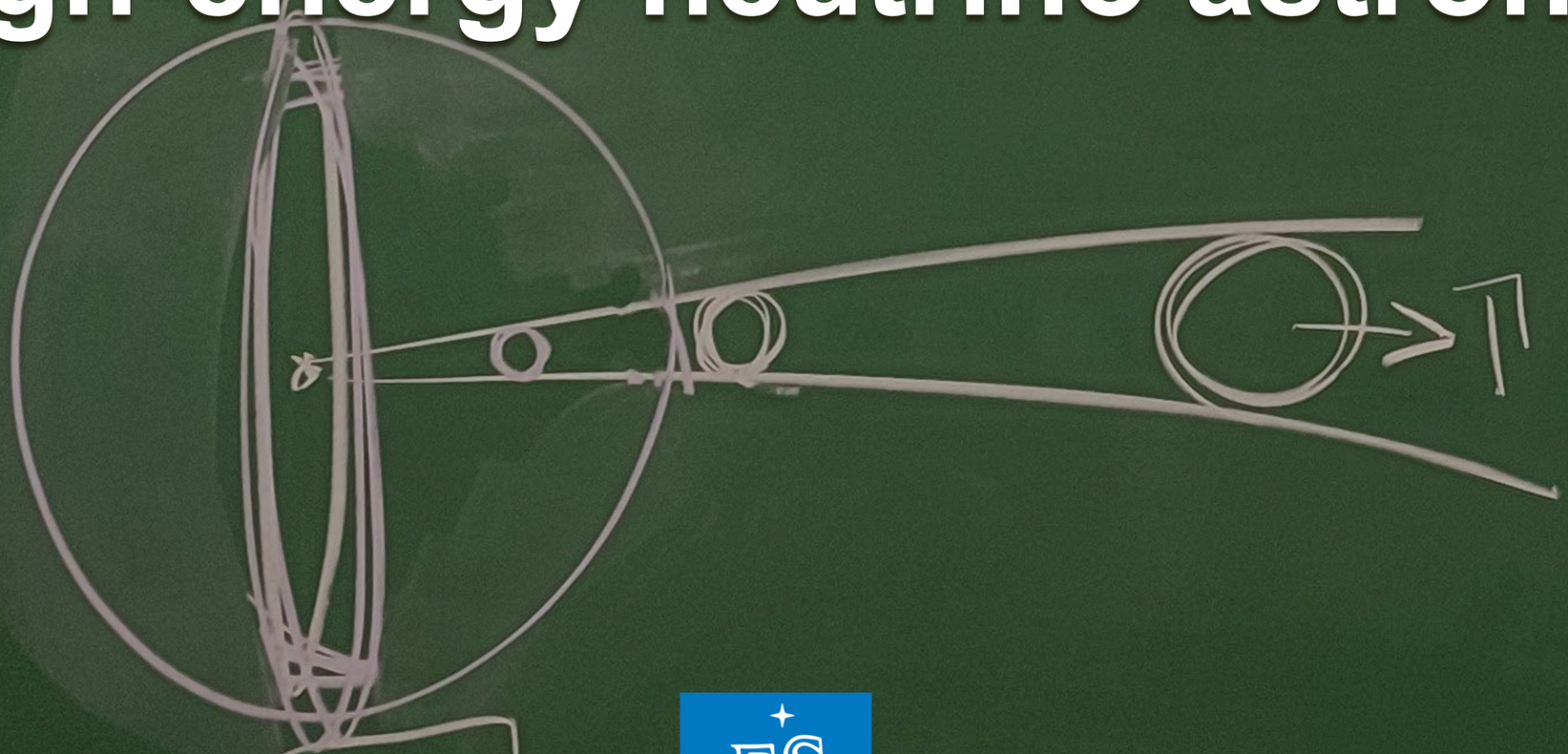
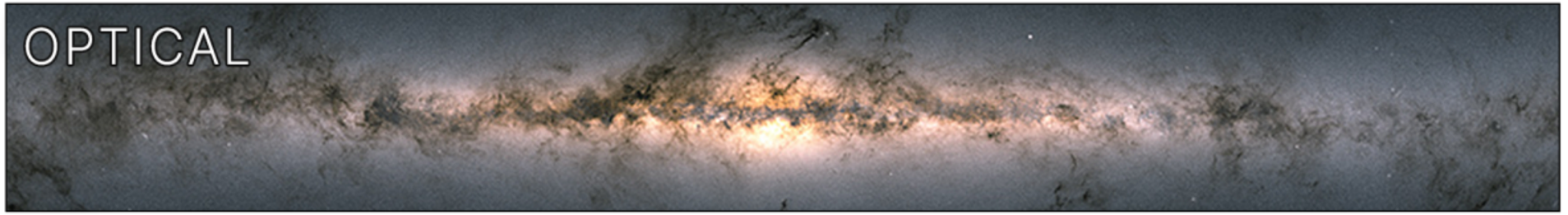
High-energy neutrino astronomy



Xavier Rodrigues

NuPhys2023
King's College, London, UK
December 18 2023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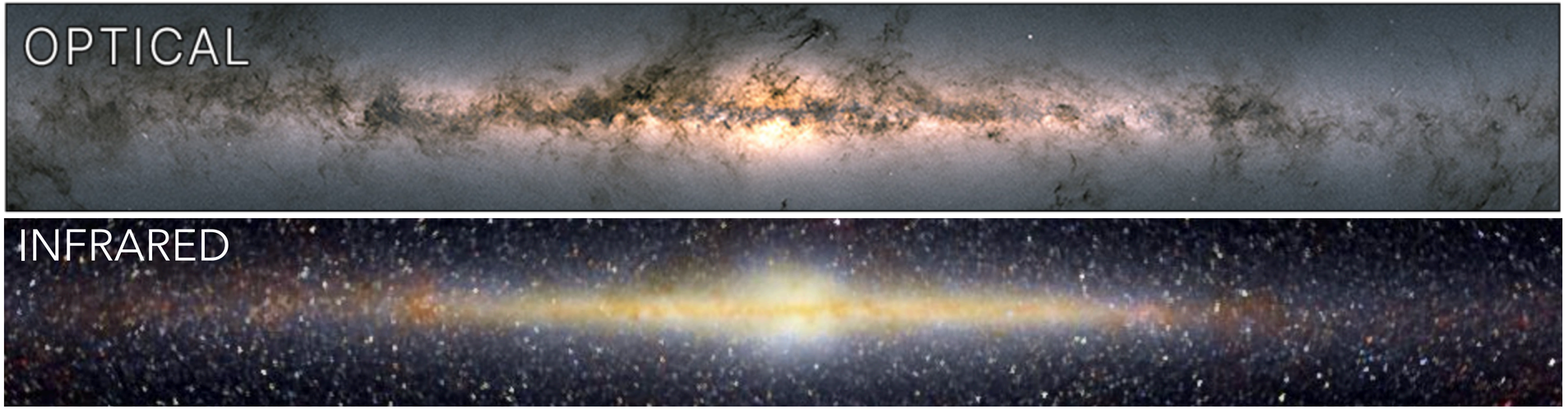
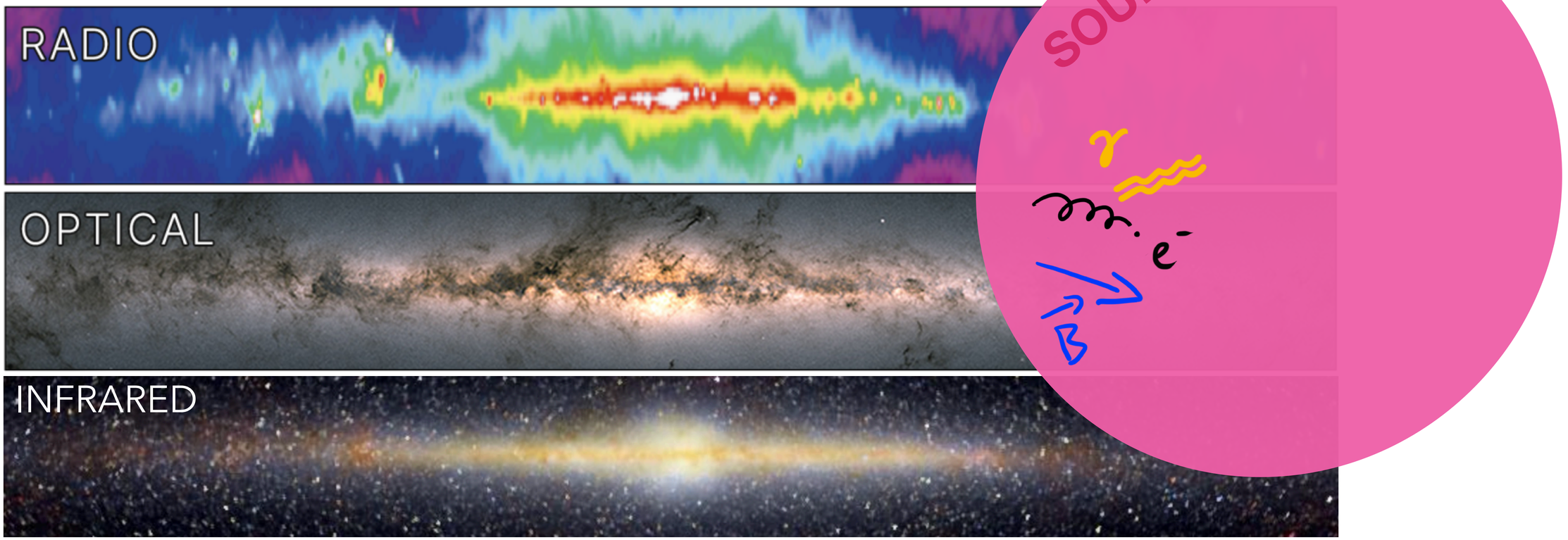

OPTICAL
INFRARED


RADIO
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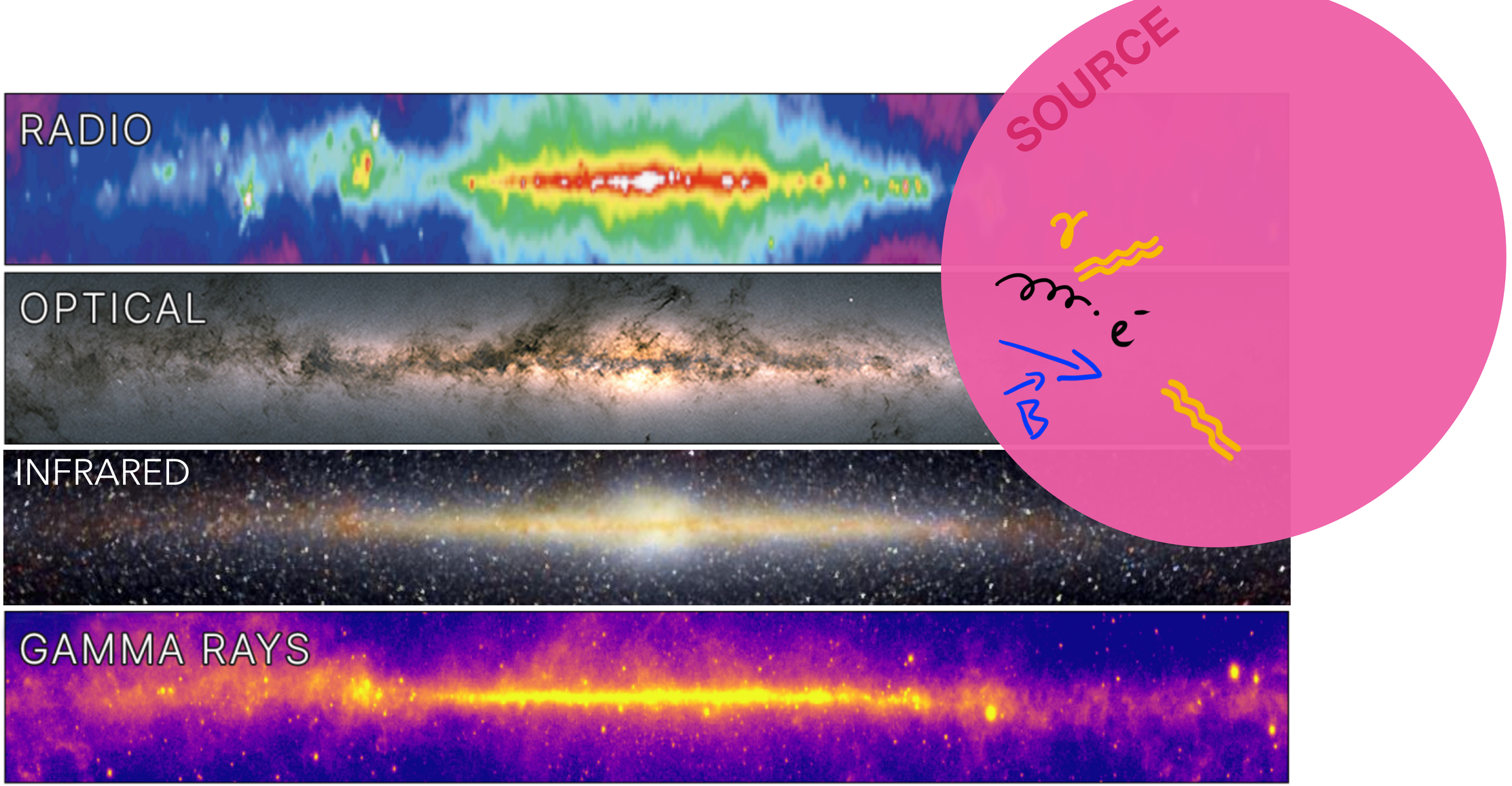
RADIO
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INFRARED
GAMMA RAYS
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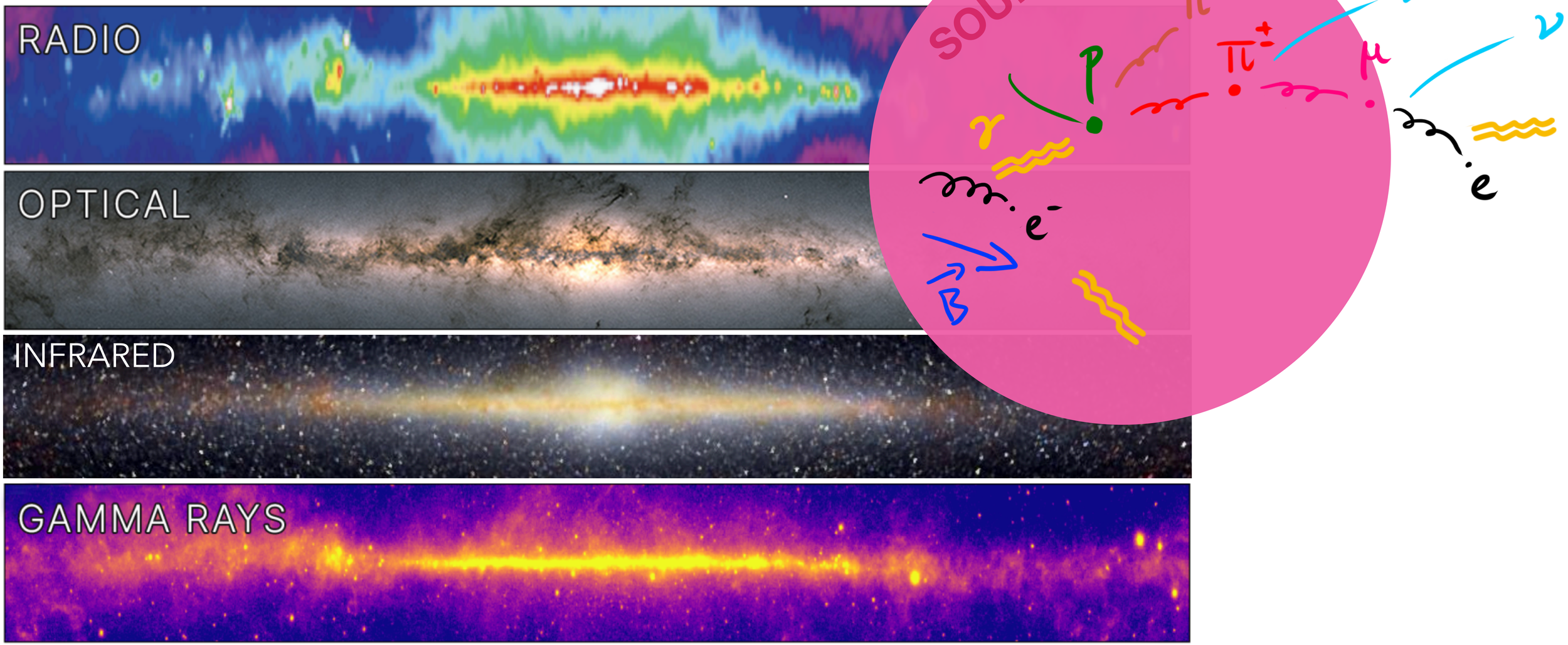
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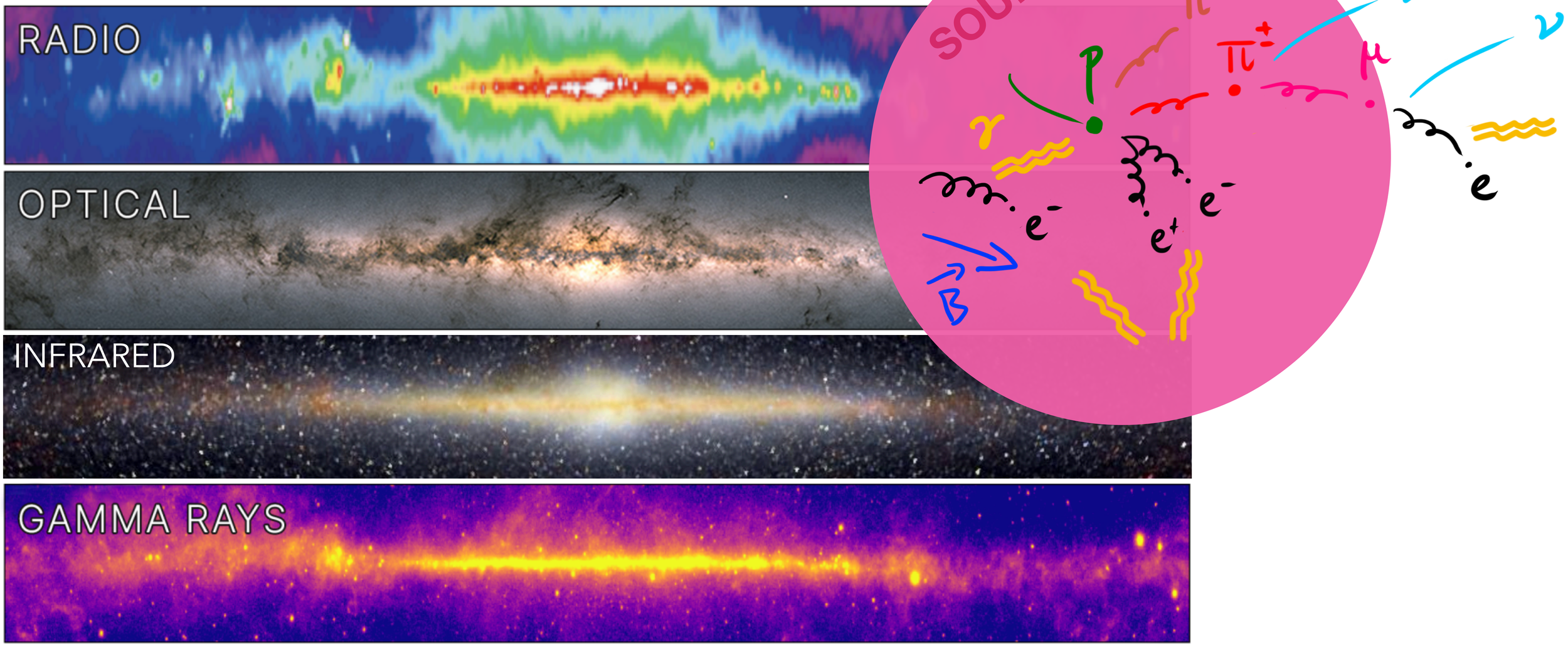
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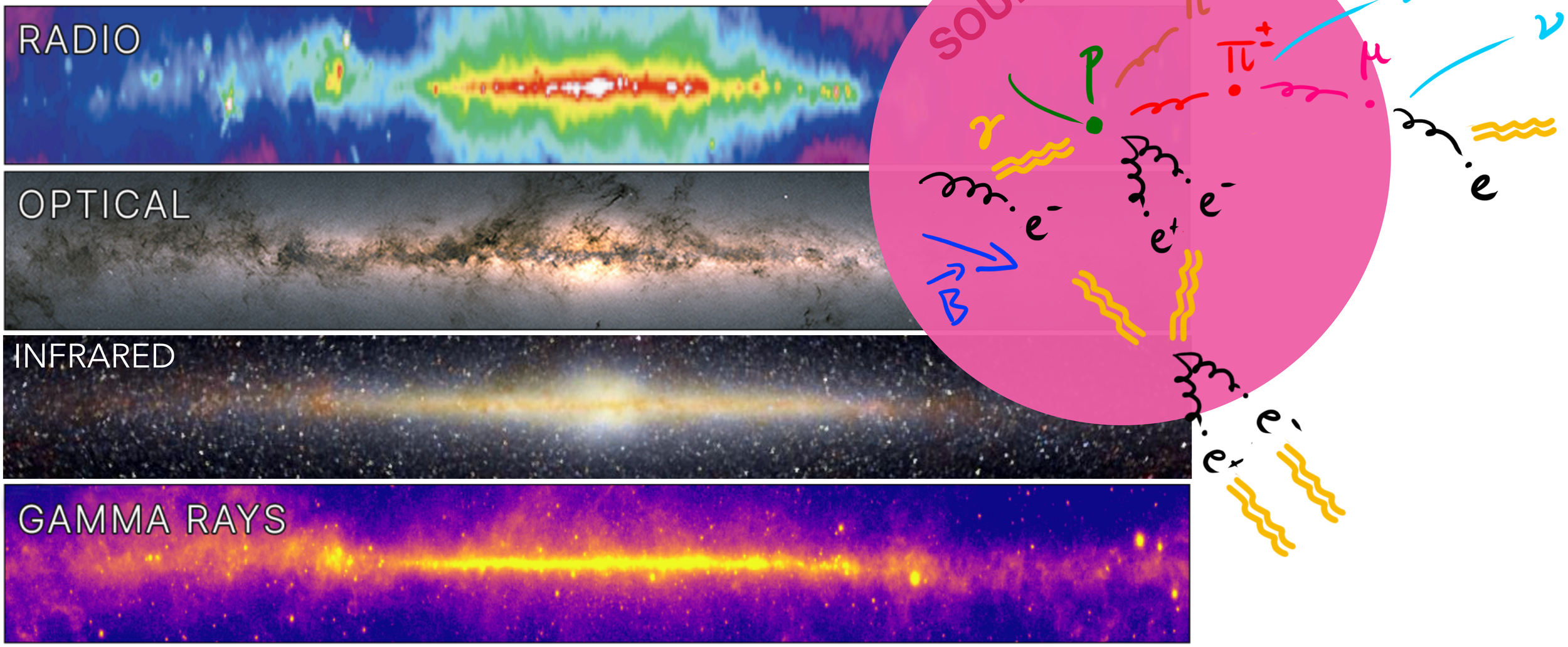
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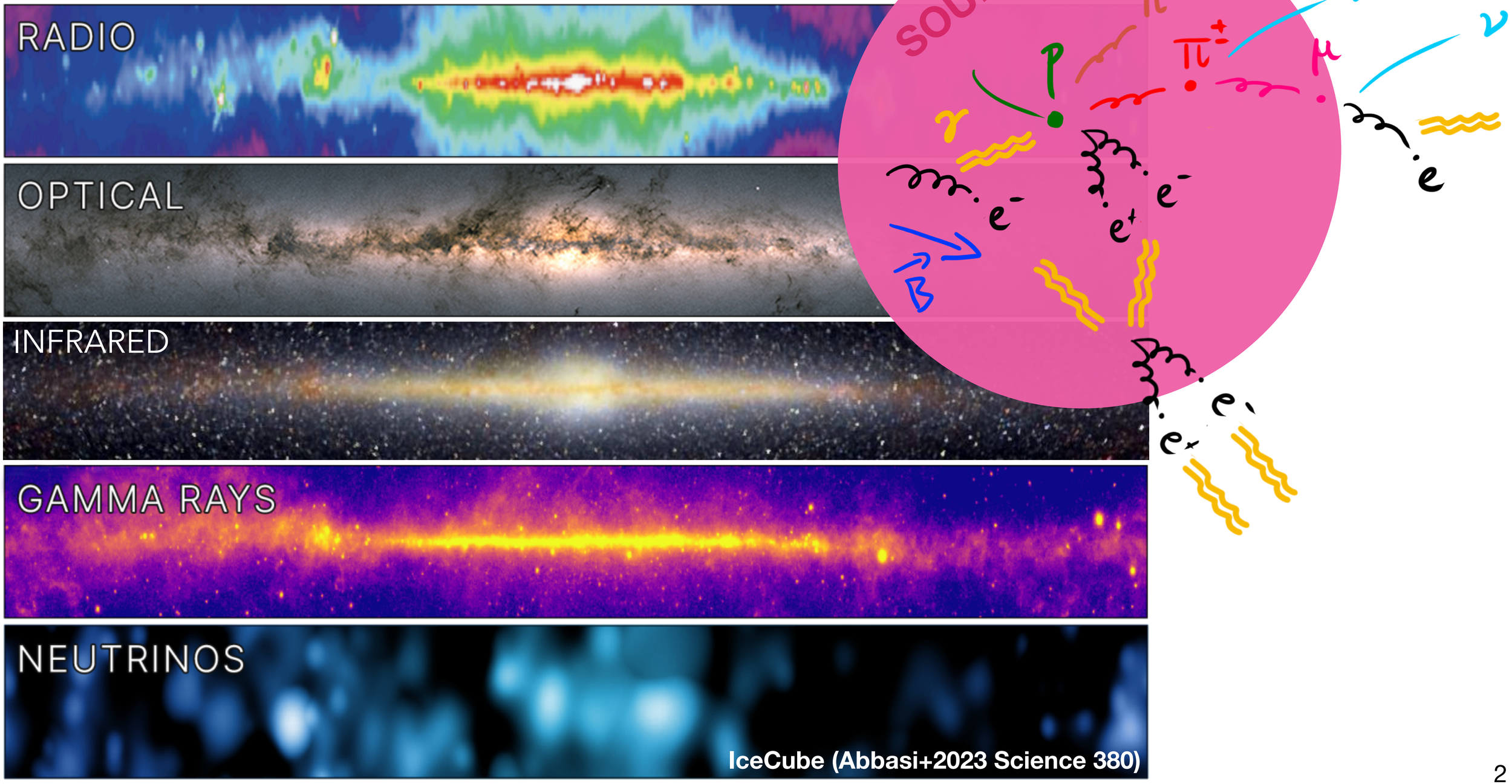
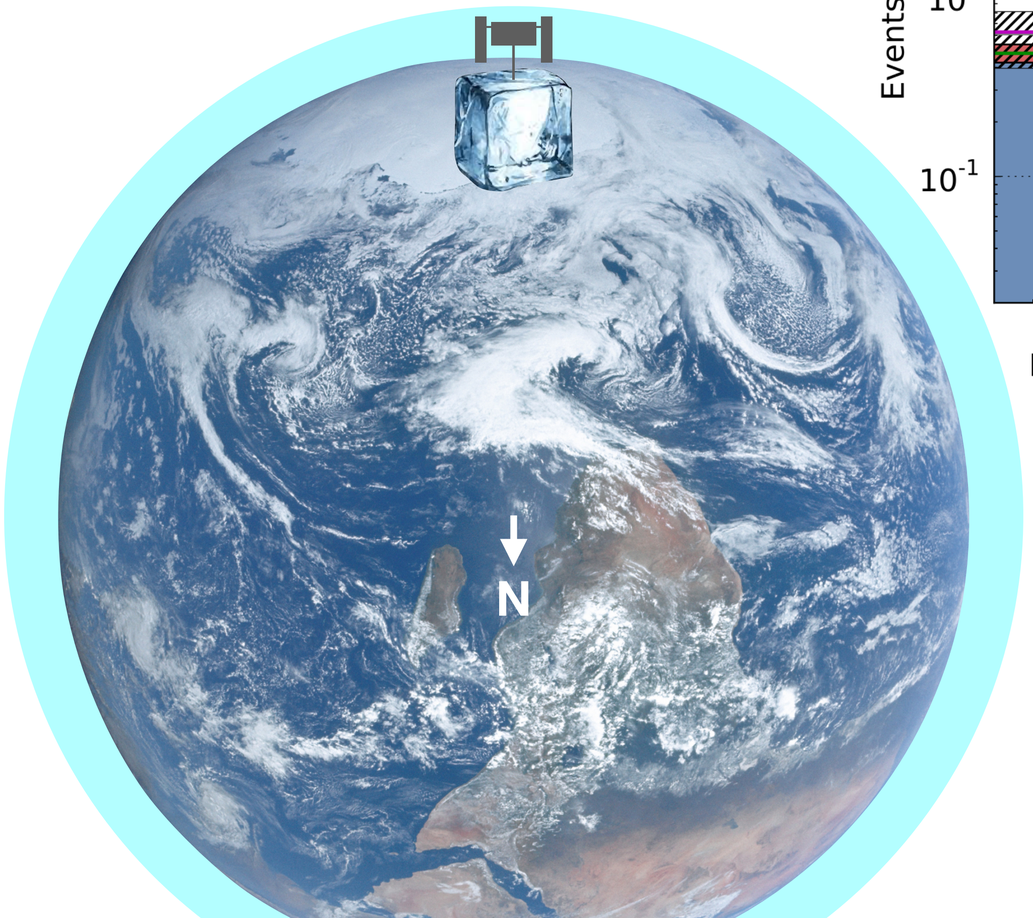
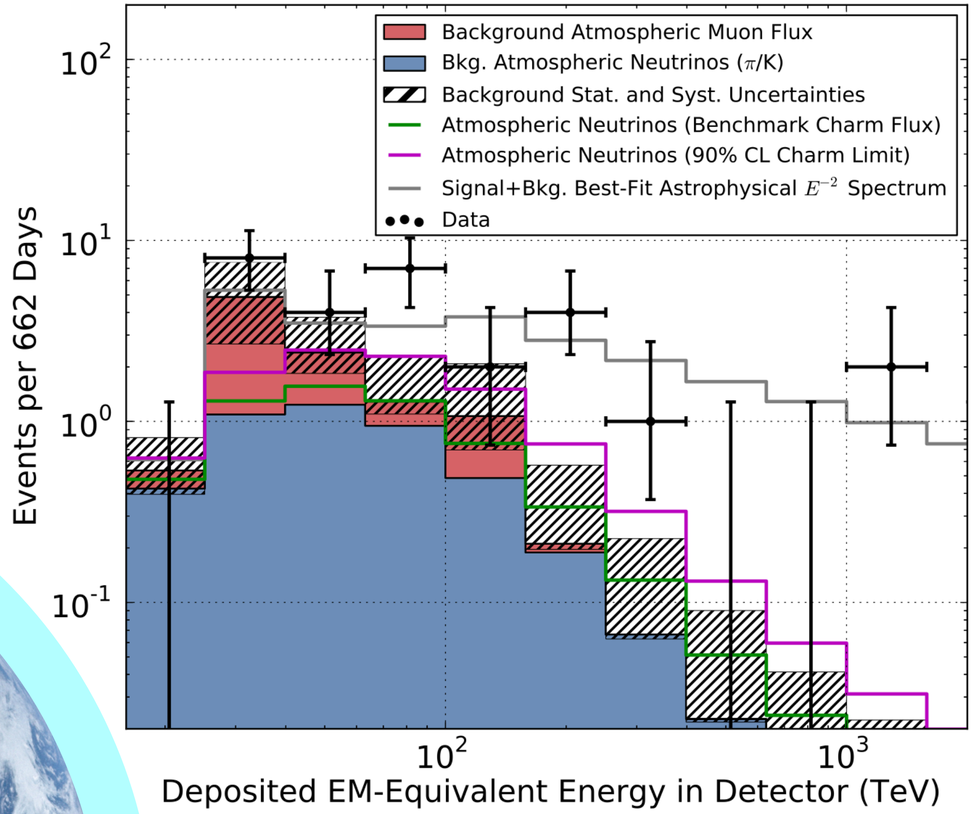


