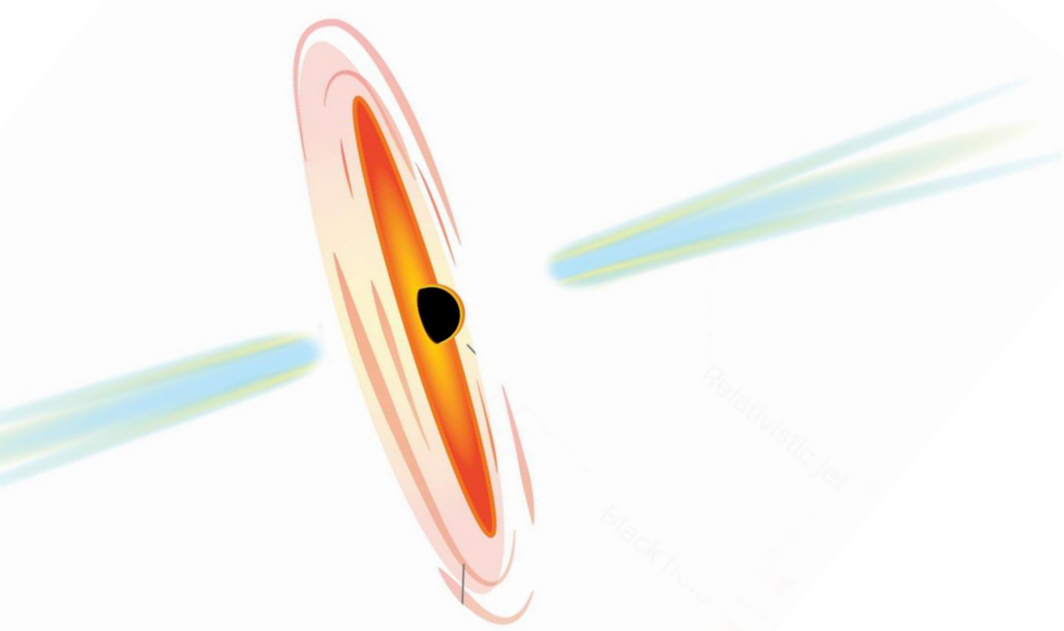
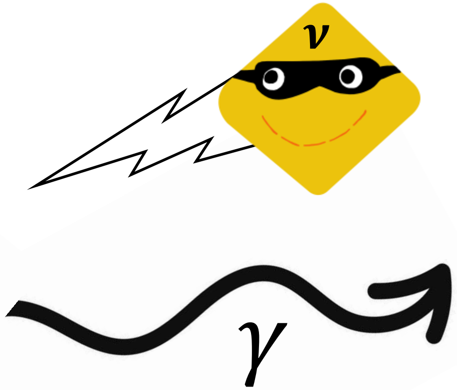
Constraining the Physics of Very-High-Energy Emission of Blazars through radio observations

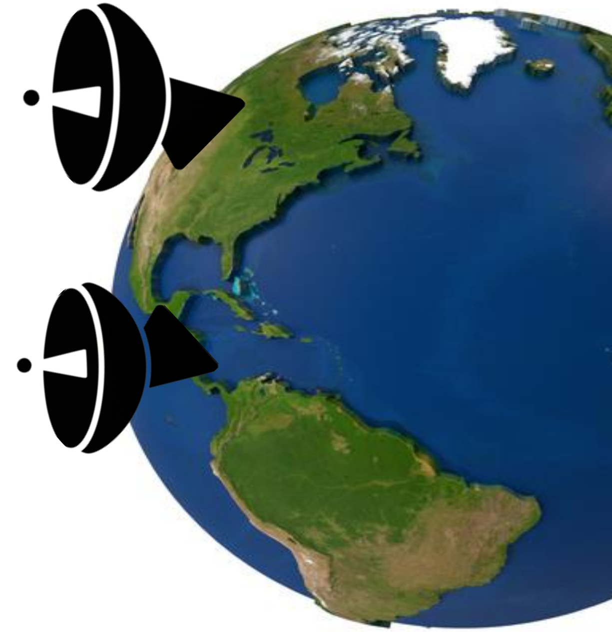
Florian Eppel

JMU Würzburg & MPIfR Bonn



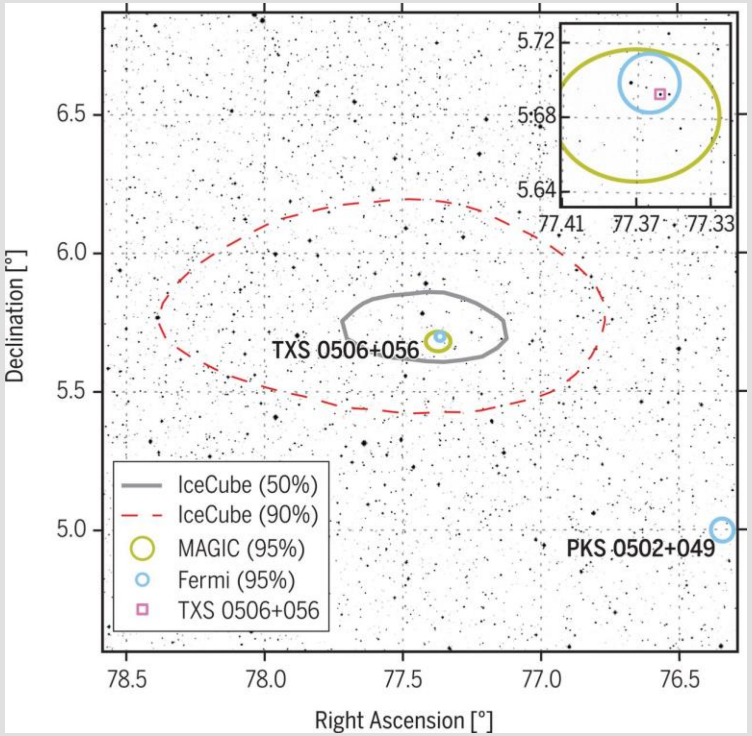
Credit: Sophia Dagnello, NRAO/AUI/NSF





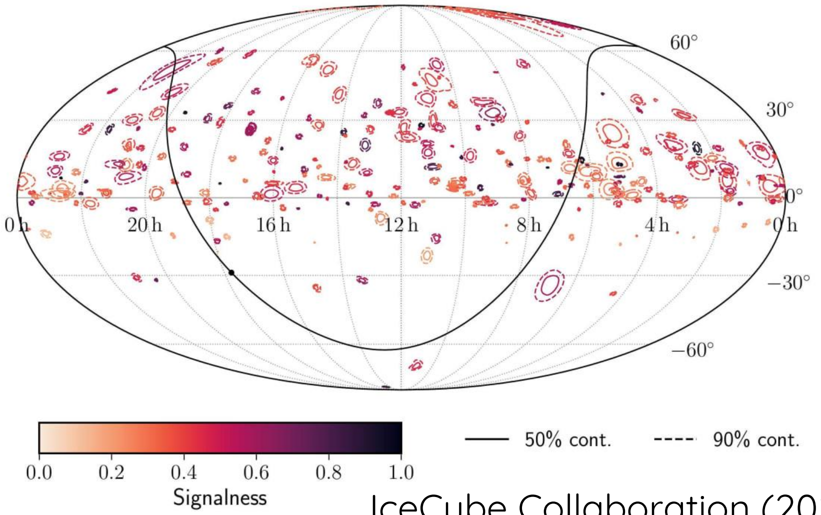
On behalf of AG Kadler: M. Kadler, J. Eich, L. Haury, J. Heßdörfer, D. Kirchner, L. Ricci, F. Rösch, W. Schulga, H. Shetgaonkar, C. Wendel, J. Wongphechauxsorn + many collaborators

High-Energy Neutrinos



Localization Region of IC170922A (IceCube Collaboration et al. 2018)

Map of High-Energy Neutrino Alerts



IceCube Collaboration (2022)

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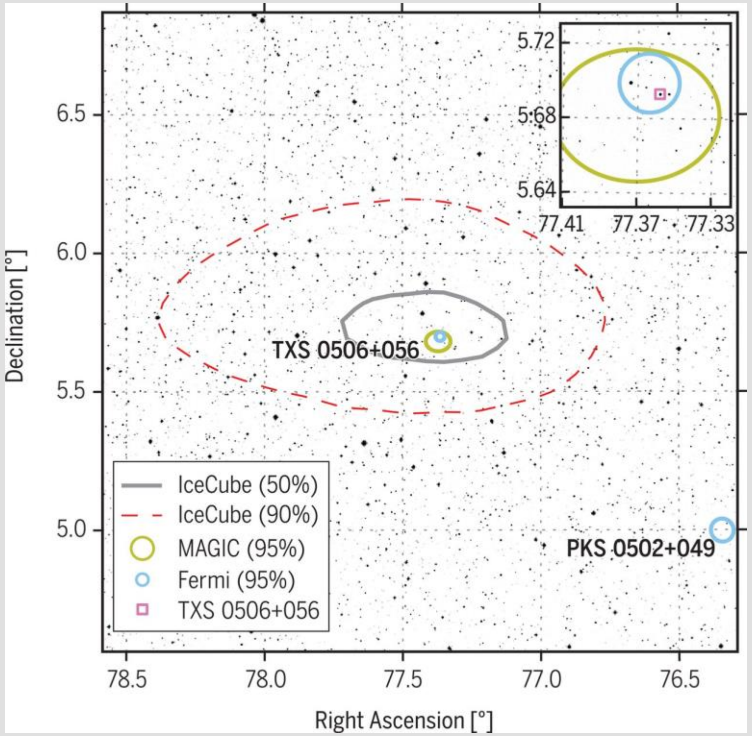

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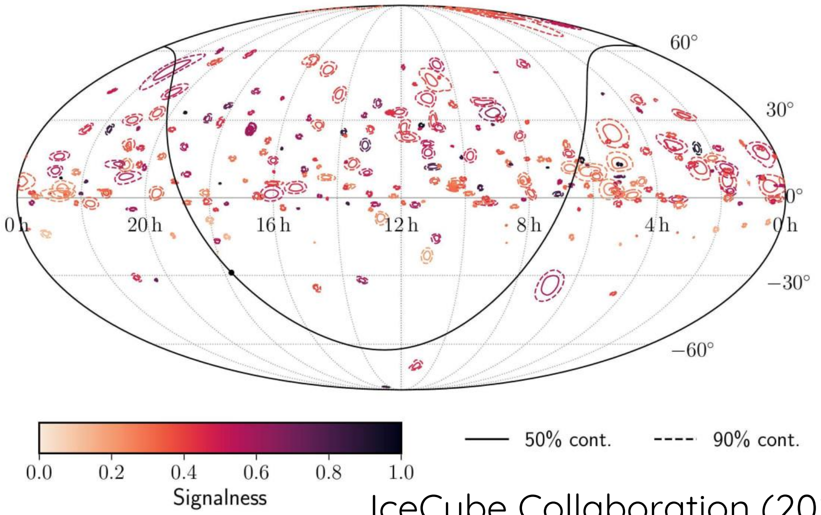

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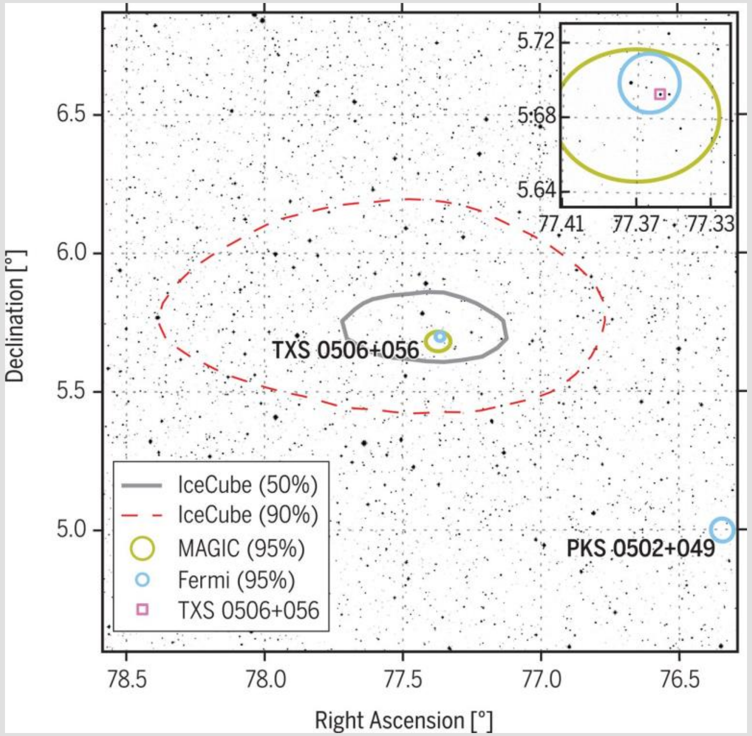
Where do high-energy neutrinos come from?

