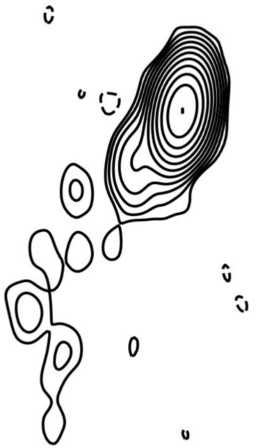
The parsec-scale regions of candidate neutrino-emitter blazars



Cristina Nanci

University of Bologna - INAF - Institute of Radio Astronomy
PhD supervisor: Dr. Roberta Zanin

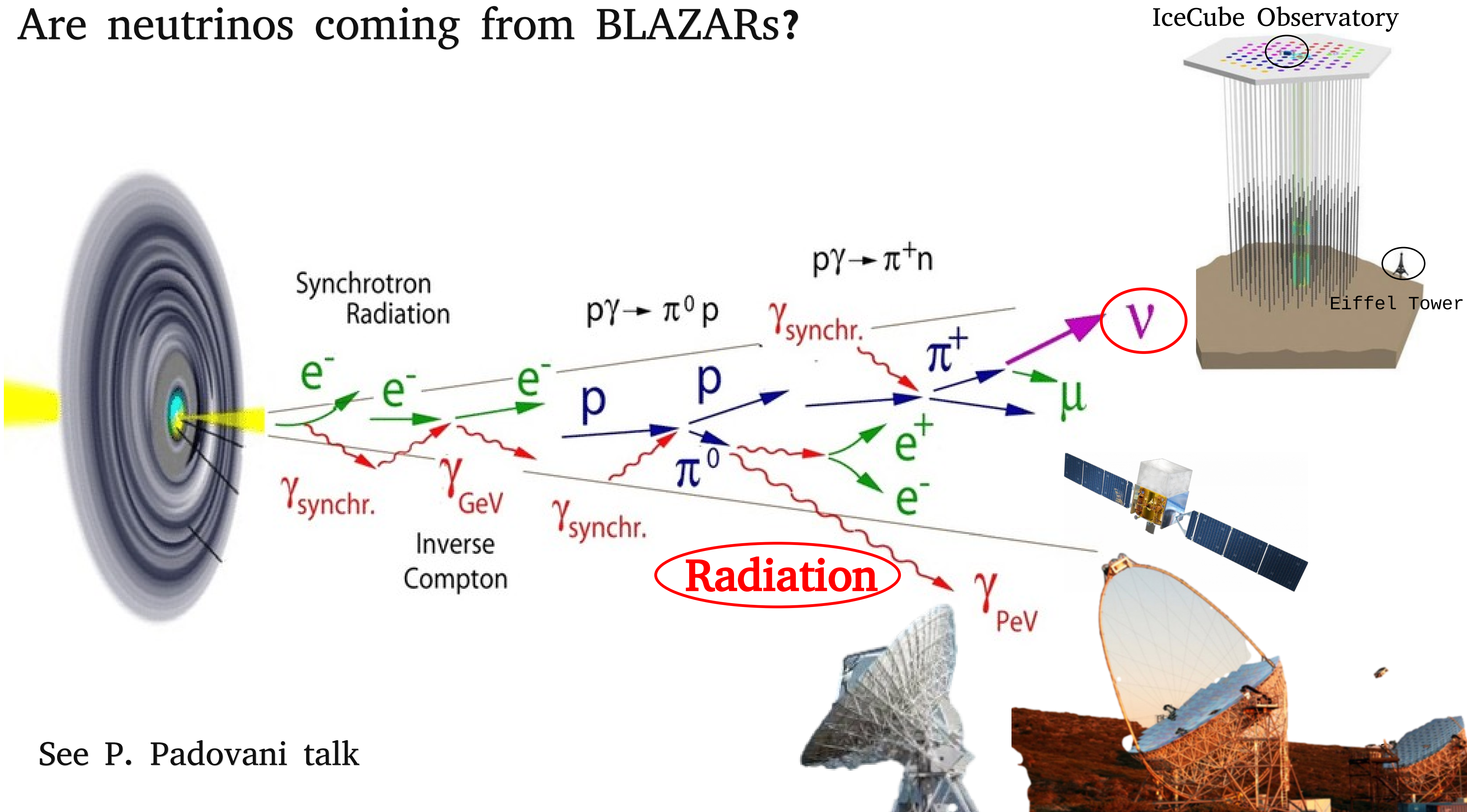
with M. Giroletti, M. Orienti, G. Migliori, J. Moldón, S. Garrappa, M. Kadler, E. Ros, S. Buson, T. An, M. A. Pérez-Torres et al.

OAS Very High Energy Meeting:
towards Astri and CTA

9th June 2022

INAF IRA

Are neutrinos coming from BLAZARs?

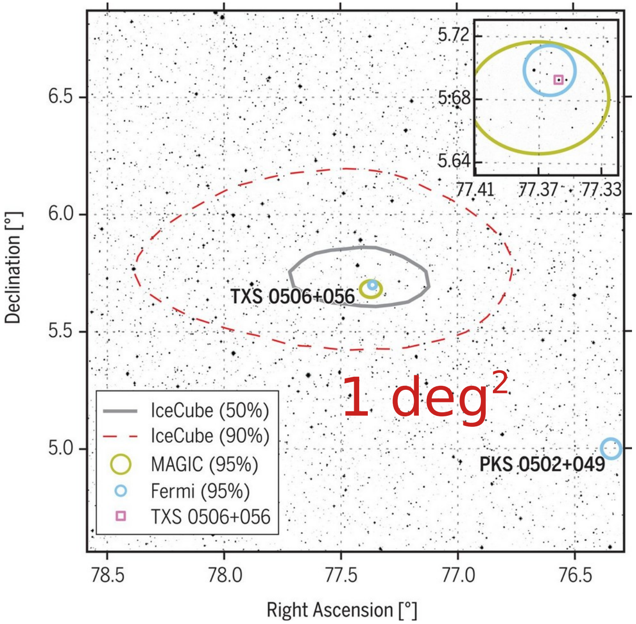


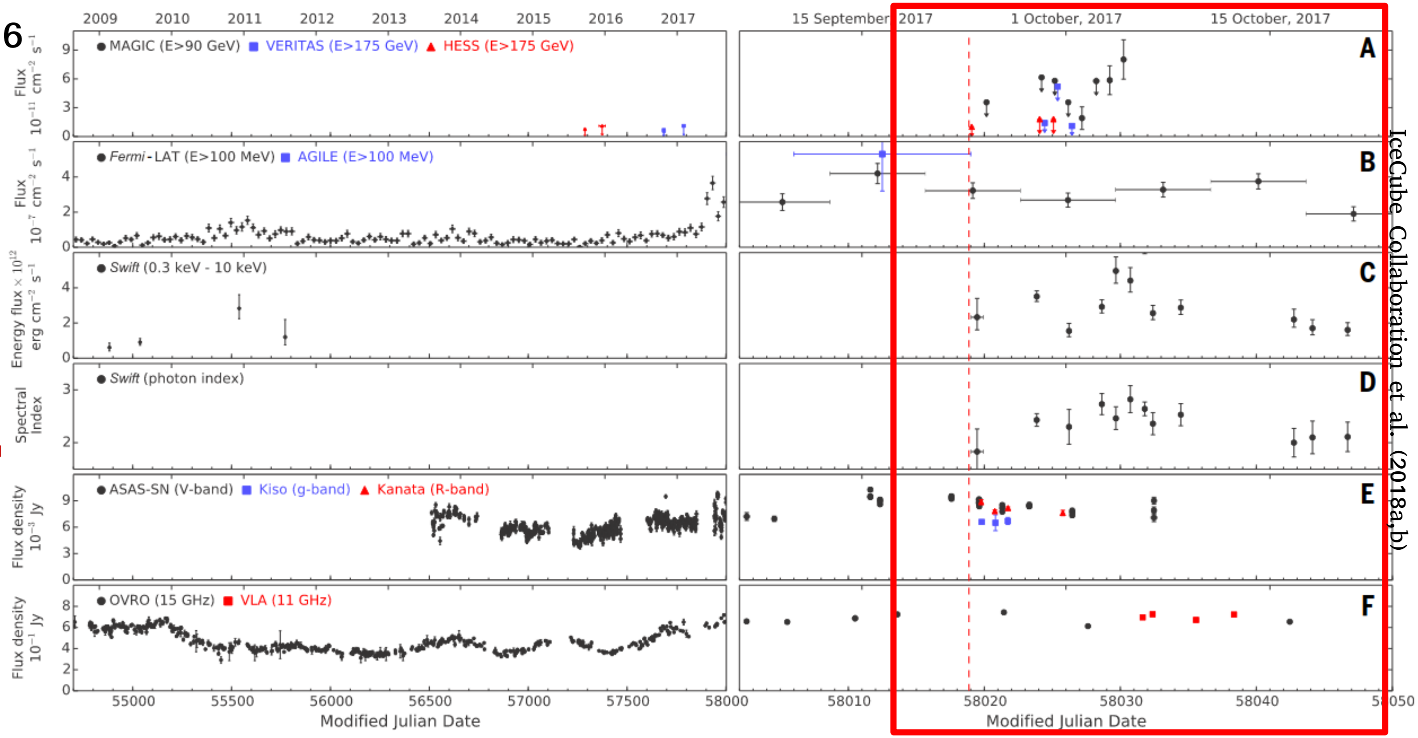
See P. Padovani talk

Sept. 2017: IC 170922A

- 290 TeV
- 56% probability to be of astrophysical origin
- In spatial and temporal coincidence with a flare from TXS 0506+056

TXS 0506+056 flare at all the bands when the neutrino arrived

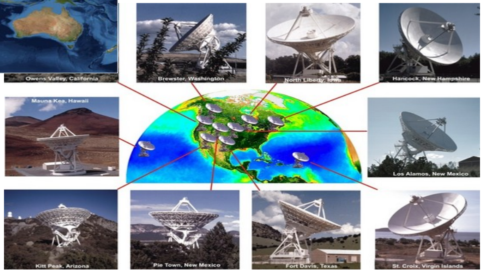




IceCube Collaboration et al. (2018a,b)

A powerful tool: the very long baseline interferometry **(VLBI)** networks

EVN
European **V**LBI **N**etwork
(worldwide antennas, mainly in Europe)



VLBA
Very **L**ong **B**aseline **A**rray
(American antennas)

e-MERLIN

Multi-**E**lement **R**adio **L**inked **I**nterferometer **N**etwork (UK)

EAVN
East **A**sia **V**LBI **N**etwork
(Asian antennas)

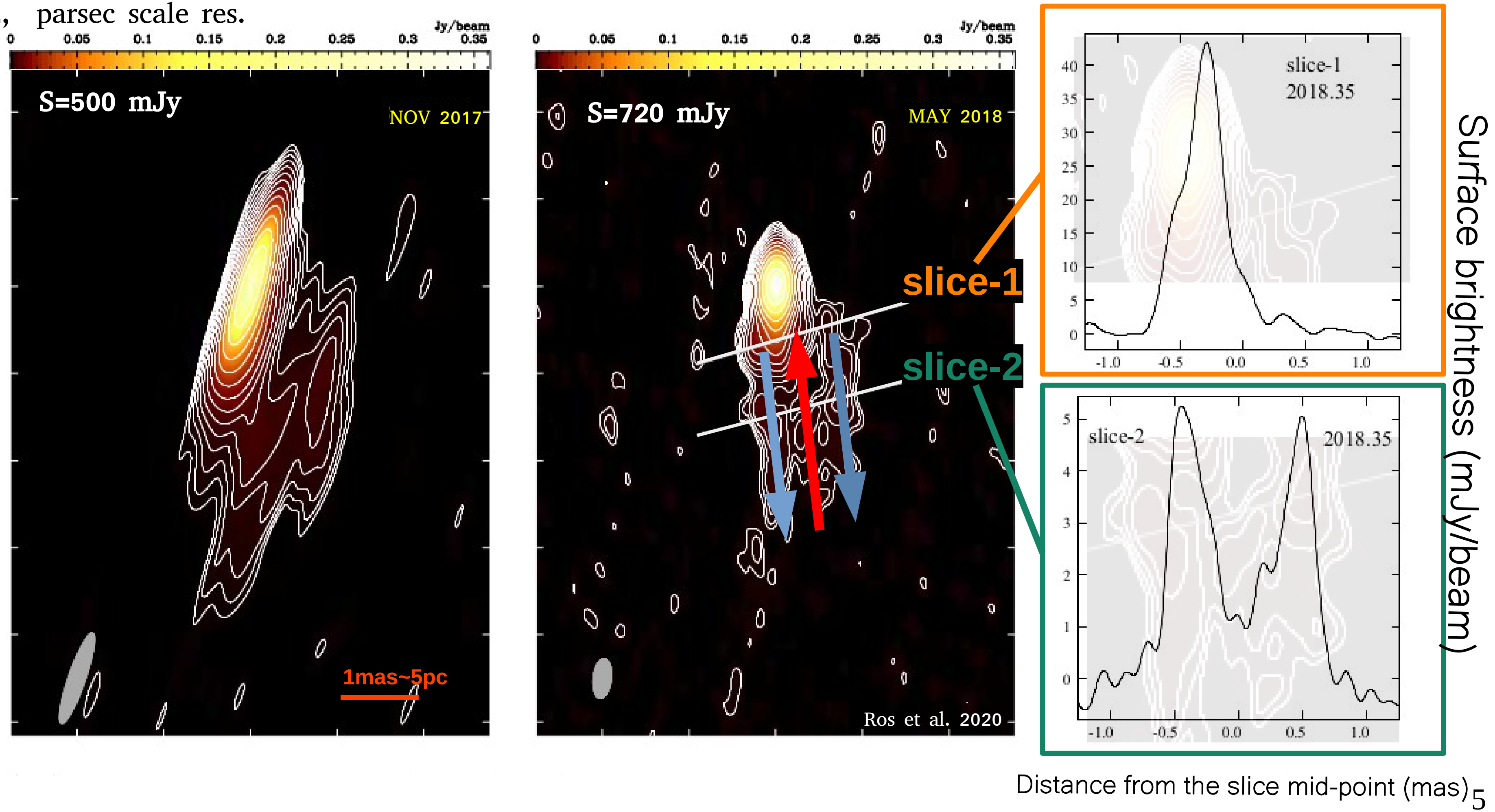
angular resolution ∝ λ/D where D is ∝ thousands of km!

→ milliarcsec resolution!

(parsec resolution at z of our sources)

VLBI study on TXS0506+056 - I

43 GHz, parsec scale res.

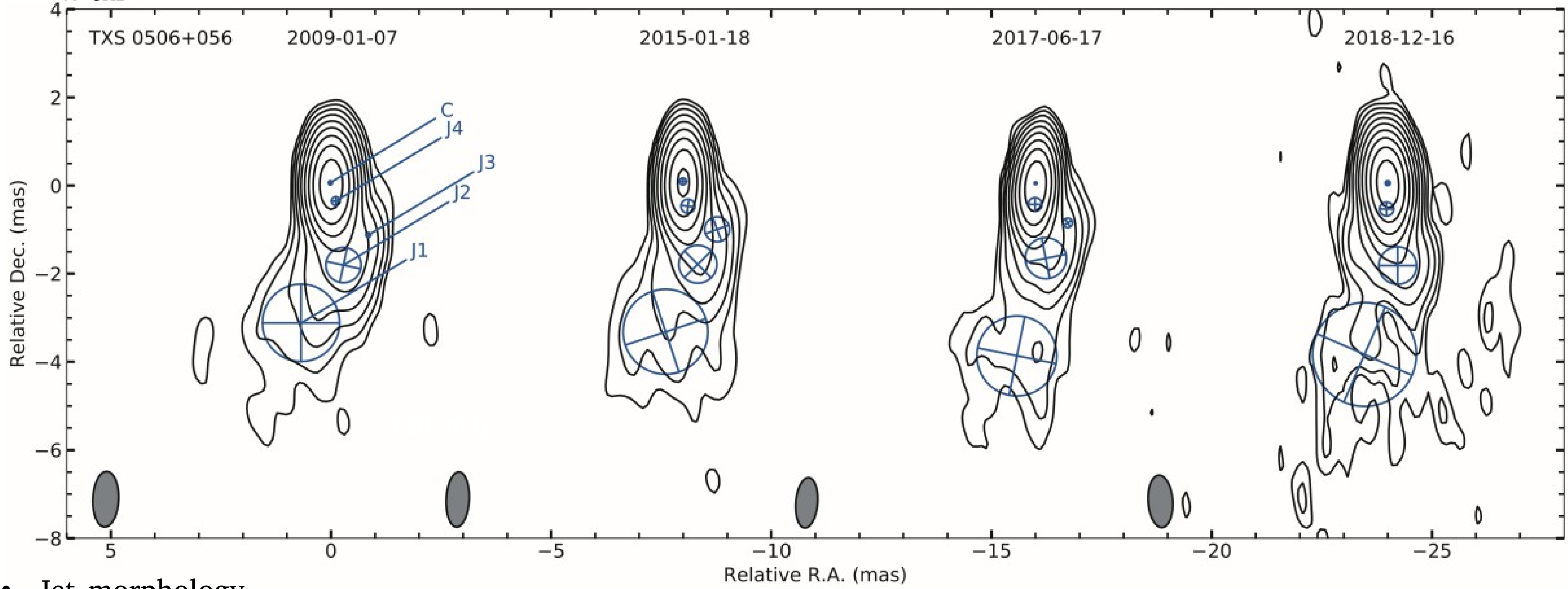


Signature of layers in the jet → region of efficient neutrino production (Tavecchio et al. 2014, Righi et al. 2017)

VLBI study on TXS0506+056 - II

Li et al. 2020

15 GHz



- Jet morphology
- Jet component kinematics
- Brightness temperature, position angle evolution
- The flare occurred in the core (pc-scale)
- Magnetic field strength before and after the neutrino event