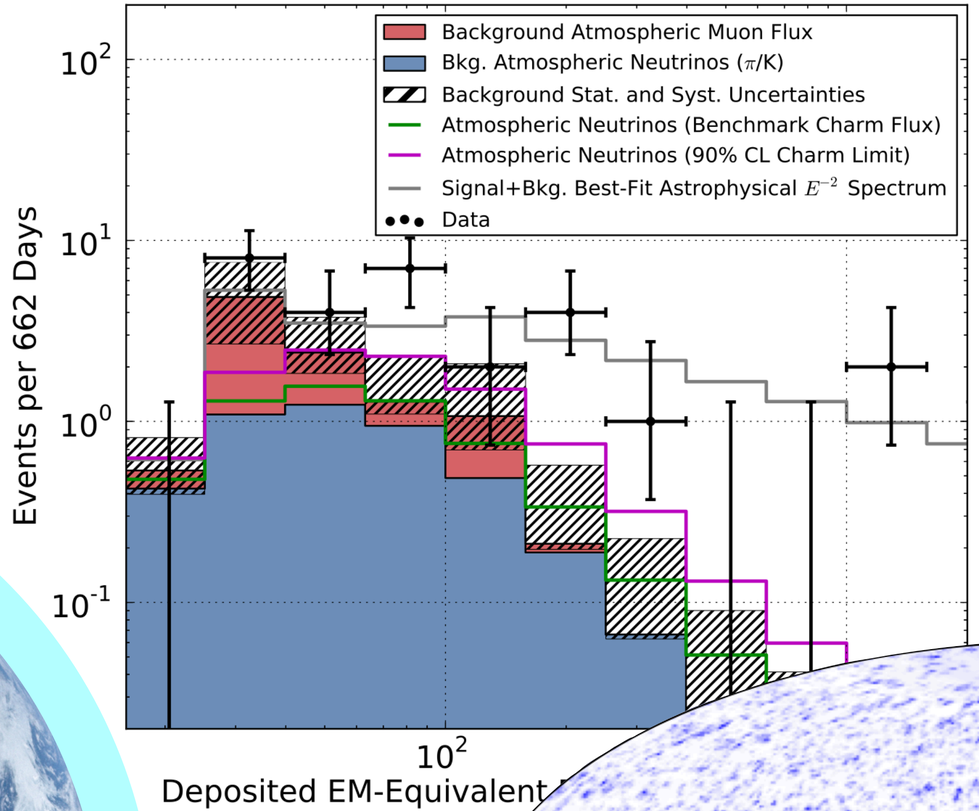
IceCube (Abbasi+2023 Science 380)

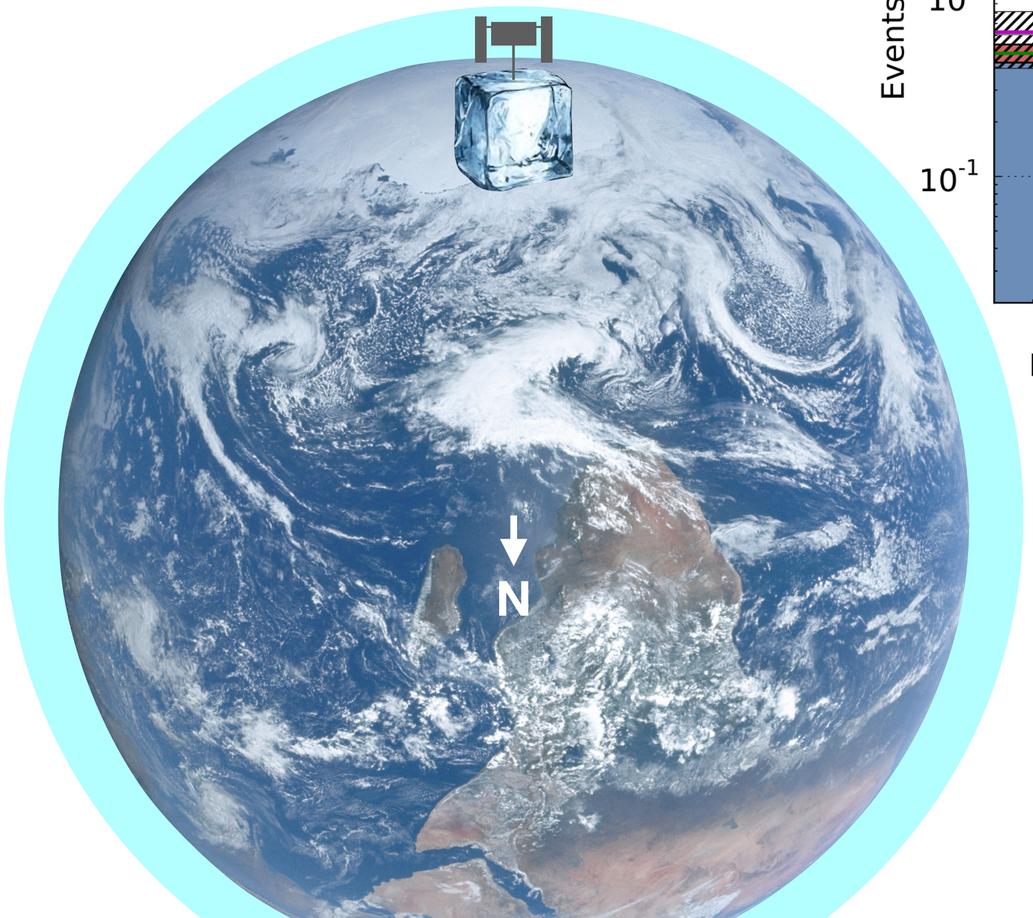


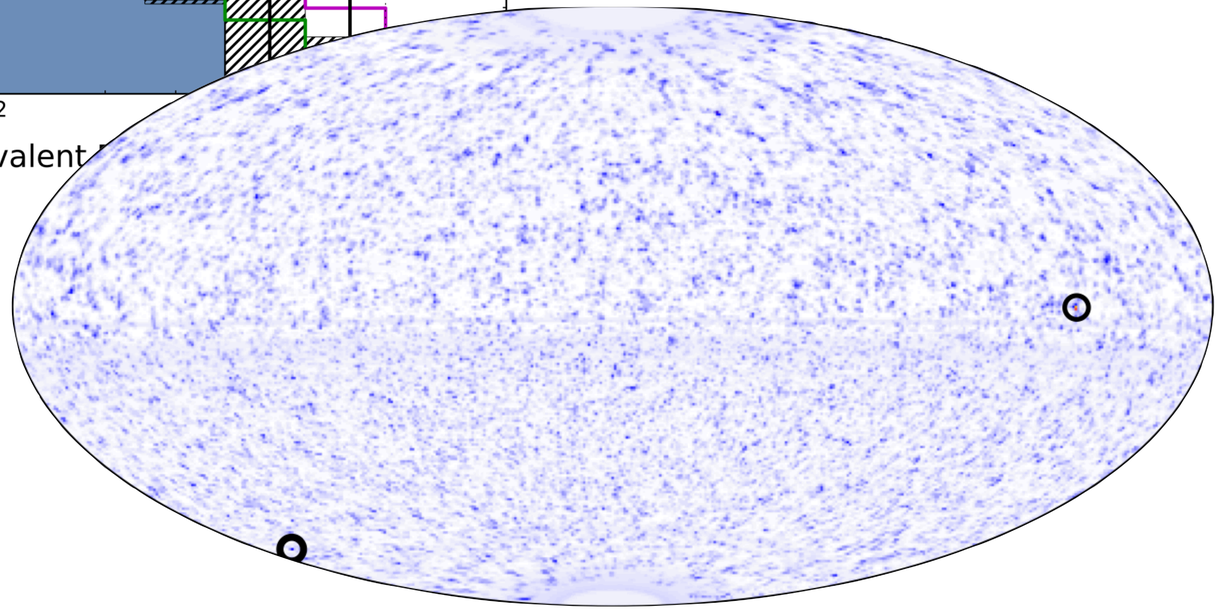
IceCube Collaboration, Science 342 (2013)



IceCube Collaboration, Science 342 (2013)

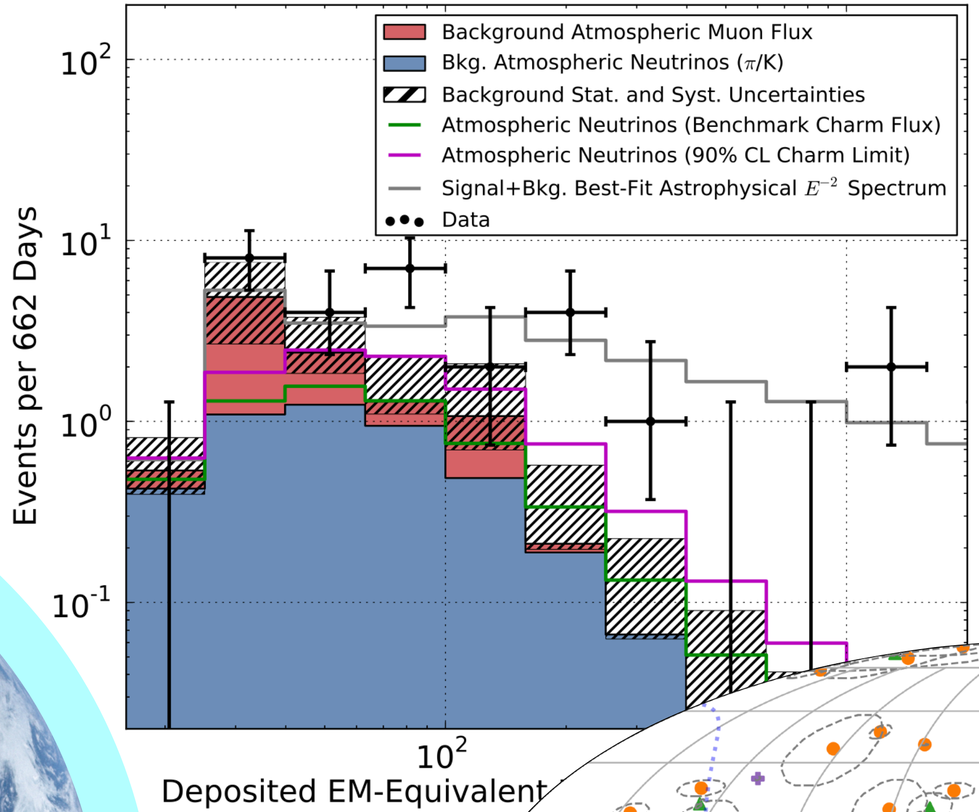


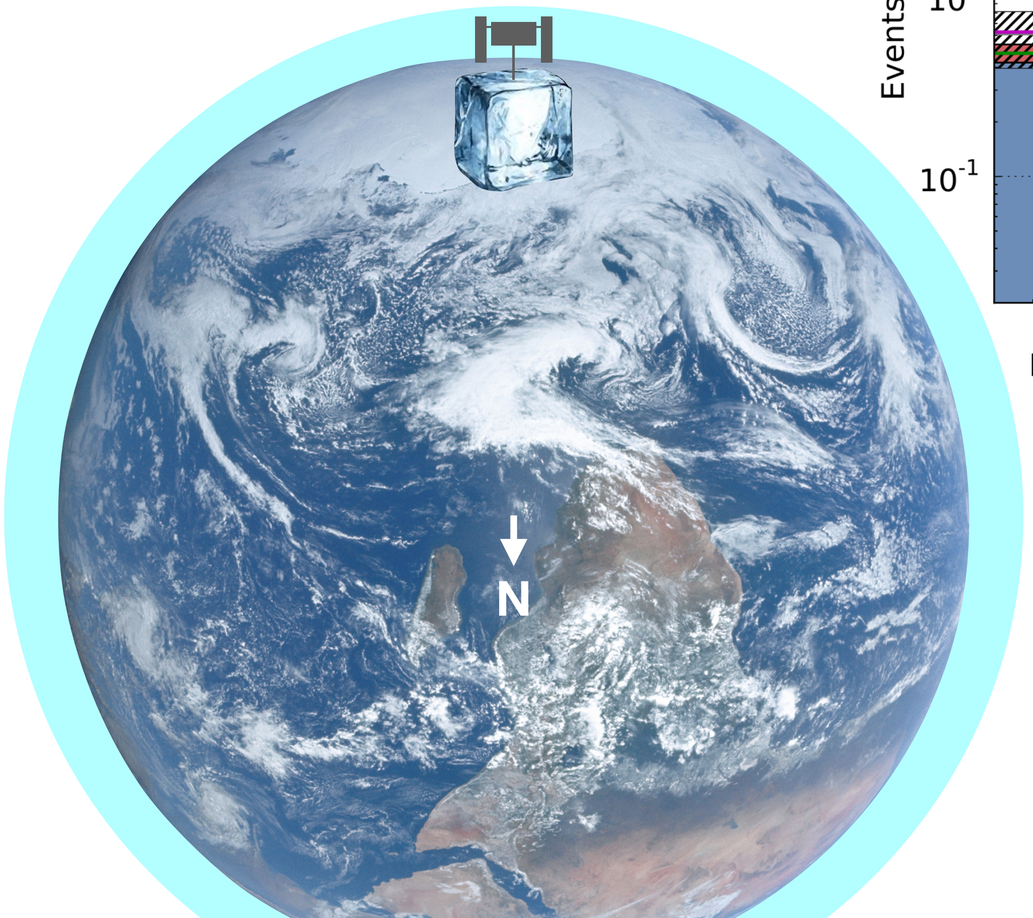


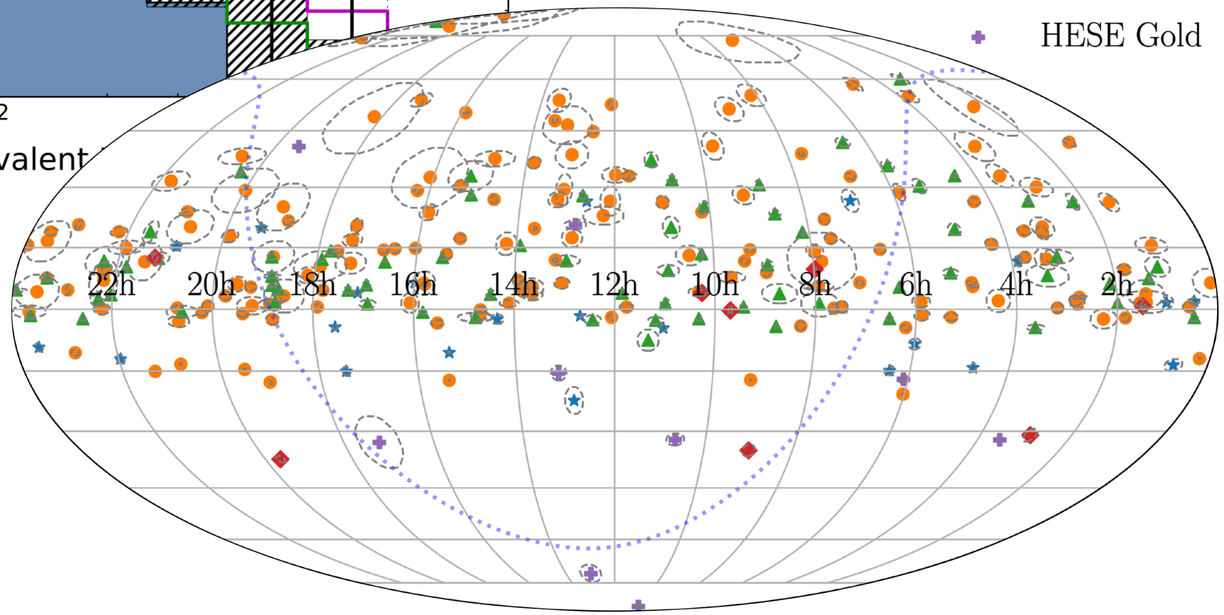


IceCube Collaboration, PRL 124 (2020)

IceCube Collaboration, Science 342 (2013)



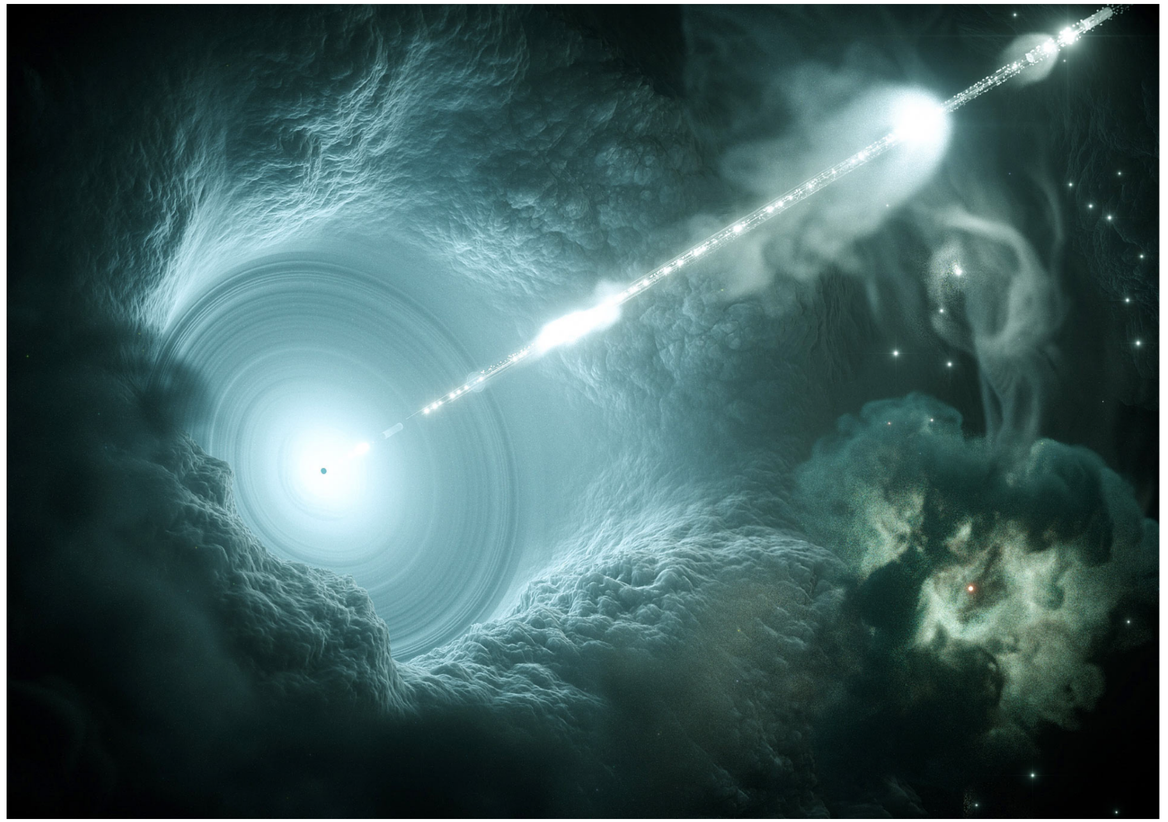




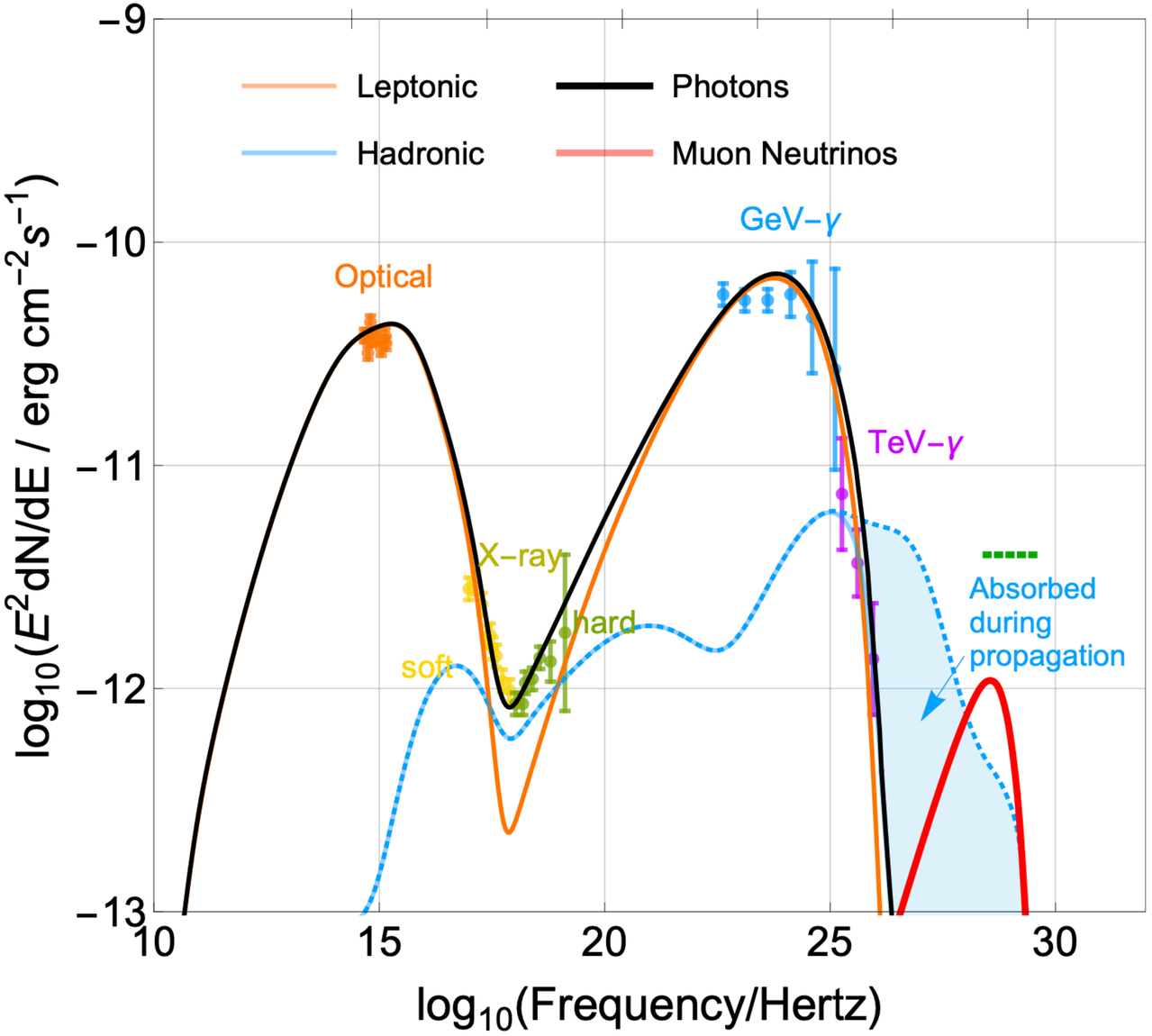
IceCat1 (Abbasi+2023 ApJS 269)