High-Energy Neutrinos



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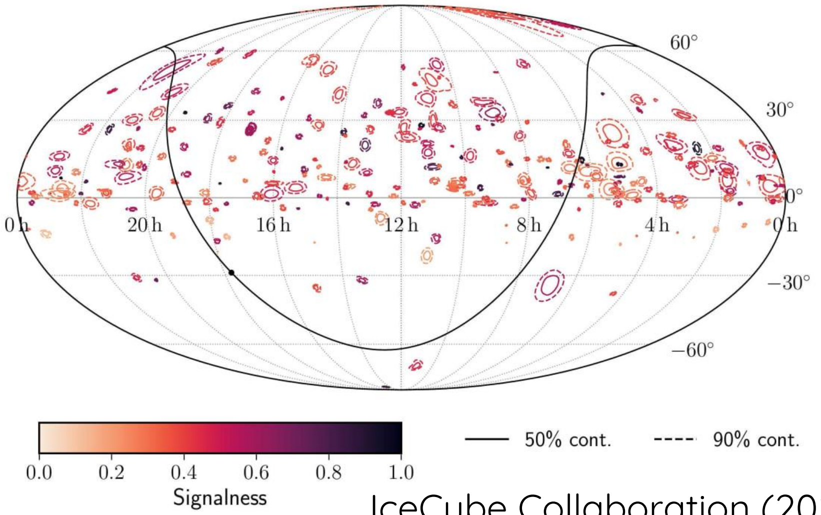

IceCube Collaboration (2022)

Where do high-energy neutrinos come from?

-> Some indications hint towards blazars!

What are the physics behind it?

TeV-Gamma Rays

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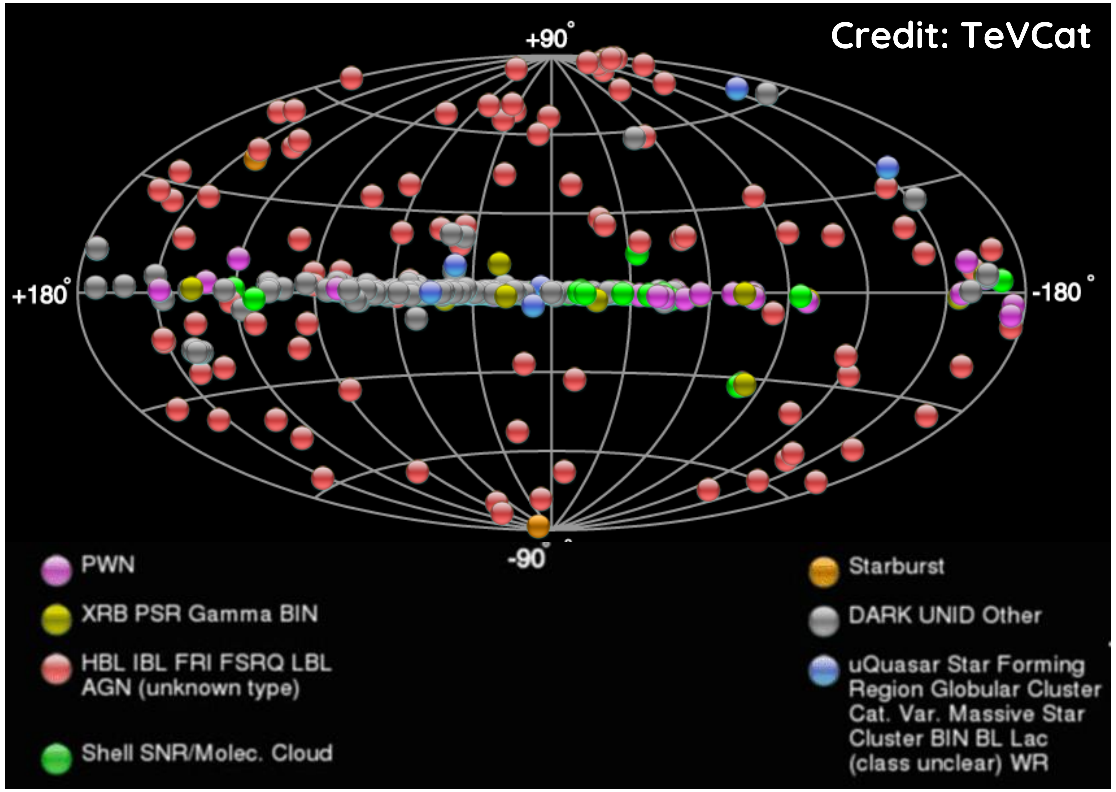
TeV-detected sources



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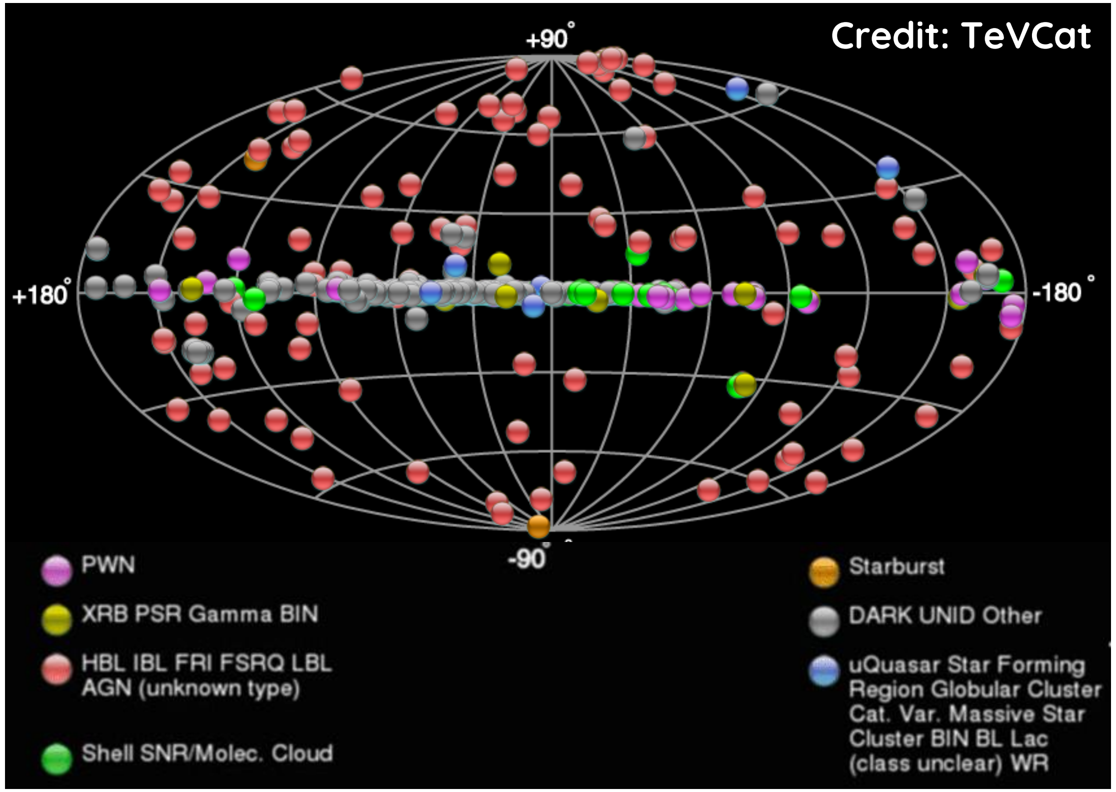

-> Extragalactic population dominated by blazars

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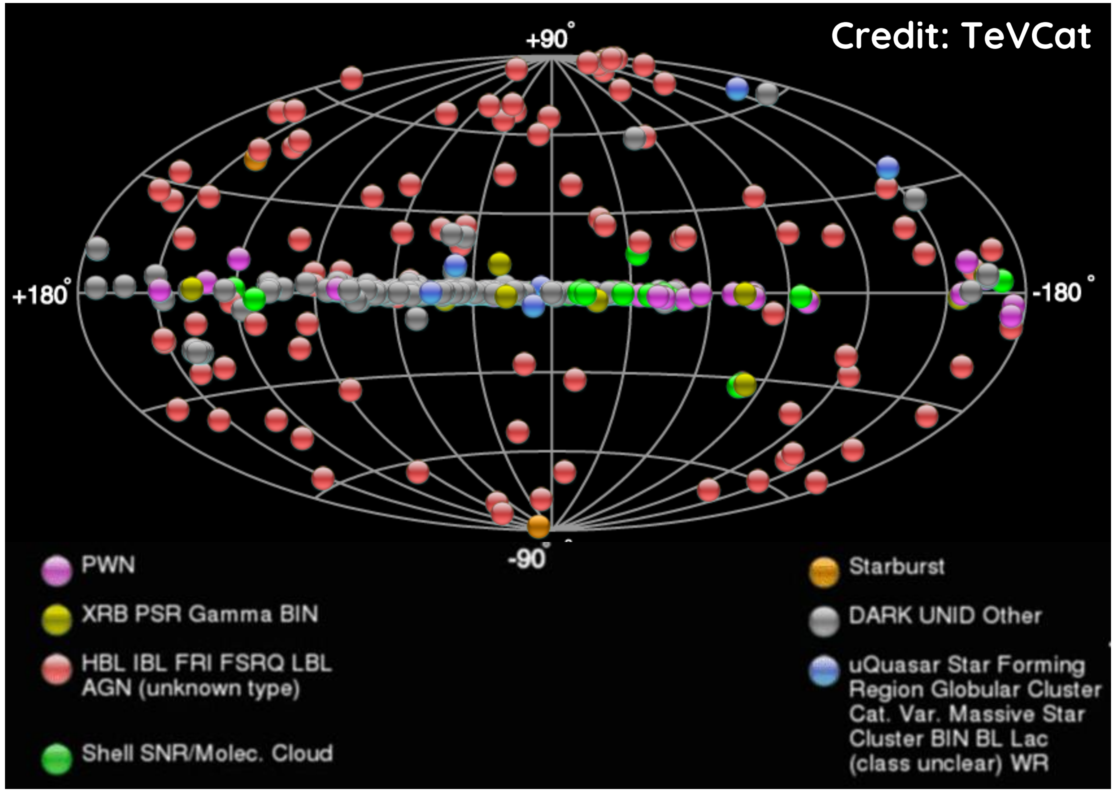

