mpc
4.2 σ significance

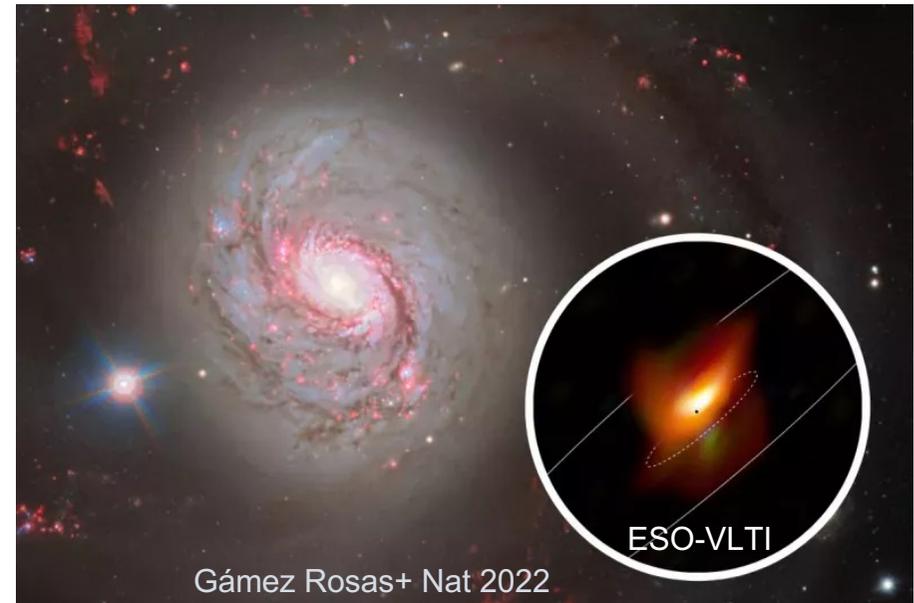
NGC 1068 (M77)



Seyfert-2 galaxy at 14.4 Mpc
4.2 σ significance
about 80 neutrinos in more than 10 yr



Radio emission from the central regions is visible.



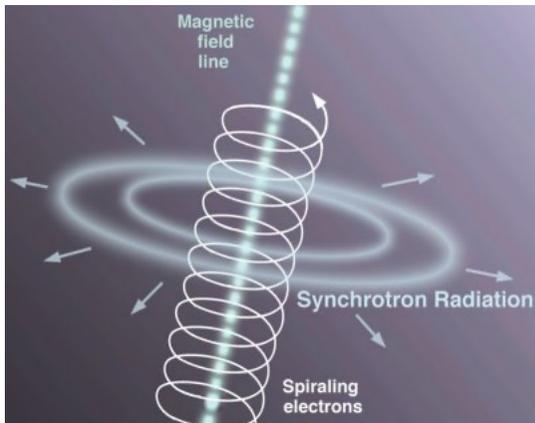
The dusty torus obscures the inner part of the galaxy hosting the SMBH, including γ -rays.
Radio emission can escape.
 γ -rays – neutrinos correlation is not a rule!

Radio emission – synchrotron spectra



Neutrino sources: high energy processes

Interaction between high energy electrons and magnetic field → Synchrotron emission