Modeling active black holes

TXS 0506+056

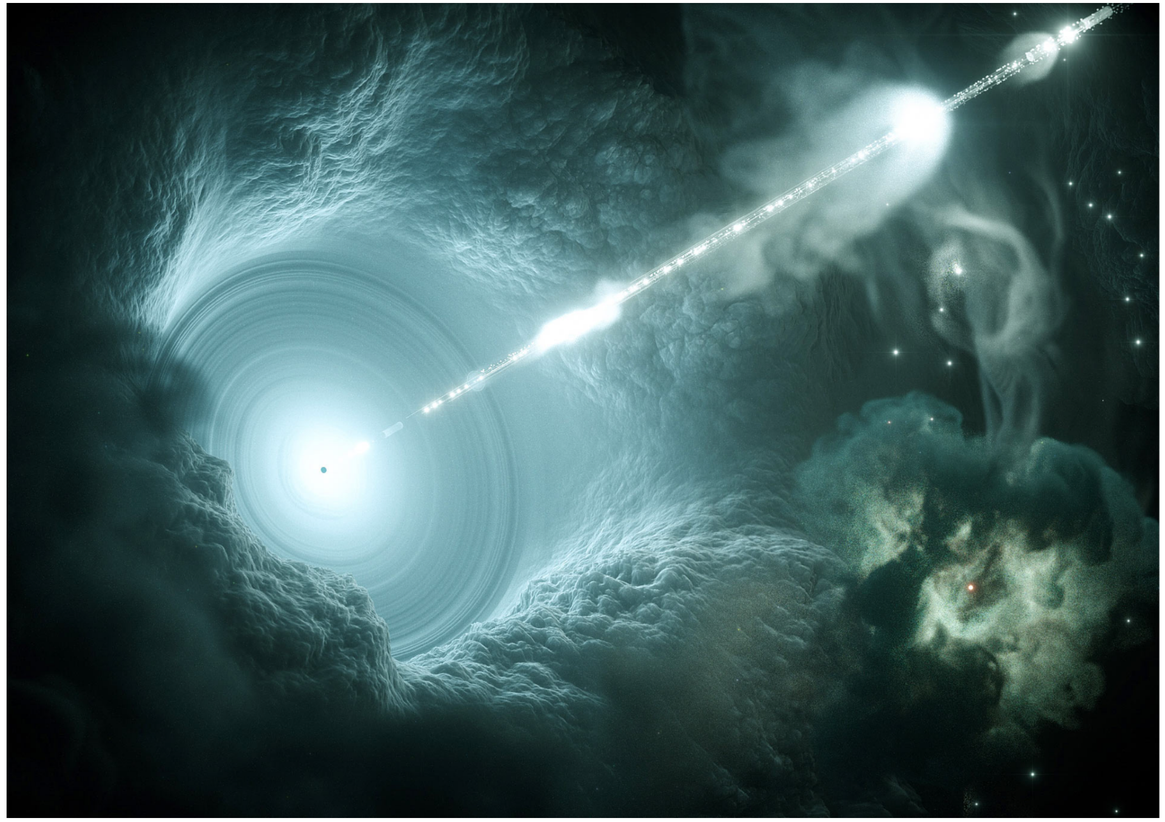


Modeling active black holes

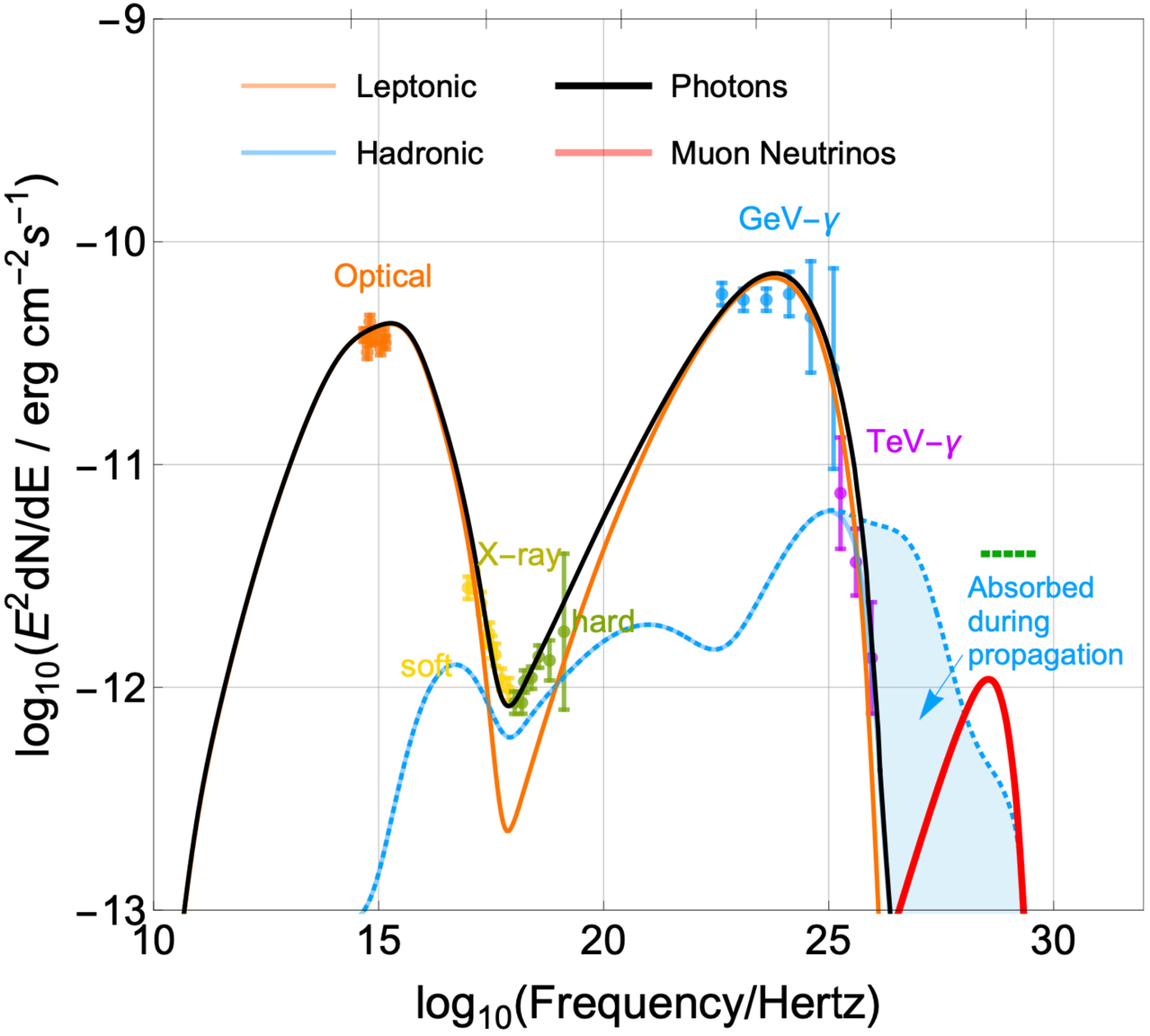


Gao+ Nature 3 (2019)

TXS 0506+056



Modeling active black holes



Gao+ Nature 3 (2019)

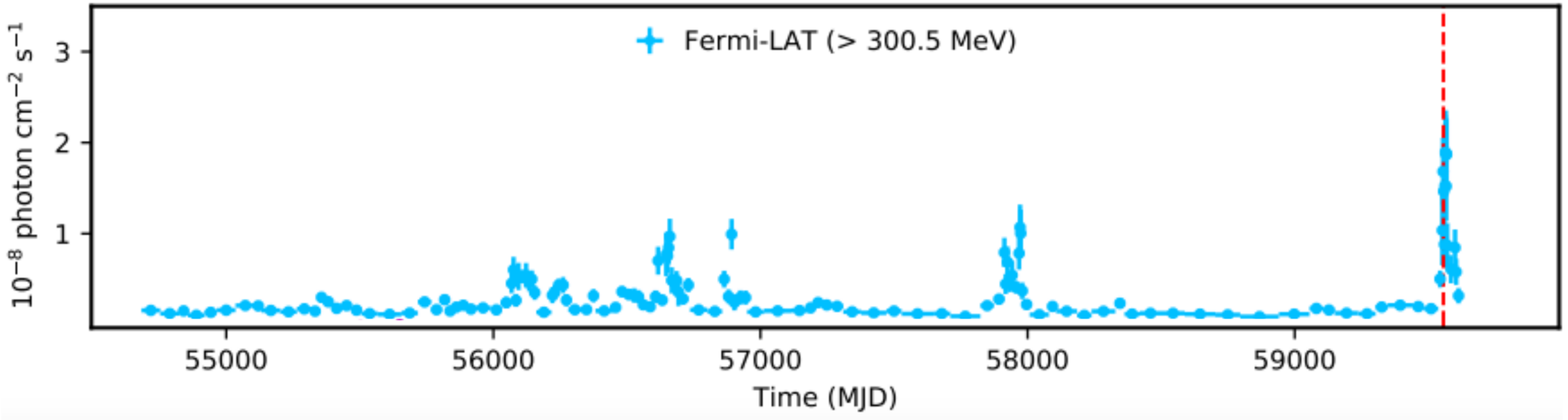
Astrophysical **M**ultiwavelength and **M**ulti**M**essenger Computation Software

Coming out <u>this week</u> as open source software!

This Friday,
look in the arXiv for
Klinger, Rudolph, Rodrigues et al

What is a hadronic signature?

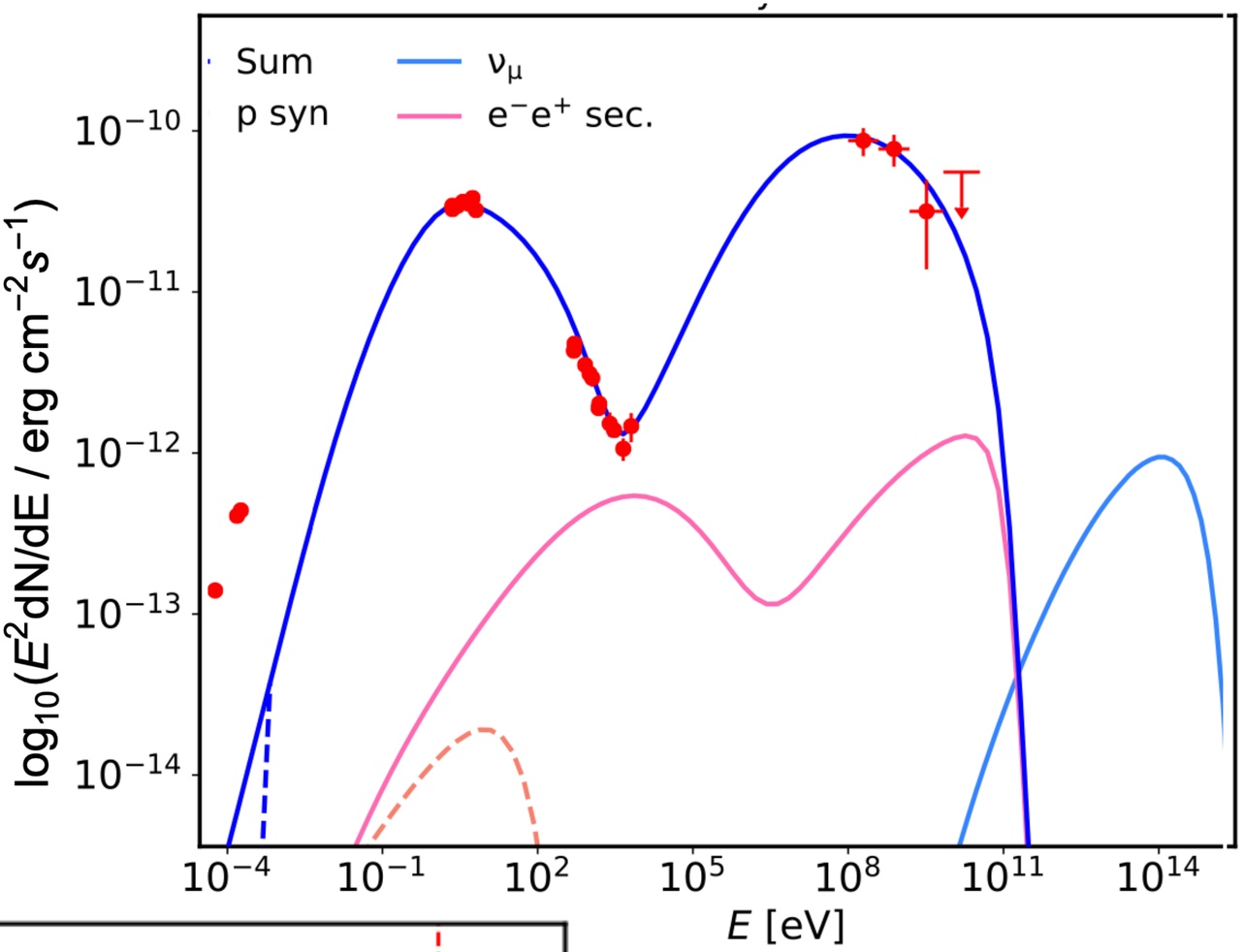
PKS 0735+17

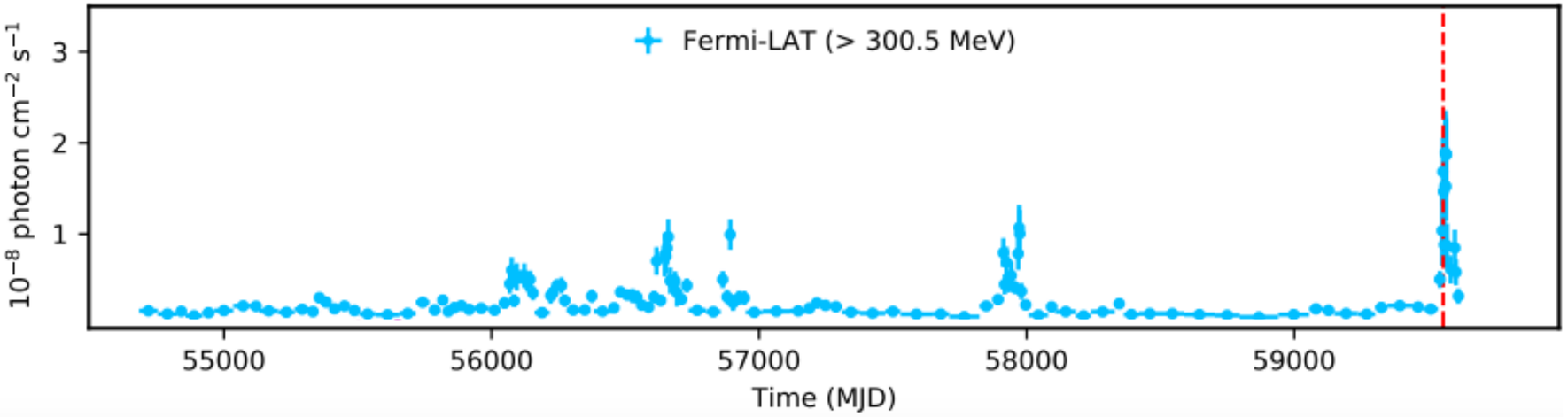


Sahakyan+ MNRAS 519 (2022)

What is a hadronic signature?

PKS 0735+17





Sahakyan+ MNRAS 519 (2022)

What is a hadronic signature?

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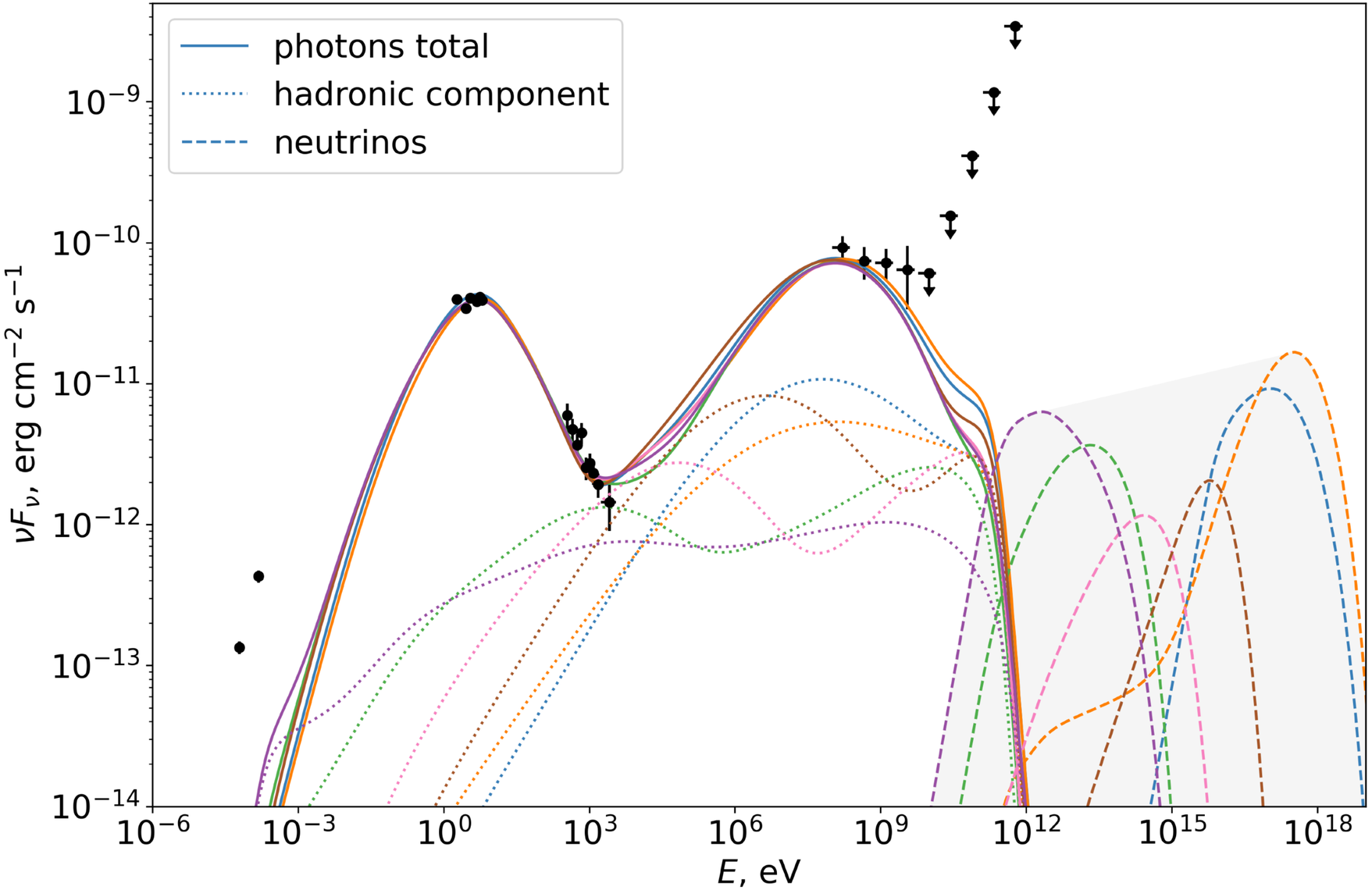
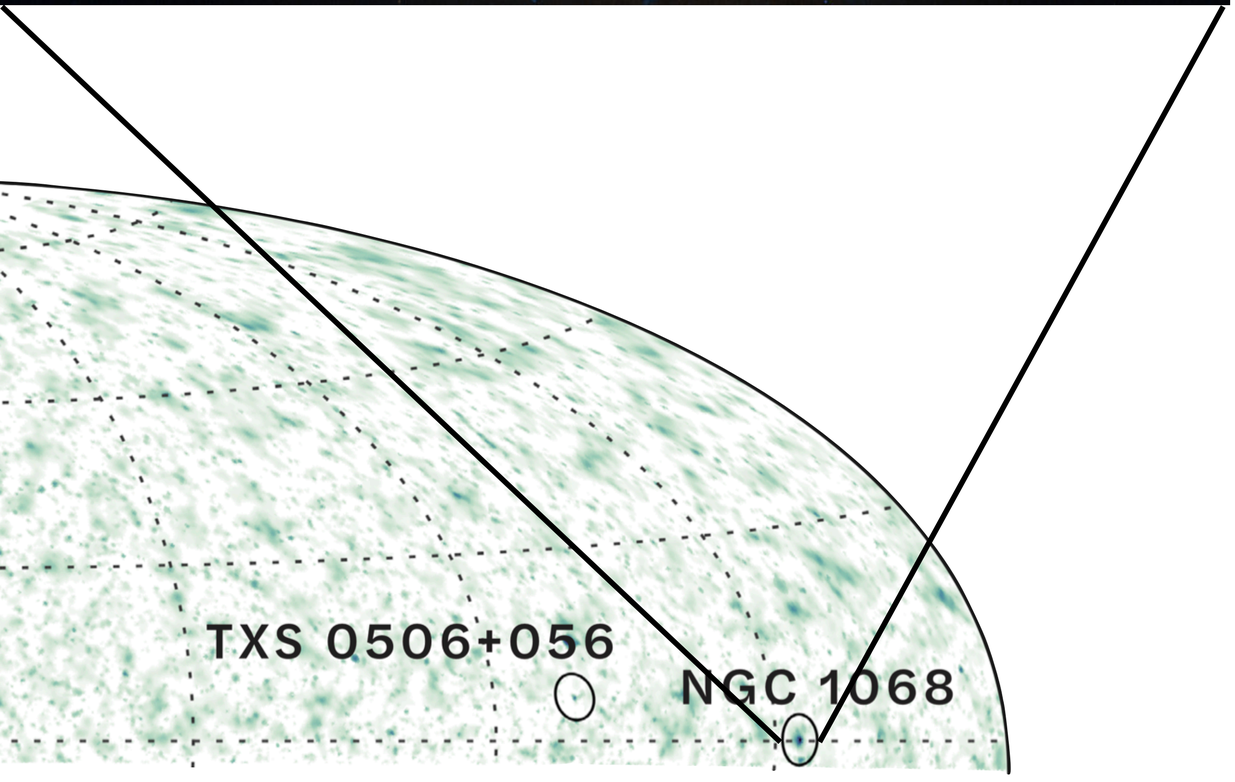


Omeliukh+ ICRC 2023

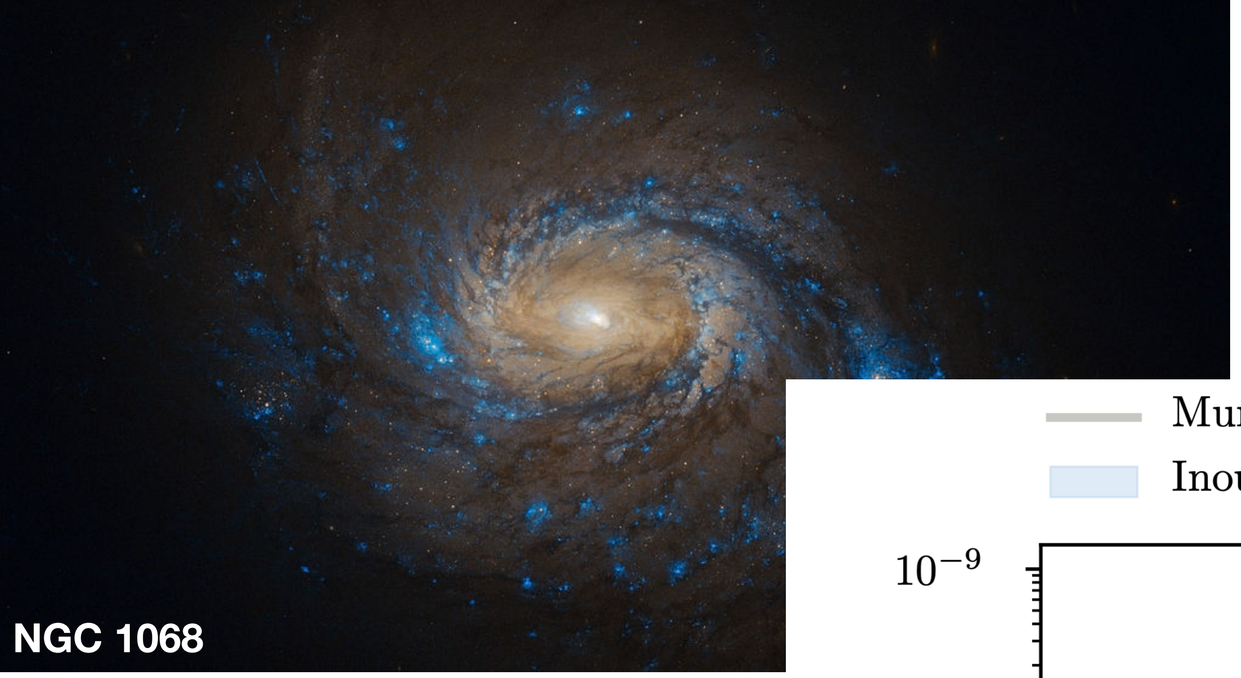
Steady neutrino emission from a star-forming galaxy (4.5 σ)

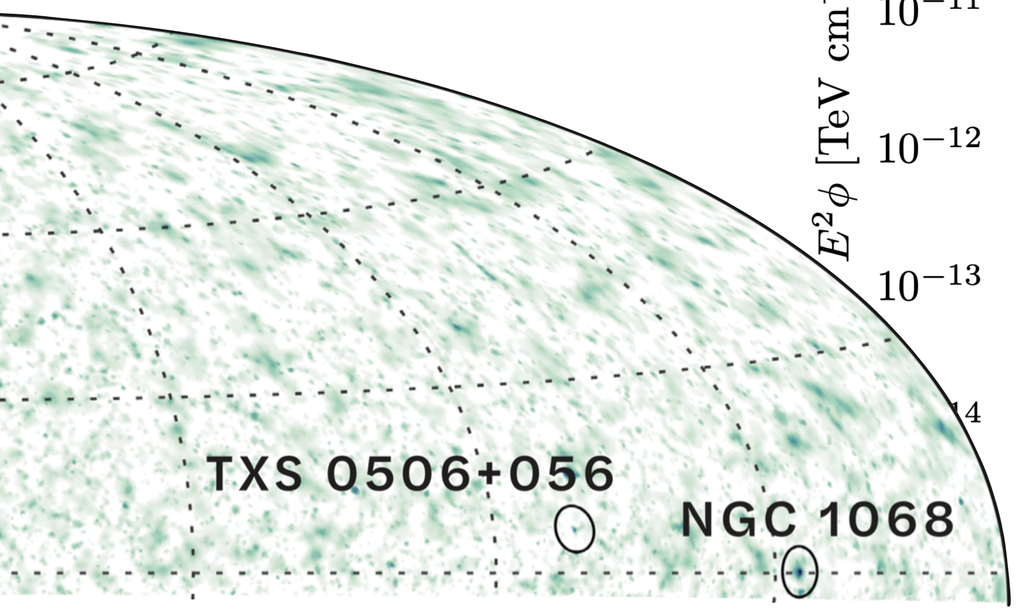
IceCube Collaboration, Science 378, 2022

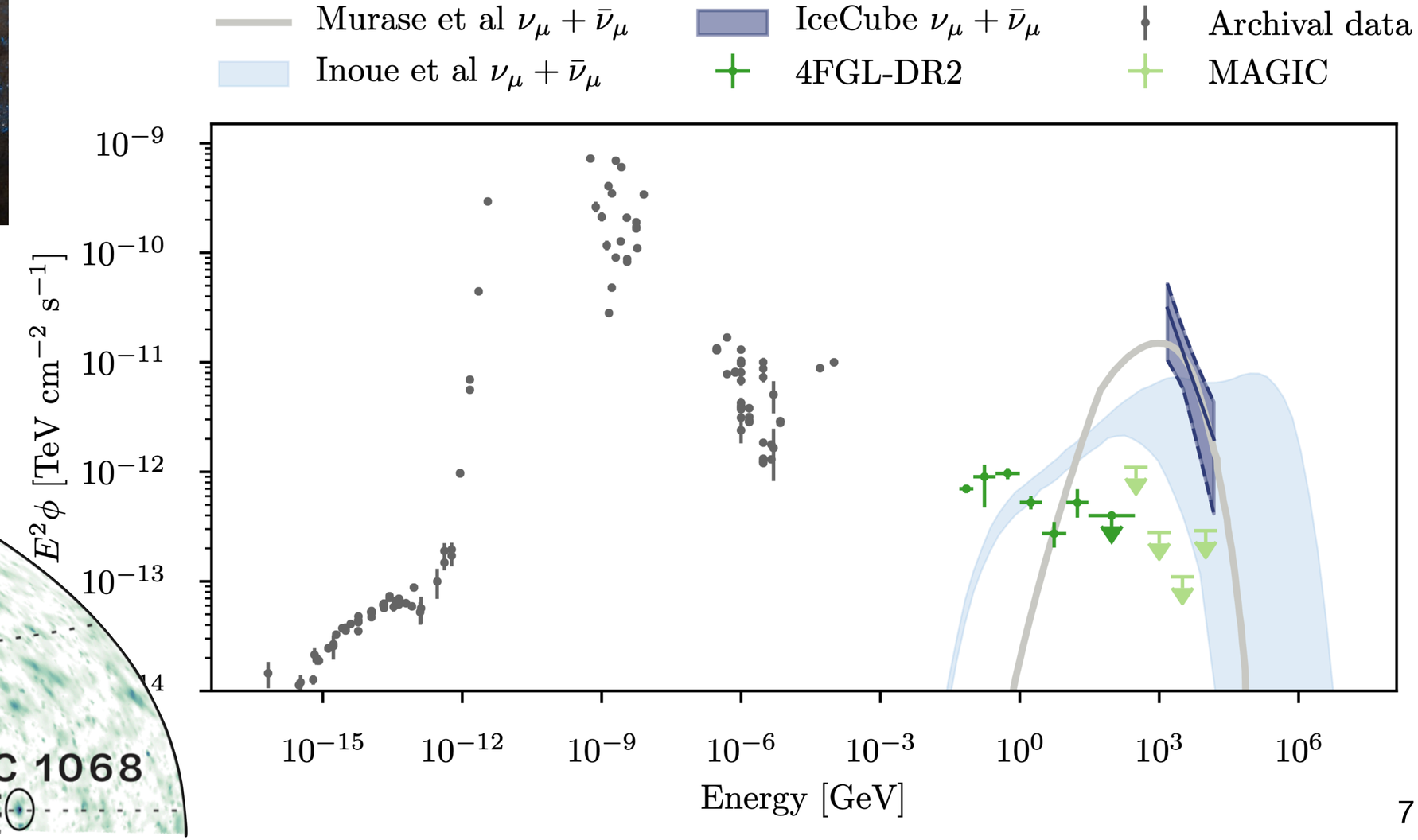


Steady neutrino emission from a star-forming galaxy (4.5 σ)

