Multi-messenger signatures of high-energy neutrino and ultra-high energy cosmic ray sources

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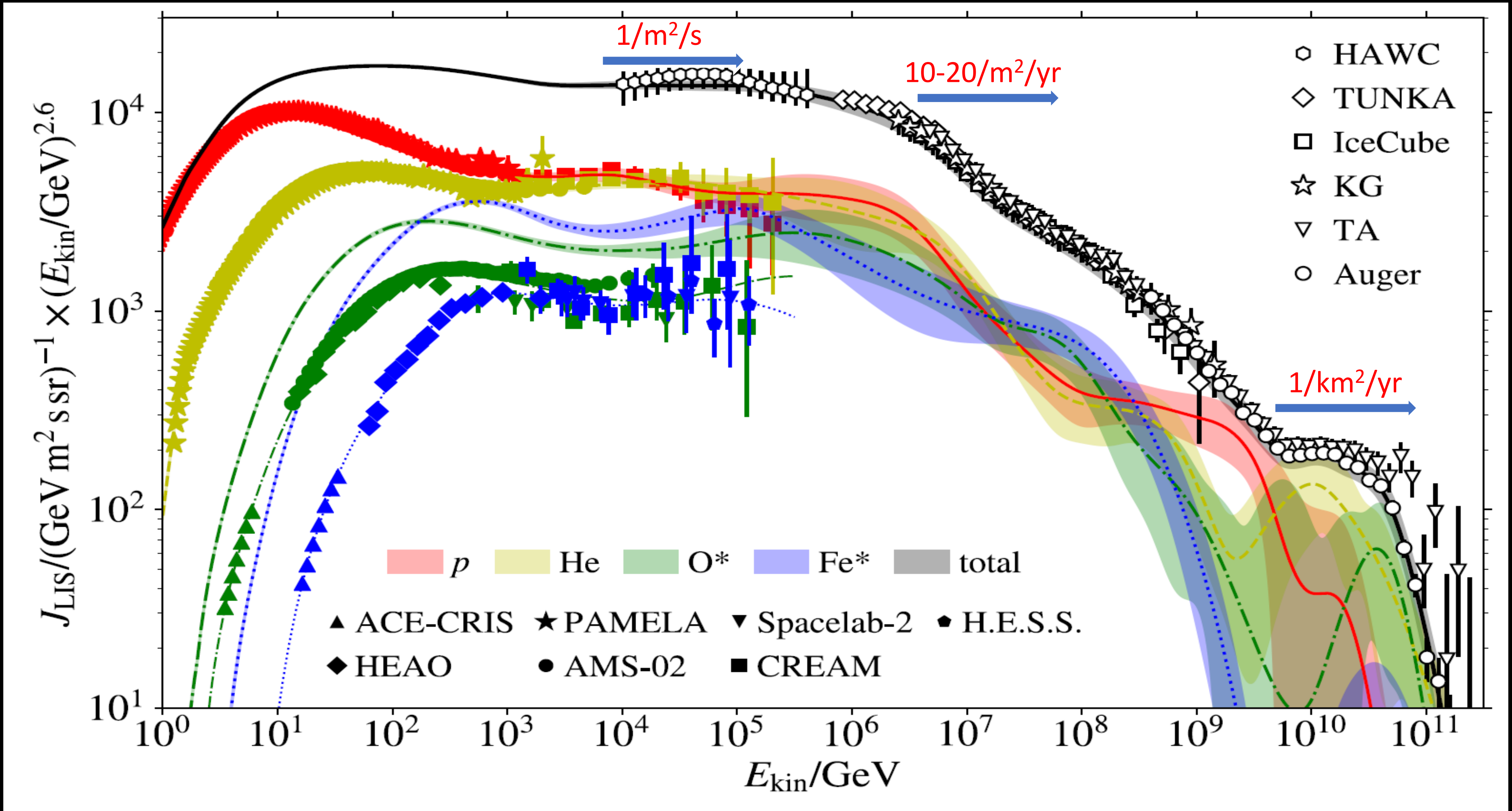
Cosmic rays

Dembinski, AF, Engel, Gaisser, Stanev
PoS(ICRC2017)533



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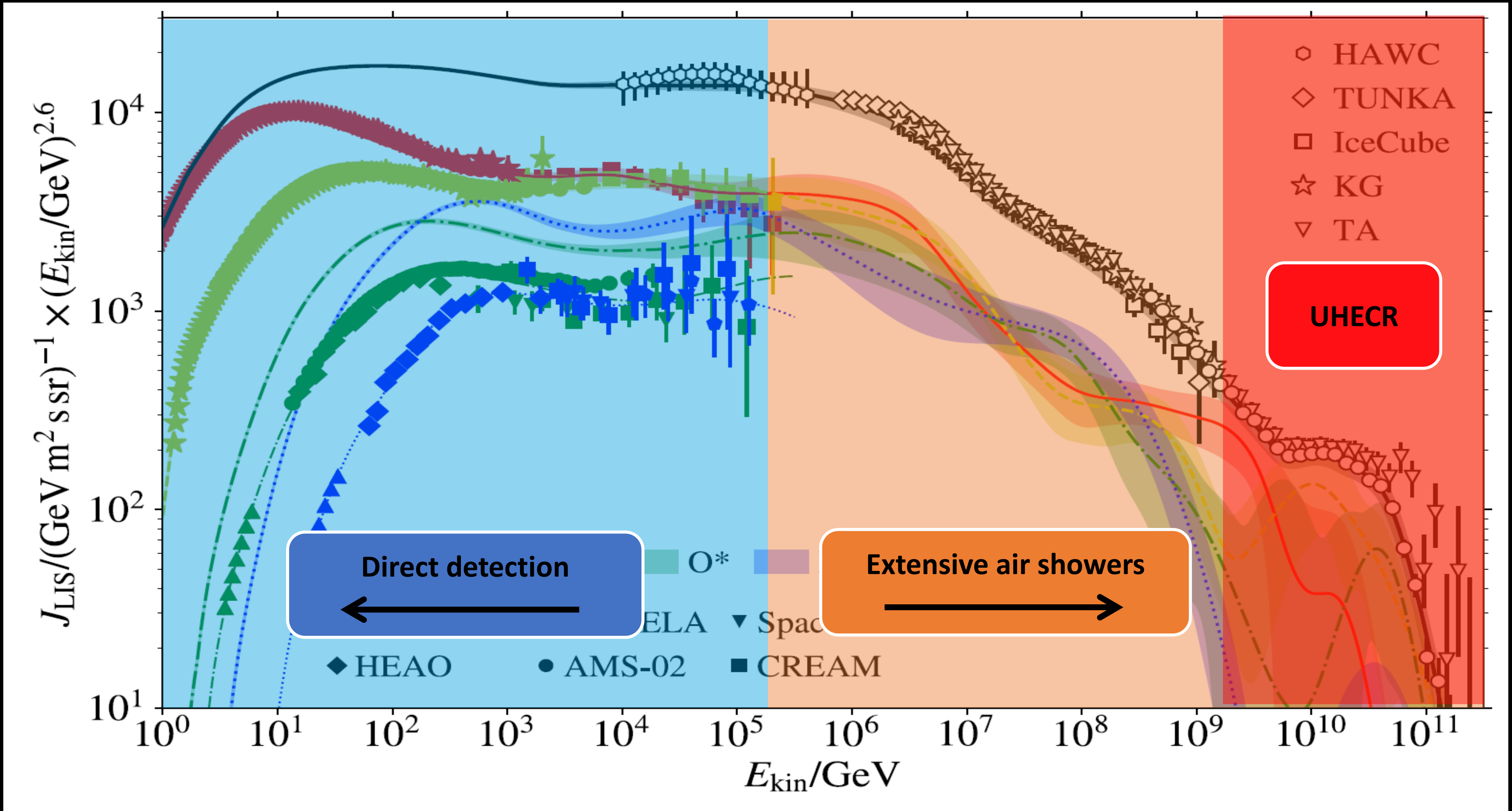
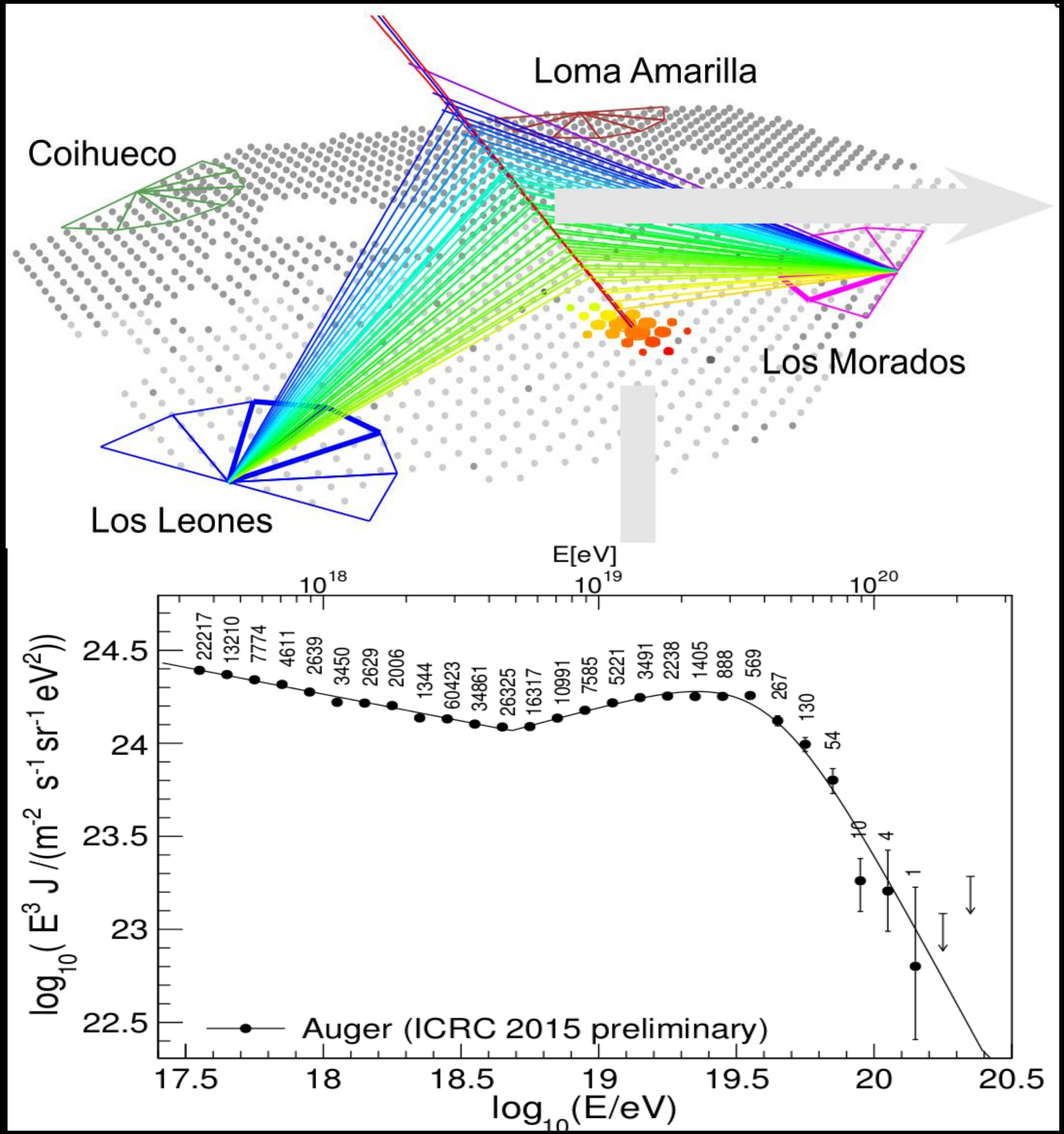
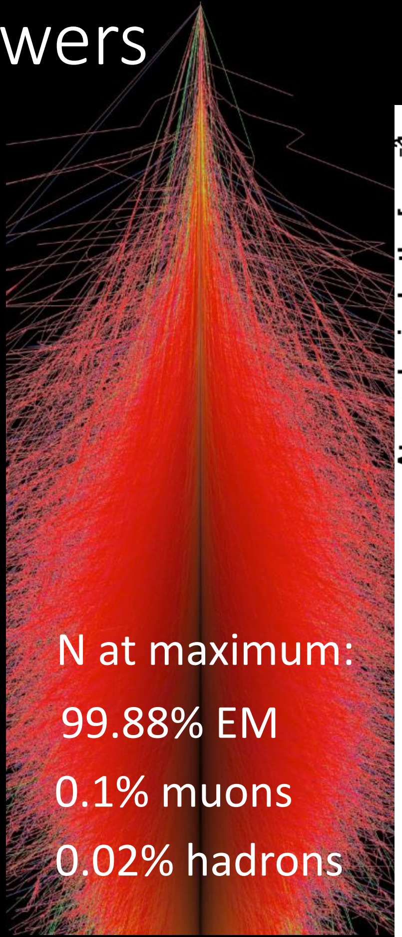
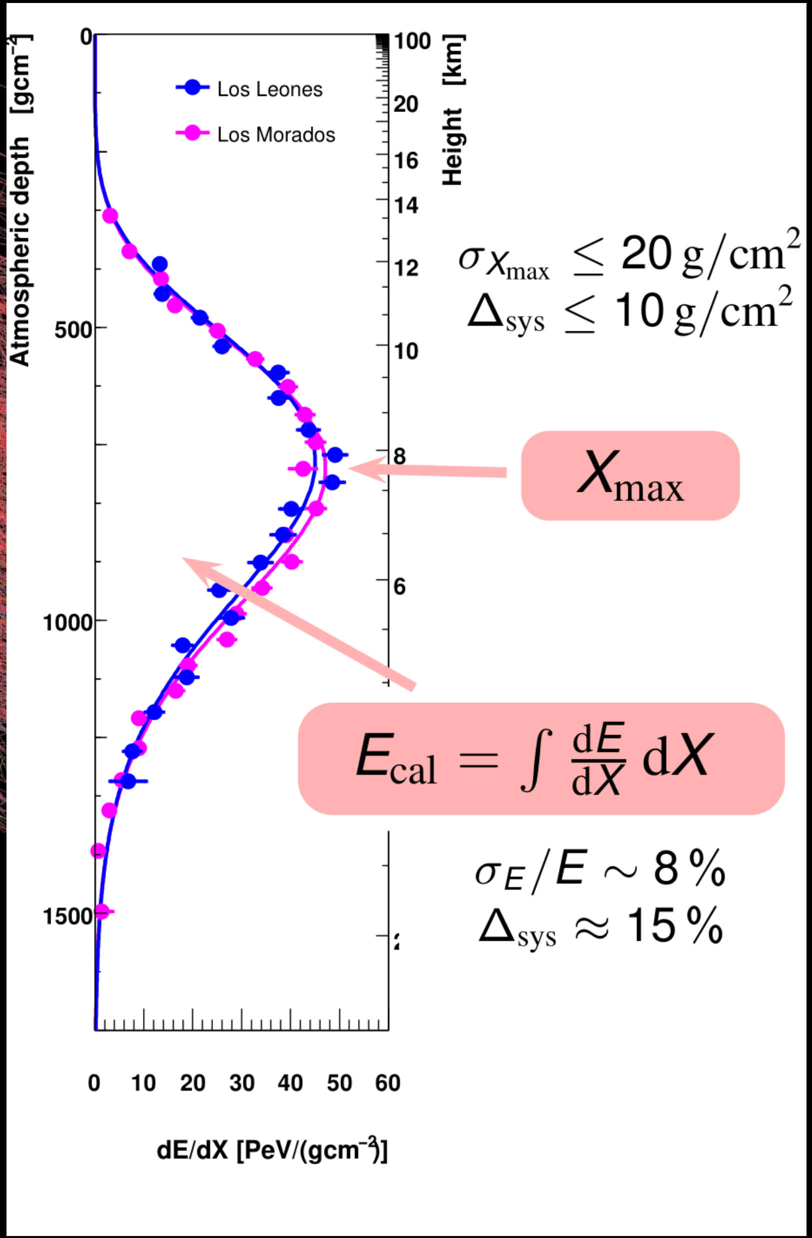


Indirect detection via extensive air showers

M. Unger, ICRC2017







$\sigma_{X_{max}} \leq 20\,\mathrm{g/cm^2}$

$\Delta_{sys} \leq 10\,\mathrm{g/cm^2}$

X_{max}

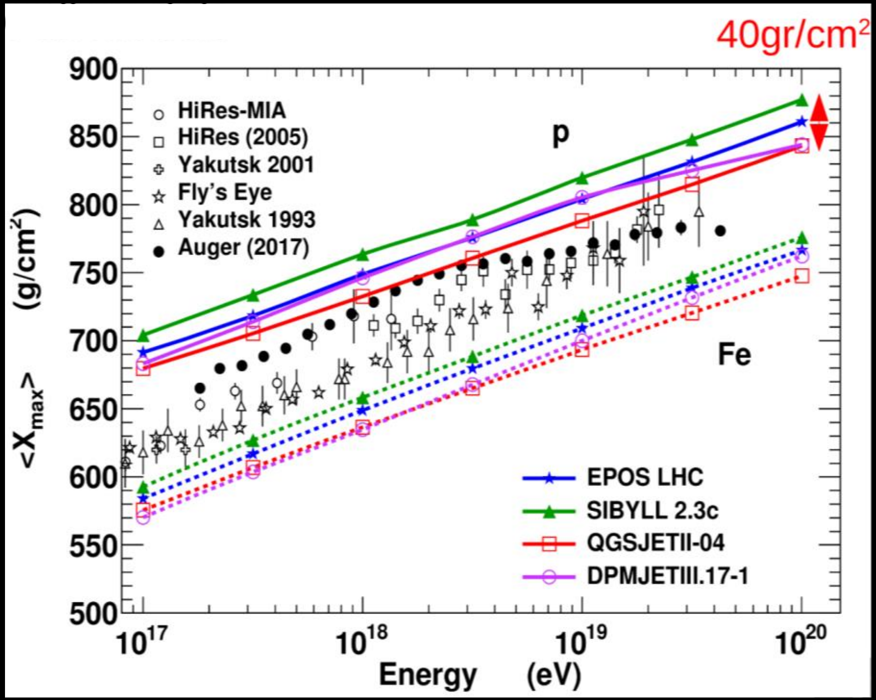
$E_{cal} = \int \frac{dE}{dX}\,dX$

$\sigma_E/E \sim 8\,\%$

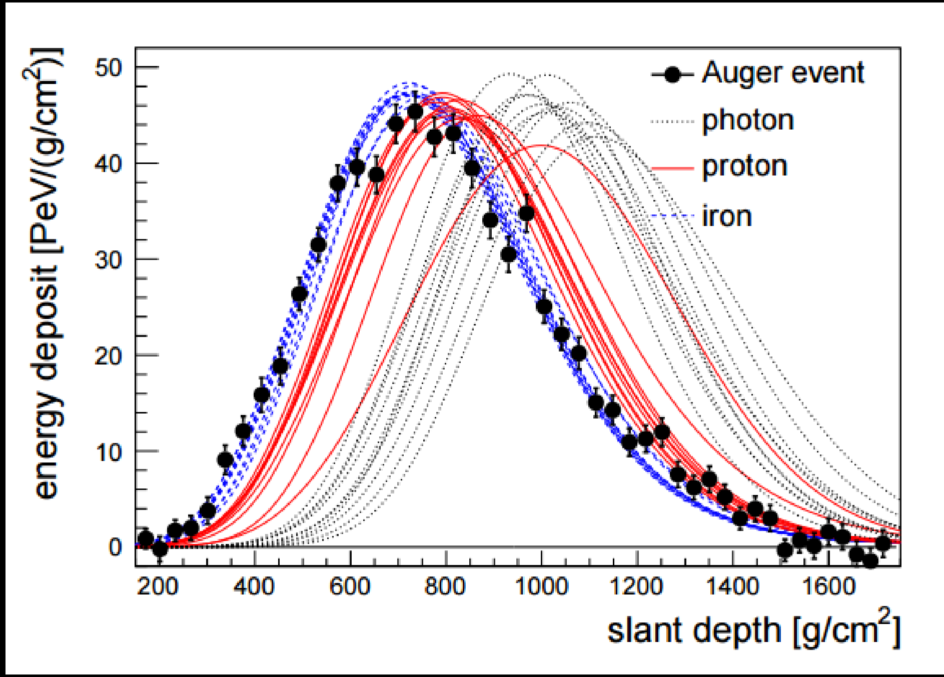
$\Delta_{sys} \approx 15\,\%$

Cosmic ray mass (element) determination is model dependent

T. Pierog 2018



Auger, ICRC 2015



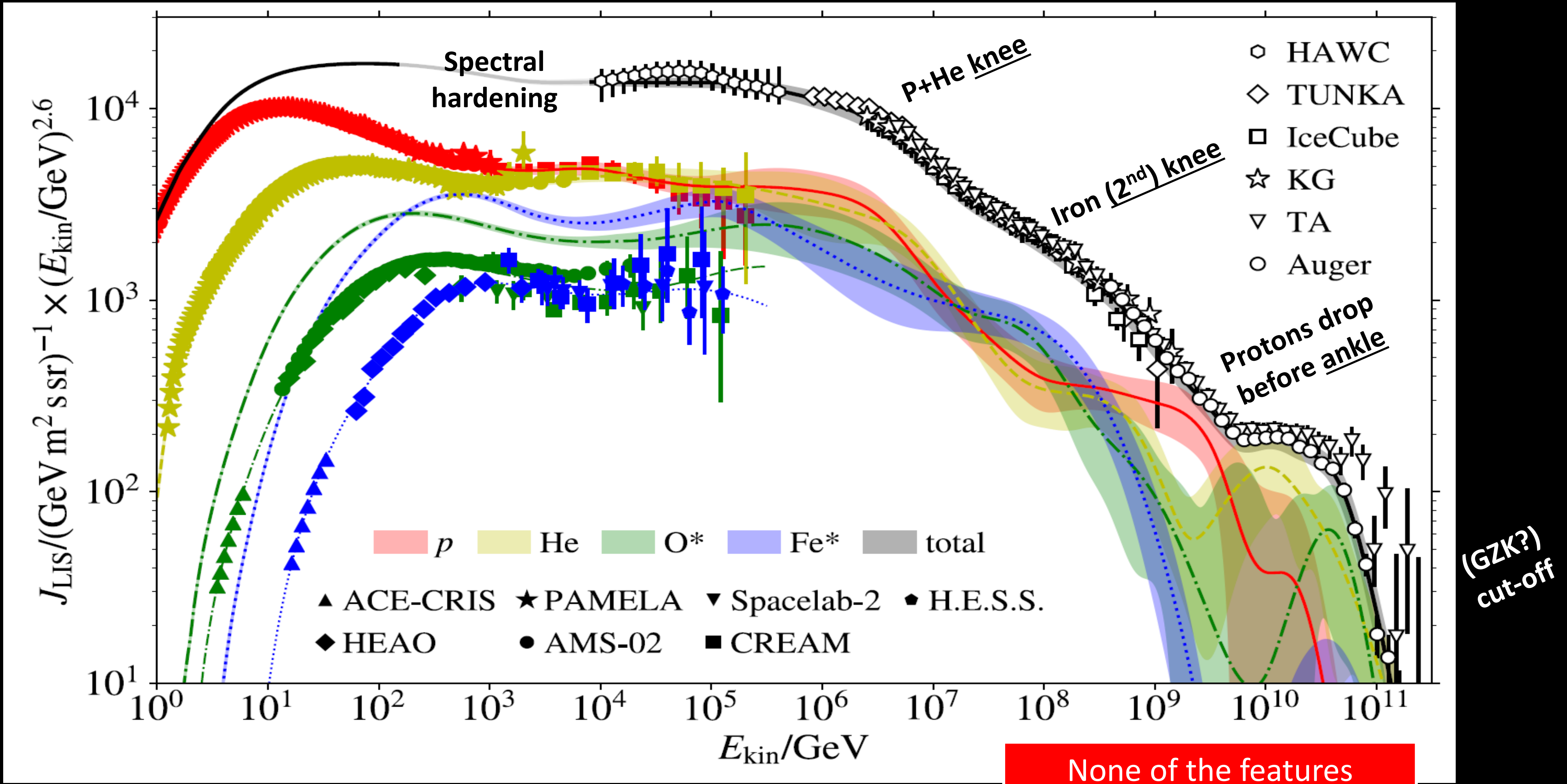
$$\langle X_{\max}^{p} \rangle \approx \lambda_p + X_0 \ln\left(\frac{\kappa_{\mathrm{ela}} E}{2N\varepsilon_c^{\mathrm{em}}}\right)$$

Parameters from simulation of particle interactions

Infer mass from fitting simulated templates. Different observables available for cross check, but not fully consistent.

So we know about cosmic rays?

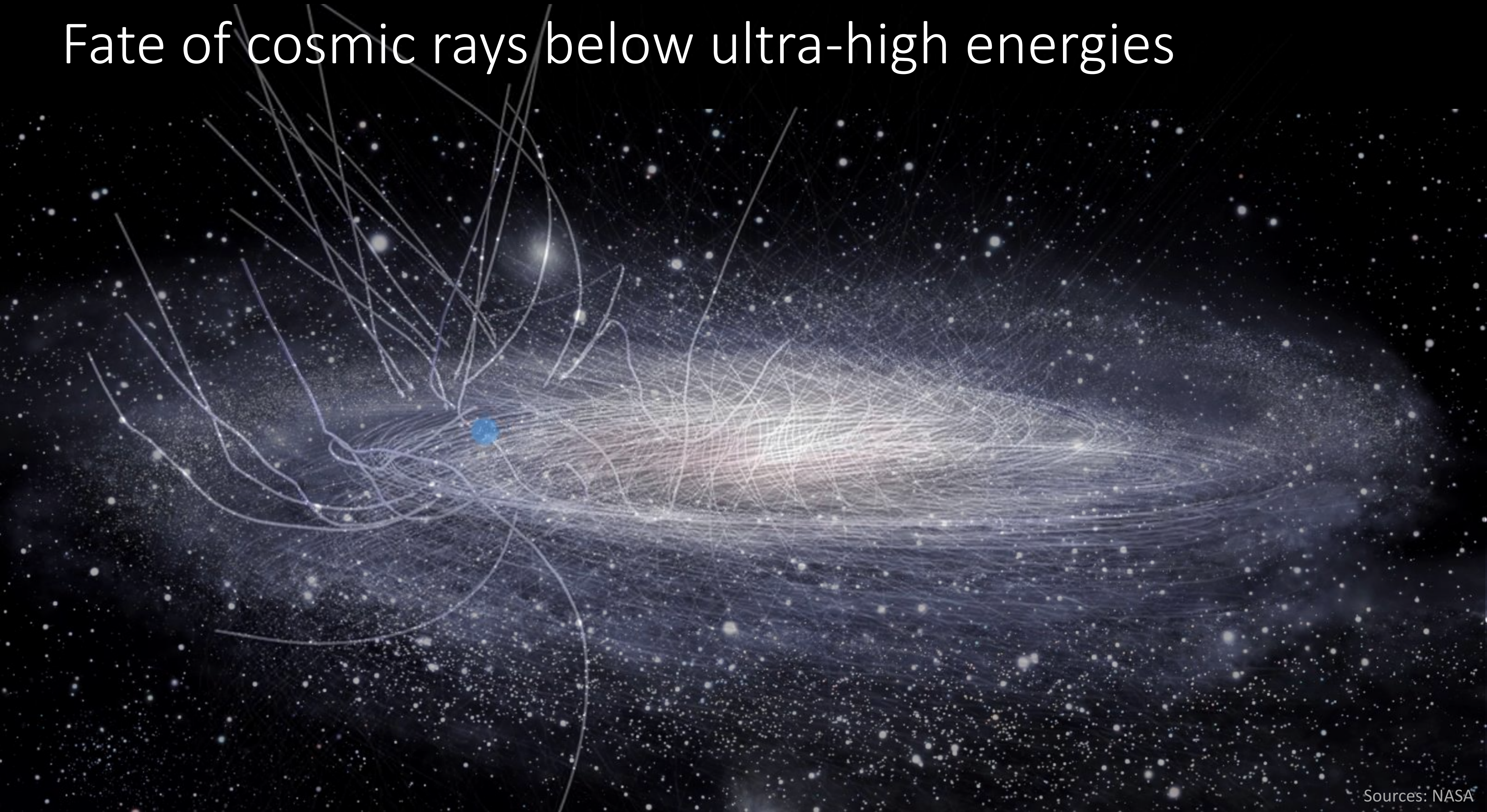
Dembinski, AF, Engel, Gaisser, Stanev
PoS(ICRC2017)533



None of the features unambiguously explained!

Fate of cosmic rays below ultra-high energies

Fate of cosmic rays below ultra-high energies

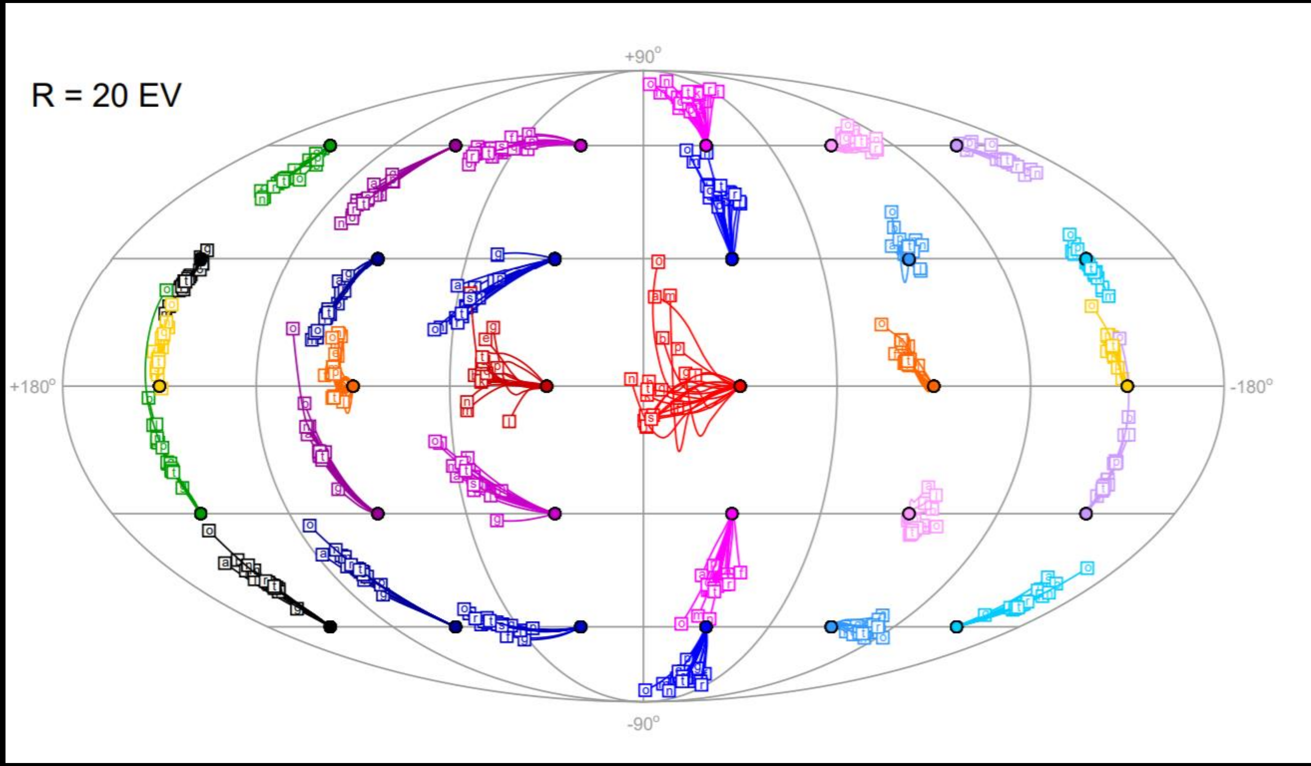


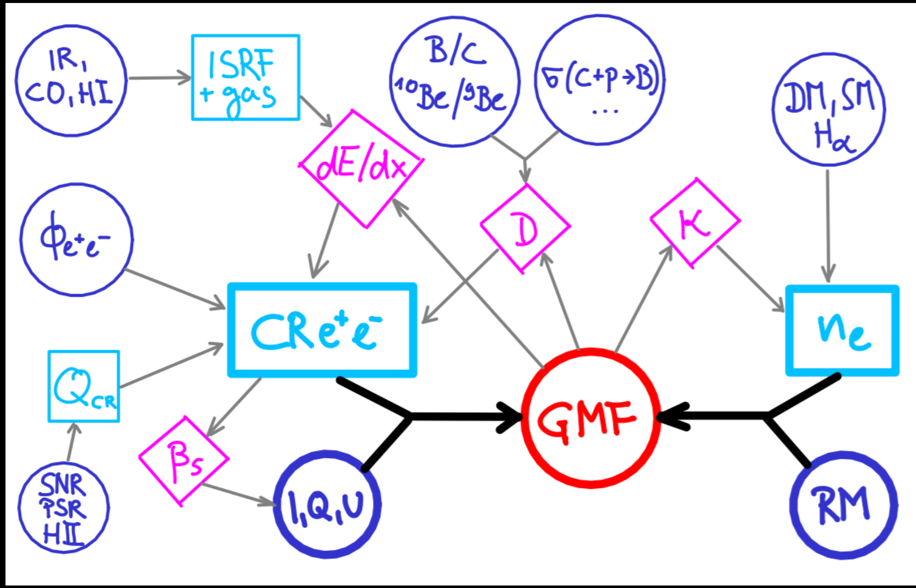
Sources: NASA

Effect of the galactic magnetic field on UHECR

- Letters = different models ~ uncertainties
- Image corresponds to 20 EeV protons
- Experiments measure energy (not rigidity) & UHECR are mixed nuclei
- Challenging, even at very high energies