Frequency of emission

$$\nu \propto E^2 B$$

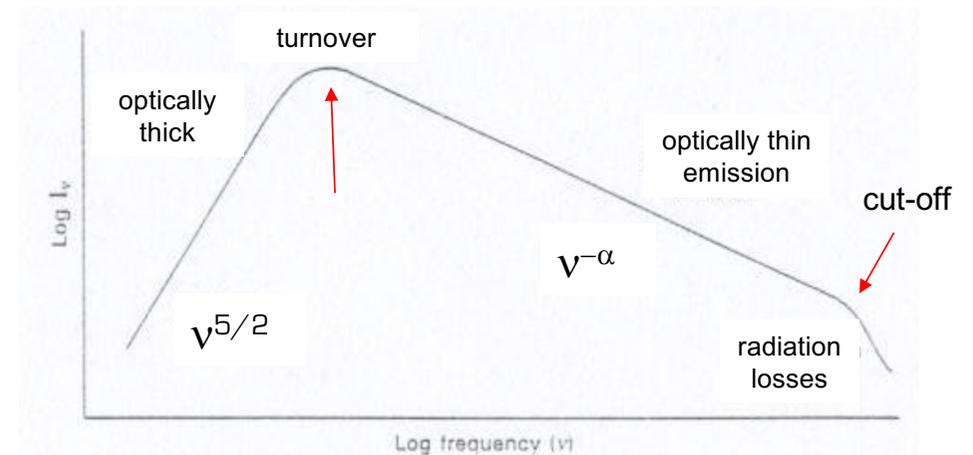
for a power spectrum of electrons

$$N(E) \propto E^{-\delta}$$

spectral index α in optically thin regime

$$\alpha = \frac{\delta - 1}{2}$$

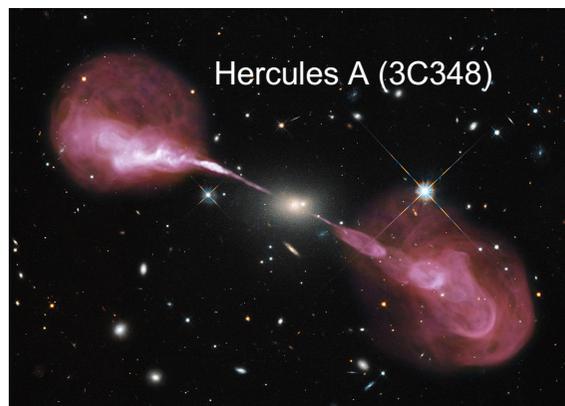
Schematic spectrum of Synchrotron source



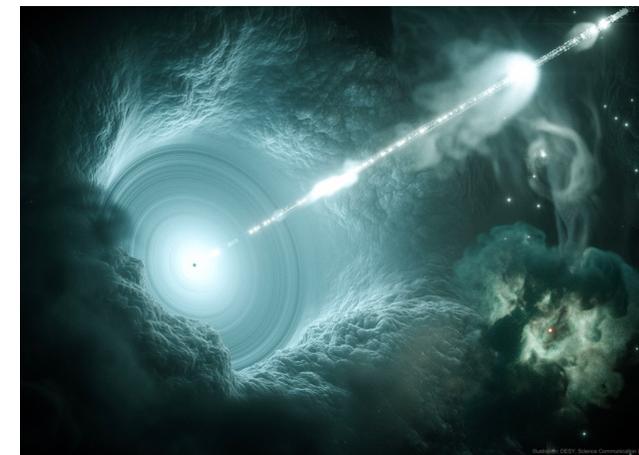
high frequency cut-off depending on radiation losses (cooling):

Synchrotron losses $P_{synch} \propto E^2 B^2$
Inverse Compton losses $P_{IC} \propto E^2 n_{ph}$

Active Galactic Nuclei / Blazars



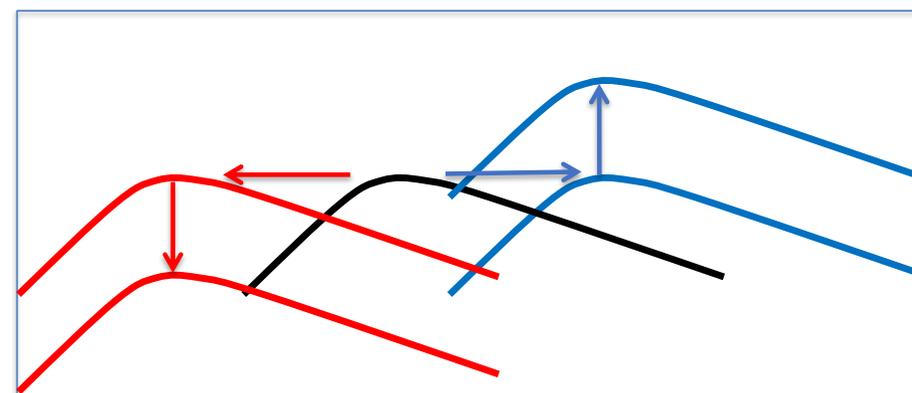
In Blazars:
Jet towards Earth



Doppler Boosting:
Blue/red shift
Big enhancement of the radio flux
for approaching jet