IceCube Collaboration, Science 378, 2022

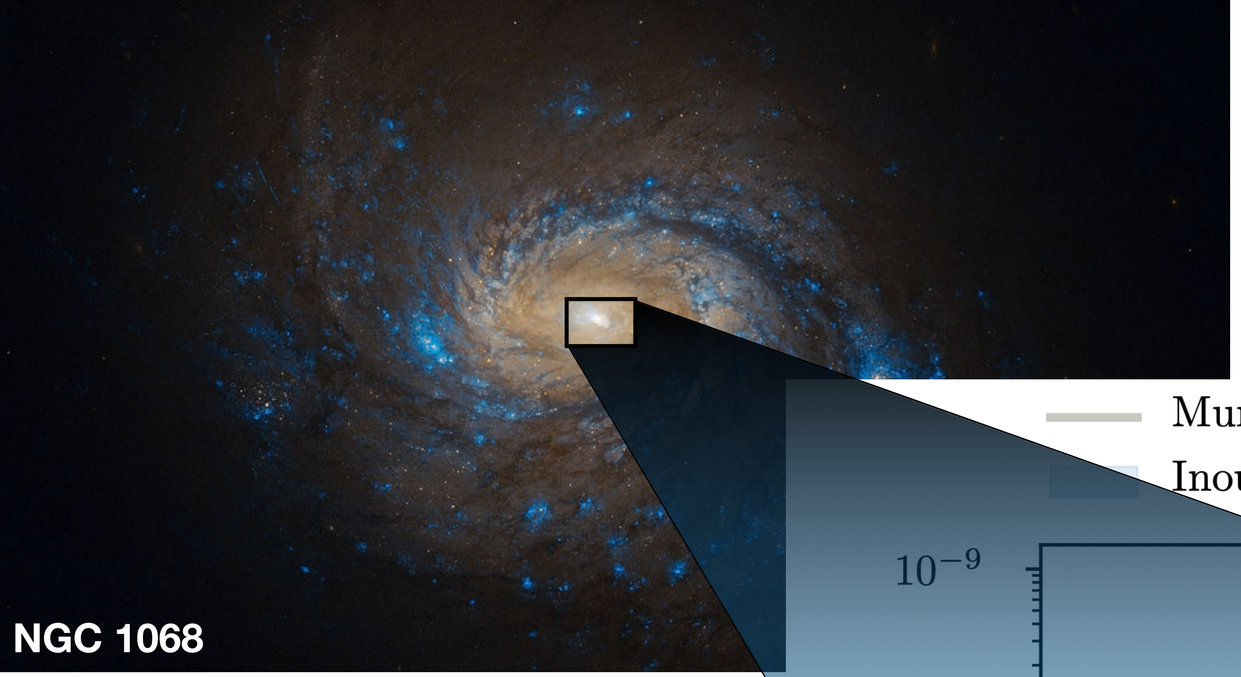


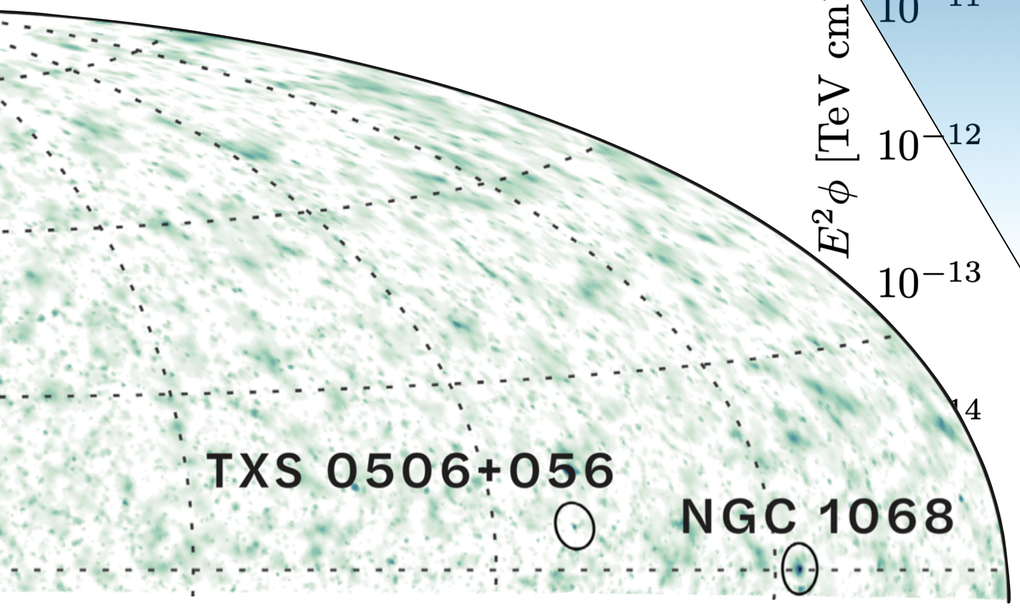


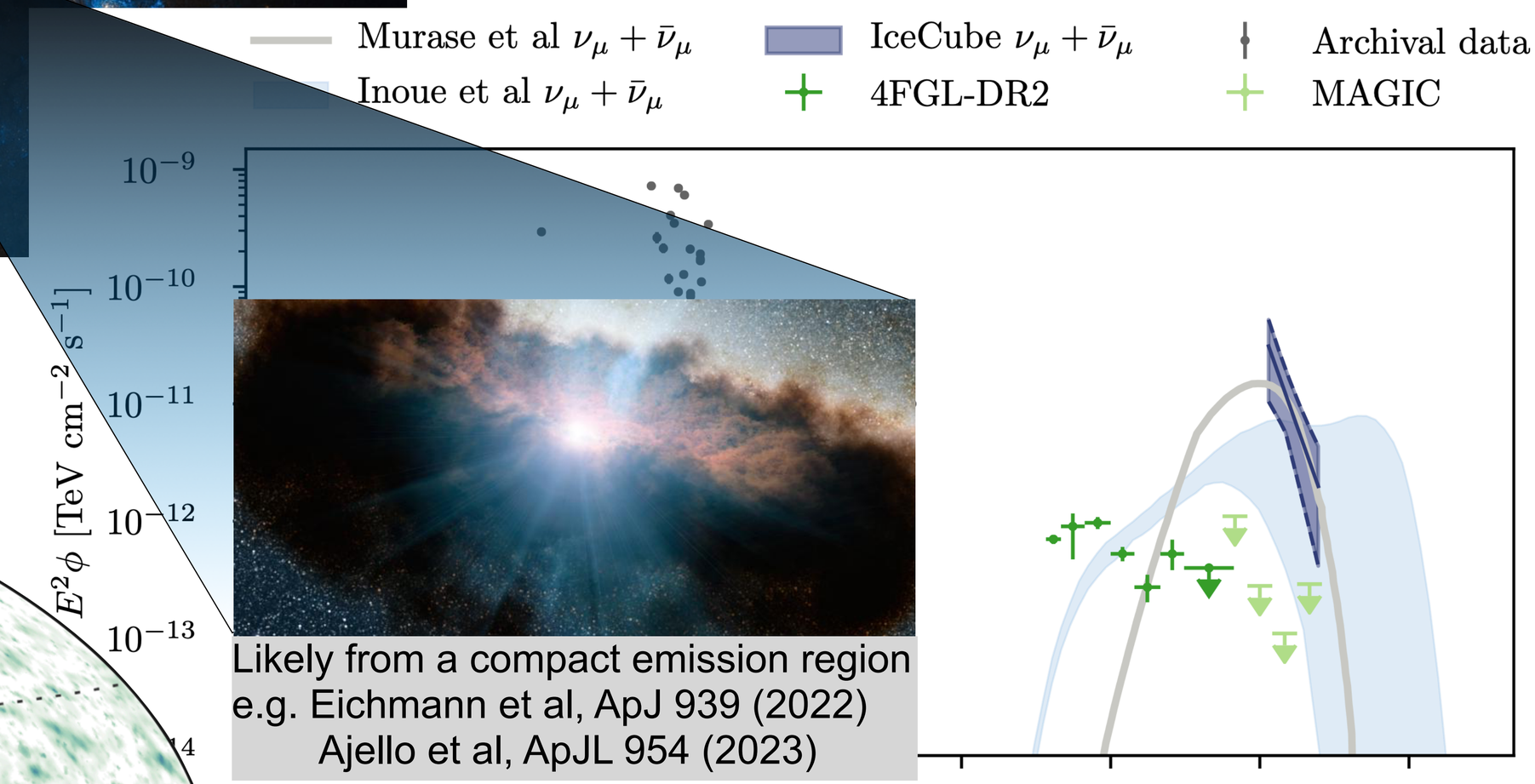


Steady neutrino emission from a star-forming galaxy (4.5 σ)

IceCube Collaboration, Science 378, 2022

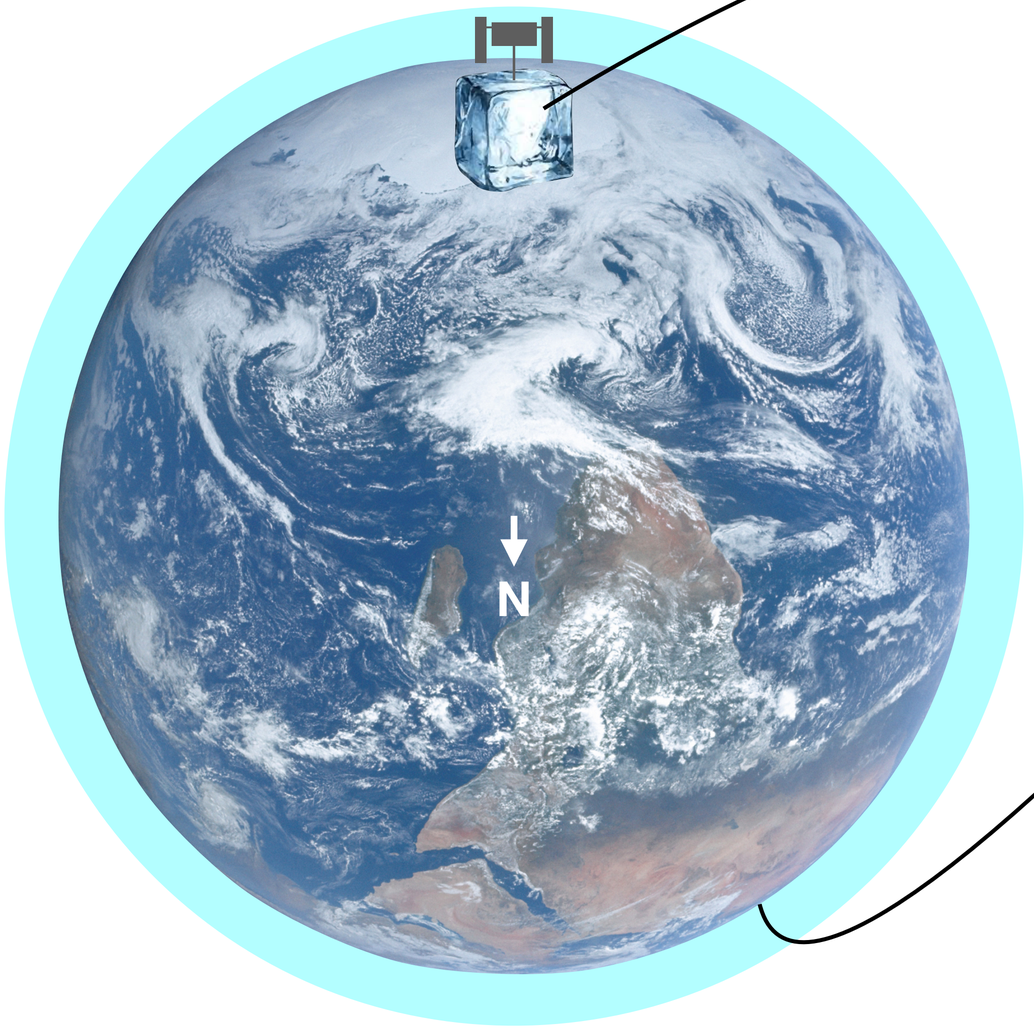




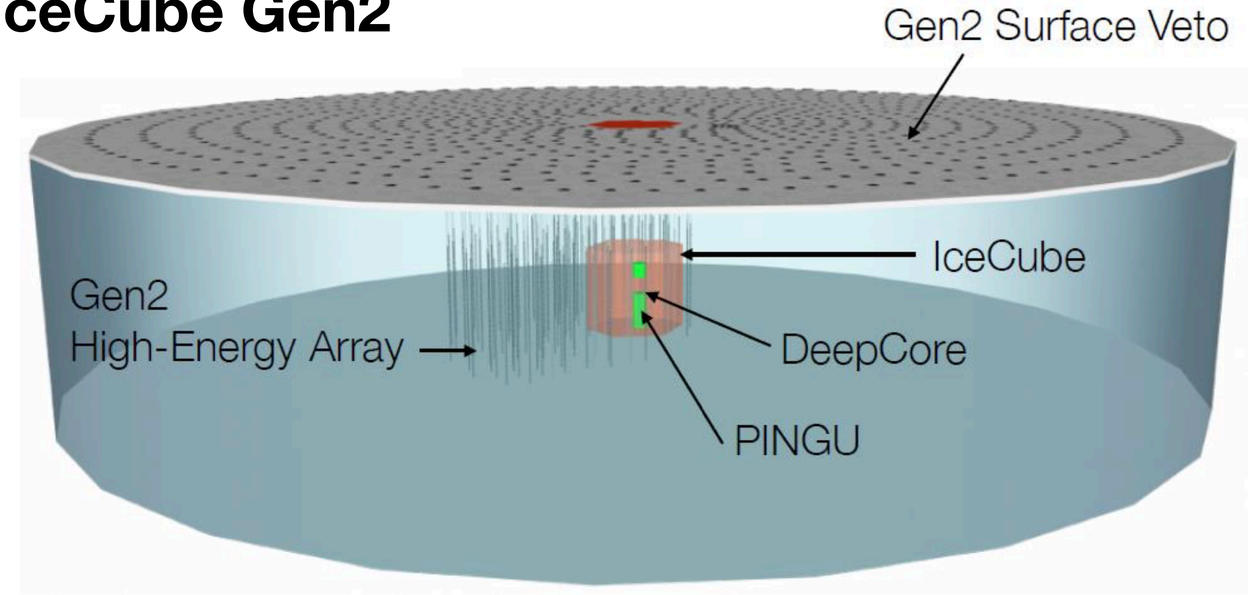


Likely from a compact emission region
e.g. Eichmann et al, ApJ 939 (2022)
Ajello et al, ApJL 954 (2023)

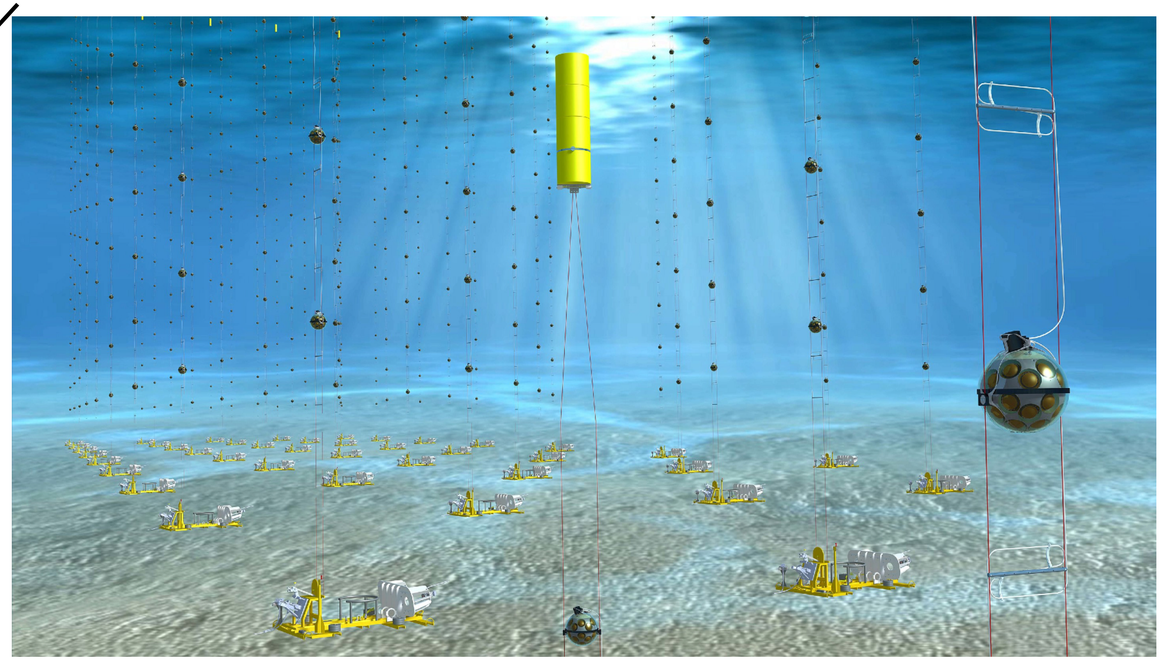
The future is looking bright in neutrinos



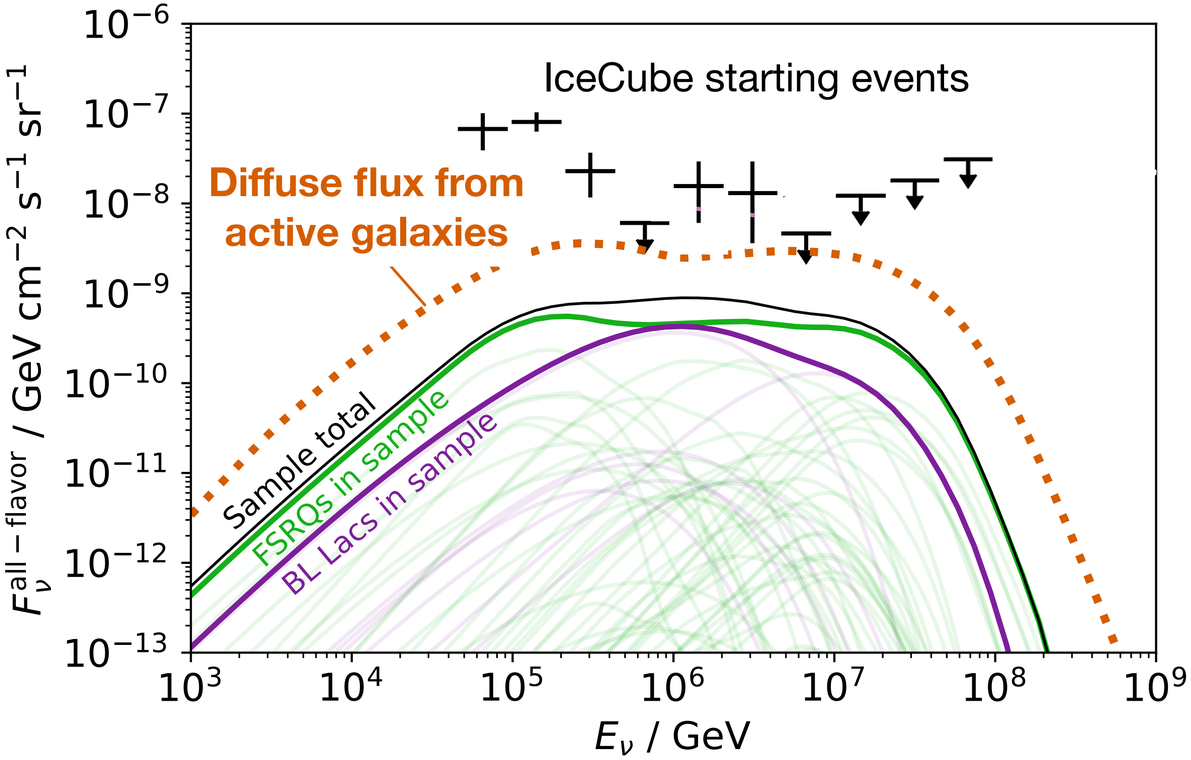
IceCube Gen2



KM3NeT



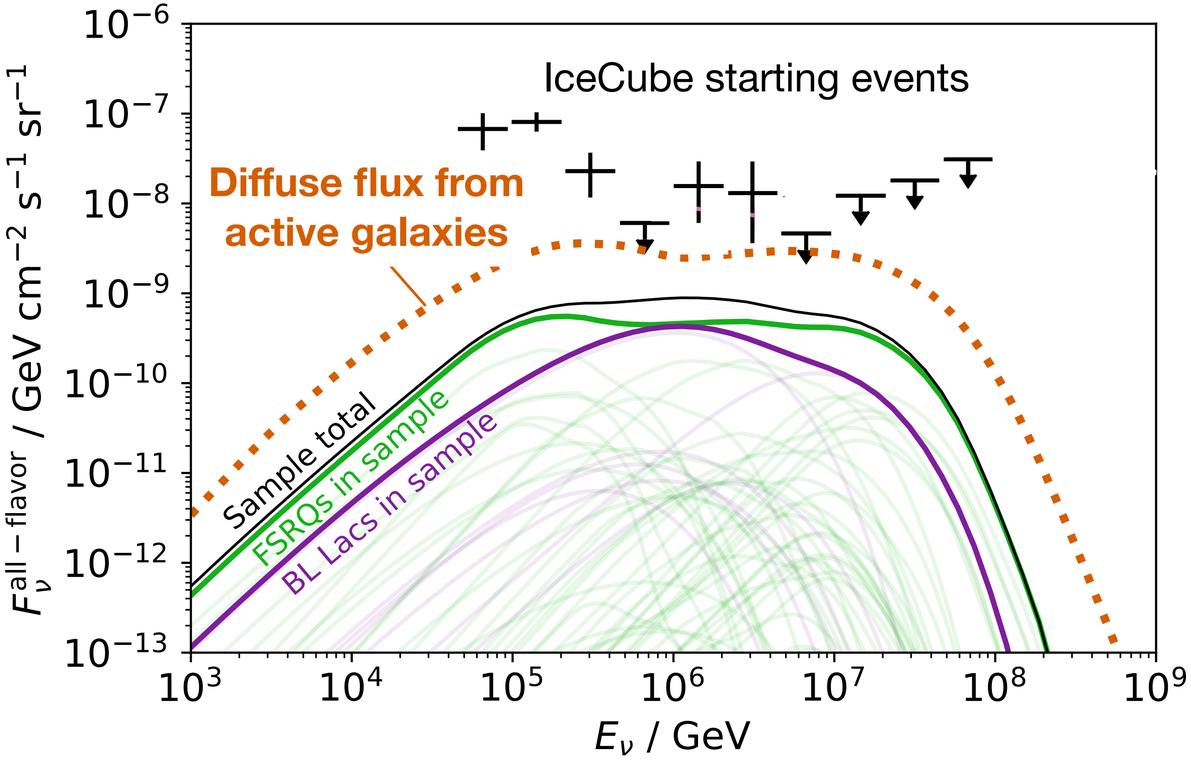
The future is looking bright in neutrinos



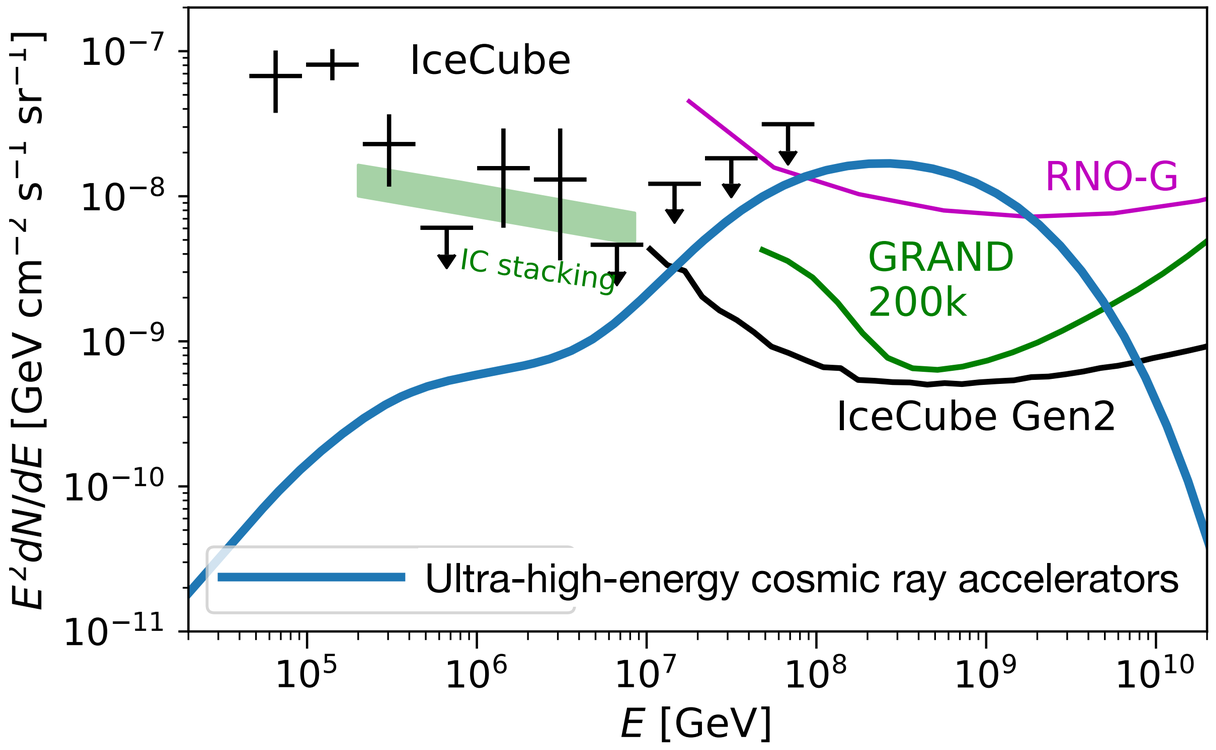
XR+ 2023 (A&A, forthcoming)

Gen2 will start probing steady-state emission from the active black hole population…

The future is looking bright in neutrinos



XR+ 2023 (A&A, forthcoming)



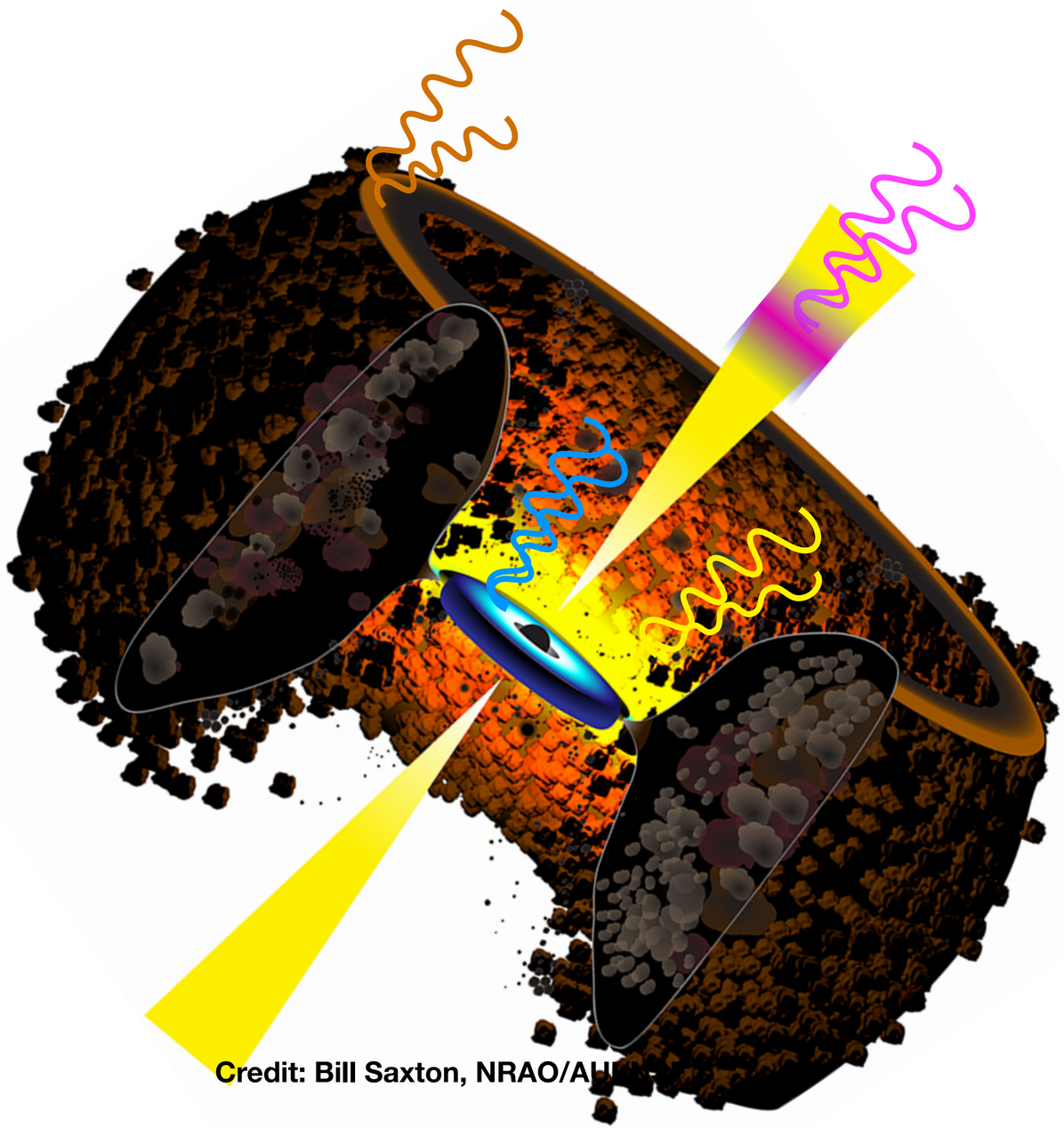
XR+ PRL 126 (2020)