Conversion of magnetic energy → particle energy → ongoing particle acceleration

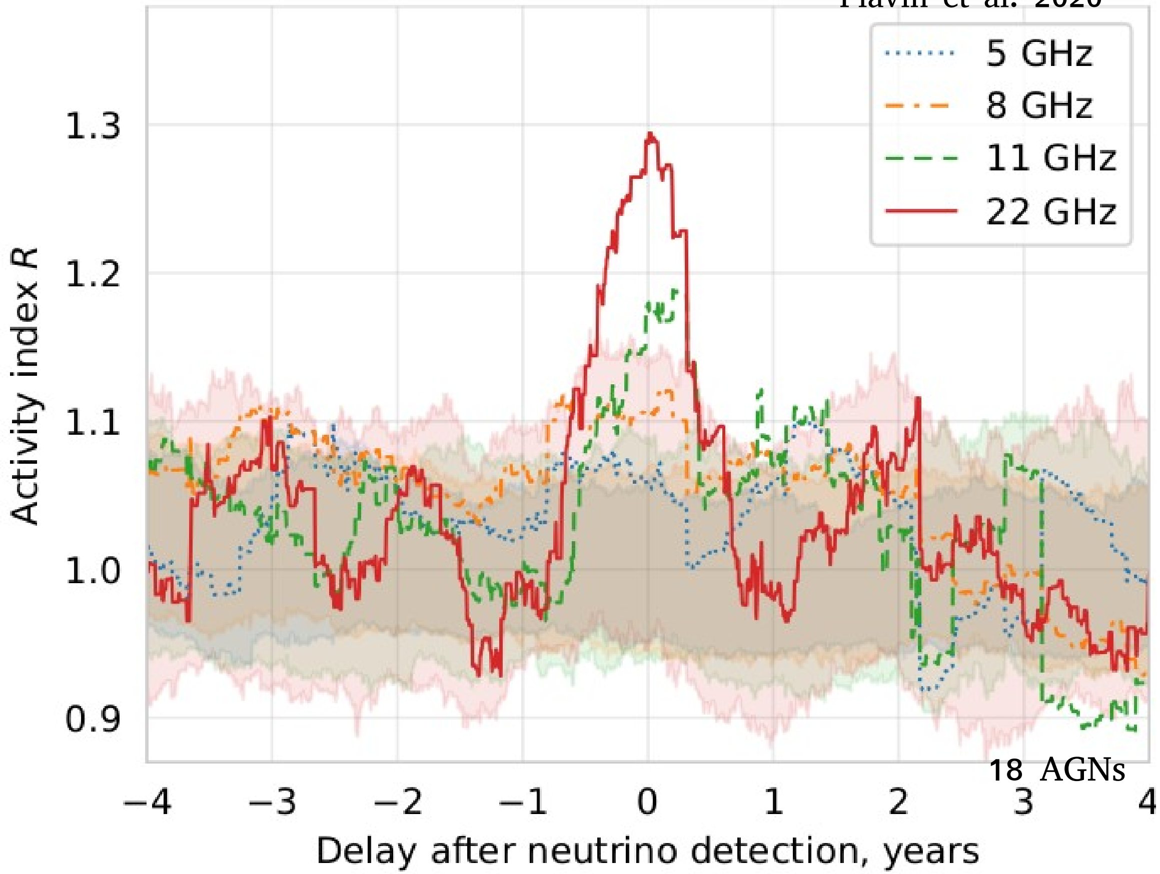
VLBI population studies

Plavin et al. 2020,2021

-significant **positional** association of bright VLBI blazars with neutrinos

-significant **temporal** association of VLBI flares with neutrinos

Plavin et al. 2020



18 AGNs

Our VLBI study

Search for other neutrino emitter blazars through VLBI follow-ups

Between 2019 and 2020

+ 4 new VLBI follow ups of NEUTRINO events

on a total of ~8 events followed with VLBI and published so far

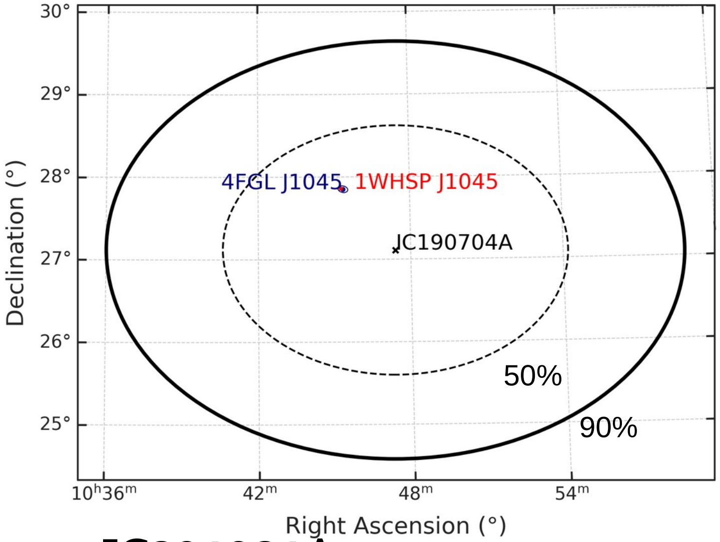
→ 10 radio sources candidate counterparts

→ 5 “best” candidates

- Blazar-like
- γ-ray associated

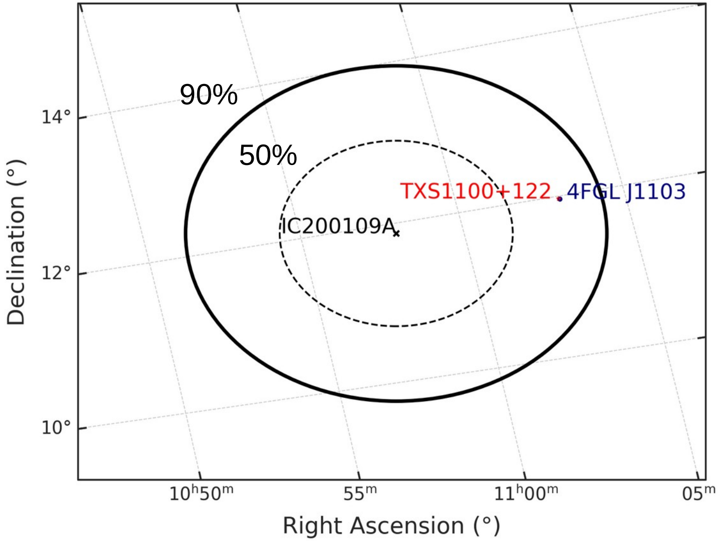
Nanci et al. 2022

IC190704A



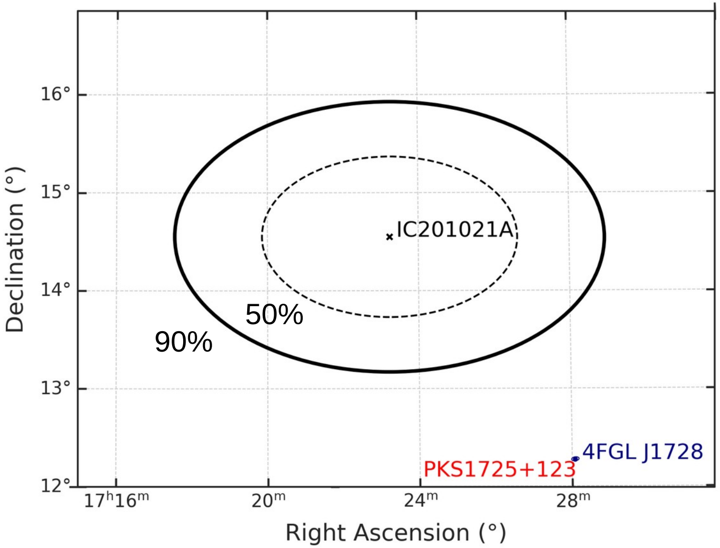
BRONZE
155 TeV
20 deg²

IC200109A



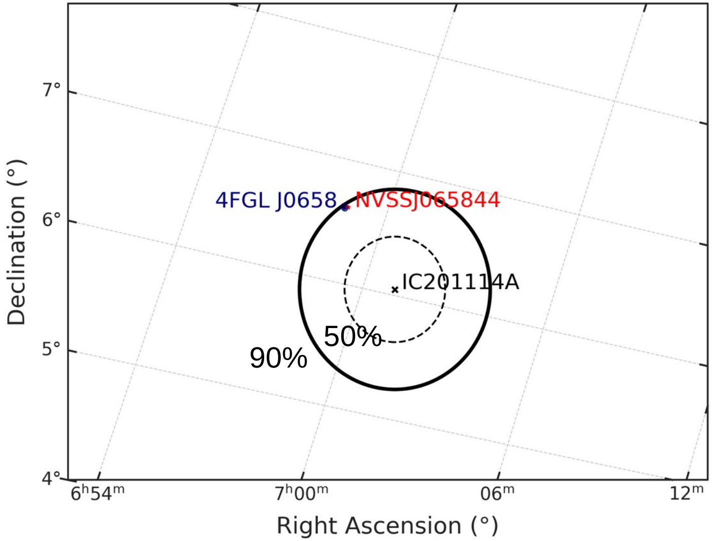
GOLD
375 TeV
26 deg²

IC201021A



BRONZE
105 TeV
6 deg²

IC201114A



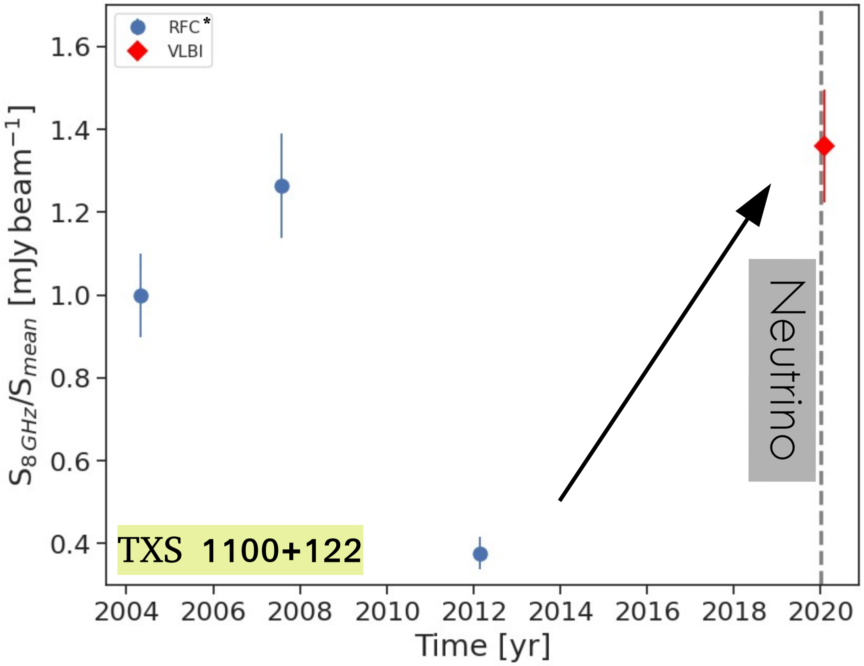
GOLD
214 TeV
4 deg²

Nanci et al. 2022

Our VLBI study: Does neutrino emission correspond to **enhanced radio activity?**

1. 1WHSP J104516.2+275133 – IC 190704A → **FIRST VLBI OBSERVATION** → NO ARCHIVAL DATA for comparison

2. TXS 1100+122 – IC 200109A → **VLBI OBSERVATION** → hints of enhanced activity
+ **RATAN-600** observations at 2.3, 5, 8, 11, 22 GHz (Kovalev et al.2020a)



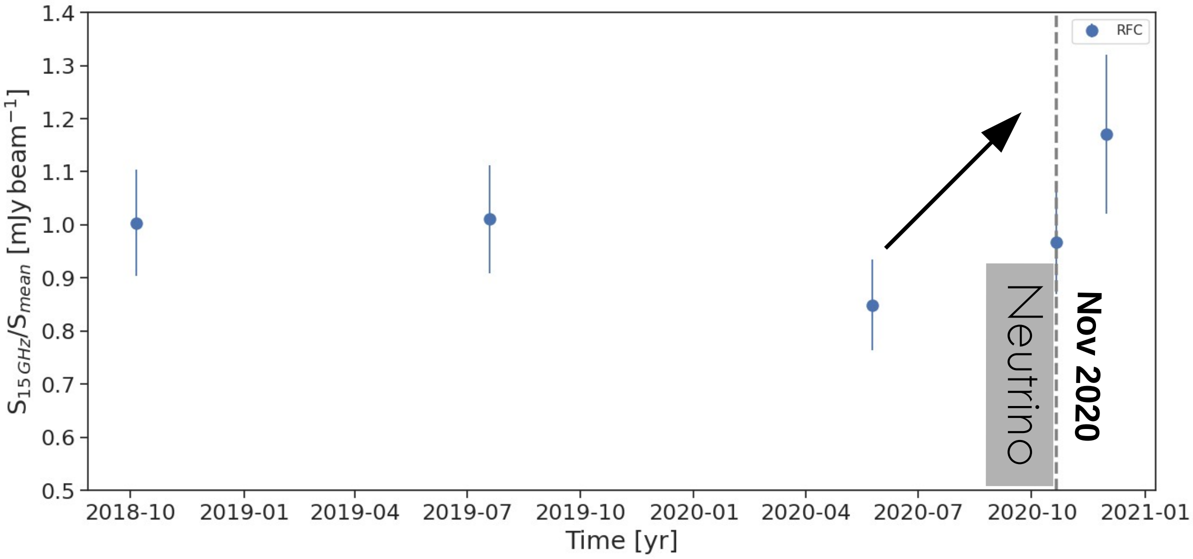
*Radio Fundamental catalog

Nanci et al. 2022

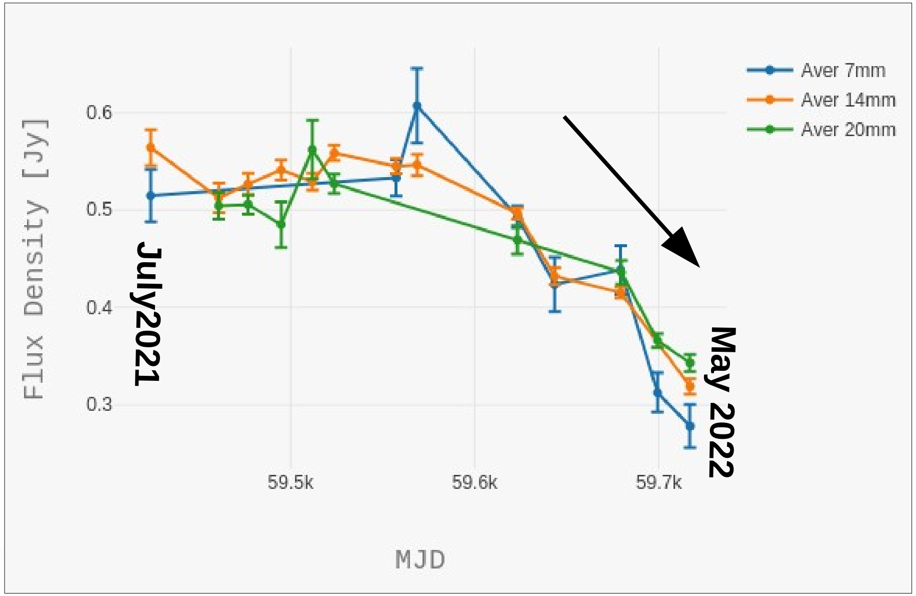
Our VLBI study: Does neutrino emission correspond to **enhanced radio activity?**

3. PKS 1723+125 – IC 201021A → enhanced activity

MOJAVE*



TELAMON* – after IC 201021A



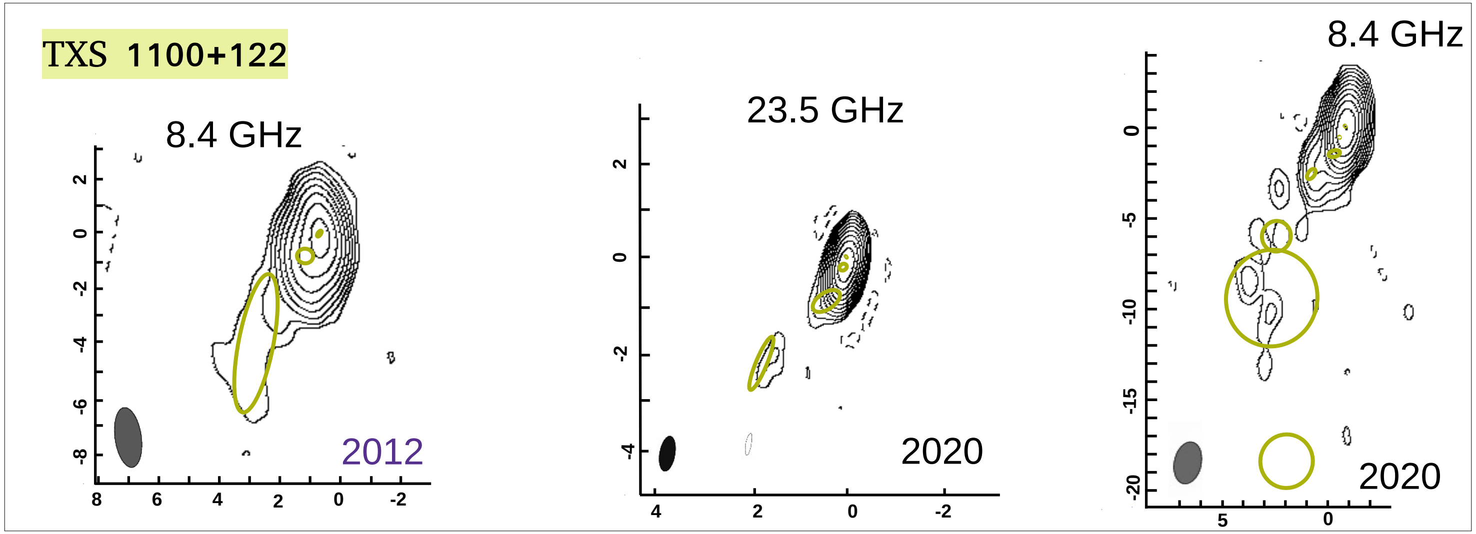
*Monitoring Of Jets in Active galactic nuclei with VLBA Experiments

*Effelsberg Monitoring of AGN Jets with Very-High-Energy Astroparticle Emissions (Kadler et al. 2021)

time

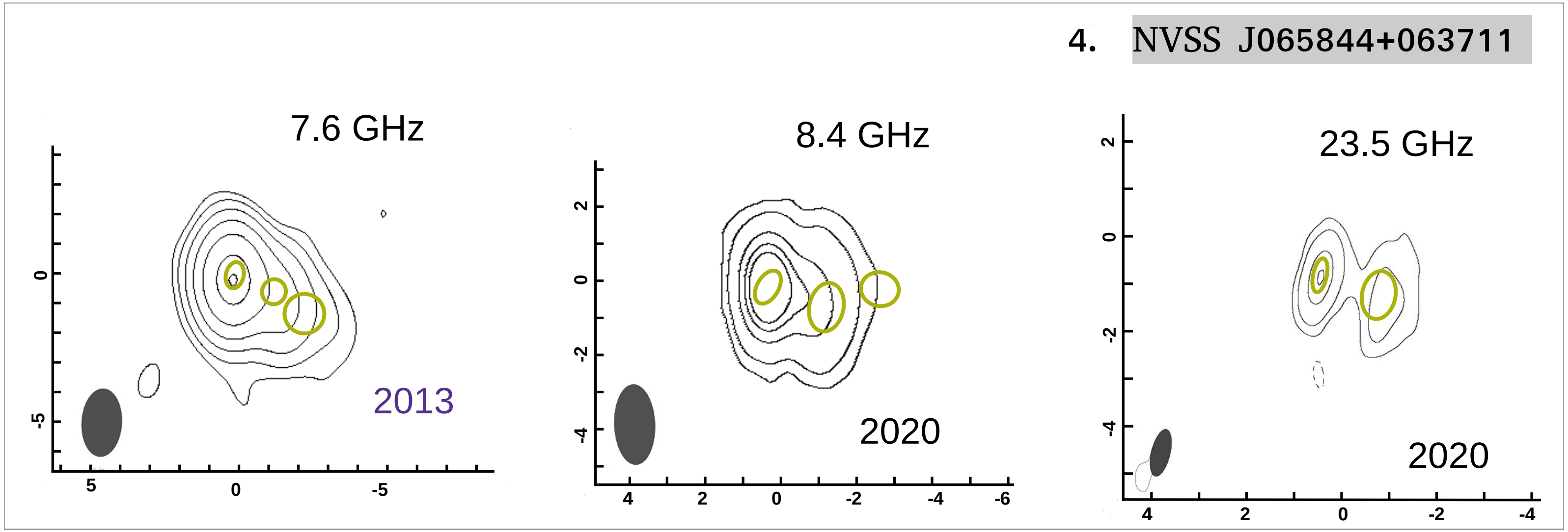
Nanci et al. 2022

Our VLBI study: Can we see **recurring radio properties** linked to neutrino production?