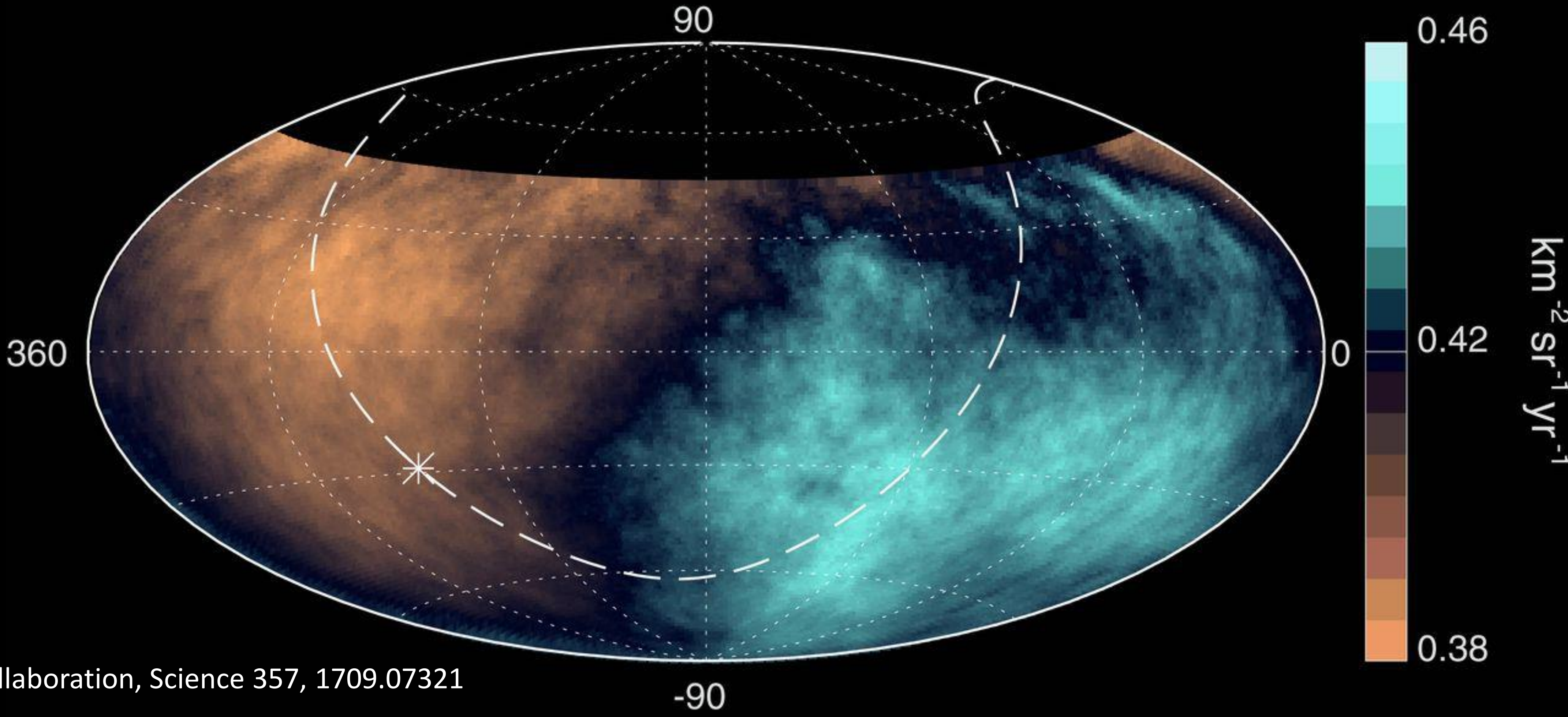
Unger, Farrar 2019, 1901.04720





Sources: NASA

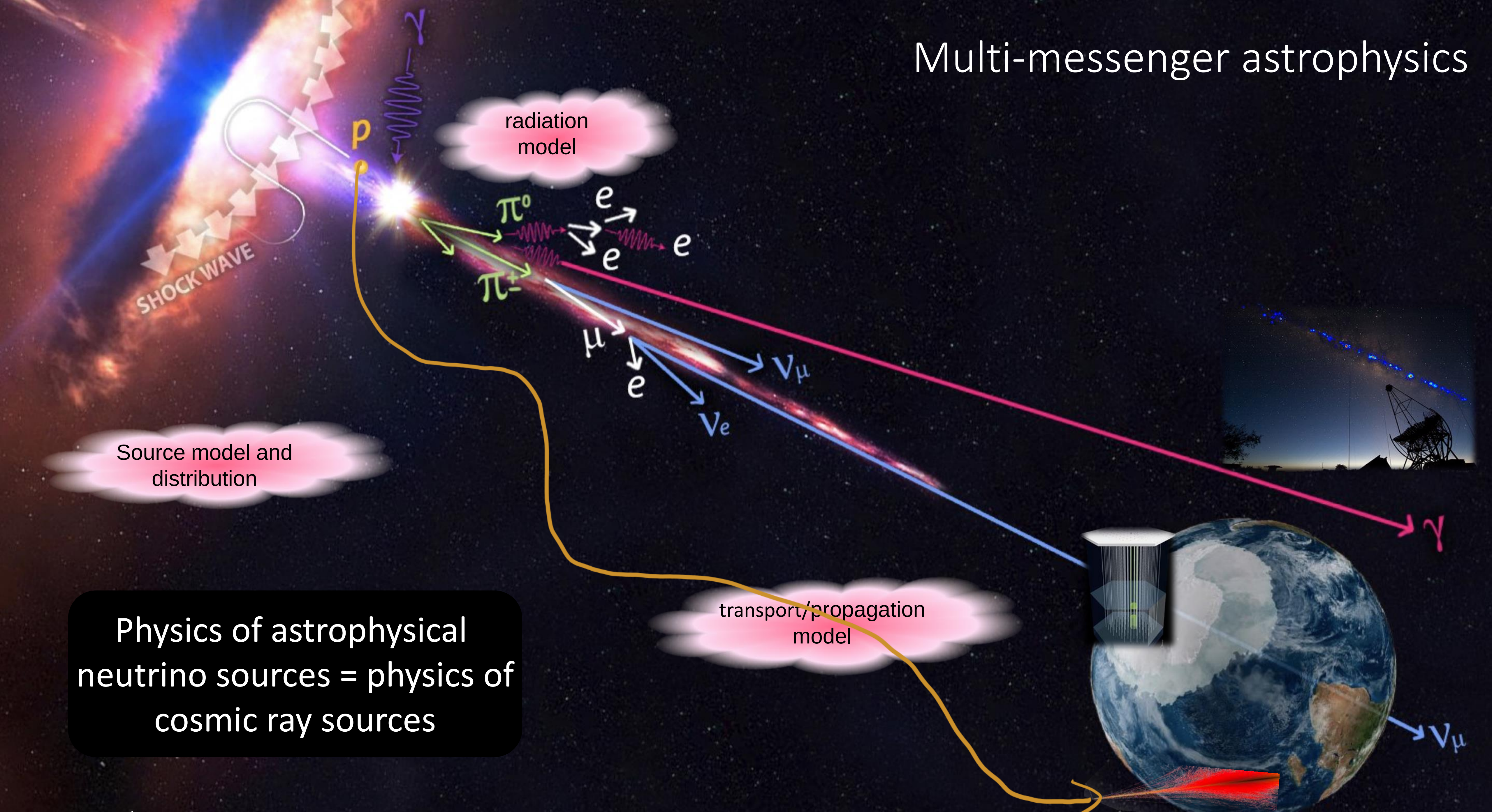
Strong anisotropy evident in UHECR arrival directions



Pierre Auger Collaboration, Science 357, 1709.07321

Strong amplitude (7%), but no substructures, spots, quadrupole, etc.
GMF effect must be large, this means the composition of UHECR in the CNO mass group

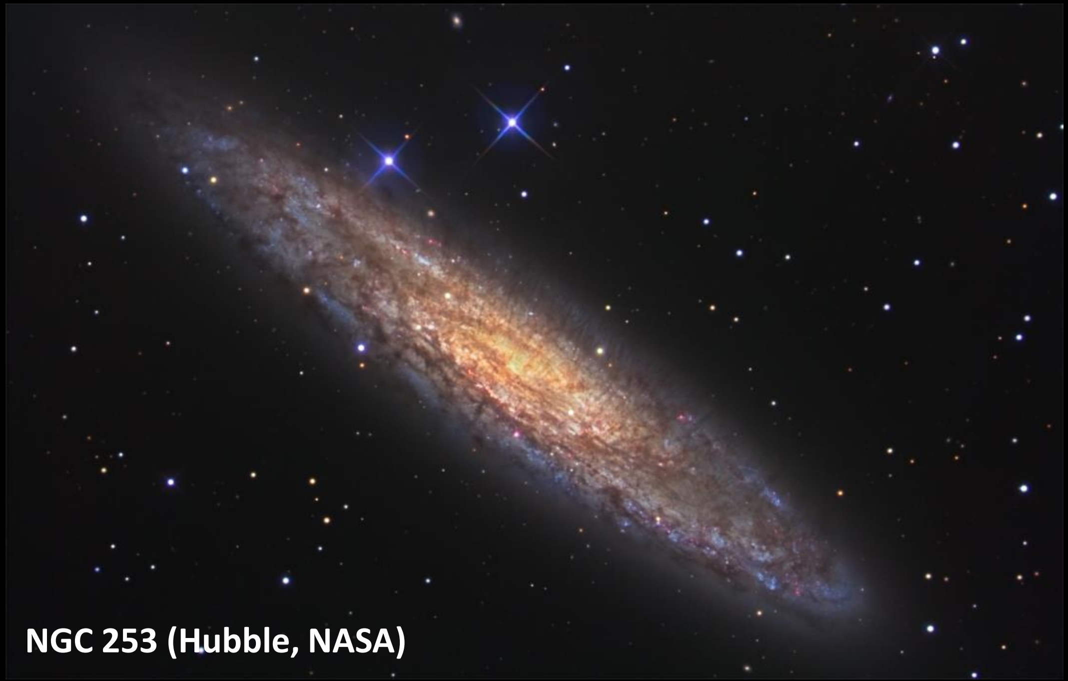
Multi-messenger astrophysics



Physics of astrophysical neutrino sources = physics of cosmic ray sources

Credit: NASA/IceCube 1903.04447

Extragalactic accelerators

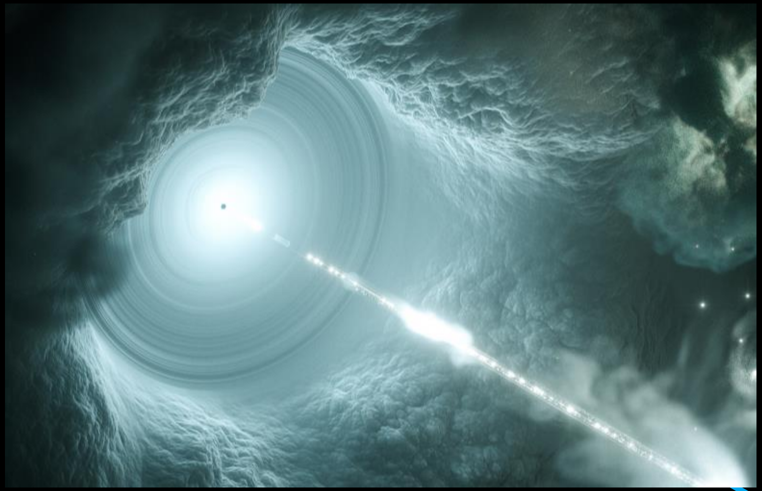


- **Radiation dominated** environments (e.g. Blazars)
- Usually **compact sources** (size vs. energy density)
- **Photo-hadronic**/-nuclear interactions
- Typical interaction **energies** $\sqrt{s} \sim 20 - 2000$ **MeV**
- Not evident that high-energy radiation is hadronic (π^0)

- **Matter dominated** environments (Starburst galaxies)
- **Extended sources** (not so high radiation density)
- **Likely hadronic** interactions, pp, GeV – PeV (lab)
- Maybe not the sources of UHECR but can be “hosts”
- Mixture of different accelerators (Supernovae, Pulsars, etc., jet lobes)

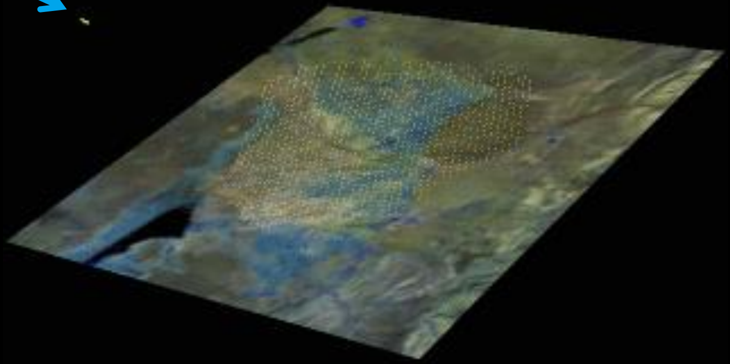
Origin of the features in UHECR spectrum and composition?

Generic accelerator



Simulate transport of cosmic rays through extragalactic medium

Interpret Pierre Auger data



Assume that there is **one dominant type** of UHECR accelerators

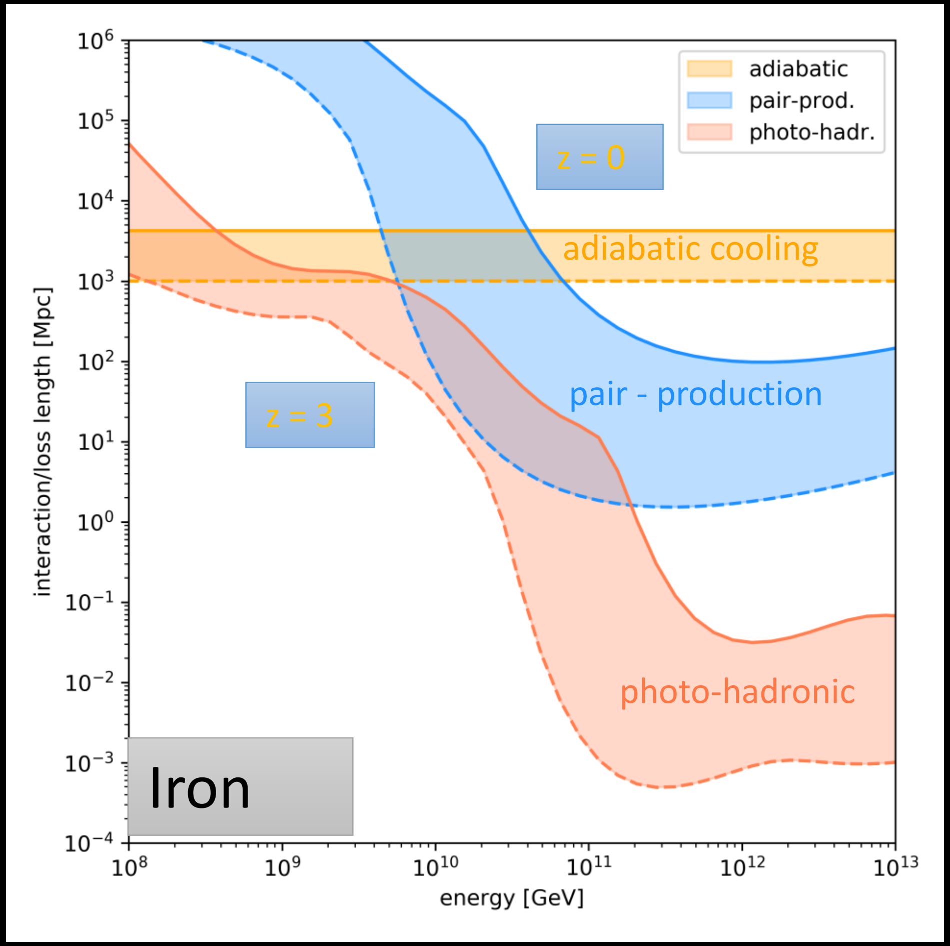
Extragalactic transport of UHECR

Heinze, AF, Boncioli, Winter, ApJ 873

$$\partial_t Y_i(E,z) = +\partial_E(HEY_i) - \partial_E\left(\frac{dE}{dt}Y_i\right) - \Gamma_i Y_i + \sum_j Q_{j\to i} + \mathcal{L}_i$$

comoving particle density | adiabatic cooling | pair - production | photo-nuclear | Injection

- Initial injection of **nuclei up to iron**
- Disintegration (Giant Dipole Resonance + photo-meson production)
- About 50 species × size of E-grid (~150) coupled partial differential equations (~8000)
- All coefficients **time and energy dependent**



New code *(with Jonas Heinze) with the aim to be fast, generic, open source radiation code*

PriNCe = Propagation including Nuclear Cascade equations

Propagation Code - PriNCe

- Pure **Python** + **Numpy, Scipy, Intel MKL**
- Computational acceleration through **vectorization**/parallelization & **sparse matrix** formats
- **20s – 40s** for one complete calculation (depending on number of nuclear species few tens ms for protons)
- **More efficient** for studies of model uncertainties **than Monte Carlo** (cross-section, photon fields etc.)

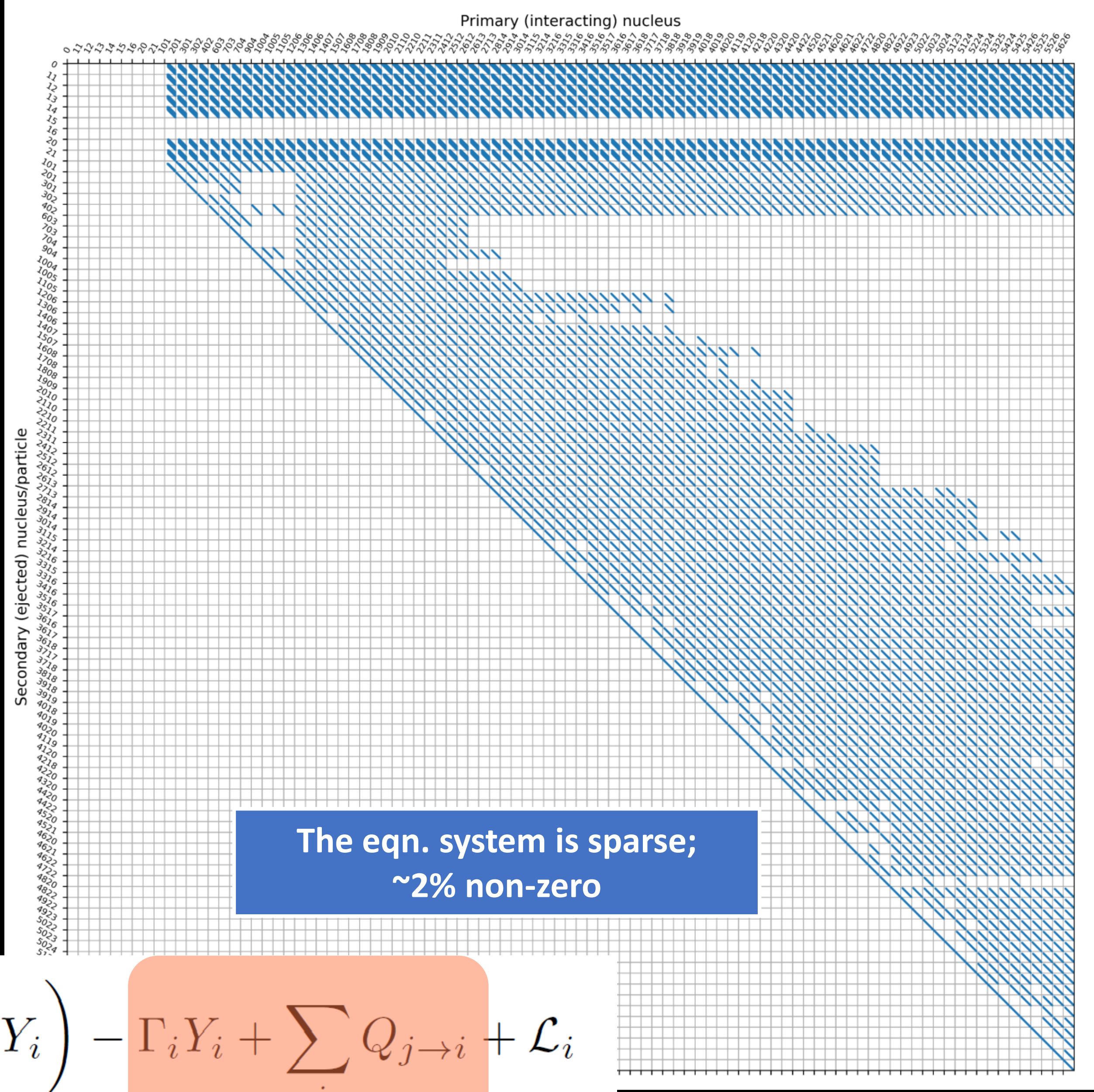


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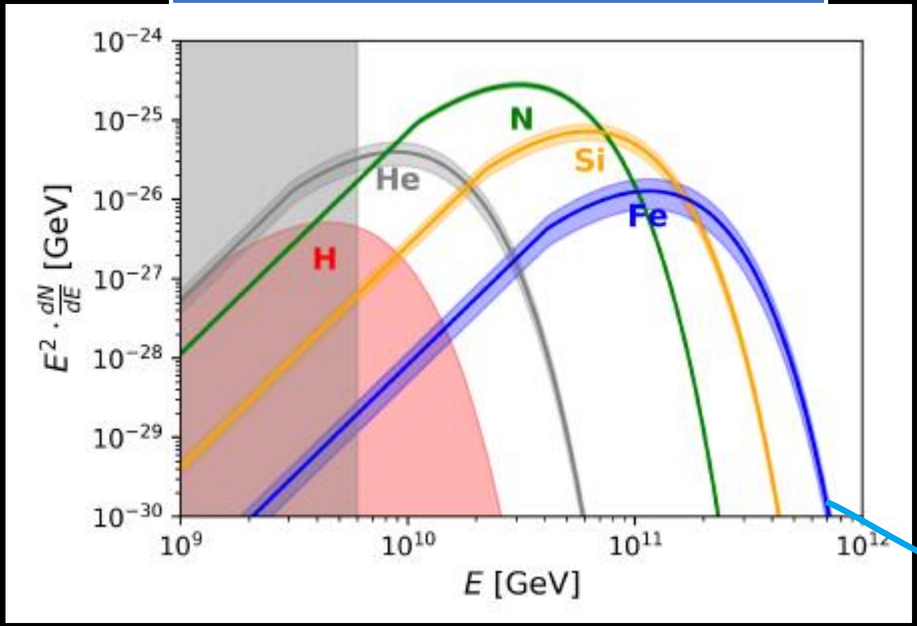
photo-nuclear

Origin of the features in UHECR spectrum and composition?

Heinze, AF, Boncioli, Winter, ApJ 873

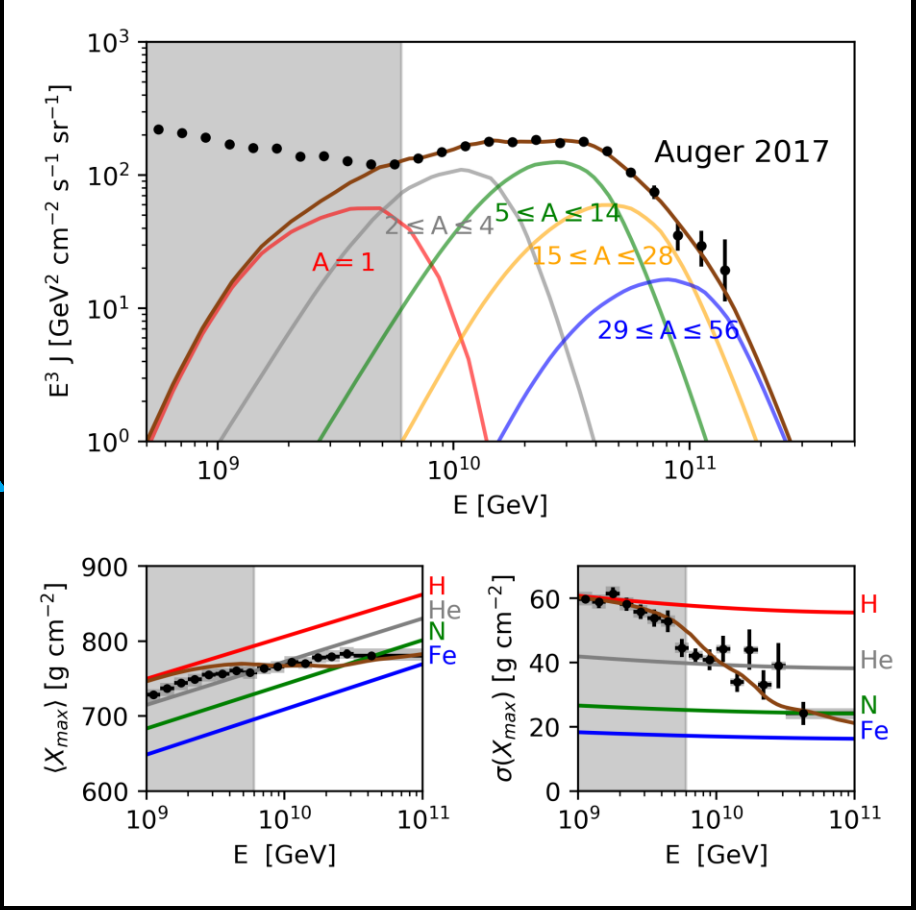
Rigidity dependent accelerator



Assumption: there is one dominant source type, accelerating nuclei according to their rigidity (~Z)

Simulate transport of cosmic rays through extragalactic medium

Fit: free parameters of the accelerator and the evolution m



Rigidity dependent spectrum:

$$J_A(E) = \mathcal{J}_A \left(\frac{E}{10^9 \text{ GeV}} \right)^{-\gamma} \times f_{\text{cut}}(E, Z_A, R_{\text{max}}) \times n_{\text{evol}}(z)$$

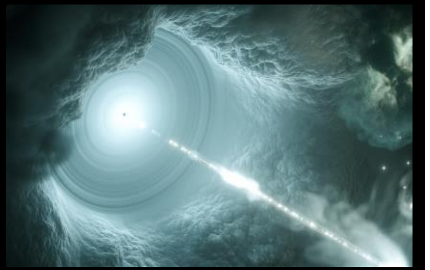
Cosmological density evolution:

$$n_{\text{evol}}(z) = (1 + z)^m$$

Model dependence of the interpretation

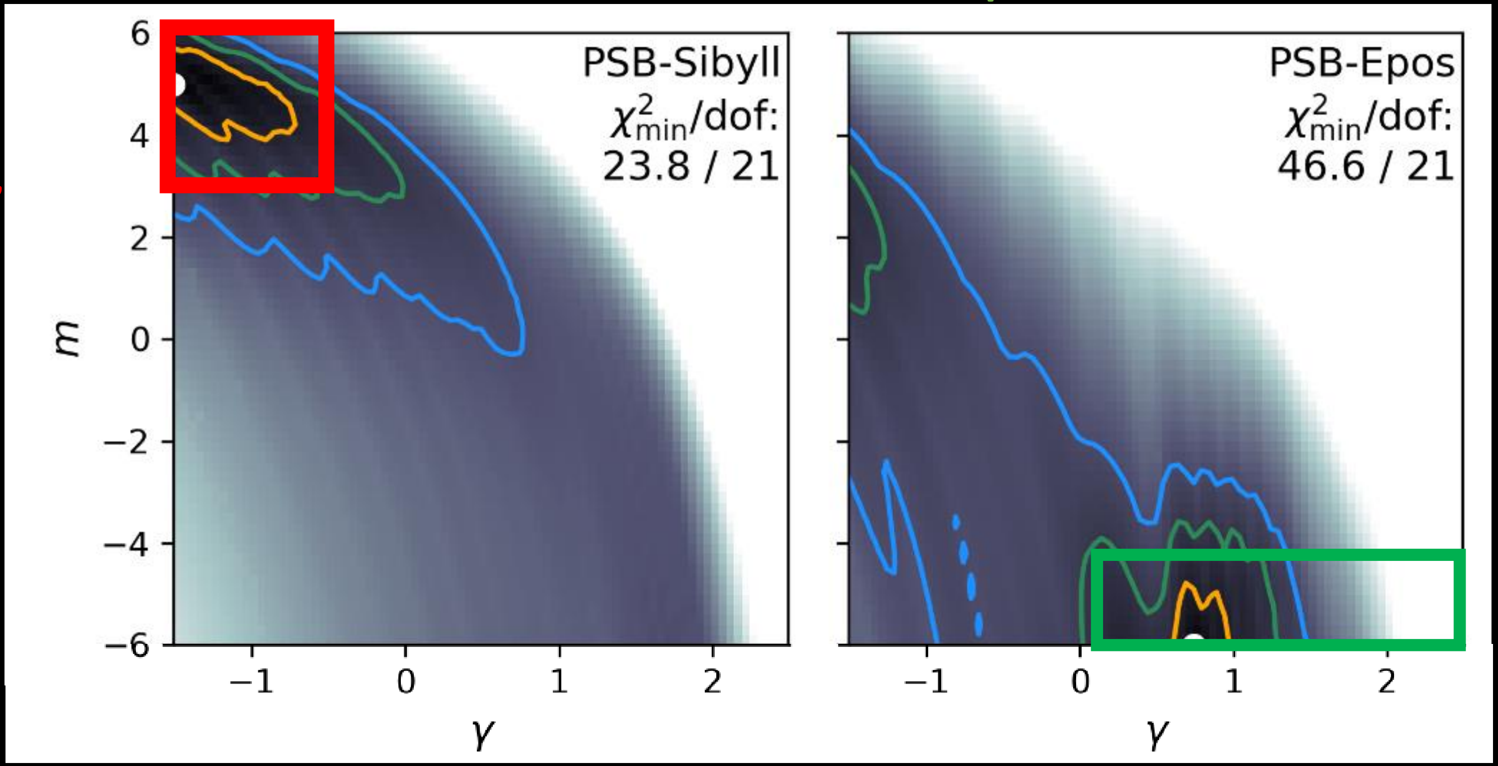
Compared in $\gamma - m$ space

Density evolves like:
Stars,
Galaxies, Supernovae,
AGN



Sibyll 2.3

Epos-LHC



Few strong local sources, or intermediate mass black holes

See also: Auger Collaboration JCAP02(2013)026
Auger Collaboration JCAP04(2017)038

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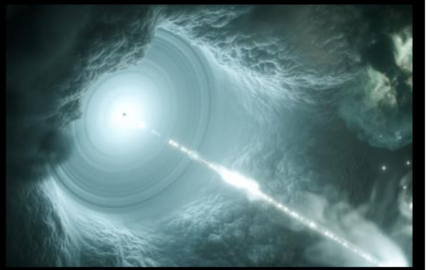
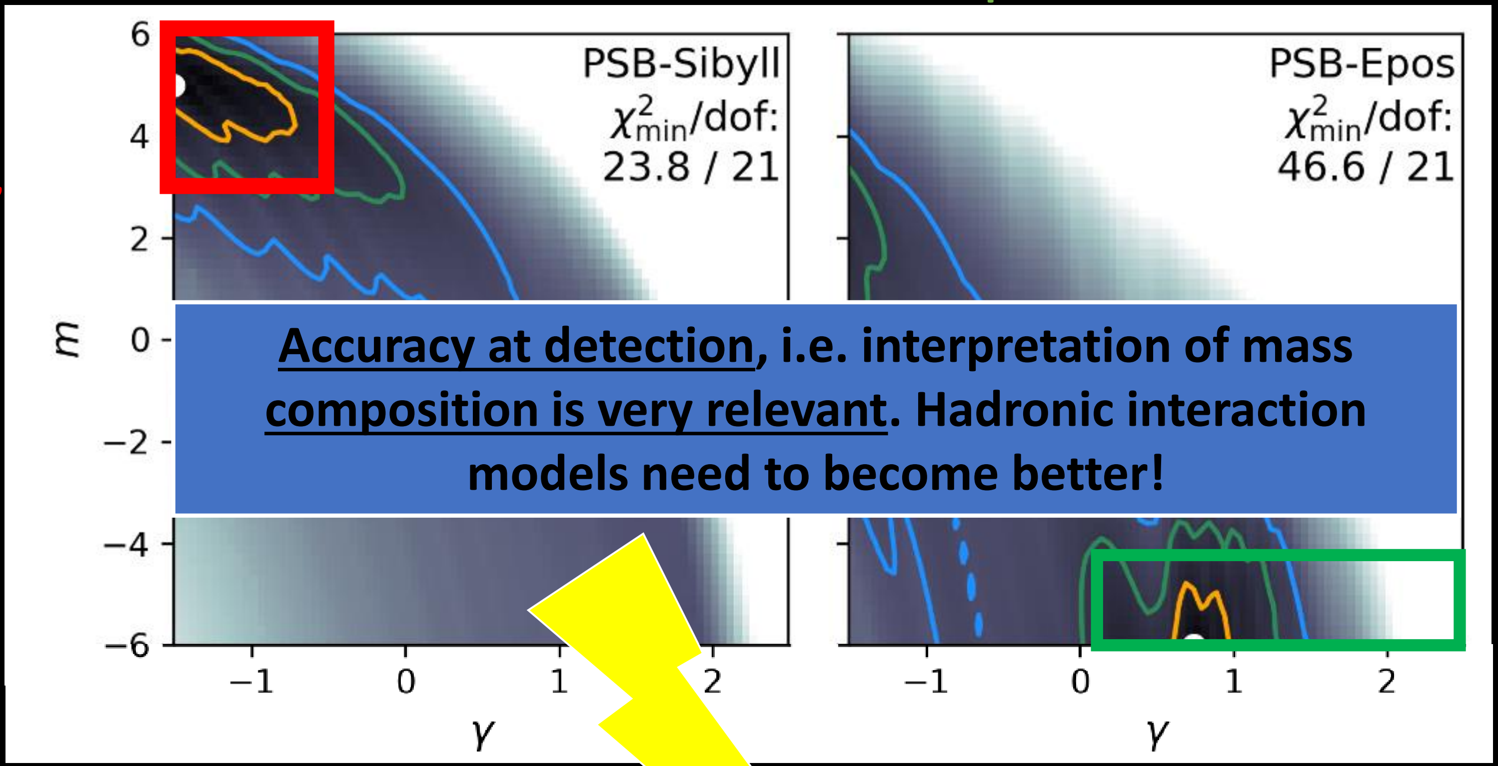



NASA



Accuracy at detection, i.e. interpretation of mass composition is very relevant. Hadronic interaction models need to become better!

