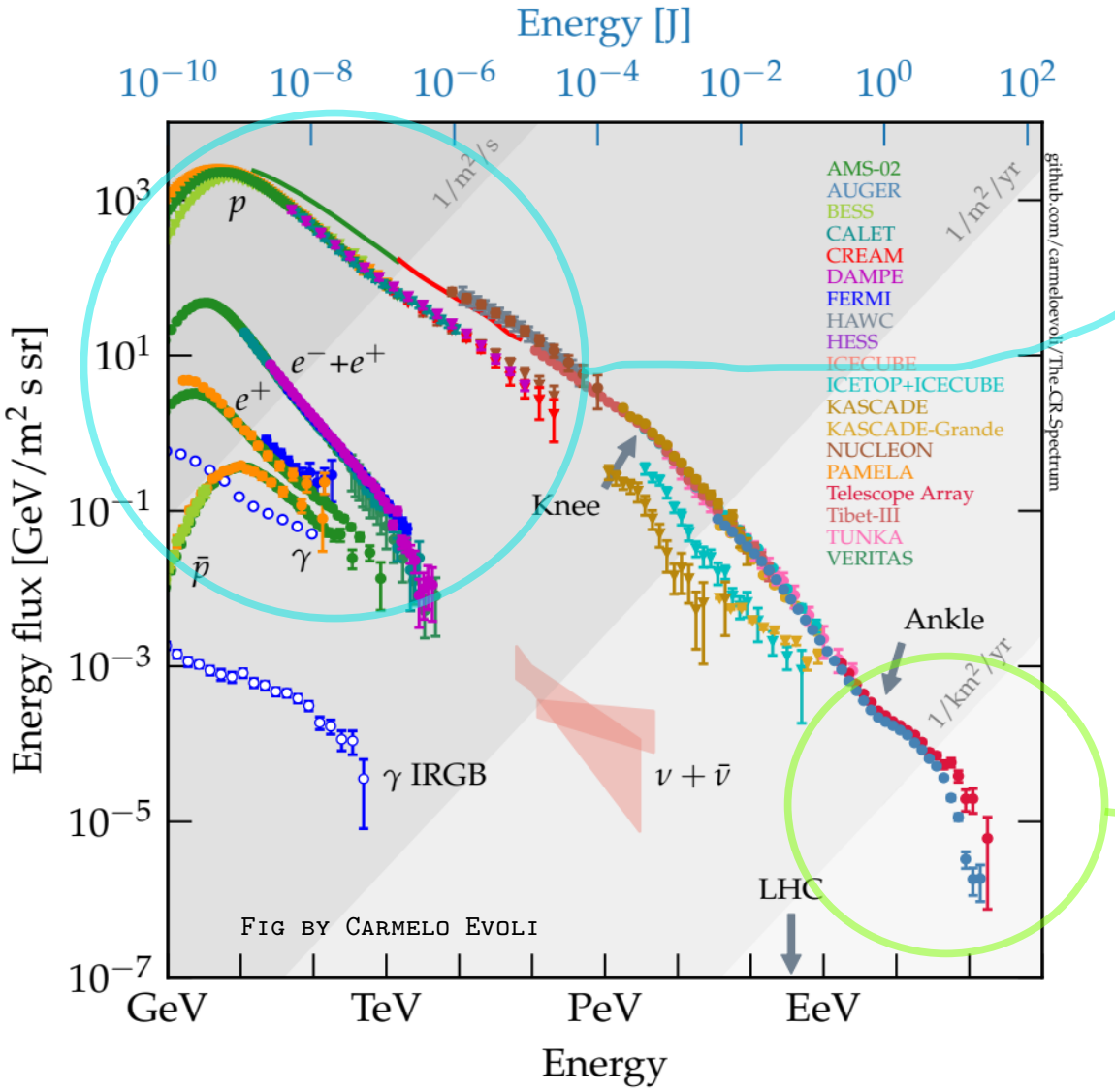
Very-high-energy emission from microquasar jets