Synchrotron spectrum at rest
Approaching blob
Receding blob



Searching for Radio - Neutrino correlation



AGN/Blazars: Neutrino-flares correlation

IceCube E>200TeV (56 events)

VLBI sample (Geo, Mojave, CRF...) 3388 sources

AGN in direction of neutrino events have higher VLBI flux (core)

Activity index

RATAN-600 monitoring 5-8-11-22GHz

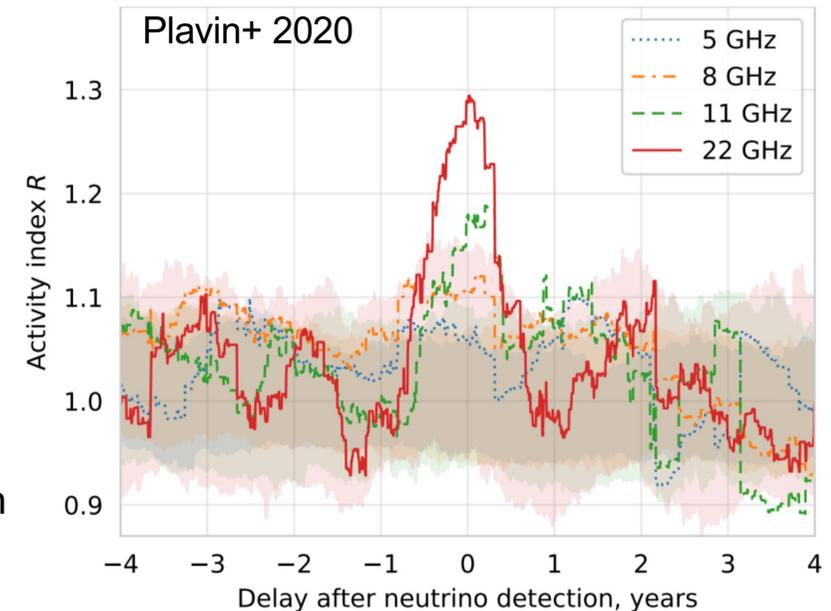
Correlation radio flux and neutrino detection

tight correlation at high frequency

«Our study invokes **statistical power of radio observations** to the problem of high-energy neutrino origin»

Importance of observational campaigns at radio wavelengths with

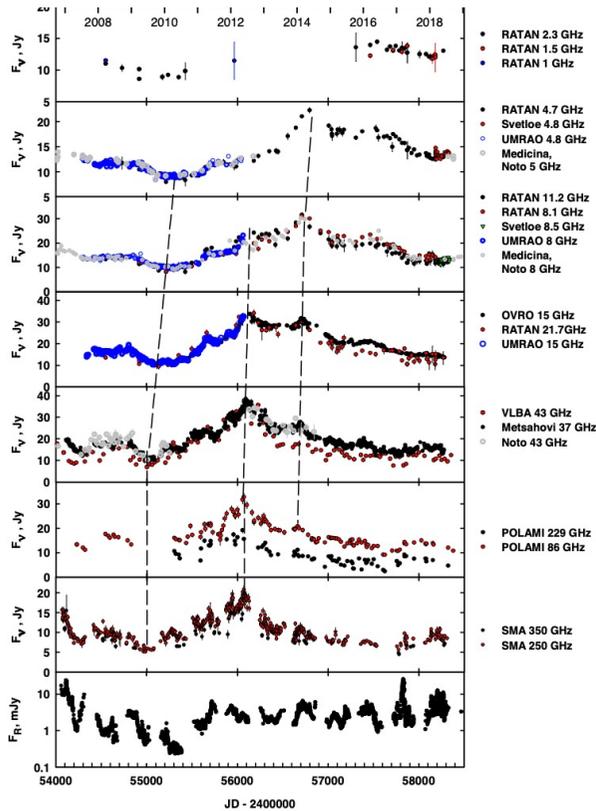
- VLBI
- Single dish at high radio frequency, on a regular basis



(a) All sources: 18 AGN close to neutrino events.