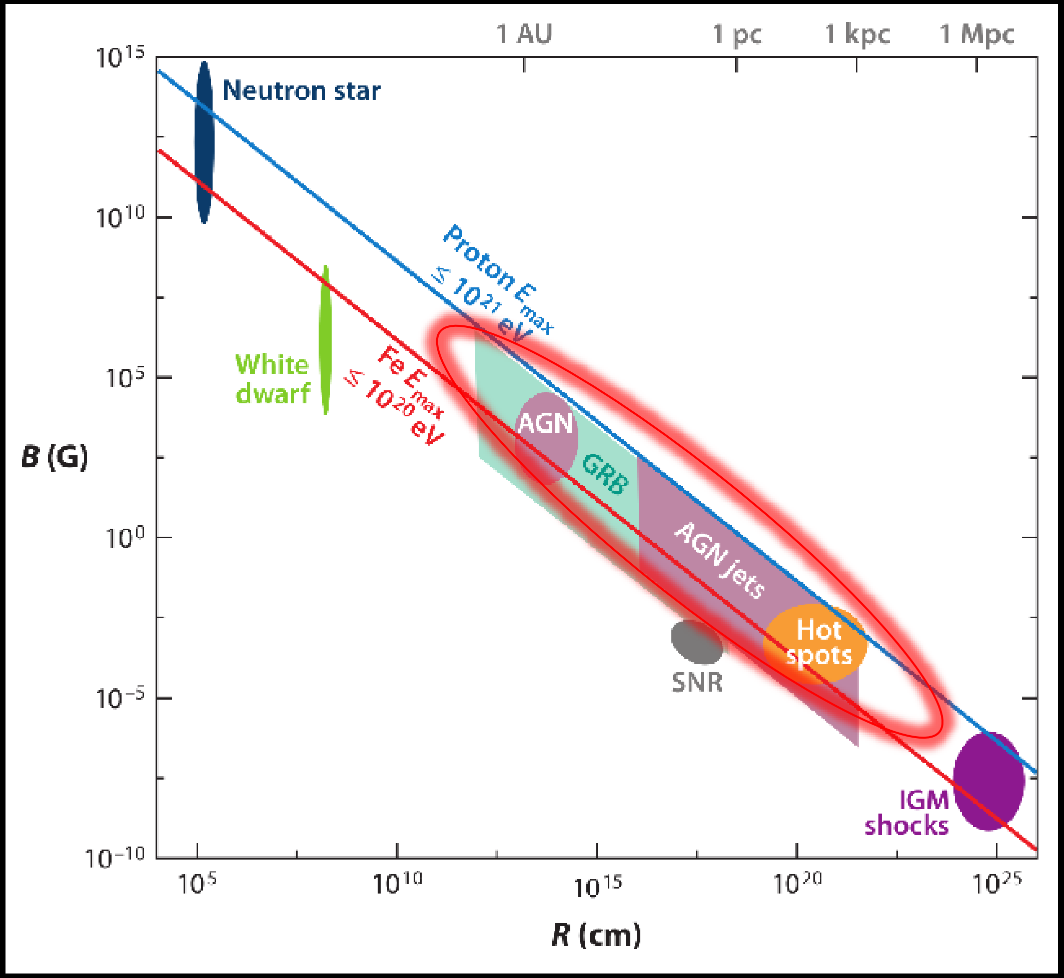

NASA, ESA,…


CXC/M. Weiss

Few strong local sources, or intermediate mass black holes

See also: Auger Collaboration JCAP02(2013)026
Auger Collaboration JCAP04(2017)038

UHECR source candidates?



First constraint: Non-exotic acceleration mechanisms constrain **size** and **magnetic field** of the source

Second constraint, power budget: power in CR measured → number and output of sources must be able to sustain it

- **Most promising candidates**:
  - Active Galactic Nuclei (Supermassive Black Holes)
  - Gamma-Ray Bursts
  - Tidal disruption events
  - Star-burst galaxies

Multi-messenger connection (0^{th} order)

Photo-hadronic interactions of CR

$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{cases} n + \pi^+ & 1/3 \text{ of all cases} \\ p + \pi^0 & 2/3 \text{ of all cases} \end{cases}$$

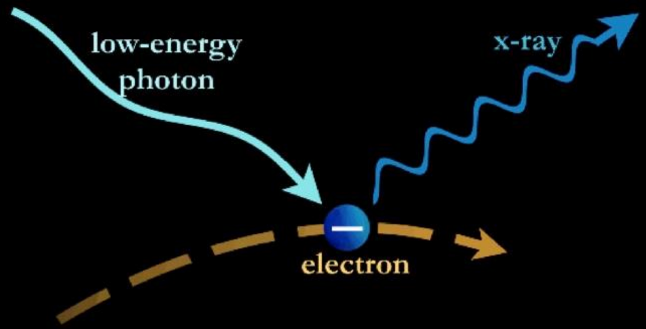
Neutrino emission

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \,,$$

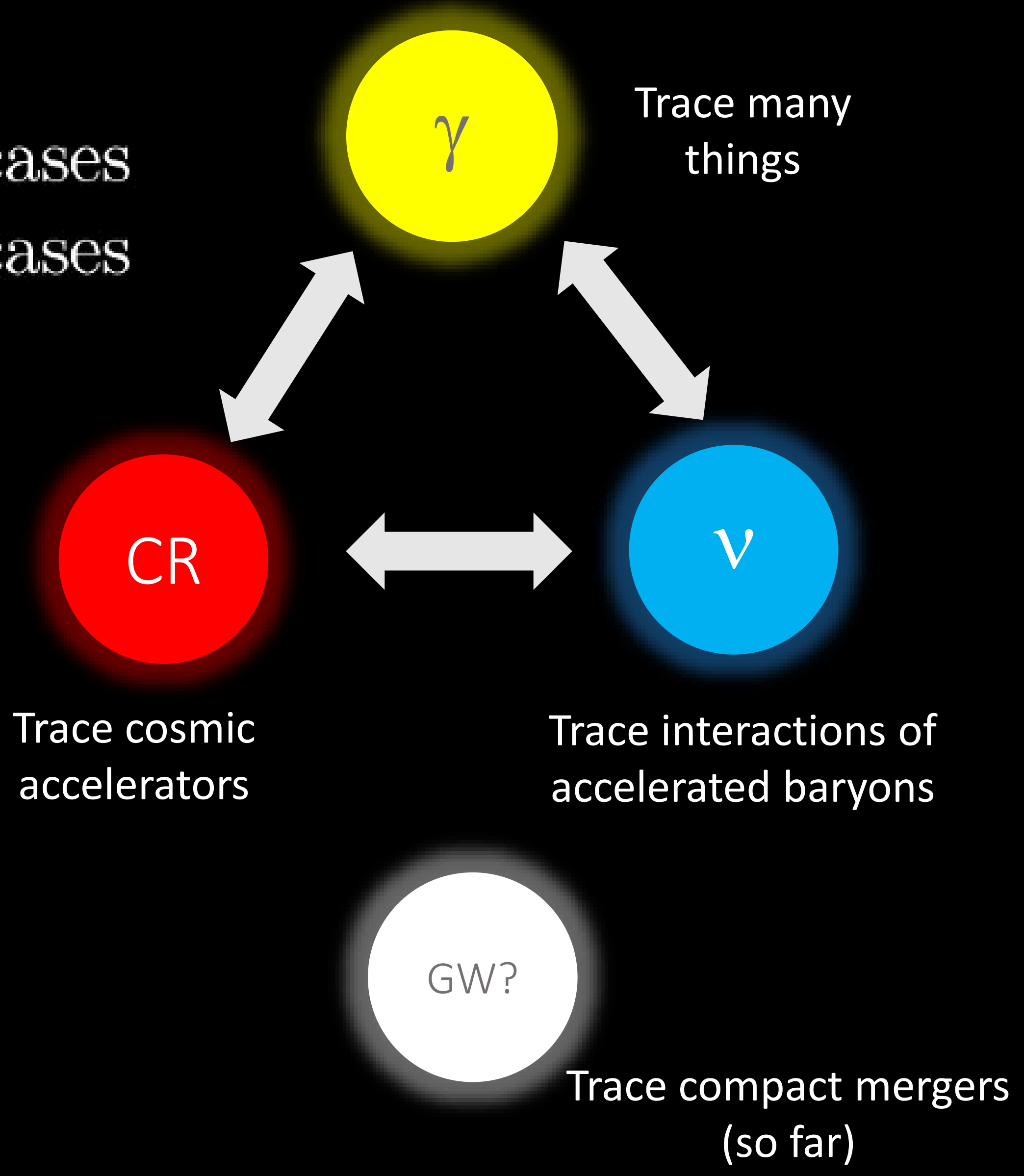
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Photon emission

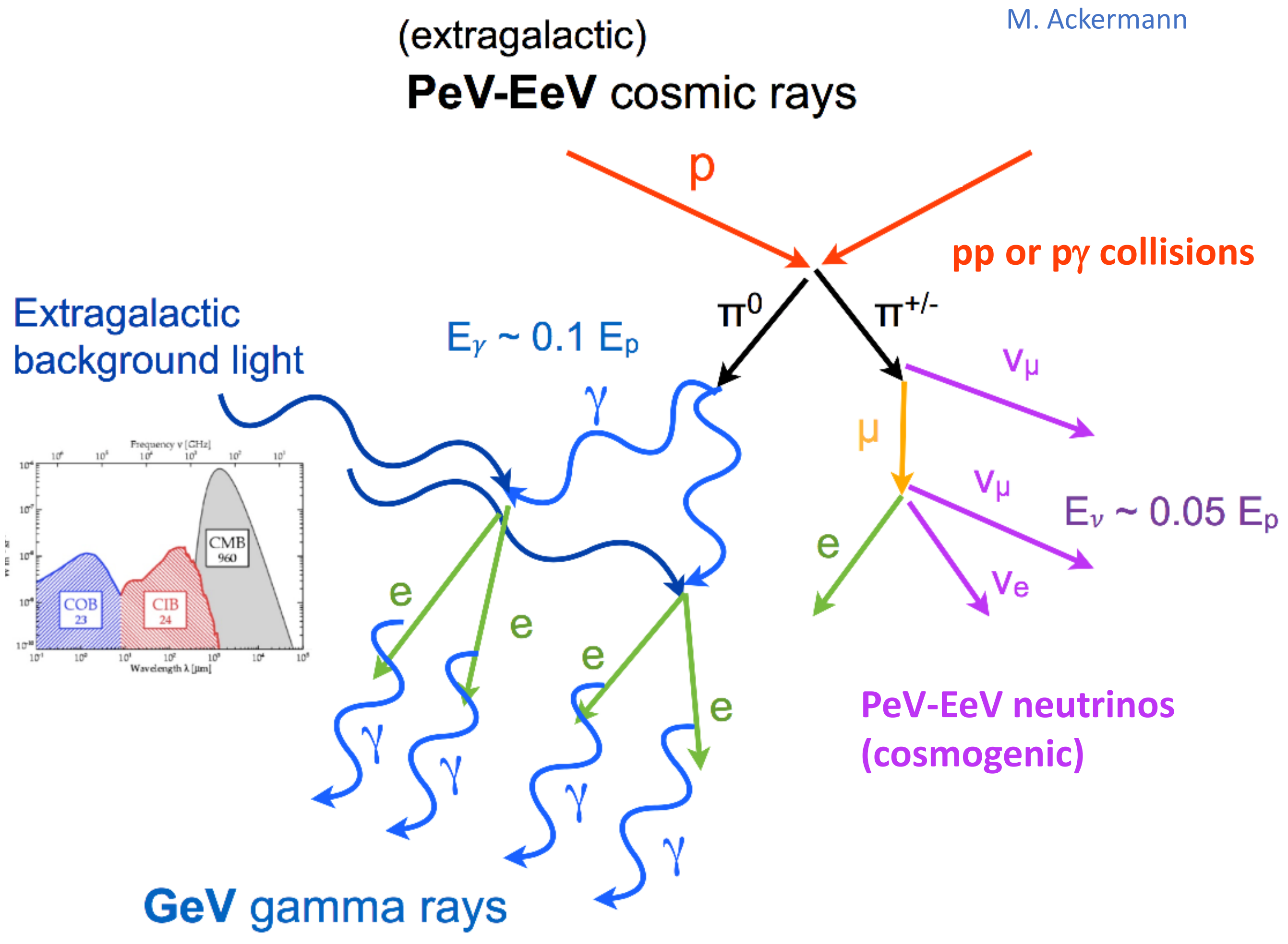
$$\pi^0 \rightarrow \gamma + \gamma$$

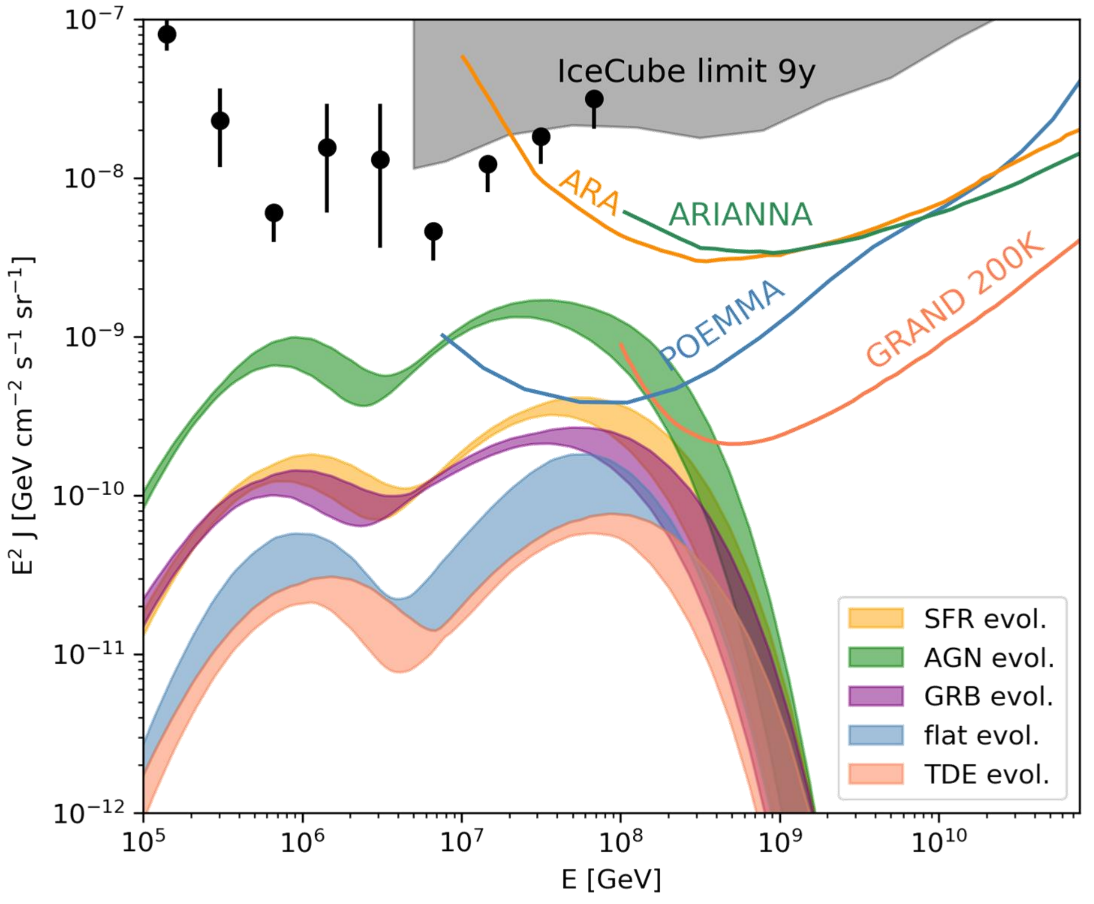


Most of the observed radiation is EM ☹



Additional multi-messenger constraints on UHECR sources?

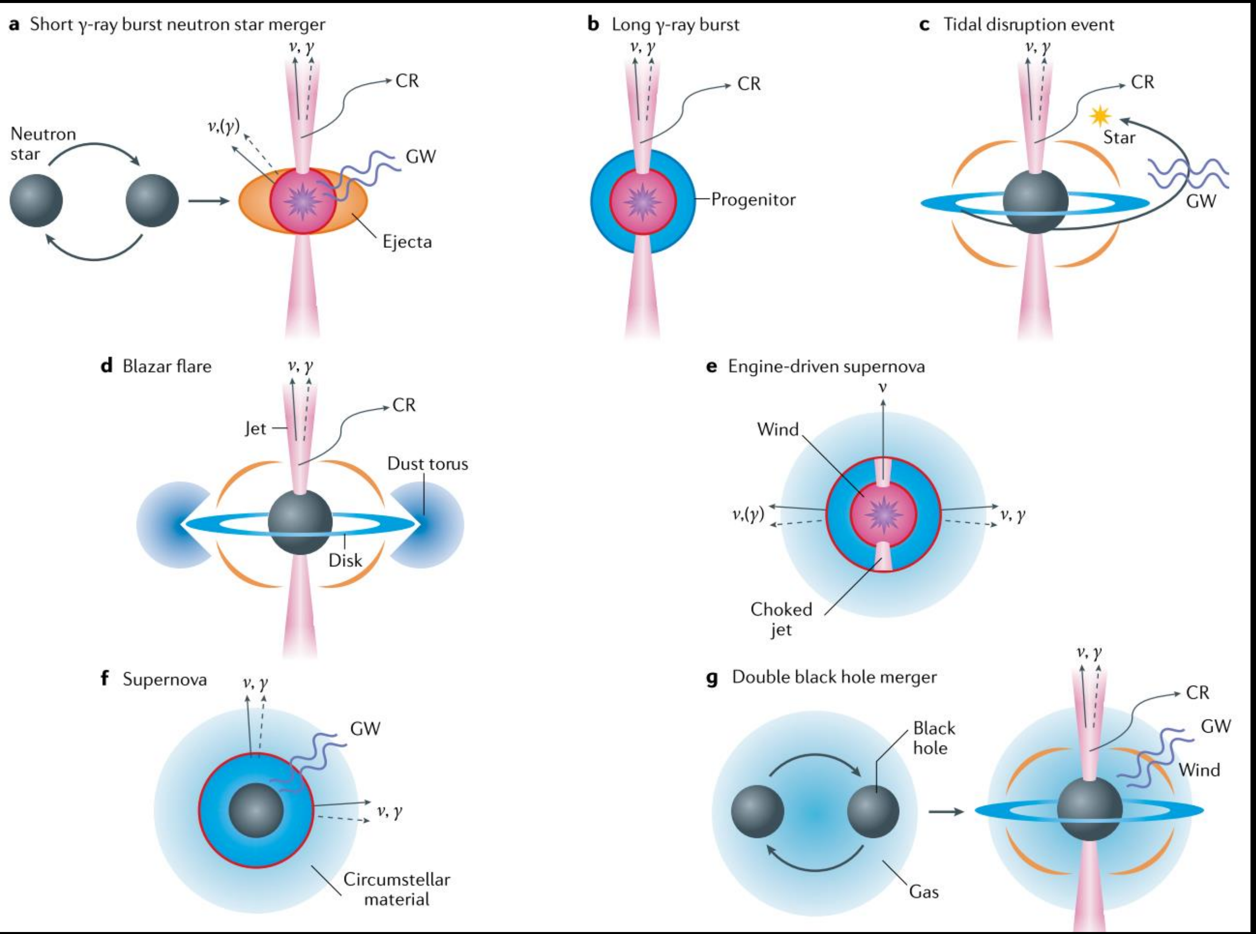




Transient source candidates

Péter Mészáros+, Nat. Phys. Rev. 2019

- Mostly jetted
- Sources not necessarily produce all messenger simultaneously



Source	Rate density [$\mathrm{Gpc^{-3}\,yr^{-1}}$]	EM Luminosity [$\mathrm{erg\,s^{-1}}$]	Duration [s]	Typical Counterpart
Blazar flare[a]	$10-100$	$10^{46}-10^{48}$	$10^{6}-10^{7}$	broadband
Tidal disruption event	$0.01-0.1$	$10^{47}-10^{48}$	$10^{6}-10^{7}$	jetted (X)
	$100-1000$	$10^{43.5}-10^{44.5}$	$>10^{6}-10^{7}$	tidal disruption event (optical,UV)
Long GRB	$0.1-1$	$10^{51}-10^{52}$	$10-100$	prompt (X, gamma)
Short GRB	$10-100$	$10^{51}-10^{52}$	$0.1-1$	prompt (X, gamma)
Low-luminosity GRB	$100-1000$	$10^{46}-10^{47}$	$1000-10000$	prompt (X, gamma)
GRB afterglow		$<10^{46}-10^{51}$,	$>1-10000$	afterglow (broadband)
Supernova (II)	10^{5}	$10^{41}-10^{42}$	$>10^{5}$	supernova (optical)
Supernova (Ibc)	3×10^{4}	$10^{41}-10^{42}$	$>10^{5}$	supernova (optical)
Hypernova	3000	$10^{42}-10^{43}$	$>10^{6}$	supernova (optical)
NS merger	$300-3000$	$10^{41}-10^{42}$	$>10^{5}$	kilonova (optical/IR)
		10^{43}	$>10^{7}-10^{8}$	radio flare (broadband)
BH merger	$10-100$	?	?	?
WD merger	$10^{4}-10^{5}$	$10^{41}-10^{42}$	$>10^{5}$	merger nova (optical)

Bartos and Murase, Ann. Rev. Phys. 2019

Last summer…

Discovery of a Cosmic-Ray Source Is a Triumph of 'Multimesssenger Astronomy'

By Harrison Tasoff, Space.com Contributor | July 12, 2018 06:29pm ET

The New York Times

It Came From a Black Hole, and Landed in Antarctica

For the first time, astronomers followed cosmic neutrinos into the fire-spitting heart of a supermassive blazar.

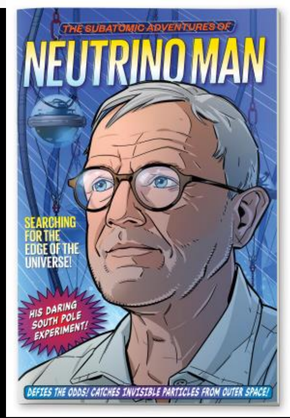
Origin of Mystery Space Radiation Finally Found

Blazing a trail: UW professor's dream leads to breakthrough in identifying origin of cosmic rays

BUSINESS INSIDER
INDIA

A ghostly particle detected in Antarctica has led astronomers to a super-massive spinning black hole called a 'blazar'

Neutrino observation points to one source of high-energy cosmic rays

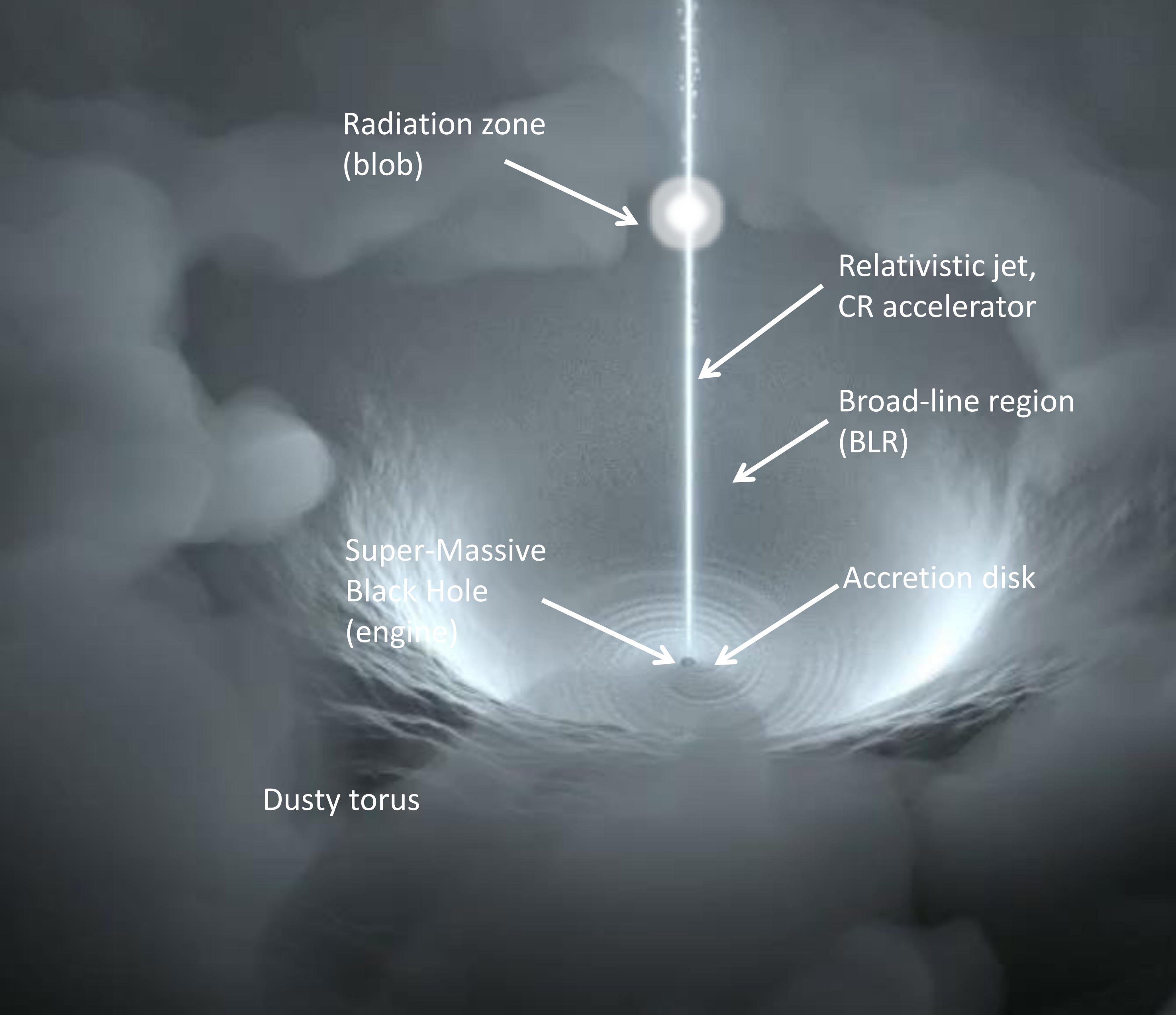


What is a blazar?

- Active core (nucleus) of a galaxy
- Emits a jet oriented towards the observer (us)
- Characteristic radiation pattern (SED)
- Bright electromagnetic flares every couple of years that last for weeks or months

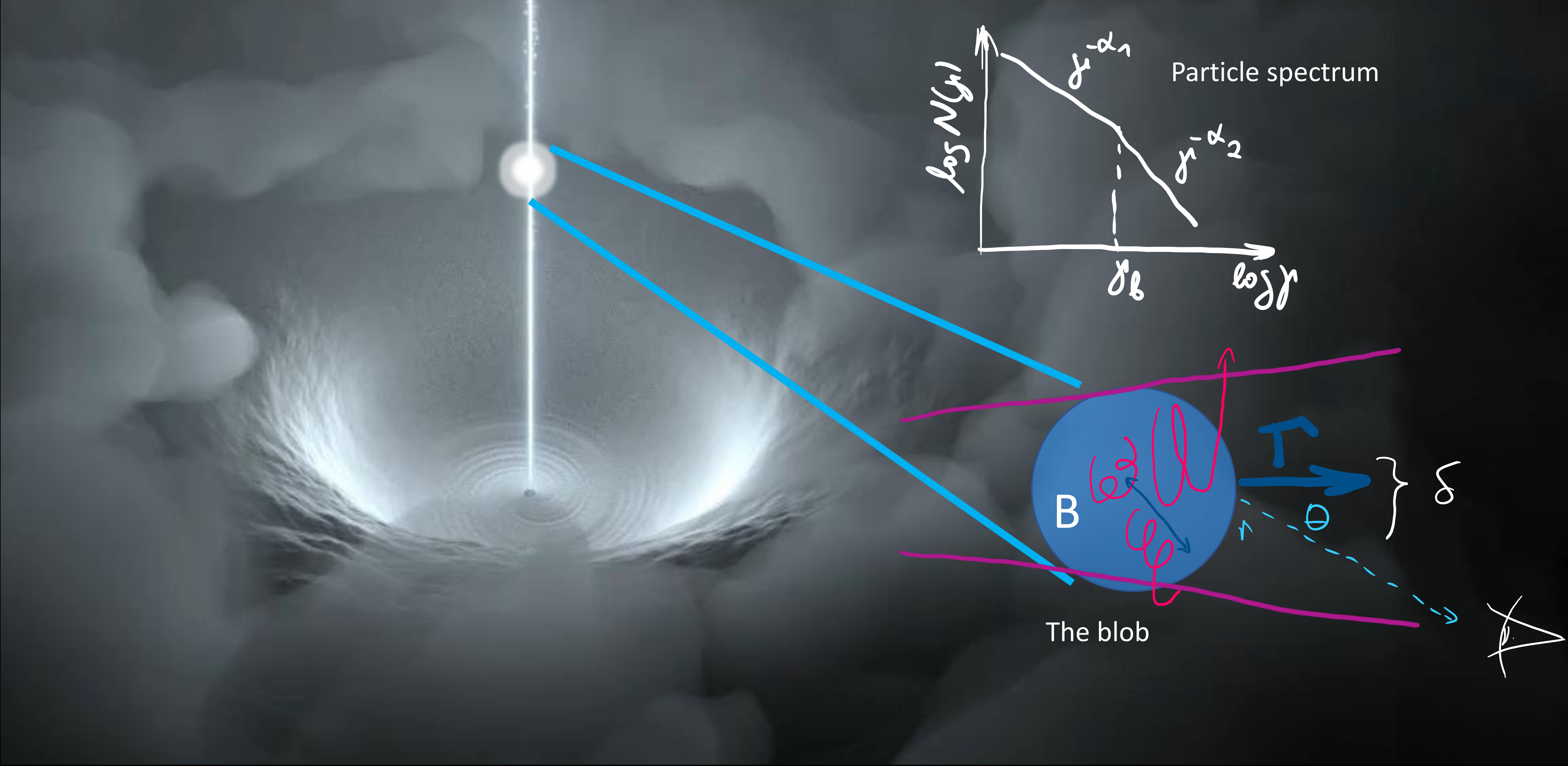
Animations by Science Communication Lab and DESY:
check out https://multimessenger.desy.de/ for interactive version

Core region of an active galaxy



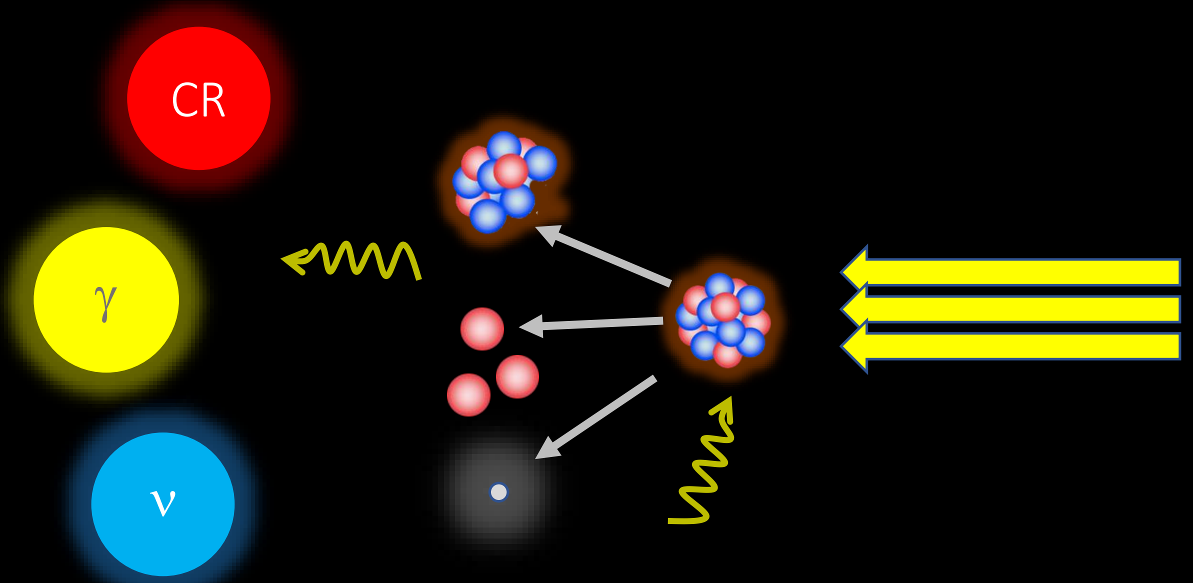
- SMBH drives accretion disk
- The radiation from the disk heats the environment; BLR and Torus
- Accretion of matter drives jet (galactic dimensions ~ kpc)
- Turbulent flow and plasma instabilities in the jet form radiation zones (blobs)
- Electrons and **protons** accelerate to ~PeV energies
- Radiation off relativistic particles produces observed spectrum

Core region of an active galaxy

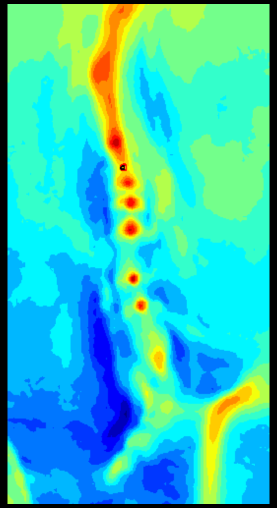


Source modeling

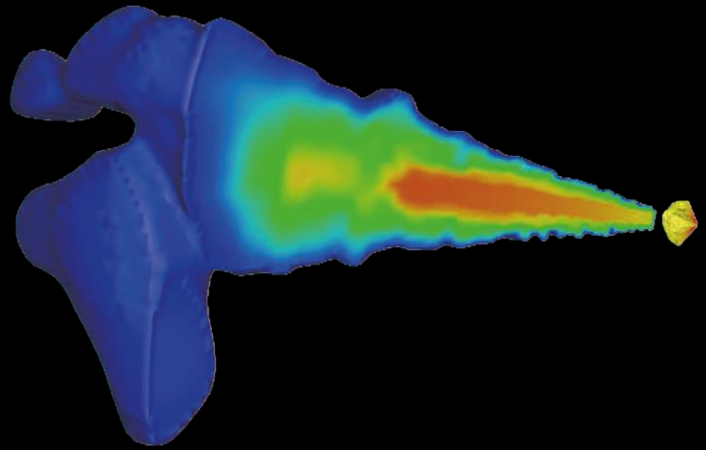
Simulations by M. Barkov & M. Pohl



Particle and photon emission



Particle acceleration



Emission of shocked plasma

In practice: thousands of coupled, stiff PDE

Source modeling

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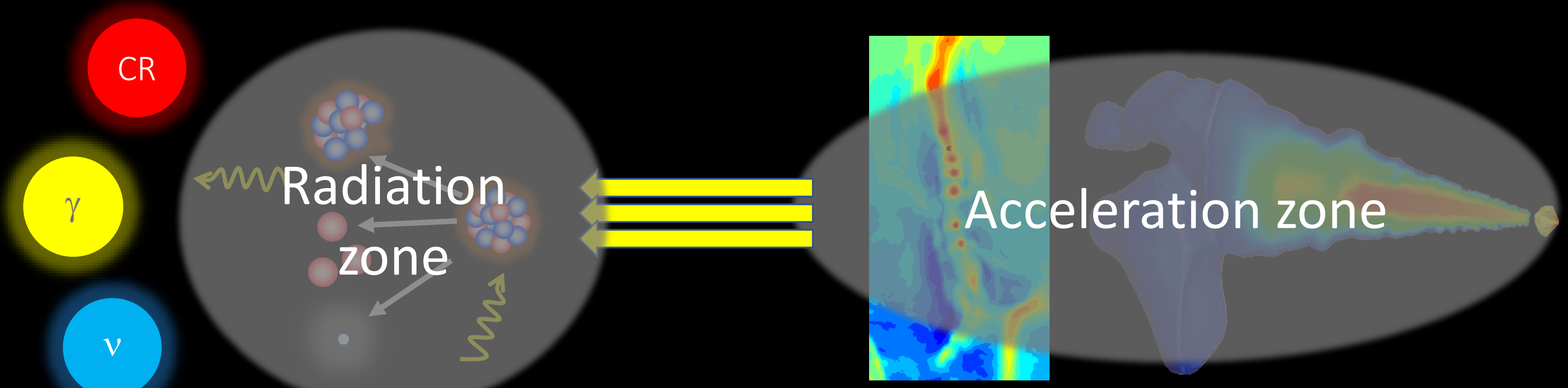

Particle and photon emission

Particle acceleration

Emission of shocked plasma

$$\frac{\partial N_i}{\partial t} = \frac{\partial}{\partial E}\left(-b(E)N_i(E)\right) - \frac{N_i(E)}{t_{\rm esc}} + \tilde{Q}_{ji}(E)$$

Evolution of particle densities in time

Cooling (energy losses)

Escape from radiation zone

Injection from shock and conversion from other particle types

In practice: thousands of coupled, stiff PDE

What really happened…

RESEARCH ARTICLE

Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverp…

+ See all authors and affiliations

Science 13 Jul 2018:
Vol. 361, Issue 6398, eaat1378
DOI: 10.1126/science.aat1378

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Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

IceCube Collaboration[*,†]

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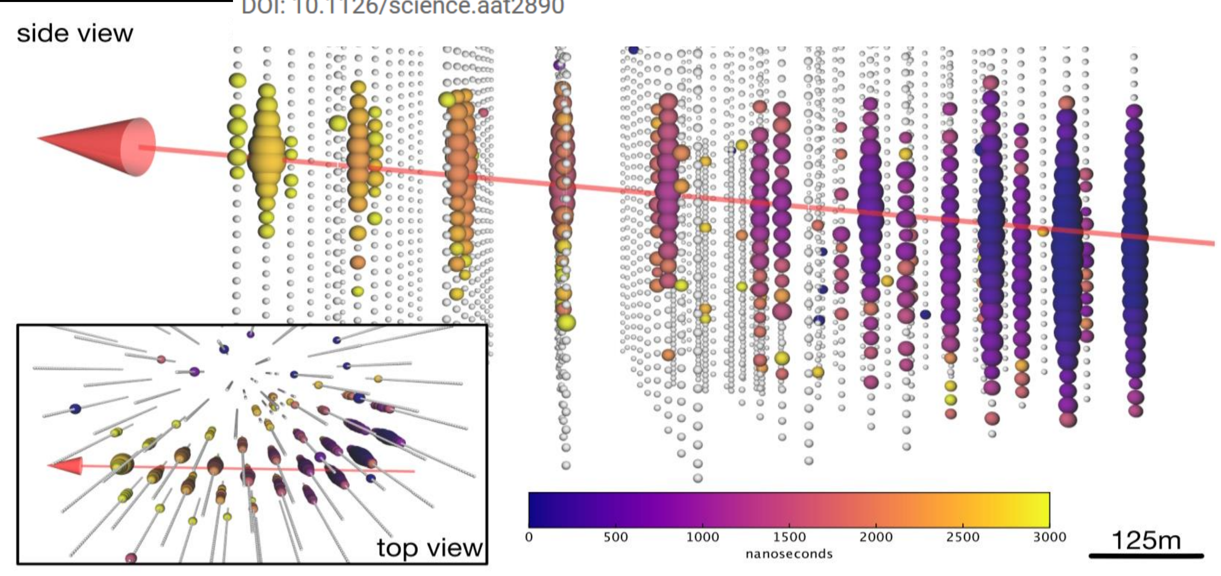

+ ~10 papers on day 1

nature astronomy

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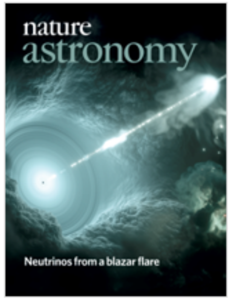
Volume 3 Issue 1, January 2019



Neutrinos from a blazar flare

Blazars, powered by an accreting supermassive black hole, launch collimated relativistic outflows (pictured) that are among the brightest persistent radiation sources in the Universe. The recent IceCube detection of a very-high-energy neutrino from the blazar TXS0506 + 056 in coincidence with a multi-wavelength flare implies that blazars can accelerate cosmic rays beyond petaelectronvolt energies, challenging conventional theoretical… show more

Image: DESY, Science Communication Lab. Cover Design: Allen Beattie.