Jet kinematics and morphology

→ will come with monitoring of the sources

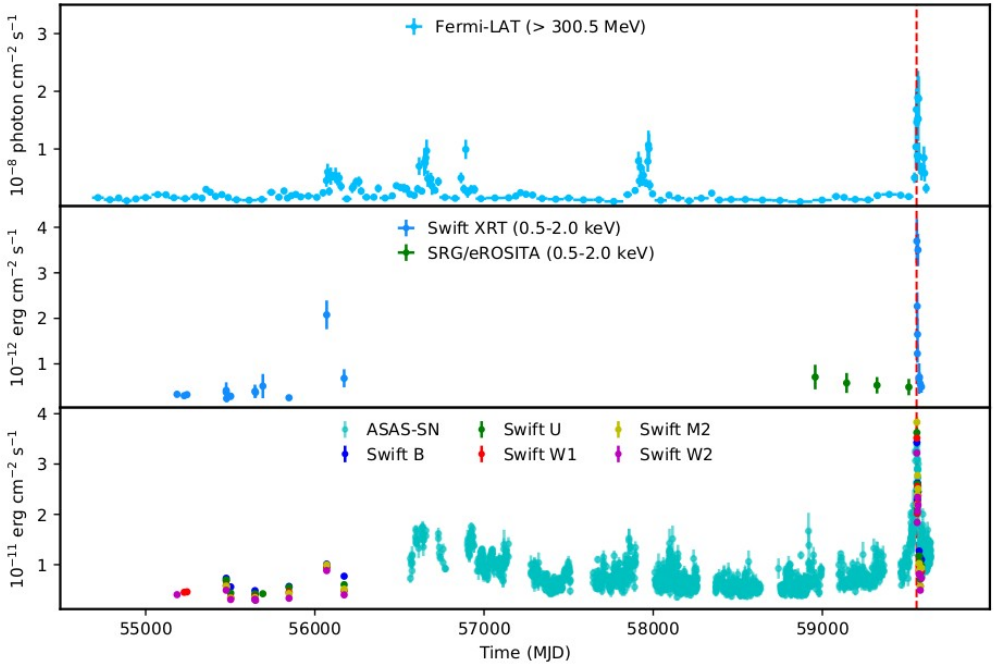


Nanci et al. 2022

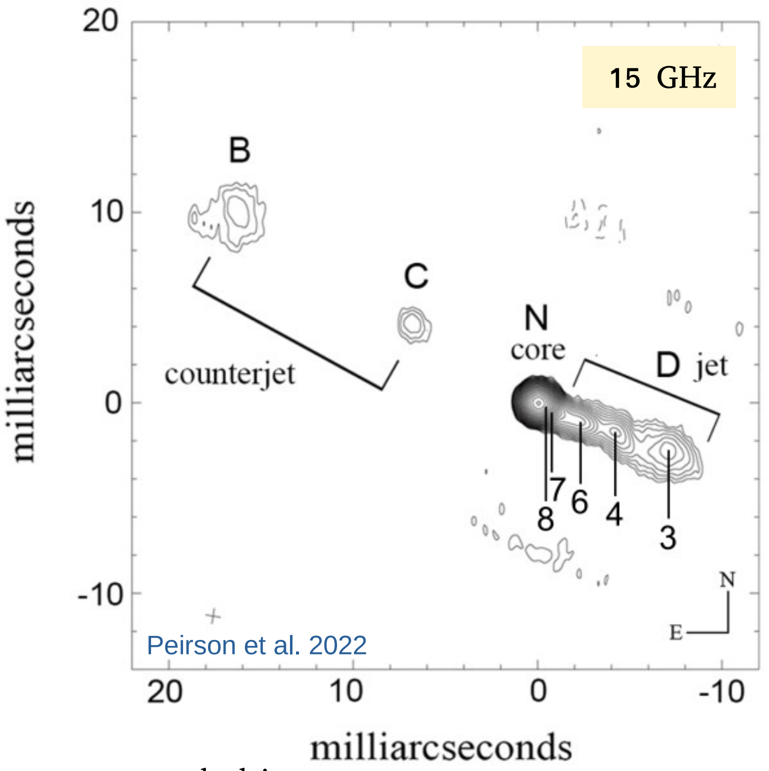
Our future VLBI study: new VLBI follow-ups

1. IC-211208A (bronze) – **PKS 0735+17** (z=0.424)
   → in flare at the neutrino arrival

Sahakyan et al. 2022



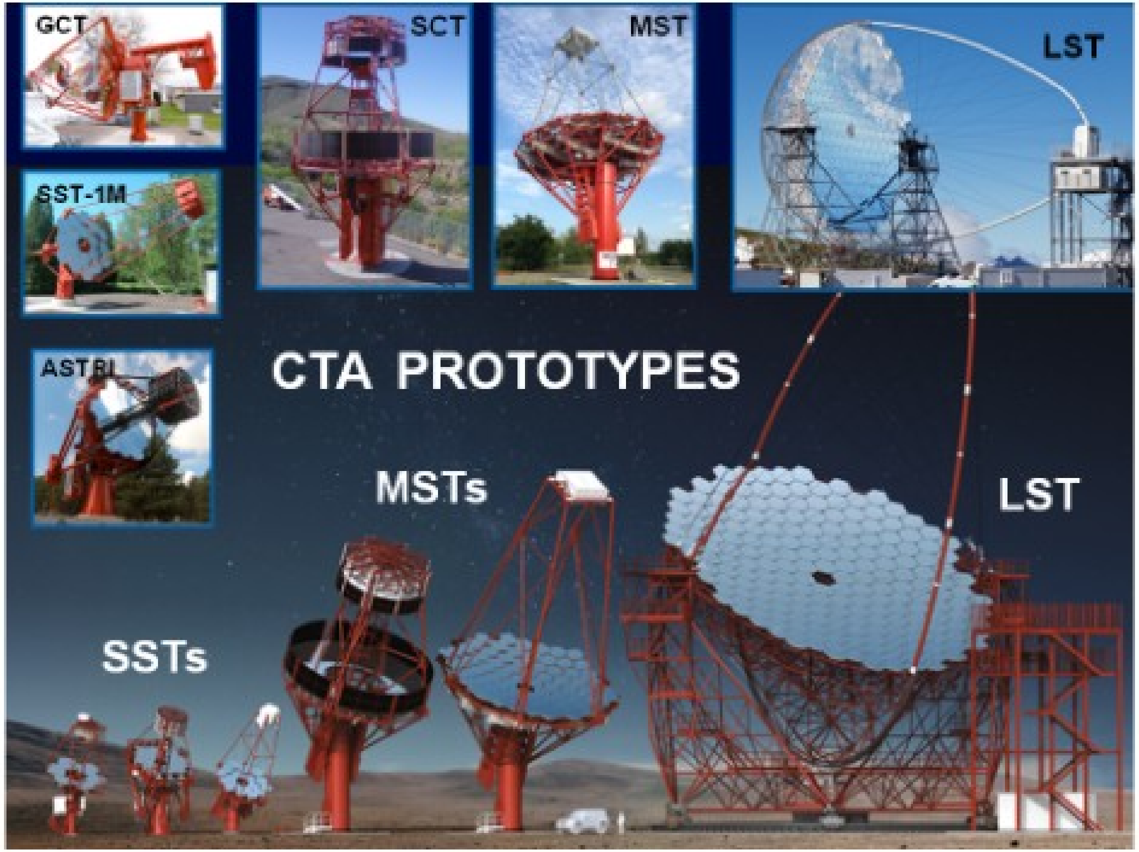
2. IC-220205A (bronze) – **PKS 1431+134** (z=0.247)
   → lensed object, **1**st blazar with counter jet



stacked image
of 23 epochs by
MOJAVE

Stay tuned...

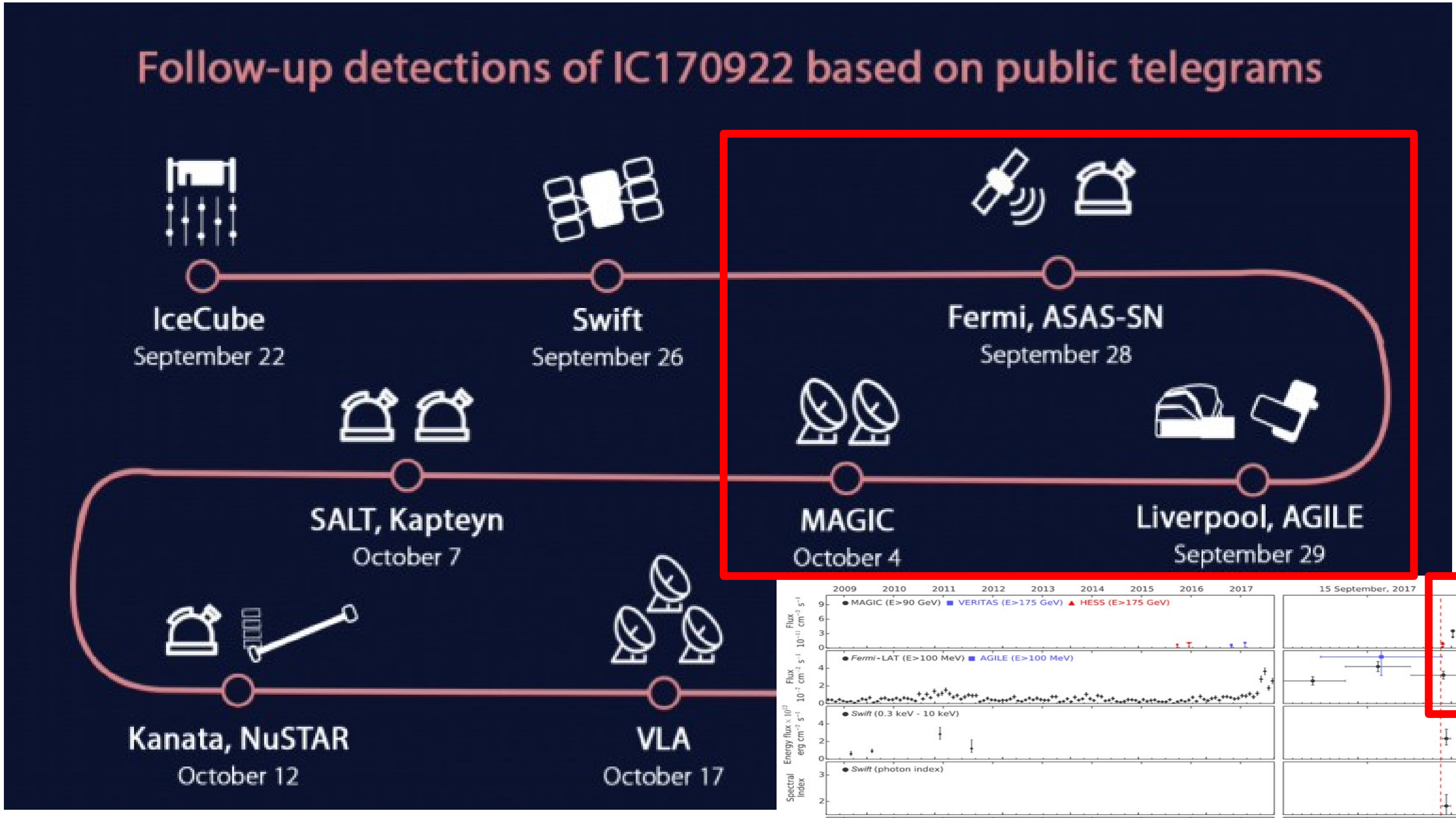
Towards Astri and CTA in the neutrino counterparts research



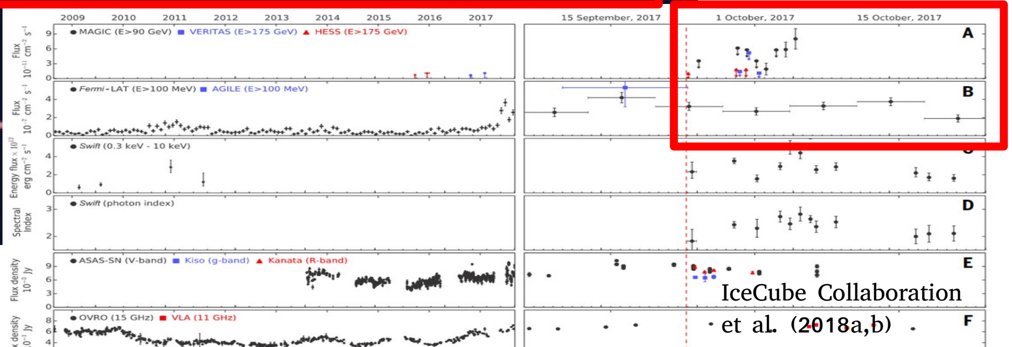
Towards Astri and CTA in the neutrino counterparts research

- KSP Transients: High-energy neutrino transients

CTA follow-ups of neutrino alerts



TXS 0506+056 flare at all the bands when the neutrino arrived



IceCube Collaboration et al. (2018a,b)

Towards Astri and CTA in the neutrino counterparts research

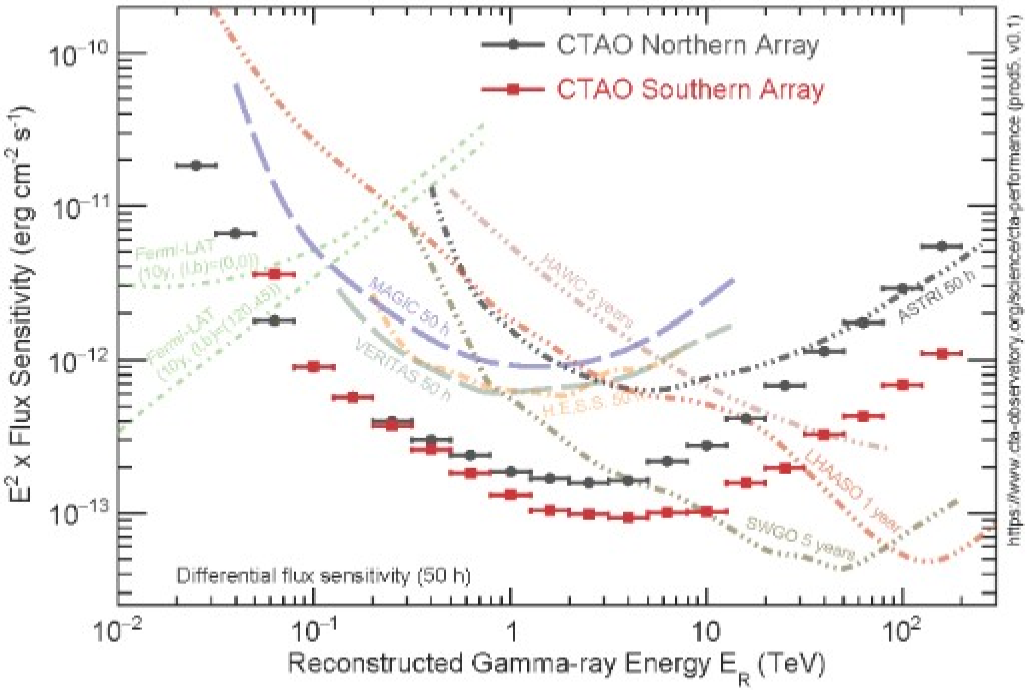
-Understanding **TeV-blazars**: among the most promising neutrino-emitter candidates

(e.g., Tavecchio et al.2014, Padovani et al.2015, Giommi et al.2020)

With the CTA sensitivity:

- discover the "high" redshift TeV-blazar population
- Not only TeV-blazars in flaring state

Sitarek et al. 2022



With the CTA energy resolution:

Better constraints on the TeV-blazars SEDs at the highest energies

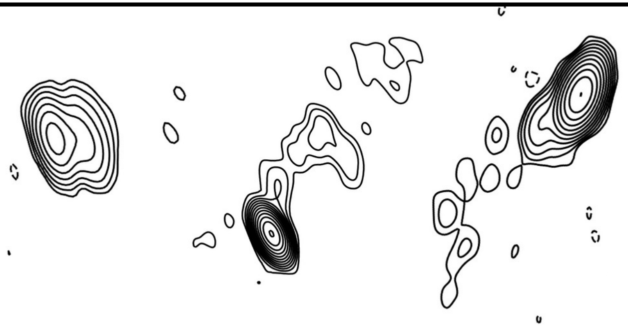
→ constraints on the emission models

With the CTA monitoring of TeV-blazars:

Locate the gamma-ray emission region

Summary

PAST..



+ 4 neutrinos follow-ups with VLBI (**+ 10** radio candidates)

- VLBI classification of the cospatial sources
- Check of the state of activity at the neutrino arrival
- Working on the jet kinematics

PKS 1725+123: ~ **enhanced** state of activity
TXS 1100+122: ~ hint of **enhanced** state of activity

Nanci et al.2022

time

..PRESENT..

+ 4 NEW neutrinos follow-ups with VLBI ..more are expected

..FUTURE!

- CTA+MWL follow-up of neutrino events
- CTA – VLBI synergies to address the open questions on TeV-blazars and their possible connection with neutrinos

Thank you for your attention!

backup slides

Our future VLBI study: new VLBI follow-ups

1. IC-211208A (bronze) – **PKS 0735+17** (z=0.424)
   → in flare at the neutrino arrival

2. IC-220205A (bronze) – **PKS 1431+134** (z=0.247)
   → lensed object, 1st blazar with counter jet

3. IC-220205B (gold) – **PKS 1741-03** (z=1.054)
   → in Plavin et al. 2020

4. IC-220425A (gold) – **TXS 1749-101**
   → previous association with a 2018-ICevent
   – **TXS 1742-078**
   → flaring state

Stay tuned...

Some numbers on IceCube events

From 2019-07-04 to 2020-11-14

33 IceCube alerts

→ 12 Gold events

→ 5 of them with at least 1 gamma-ray source in the 90% loc.area

Gold events:

1. IC190704A - 1WHSP J104516.2+275133

2. IC190730A - PKS 1502+106

3. IC191001A - AT2019dsg

4. IC200109A - TXS 1100+122

5. IC200530A - Type IIn superluminous supernova

High-resolution VLBI observations of and modelling the radio emission from the TDE AT2019dsg

Prashanth Mohan,[1] Tao An,[1] Yingkang Zhang,[1] Jun Yang,[2] Xiaolong Yang,[1] and Ailing Wang[1,3]

A ring accelerator? Unusual jet dynamics in the IceCube candidate PKS 1502+106

S. Britzen[1★], M. Zajaček[1,2,3], L.Č. Popović[4,5], C. Fendt[6], A. Tramacere[7], I.N. Pashchenko[8], F. Jaron[1,9,10], R. Pánis[11], L. Petrov[12], M.F. Aller[13], and H.D. Aller[13]

Is the high-energy neutrino event IceCube-200530A associated with a hydrogen rich superluminous supernova?

Tetyana Pitik,[1,2] Irene Tamborra,[1,2] Charlotte R. Angus,[2] and Katie Auchettl[3,4,5]

+ 4 new VLBI follow ups of NEUTRINO events!

on a total of ~**8 events followed with VLBI and published** so far

Before and contemporary to our work:

- PKS B1424 − 418 – Kadler et al. (2016)
- TXS 0506-056 – Kun et al. (2019), Li et al. (2020), Ros et al. (2020) and others
- PKS 1502+106 – Britzen et al. (2021)
- AT2019dsg – Prashanth et al. (2021)
- **Nanci et al.** +4 VLBI follow-ups

Observing the inner parsec-scale region of candidate neutrino-emitting blazars

C. Nanci[1,2], M. Giroletti[2], M. Orienti[2], G. Migliori[2], J. Moldón[3], S. Garrappa[4], M. Kadler[5], E. Ros[6], S. Buson[5], T. An[7], M. A. Pérez-Torres[3], F. D'Ammando[2], P. Mohan[7], I. Agudo[3], B. W. Sohn[8], A.J. Castro-Tirado[3], Y. Zhang[7]

Stay tuned for follow-ups of new events!