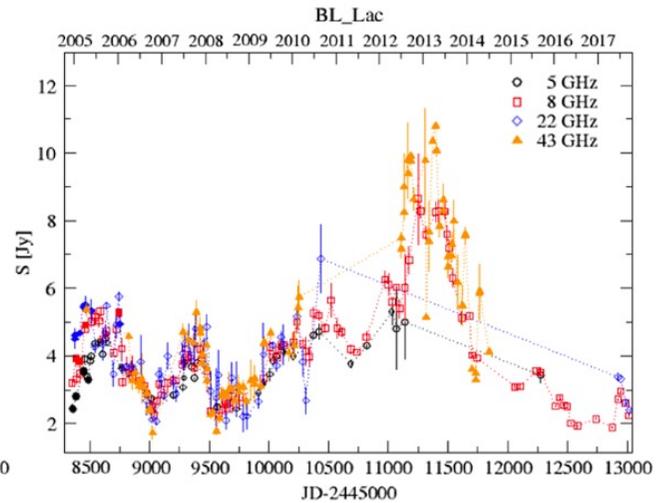
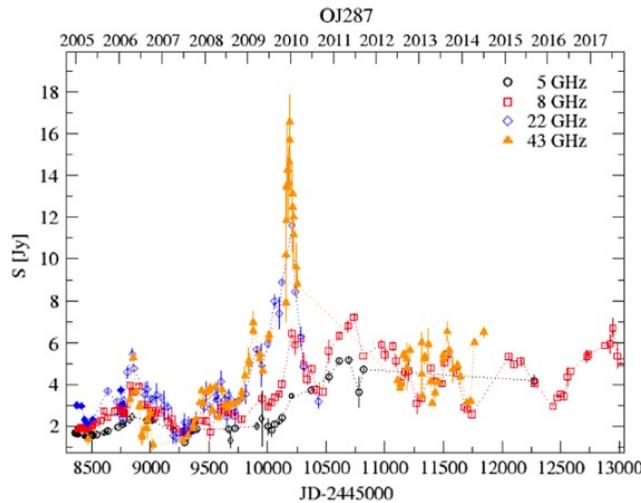
Searching for Radio - Neutrino correlation

Experience of INAF with our radio telescope in monitoring blazars



3C279
2007-2018

Light curves at radio:
flares are prompt at higher
frequency



During high activity periods, the observed
flux density is higher at higher frequency
Emission peaked at high frequency

At smaller scale: micro quasars

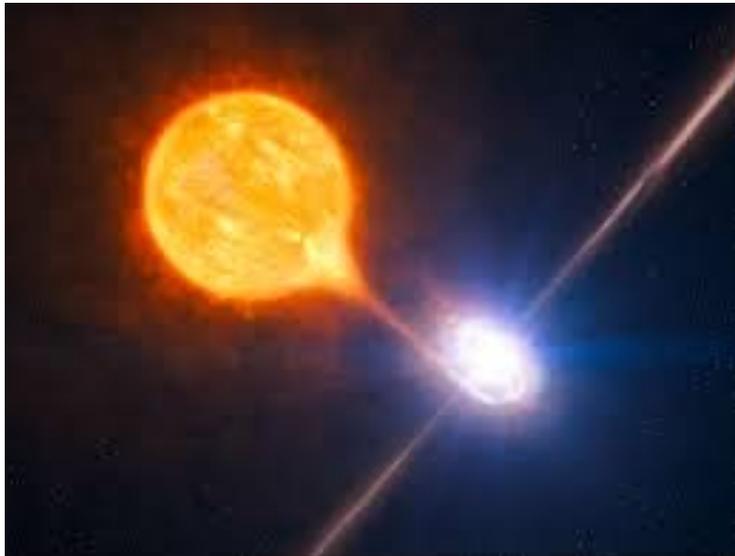
Final stages of High mass stellar evolution