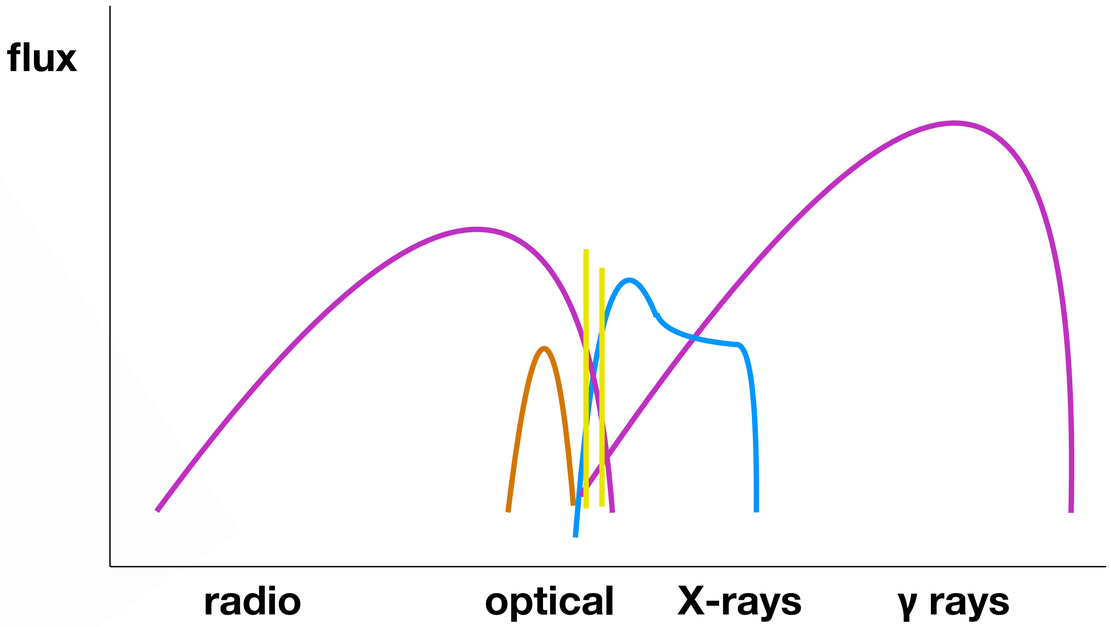
Gen2 will start probing steady-state emission from the active black hole population…