IceCube-211208A

```
TITLE:   GCN CIRCULAR
NUMBER:  31191
SUBJECT: IceCube-211208A - IceCube observation of a high-energy neutrino
candidate track-like event
DATE:    21/12/08 21:28:14 GMT
FROM:    Marcos Santander at U. Alabama/IceCube  <jmsantander@ua.edu>

The IceCube Collaboration (http://icecube.wisc.edu/) reports:

On 2021-12-08 at 20:02:51.1 UT IceCube detected a track-like event with a
moderate probability of being of astrophysical origin. The event was selected by
the ICECUBE_Astrotrack_Bronze alert stream.  The average astrophysical neutrino
purity for Bronze alerts is 30%. This alert has an estimated false alarm rate of
1.197 events per year due to atmospheric backgrounds. The IceCube detector was
in a normal operating state at the time of detection.

After the initial automated alert (https://gcn.gsfc.nasa.gov/notices_amon_g_b
/136015_21306805.amon, more sophisticated reconstruction algorithms have been
applied offline, with the direction refined to:
```

TELAMON, Metsahovi, Medicina, OVRO and RATAN-600 programs find a long-term radio flare in PKS0735+17 coincident with IceCube-211208A

ATel #15105; *Matthias Kadler (JMU Wuerzburg), Petra Benke (MPIfR), Andrea Gokus (JMU Wuerzburg & FAU Erlangen-Nuremberg), Jonas Hessdoerfer (JMU Wuerzburg), Jonas Sinapius (DESY) & Philip Weber (JMU Wuerzburg), for the TELAMON Team, Merja Tornikoski (Aalto University MetsÃ¤hovi Radio Observatory), Simona Righini (INAF/IRA) and Nicola Marchili (INAF/IRA), Talvikki Hovatta (Finnish Centre for Astronomy with ESO), Anthony C. Readhead (OVRO, Caltech), Sebastian Kiehlmann (IoA FORTH, OVRO), Yuri A. Kovalev (ASC Lebedev), Alexander V. Popkov (MIPT, ASC Lebedev), Yuri Y. Kovalev (ASC Lebedev, MIPT, MPIfR)*

IceCube-220205B

```
TITLE:   GCN CIRCULAR
NUMBER:  31554
SUBJECT: IceCube-220205B - IceCube observation of a high-energy neutrino
candidate track-like event
DATE:    22/02/05 22:03:46 GMT
FROM:    Marcos Santander at U. Alabama/IceCube  <jmsantander@ua.edu>

The IceCube Collaboration (http://icecube.wisc.edu/) reports:

On 2022-02-05 at 20:08:10 UT IceCube detected a track-like event with a high
probability of being of astrophysical origin. The event was selected by the
ICECUBE_Astrotrack_GOLD alert stream.  The average astrophysical neutrino purity
Gold alerts is 50%. This alert has an estimated false alarm rate of 0.734 events
per year due to atmospheric backgrounds. The IceCube detector was in a normal
operating state at the time of detection.

Due to a technical issue, the automated GCN notice for this event could not be
circulated. The initial position was reconstructed by the IceCube online system
and the best-fit parameters are listed below:

Date: 2022-02-05
Time:  20:08:10.59 UT
RA: 266.80 deg (J2000)
Dec: -3.58 deg (J2000)
Error radius: 0.51 deg (90%)

Initial signal probability: 59.5%
Initial neutrino energy: 215.9 TeV

Attempts to use a more sophisticated algorithm that provides refined position
and error estimates encountered issues, so further studies will have to be
performed before an update is available. Given the topology of the light
deposition in the detector, we estimate that the initial direction listed above
still provides a good characterization of the event.

We encourage follow-up by ground and space-based instruments to help identify a
possible astrophysical source for the candidate neutrino.

Several gamma-ray sources listed in the 4FGL Fermi-LAT catalog are located near
the best-fit neutrino candidate position, 3 of them within a 1 degree radius.
These sources are: 4FGL J1747.8-0316 (0.34 deg away), 4FGL J1744.2-0353 (0.81
deg, associated with the source PKS 1741-03) and 4FGL J1749.8-0303 (0.84 deg).

The IceCube Neutrino Observatory is a cubic-kilometer neutrino detector
operating at the geographic South Pole, Antarctica. The IceCube realtime alert
point of contact can be reached at roc@icecube.wisc.edu
```

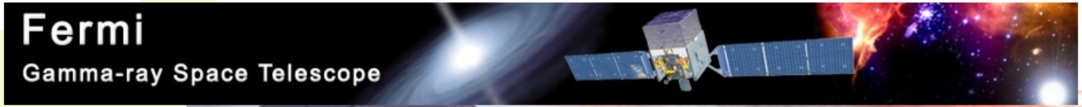
Multi-wavelength Collaboration

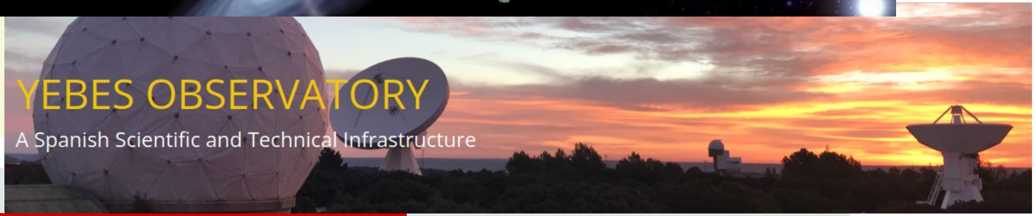
The IRAM 30m telescope is one of today's largest and most sensitive millimeter telescopes, equipped with a series of heterodyne receivers and continuum cameras operating at 3, 2, 1, and 0.9mm. High resolution spectroscopy allows to study the interplay of chemistry and the ongoing formation of stars within giant molecular clouds of the Milky Way and of nearby galaxies, out to the farthest known galaxies of the young universe. The telescope is located on Pico Veleta in the Spanish Sierra Nevada, at an altitude of 2850m.

ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY

Radio Telescope Effelsberg

TELAMON: Effelsberg Monitoring of AGN Jets with Very-High-Energy Astroparticle Emissions





TANAMI - Tracking Active Galactic Nuclei with Austral Milliarcsecond Interferometry

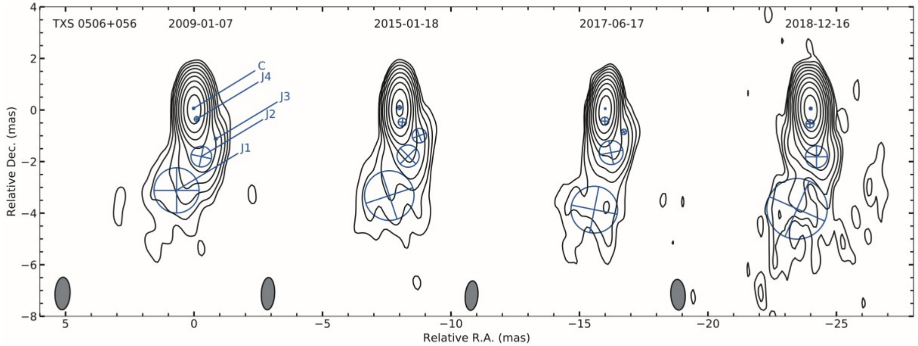
TANAMI

TANAMI (Tracking Active Galactic Nuclei with Austral Milliarcsecond Interferometry) is a multiwavelength program to monitor relativistic jets in active galactic nuclei (AGN) of the Southern Sky. TANAMI consists of 1) a VLBI core program targeting the parsec-scale structures of blazars, radio galaxies and other types of AGN, 2) complementary radio spectral and light-curve monitoring programs with ATCA and the Ceduna telescope, and 3) higher-energy multiwavelength observations with REM, *Swift*, *XMM-Newton*, *Suzaku*, *INTEGRAL*, *Fermi*/LAT and other telescopes. Currently, TANAMI is monitoring about 135 jets at different cadences based on their known variability timescale. Though a significant fraction of these were originally not known to be gamma-ray sources, the vast majority have now been detected by *Fermi* in the gamma-ray band.

VLBI study on TXS0506+056 - II

15 GHz

Li et al. 2020



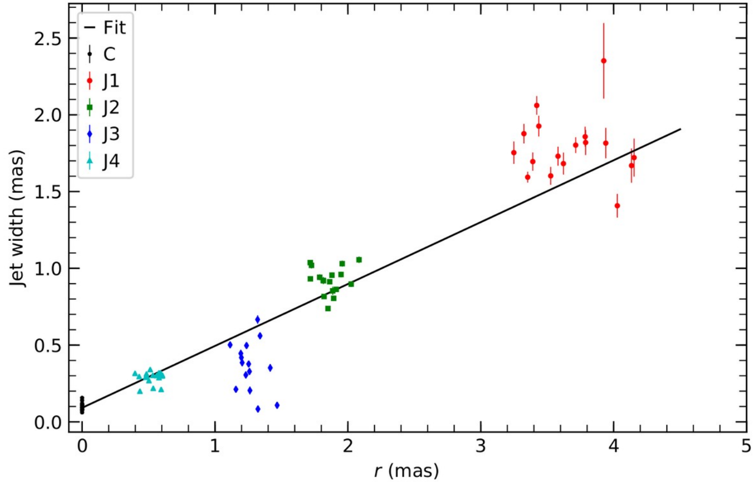
Date	ν	Comp	S	r	PA	d	$T_{\rm b,obs}$	δ
(Y-M-D)	(GHz)		(mJy)	(mas)	(°)	(mas)	(10^{11} K)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2009-01-07	15.4	C	354.9±0.9	0	0	0.092±0.001	2.91	5.81
		J4	101.8±0.70	0.435±0.001	−163.2±0.1	0.199±0.001		
		J3	7.8±0.60	1.467±0.018	−143.8±0.5	0.108±0.015		
		J2	46.2±1.35	1.893±0.016	−170.9±0.1	0.804±0.011		
		J1	24.7±2.90	3.249±0.072	168.2±0.3	1.753±0.050		

comp	N	$\langle S \rangle$	$\langle r \rangle$	$\langle \vartheta \rangle$	$\mu_{\rm app}$	$\beta_{\rm app}$
		(mJy)	(mas)	(°)	(mas $\rm yr^{-1}$)	(c)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
J1	17	20.8	3.669	172.1	0.071±0.016	1.49±0.34
J2	17	46.8	1.865	188.0	0.013±0.007	0.28±0.15
J3	15	11.4	1.265	218.8	0.017±0.007	0.35±0.15
J4	17	98.2	0.524	186.6	0.019±0.003	0.41±0.06

NOTE— (1) Component name, (2) nu … (3) mean flux density at 15 GHz, (4) me … (5) mean position angle with respect to the core feature, (6) proper motion, (7) apparent speed in units of the speed of light.

Kinematics

conical jet body

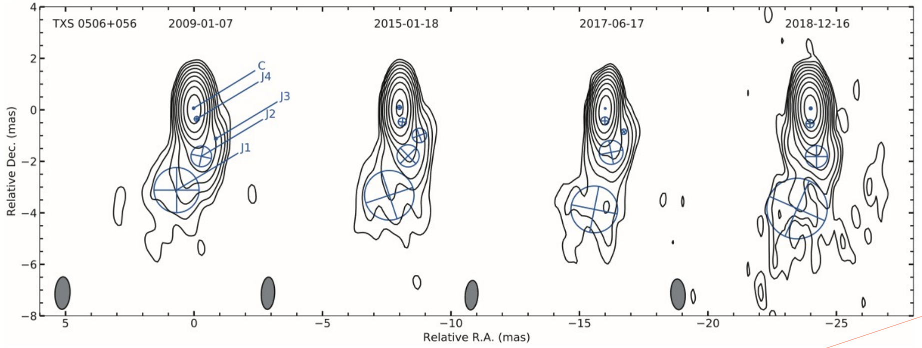


VLBI study on TXS0506+056 - II

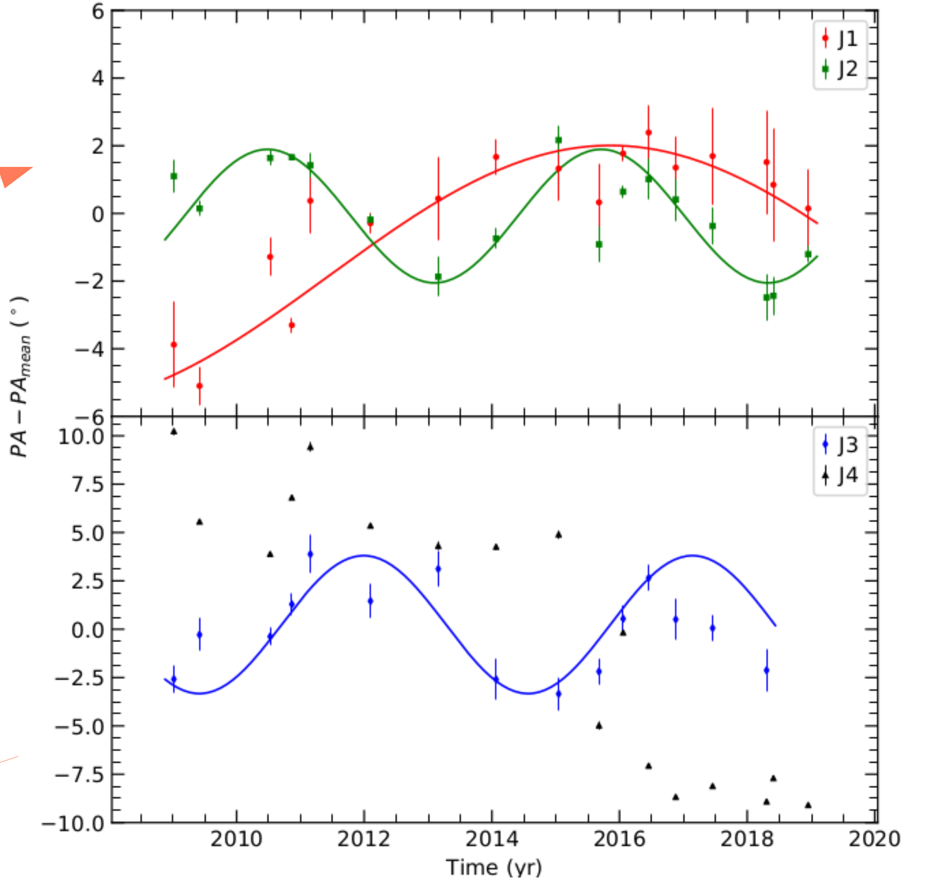
15 GHz

Li et al. 2020

precessing motion
(e.g., along a helical trajectory)



Date	ν	Comp	S	r	PA	d	$T_{\rm b,obs}$	δ
(Y-M-D)	(GHz)		(mJy)	(mas)	(°)	(mas)	(10^{11} K)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2009-01-07	15.4	C	354.9±0.9	0	0	0.092±0.001	2.91	5.81
		J4	101.8±0.70	0.435±0.001	−163.2±0.1	0.199±0.001		
		J3	7.8±0.60	1.467±0.018	−143.8±0.5	0.108±0.015		
		J2	46.2±1.35	1.893±0.016	−170.9±0.1	0.804±0.011		
		J1	24.7±2.90	3.249±0.072	168.2±0.3	1.753±0.050		

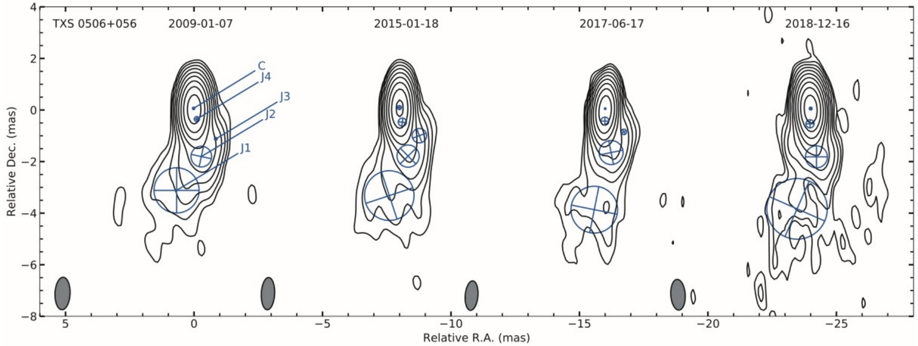


Sinusolidal fit:
→ precession with a period of about 5 years
For J2 and J3
→ precession with a period of about 17 years
For J1

VLBI study on TXS0506+056 - II

15 GHz

Li et al. 2020



Date	ν	Comp	S	r	PA	d	$T_{\rm b,obs}$	δ
(Y-M-D)	(GHz)		(mJy)	(mas)	(°)	(mas)	(10^{11} K)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2009-01-07	15.4	C	354.9±0.9	0	0	0.092±0.001	2.91	5.81
		J4	101.8±0.70	0.435±0.001	−163.2±0.1	0.199±0.001		
		J3	7.8±0.60	1.467±0.018	−143.8±0.5	0.108±0.015		
		J2	46.2±1.35	1.893±0.016	−170.9±0.1	0.804±0.011		
		J1	24.7±2.90	3.249±0.072	168.2±0.3	1.753±0.050		

Apparent core position shift → synchrotron self-absorption in the radio core

The projected core shift:

$$\Delta r_{\rm proj} = \frac{\Delta d}{2\tan\phi_{\rm proj}}$$

The core shift:

$$\Omega_{r\nu} = 4.85\times10^{-9}\frac{D_L \Delta r_{\rm proj}}{(1+z)^2(\nu_1^{-1}-\nu_2^{-1})}\ \text{pc GHz}$$

projected jet half opening angle (in degrees)

core size difference between two frequencies(mas)

$$T_{\rm b} = 5.44\times10^9\frac{S_{\rm core}(1+z)}{\theta_{\rm maj}\theta_{\rm min}}\ \text{K}$$

$\delta = T_{\rm b,obs} / T_{\rm b,int}$

Assuming $T_{\rm b,int} = T_{\rm b,eq}$

eq=equipartition of energy between the radiating particles and magnetic fields ($T_{\rm b,eq} = 5\times10^{10}$ K (Readhead 1994))

$$B_1 \cong \left(\frac{\Omega_{r\nu}^3(1+z)^2}{\delta^2\phi\sin^2\theta}\right)^{1/4}$$

$$B_{\rm core} = B_1(r_{\rm core}/(1\ \text{pc}))^{-1}$$

Towards Astri and CTA in the neutrino counterparts research

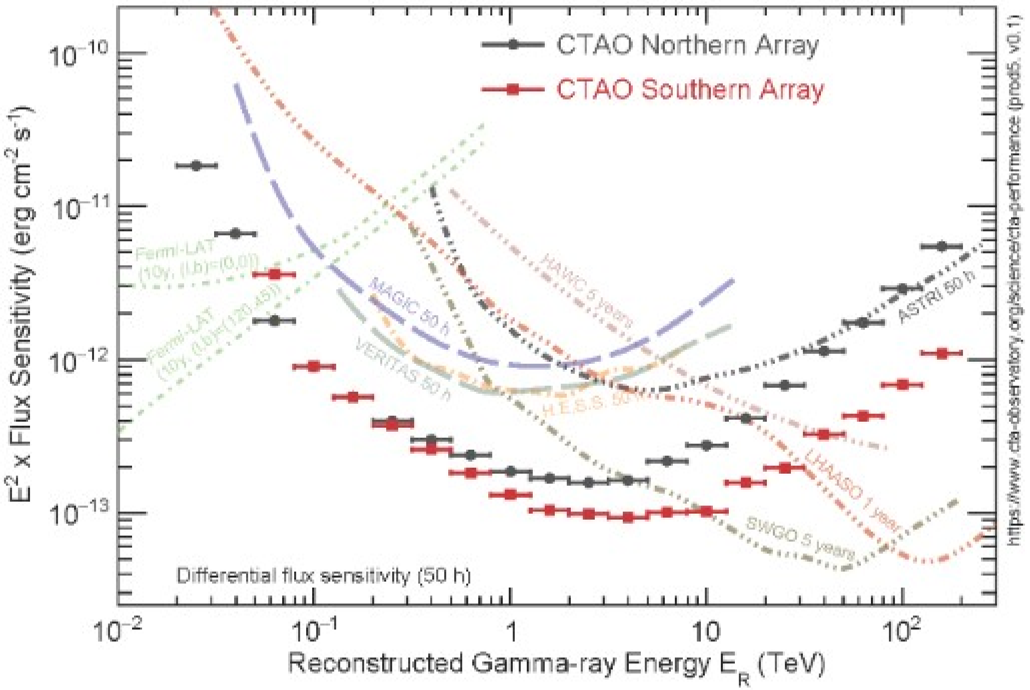
-Understanding **TeV-blazars**: among the most promising neutrino-emitter candidates