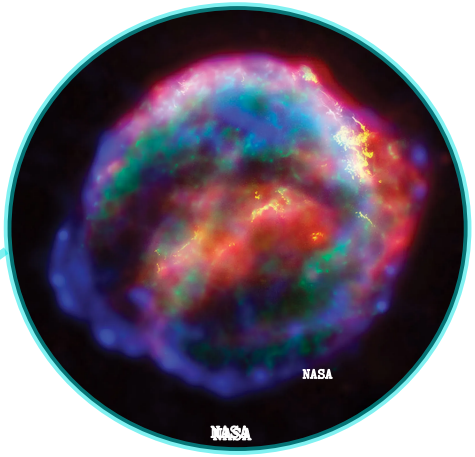
CTAO-KM3Net community day

September 8th 2025

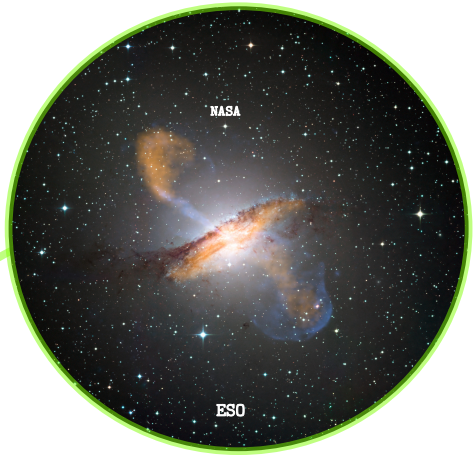
Laura Olivera-Nieto

The origin of cosmic rays



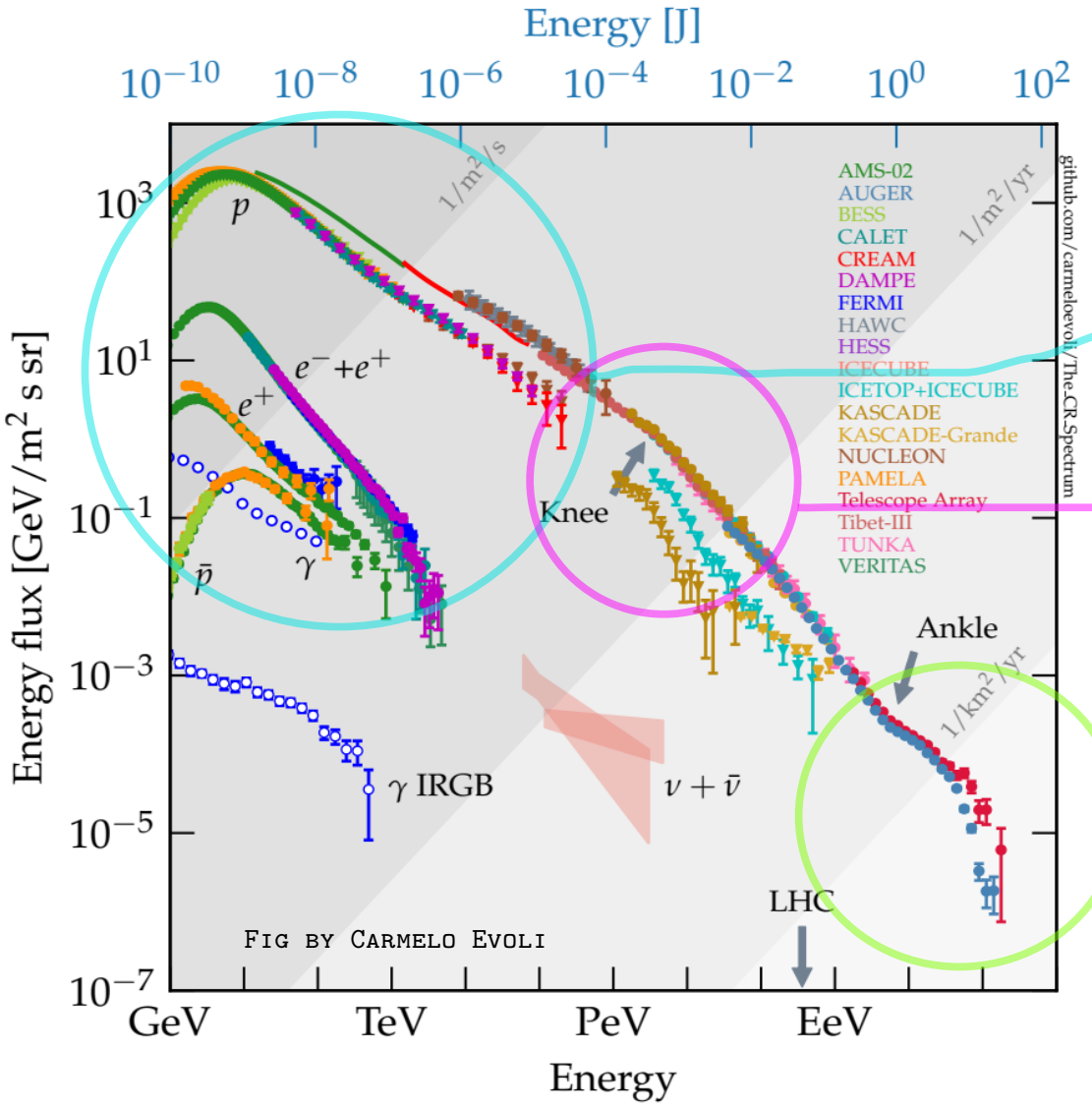


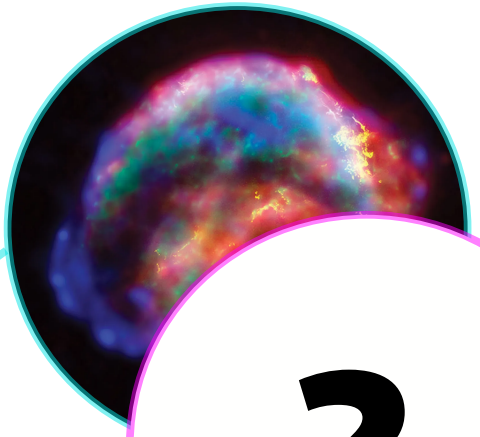
supernova remnants



sources outside our Galaxy

The origin of cosmic rays



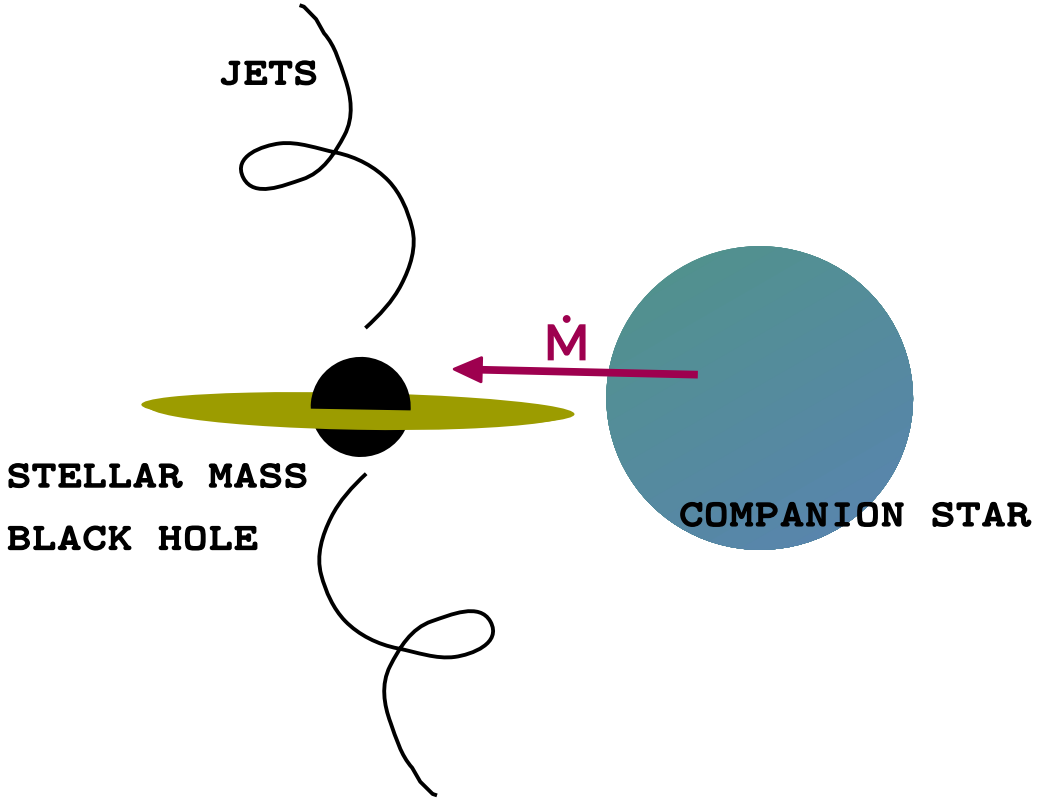


supernova remnants

?

sources outside our Galaxyn

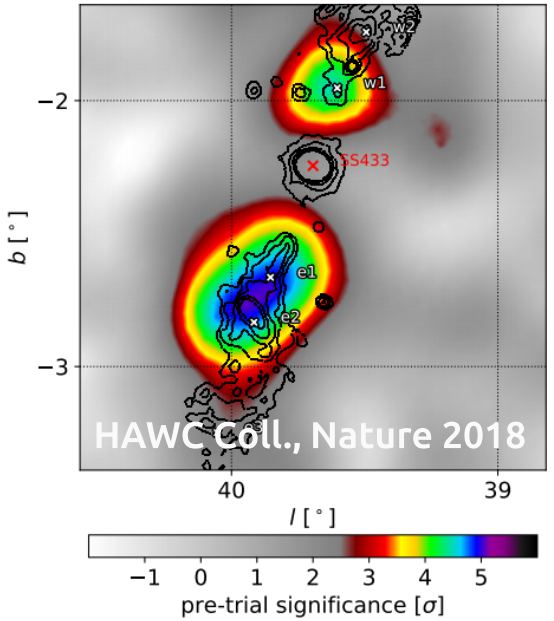
Microquasars