…and open a new window into the extremely-high-energy Universe

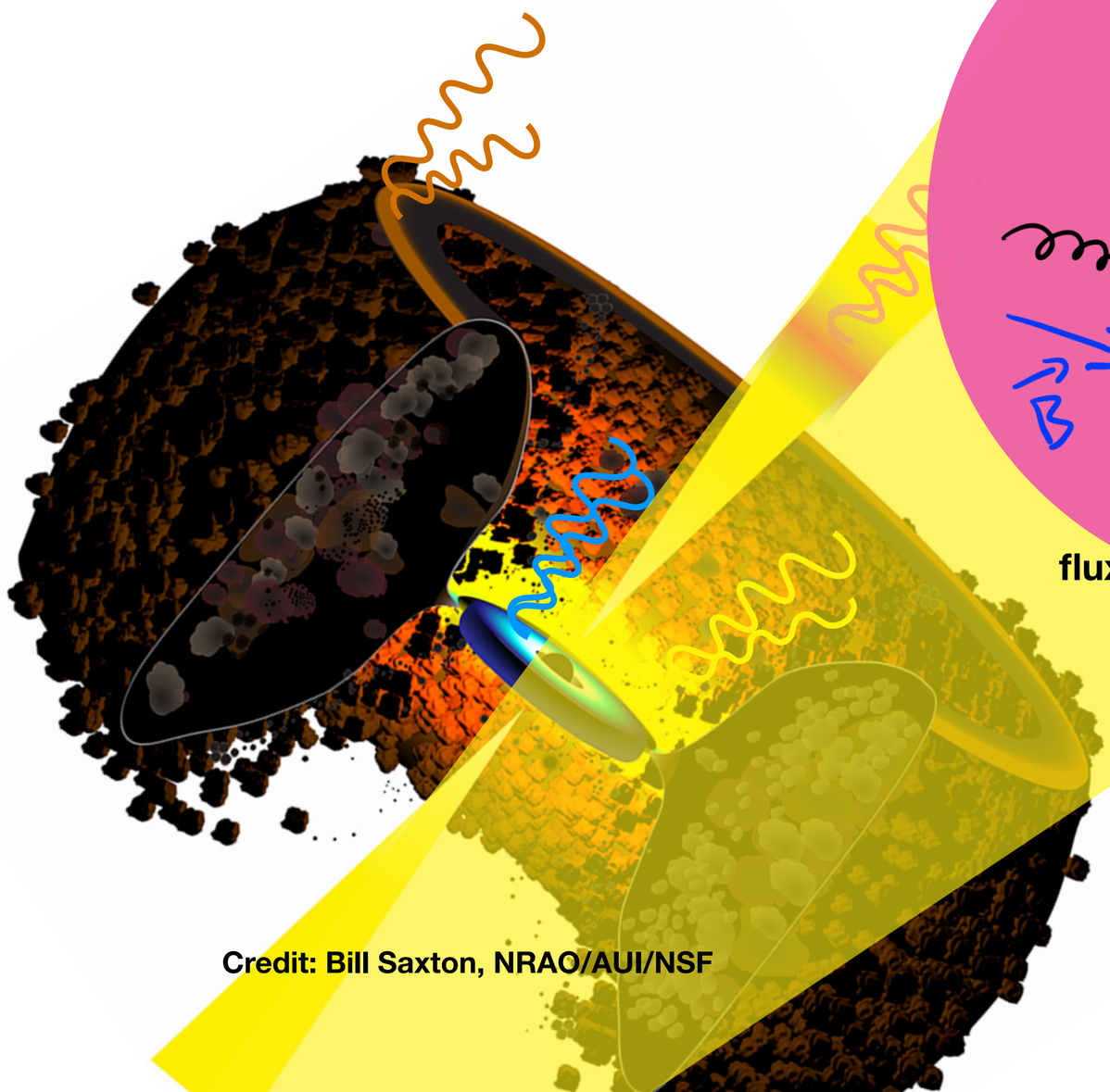
Backup slides

Modeling active galaxies

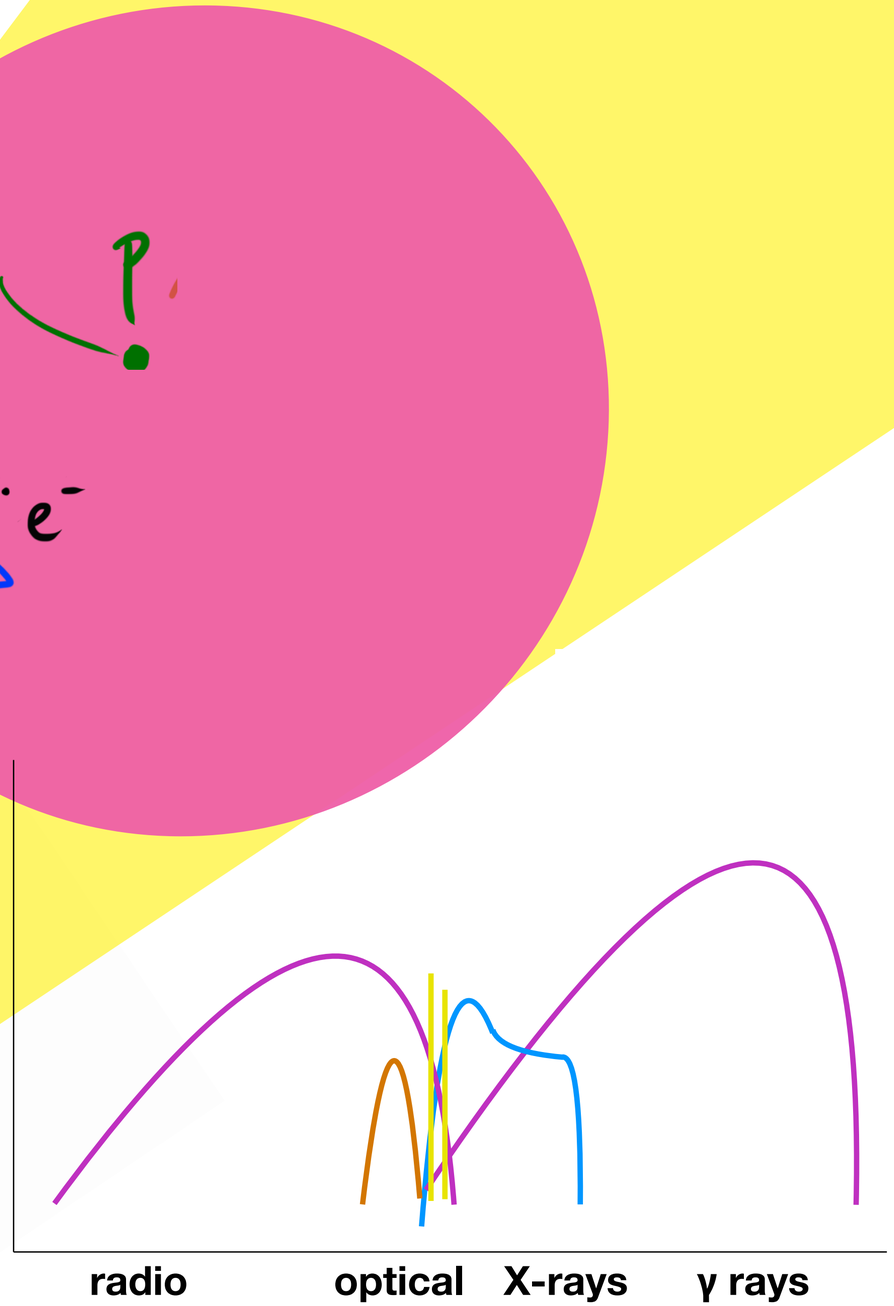




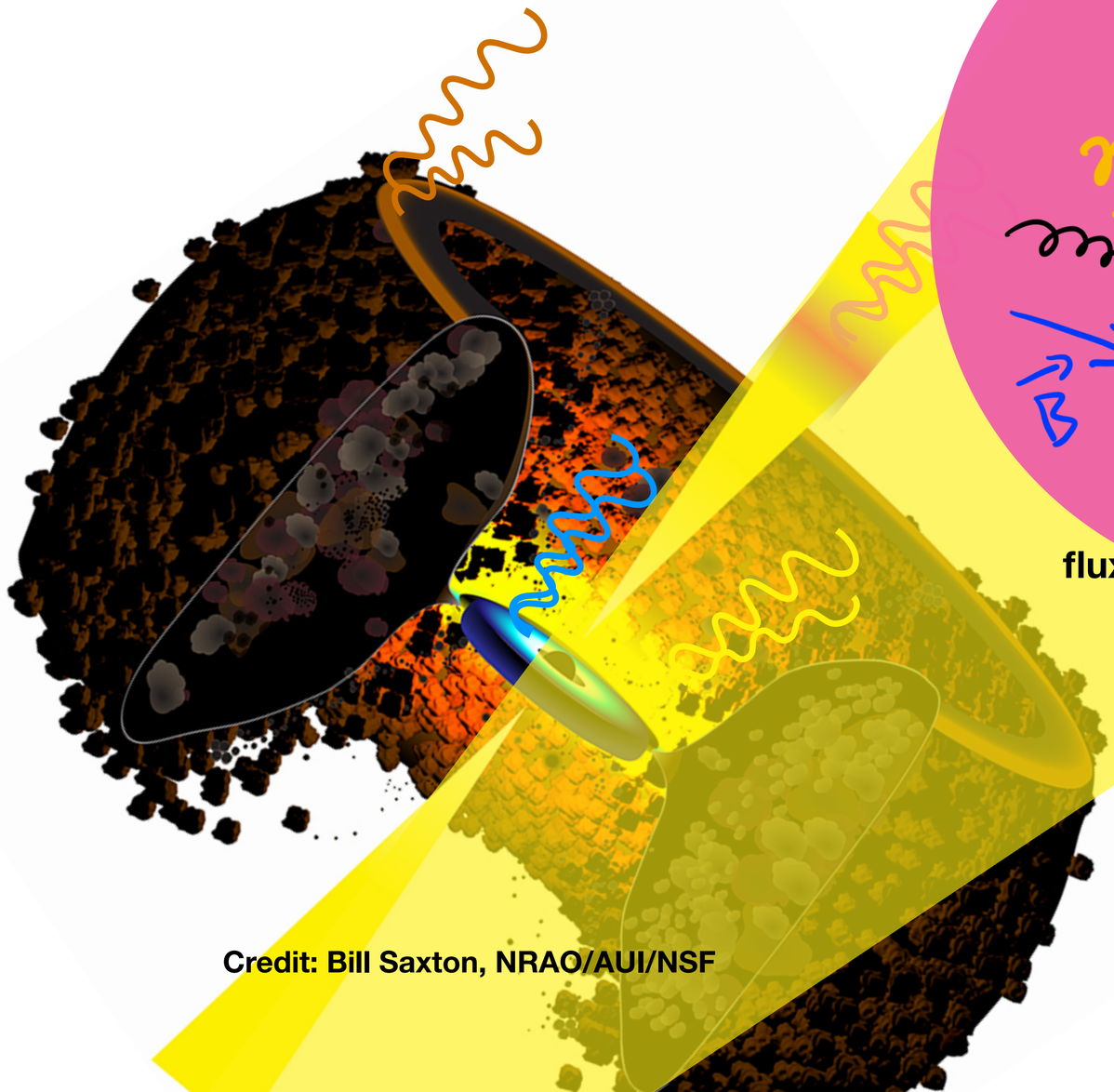
Modeling active galaxies



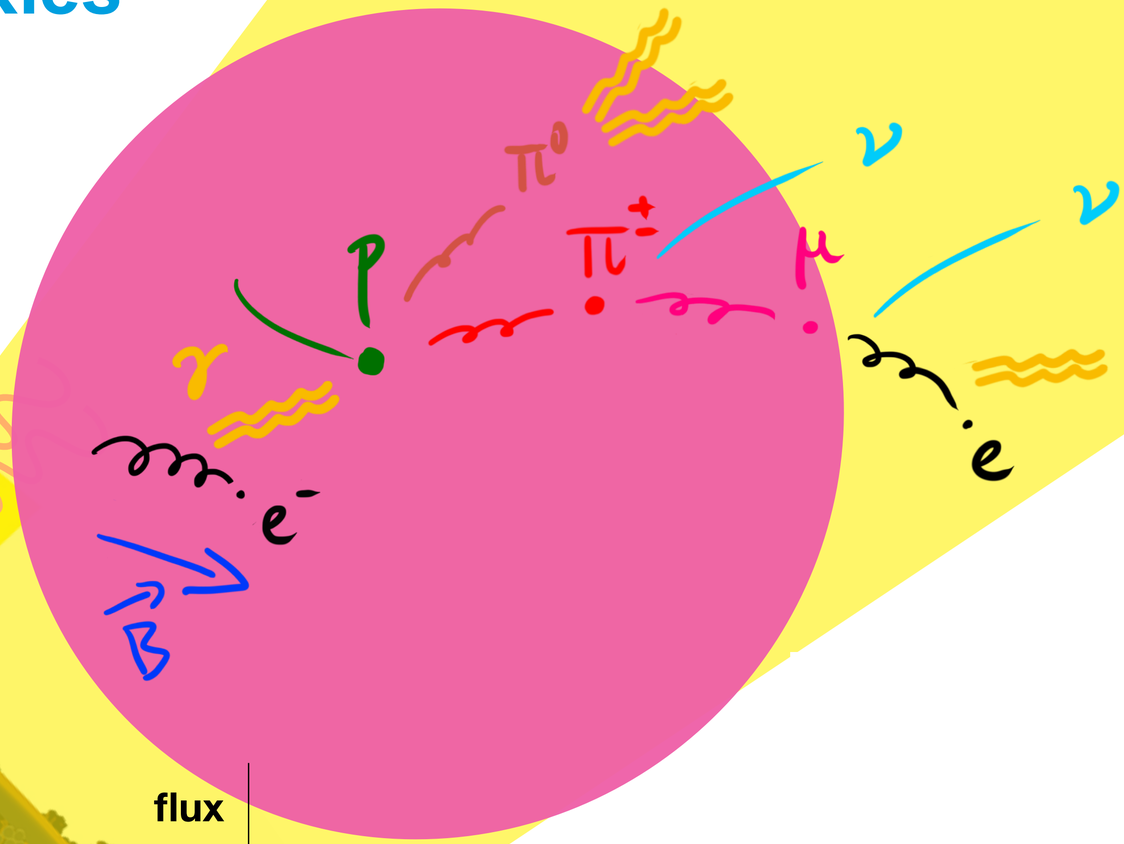
Credit: Bill Saxton, NRAO/AUI/NSF

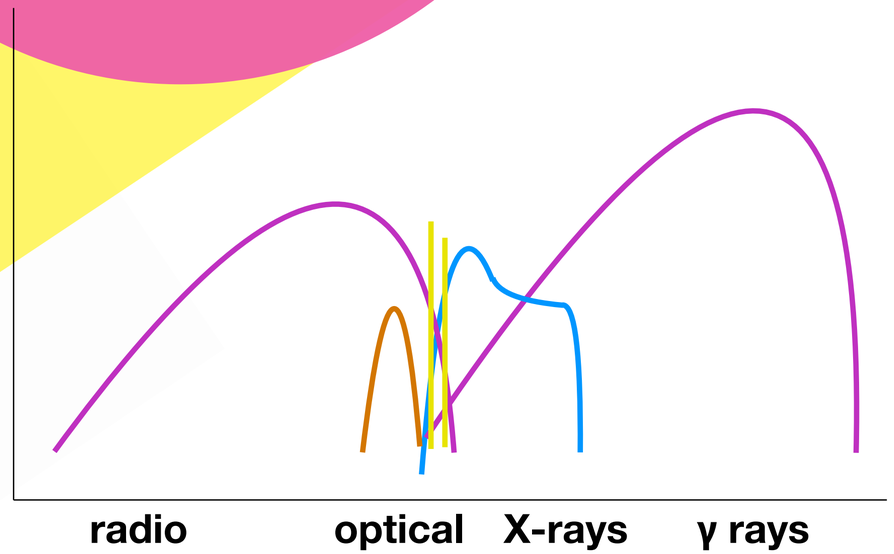


Modeling active galaxies

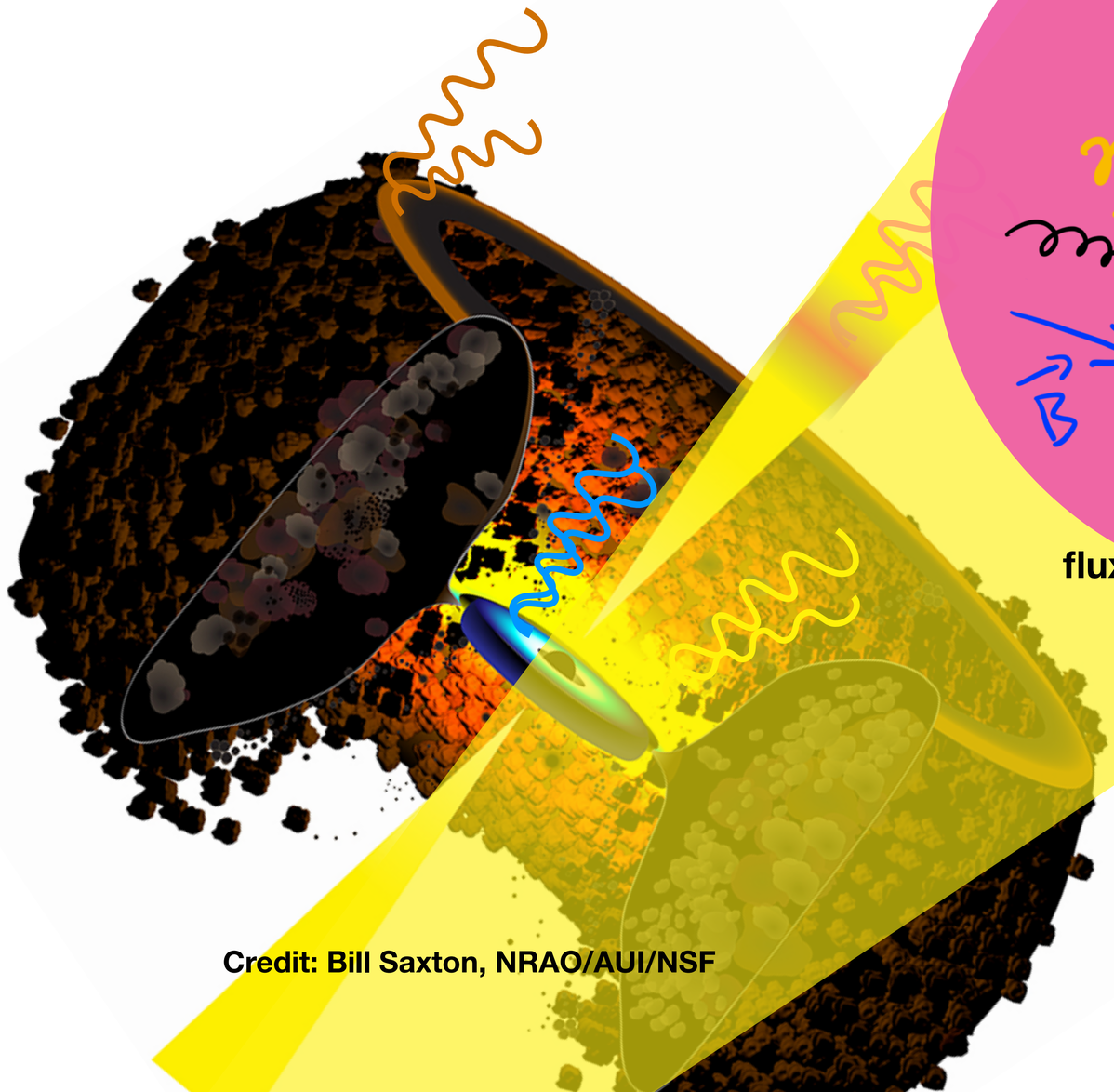


Credit: Bill Saxton, NRAO/AUI/NSF

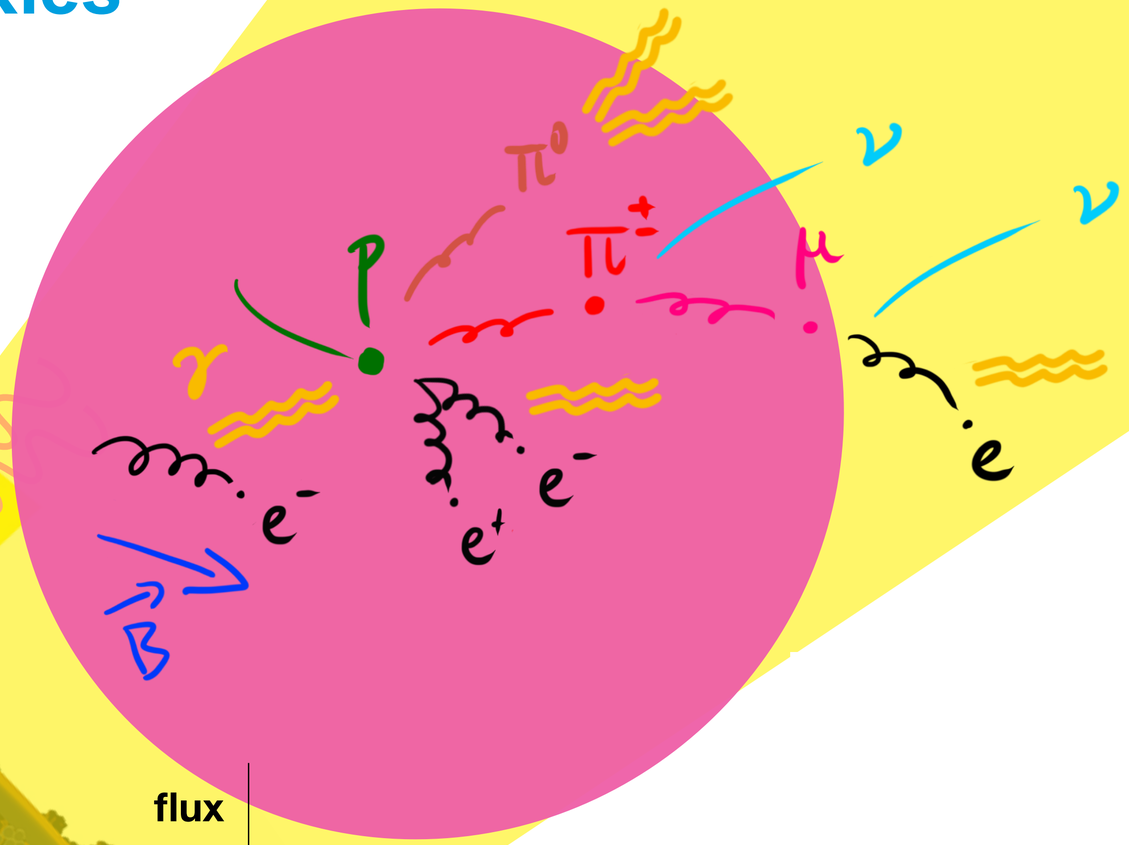


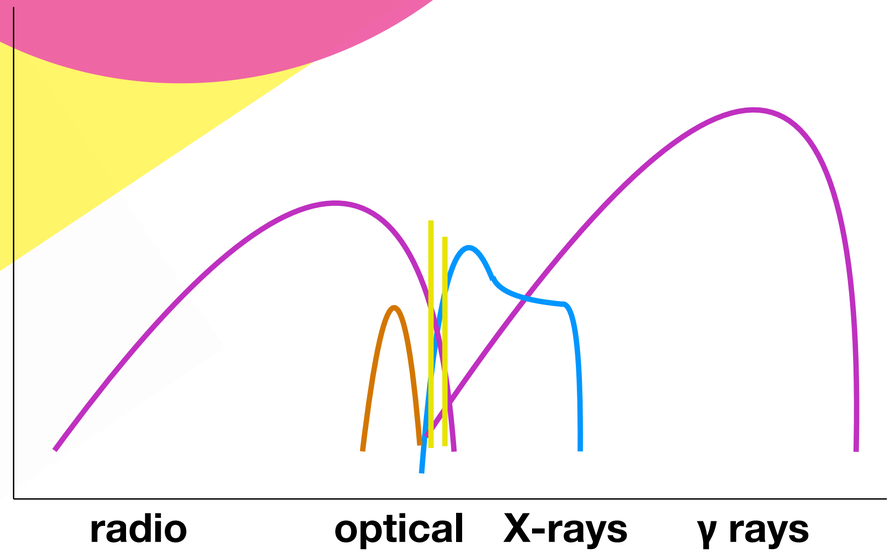


Modeling active galaxies

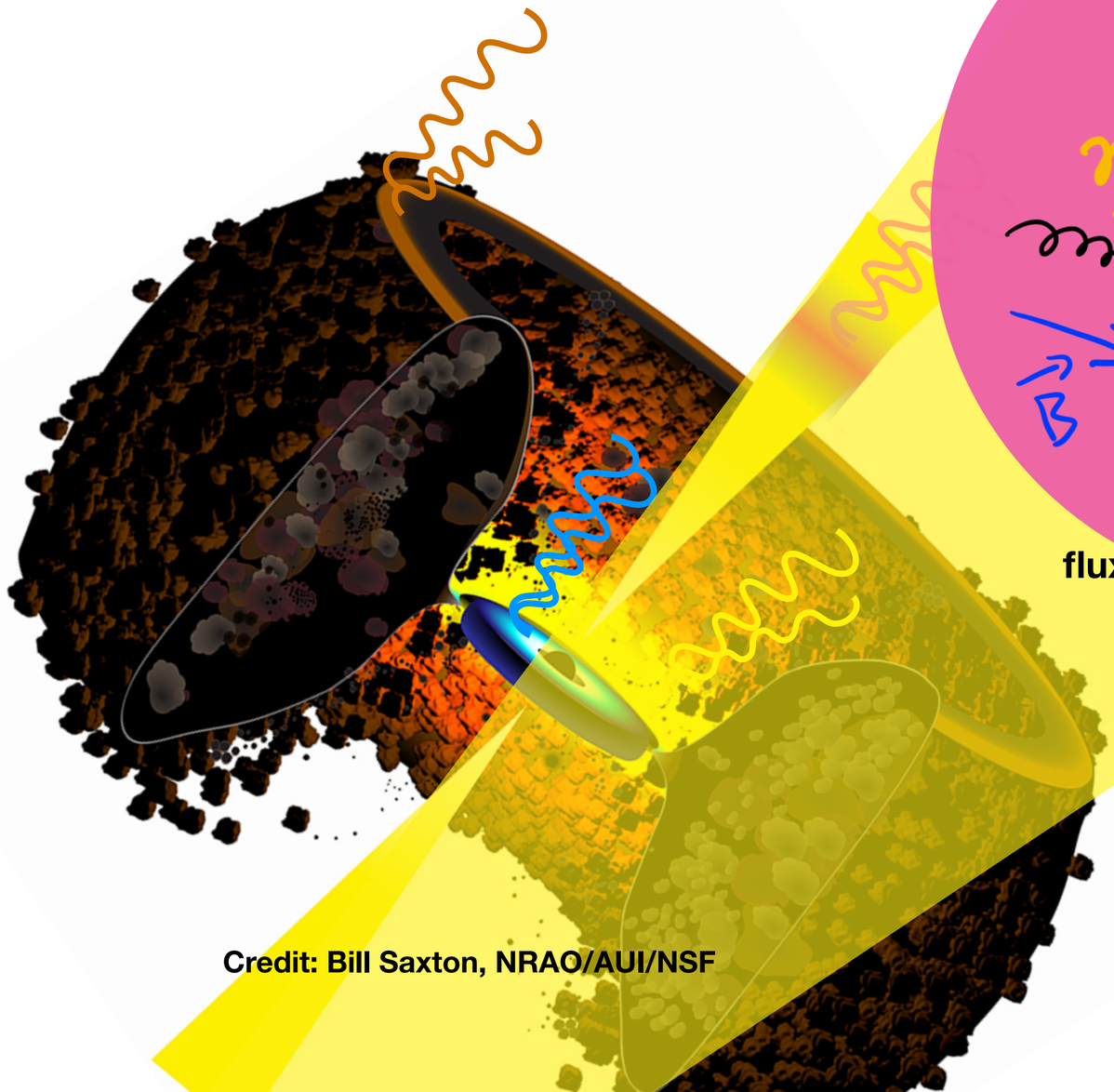


Credit: Bill Saxton, NRAO/AUI/NSF





Modeling active galaxies



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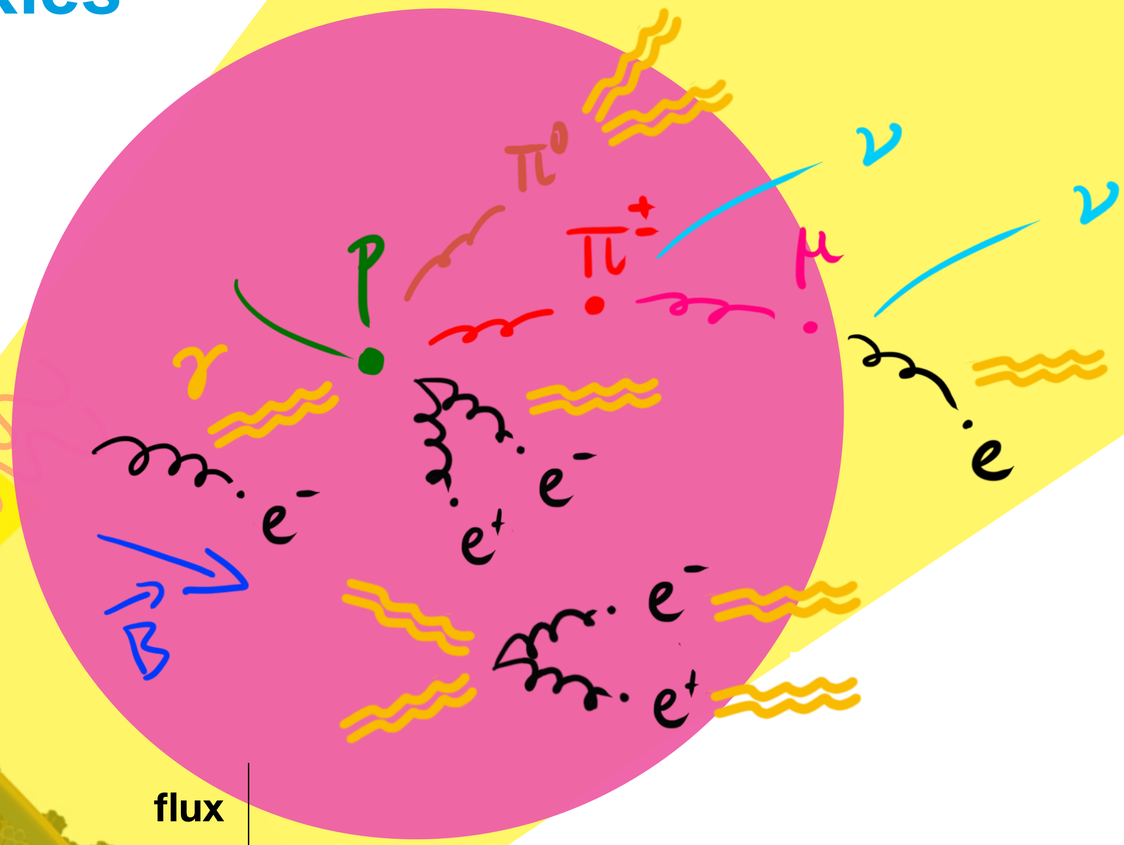
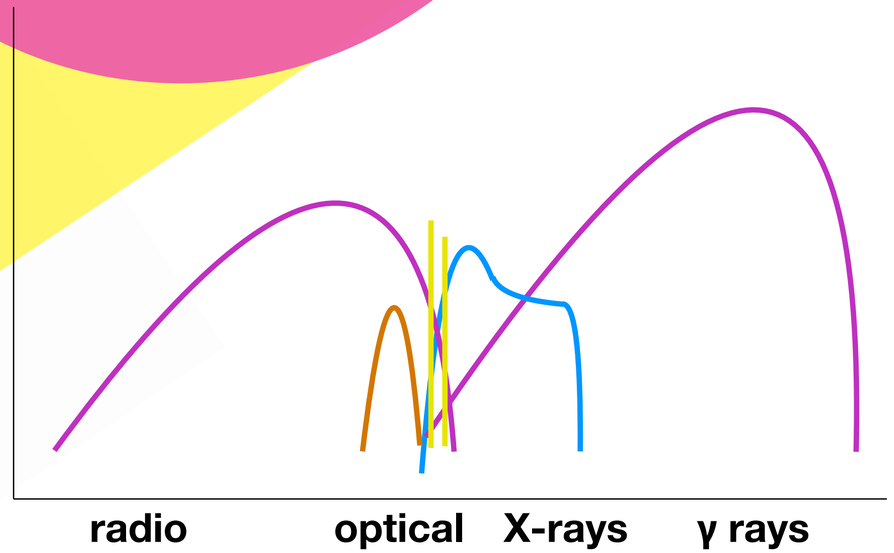
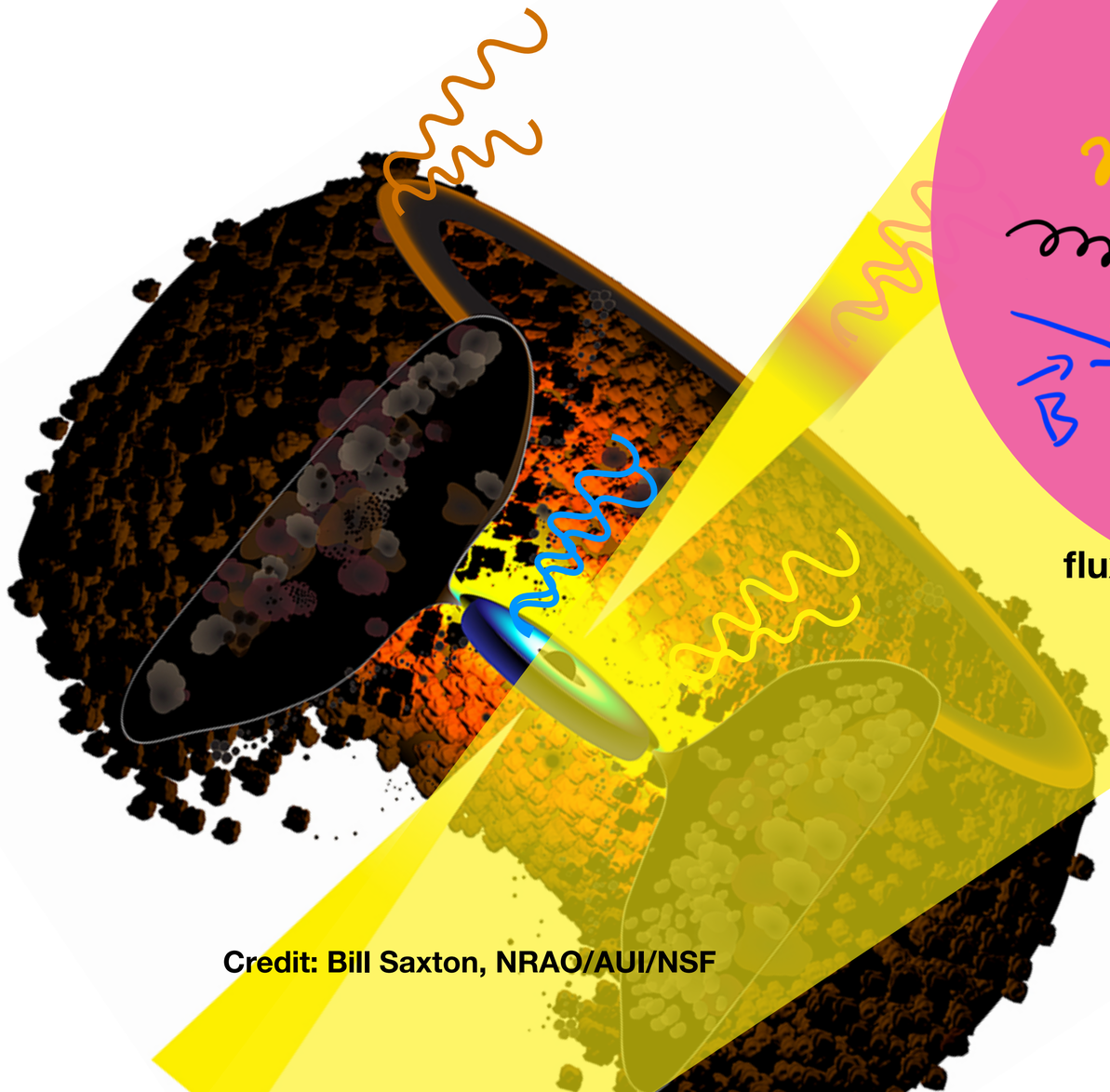
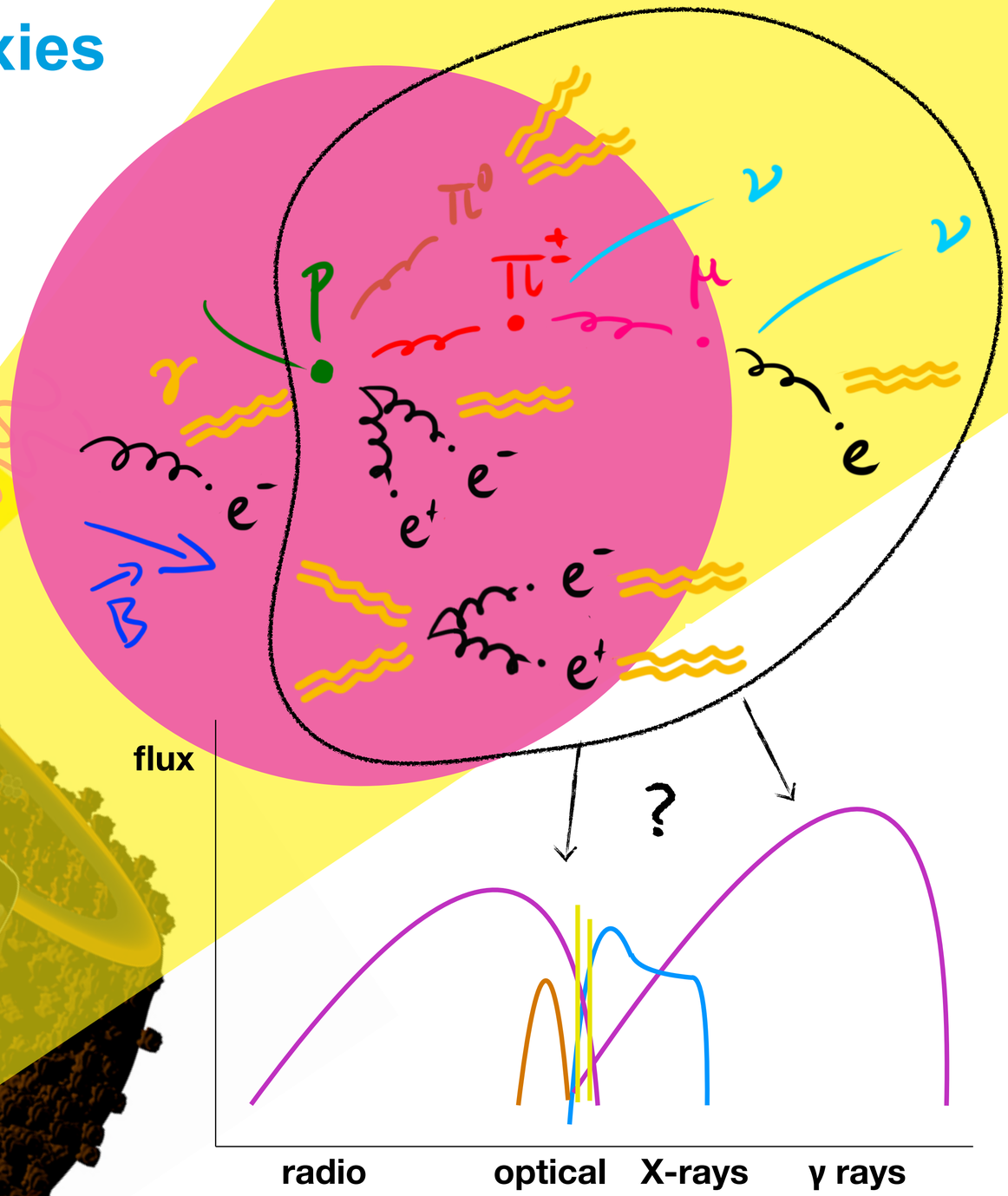




Modeling active galaxies

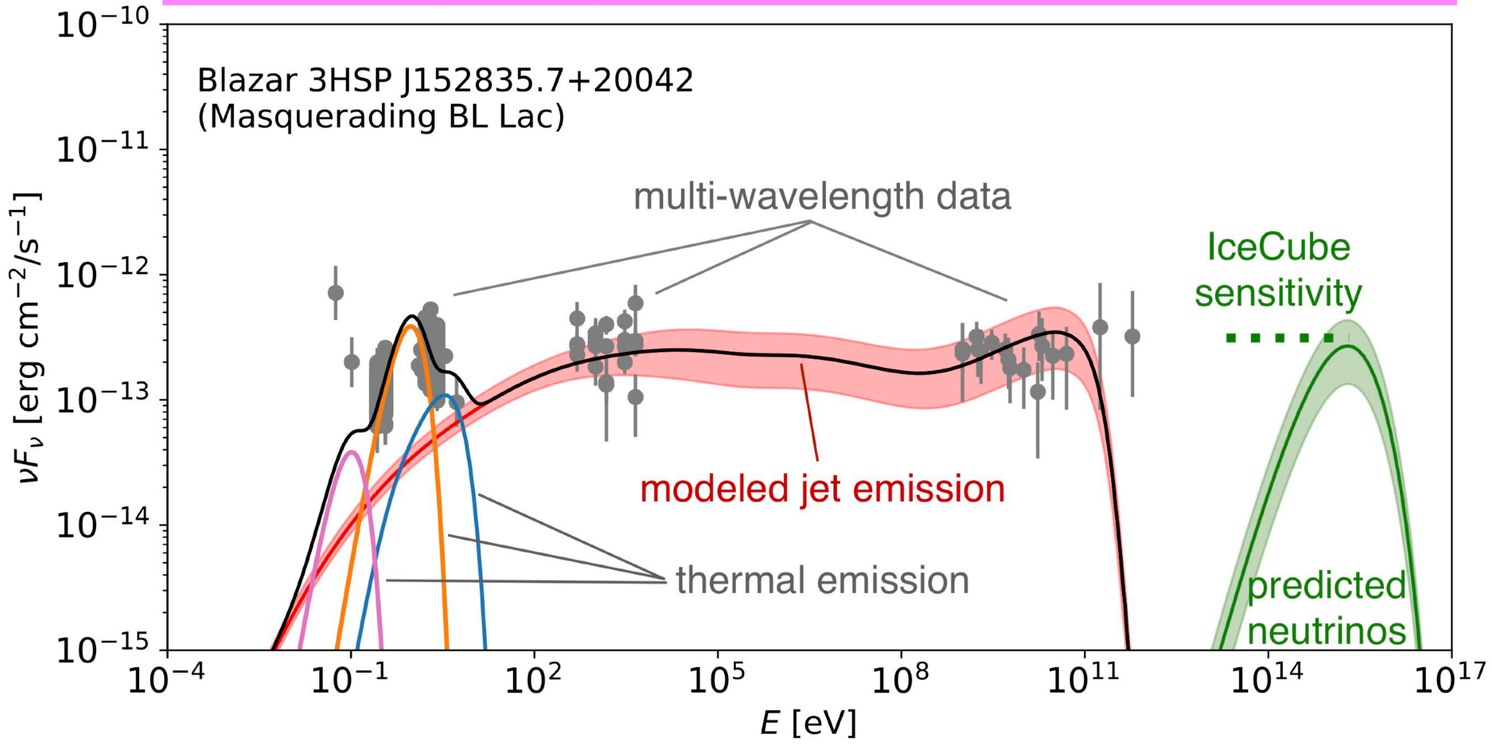


Credit: Bill Saxton, NRAO/AUI/NSF



Spectra of **I**ceCube **N**eutrino Candidate Sources **(SIN)**

Modeling a sample of **~50 HBL IceCube candidates**

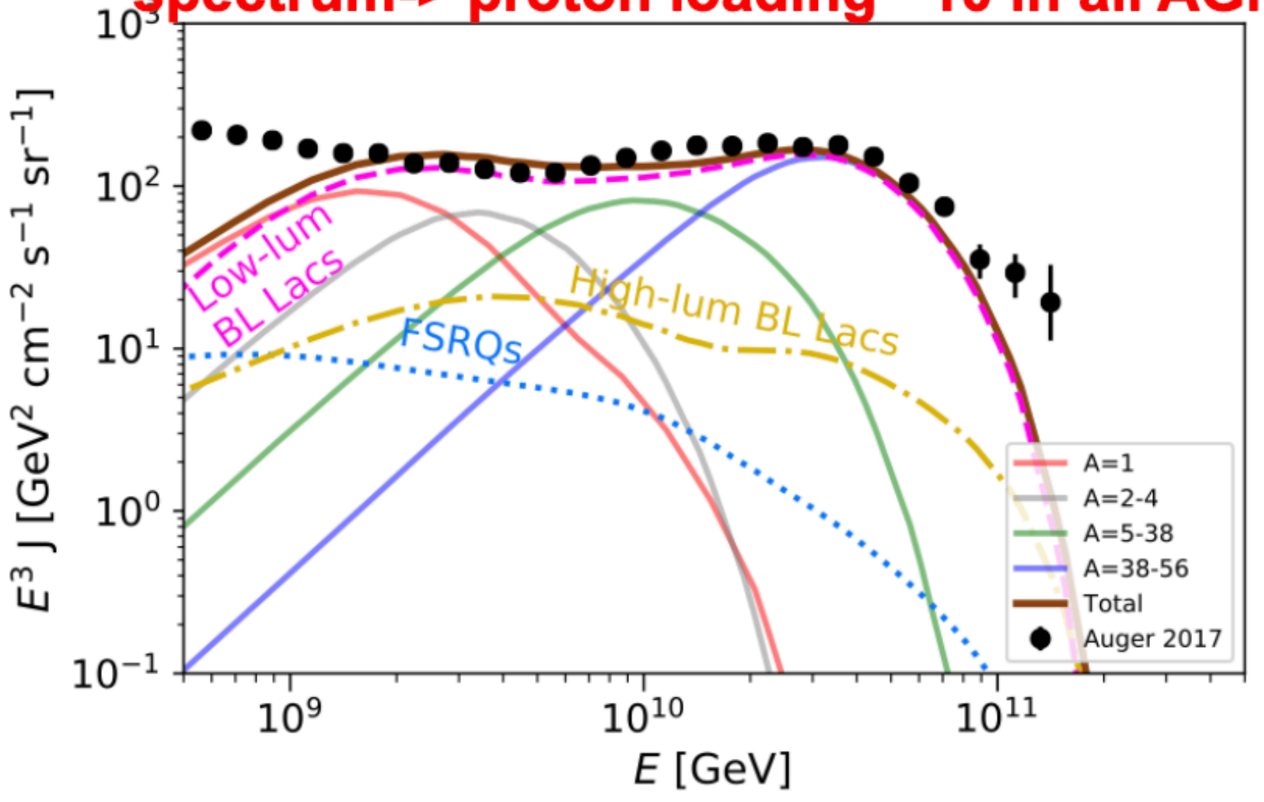


Ongoing collaboration with

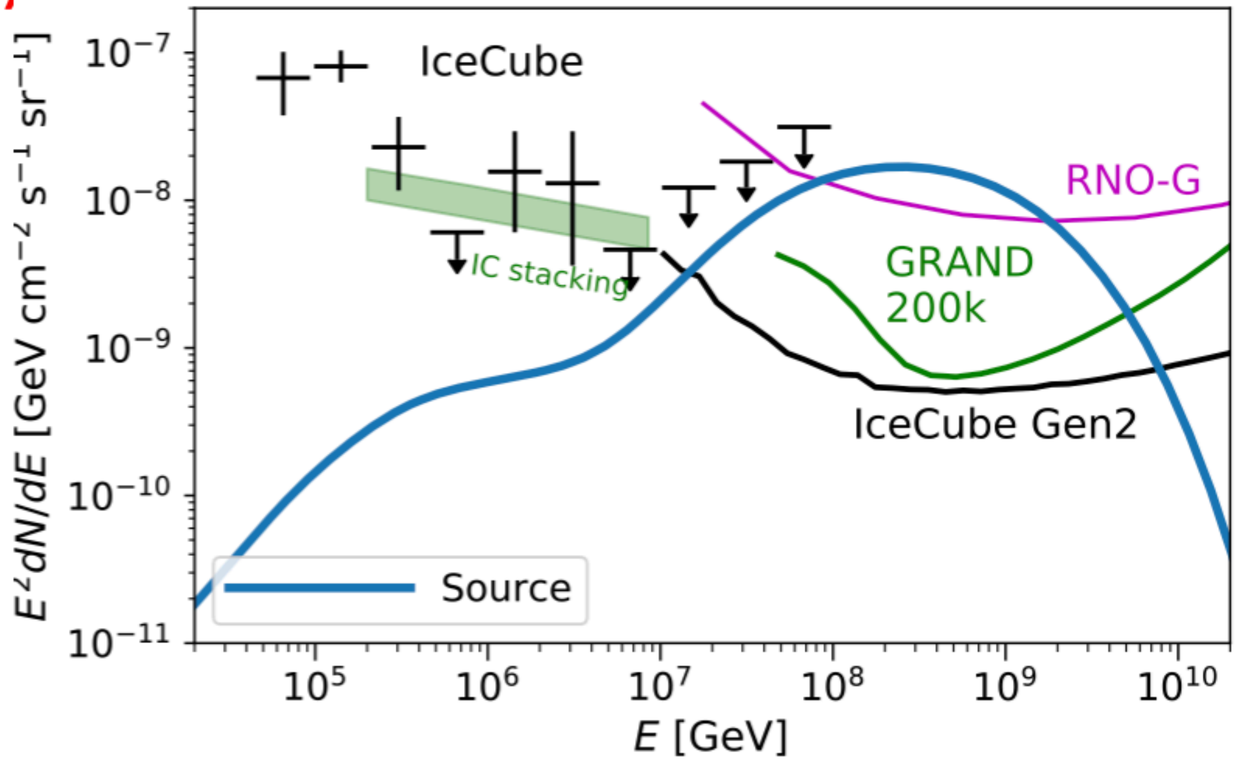
P. Padovani
M. Karl
P. Giommi
M. Wolf
S. Paiano
C. Bellenghi
R. Falomo
E. Resconi
M. Petropoulou
F. Oikonomou

What about the ultra-high energies?

Assuming AGN are accelerators of UHECRs…
(Best-case scenario, AGN exhaust the Auger spectrum-> proton loading ~10 in all AGN!)

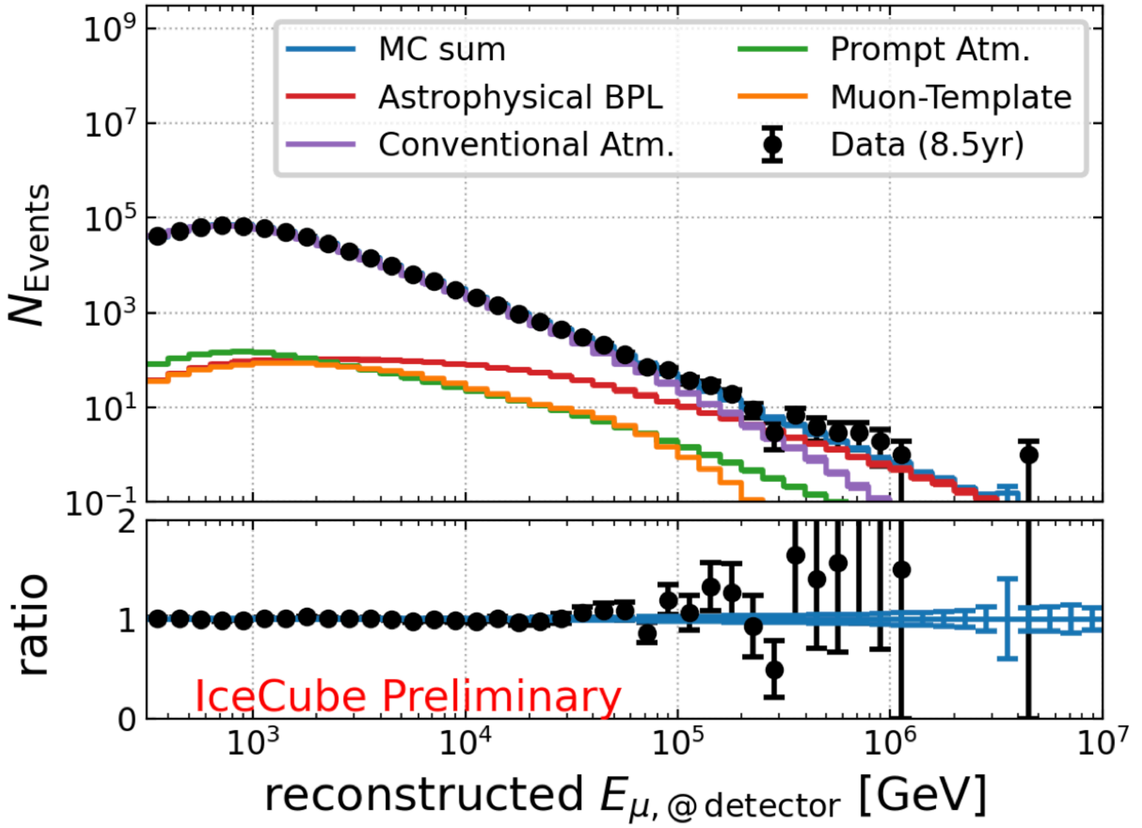


…we may currently be missing the bulk of their multi-messenger emission.