(e.g., Tavecchio et al.2014, Padovani et al.2015, Giommi et al.2020)

With the CTA sensitivity:

- discover the “high” redshift TeV-blazar population
- Not only TeV-blazars in flaring state

Sitarek et al. 2022



With the CTA energy resolution:

Better constraints on the TeV-blazars SEDs at the highest energies

→ constraints on the emission models

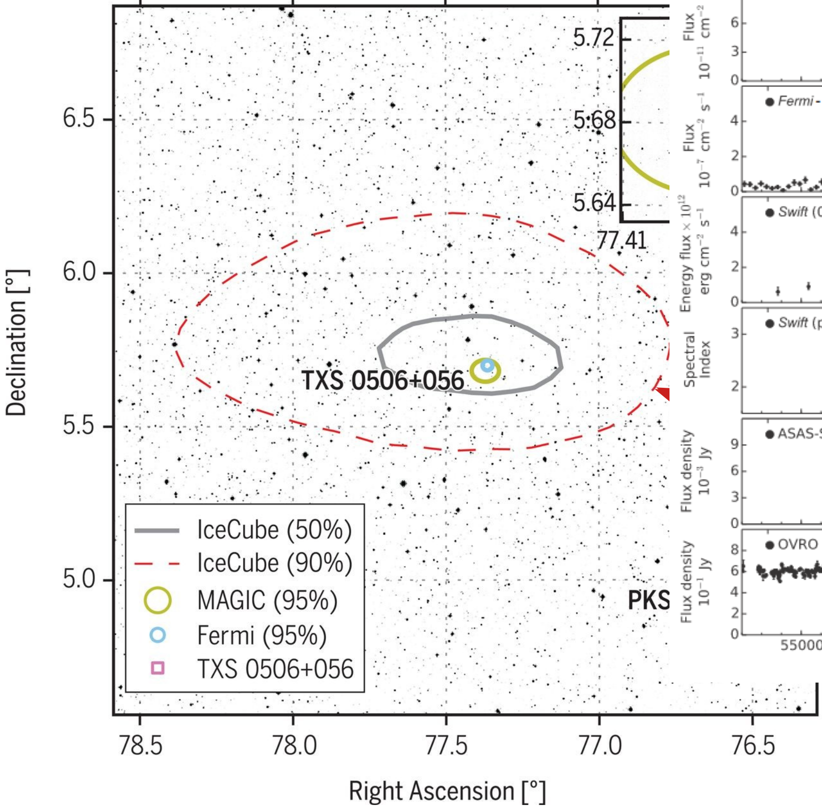
With the CTA monitoring of TeV-blazars:

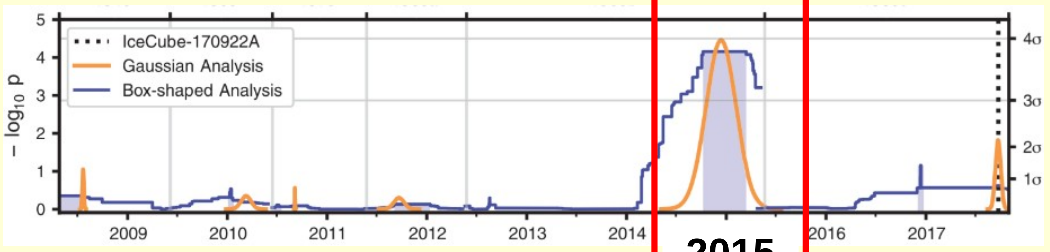
Locate the gamma-ray emission region

$$R \lesssim \frac{c t_{\mathrm{var}} \delta}{1+z}$$

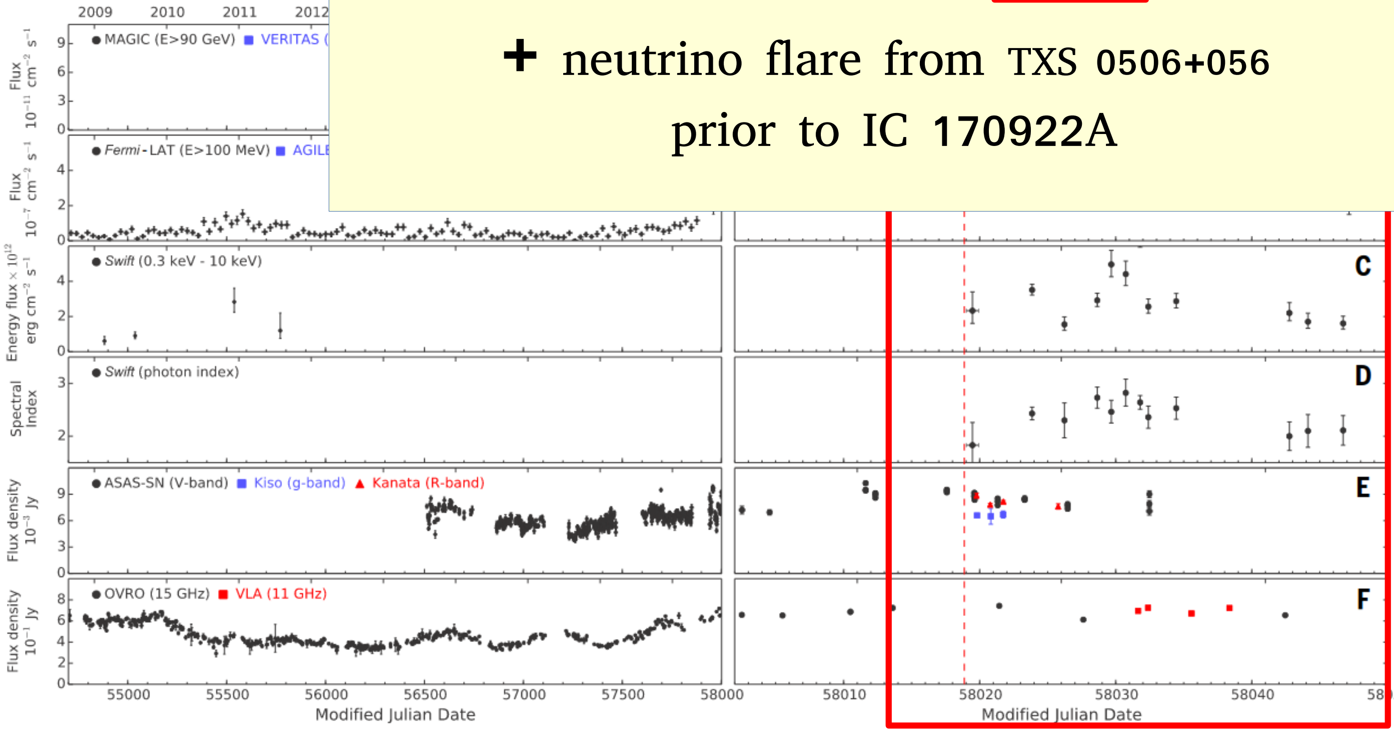
Sept. 2017: IC 170922A

- 290 TeV
- 56% probability to be of astrophysical origin
- In spatial and temporal coincidence with a flare from TXS 0506+056





+ neutrino flare from TXS 0506+056 prior to IC 170922A



TXS 0506+056 flare over all the bands when the neutrino arrived

What we can do from the VLBI point of view?

Search for other neutrino-emitter blazars

→ Multi-epoch and multi-frequency VLBI follow-ups of new neutrino events

1. Characterization of the radio sources

VLBI vs arcsecond scales

The archive :

The NRAO VLA Sky Survey **(NVSS)** - 1.4 GHz - 45 arcsec resolution

The Faint Images of the Radio Sky at Twenty-Centimeters **(FIRST)** - 1.4 GHz - 6 arcsec resolution

The Very Large Array Sky Survey **(VLASS)** - 3 GHz - 2 arcsec resolution

What we can do from the VLBI point of view?

Search for other neutrino-emitter blazars

→ Multi-epoch and multi-frequency VLBI follow-ups of new neutrino events

1. Characterization of the radio sources

2. Does neutrino emission correspond to **enhanced radio activity** ?

VLBI today vs VLBI yesterday

VLBI yesterday :

The Radio Fundamental Catalog **(RFC)** → VLBI observations of thousands of sources

------------- VLBI follow-up when the neutrino -----------

(1) has a positional consistency with at least 1 Fermi-LAT sources
(2) has a positional consistency with a radio source

+ 4 new NEUTRINO events!

	IC Name	Alert Type	Loc. region (90%) (deg^2)	Energy (TeV)	Number γ-ray sources (in 90% loc)	Total of radio sources observed
1	IC 190704A	Bronze (30%)	20	155	2	2
2	IC 200109A	Gold (50%)	26	375	2	3
3	IC 201021A	Bronze	6	105	1	2
4	IC 201114A	Gold	4	214	1	3

→ 10 radio sources

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- Blazar-like: flat spectrum, no extended emission
- γ-ray associated

→ 10 radio sources → 5 good candidates

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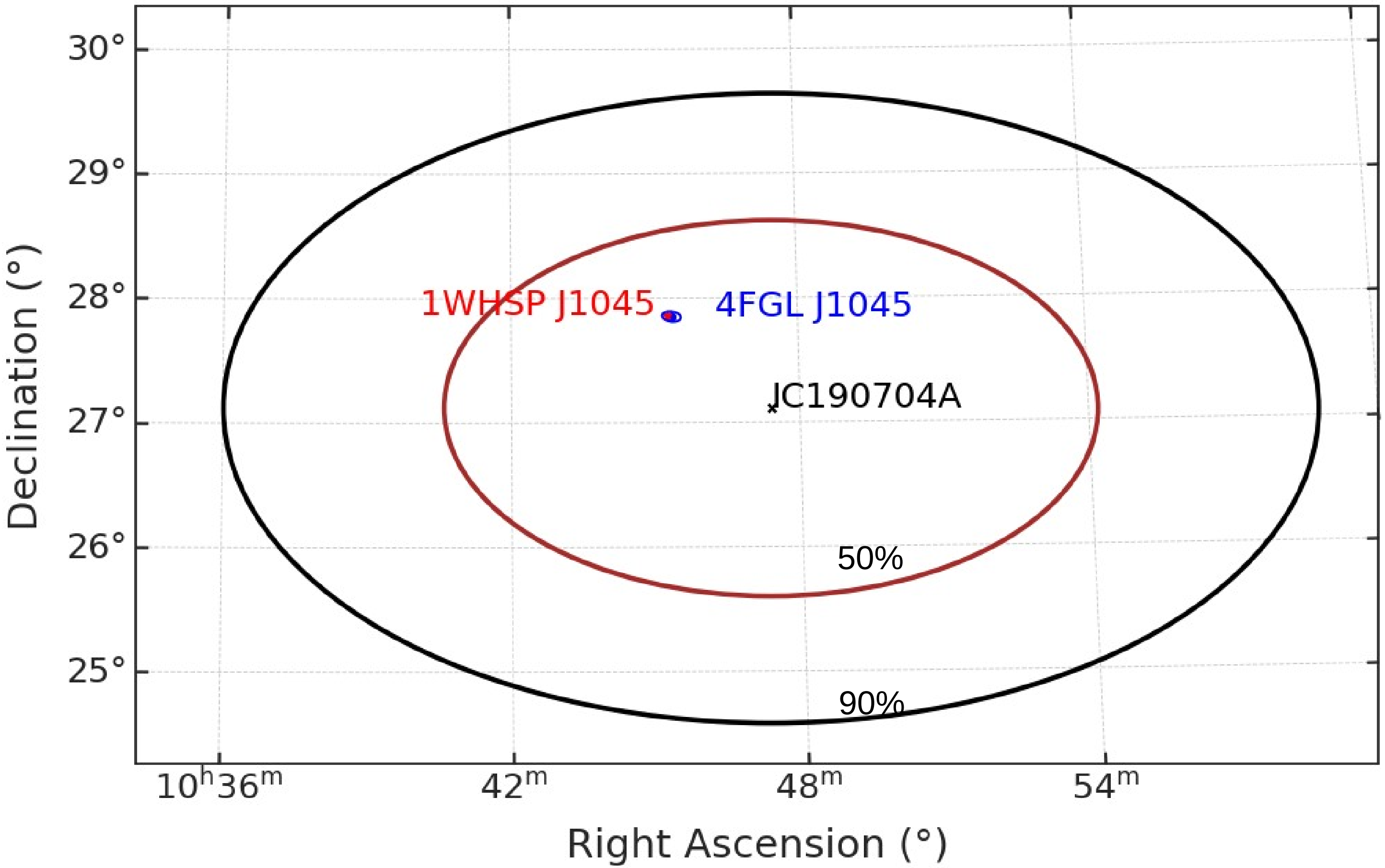
- Blazar-like: flat spectrum, no extended emission
- γ-ray associated

- Similar to TXS 0506+056
- In agreement with thoretical predictions

→ 10 radio sources → 5 good candidates

1st Event

Neutrino IC190704A



Gamma-ray

4FGL J1045.3+2751
-new detection

Neutrino

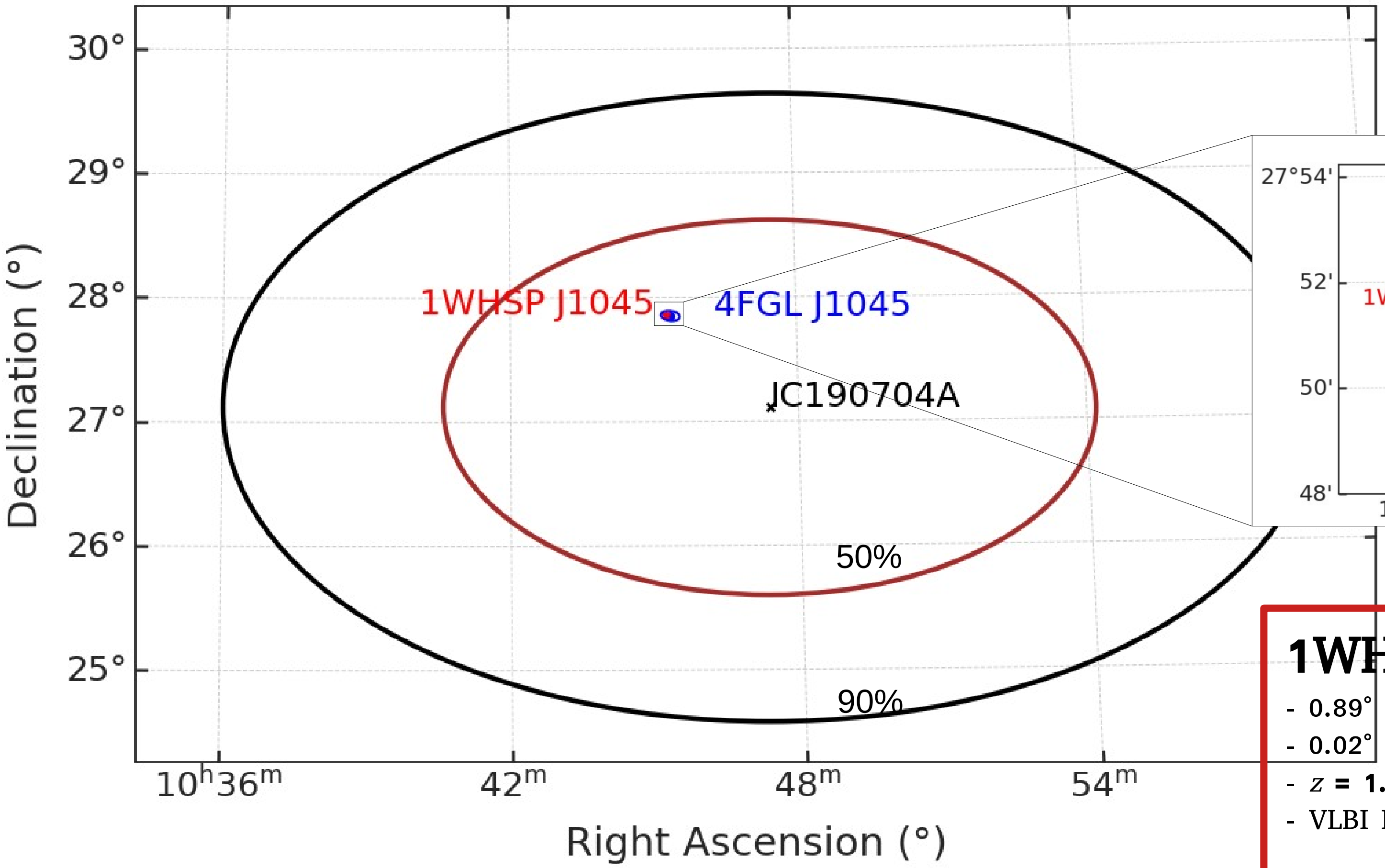
-BRONZE
-155 TeV
-20 deg² (90%)