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Doppler Crisis

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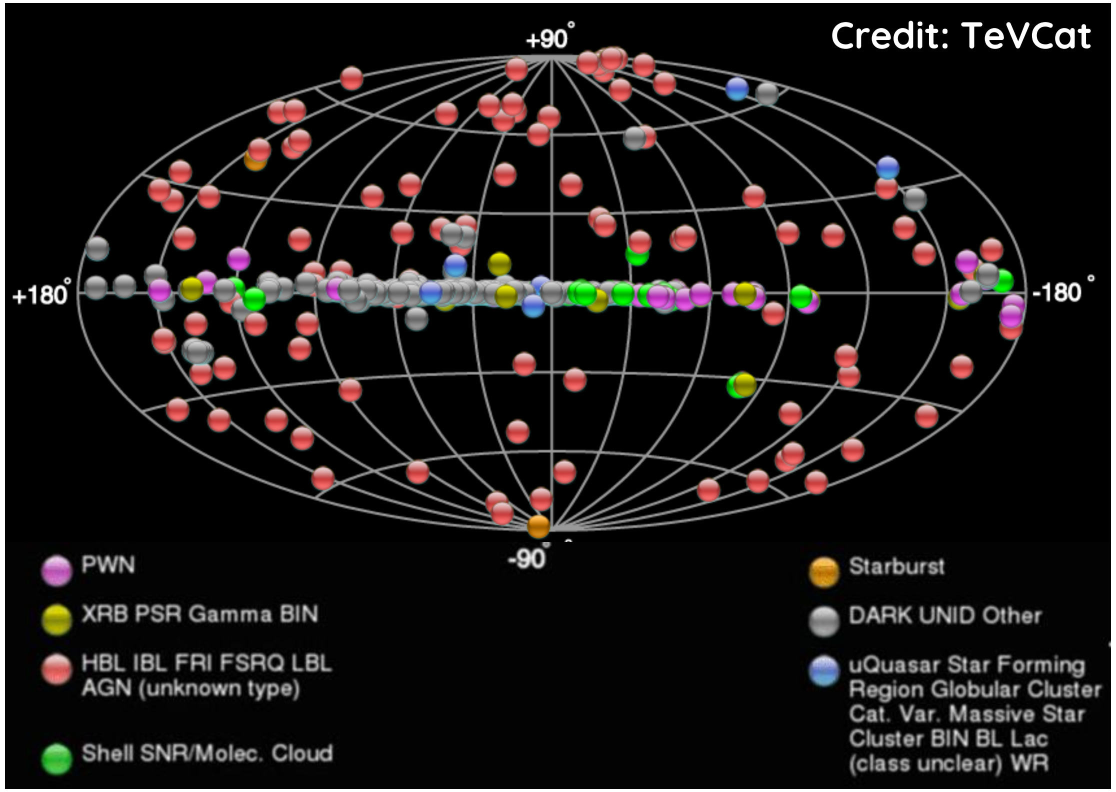

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- Highly variable TeV-emission requires high Doppler factors up to D>40 (e.g., Tavecchio et al. 2010)

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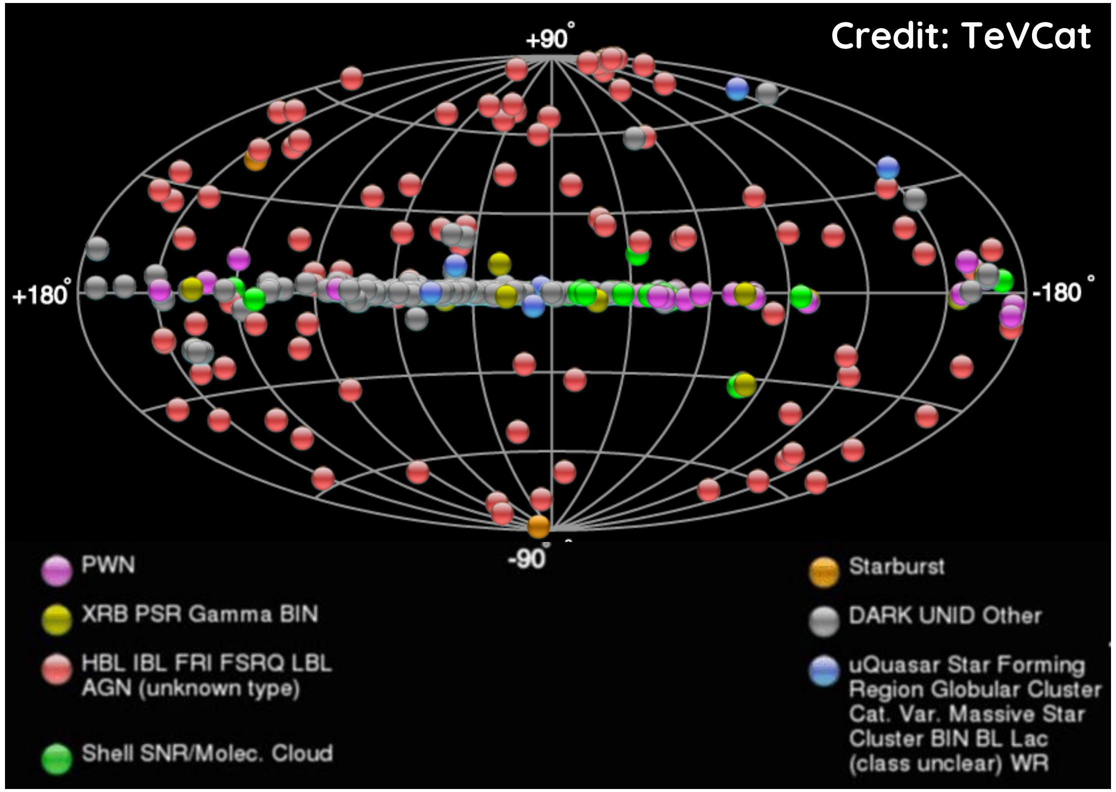

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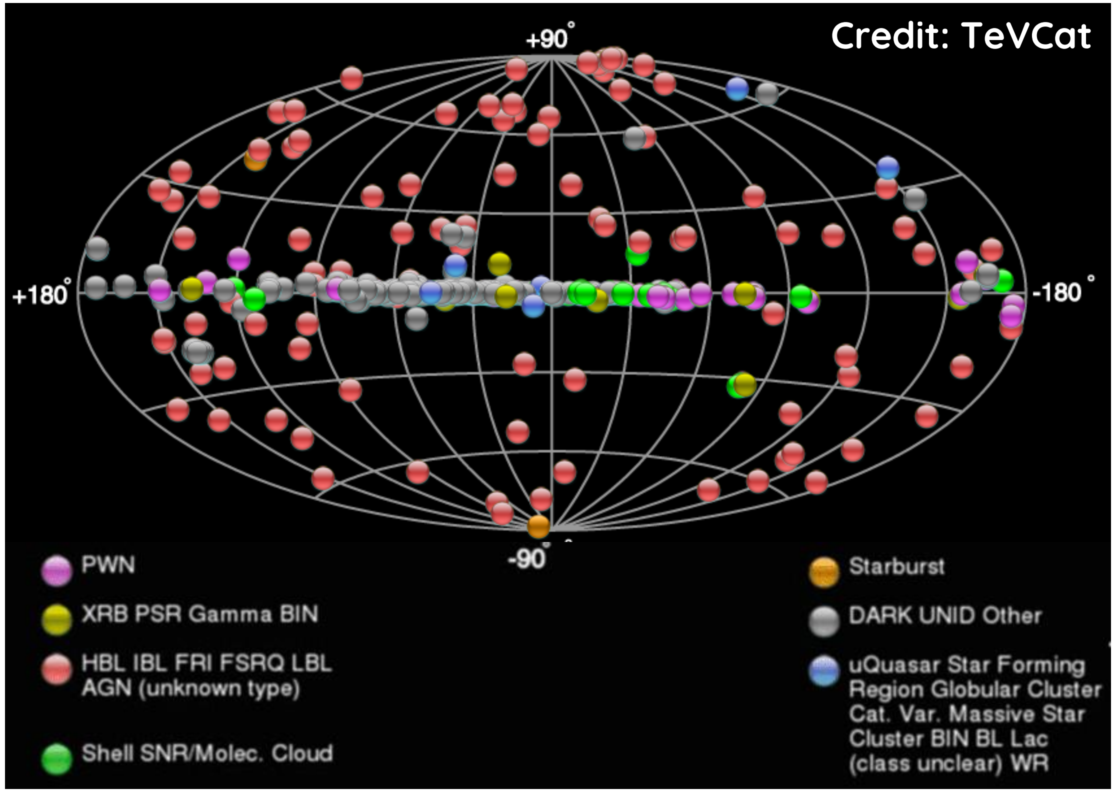

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Possible Scenarios:

-> Spine-Sheath Structure (Ghisellini et al., 2005)

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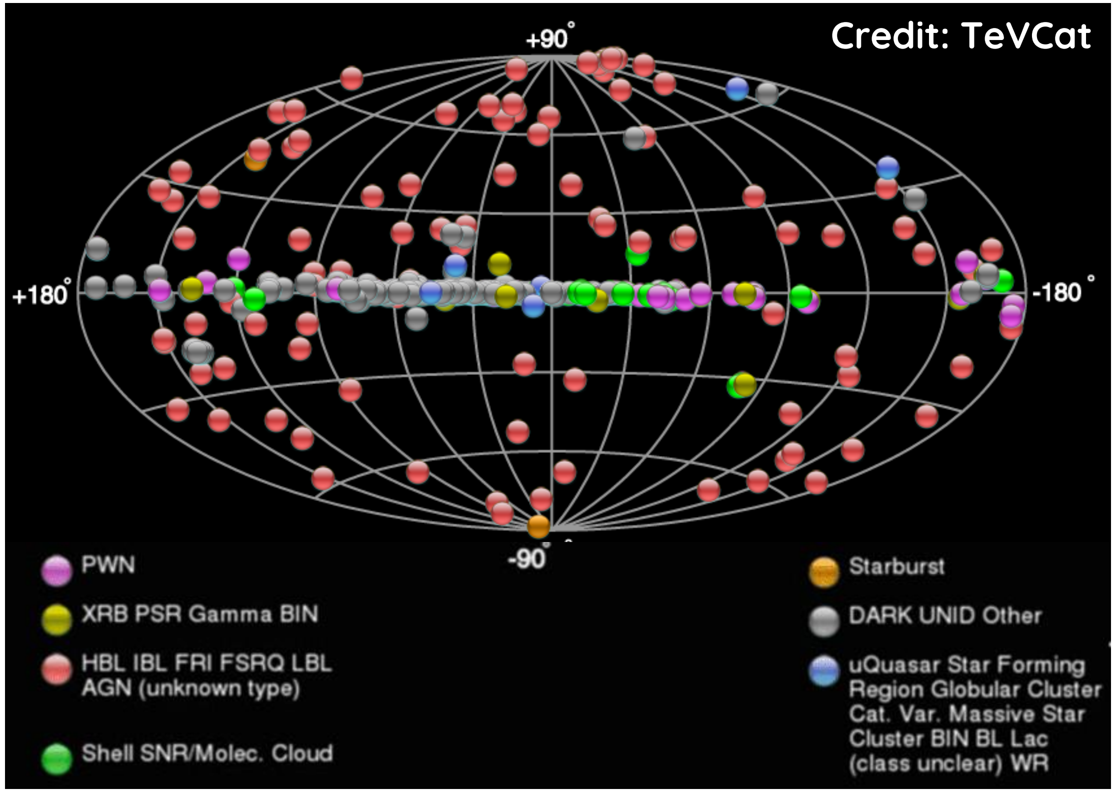

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Possible Scenarios:

-> Spine-Sheath Structure (Ghisellini et al., 2005)

-> Standing Recollimation Shocks (Hervet et al., 2019)

Why Radio?