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Multimessenger observations of a flaring blazar coincid… 170922A

2017 Multimessenger (MM) event

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverp…

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Historical event

Science 13 Jul 2018:
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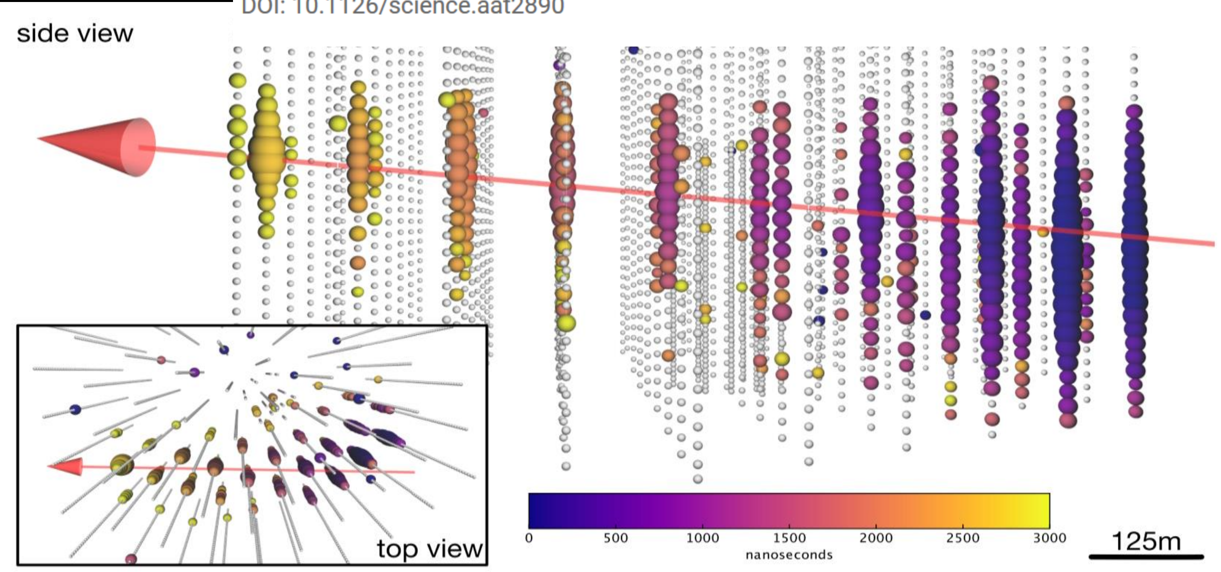

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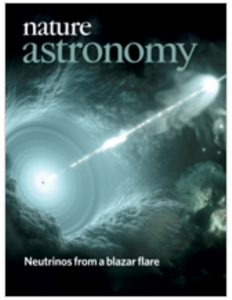


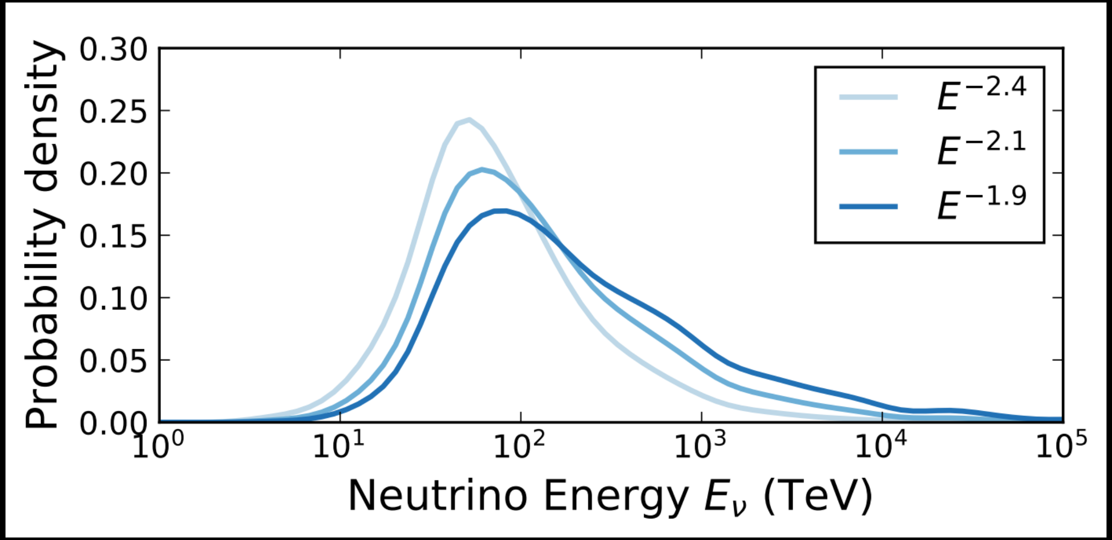
Neutrinos from a blazar flare

Blazars, powered by an accreting supermassive black hole, launch collimated relativistic outflows (pictured) that are among the brightest persistent radiation sources in the Universe. The recent IceCube detection of a very-high-energy neutrino from the blazar TXS0506 + 056 in coincidence with a multi-wavelength flare implies that blazars can accelerate cosmic rays beyond petaelectronvolt energies, challenging conventional theoretical… show more

Image: DESY, Science Communication Lab. Cover Design: Allen Beattie.

Energy of the MM event

IceCube, Fermi, MAGIC,++, Science 2018

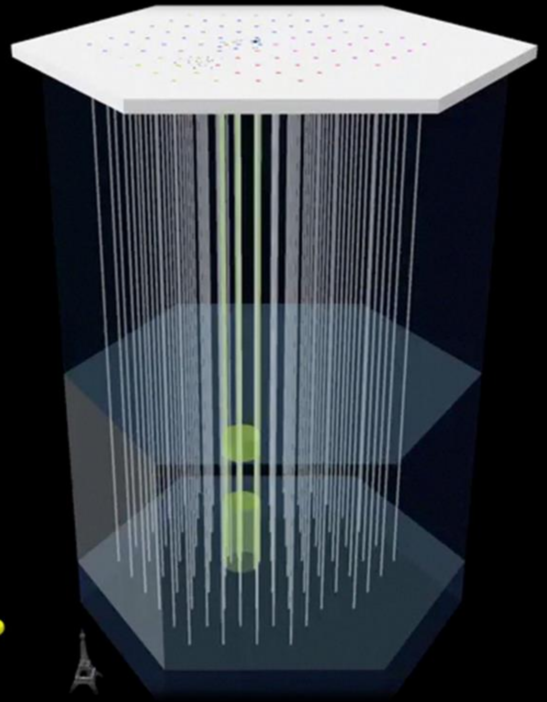


Neutrino energy around a **few hunderds TeV**

Good energy resolution for tracks in IceCube

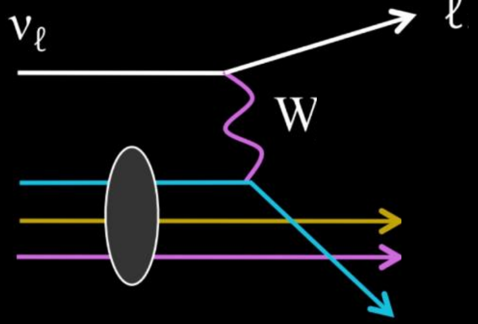
$$\sqrt{\langle \psi^2_{\nu\mu} \rangle} \propto \sqrt{m_p / E_\nu}$$

for Ev $\gtrsim$ TeV, $\theta_{\nu\mu} \lesssim 1^o$



Unknown momentum transfer

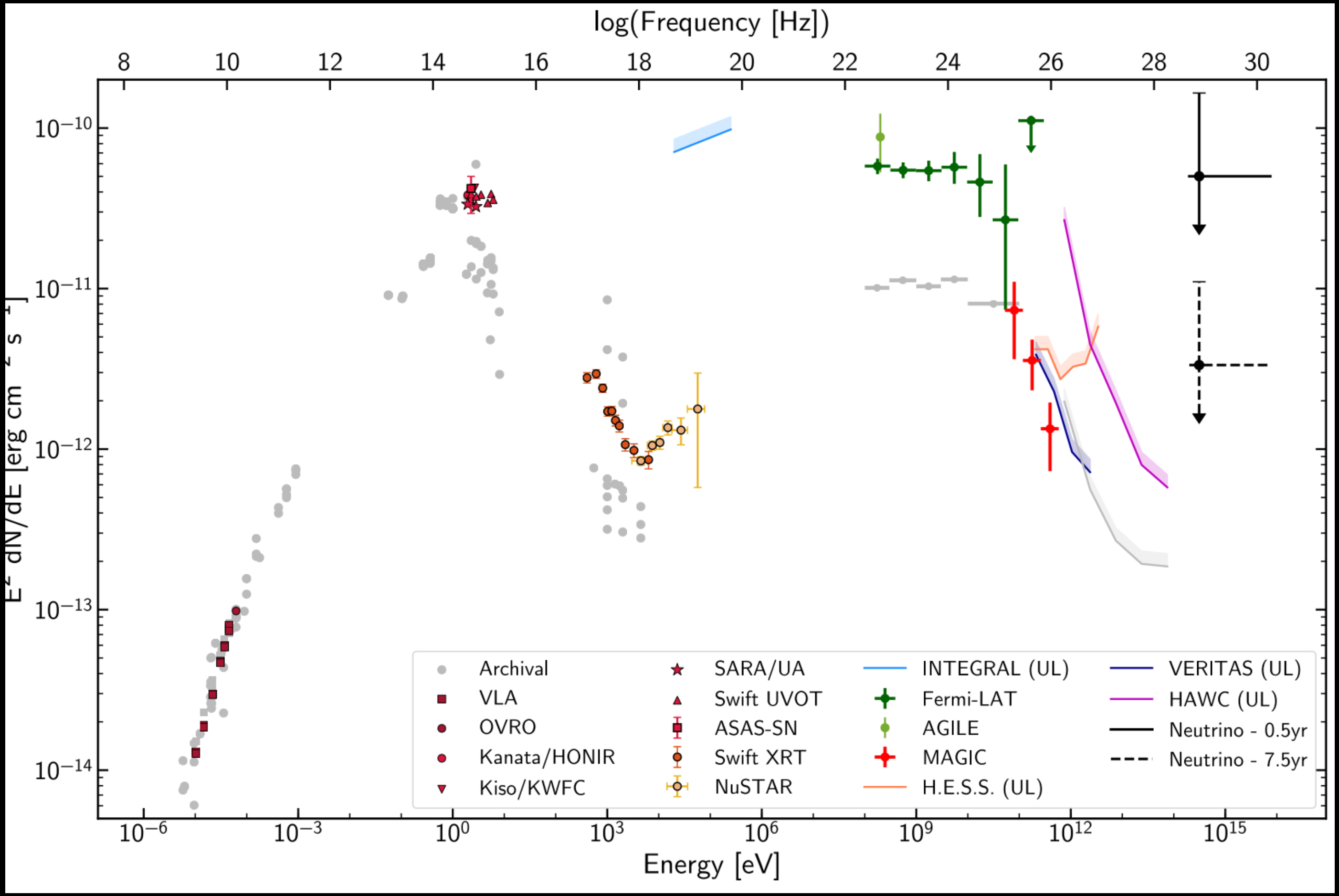
Unknown initial energy



Unknown distance/energy loss

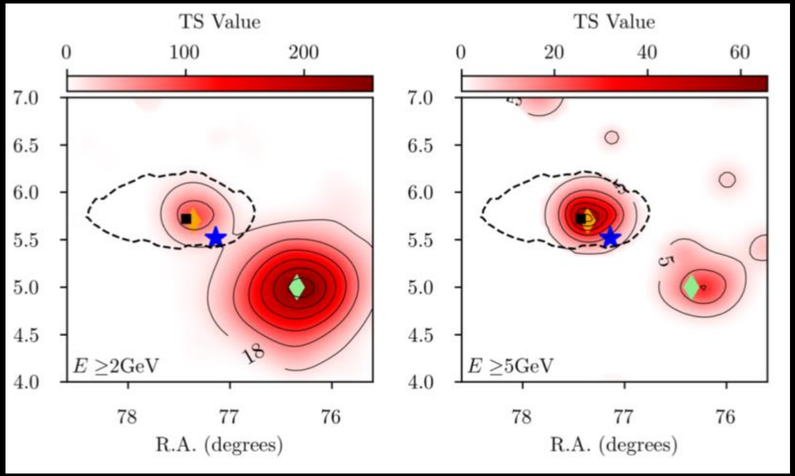
Theoretical challenges of the TXS0506+056 MM observation

IceCube, Fermi, MAGIC,++, Science 2018



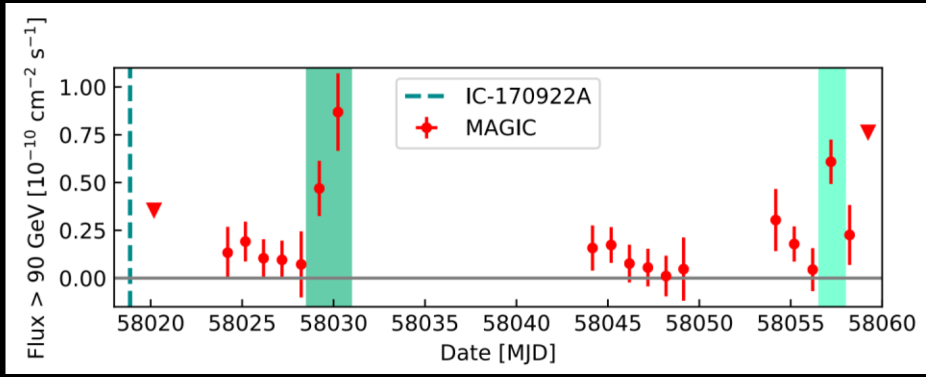
Why is the **neutrino** is detected **during a flare and not during quiscence?**

Padovani, Resconi, Glauch, Huber, et al. (MNRAS 2018)



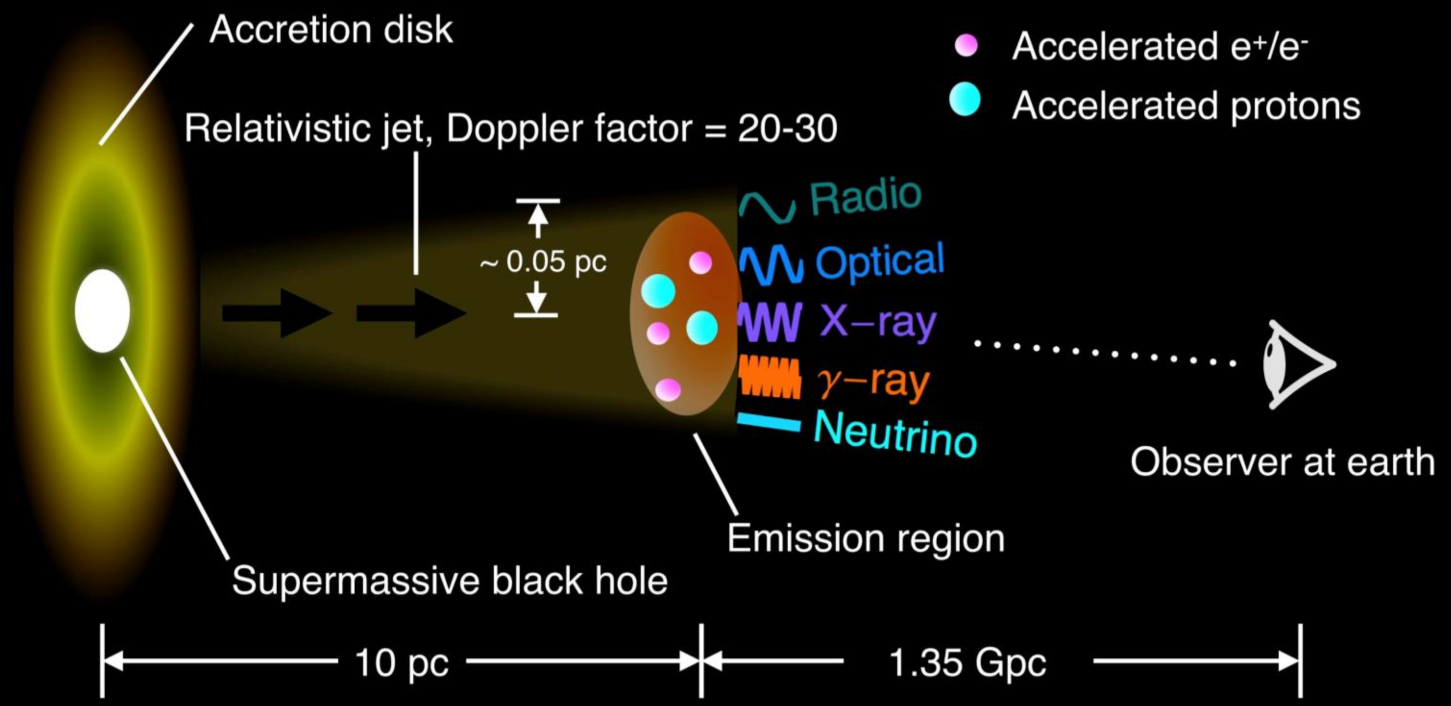
Source **confusion unlikely**

MAGIC, ApJL, 2018



Delayed or **flikering** emission of **TeV photons**

("Canonical") modeling TXS



- **One or multiple** emission regions (**blob** or plasmoid)
- **Spherical** in its rest frame
- Particle momenta and radiation **isotropic**
- **Injection** of accelerated particles (**no** explicit **simulation**)
- Particles **escape** at **constant** rate

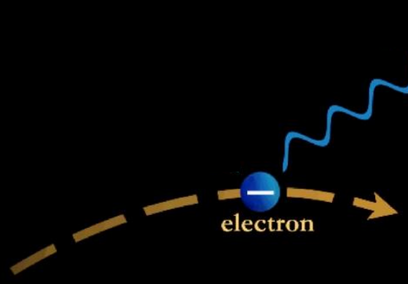
Time-dependent lepto-hadronic Code (AM^3) (Gao, Pohl, Winter APJ 843, 2017)

$$\partial_t n(\gamma,t) = -\partial_\gamma\{\dot\gamma(\gamma,t)n(\gamma,t) - \partial_\gamma[D(\gamma,t)n(\gamma,t)]/2\} - \alpha(\gamma,t)n(\gamma,t) + Q(\gamma,t)$$

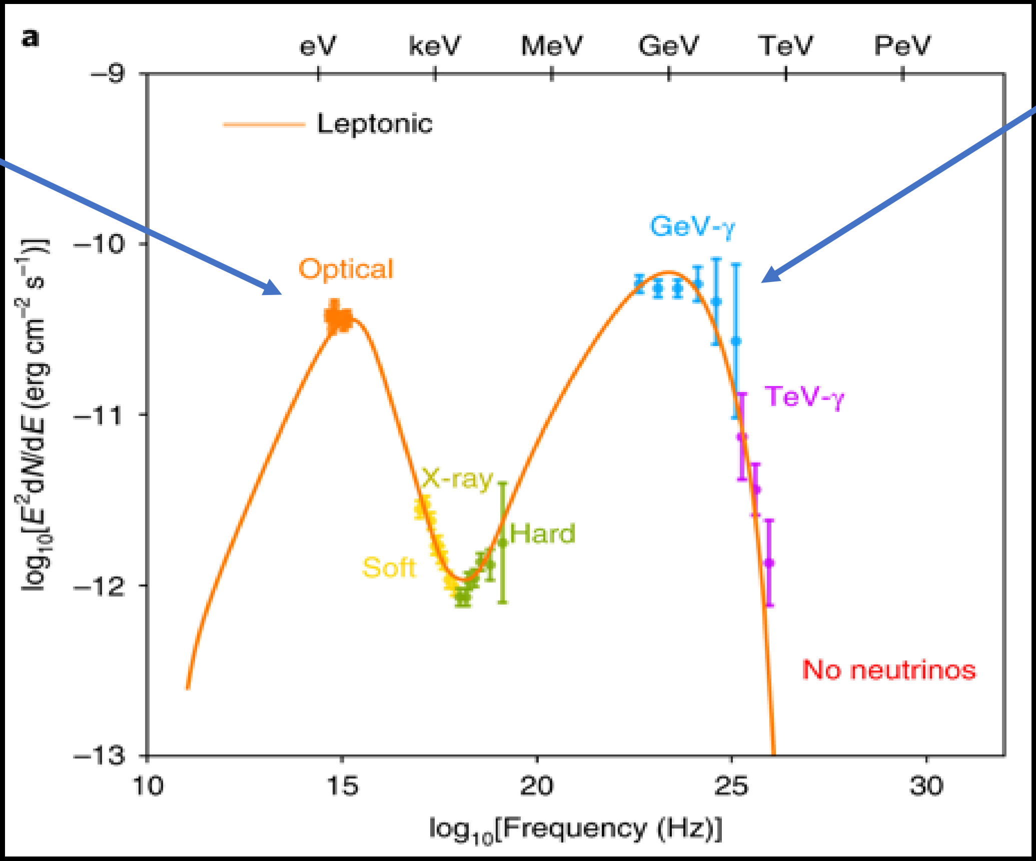
The “canonical” blazar SED – synchrotron self-Compton model

Synchrotron peak:

- off electrons
- Defines..
  - **magnetic field**
  - **doppler factor**
  - **shape of** electron **spectrum**



Radio,
Optical,
Soft X-ray

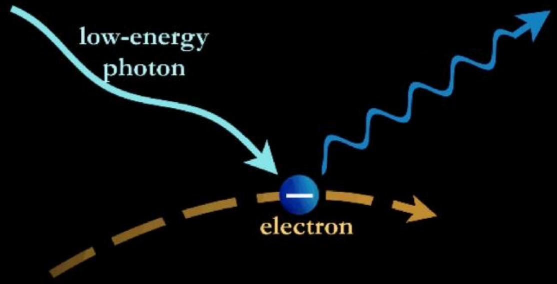


Gao, AF, Winter, Pohl, Nat.Astron. 3 (2019)

Synchrotron self-Compton (SSC) peak:

- synchrotron spectrum up-scattered by prim. electrons
- Depends on all variables
- In particular target densities

X-rays
Gamma-rays
TeV



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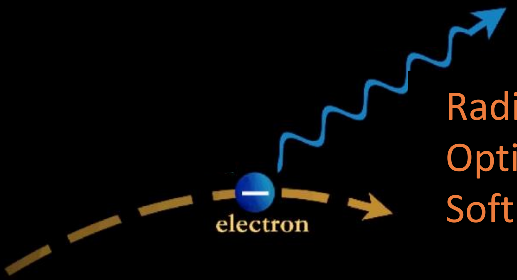

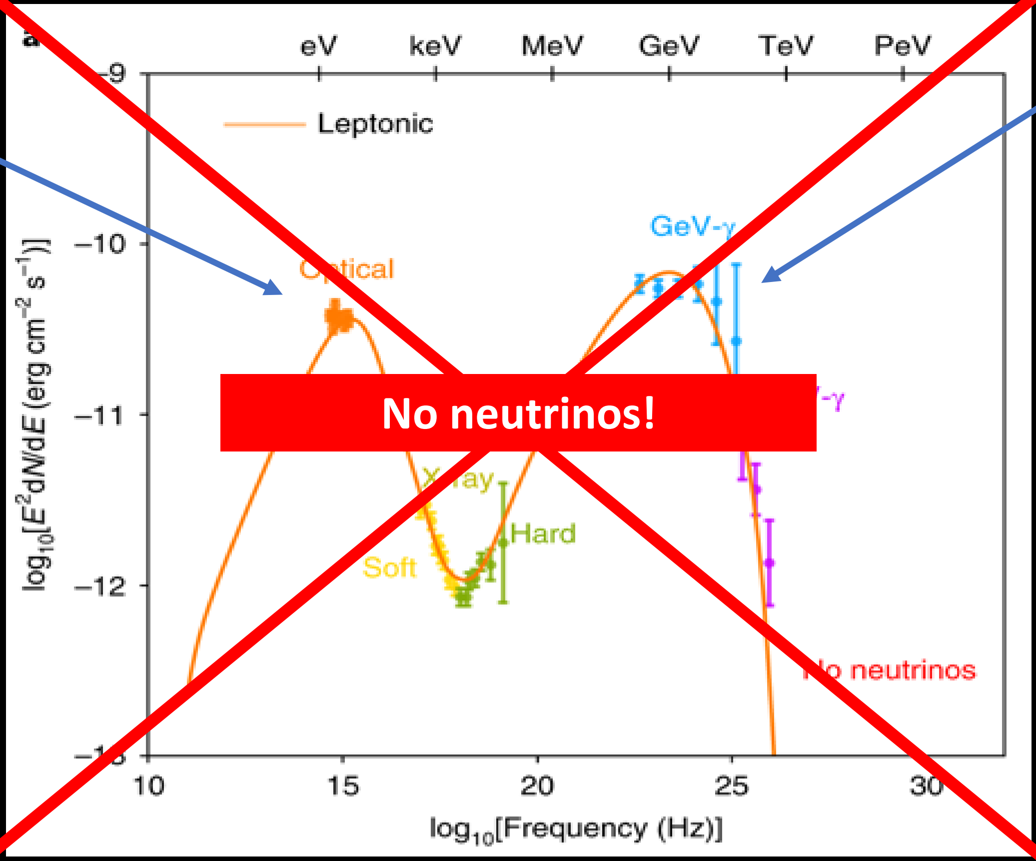

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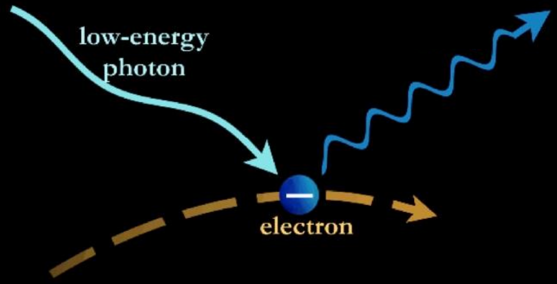
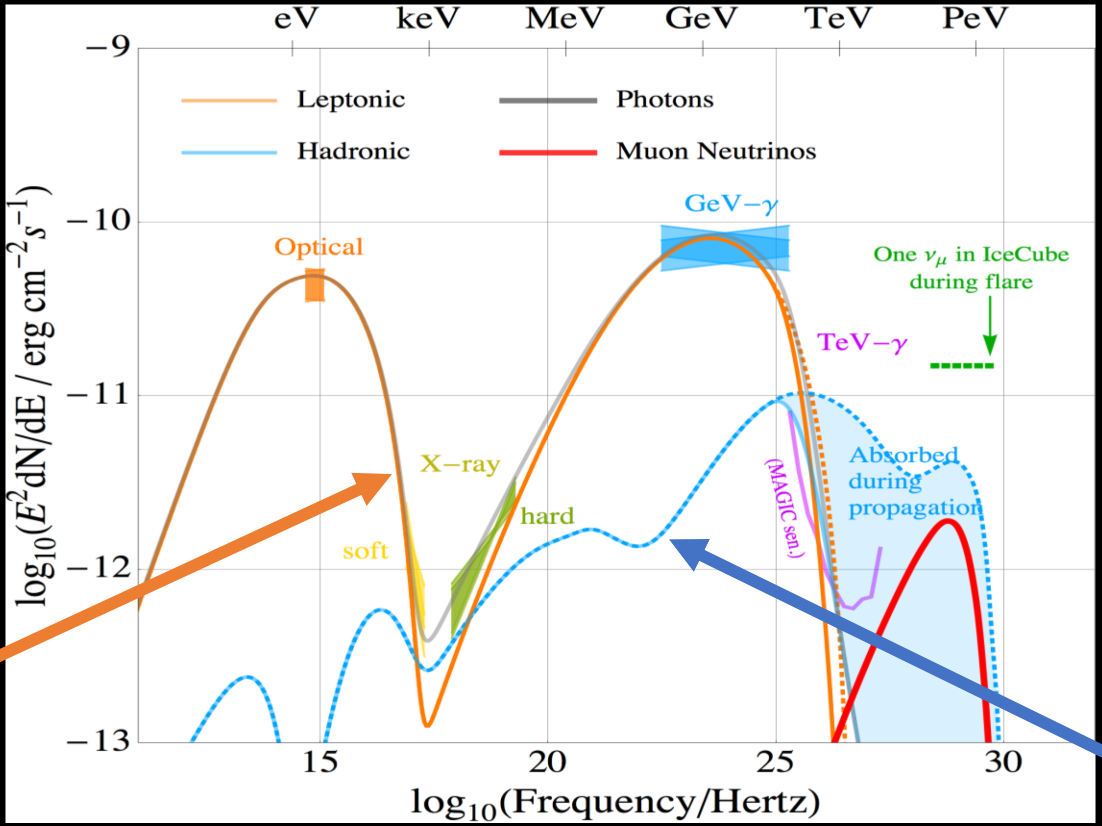
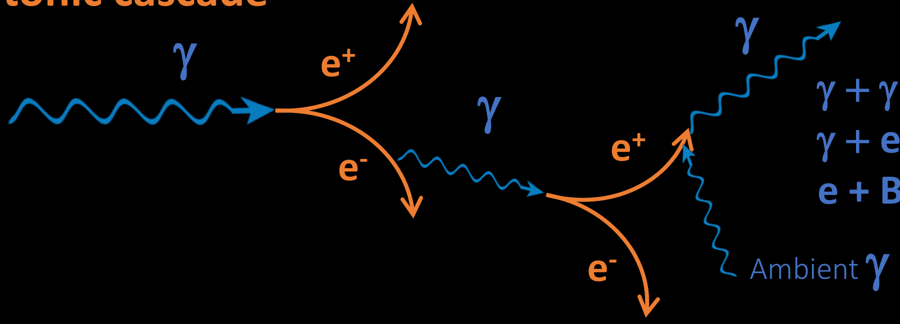


Lepto-hadronic (one-zone) model

Gao, AF, Winter, Pohl, Nat.Astron. 3 (2019)



Leptonic cascade

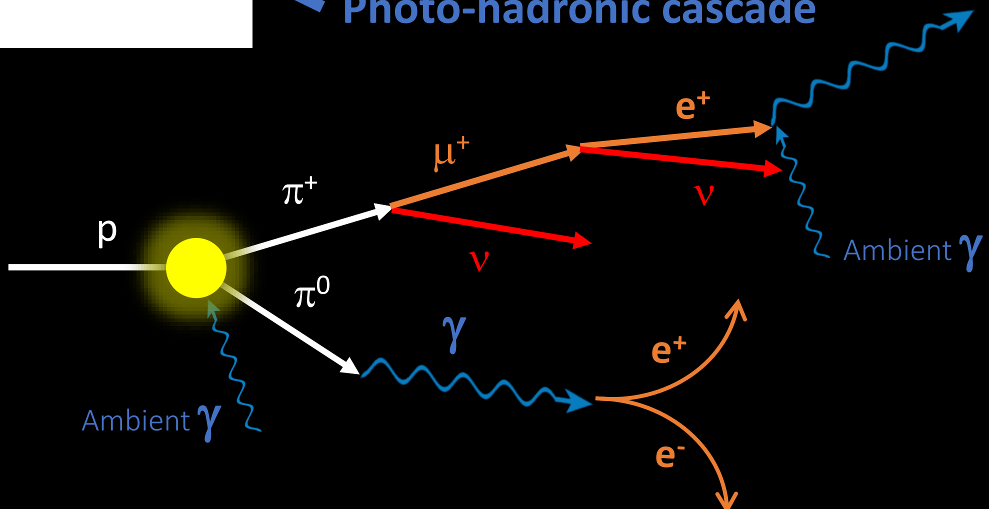


$\gamma + \gamma \rightarrow e^+ + e^-$

$\gamma + e \rightarrow \gamma + e$ (IC)

$e + B \rightarrow e + \gamma$ (syn.)