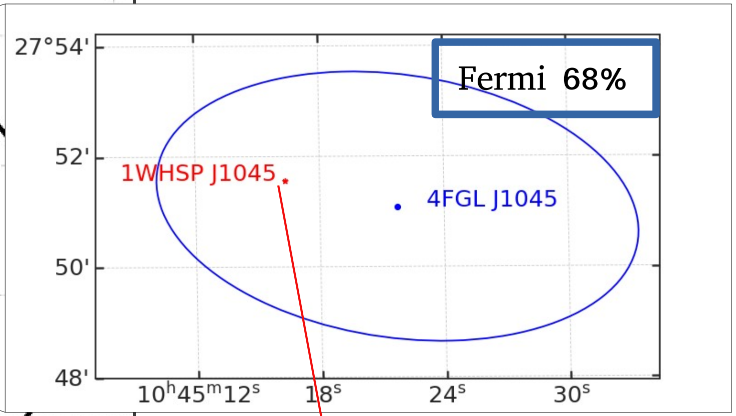
Neutrino IC190704A

1

Gamma-ray

4FGL J1045.3+2751
-new detection



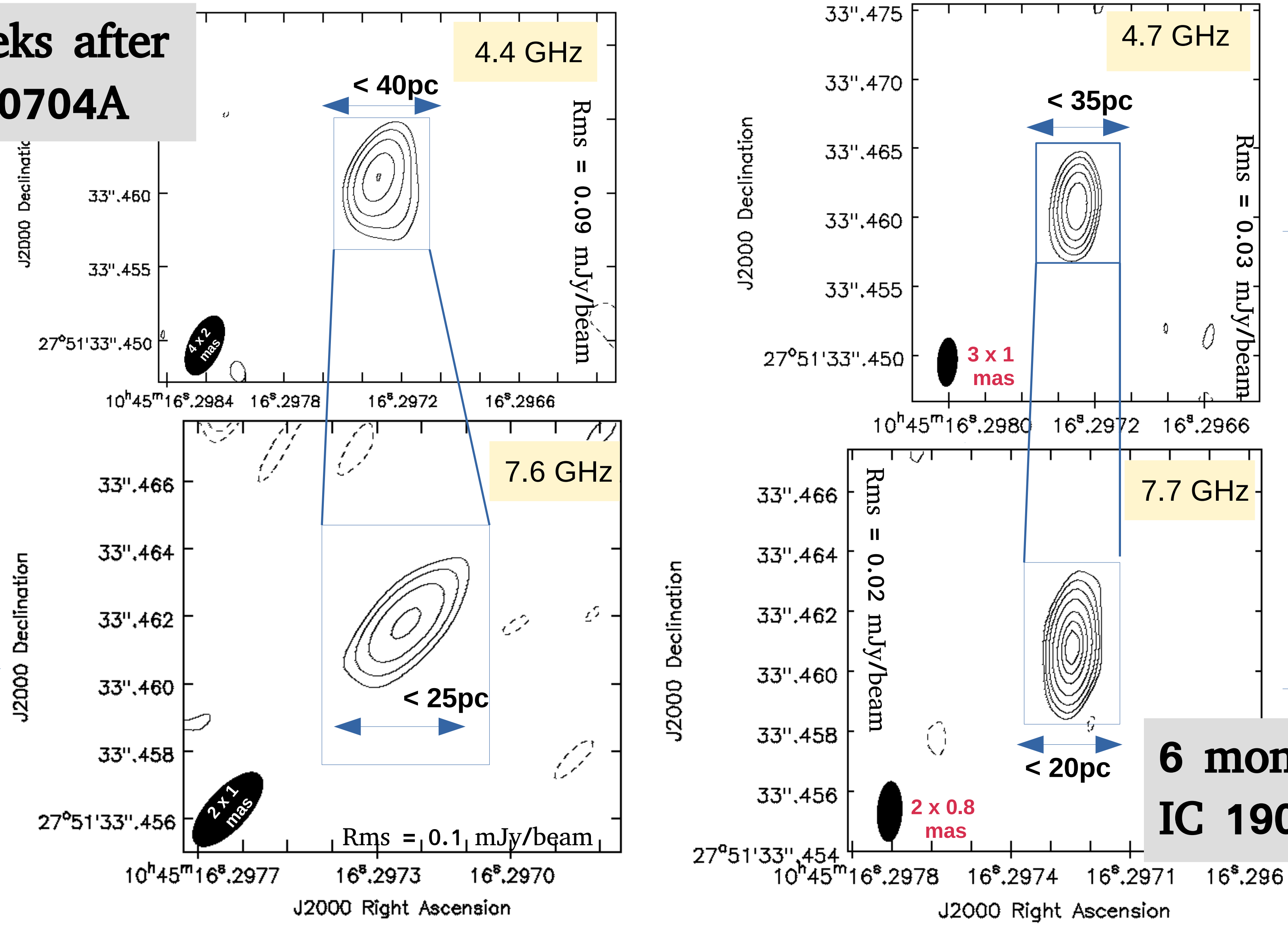


VLBI

1WHSP J104516.2+275133

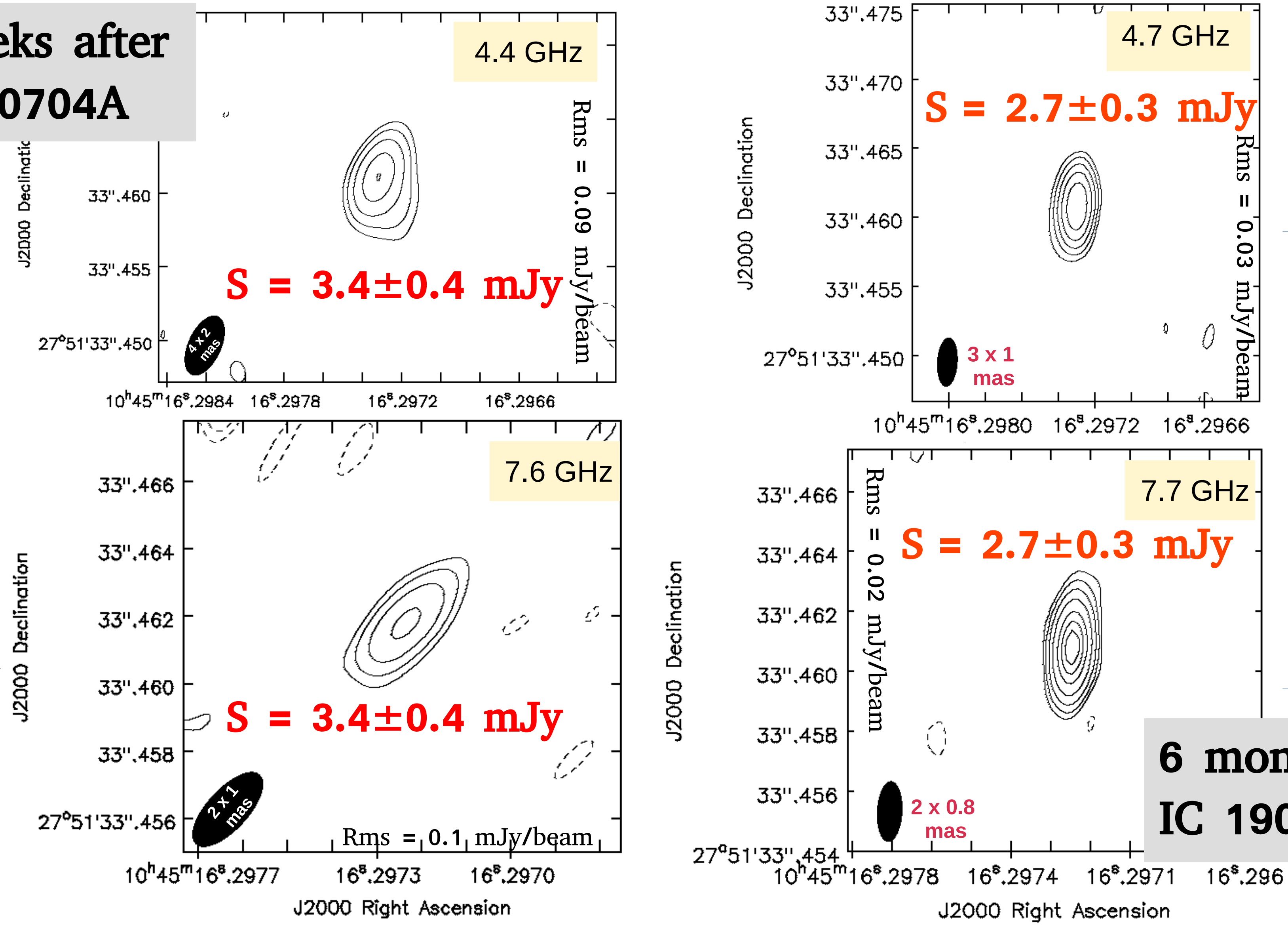
- **0.89°** from IC190704A;
- **0.02°** from 4FGL counterpart
- z = **1.914**
- VLBI Luminosity(5 GHz) ~ **4 x 10 [25] W/Hz**

2 weeks after IC 190704A



6 months after IC 190704A

2 weeks after IC 190704A

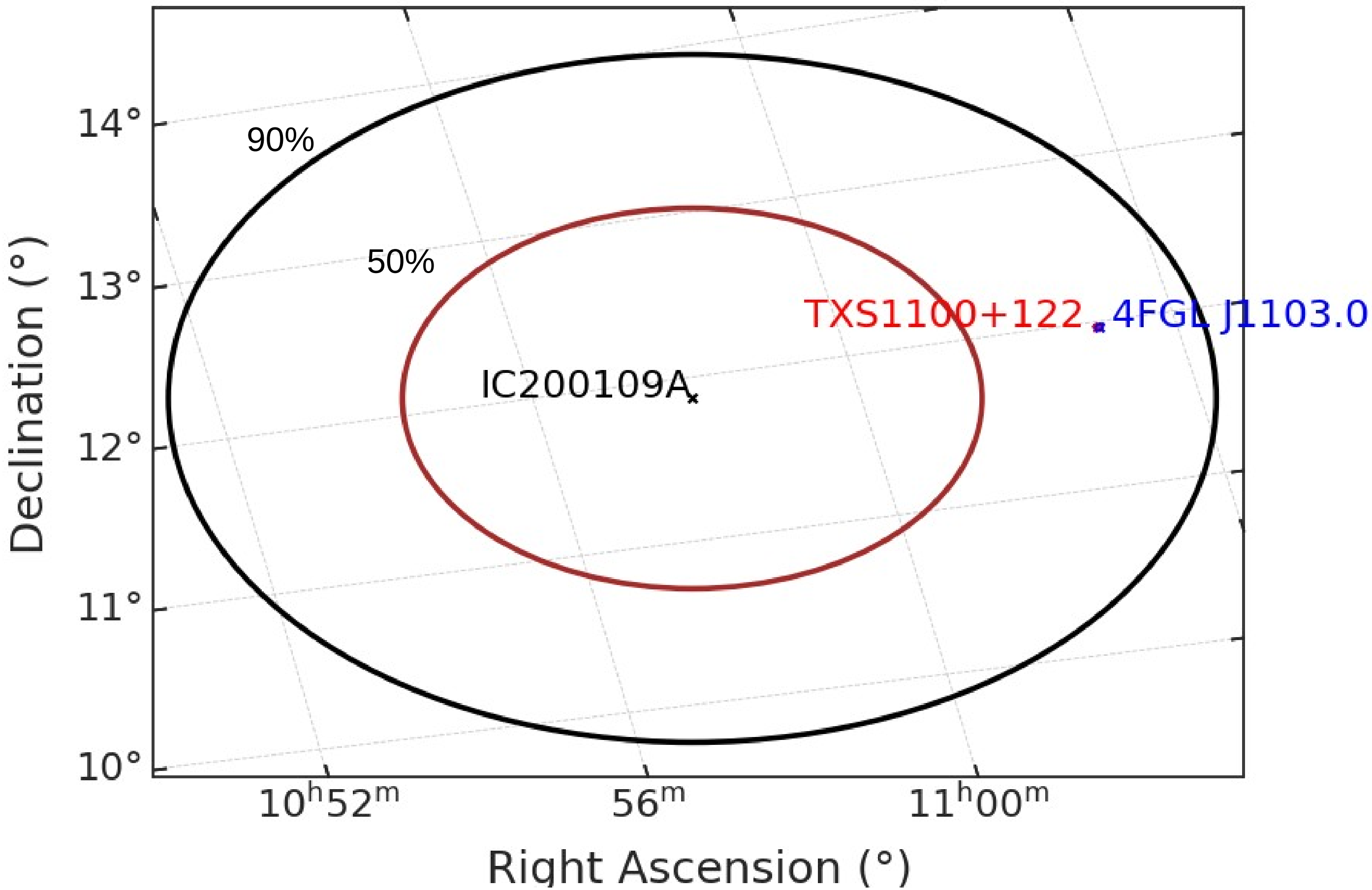


6 months after IC 190704A

2nd Event

Neutrino IC200109A

2



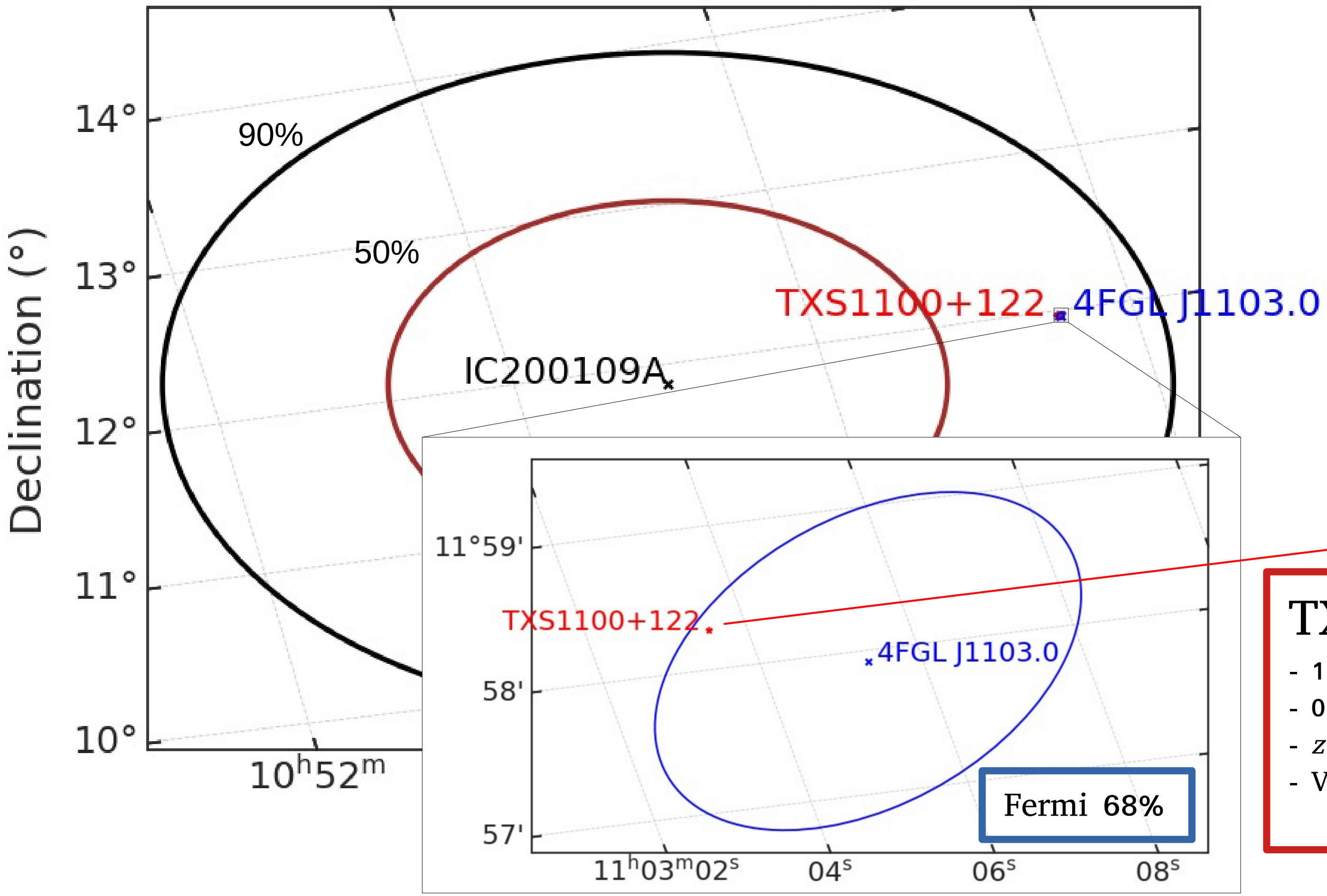
Gamma-ray

4FGL J1103.0+1157

Neutrino

- -GOLD
- -375 TeV
- -26 deg^2 (90%)

Neutrino IC200109A



2

Gamma-ray

4FGL J1103.0+1157

Neutrino

-GOLD
-375 TeV
-26 deg² (90%)

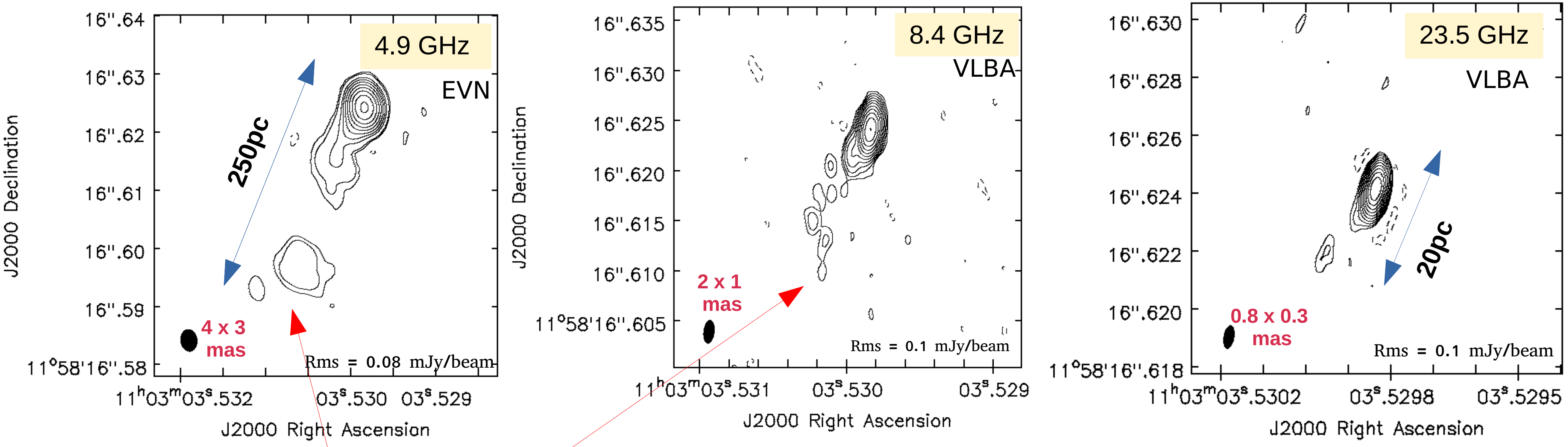
VLBI

TXS 1100+122

- 1.25° from IC200109A;
- 0.009° from 4FGL counterpart
- z = 0.91
- VLBI Luminosity(5 GHz) ~ **6.4 x 10 [26] W/Hz**

1 month after IC 200109A

2



jet!