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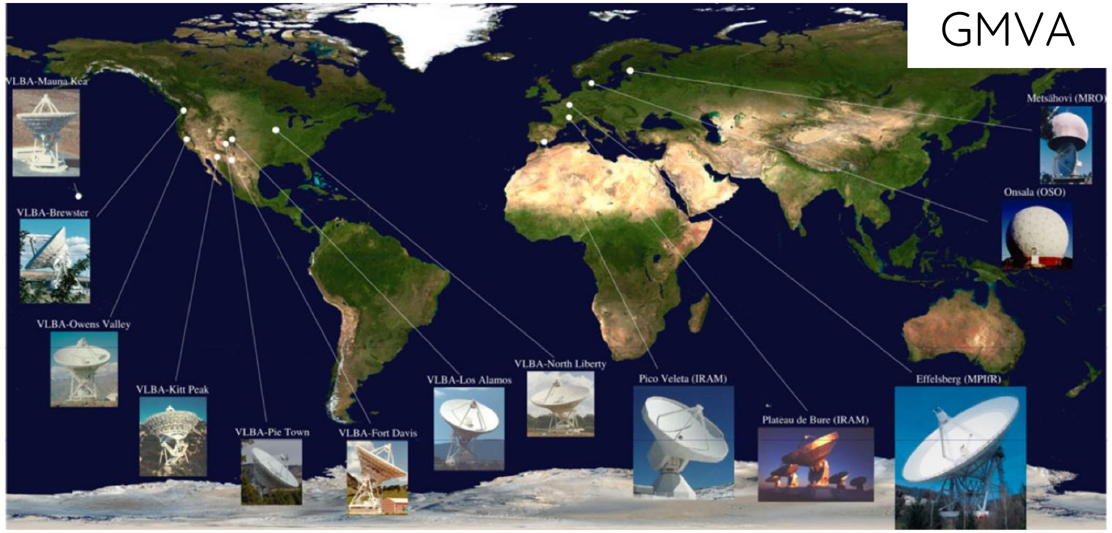
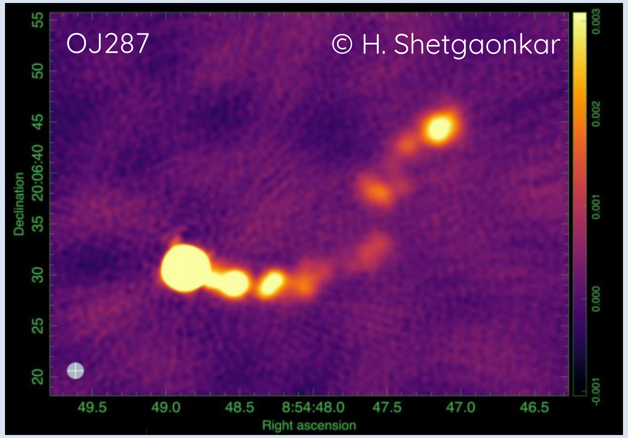
- Radio emission originates almost entirely from the plasma jet close to the central engine
- Synchrotron radiation from the jet/shocks helps to constrain models in MWL-studies
- Known correlation of high-energy and radio emission in blazars (e.g., Giroletti et al. 2016)
- Monitoring can yield important information about energy production and reasons for activity
- With **VLBI**, scales down to the the jet base can be investigated, as well as the **jet-speed, jet-geometry, doppler factor and magnetic-field**

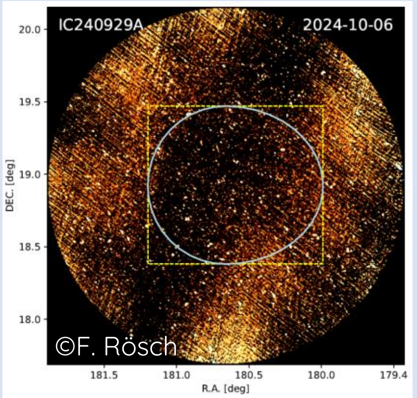
VLBA

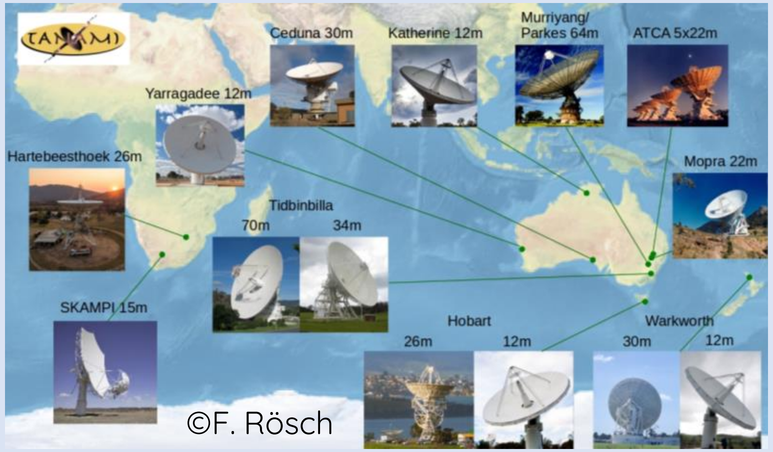


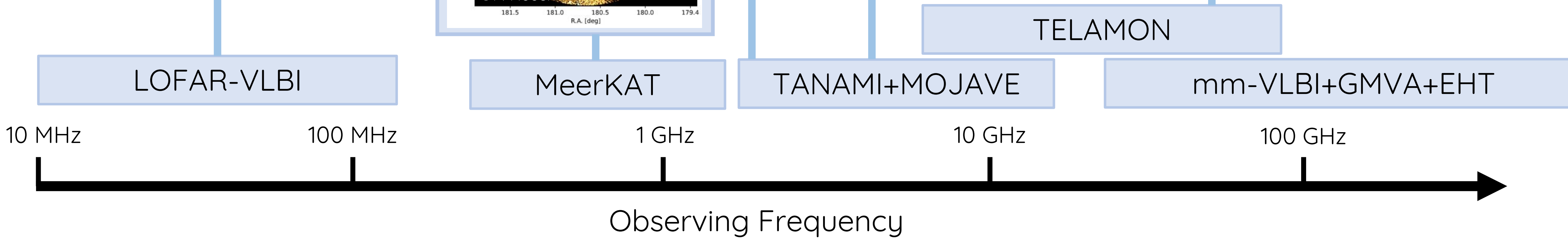
GMVA

Group activities









PG 1553+113: HBL and SMBBH

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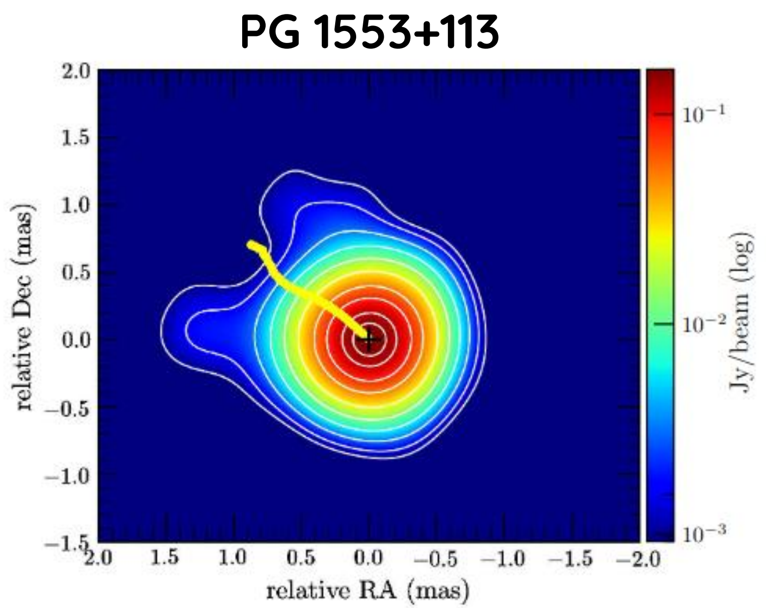

15 GHz VLBA image of PG 1553+113
(Lico et al. 2020)

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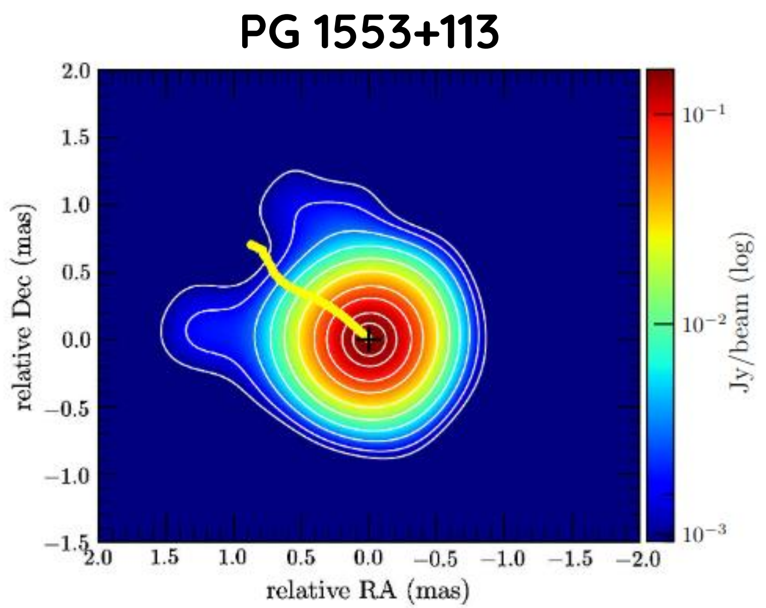

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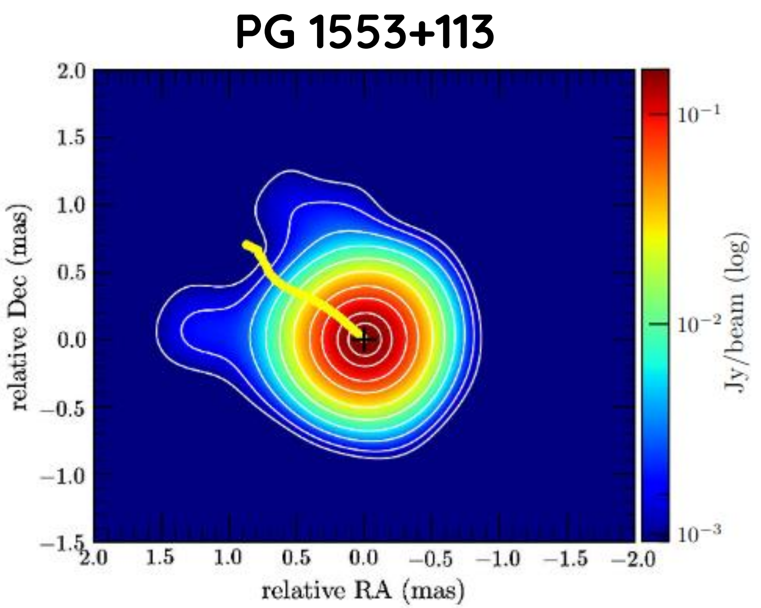