- X-ray binaries launching a (semi-)relativistic jet.
- Much less powerful than AGN (L_{edd}~10^{39} erg/s), but also much closer!
- Highly variable: generally go through short-lived phases of high activity.
- Proposed as particle accelerators since a long time, but elusive in the gamma-ray band since decades.
- Jets known/expected to contain **hadronic material**
- "Old" paradigm: point-like sources with flaring emission (like in the x-ray radio) → No detection so far.

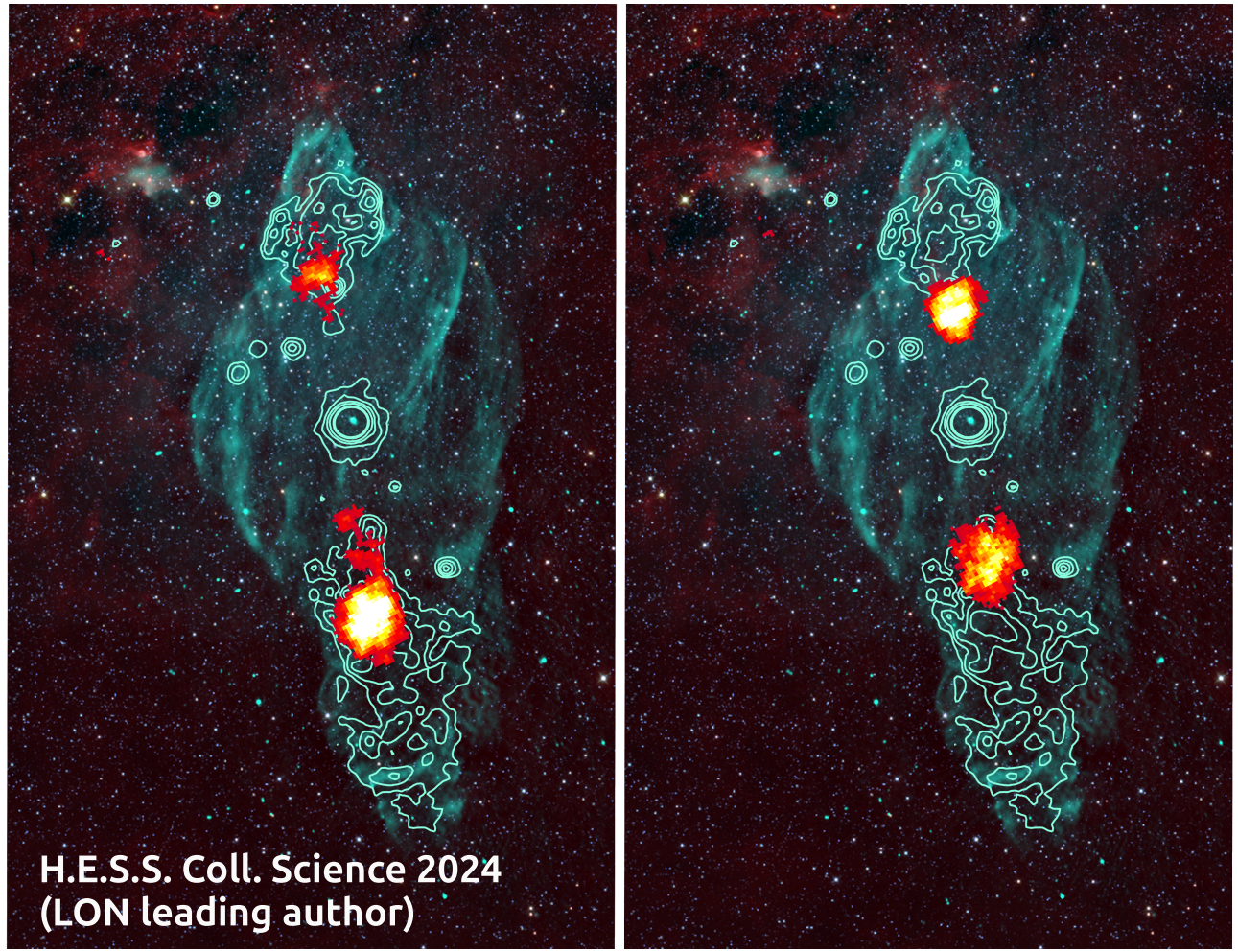
surprise!