Photo-hadronic cascade



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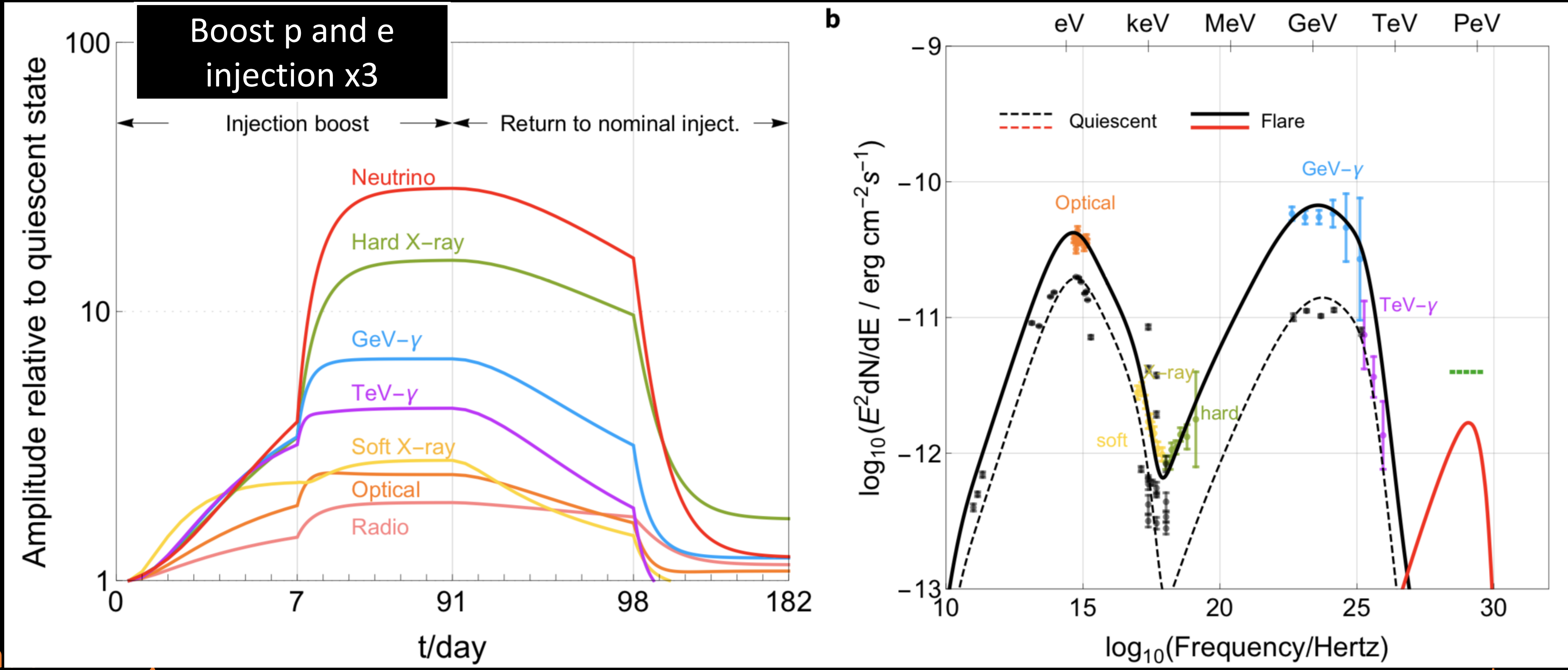
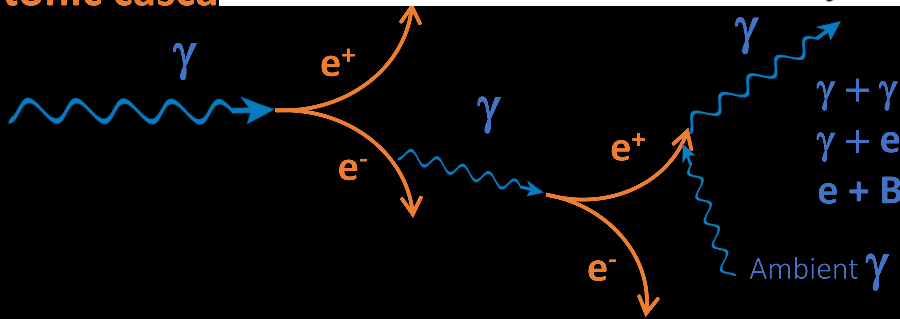
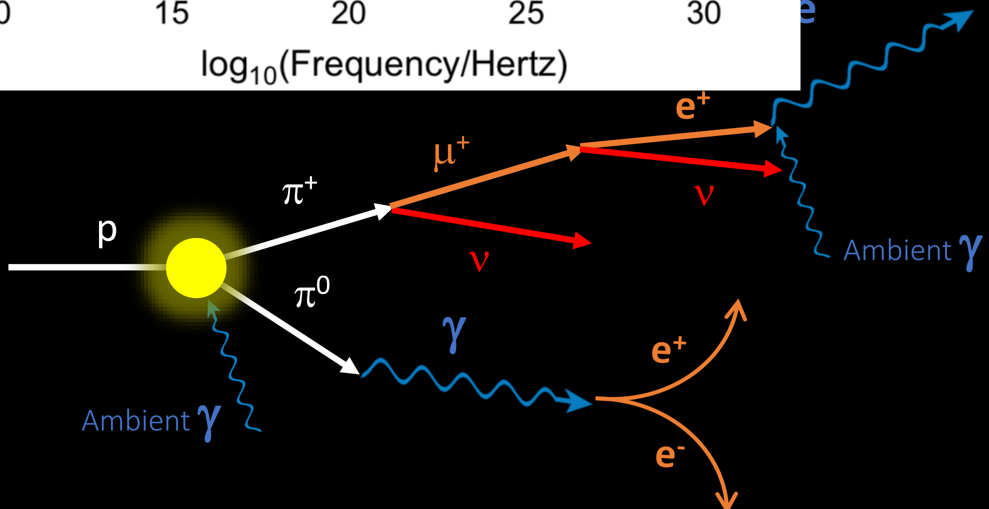
Gao, AF, Winter, Pohl, Nat.Astron. 3 (2019)



Leptonic casca



γ + γ → e⁺ + e⁻
γ + e → γ + e (IC)
e + B → e + γ (syn.)



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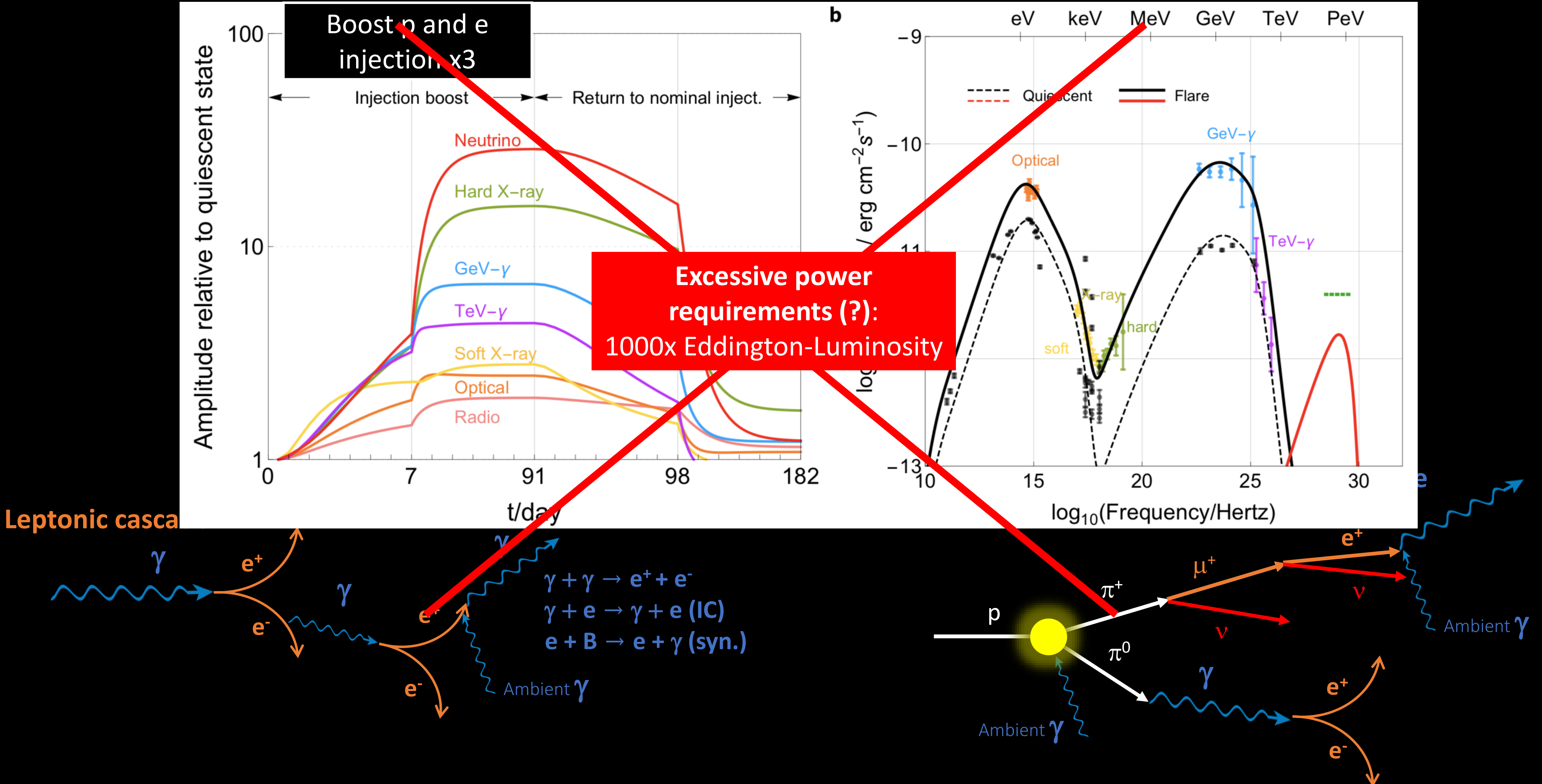
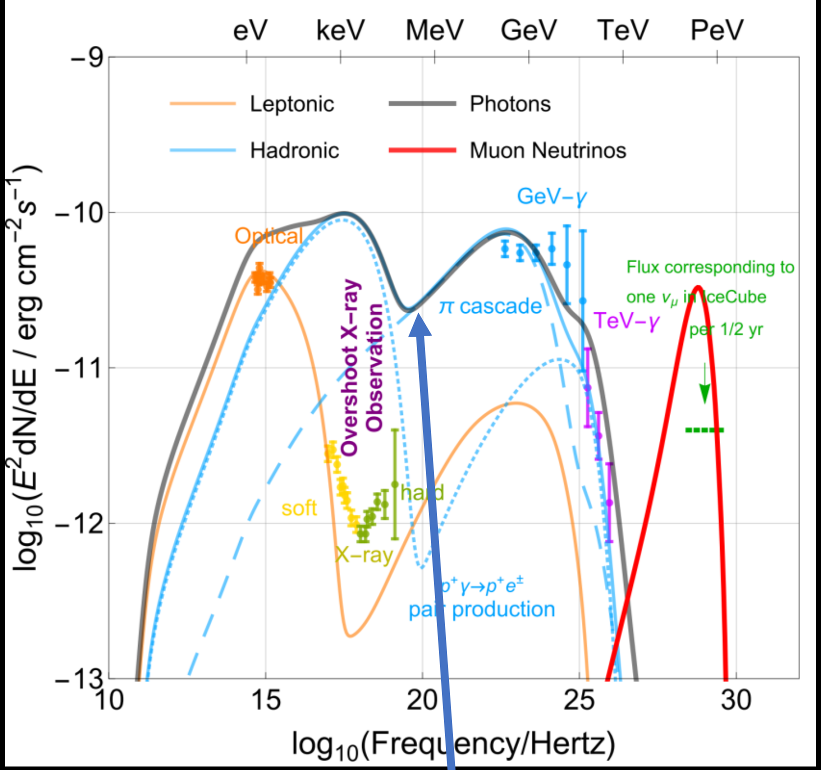
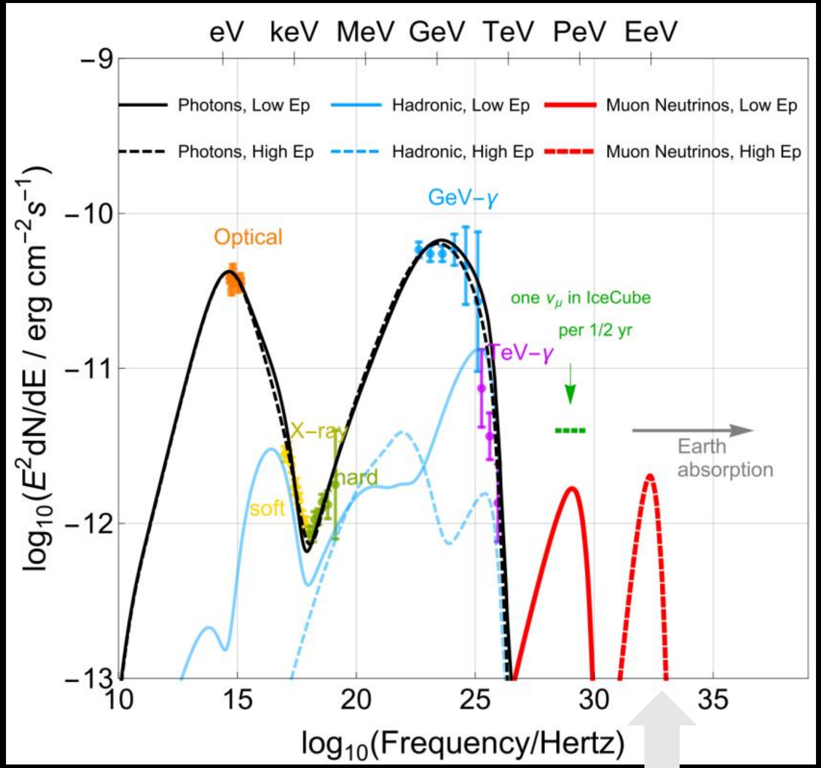


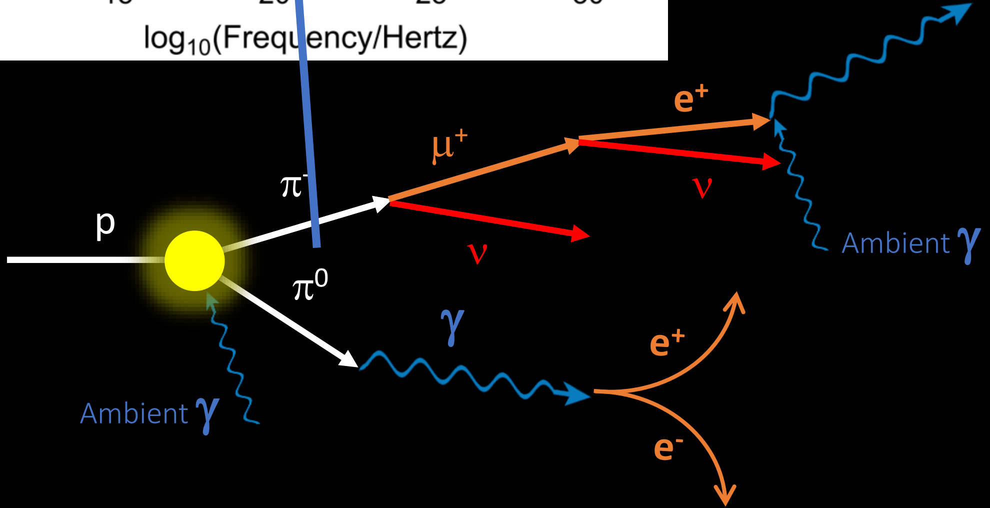
Hadronic and UHECR model excluded, as well

Hadronic (2nd peak) model



UHECR injection





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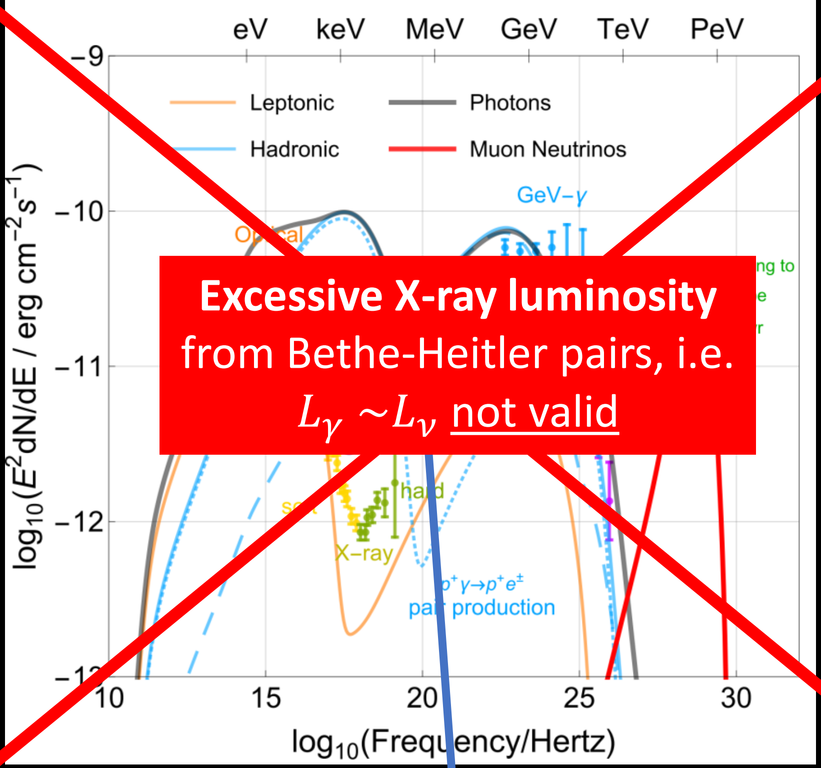
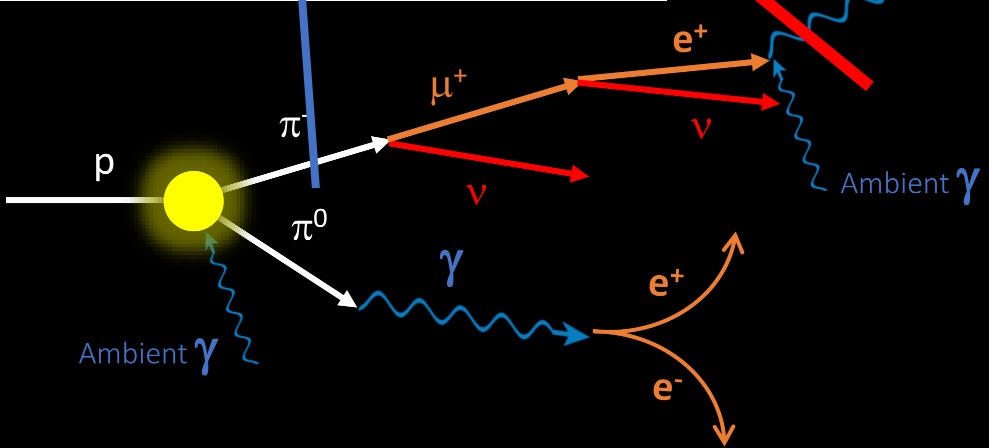


Excessive X-ray luminosity
from Bethe-Heitler pairs, i.e.
$L_\gamma \sim L_\nu$ not valid



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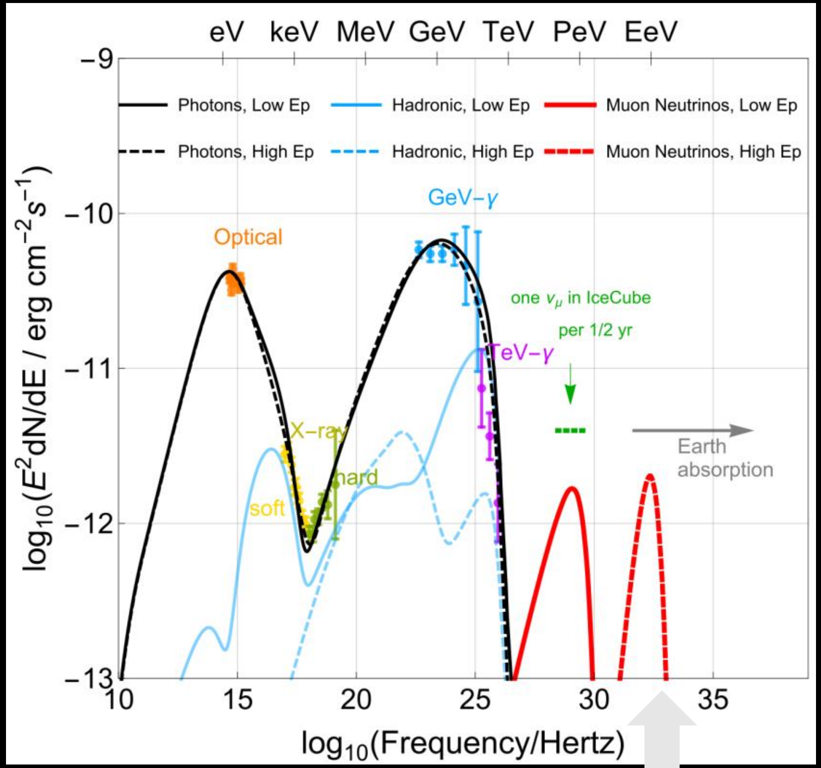

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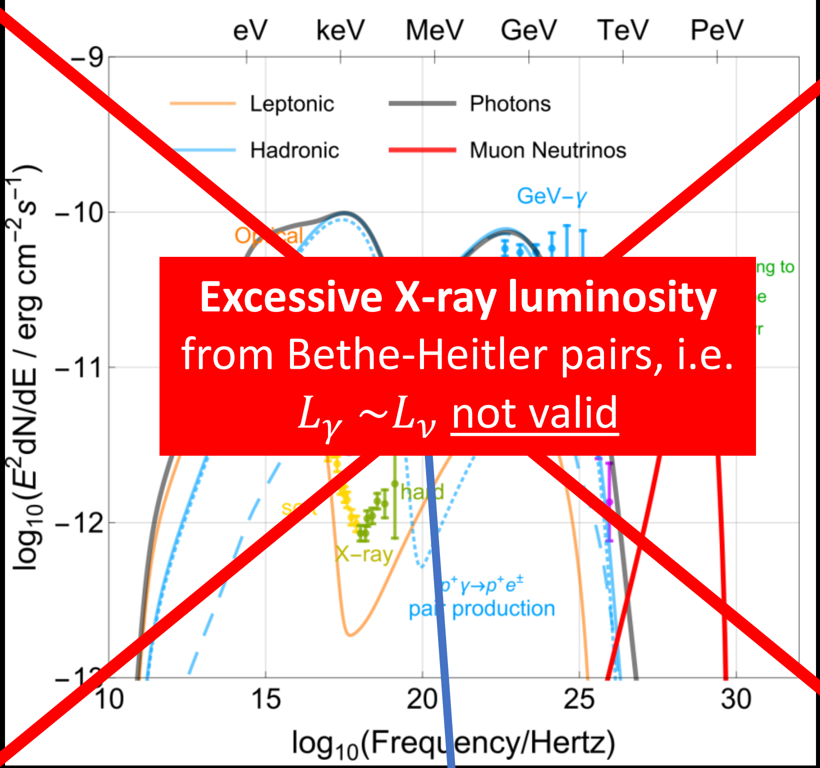

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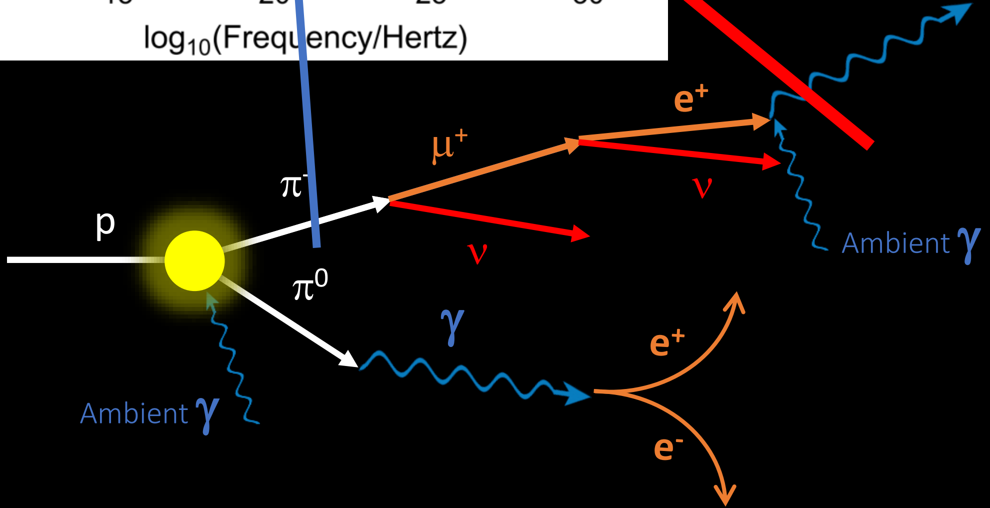
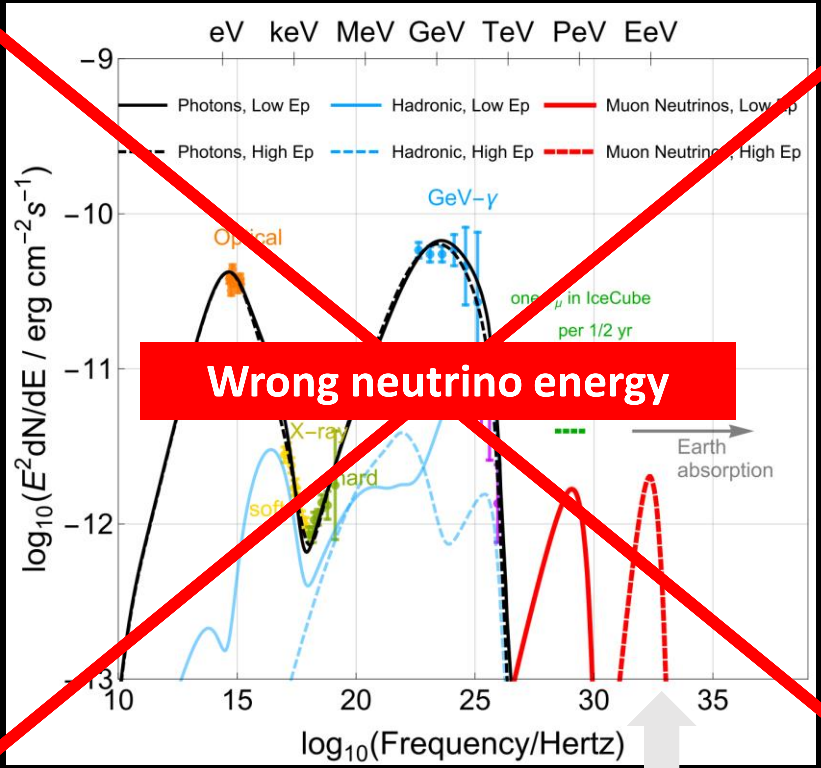


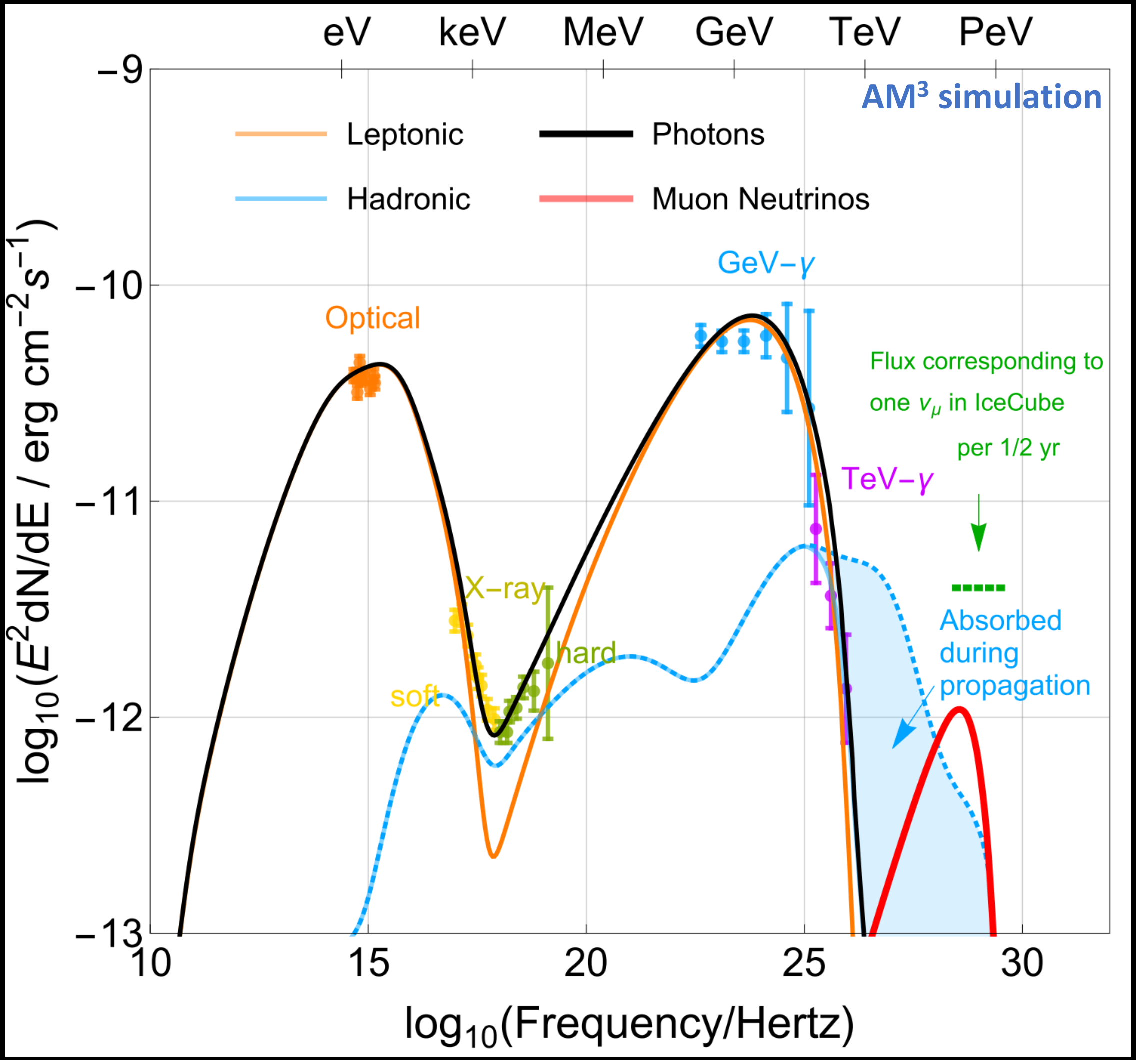
UHECR injection



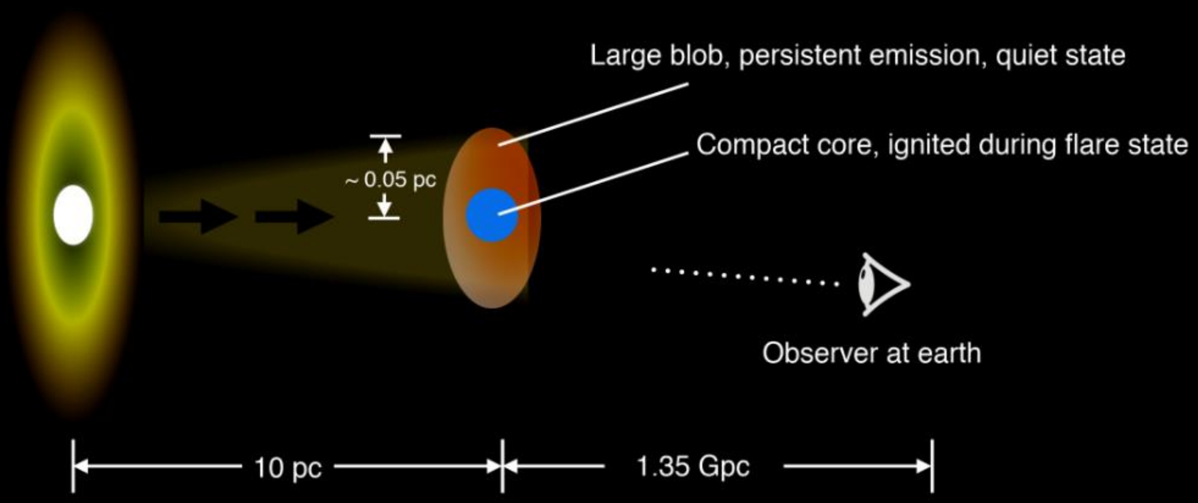
Wrong neutrino energy

Gao, AF, Winter, Pohl, Nat.Astron. 3 (2019)

More complex geometry required – two-zone (core) model



Gao, AF, Winter, Pohl, Nat.Astron. 3 (2019)



- **Large zone** r~$10^{17.5}$ cm for **quiescent** state
- **Flare** generated through formation of a **compact core** r_{core}~10^{16} cm during the short period of the flare
- To power the core **7xL_{Edd} needed** to saturate X-ray flux, quiescent state is sub-Eddington
- **Neutrino rate is ~0.3/yr**, consistent with the observation of one neutrino during the flare