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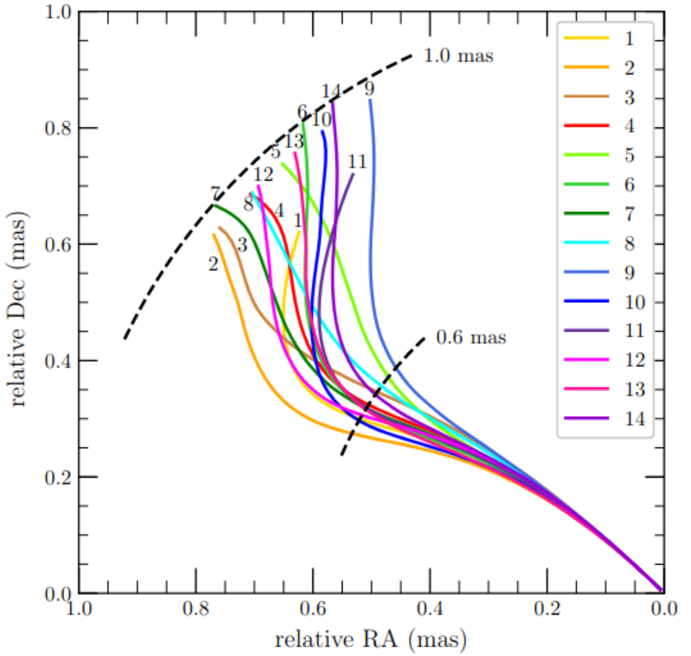
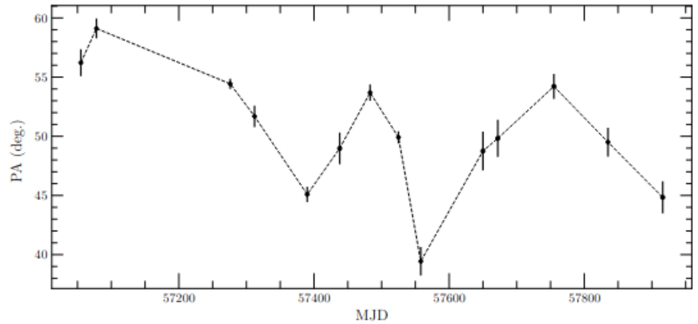
- Well studied HBL object with a known 2.2-year gamma-ray periodicity -> **super massive binary blackhole candidate**
- Previous VLBI study by Lico et al. (2020) revealed possible jet wobbling and hints of limb-brightening
- Source is affected by the Doppler-crisis (high TeV-Doppler factors, low radio Doppler factors)





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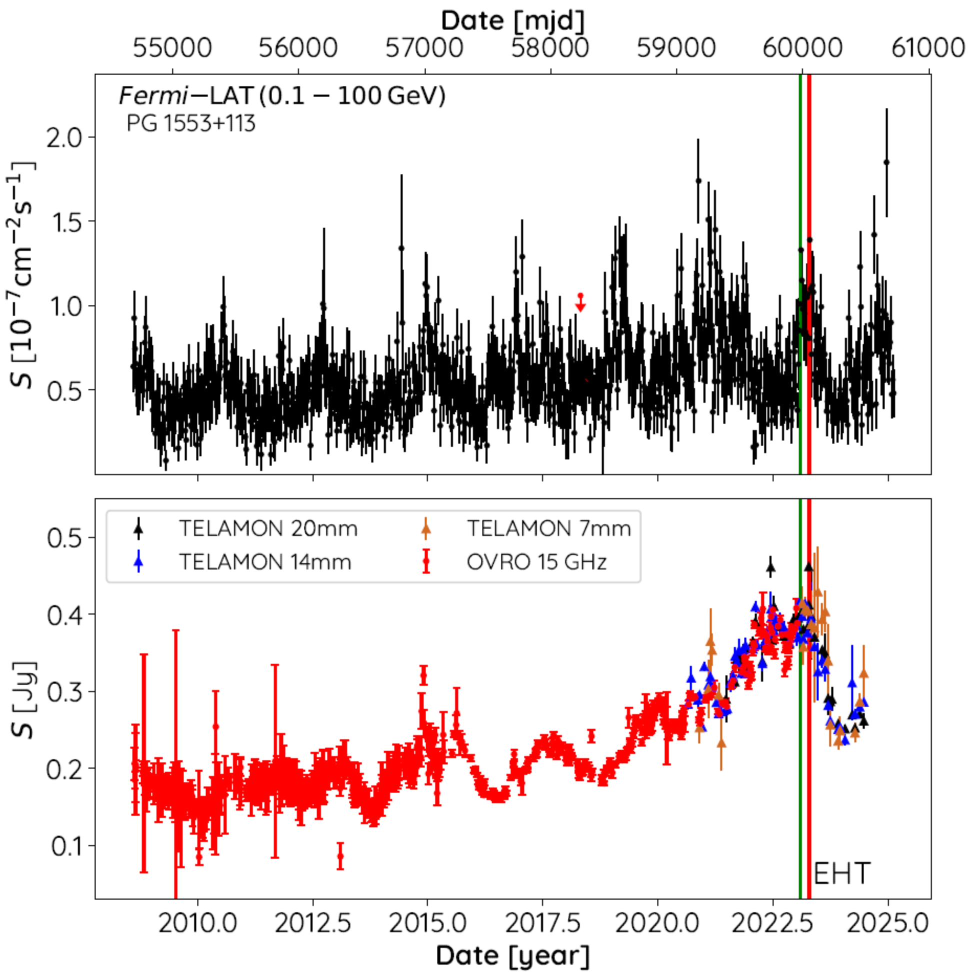

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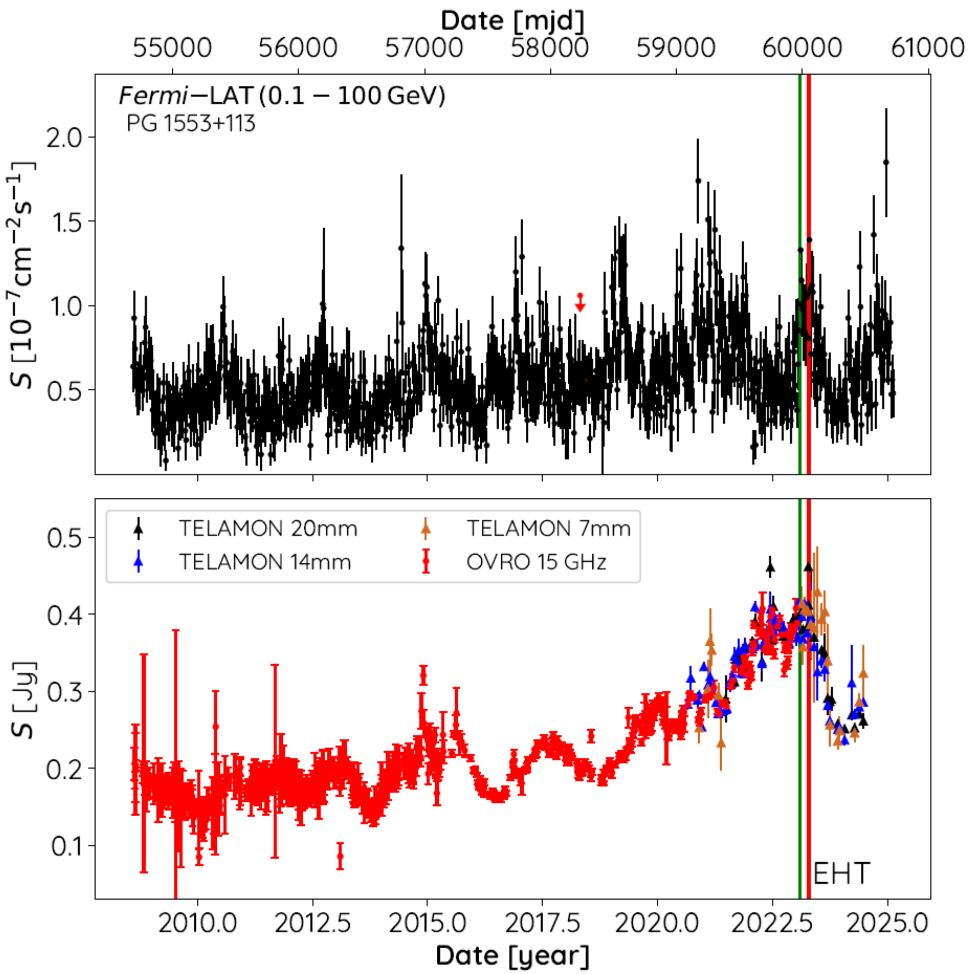

- **April 2023:** New (expected) gamma-ray maximum coupled with historical radio flare
- Triggered EHT observation with simultaneous MWL campaign

EHT

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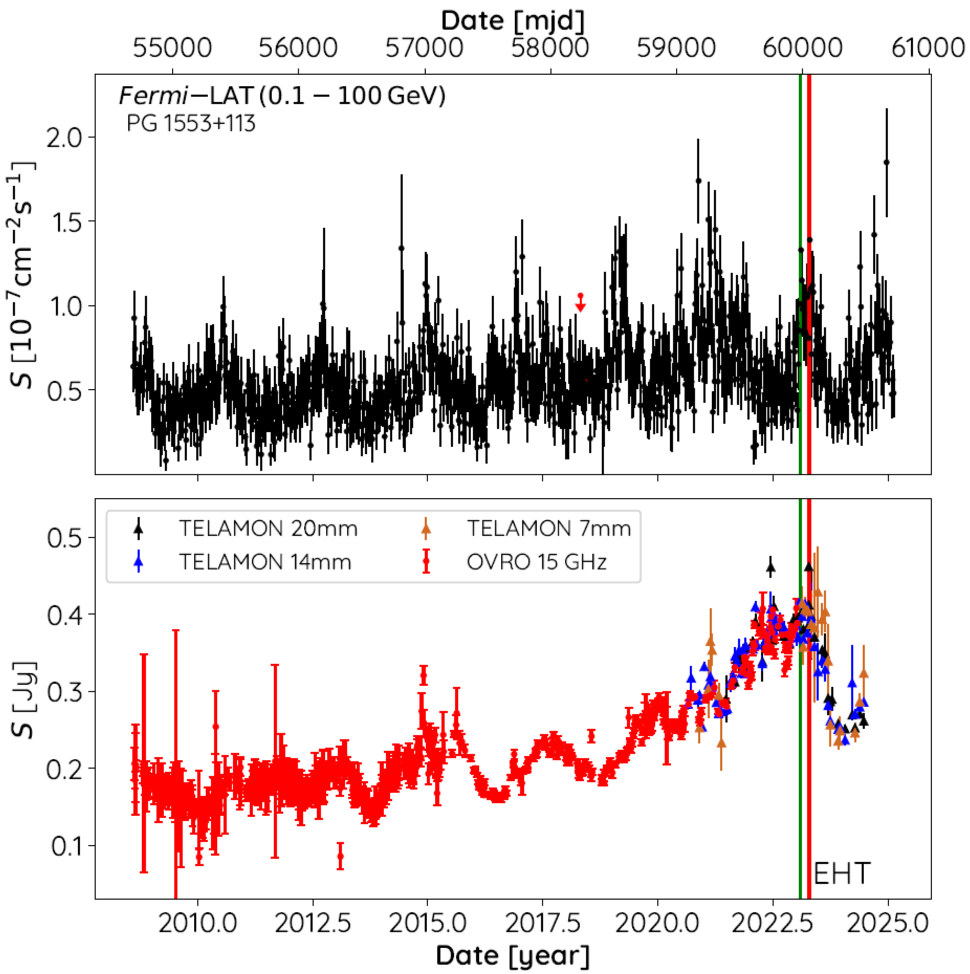