- In 2018, HAWC detected persistent TeV emission from the jets of the microquasar SS 433
- Follow-up study with H.E.S.S. revealed energy-dependent morphology in the emission of the jets, closely following x-ray morphology
- Means TeV **emission** likely made by electrons



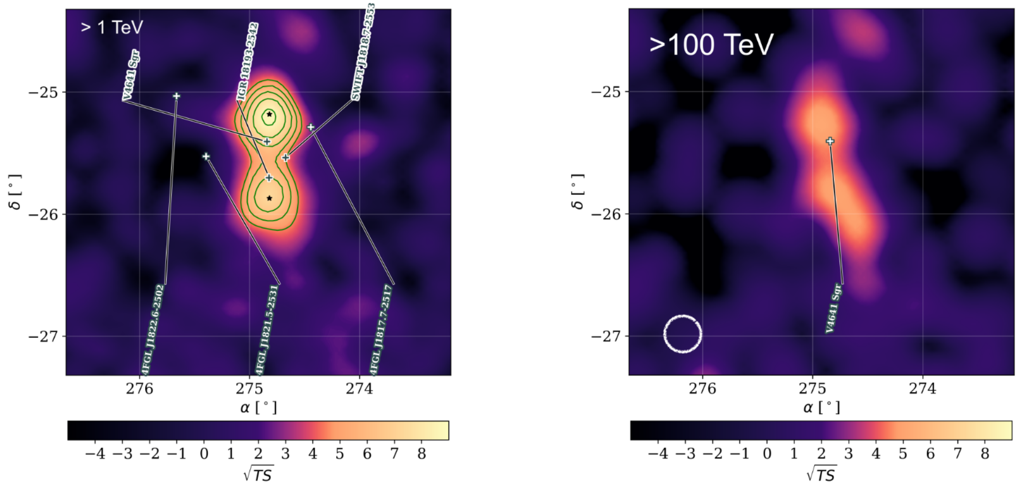
below 10 TeV

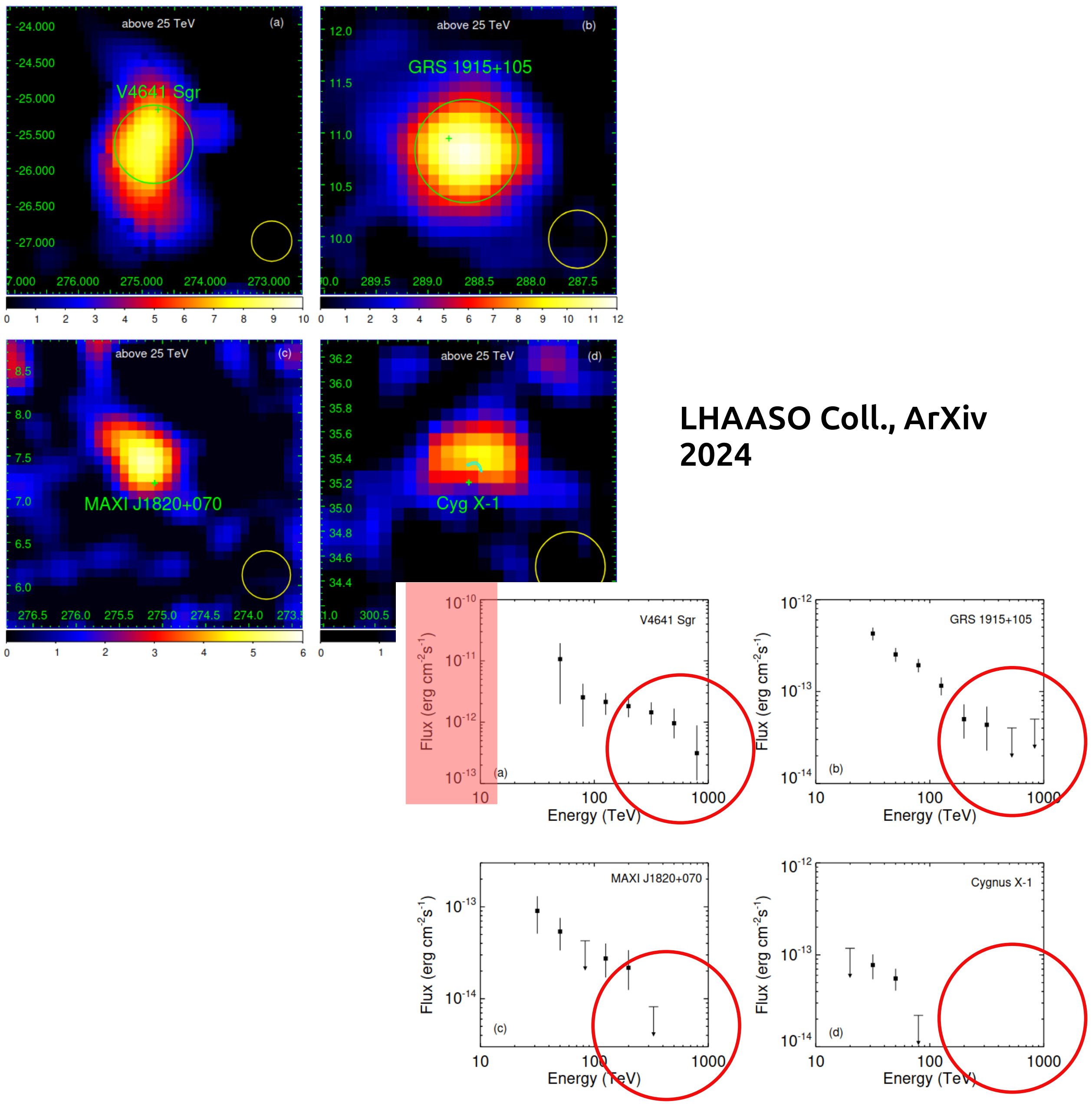
above 10 TeV



… and more!

HAWC Coll., Nature 2024





LHAASO Coll., ArXiv 2024

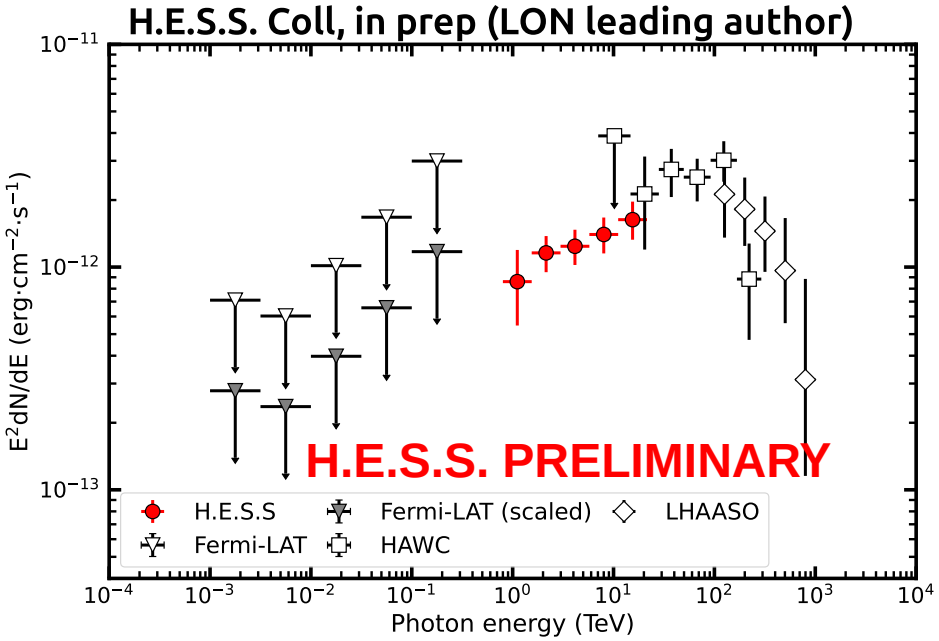
- Emission detected around 4 more sources!
- Emission extended in all cases: 10s pc spatial scales!
- V4641 Sgr stands out: 10 times brighter and detected out to **photon energies of almost 1 PeV!**

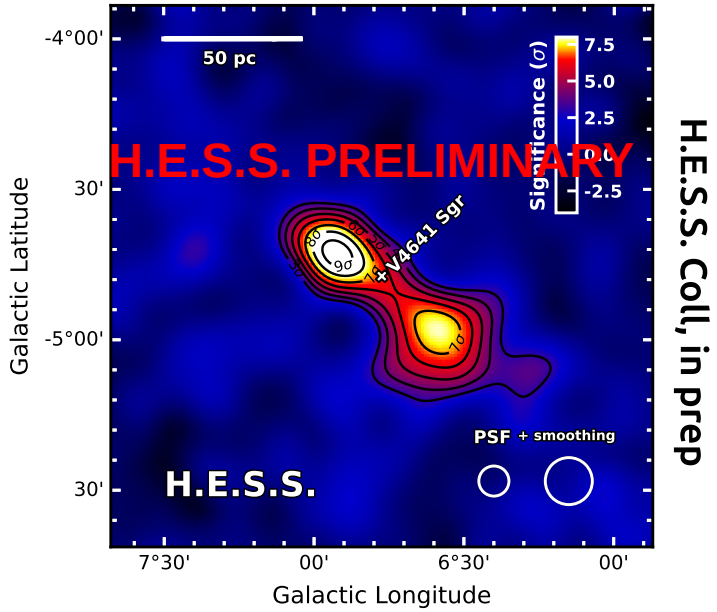
V4641 Sgr

- Discovered in 1999 when it underwent a super-Eddington outburst, but relatively "quiet" since: most of the time in quiescence + small (10^{36}erg/s) outbursts.
- During 1999 outburst, reports of a jet aligned with l.os. – but TeV emission is ~100pc long!
- "Normal" x-ray binary: extraordinary gamma-ray source: **first source discovered with spectral peak at 100 TeV**

H.E.S.S. Coll. 2024 (SB 433)

- $L_\gamma \sim 5 \cdot 10^{34}$erg/s → source must have been more active in past
- Follow-up with H.E.S.S. reveals hints of two components in morphology and no energy dependent morphology.
- No known x-ray or radio counterpart to the extended emission.
- Can we **confirm** it is a cosmic ray source?