The giant star exploded as SN \rightarrow compact object

Compact object: BH or NS Accretion disks and jets

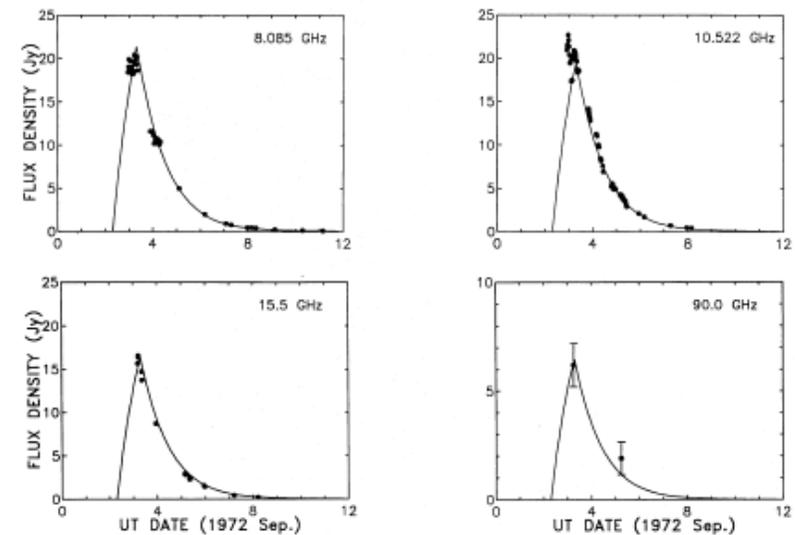
Emission: radio, X, γ -ray

Strong interaction with the ISM \rightarrow γ -ray, neutrinos?



Radio behaviour characterized by flares

Radio light-curve during flares of Cyg X-3



Our project:

Science: The radio monitoring



Searching for electromagnetic (radio) counterparts of neutrino sources.

- Selection of a **sample of radio sources** that are candidates high energy neutrinos.
- **Monitoring** a sample of neutrino source candidates with Noto 32m radio telescope.
- **Regular observations** of the sample at high frequency (**20-100 GHz**).
- Follow-up observations in case of detection with **KM3NeT**.
- Triggering **KM3NeT** search in case of high state of activity at radio.

PNRR, project KM3NeT4RR, lead by INFN.

CUP I57G21000040001

WP 7, Activity “Electromagnetic Follow-ups of Neutrino Sources and monitoring of neutrino source candidates”

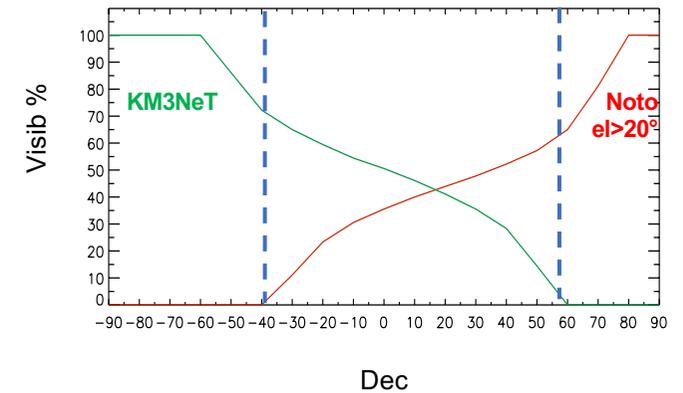
INAF-Osservatorio Astrofisico di Catania

KM3NeT and Noto radio telescope



Very close on Earth
Different sky with good overlap
Noto down to -40° (82% Sky)
KM3Net up to 50° (87% Sky)