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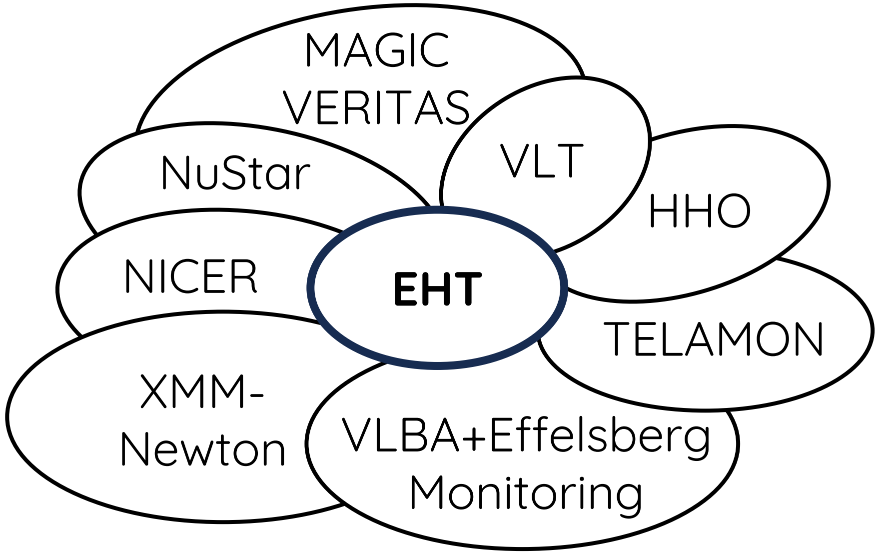

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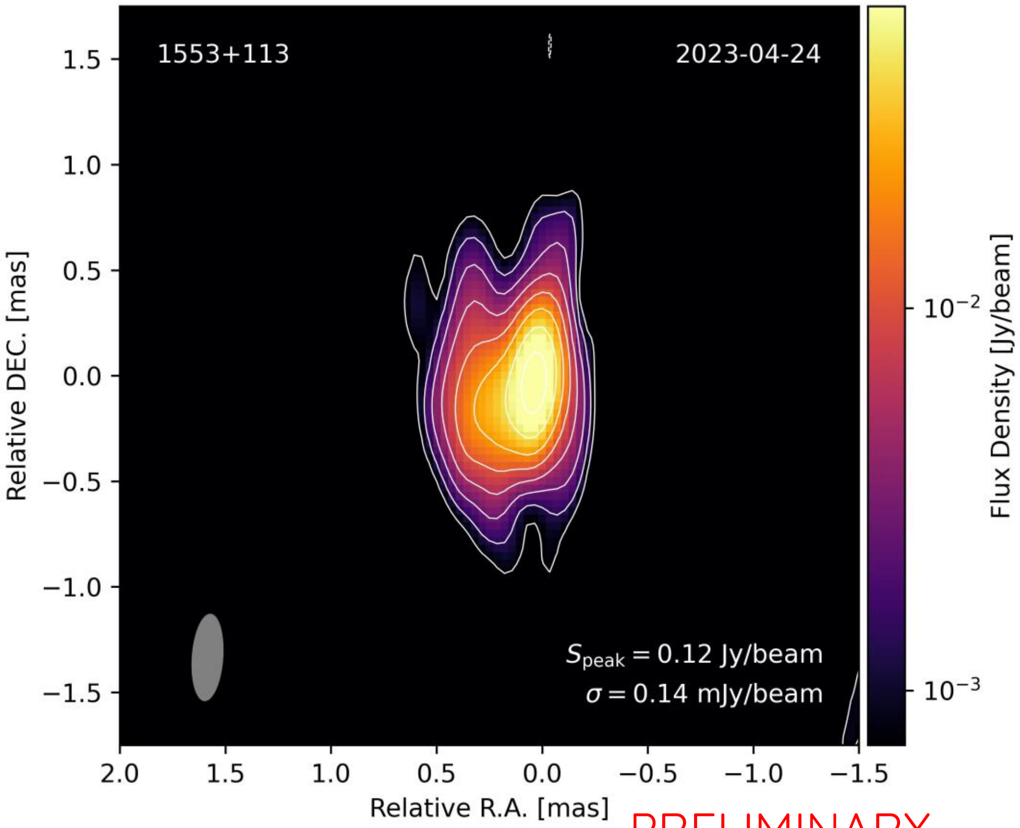
VLBA+Effelsberg 43 GHz



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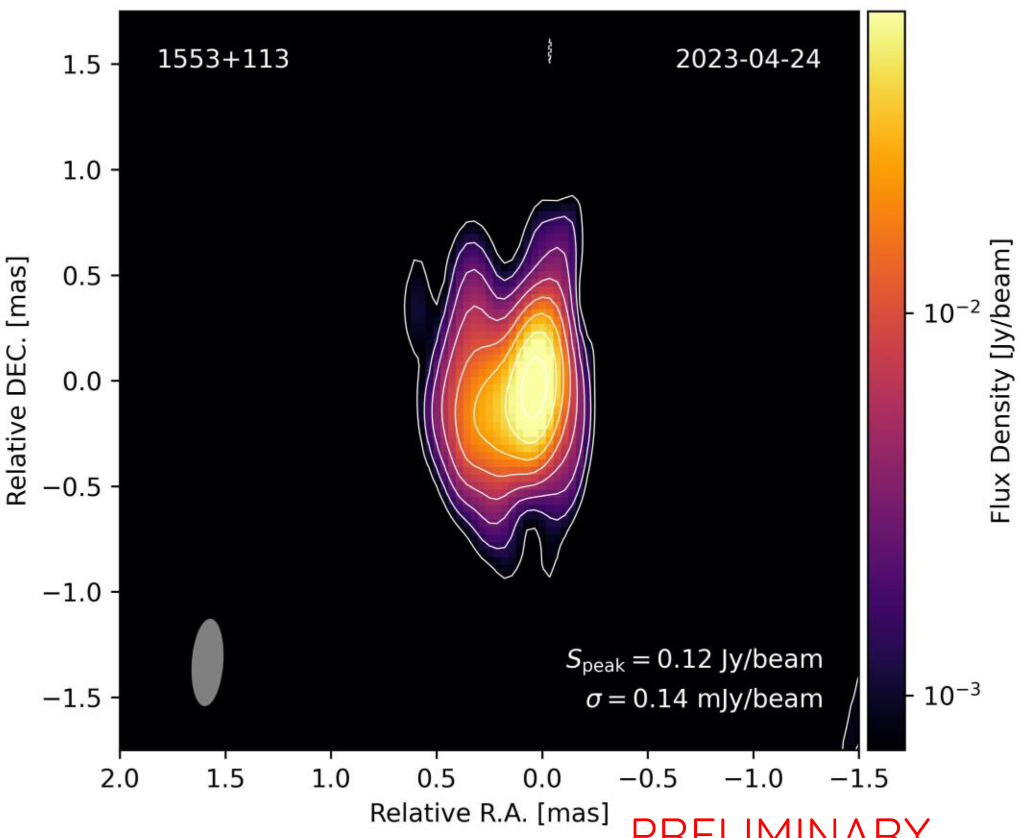

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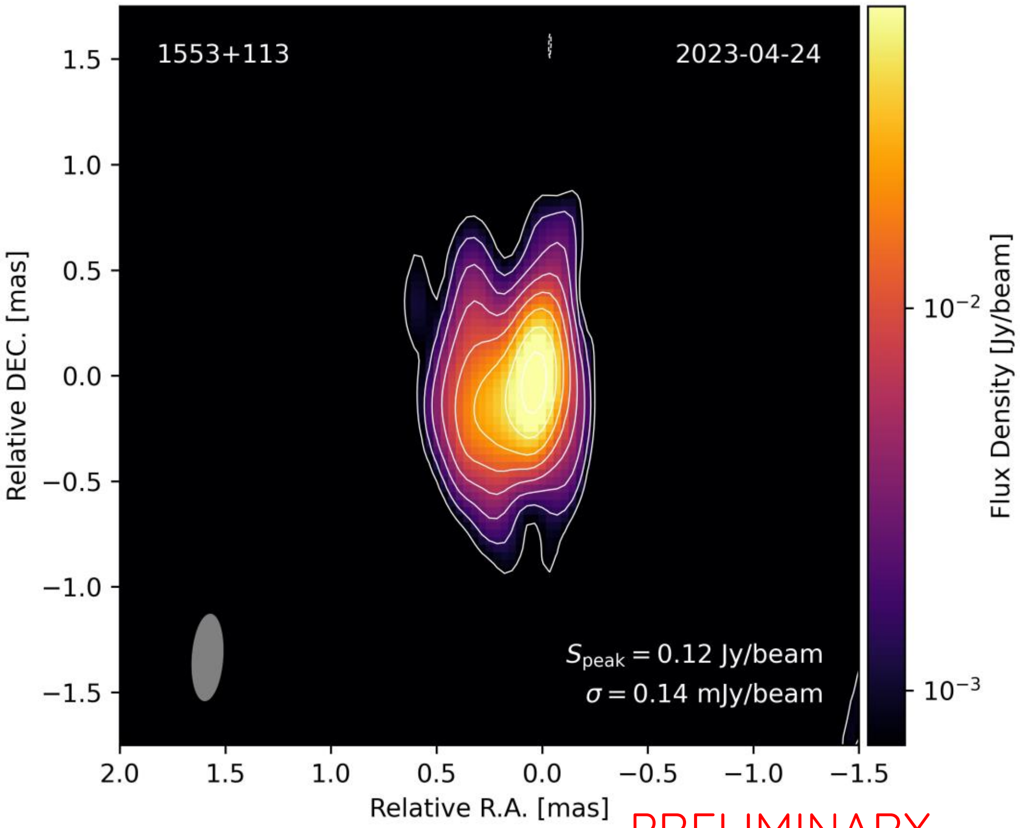

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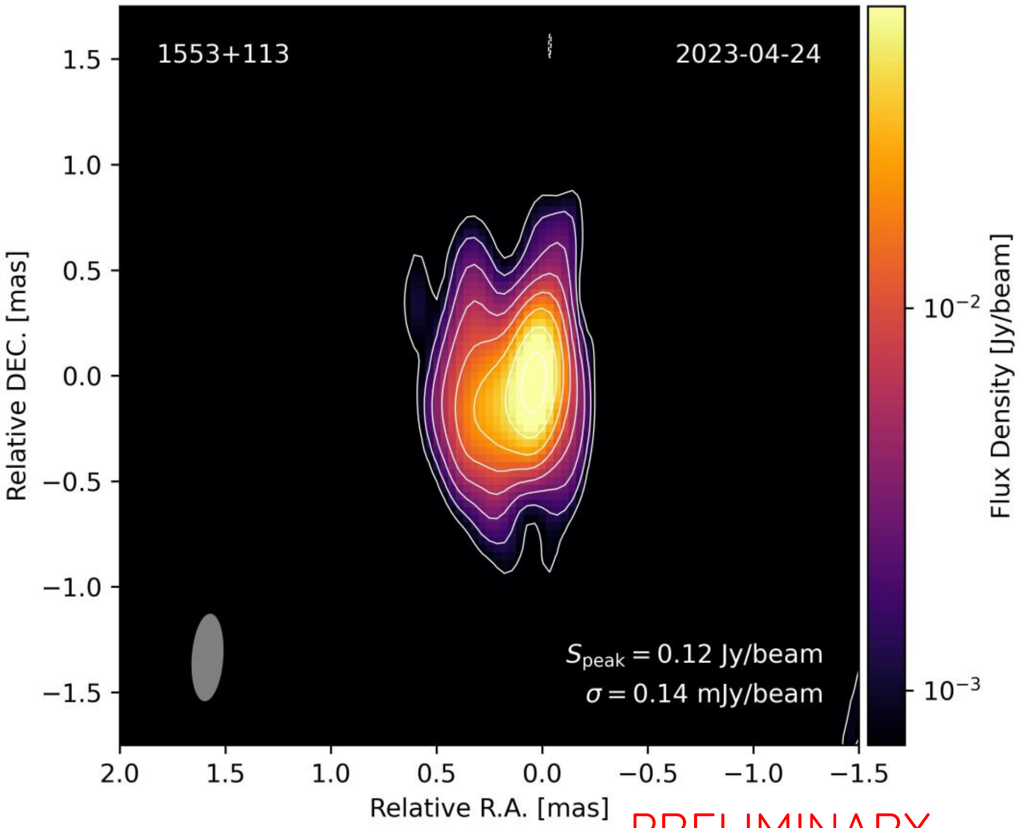