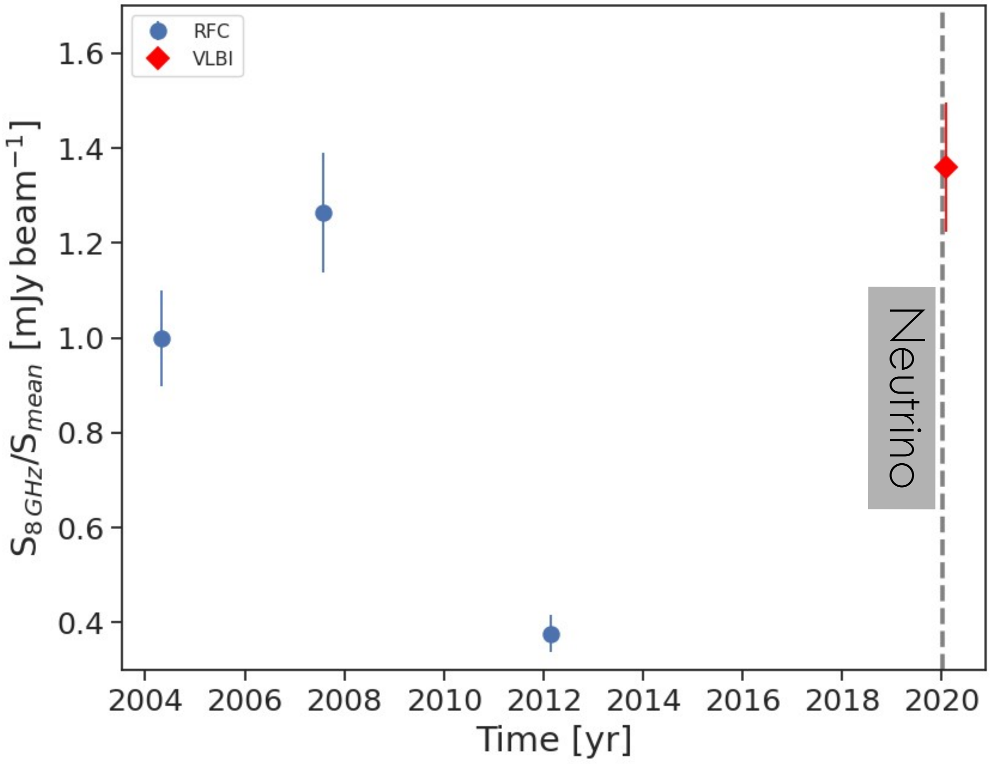
8.4 GHz

S_{peak} ~ 380 mJy/beam

S_{int} ~ 409 mJy

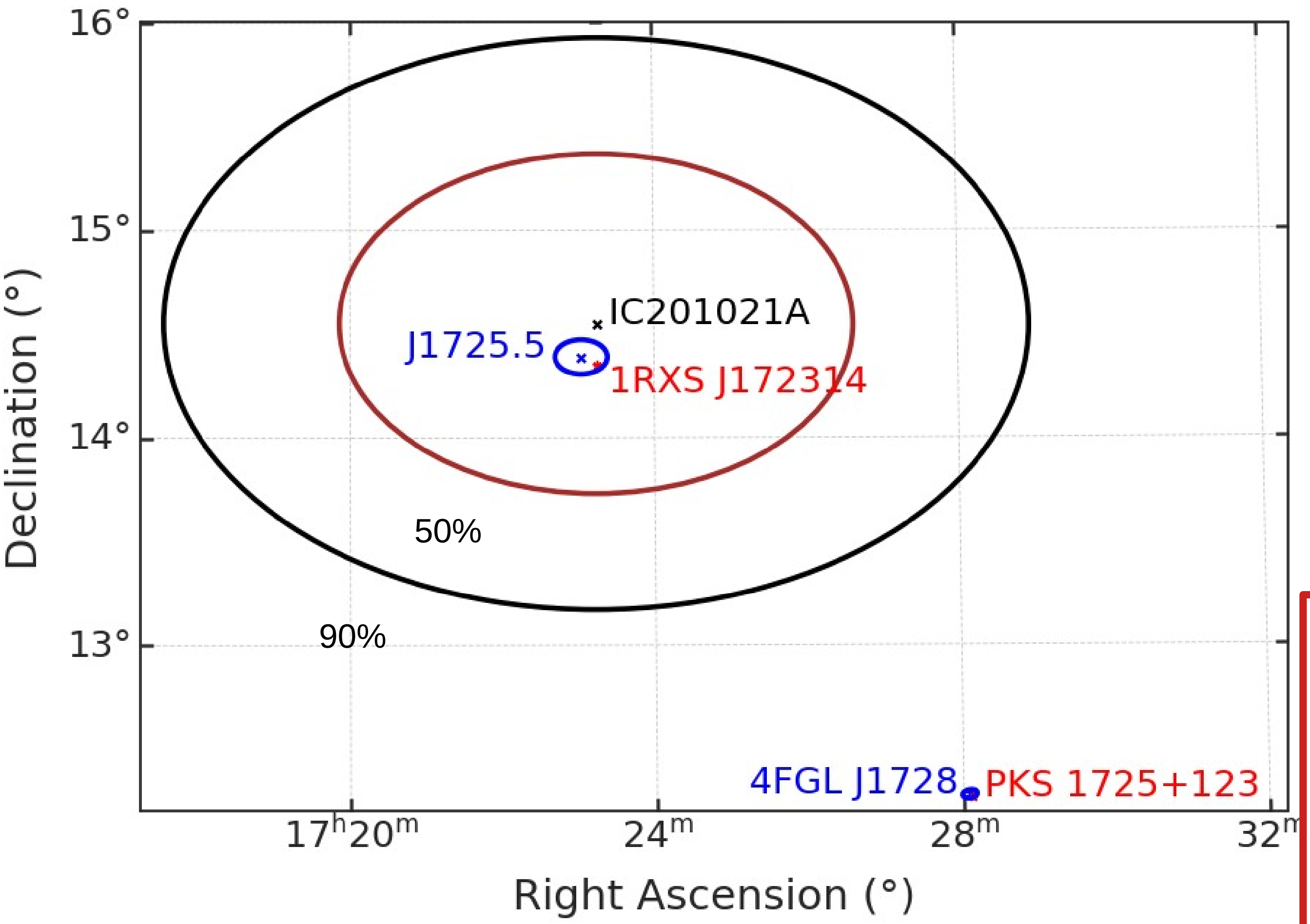
TXS 1100+122 pc/kpc properties

- neutrino follow-up data vs VLBI archival data → **hints(?) of enahanced activity at pc scales**
  Kovalev et al.2020a confirm **high state** with RATAN-600 observations (at 2.3, 5, 8, 11, 22 GHz)



3rd Event

Neutrino IC201021A



Gamma-ray

New det.: J1725.5+1312 (1)
4FGL J1728.0+1216 (2)

Neutrino

-BRONZE event
-105 TeV
-6 deg^2 (90%)

VLBI

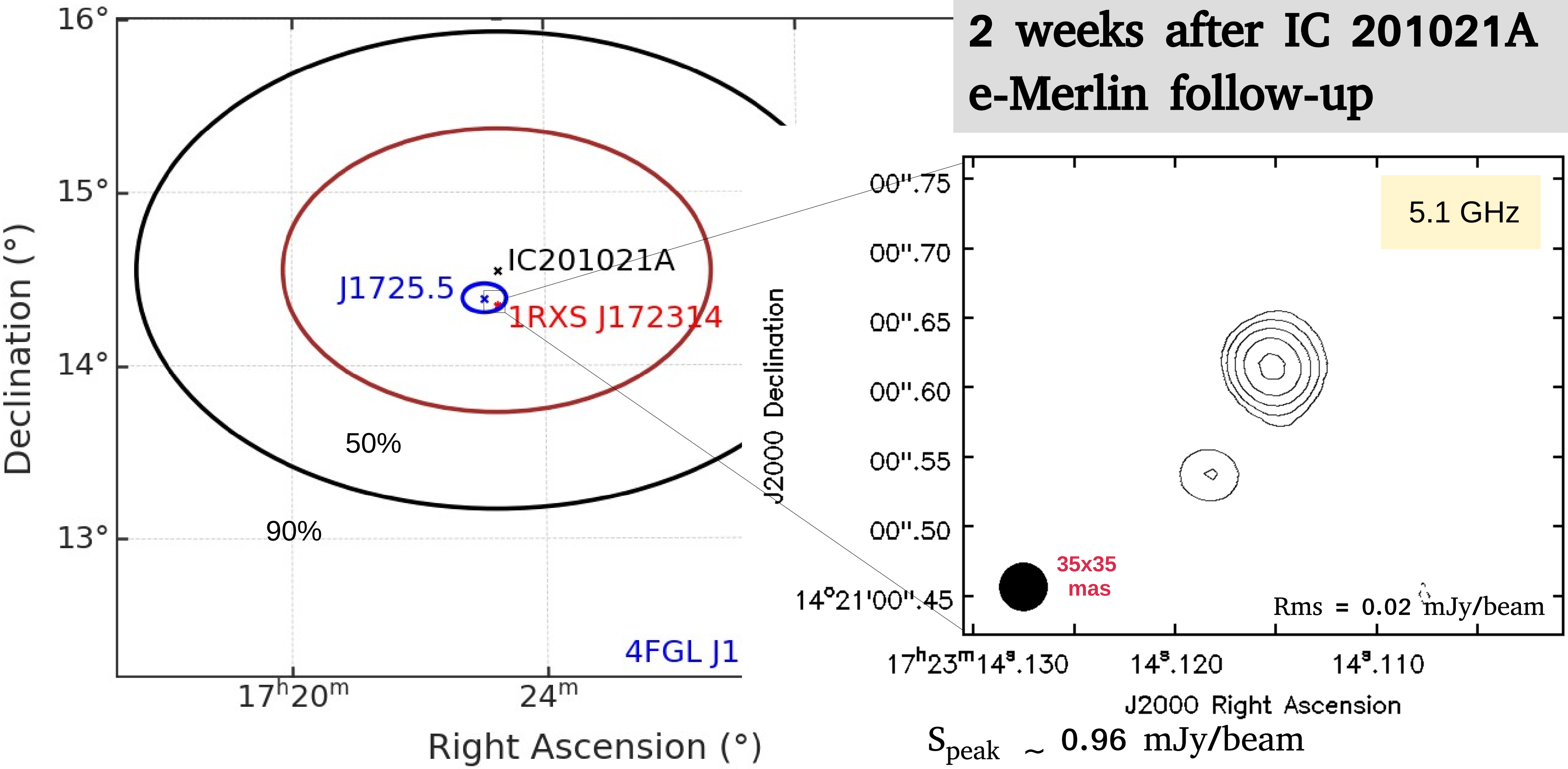
(1) No catalogued radio counterpart but a source is detected in the VLASS
-possible X-ray counterpart: 1RXS J172314.4+142103-

(2) PKS 1725+123

- 2.57° from IC201021A;
- 0.02° from 4FGL counterpart
- z = 0.568
- VLBI Luminosity(5 GHz) ~ 3 x 10 ^{26} W/Hz

Neutrino IC201021A - radio (1)

2 weeks after IC 201021A e-Merlin follow-up

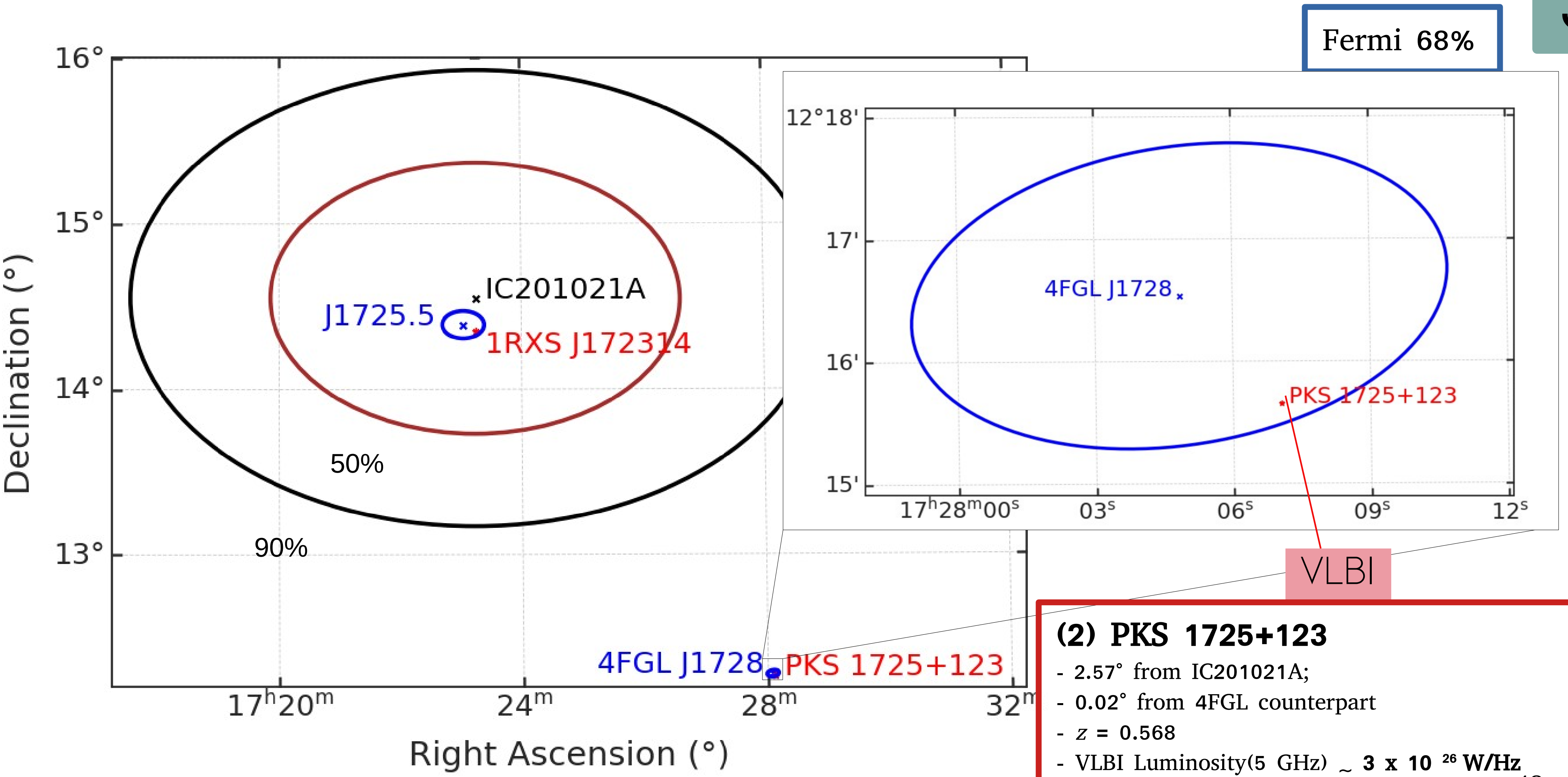


S_{peak} ~ 0.96 mJy/beam

S_{int} ~ 1.1 mJy

Neutrino IC201021A - radio (2)

3



(2) PKS 1725+123

- 2.57° from IC201021A;
- 0.02° from 4FGL counterpart
- z = 0.568
- VLBI Luminosity(5 GHz) ~ **3 x 10 ^{26} W/Hz**

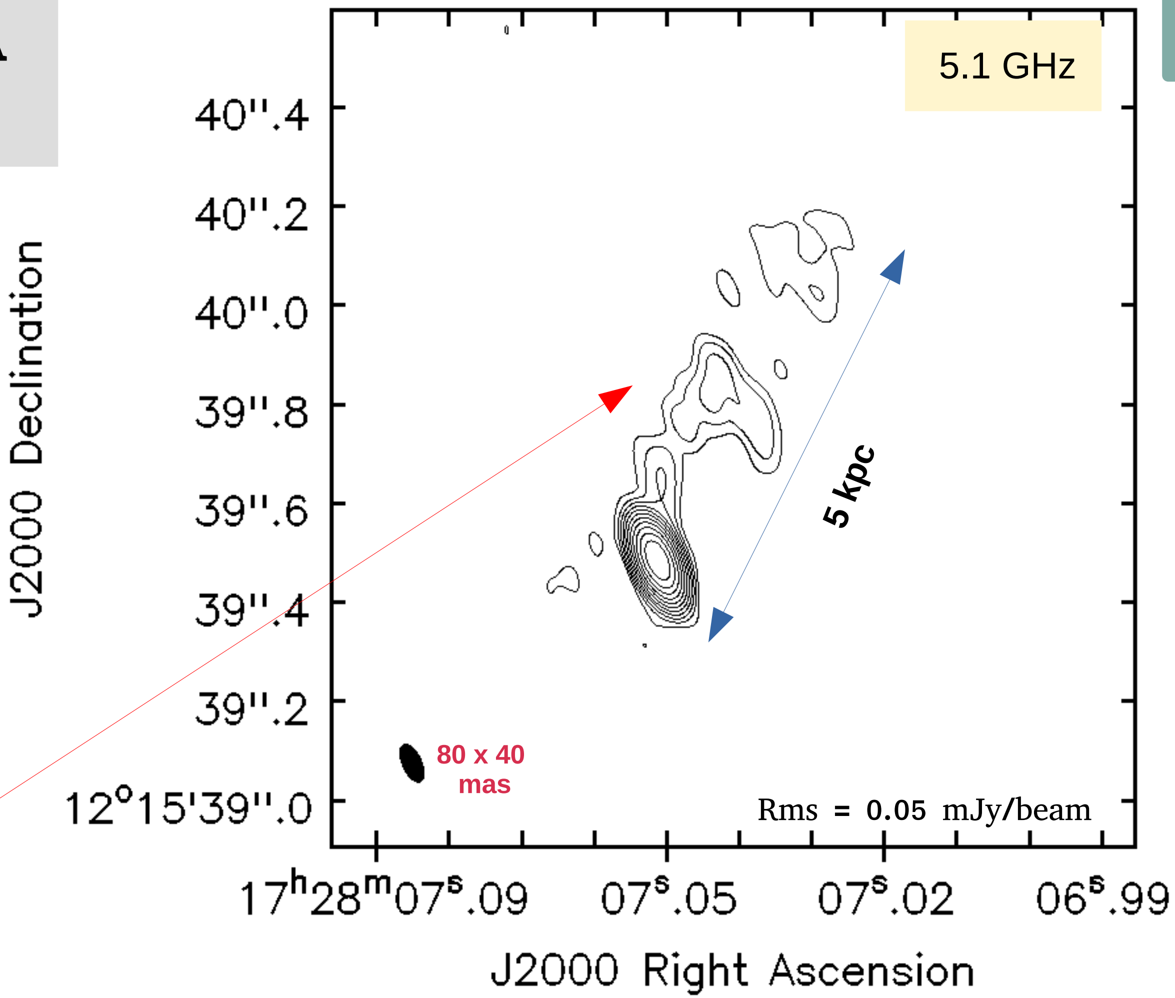
2 weeks after IC 201021A e-Merlin follow-up

3

S_{peak} ~ 323 mJy/beam

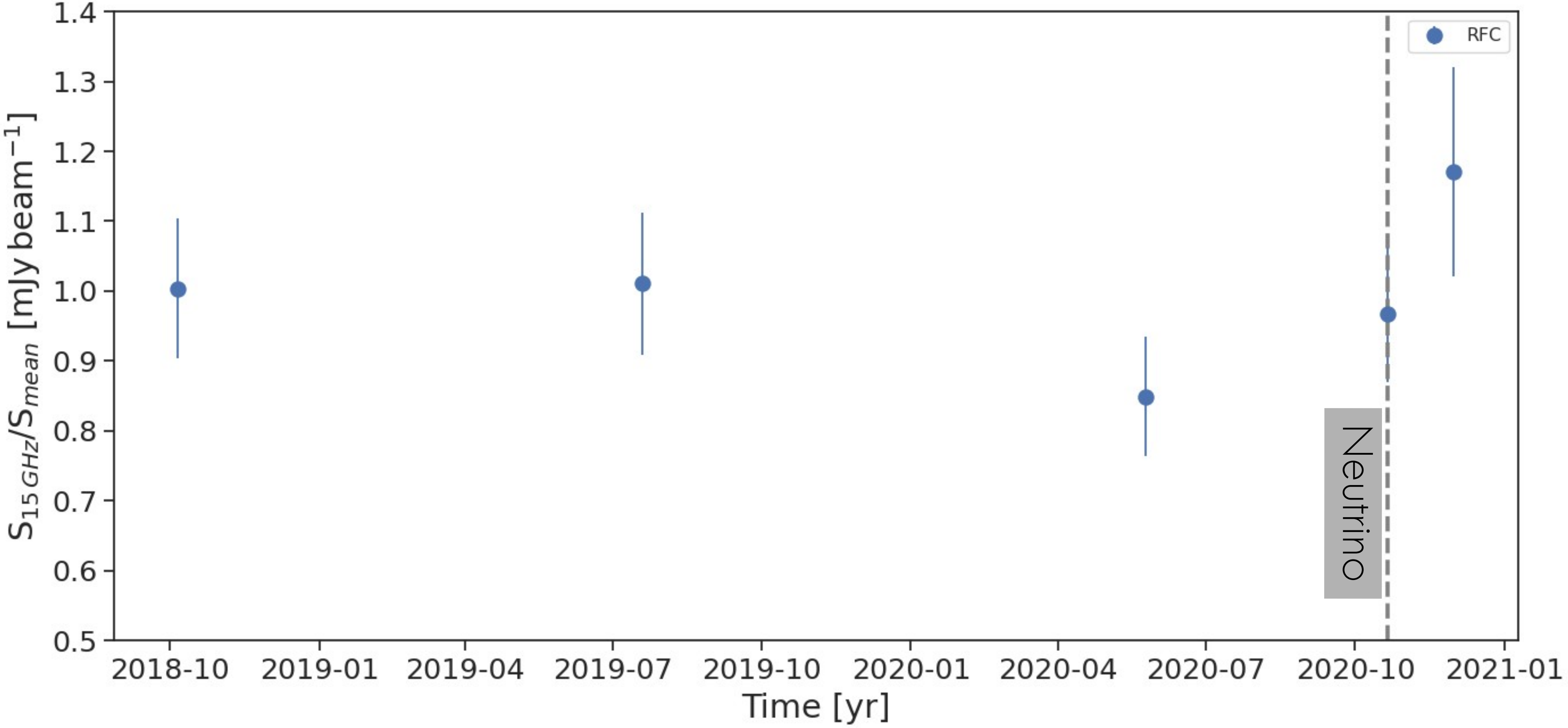
S_{int} ~ 334 mJy

jet!