About 57% Sky overlap



Selecting our sample



The most promising sources: Blazars

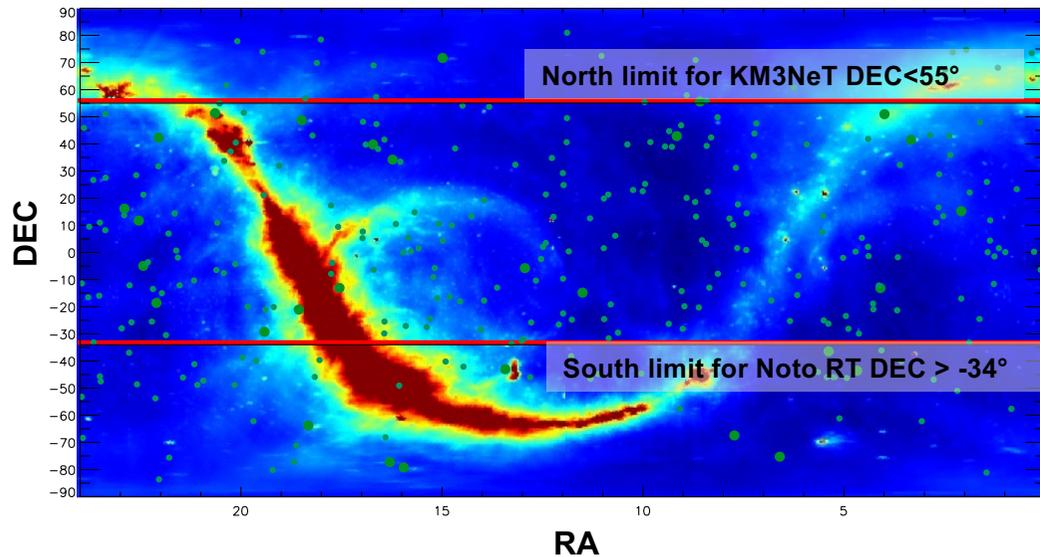
Blazars visible in our sample

selected by the [Roma-BZCAT Multi-Frequency Catalog of Blazars](#)

[Roma-BZCAT](#)