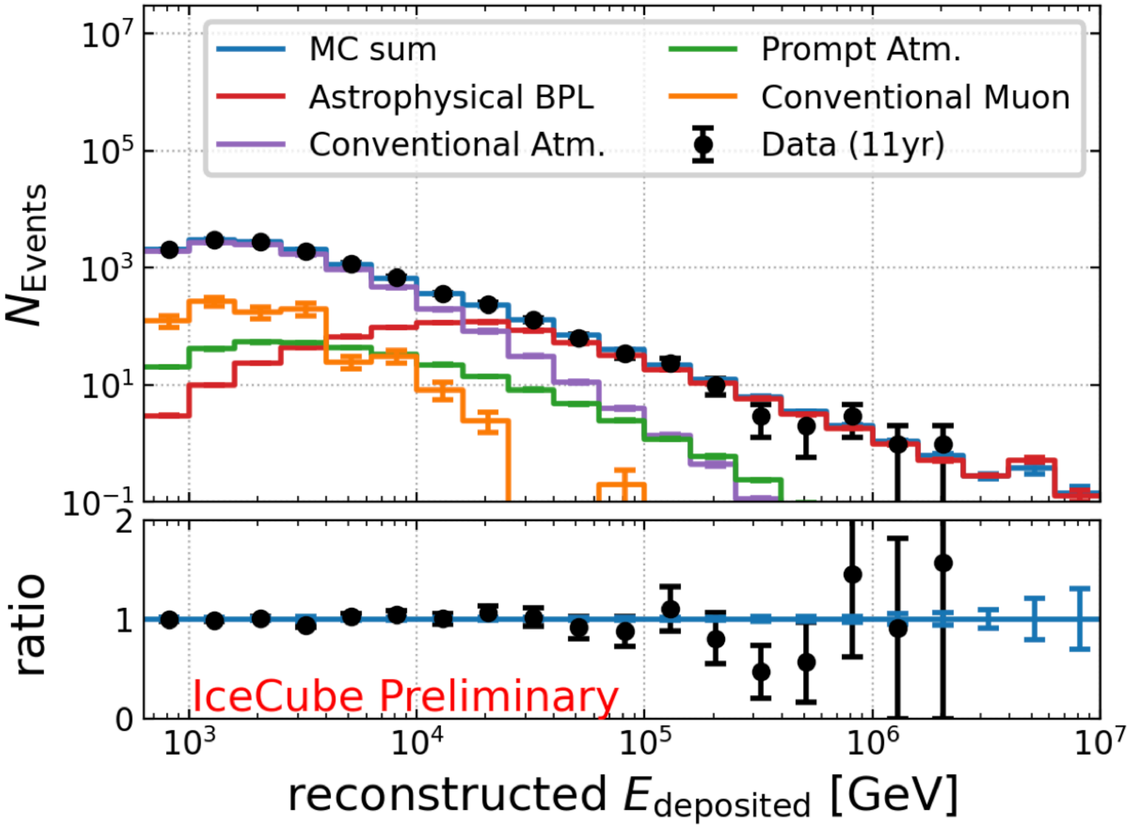


Rodrigues, Heinze, Palladino, van Vliet and Winter, PRL 126 (2021)

Track histogram

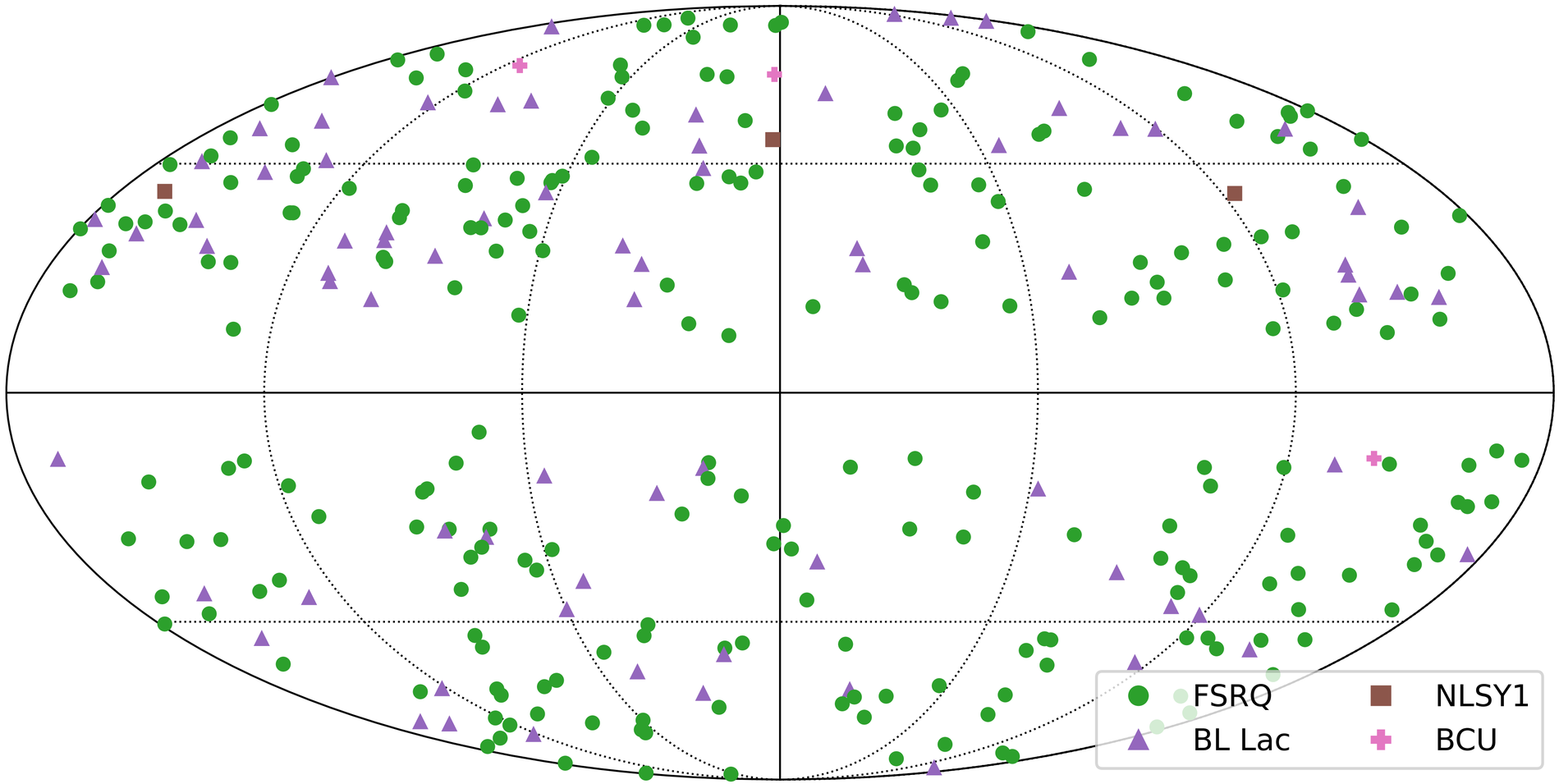


Cascade histogram



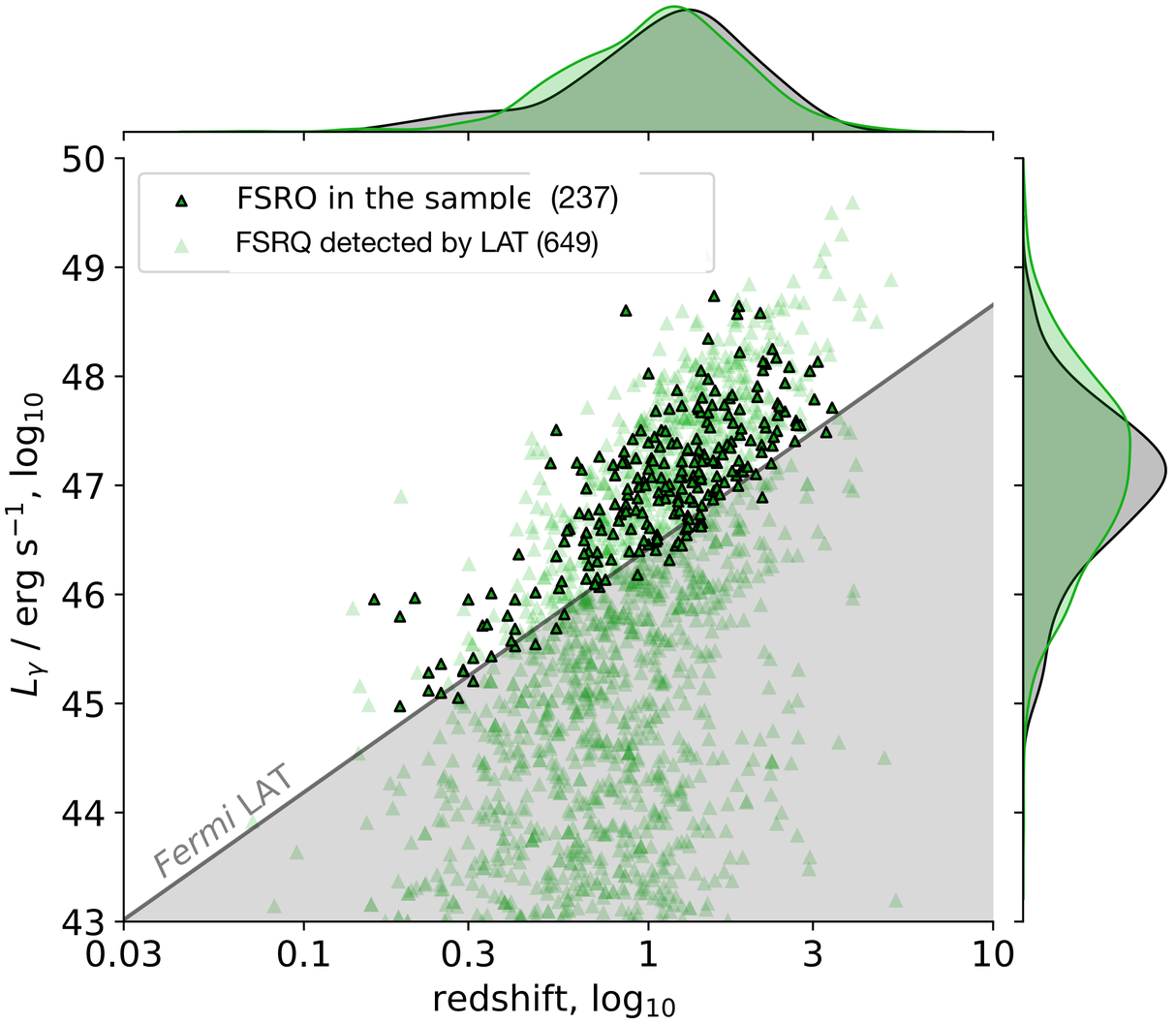
Naab+ ICRC 2023

From sources to samples



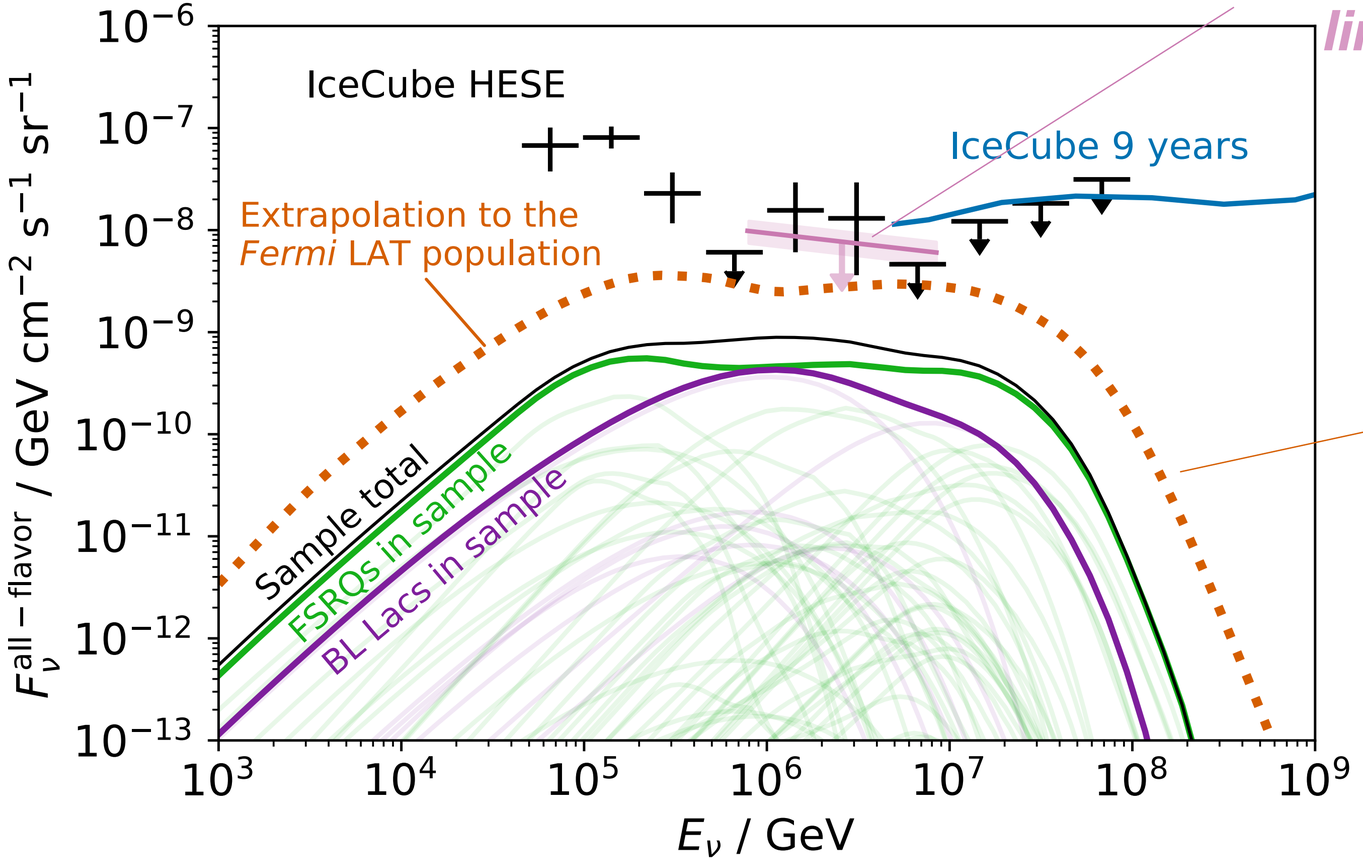
XR, Paliya, Garrappa, Omeliukh, Franckowiak & Winter (arXiv:2307.13024)

From sources to samples



XR, Paliya, Garrappa, Omeliukh, Franckowiak & Winter (arXiv:2307.13024)

Predicted diffuse flux

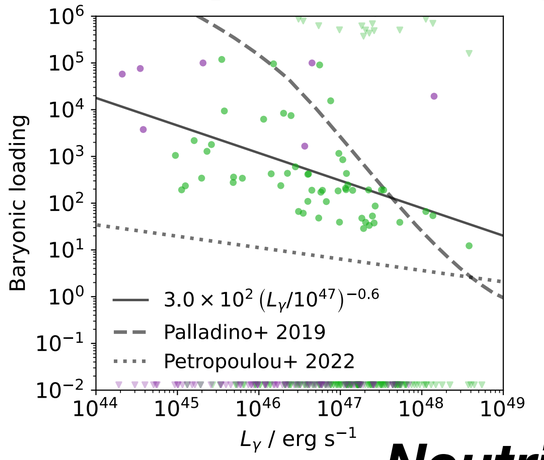


IceCube stacking limit

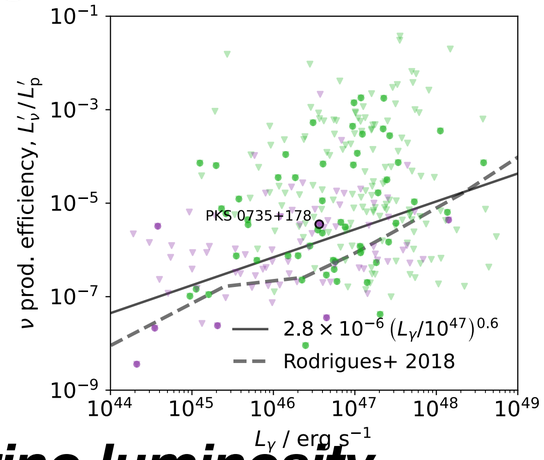
In this model, the the Fermi blazar population contributes ~20% of the IceCube diffuse flux

XR, Paliya, Garrappa, Omeliukh, Franckowiak & Winter (arXiv:2307.13024)

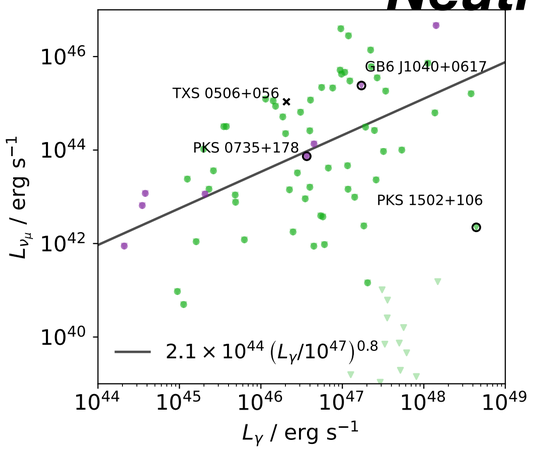
Baryonic loading

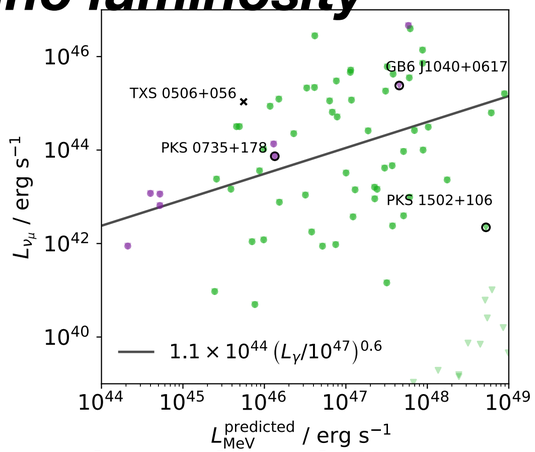


Neutrino efficiency



Neutrino luminosity

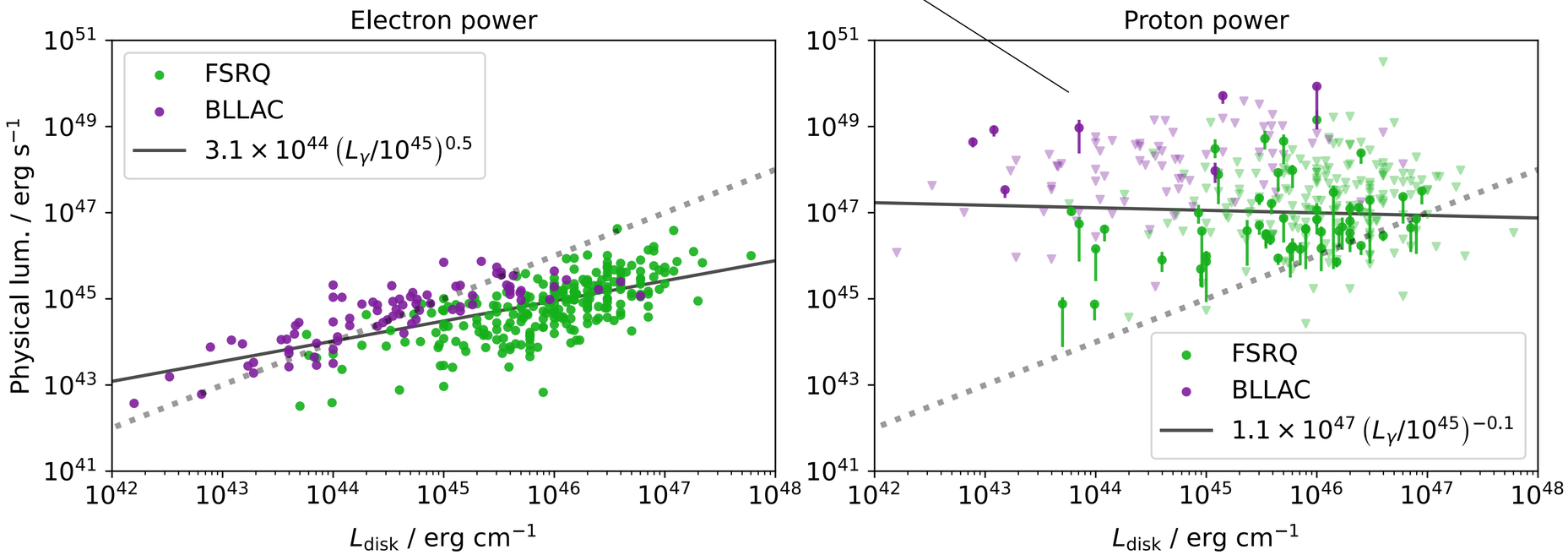




Rodrigues, Paliya, Garrappa, Omeliukh, Franckowiak and Winter (arXiv:2307.13024, submitted to A&A)

Required cosmic-ray power

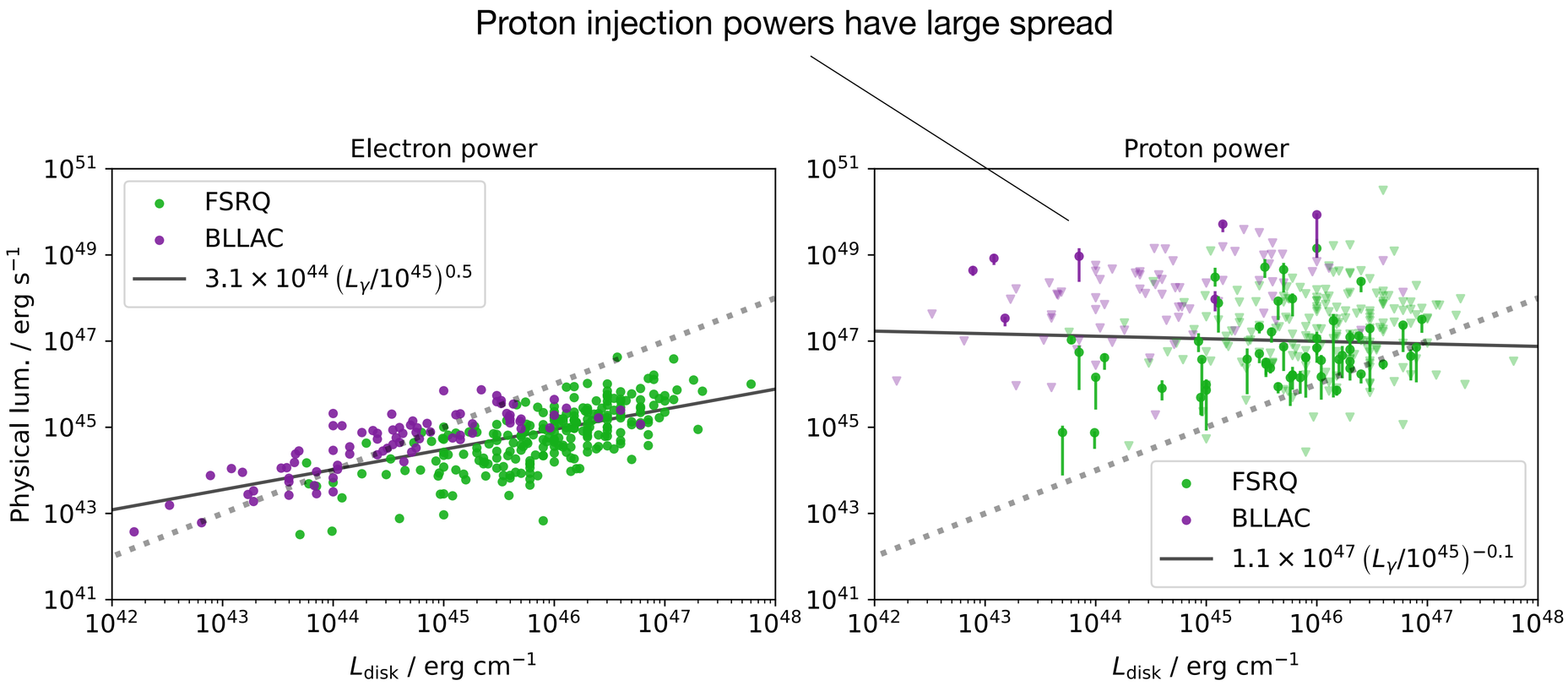
Proton injection powers have large spread
but are in mostly comparable to $L_{\rm Eddington}$



Rodrigues, Paliya, Garrappa, Omeliukh, Franckowiak and Winter (arXiv:2307.13024, submitted to A&A)

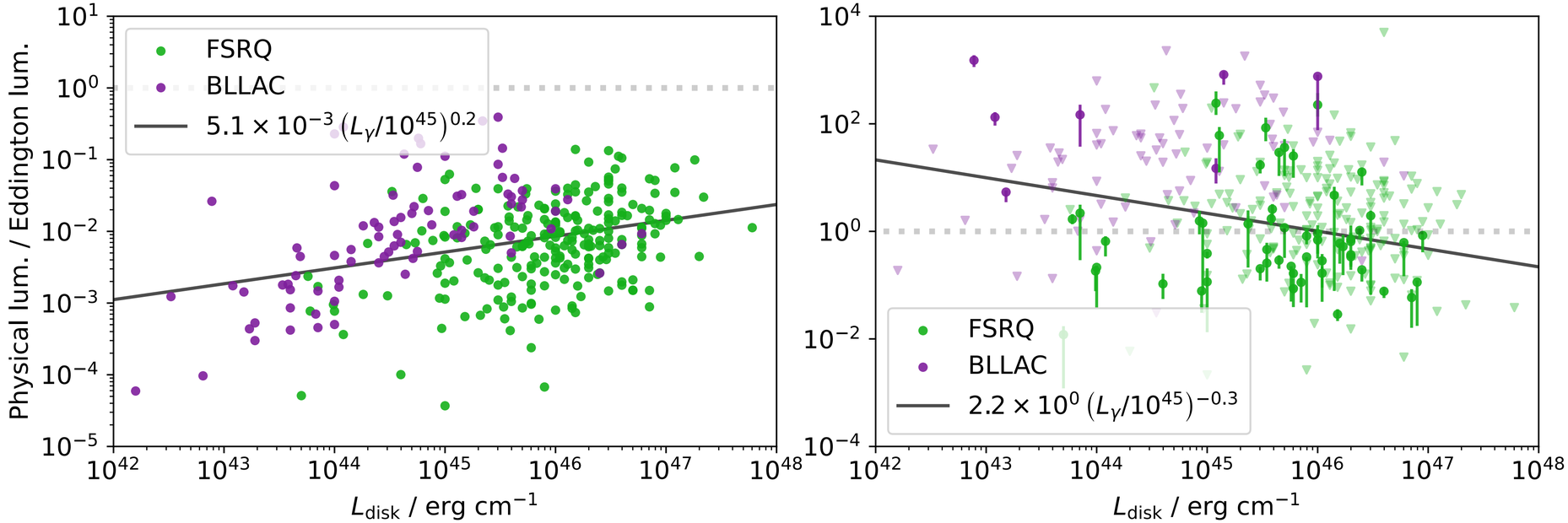
All model results available online: github.com/xrod/lephad-blazars