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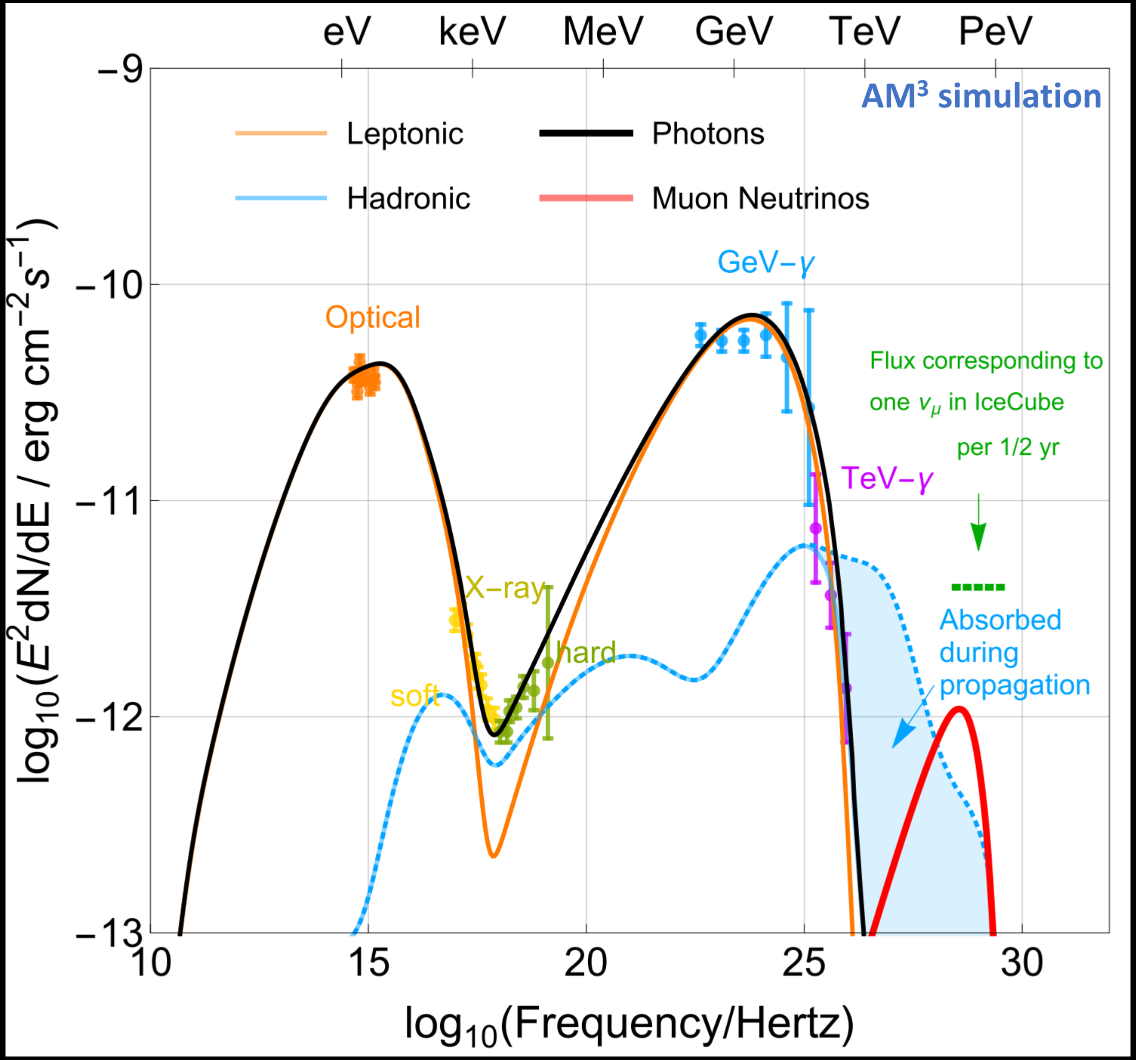
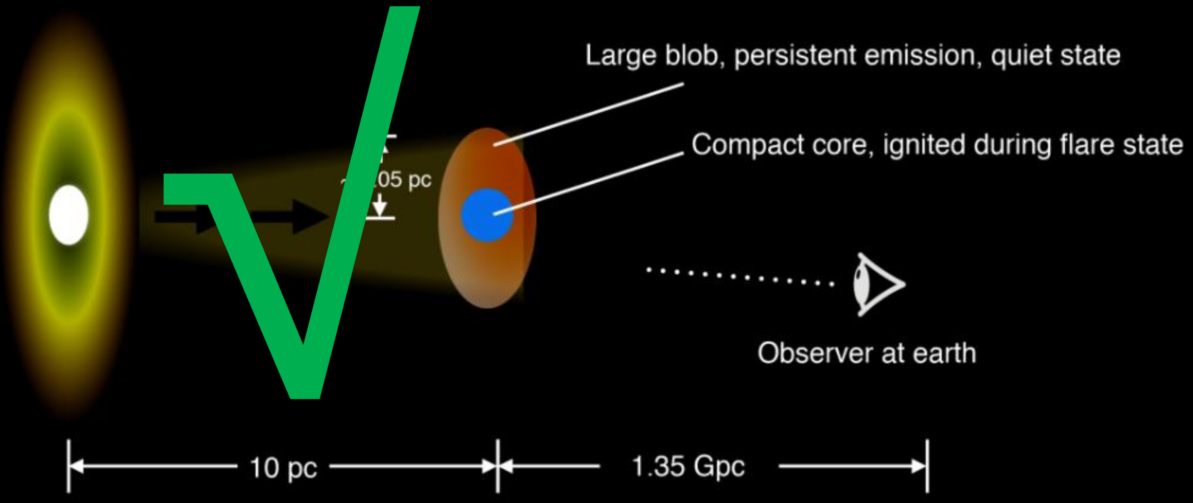


Gao, AF, Winter, Pohl, Nat.Astron. 3 (2019)



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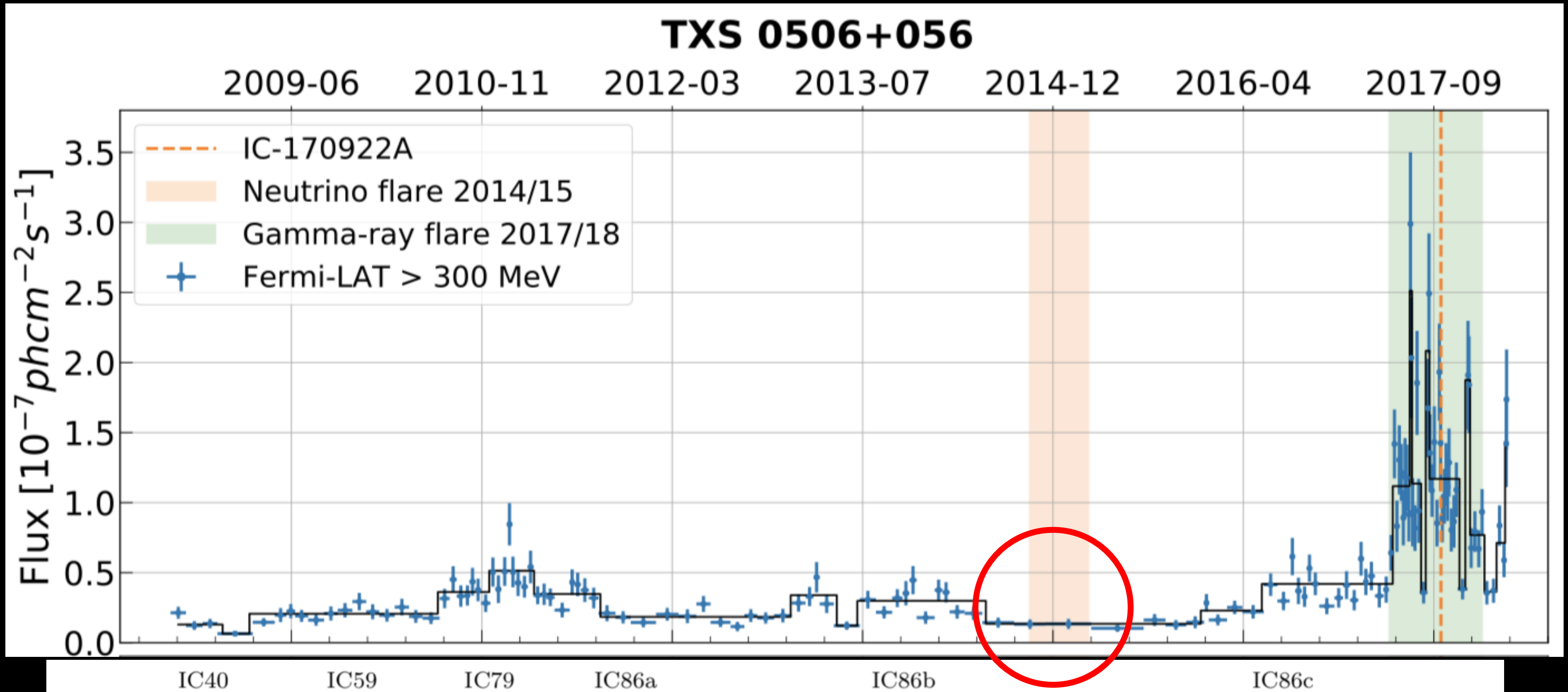
Lessons from one Multimessenger observation with a single neutrino

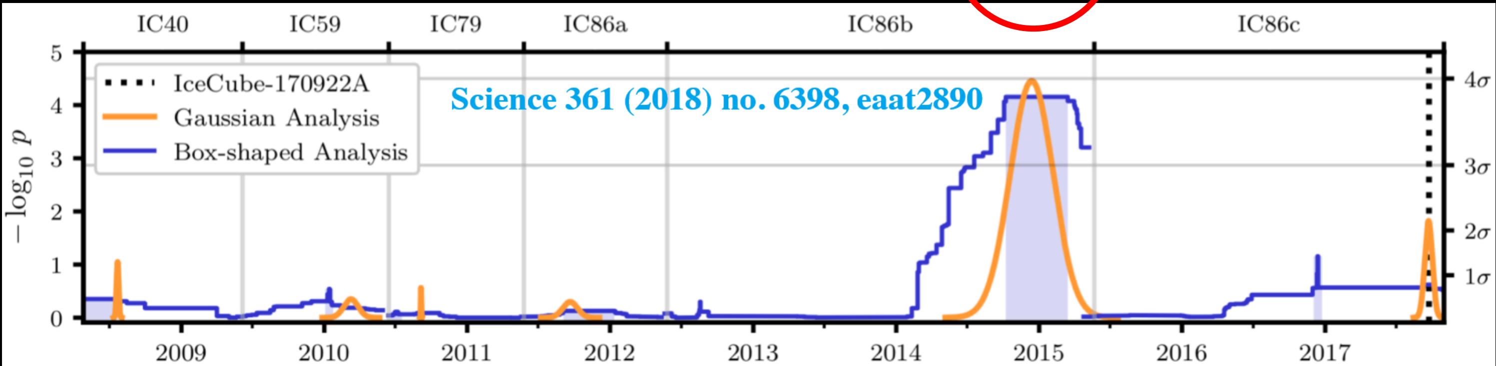
1. Some blazars can be PeV cosmic ray accelerators
2. Blazar jets can contain a significant amount of protons/nuclei
3. Simplified expectations $L_\gamma^{(2)} \sim L_\nu$ not generalizable
4. Multi-wavelength observations crucial, for TXS: X-ray and not γ-ray flux are ν flux proxies
5. Efficient neutrino emission requires super-Eddington accretion
6. Other groups arrive at similar conclusions

All statements above at 3 sigma ☺

Modeling challenges from 2014-2015 “historical” neutrino flare

S. Garrappa, A. Franckowiak, (+IceCube & Fermi Coll.), 2019, 1901.10806



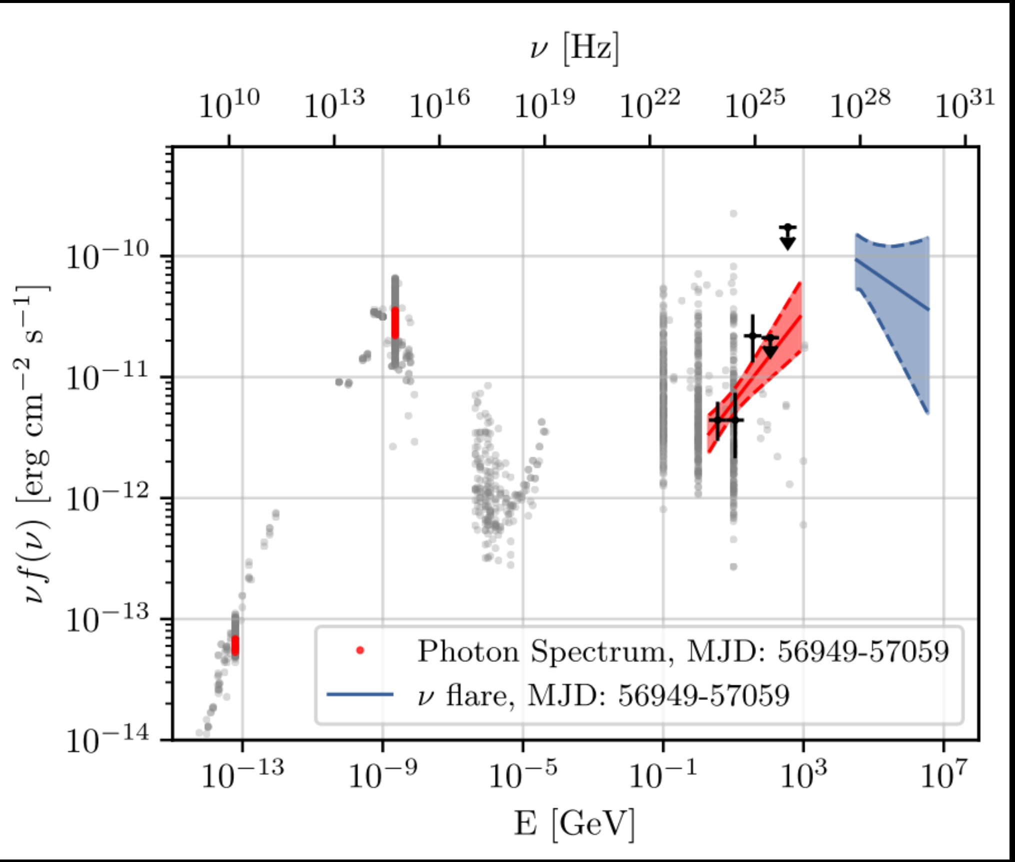


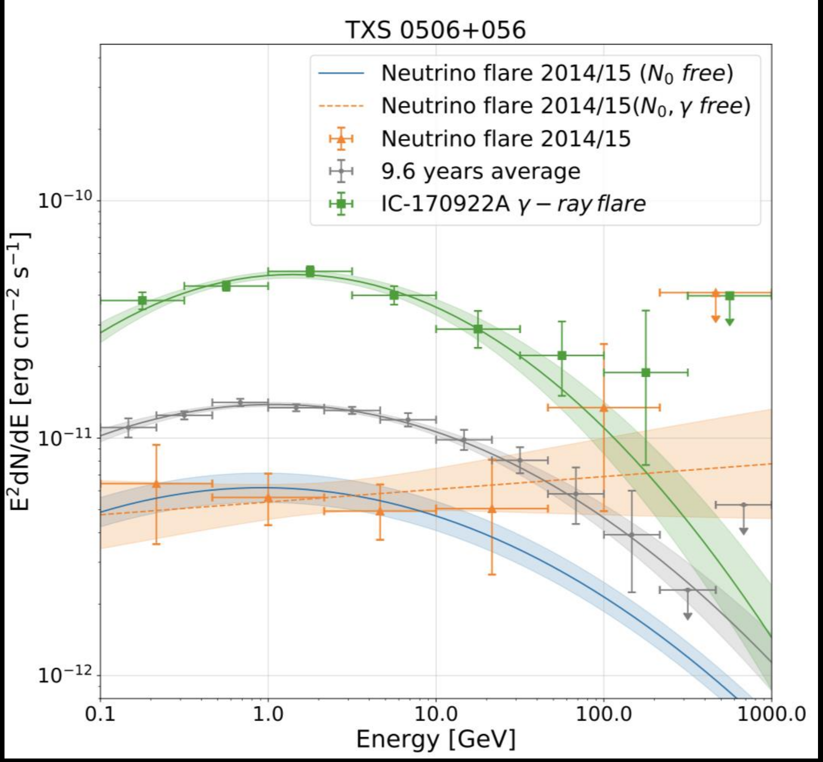
IceCube:
13 ± 5 events in ~half year, typ. energies - tens of TeV

Indications for γ-ray counterpart

S. Garrappa, A. Franckowiak, (+IceCube & Fermi Coll.), 2019, 1901.10806

Padovani, Resconi, Glauch et al. MNRAS (2018)



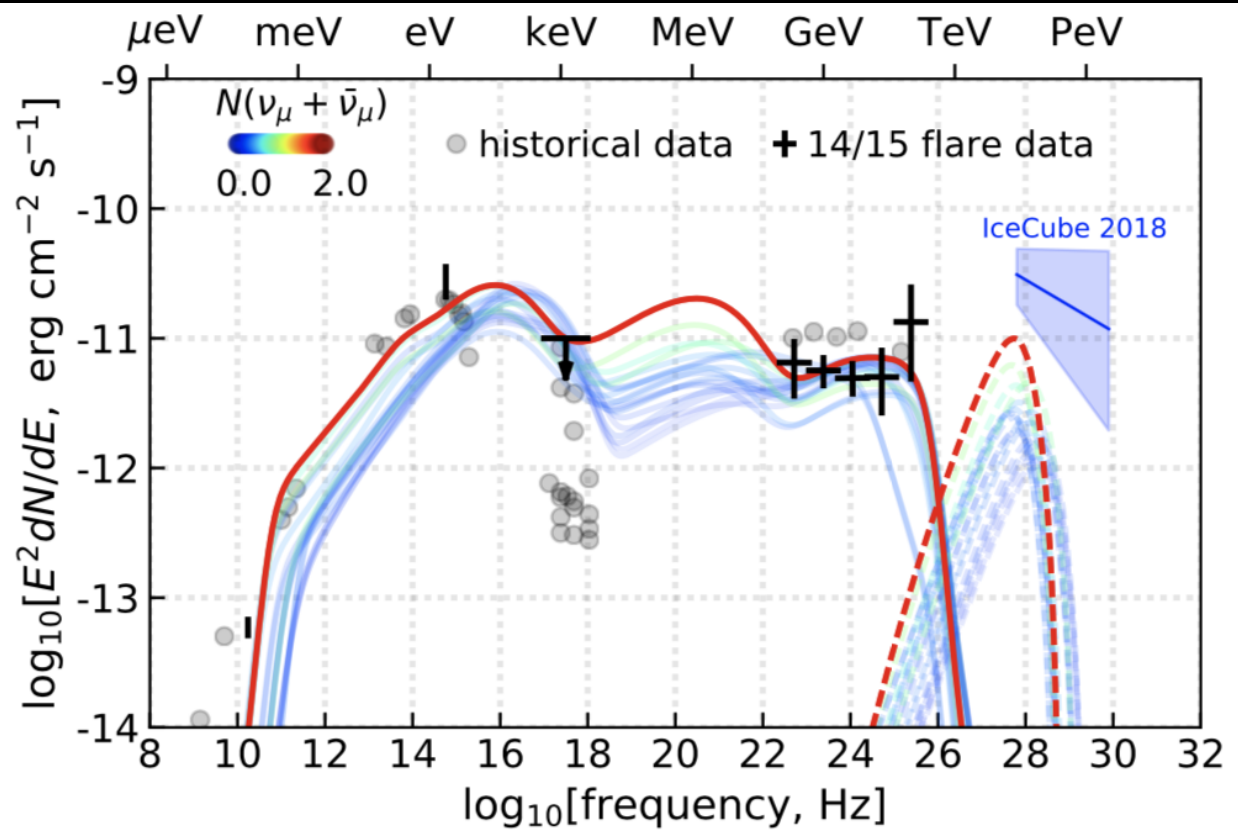


E_{min} [GeV]	power law σ^a	p-value	power law index
0.1	1.13	0.26	1.95 ± 0.12
0.5	1.97	0.05	1.88 ± 0.13
1.0	1.09	0.27	1.98 ± 0.17
2.0	2.06	0.04	1.76 ± 0.20
10.0	1.48	0.14	1.77 ± 0.40

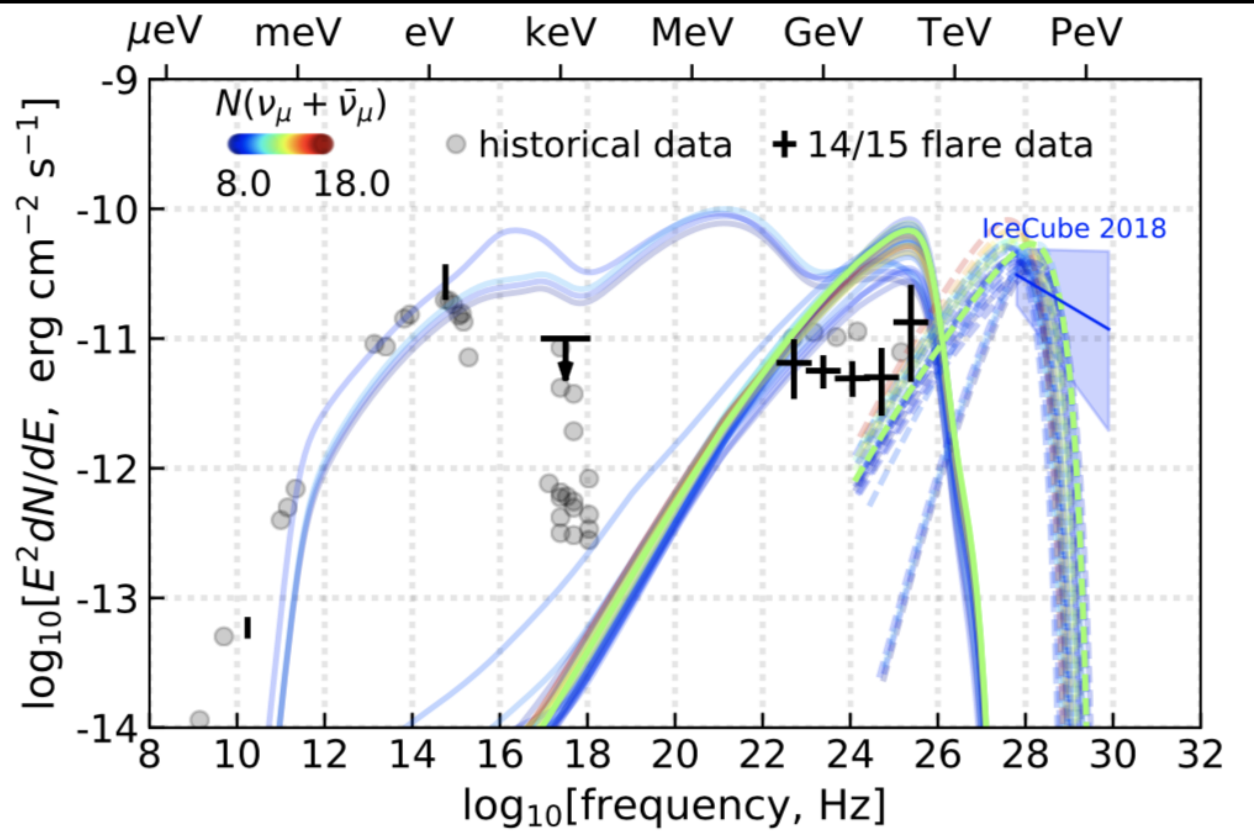
- Data **only in GeV and optical** bands
- **Neutrino** flux **higher than photon** flux
- A few gamma-ray photons can be interpreted as **hardening**

Lepto-hadronic one-zone models in tension with observations

Fitting EM constraints



Fitting neutrino count

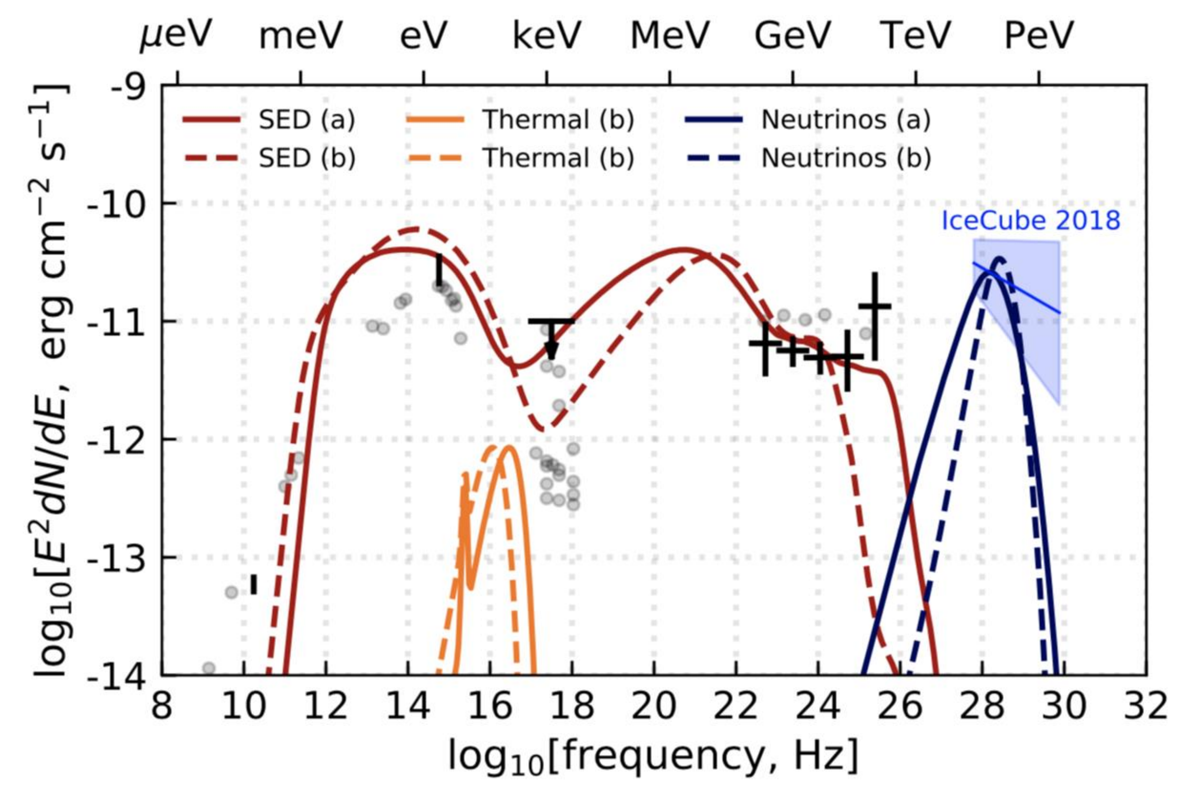


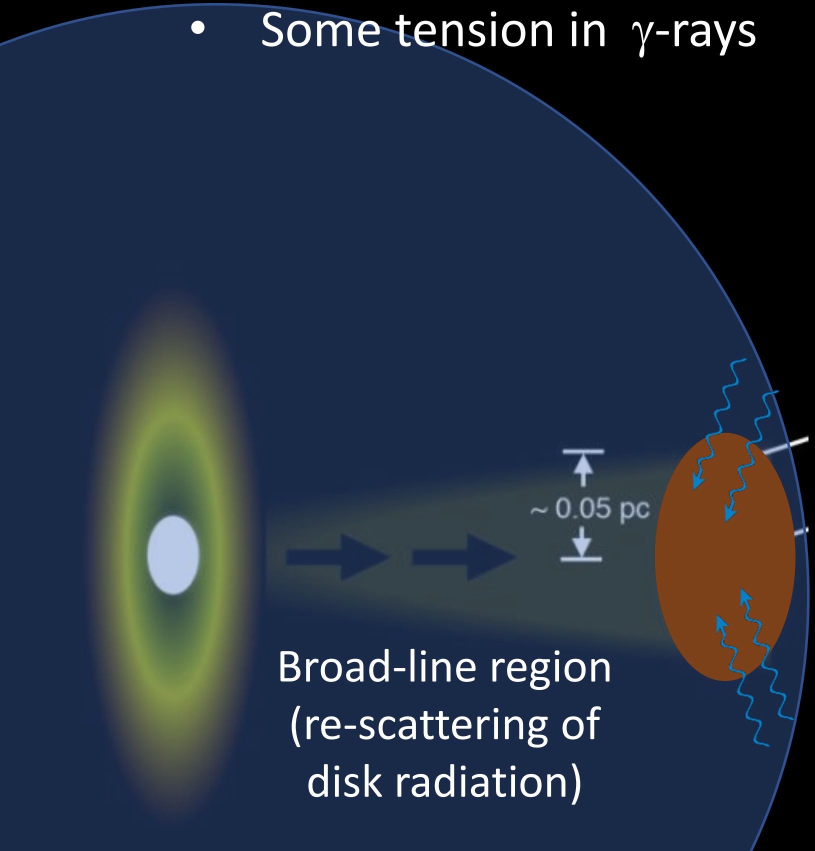
- Only **1.8 neutrinos** if model is **compatible with SED**
- Strong **overshoot** of indirect **X-ray** constraints if fitting the **neutrino number**
- Energy budget from $\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$ cascades has to be preserved

Rodrigues, Gao, AF, Palladino, ApJ 2019

Neutrino-bright masquerading FSRQ model

- 5 neutrinos
- Energy "hidden" in MeV and X-ray bands
- Disk temperature and intensity consistent with expectations
- Some tension in γ-rays





- External disk and broad line radiation blue-shifted into blob-frame
- **Boosts neutrino prod.-efficiency & γ-ray absorption simultaneously**

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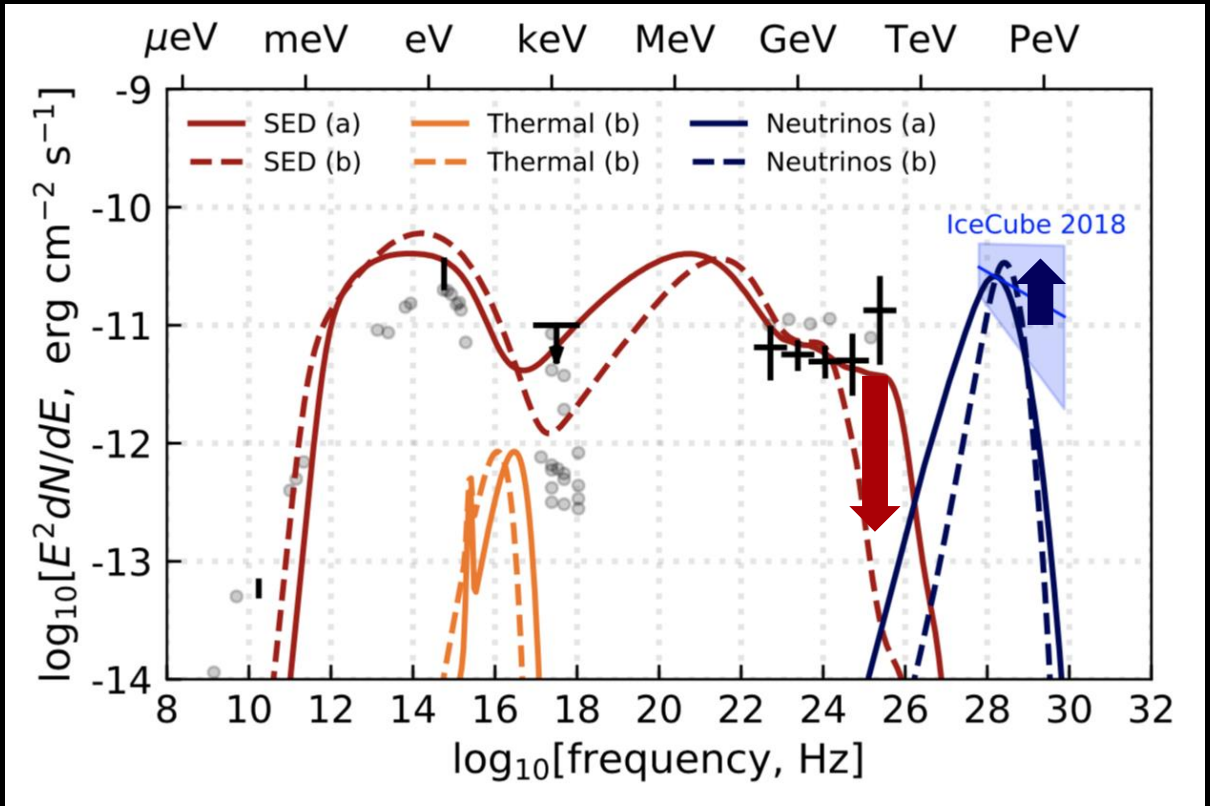

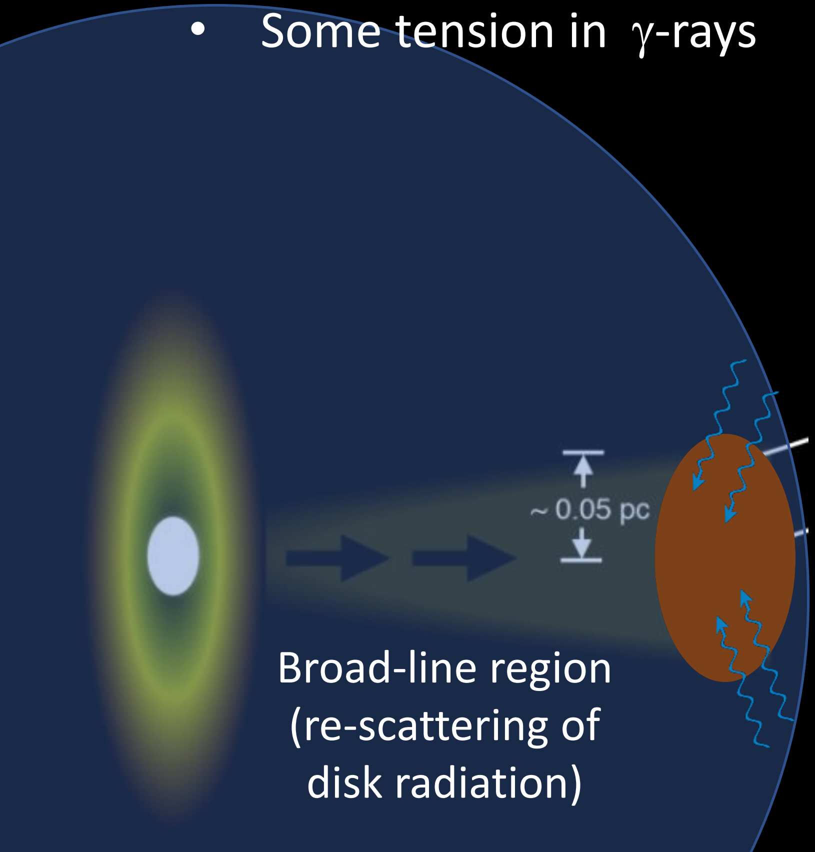

- External disk and broad line radiation blue-shifted into blob-frame
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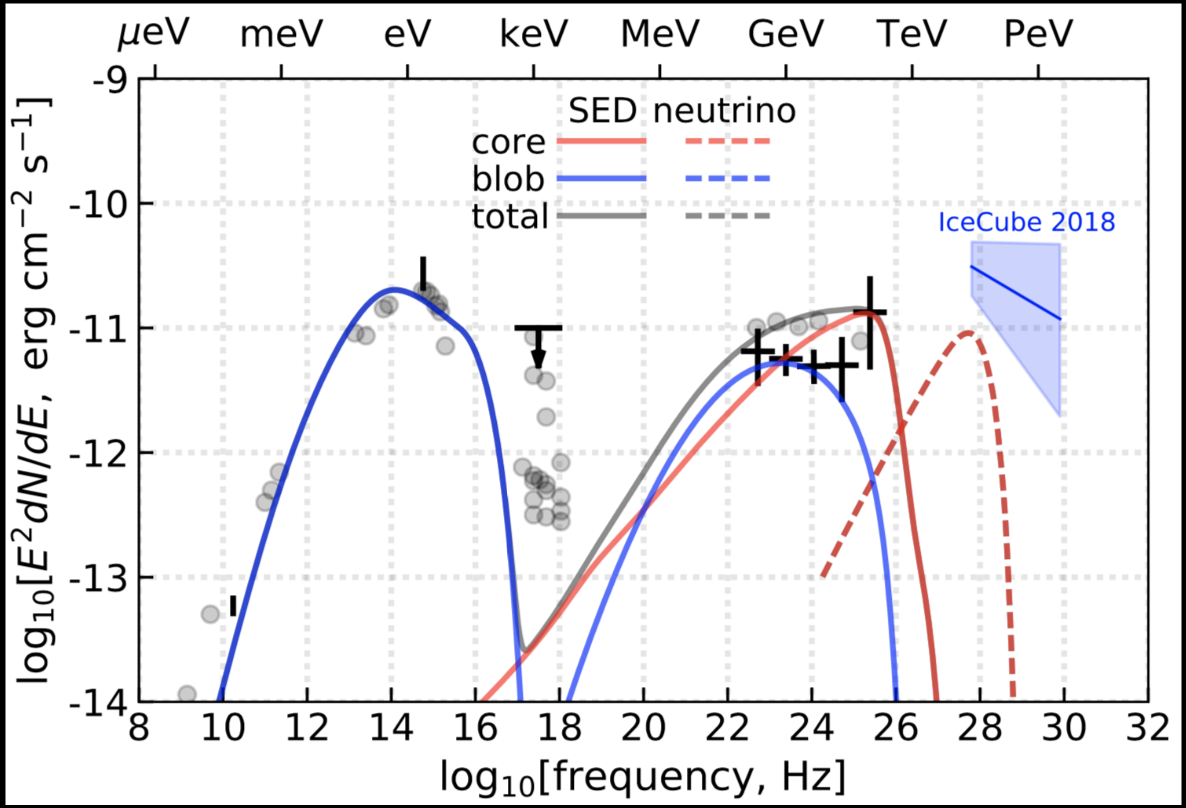
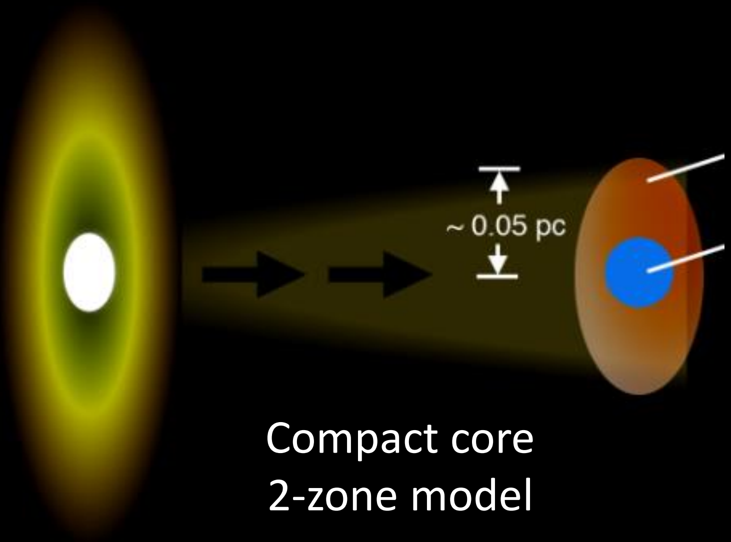
Neutrino-bright compact core model