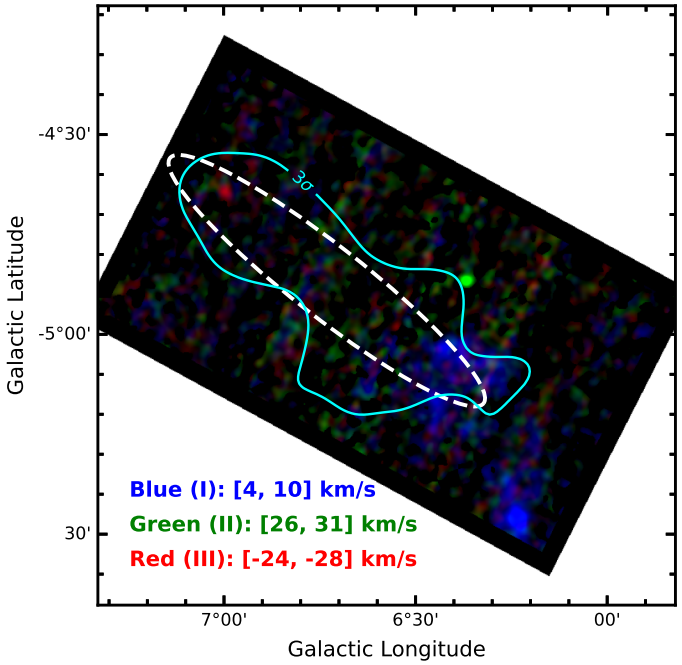




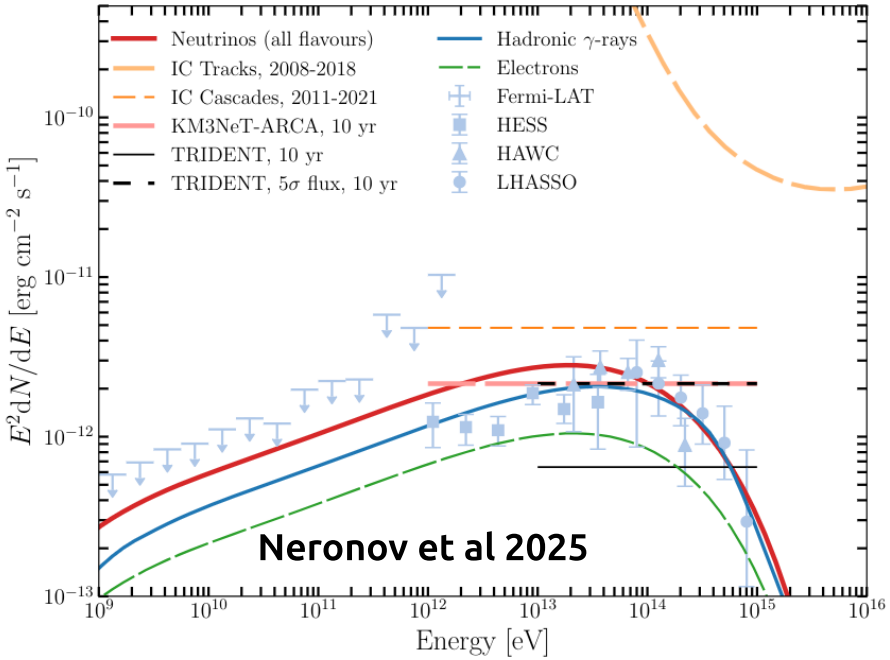
Where are the protons?

- Nope :-(
- V4641 Sgr is located ~500 pc below Galactic plane, in a low density environment.
- New CO observations (NRO) confirm $n<<1 cm^{-3}$, which poses extreme constraints to energetics in hadronic case. For example, gamma-ray luminosity + low density require $L_{source} \sim L_{edd}$ for millions of years (entire age of source)
- A leptonic scenario faces significantly less constraints, as long as B>3uG (but still requires $L_{source} \sim 10^{36}$erg/s for~10^3 yr!)

H.E.S.S. Coll, in prep

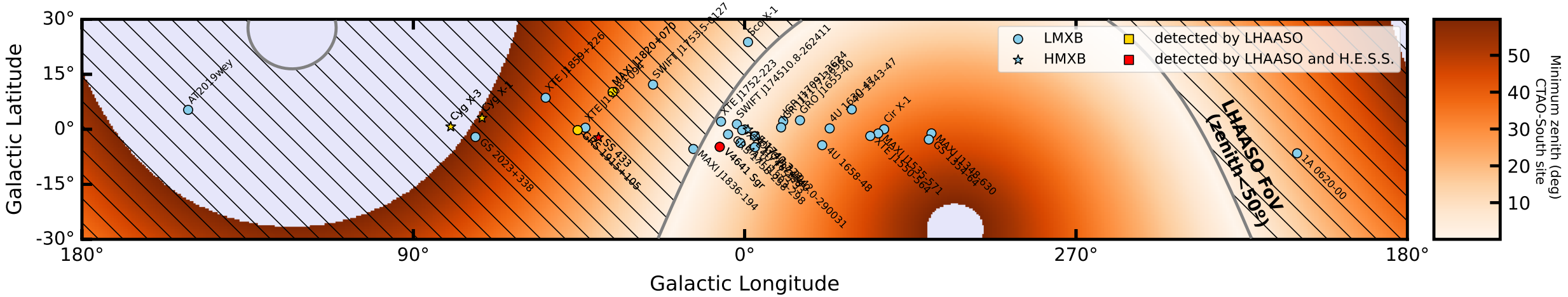


- Modeling from Neronov et al 2025 yield neutrino flux detectable by KM3Net in 10 yr!
- But gamma-rays are mostly hadronic in their work: they assume a higher density than constrained by NRO
- **What if a source like V4641 Sgr is found closer to the plane?**