PKS 1723+125 pc/kpc properties

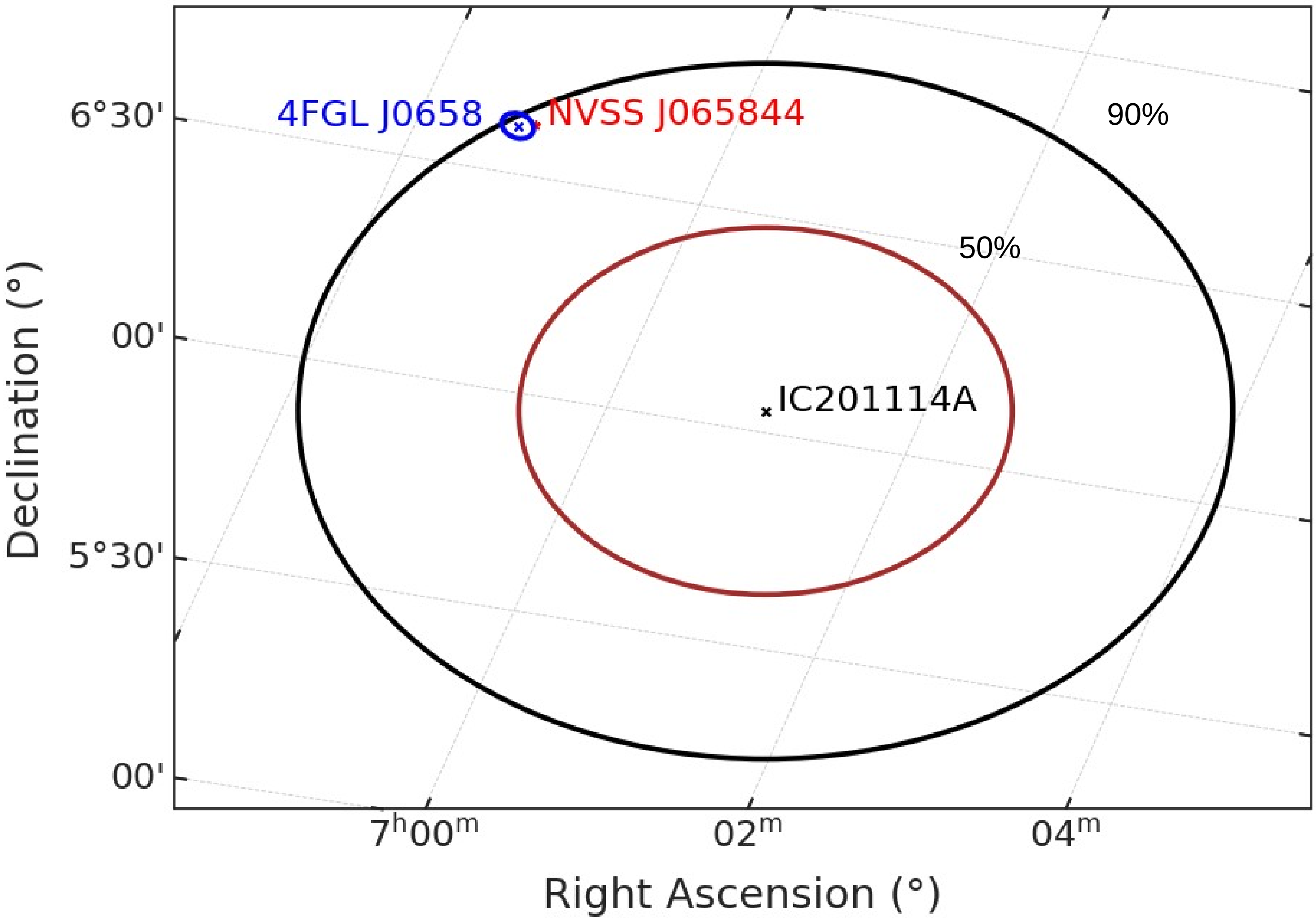
- archival VLBI data around neutrino arrival → **hints of enahanced activity at pc scales**



4th Event

Neutrino IC201114A

4



Gamma-ray

4FGL J0658.6+0636

Neutrino

- -GOLD event
- -214 TeV
- -4 deg^2 (90%)

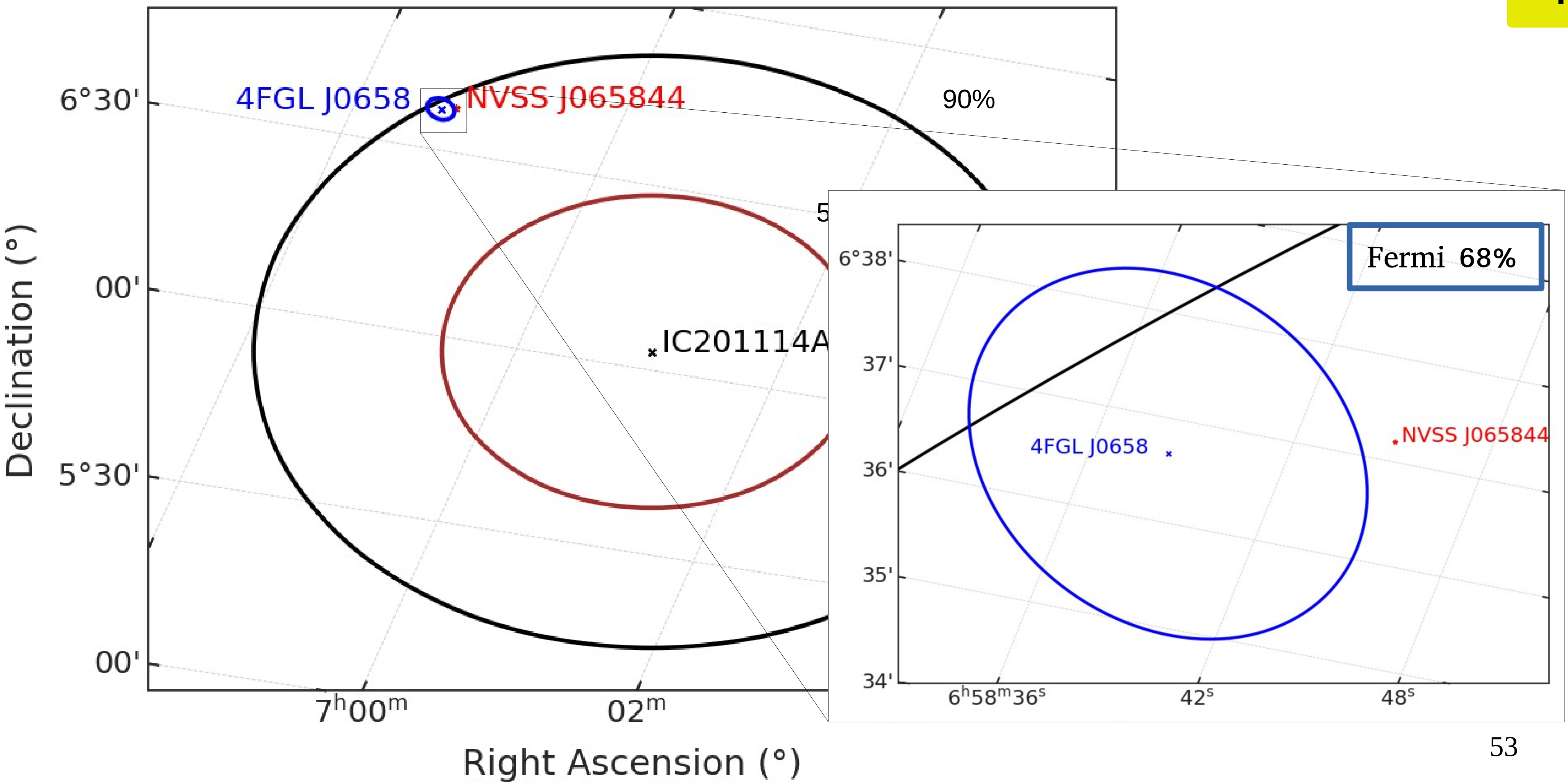
VLBI

NVSS J065844+063711

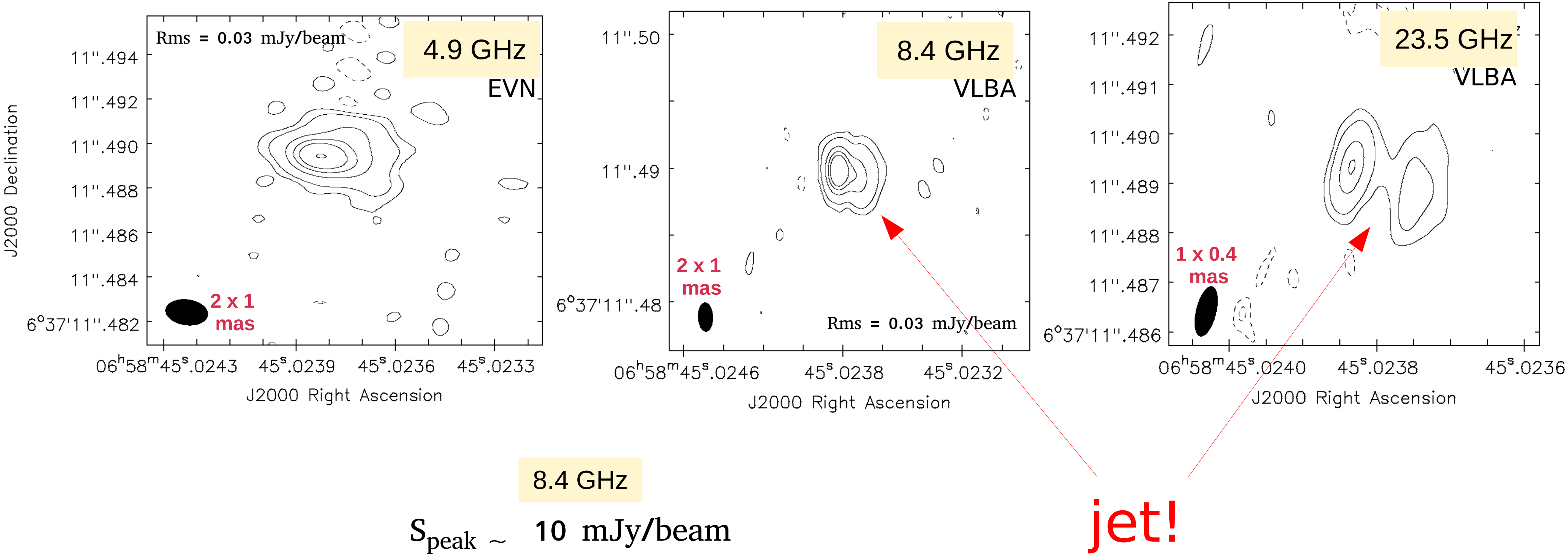
- 0.79° from IC201114A;
- 0.05° from 4FGL counterpart

Neutrino IC201114A

4



1 month after IC 201114A



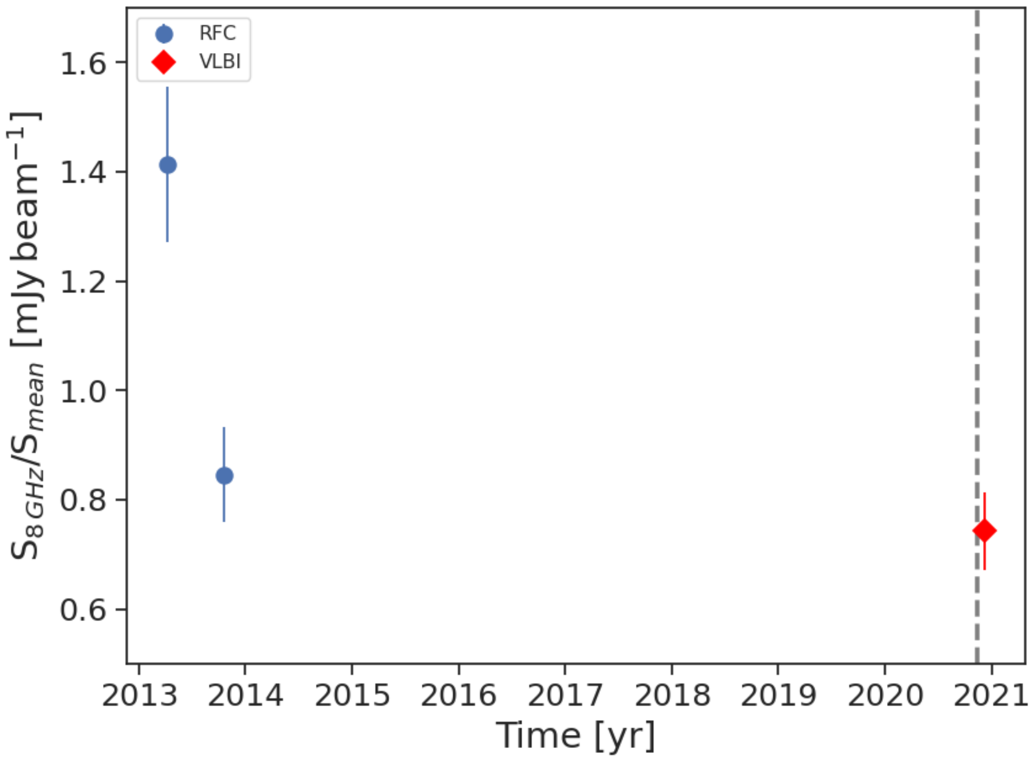
8.4 GHz

$S_{peak} \sim$ 10 mJy/beam

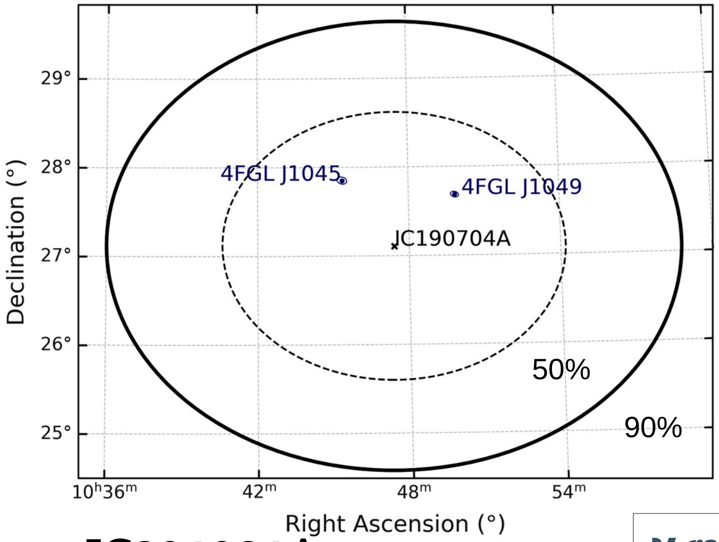
$S_{int} \sim$ 15 mJy

NVSS J065844+063711 pc/kpc properties

- neutrino follow-up data vs archival VLBI data → **lack of enahanced activity at pc scales**

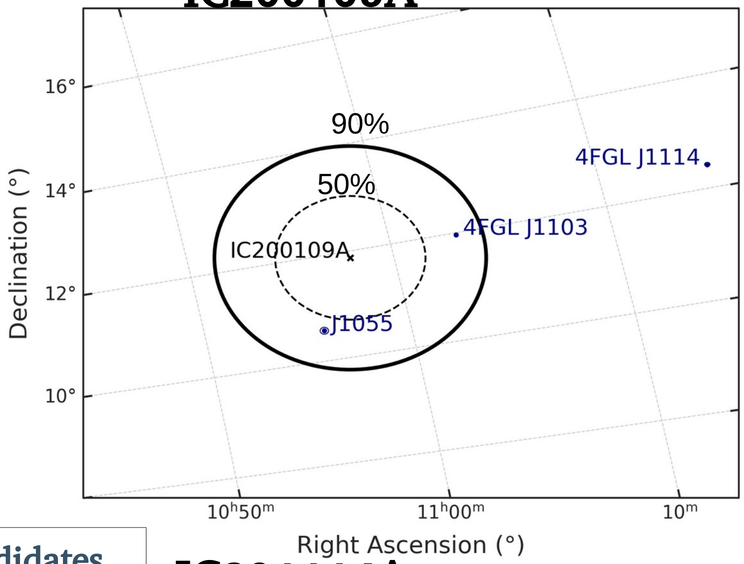


IC190704A



BRONZE
155 TeV
20 deg²

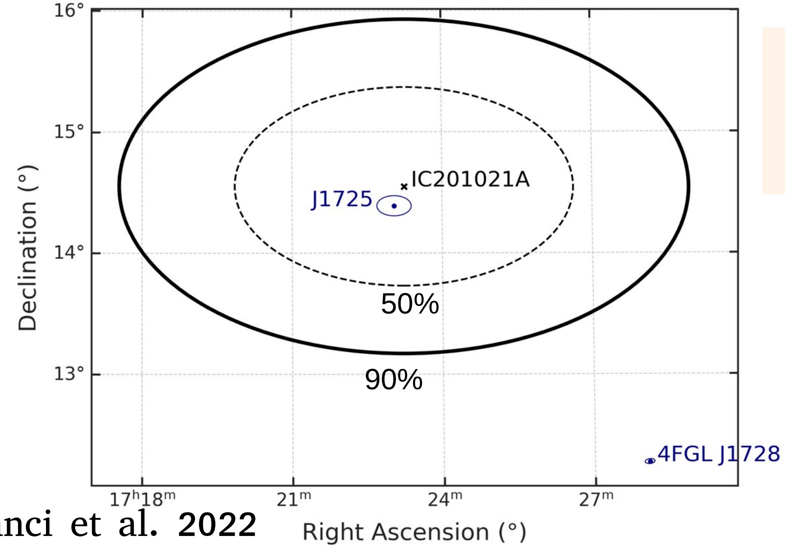
IC200109A



GOLD
375 TeV
26 deg²

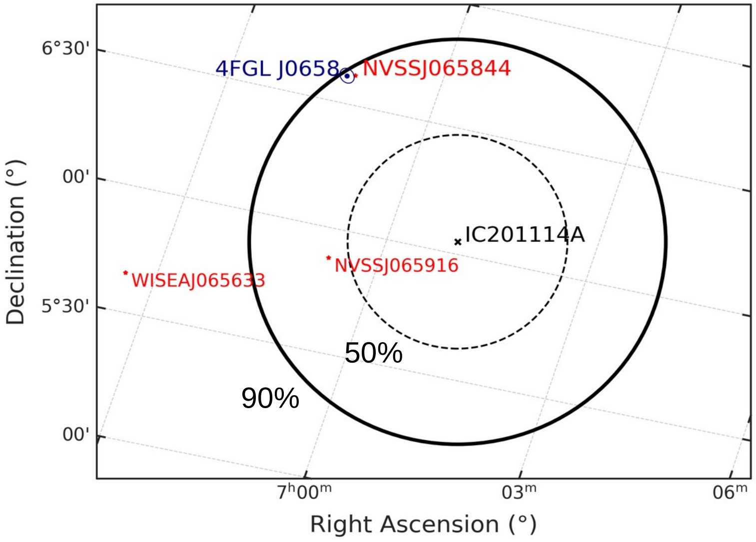
γ-ray associated candidates

IC201021A



BRONZE
105 TeV
6 deg²

IC201114A



GOLD
214 TeV
4 deg²

Nanci et al. 2022