- 1.8 neutrinos ☹
- Low X-ray flux
- IC-dominated core
- …clearly missing multi-wavelength data





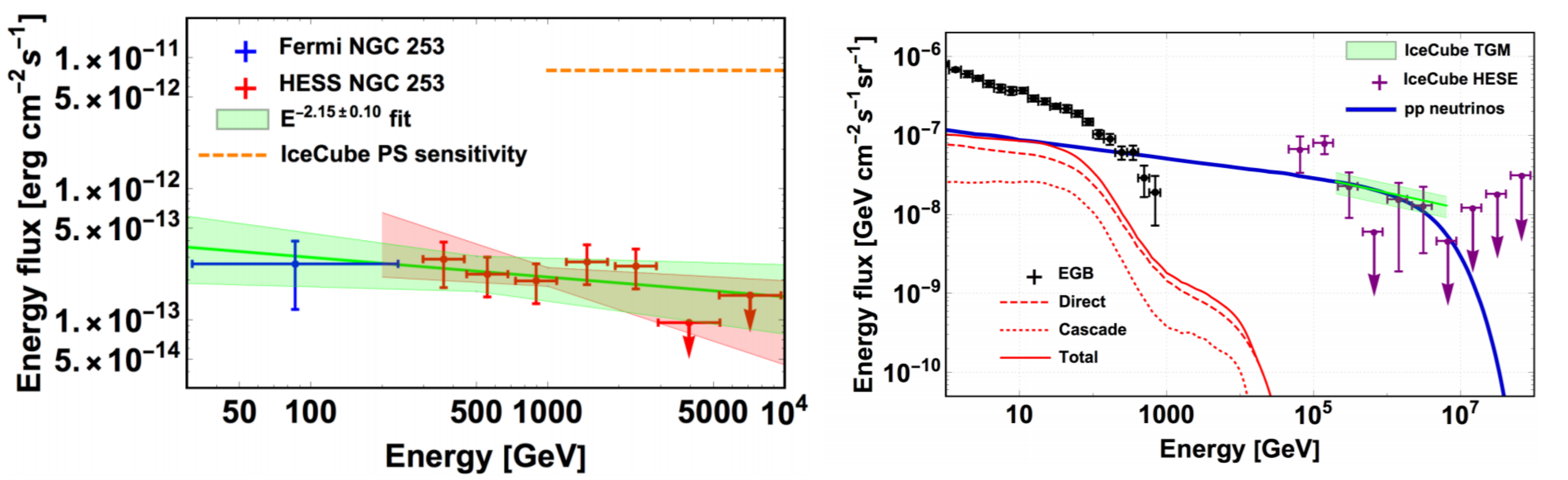
Compact core
2-zone model

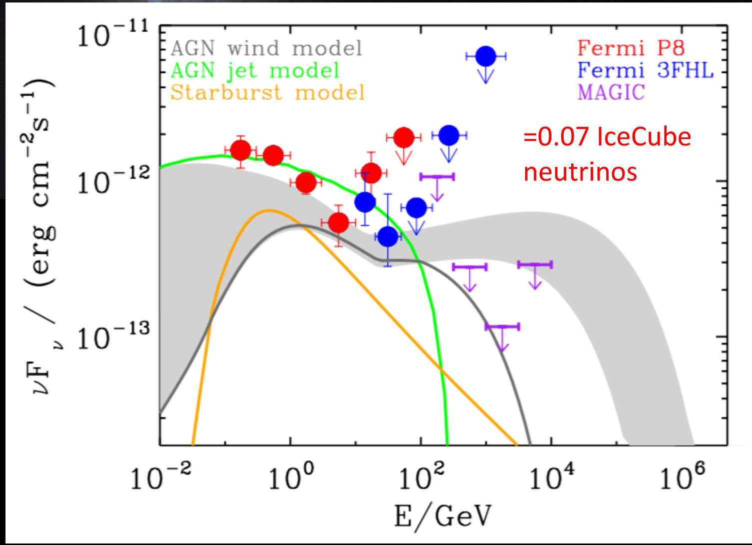
- Consistent transition between neutrino-dim and –bright states
- **Slight hardening in γ-rays expected, but no signature in other bands**

“Well-behaved neutrino” sources - HAGS

- HAGS= HAdronically Powered Gamma-ray galaxieS
- Classical “proton-proton” sources, explain in principle~80% of neutrino flux
- Fixed relation between observed gamma-ray and neutrino flux
- Worse case scenario for neutrino astronomy because faint + numerous
- More measurements (CTA) needed to identify max. acceleration

NGC1068: Acceri et al. (MAGIC), ApJ 883 2019

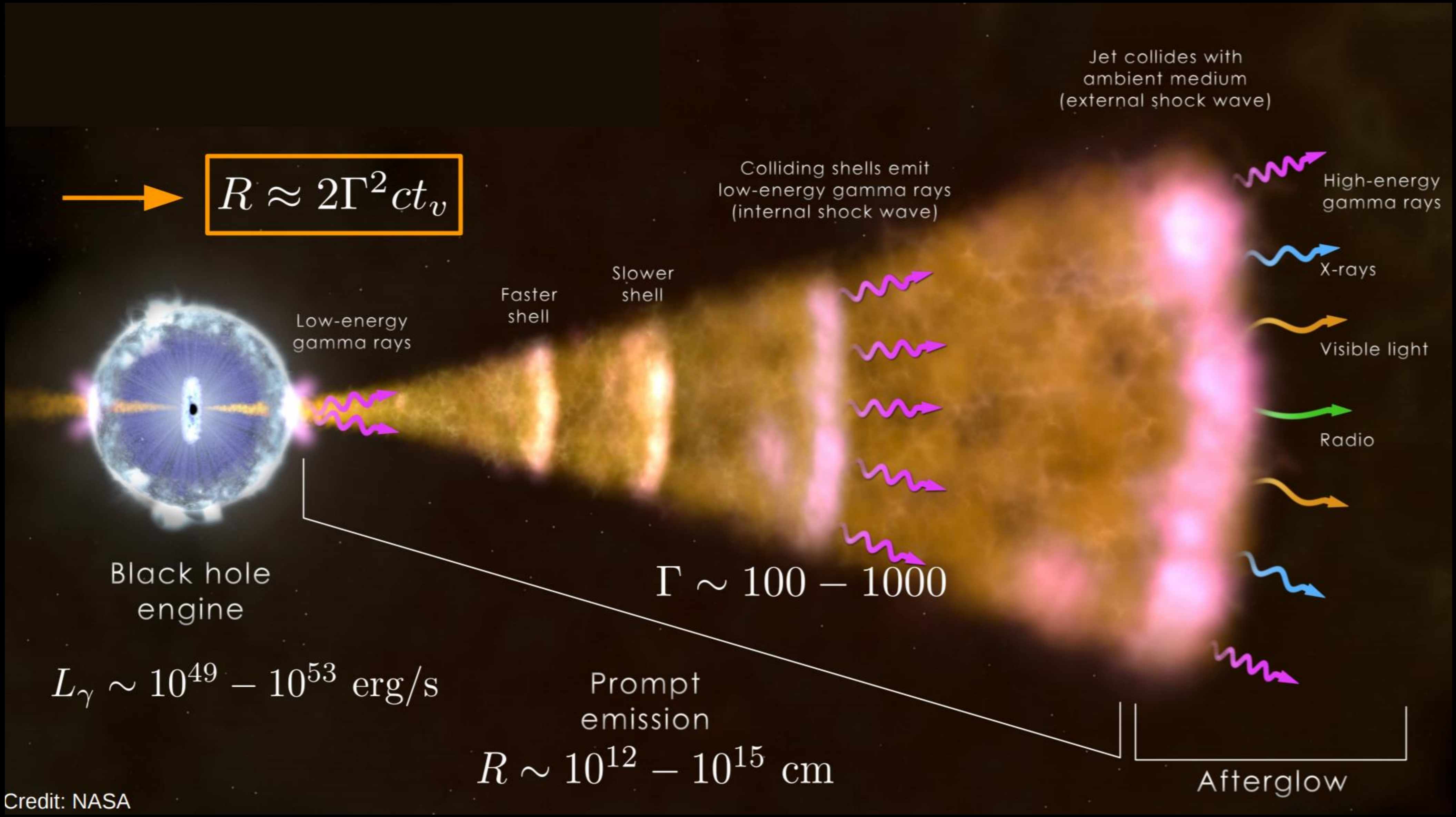




Palladino, AF, Rasmussen, Taylor JCAP 2019

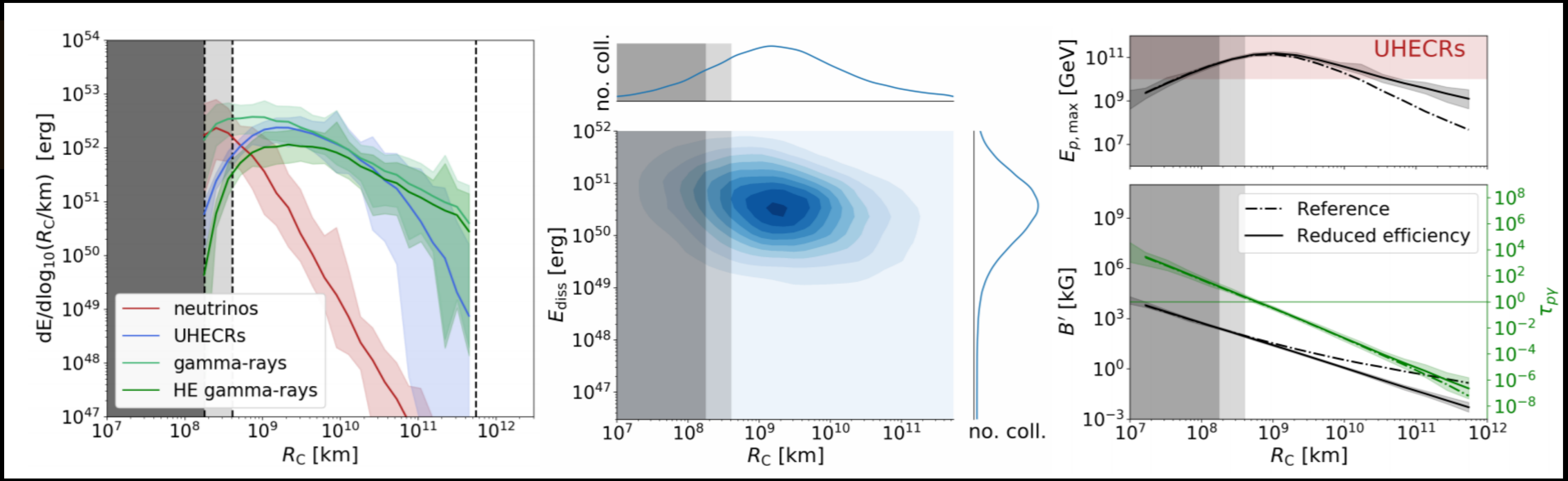
…also see Peretti et al. 1911.06163

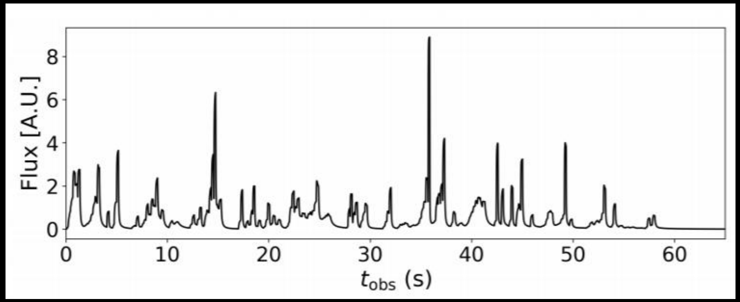
GRBs as common sources of neutrinos and UHECR



Production of multiple messenger in internal shocks

Rudolph, Heinze, AF, Winter, 1907.10633

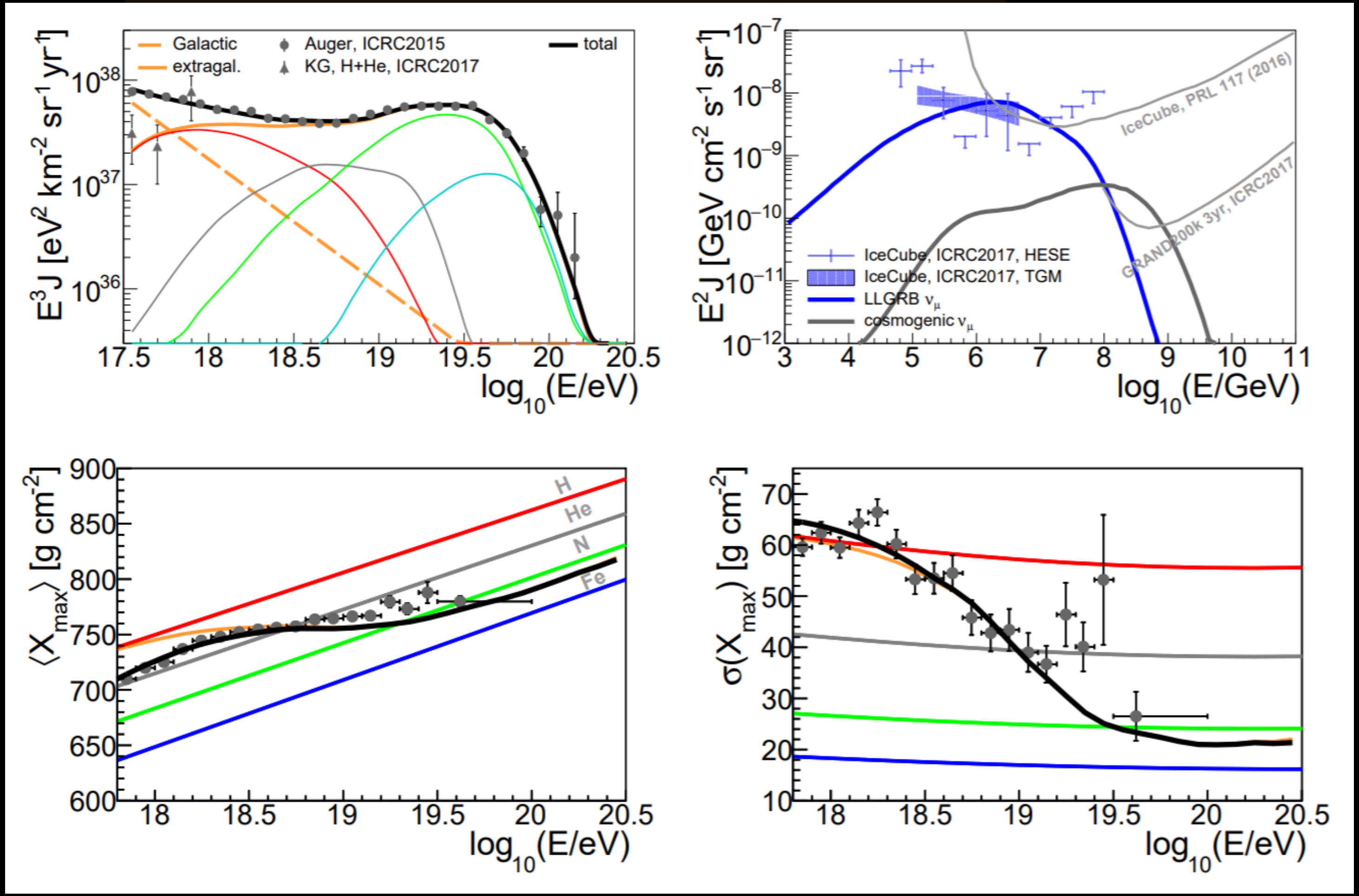


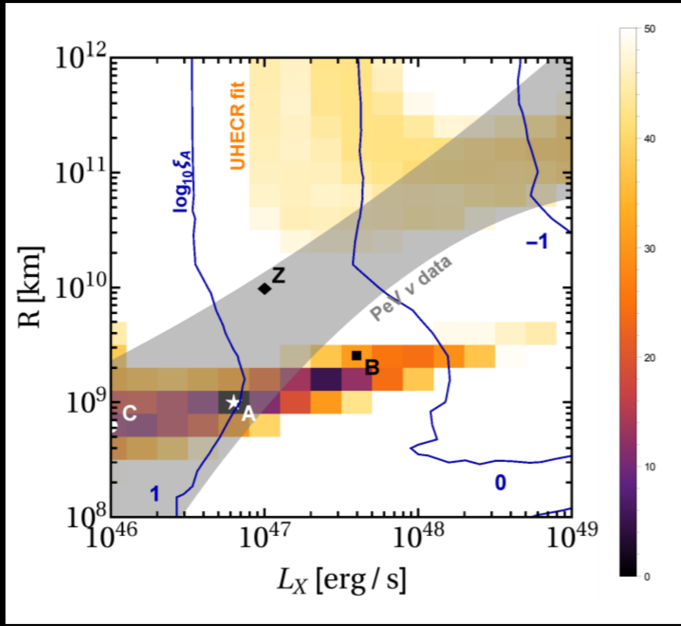


- Fully self-consistent radiation model not yet implemented incl. nuclei, neutrinos, etc.
- Multi-collision models approximate the jet dynamics and multi-messenger emission
- Messenger emission at different radii/times. Signature in spectrum or light curve of the prompt phase possibly visible (just light curve not enough)

GRBs as common sources of neutrinos and UHECR

Biehl et al, ApJ 872, 2019





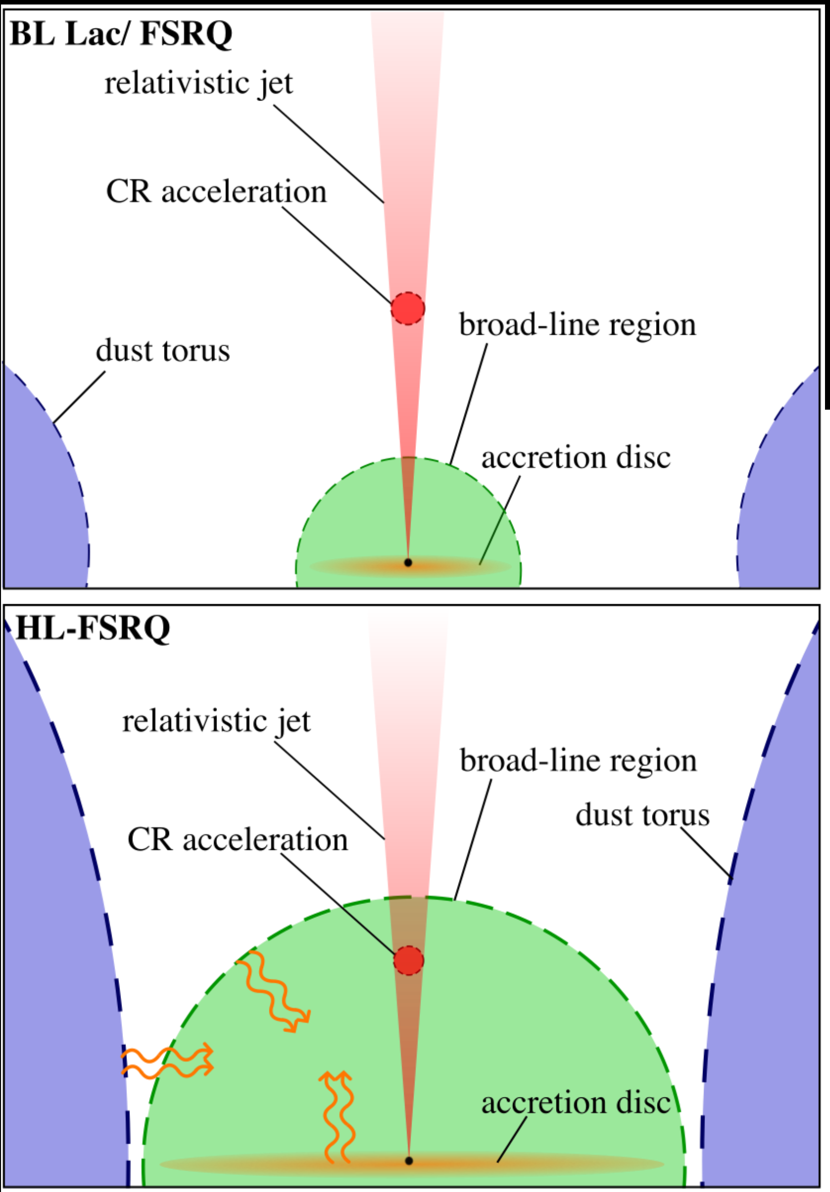
- Possible
- Many uncertainties: source density can vary by few orders of magnitude

Final remarks

1. The TXS observations not enough to claim that blazars are the sources of all IceCube neutrinos
2. Neutrino emission from blazars is (unsurprisingly) more complicated as we have hoped it to be (complex geometries, multiple zones)
3. This source can be an outlier, i.e. all source candidates still on the list
4. More multi-wavelength observations (opt. + X-Ray + Gamma) & better alert handling required and in progress
5. Theoretical tools for radiation modeling not yet established/created, far from common practices in LHC physics
6. Multimessenger astrophysics is a still an emerging field, with novel data coming in, lots of hope and talented people

BL Lacs vs Flat Spectrum Radio Quasars (FSRQ)

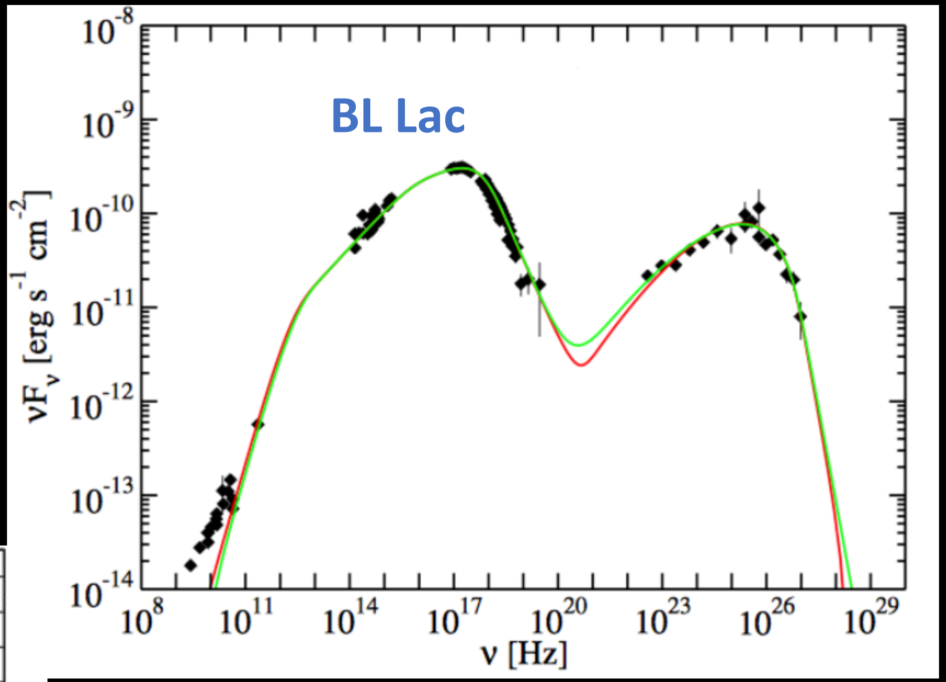
Rodrigues, AF, Gao, Boncioli, Winter, ApJ 854 (2018)

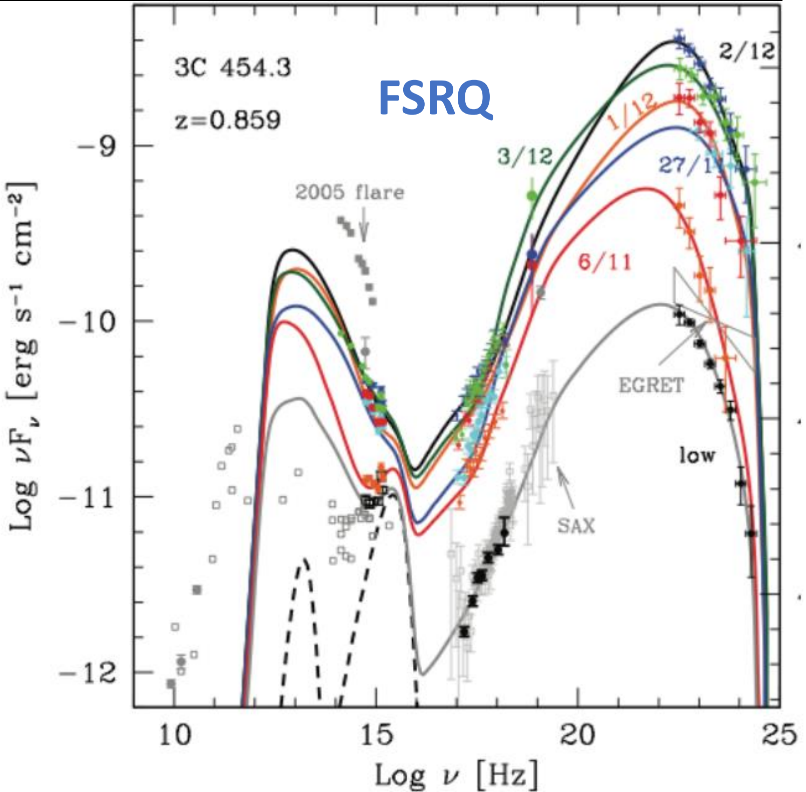


BL Lac:

1. (left) Synchrotron hump
2. (right) inverse Compton hump
3. No lines, no dust, etc.
4. Less luminous than FSRQ

Abdo+ 11





FSRQ:

1. Line, disk and thermal emission
2. High luminousity (high second peak)
3. Low maximal photon energy

Bonnoli+ 11

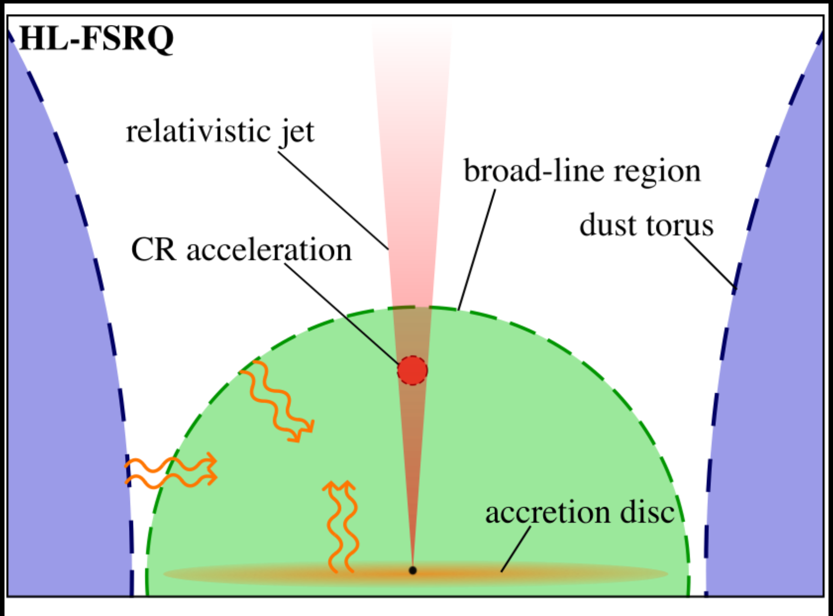
TXS is probably not a BL Lac

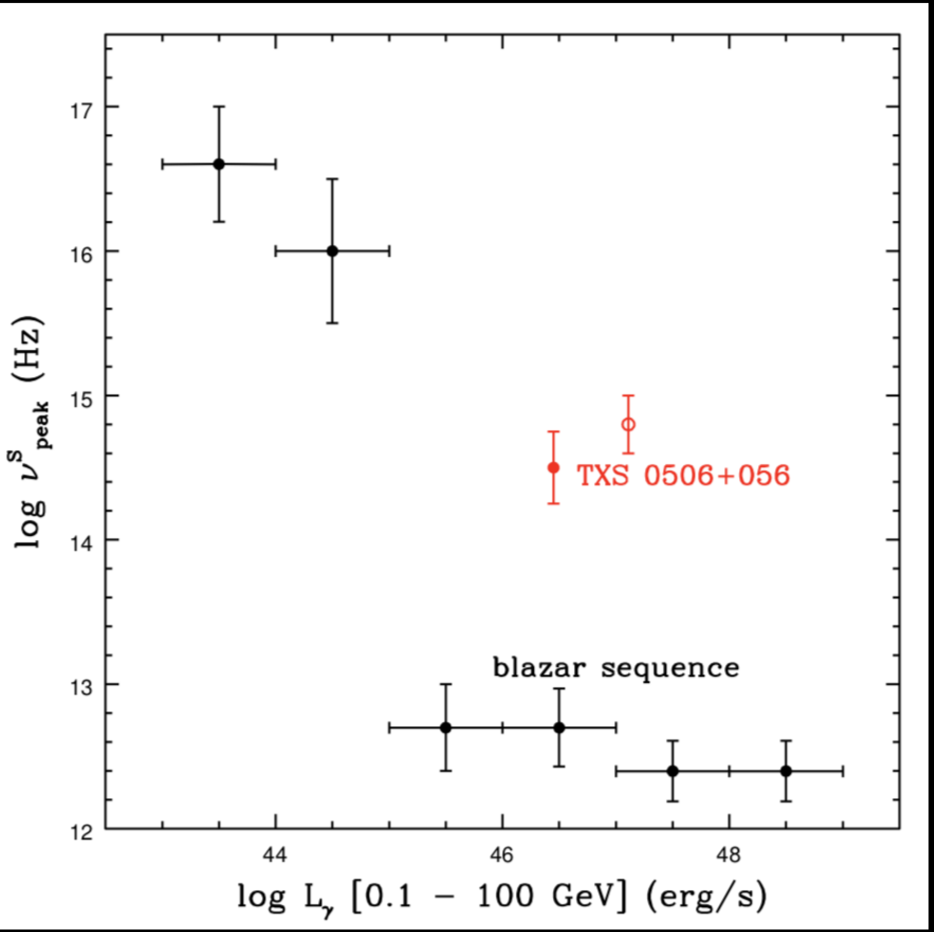
Outlier?