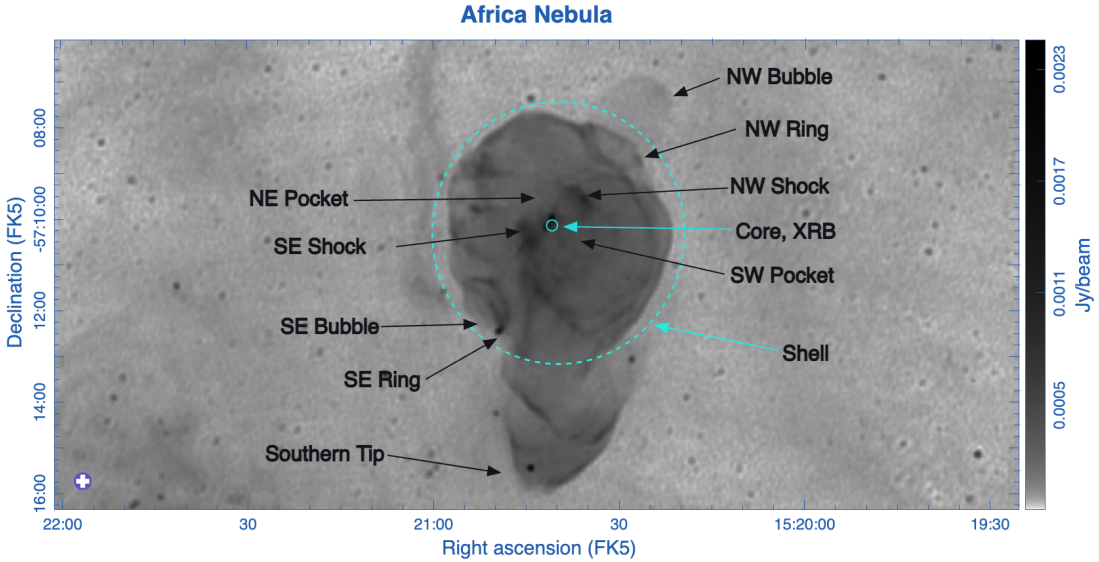
The unknown

- **All detected microquasars are on the Northern half of the sky.**
- Simply because that is where the unbiased WCDs (HAWC, LHAASO) observe
- H.E.S.S. looking for point-like sources during flares for decades (but no longer ;-))
- Sourthern sky up for grabs!
- Basically guaranteed discovery of new sources ! If any “V4641 Sgr”-like → plausible to detect neutrinos!



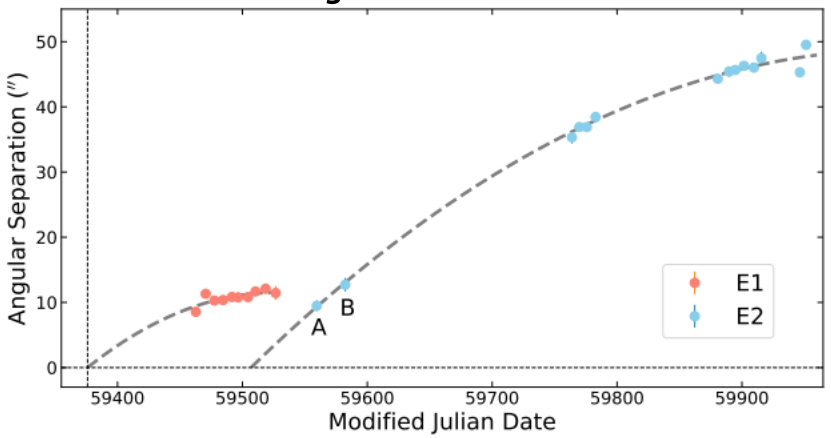
For example...

- **Cir X-1**: an x-ray binary powering an “SS 433-like” nebula being “punched” by jets
- **SWIFT J1727.8-1613:** has the largest continuous jets ever seen in an x-ray binary.
- **4U 1543-47:** hosts jets with the largest Lorentz factor ever observed in an x-ray binary
- **But also x-ray binaries which look “plain” now, since VHE emission traces past activity!**