Required cosmic-ray power



Rodrigues, Paliya, Garrappa, Omeliukh, Franckowiak and Winter (arXiv:2307.13024, submitted to A&A)

Required cosmic-ray power compared to the Eddington luminosity



Rodrigues, Paliya, Garrappa, Omeliukh, Franckowiak and Winter (arXiv:2307.13024, submitted to A&A)

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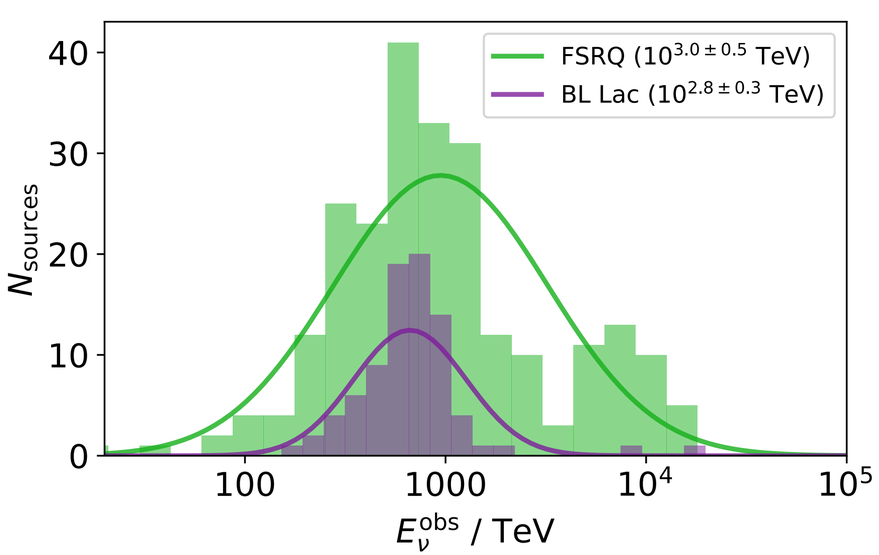
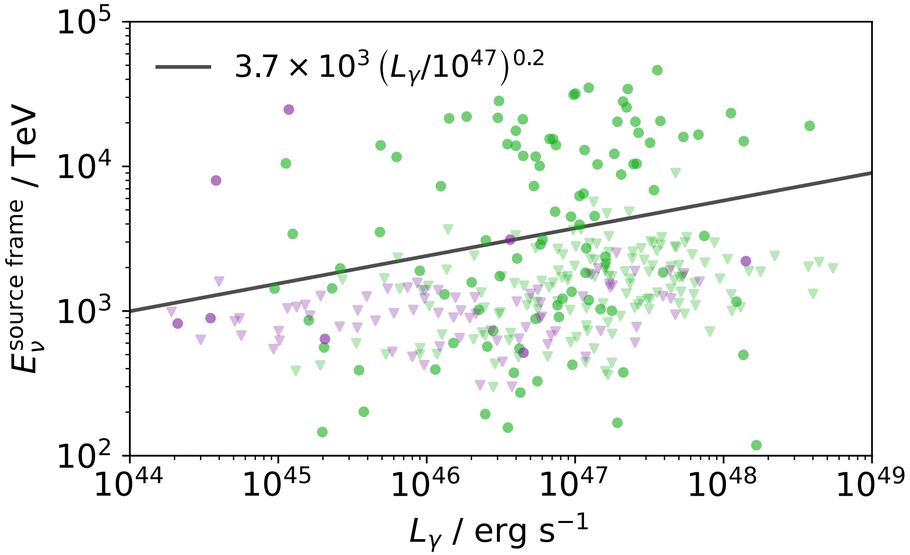
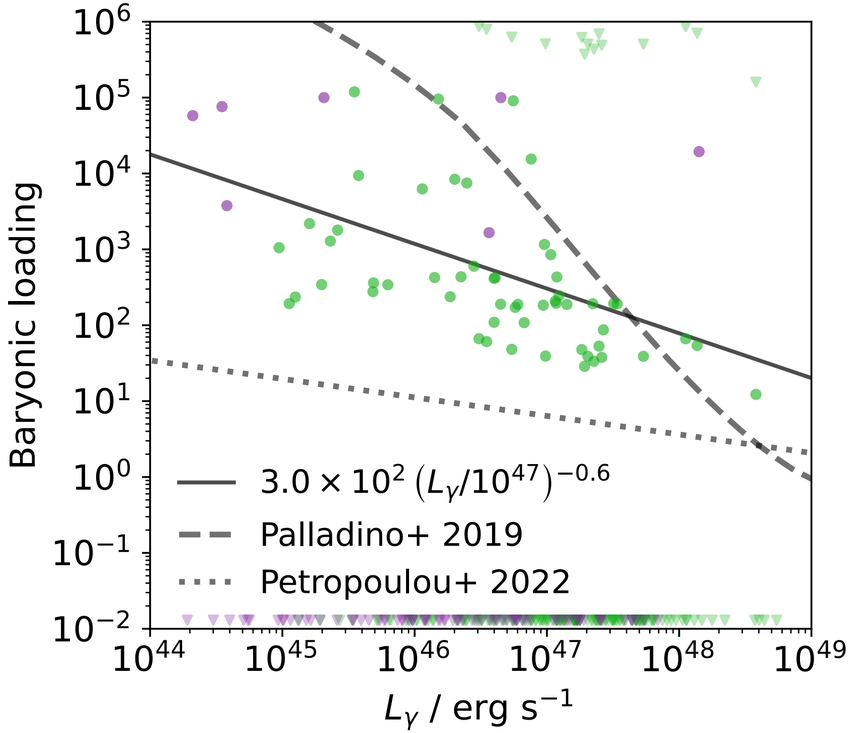


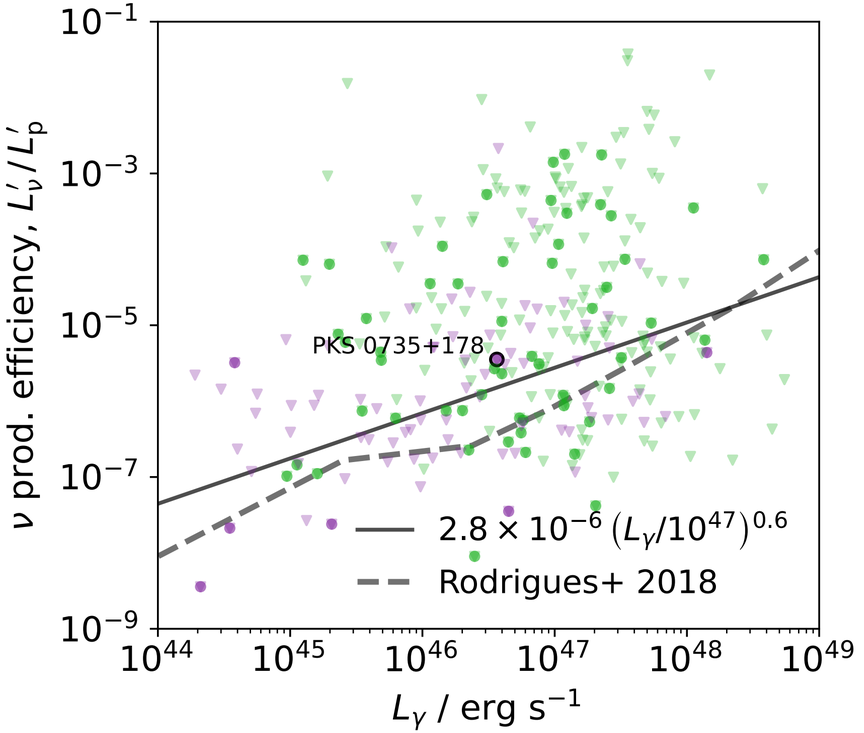


Rodrigues, Paliya, Garrappa, Omeliukh, Franckowiak and Winter (arXiv:2307.13024, submitted to A&A)

Best-fit baryonic loading (== L_p / L_e) scales inversely with L_γ

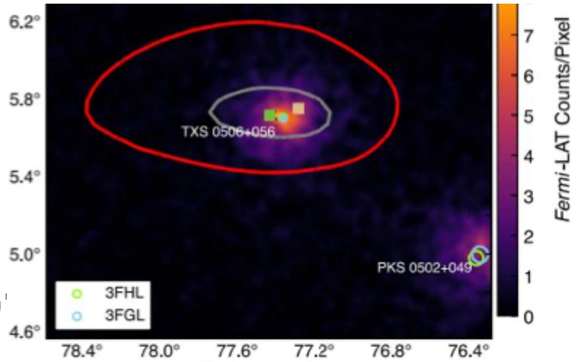


Neutrino efficiency scales positively with L_γ

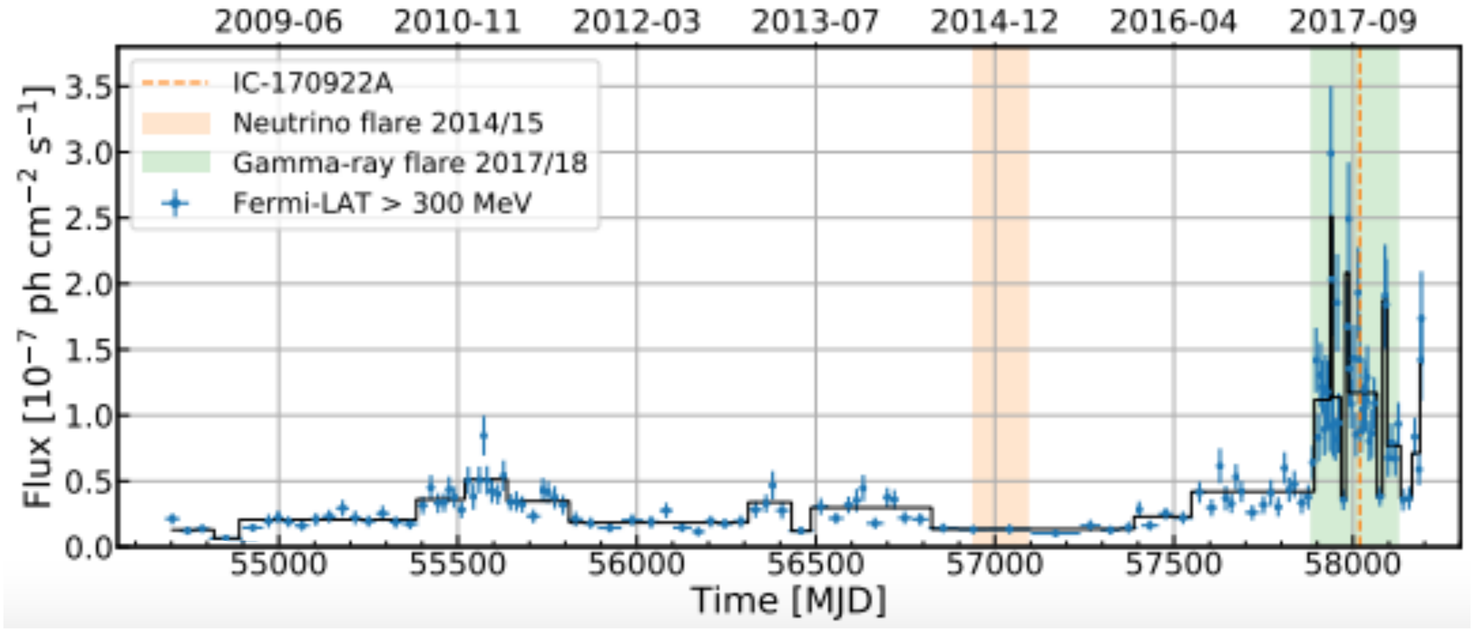


Rodrigues, Paliya, Garrappa, Omeliukh, Franckowiak and Winter (arXiv:2307.13024, submitted to A&A)

Will we find IceCube blazars in GeV γ-rays?

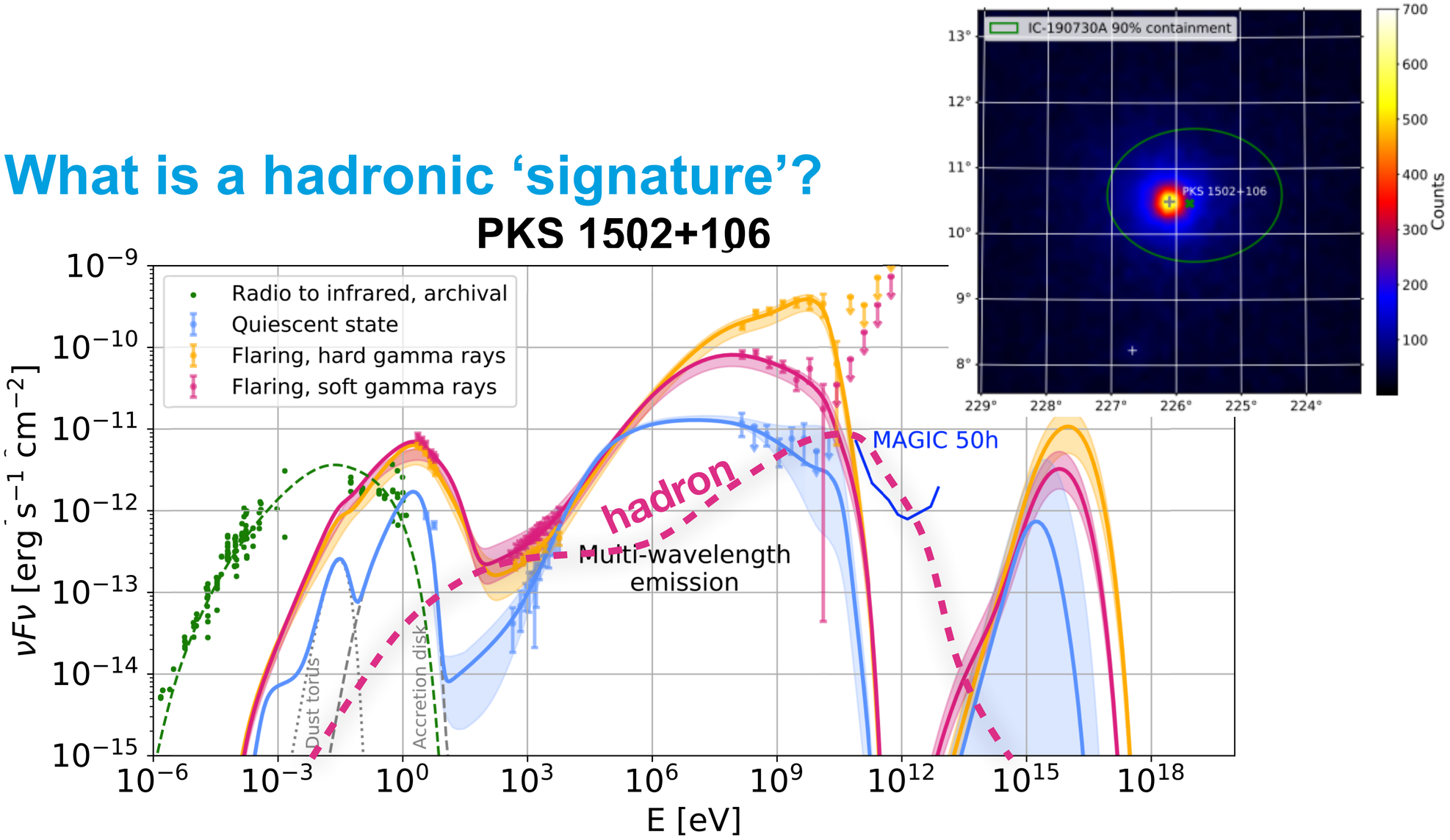


TXS 0506+056 (September 20



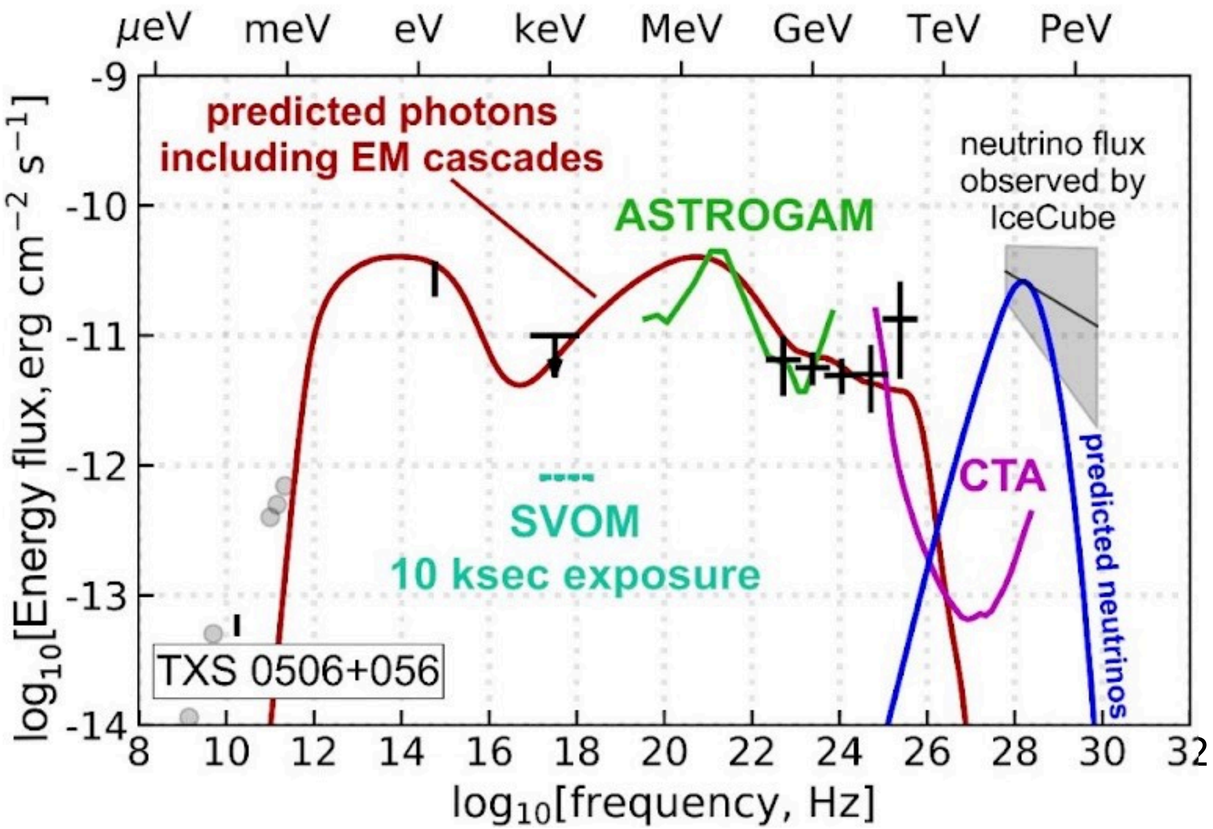
Garrappa+ 2019, ApJ 880

What is a hadronic ‘signature’?



Rodrigues, Garrappa, Gao, Paliya, Franckowiak and Winter, ApJ 912 (2021)

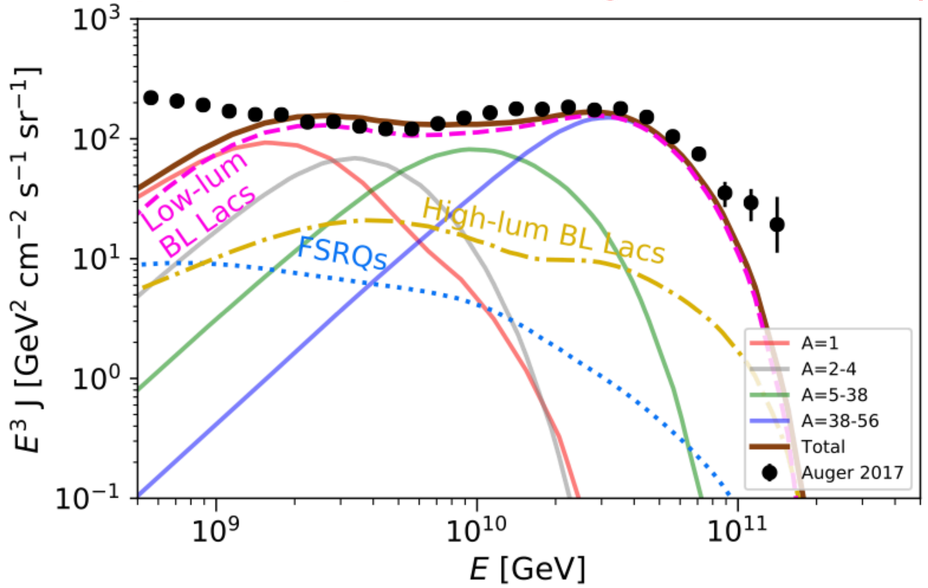
Will we find IceCube blazars in MeV gamma rays?



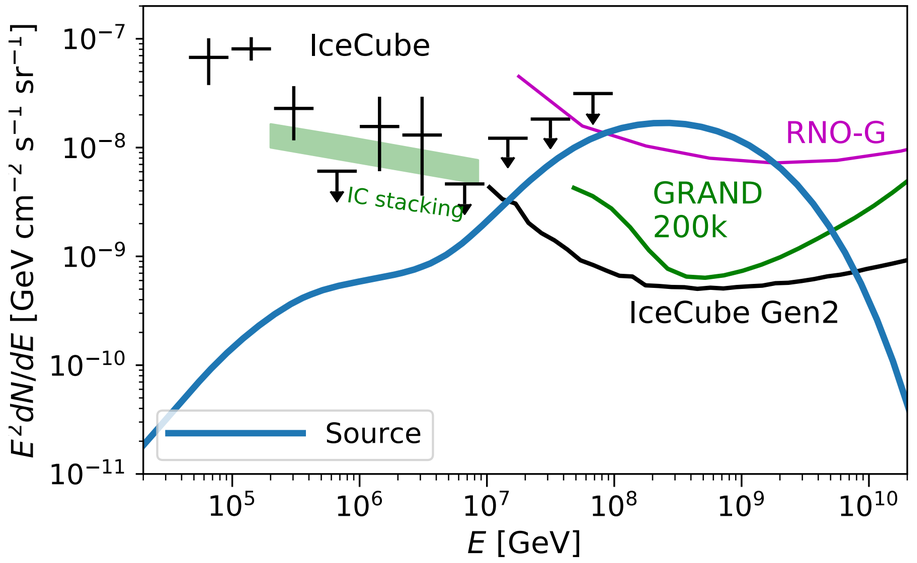
Rodrigues, Gao, Fedynitch, Palladino, Winter,

What about the ultra-high energies?

Assuming AGN are accelerators of UHECRs…
(Best-case scenario, AGN exhaust the Auger spectrum-> proton loading ~10 in all AGN!)

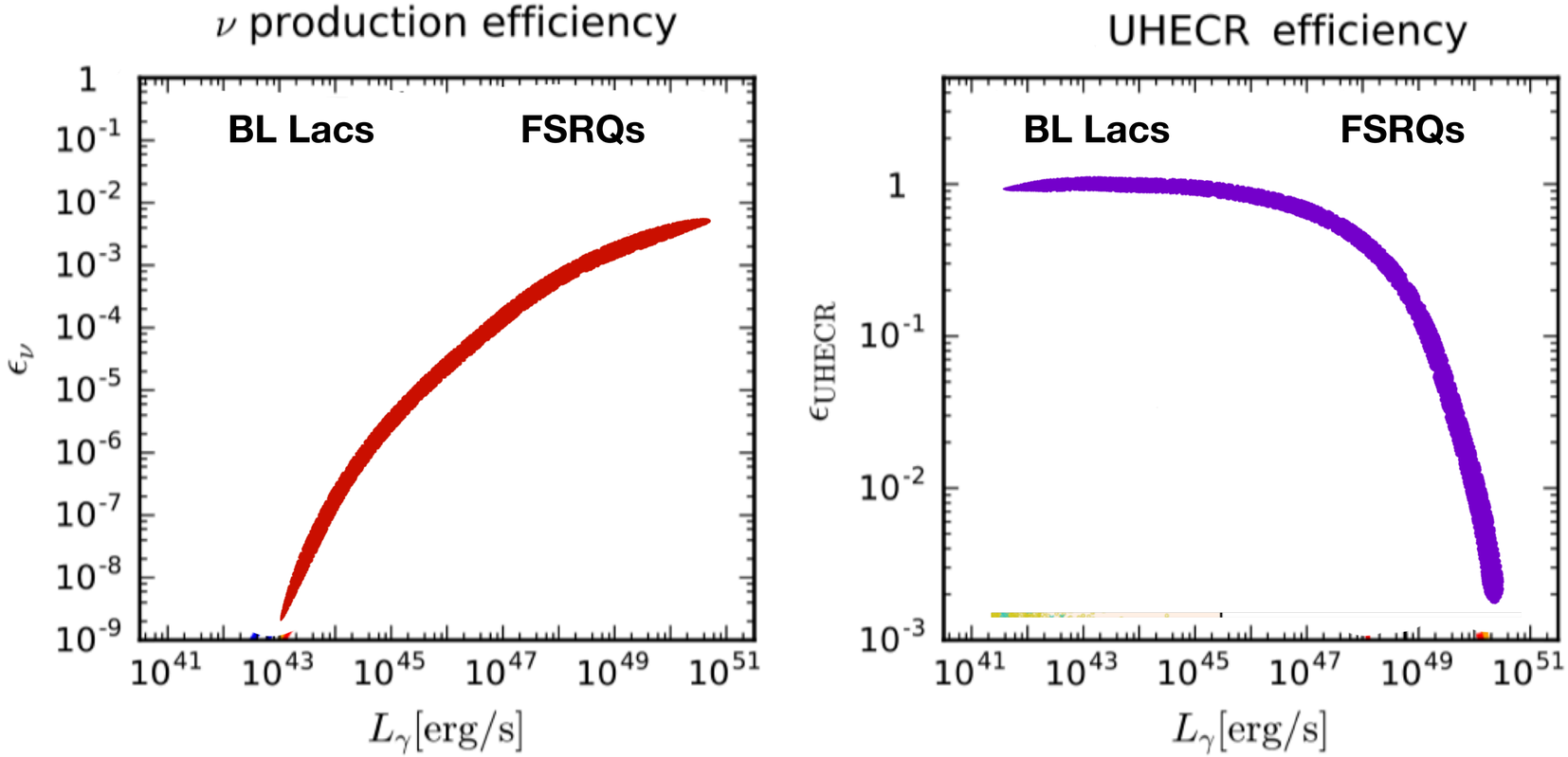


…we may currently be missing the bulk of their multi-messenger emission.



Rodrigues, Heinze, Palladino, van Vliet and Winter, PRL 126 (2021)

CRs and neutrinos from the entire blazar population

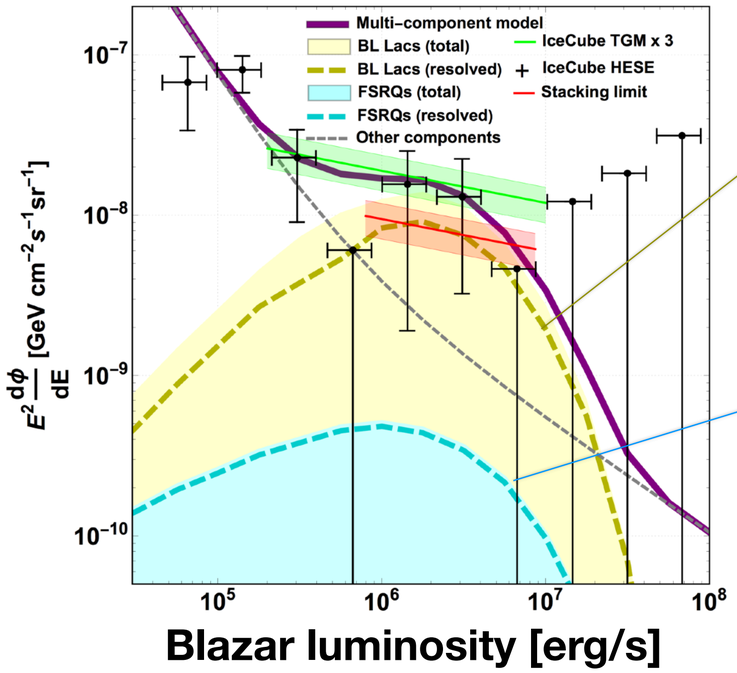


XR, Fedynitch, Gao, Boncioli, Winter, ApJ 854

Blazars as accelerators of PeV cosmic rays

Palladino, XR, Gao & Winter, ApJ 871

Diffuse neutrino flux



BL Lacs must have **high baryonic loadings** to power the

FSRQ contribution must be **highly suppressed** not to violate

Baryonic loading