1901.06998, acc. in MNRAS

TXS 0506+056, the first cosmic neutrino source, is not a BL Lac

P. Padovani[1,2]★, F. Oikonomou[1], M. Petropoulou[3], P. Giommi[4,5,6], E. Resconi[7]



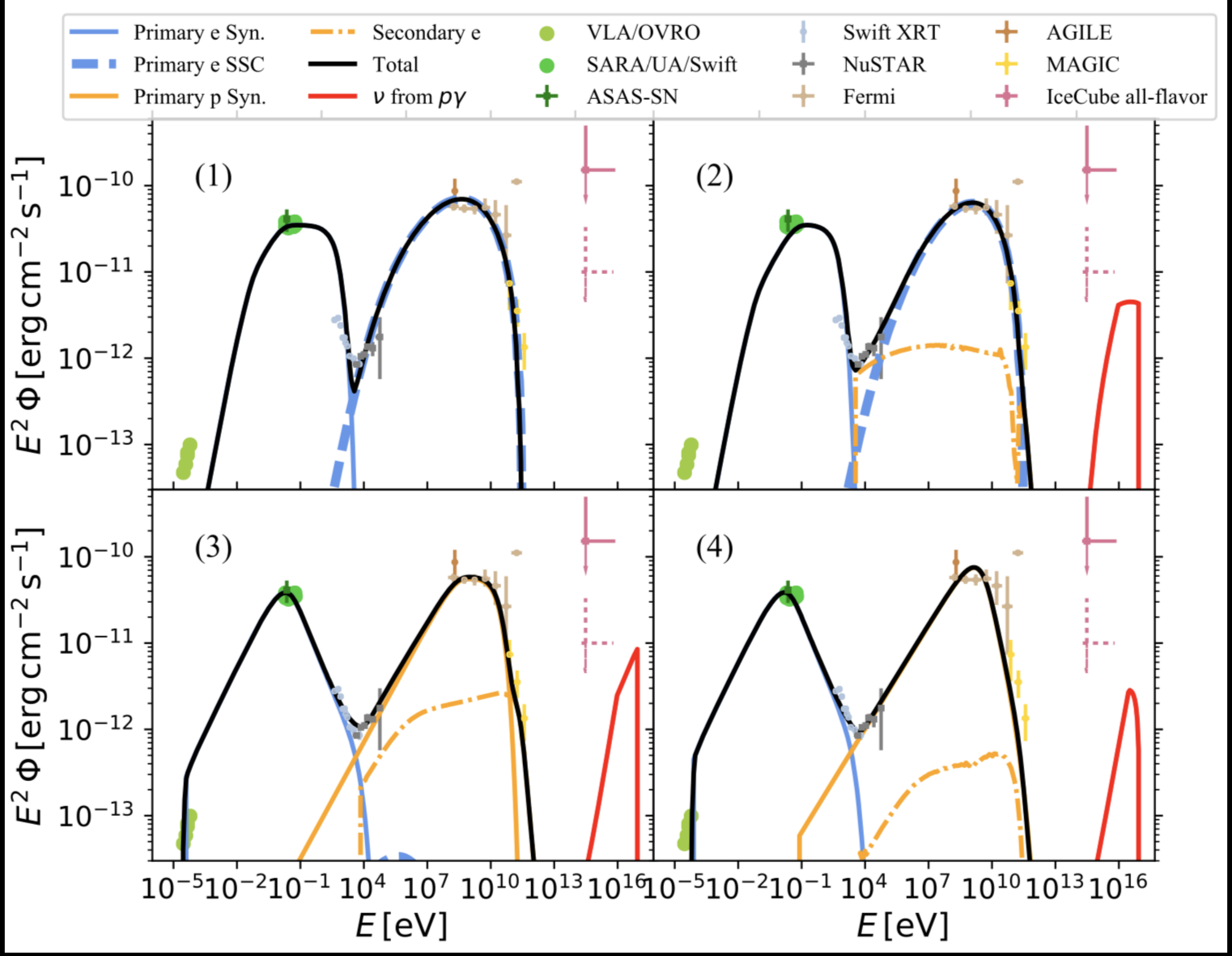


- The emission from the jet outshines the broad lines
- A combination of indications support this hypothesis
- Additional target photons from external photon fields powered by disk

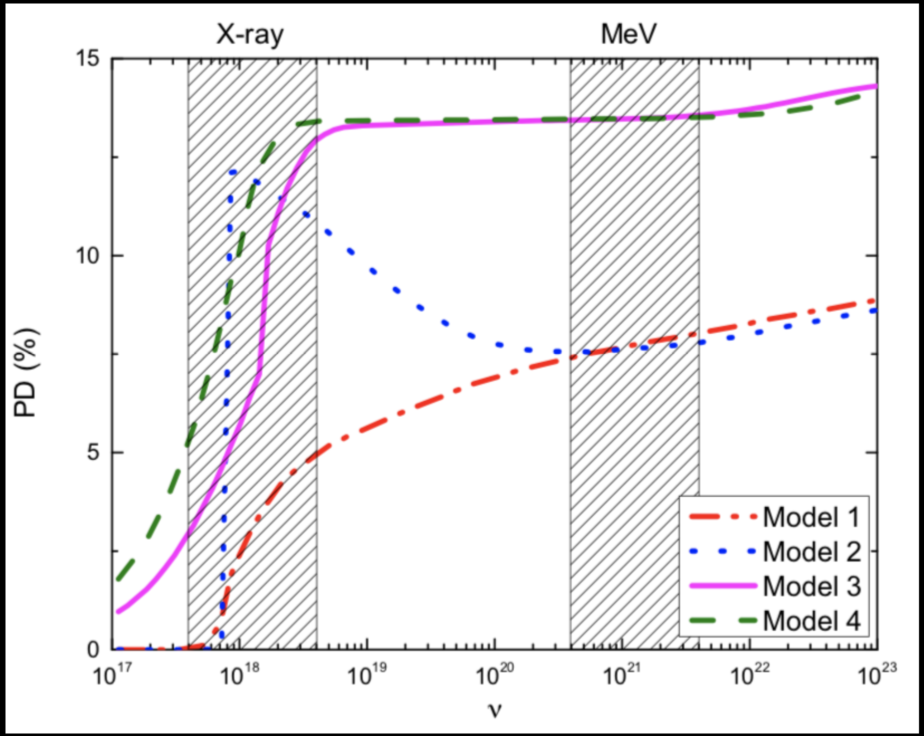
Constrain SED degeneracies and ν production mechanism?

PROBING THE EMISSION MECHANISM AND MAGNETIC FIELD OF NEUTRINO BLAZARS WITH MULTI-WAVELENGTH POLARIZATION SIGNATURES

HAOCHENG ZHANG[1], KE FANG[2,3], HUI LI[4], DIMITRIOS GIANNIOS[1,5,6], MARKUS BÖTTCHER[7], SARA BUSON[8,9,10]



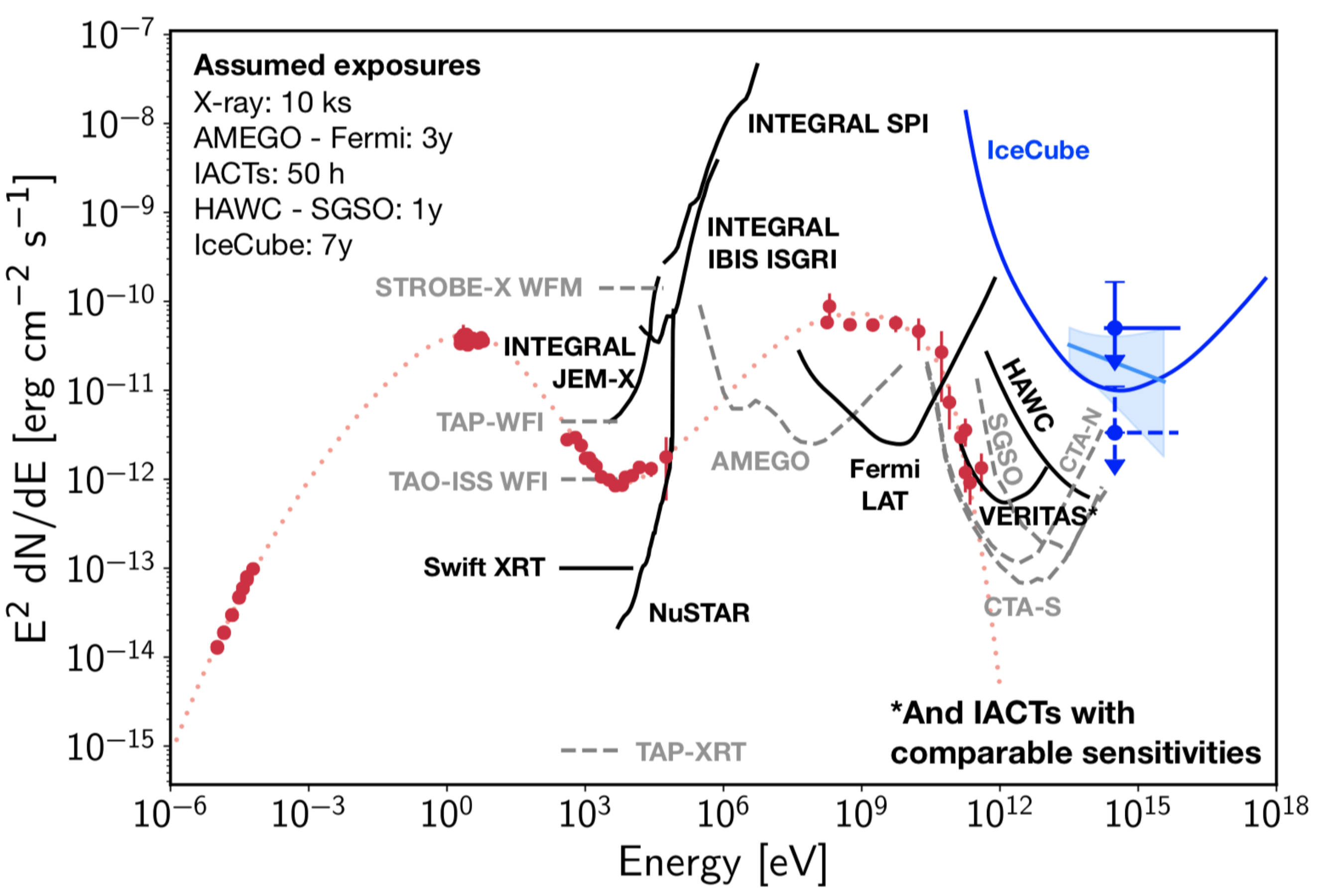
X-ray/γ-ray polarization & temporal variability disentangles scenarios

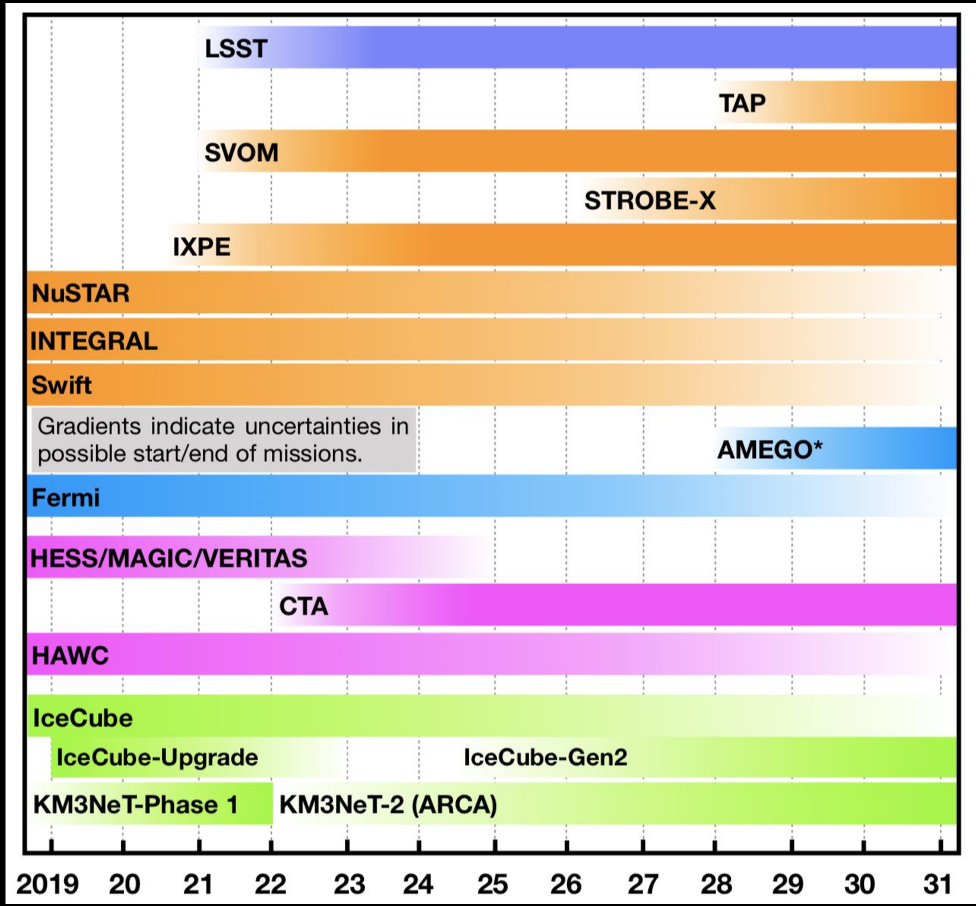


1903.01956

Future

Present and future instrument sensitivities

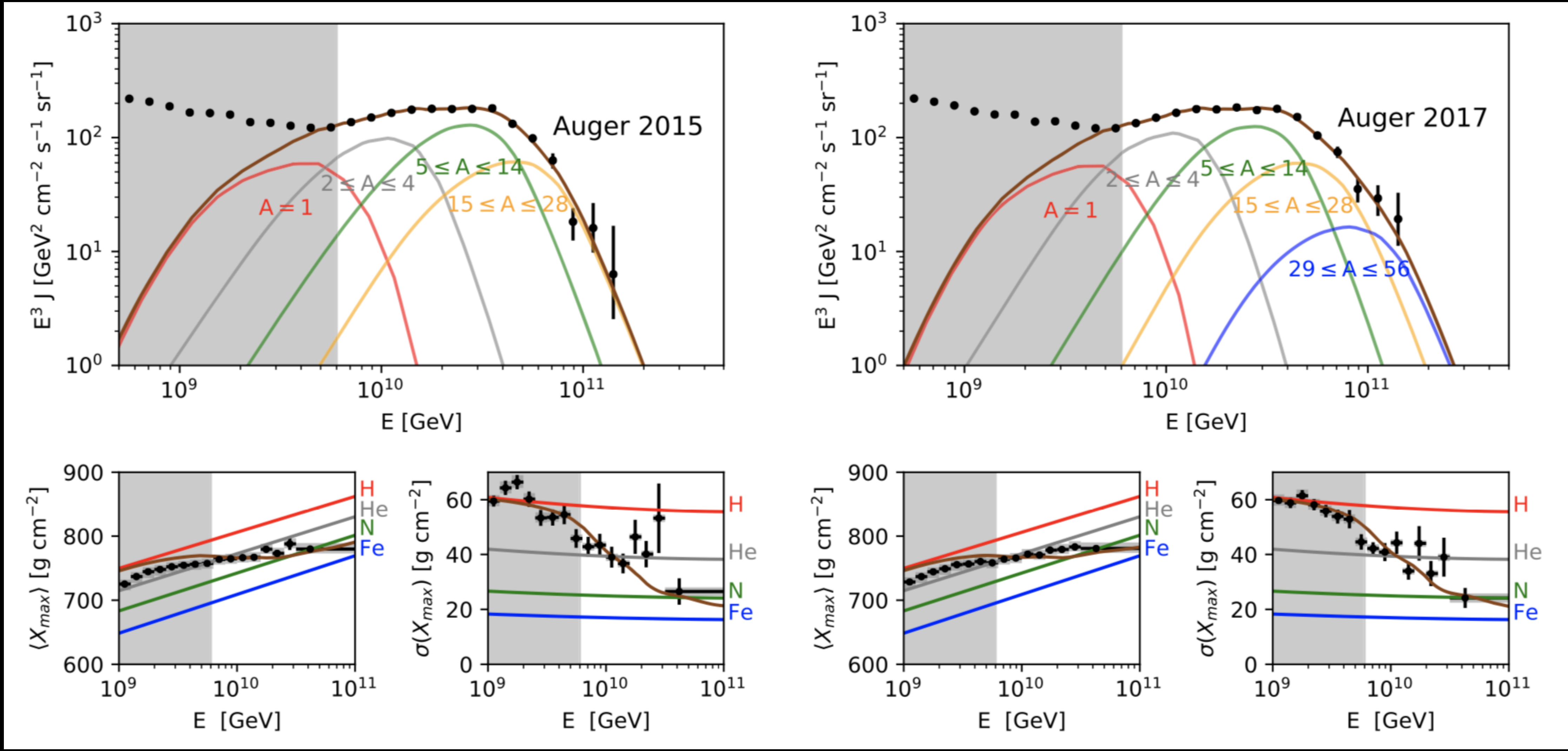




S. Buson et al., 1903.04447

Impact of “more data” on the fit

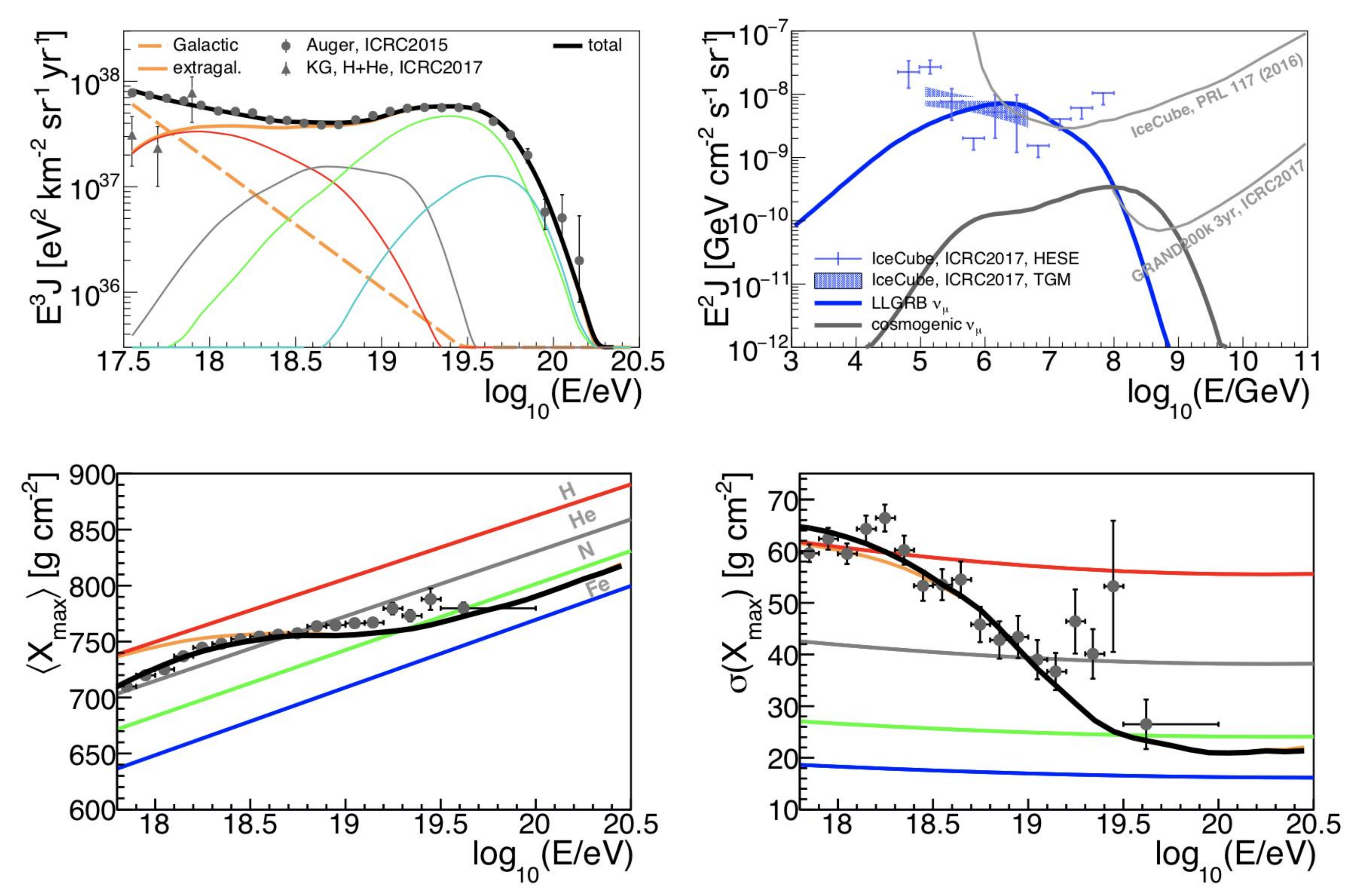
Heinze, AF, Boncioli, Winter, ApJ 873



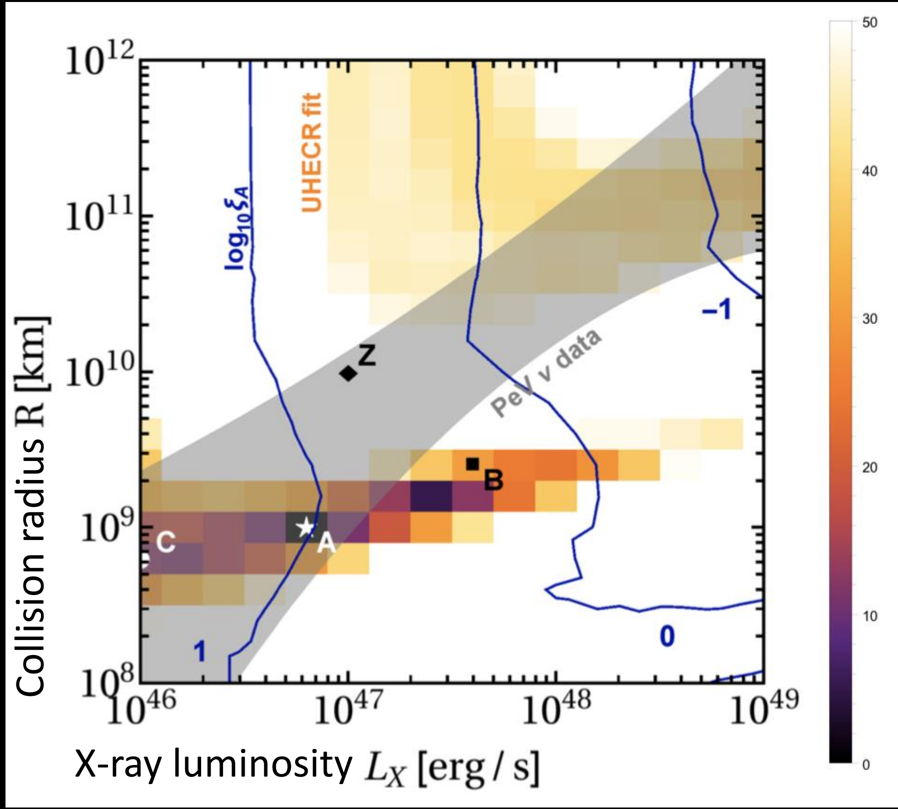
Fit conditions identical to Auger’s “Combined Fit”, i.e. flat evolution (m=0)

Multi-messenger results for low luminosity GRBs

Fit Auger spectrum and composition + diffuse IceCube neutrinos



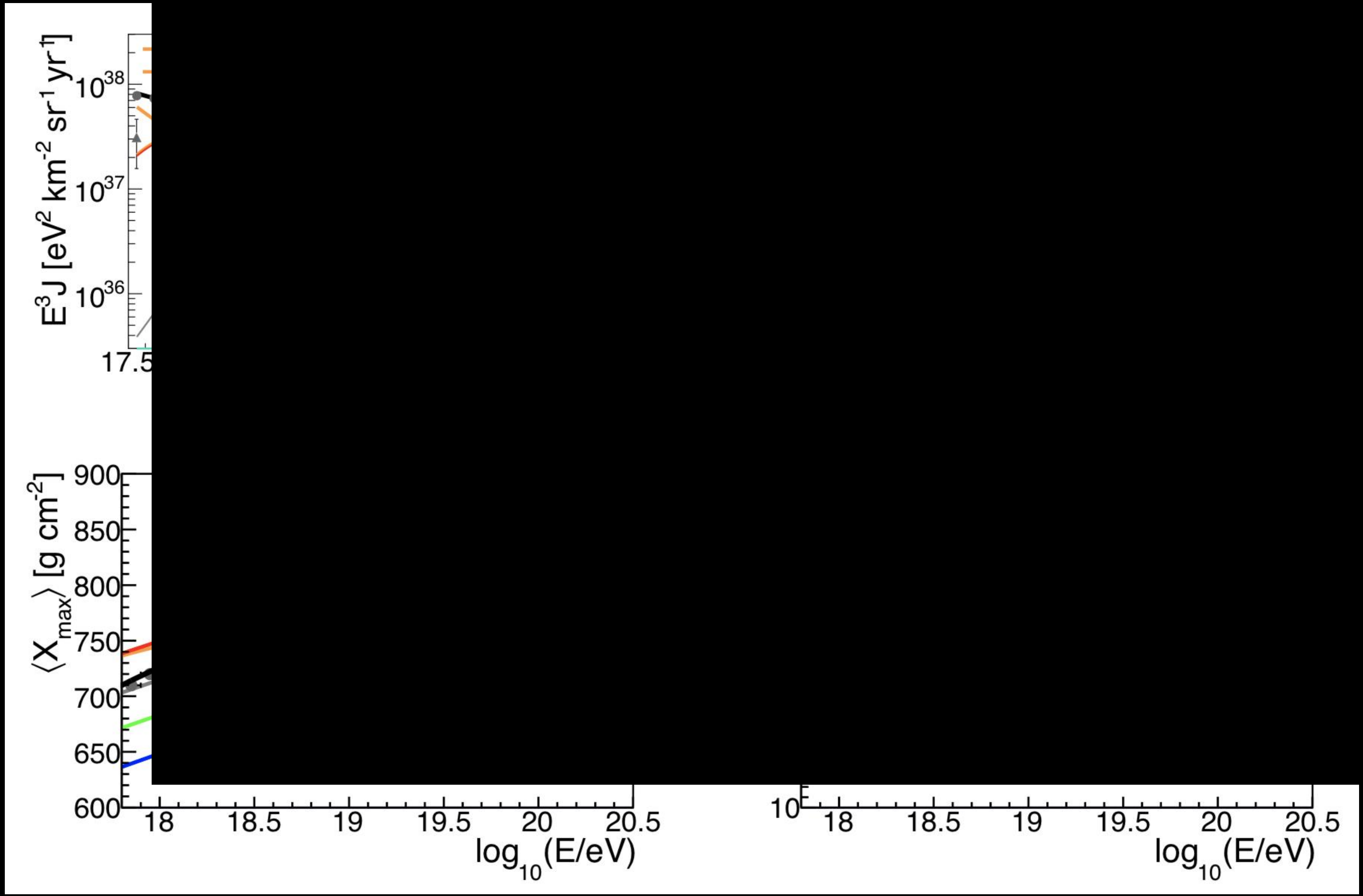
Infer source properties & compare to other observations



Boncioli, Biehl, Winter, 1808.07481

Multi-messenger results for low luminosity GRBs

Fit Auger spectrum and composition + diffuse IceCube neutrinos



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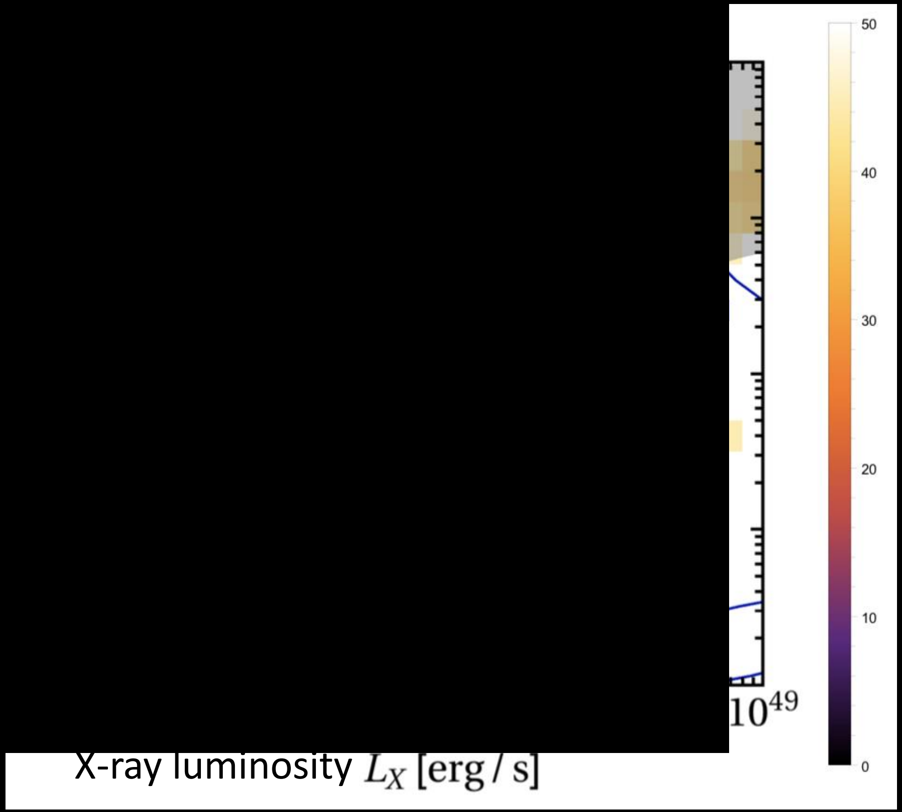
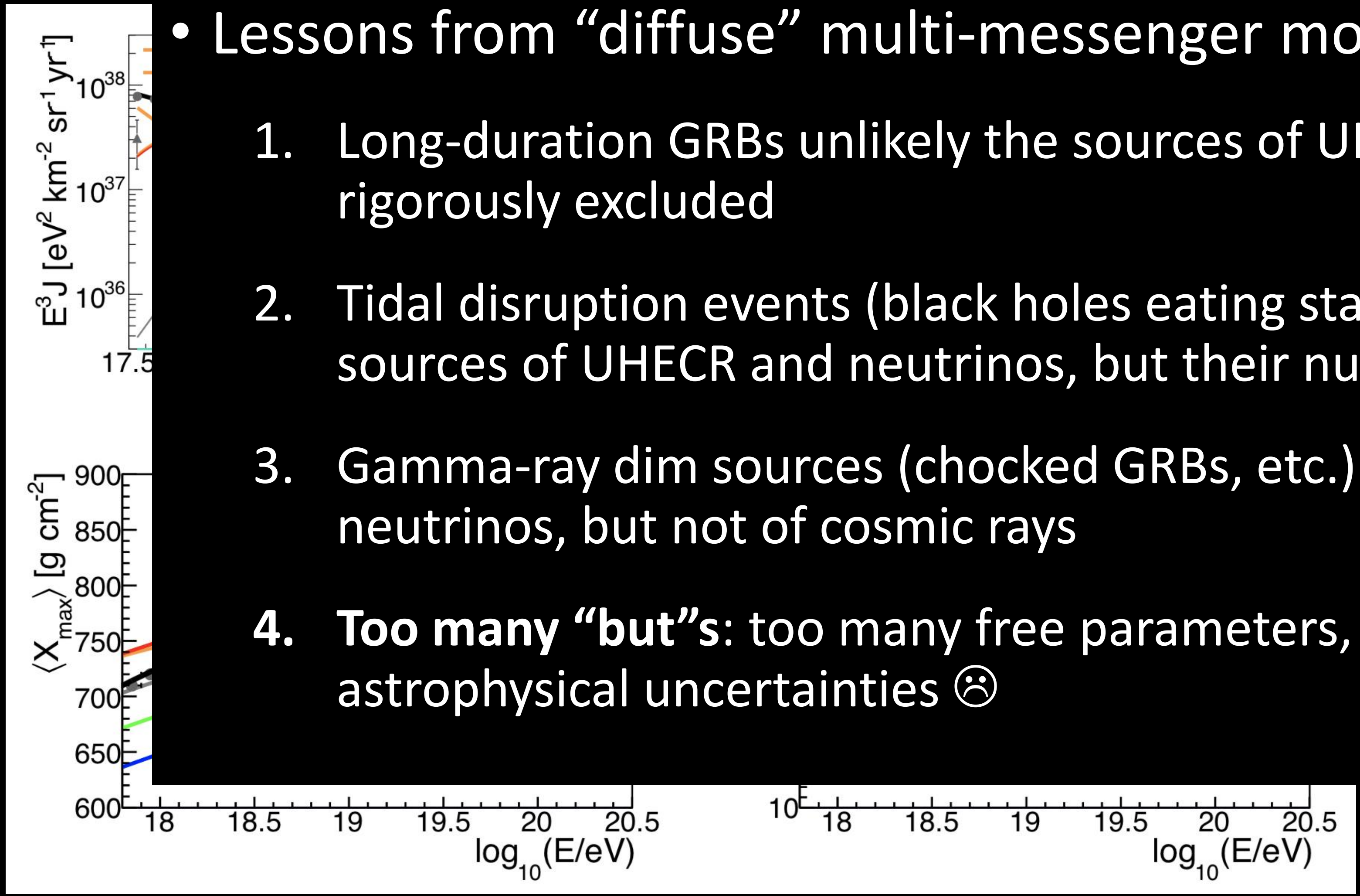


Boncioli, Biehl, Winter, 1808.07481

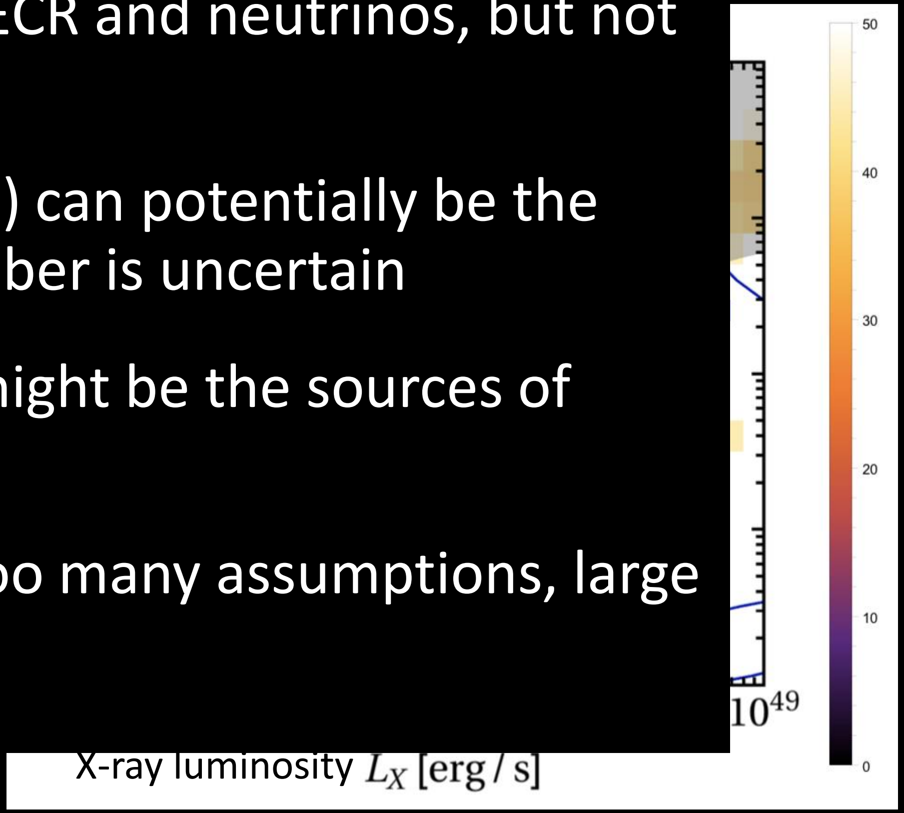
Multi-messenger results for low luminosity GRBs

Fit Auger spectrum and composition + diffuse IceCube neutrinos



- Lessons from "diffuse" multi-messenger models:

  1. Long-duration GRBs unlikely the sources of UHECR and neutrinos, but not rigorously excluded
  2. Tidal disruption events (black holes eating stars) can potentially be the sources of UHECR and neutrinos, but their number is uncertain
  3. Gamma-ray dim sources (chocked GRBs, etc.) might be the sources of neutrinos, but not of cosmic rays
  4. **Too many "but"s**: too many free parameters, too many assumptions, large astrophysical uncertainties ☹



Boncioli, Biehl, Winter, 1808.07481