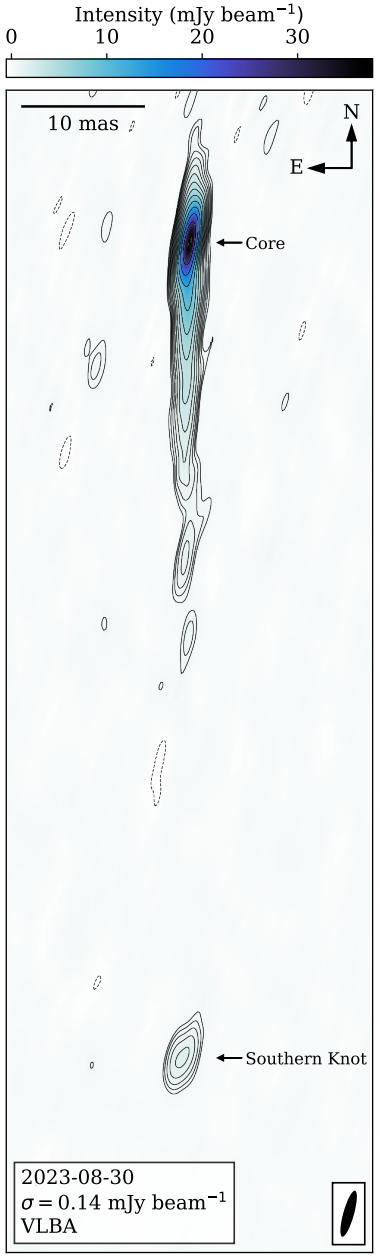


Cir X-1: Gasealahwe et al 2025

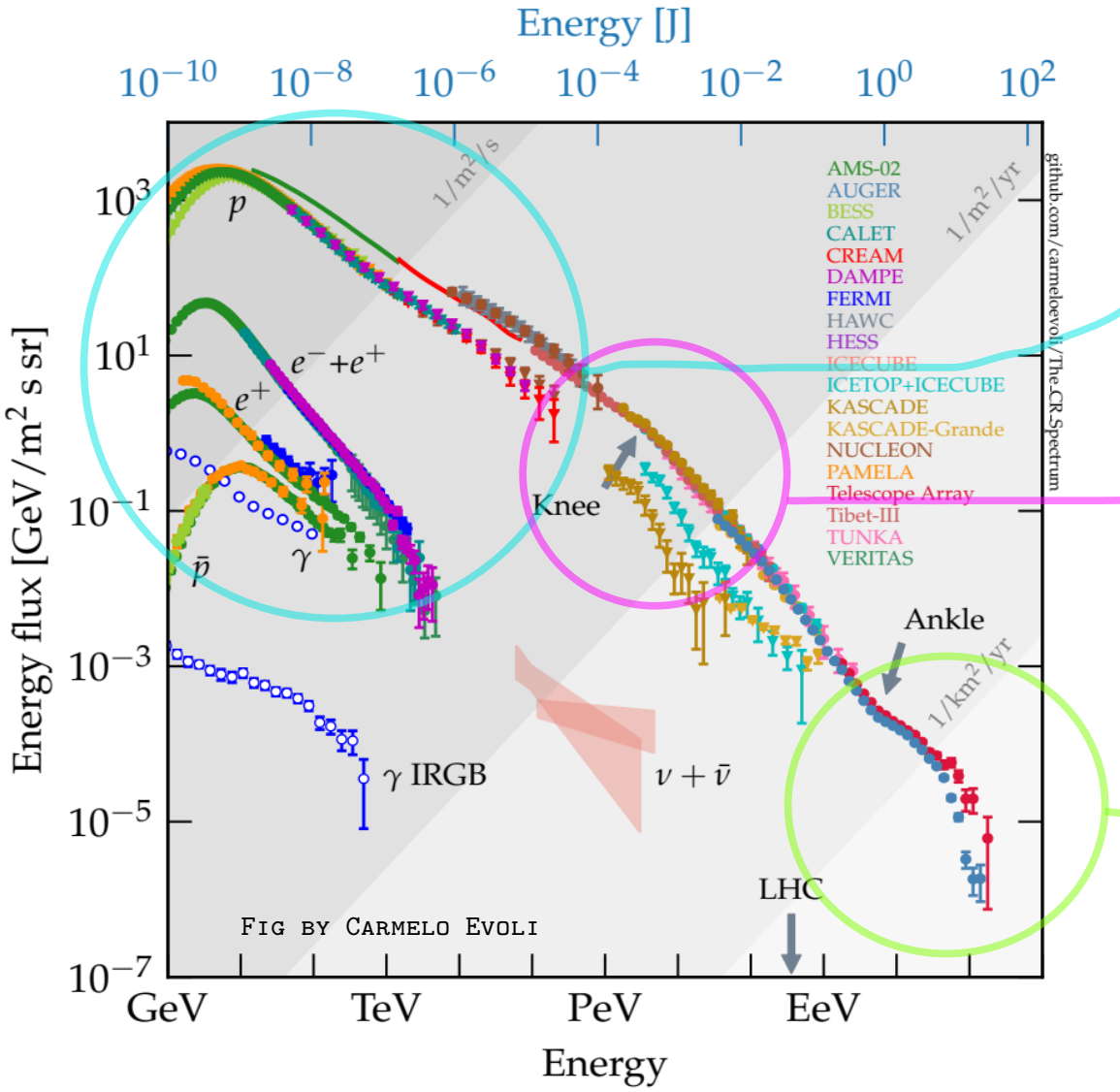
4U 1543-47: Zhang et al 2025

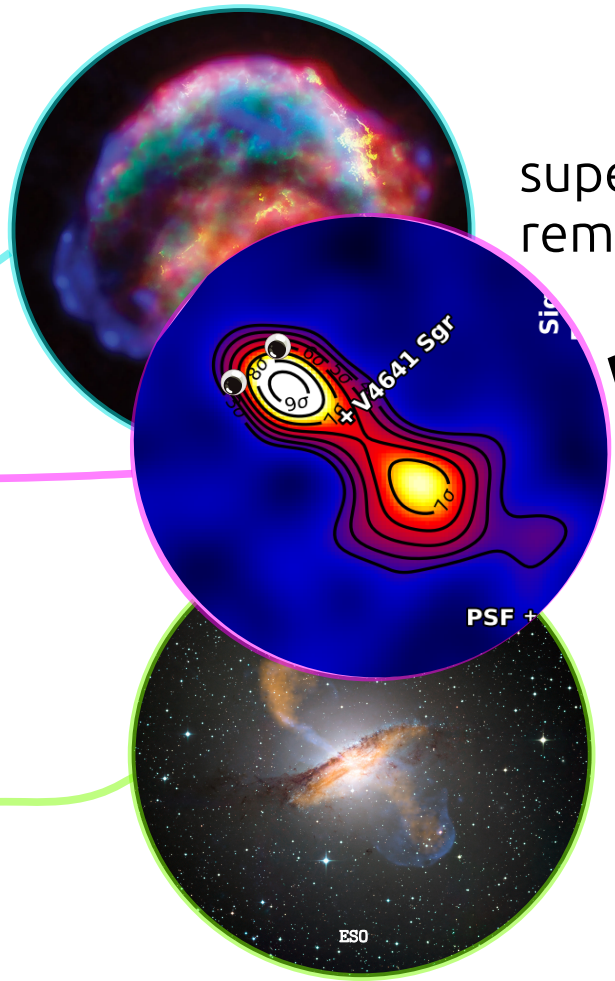


SWIFT J1727.8-1613: Wood et al 2024



The origin of cosmic rays





supernova remnants

?

sources outside our Galaxy

Thanks!