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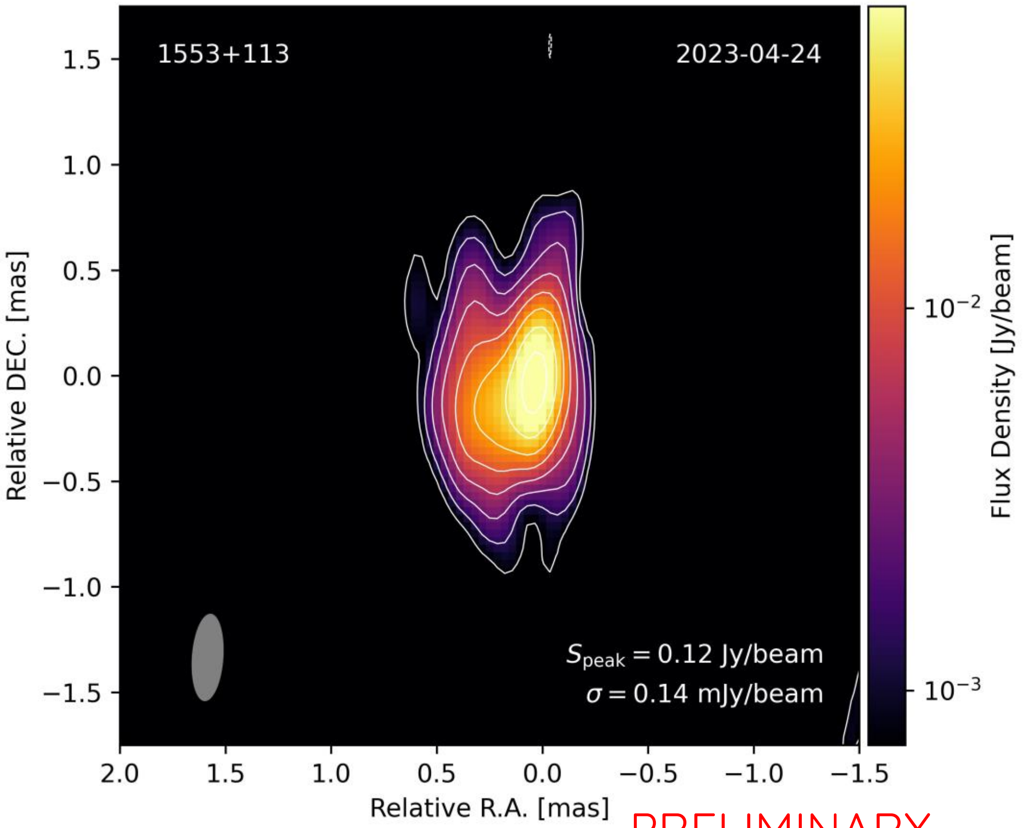

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→ will enable us to constrain MWL short-term (intra-day) variability at the high state close to the EHT observation

New GMVA monitoring upcoming

Source	Class[a]	S^{b}_{3mm} [Jy]	Redshift	ALMA Band 3	ATCA	TELAMON 19–44 GHz	MOJAVE 15 GHz	BEAM-ME 43 GHz	TANAMI 8 GHz
S2 0109+22[1]	IBL	0.6–2	0.265	✓	✓	✓	✓		
3C 84[†]	RG	13.5–26	0.0176	✓			✓	✓	
PKS 0346-27	FSRQ	0.5–2.7	0.991	✓	✓		(✓)		✓
TXS 0506+056[ν]	IBL/HBL	0.5–2.3	0.3365	✓	✓	✓	✓		
S5 0716+714	IBL	1–10	0.2304			✓	✓	✓	
PKS 0736+017	FSRQ	0.9–3.2	0.18941	✓	✓	✓	✓		
OJ 287[†]	LBL	2.3–8.8	0.306	✓	✓		✓	✓	
S4 0954+65	LBL	0.5–7	0.3694			✓	(✓)	✓	
TON 0599	FSRQ	0.3–6.7	0.724745	✓	✓	✓	✓	✓	
4C +21.35	FSRQ	0.3–2.0	0.43	✓	✓	✓	✓	✓	
M87[†,2]	RG	3–4	0.00436		✓		✓		
3C 279[†,2]	FSRQ	5–30	0.536	✓	✓		✓	✓	✓
OP 313	FSRQ	0.4–2.9	0.997	✓		✓	✓	(✓)	
PKS 1510-089	FSRQ	0.9–5.0	0.36	✓	✓		✓	✓	✓
Ap Lib	LBL	1.3–4.1	0.049	✓	✓		(✓)		✓
OT 081[†ν]	LBL	1.5–6.8	0.32	✓	✓	✓	✓	✓	
BL Lac[†]	IBL	1–8	0.0686	✓		✓	✓	✓	

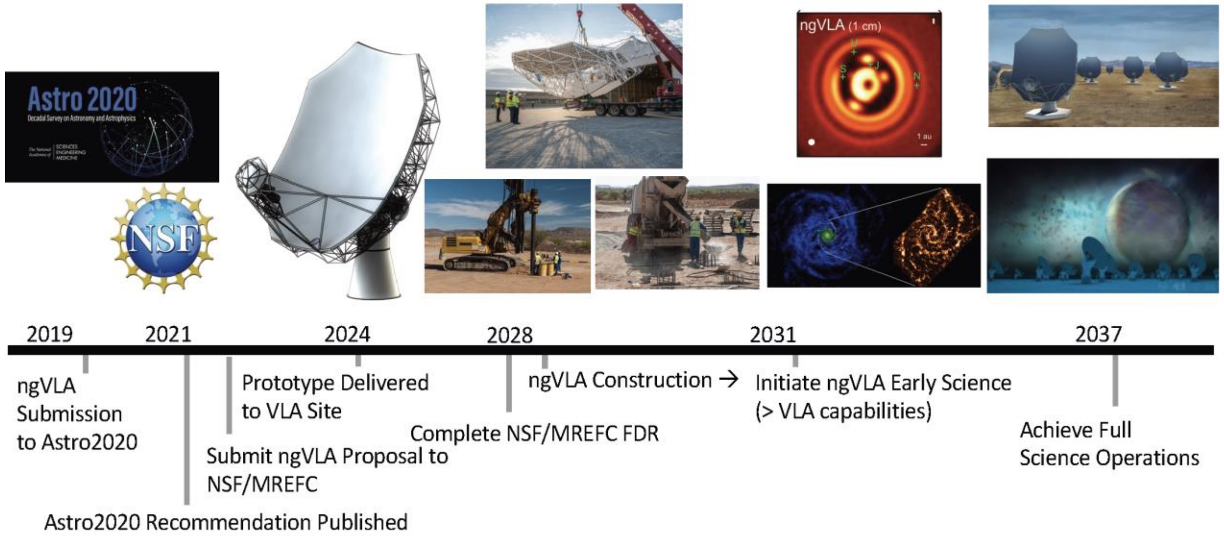
- Expanding individual case studies to a larger sample
- Observations granted for **Oct 25, Apr+Oct 26 at 3mm**
- Using upgraded GMVA array (incl. APEX, KVN and GLT) for highest-resolution possible at 86 GHz/3mm

Next-Generation VLBI

New major radio facilities coming up in the next 10-20 years

operating at 1 - 120 GHz

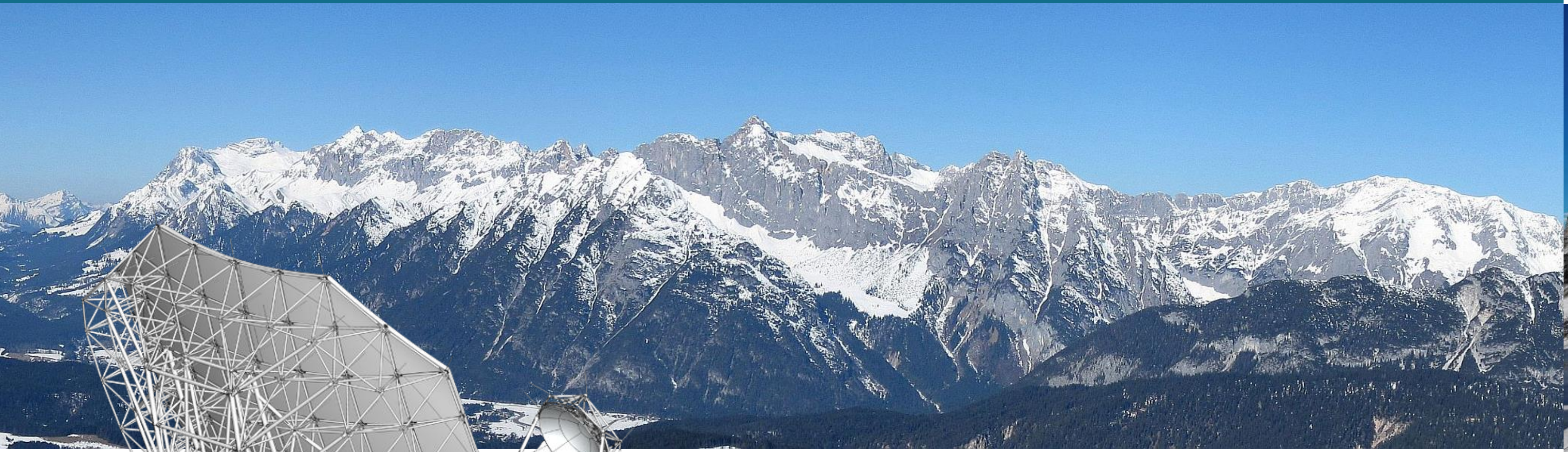
operating at 0.35 – 15.4 GHz (SKA-Mid)

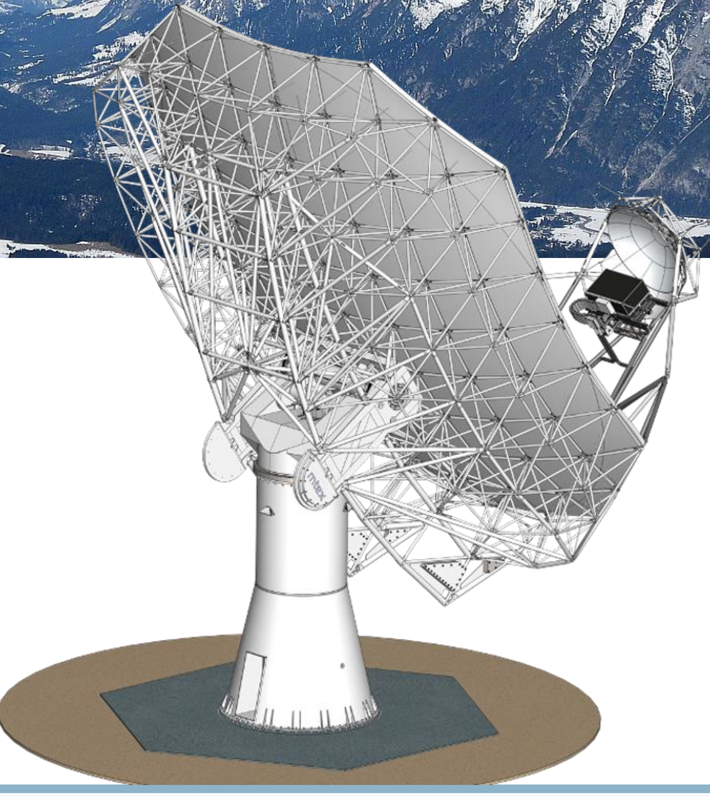


Will enable unique synergies with CTAO, IceCube-Gen2, KM3NeT and many more

See Kadler+2025, Proceedings of the 16th EVN Symposium

Wetterstein Millimeter Telescope





Germany‘s highest altitude research station (2650m)