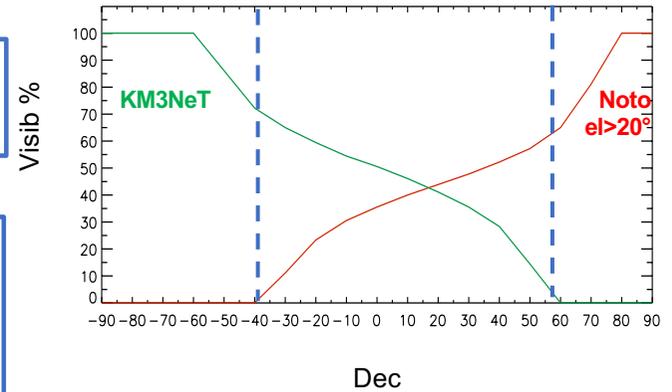
3561 Blazar sources

290 with $F_{1.4 \text{ GHz}} > 1 \text{ Jy}$



216 with $-34^\circ < \text{DEC} < 55^\circ$

38 strong flux $> 2 \text{ Jy}$ at 1.4 GHz
High directivity



Selecting our sample

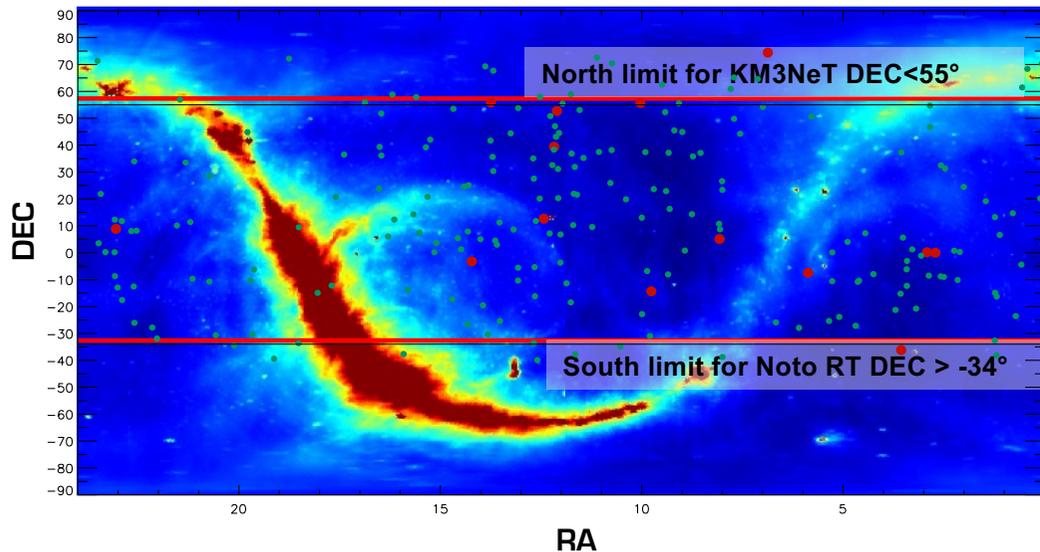
The most promising sources: Seyfert Galaxies

Seyfert Galaxies visible in our sample

selected by the [Turin-SyCAT: A multifrequency catalog of Seyfert galaxies \(Pena-Herazo 2022\)](#)

VizieR On-line Data Catalog:
J/A+A/659/A32

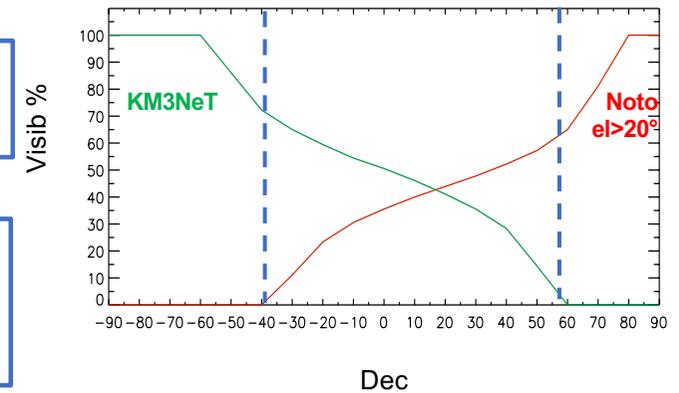
214 Seyfert galaxies radiosources



TBD: Variability? Spectral index?

181 with ●
 $-34^\circ < \text{DEC} < 55^\circ$

13 strong ●
flux > 100 mJy
at 1.4 GHz



Selecting our sample

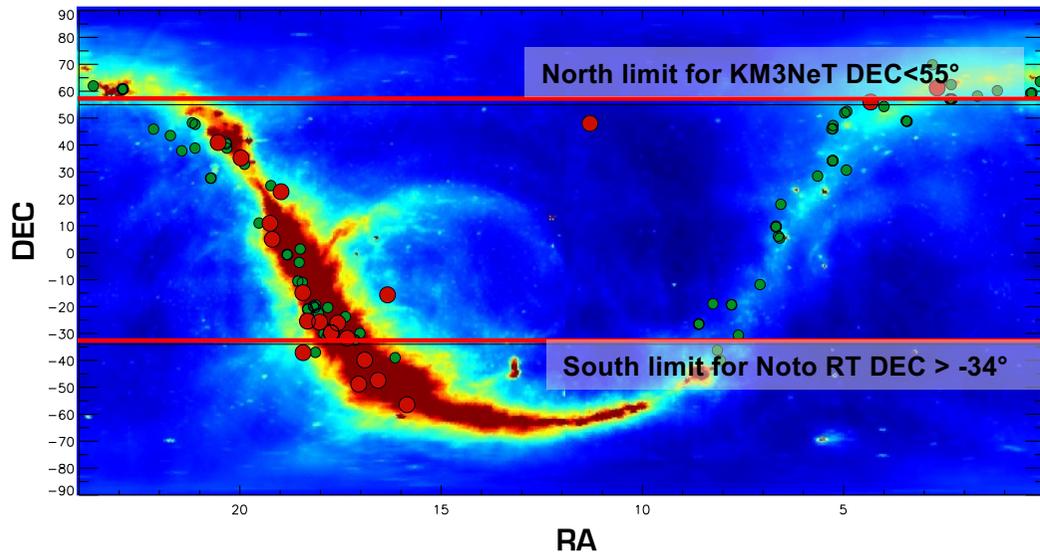
The most promising sources: Microquasars

Microquasars visible in our sample

selected by the Microquasar candidates (Combi+, 2008)

VizieR On-line Data Catalog:
J/A+A/477/125

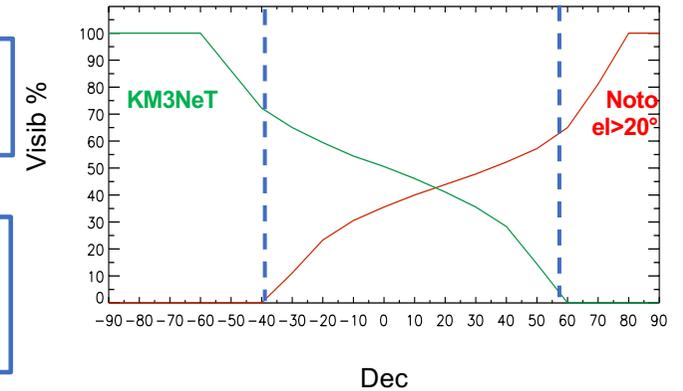
86 Microquasar candidates $|b| < 10^\circ$



TBD: Variability?

63 with
 $-34^\circ < \text{DEC} < 55^\circ$

Plus
17 classical
(Cyg X-3, SS433...)



Upgrade of the telescope for mm observations

Total Surface Accuracy (RMS): 350 μm
(main mirror + **new secondary mirror**)

Tri-band receiver in secondary focus (PON fundings)

New acquisition system for **simultaneous** acquisition
at **22, 44, 86, 100 GHz** with **high sensitivity**



Our project: Technology: refurbishment of Noto RT

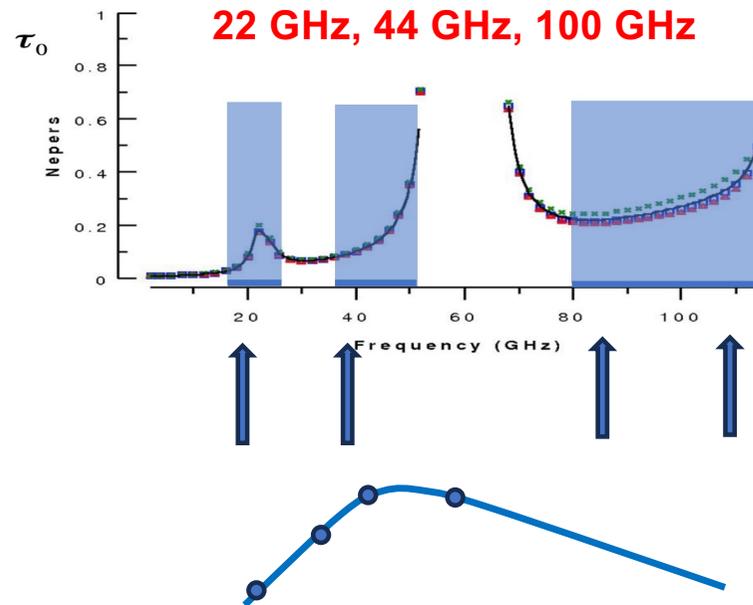


Tri-band receiver in secondary focus

Simultaneous acquisition in 4 bands, two polarizations



Instantaneous bandwidth: 4GHz



New acquisition system



Thank you