UFS Schneefernerhaus

Bayerisches Staatsministerium für Umwelt und Verbraucherschutz

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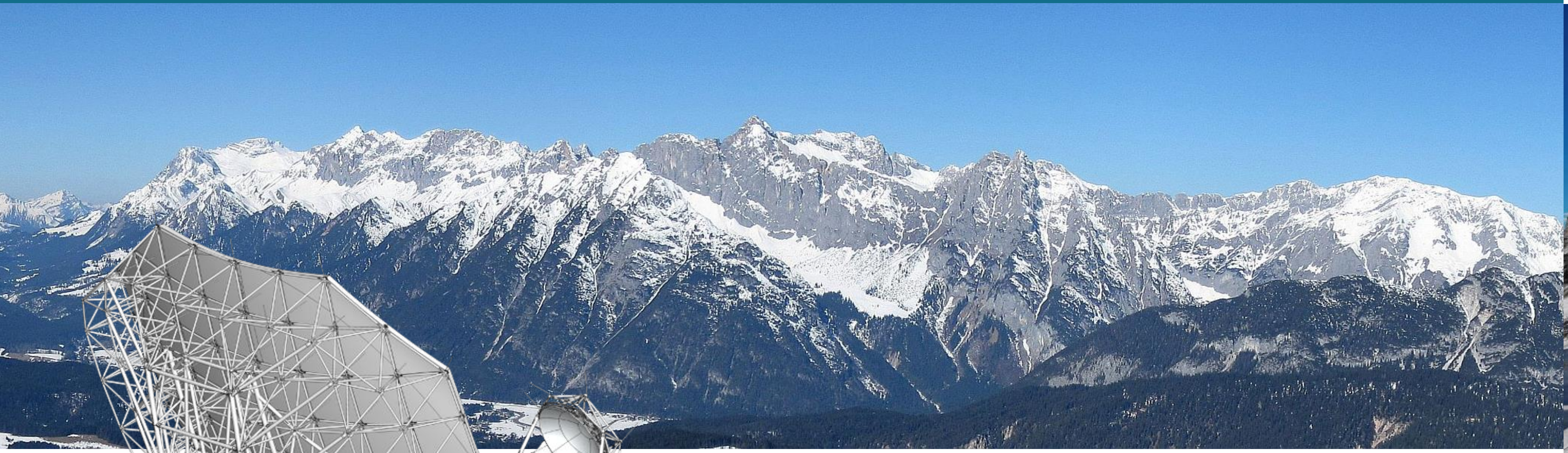

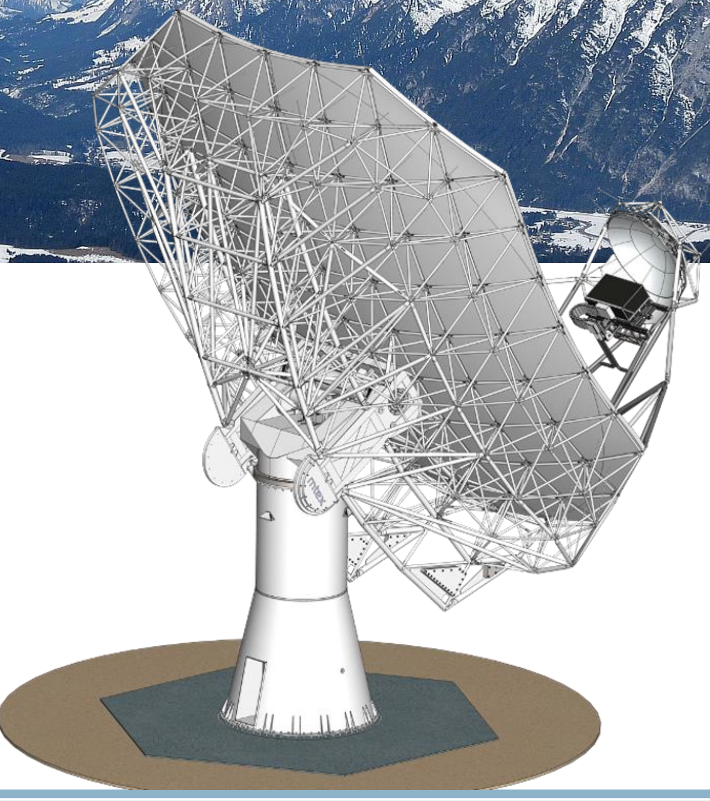

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UFS Schneefernerhaus

- High altitude data collection for climate, atmospheric, bio, hydro, geosphere and environmental research and medicine
- 11-story building, former hotel, since 1990 research station

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18m ngVLA Design

- 1.2-120 GHz (goal 230 GHz)
- Single dish and VLBI facility
- Immediate integration with the EVN & GMVA
- German contribution to ngVLA
- German antenna for SKA-VLBI
- First element of future LEVERAGE concept

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Science Program

- Black Holes and Relativistic Jets (JMU, MPIfR)
- Protoplanetry Disks (LMU)
- Dark Matter (MPA)
- Galaxy Evolution (MPIA)
- Additional partnerships invited!

+interdisciplinary topics and environmental research

Summary & Outlook

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- Radio observations can help to distinguish between different scenarios to understand the physics of VHE production for Doppler-Crisis blazars and Neutrino-Candidate sources

- Upcoming next-generation high-energy facilities like KM3Net, IceCube-Gen2, and CTAO will enable unique synergies with next-generation radio facilities like ngVLA, SKA, and WMT

Time for questions (and lunch)!

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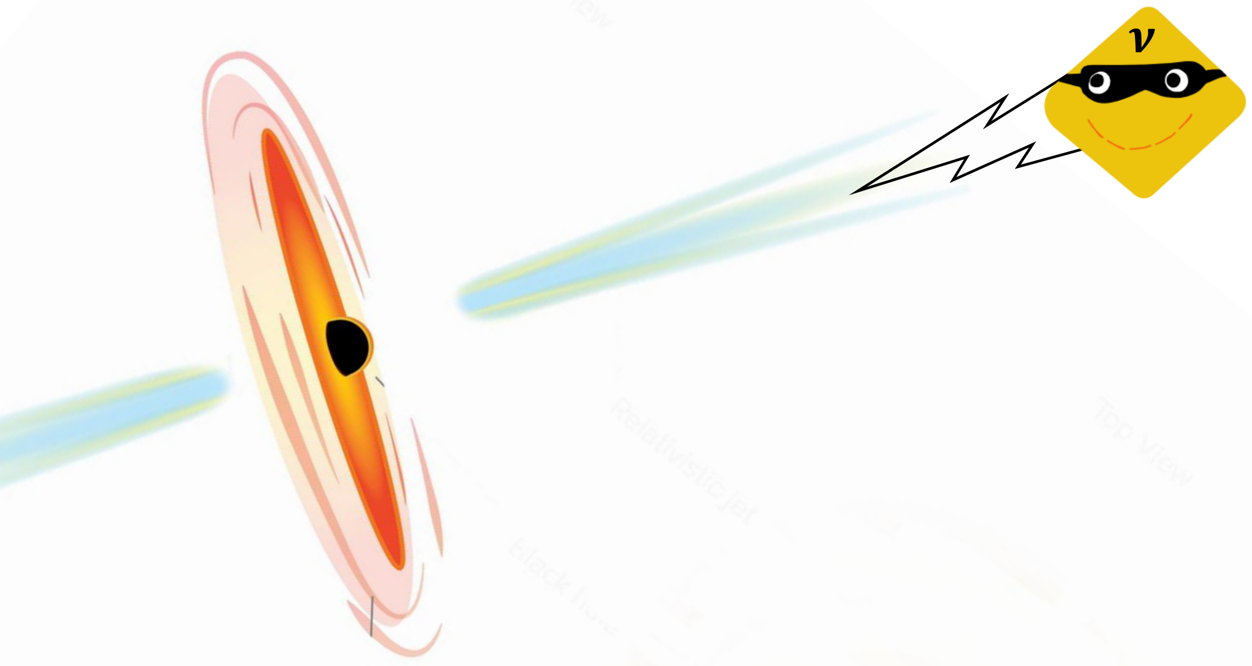
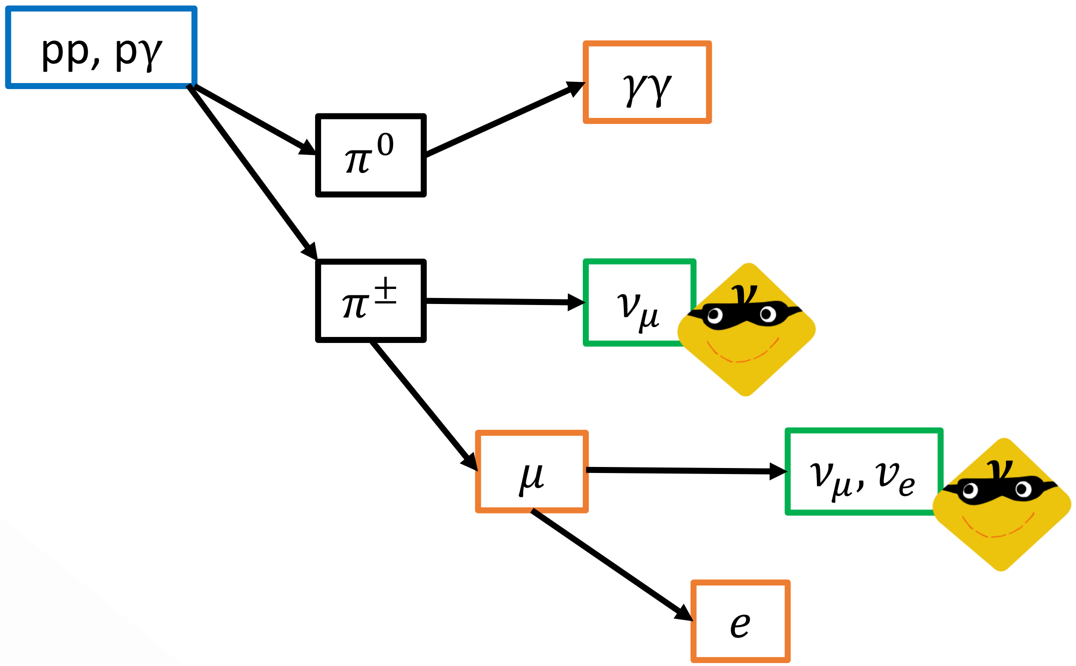
some lunch suggestions from your friendly neighborhood radio astronomer
- with inspiration from the AIPS Cookbook

Neutrino production in blazars

- High energy protons required E > 10^{16} eV
- pp or pγ process





Credit: Sophia Dagnello, NRAO/AUI/NSF