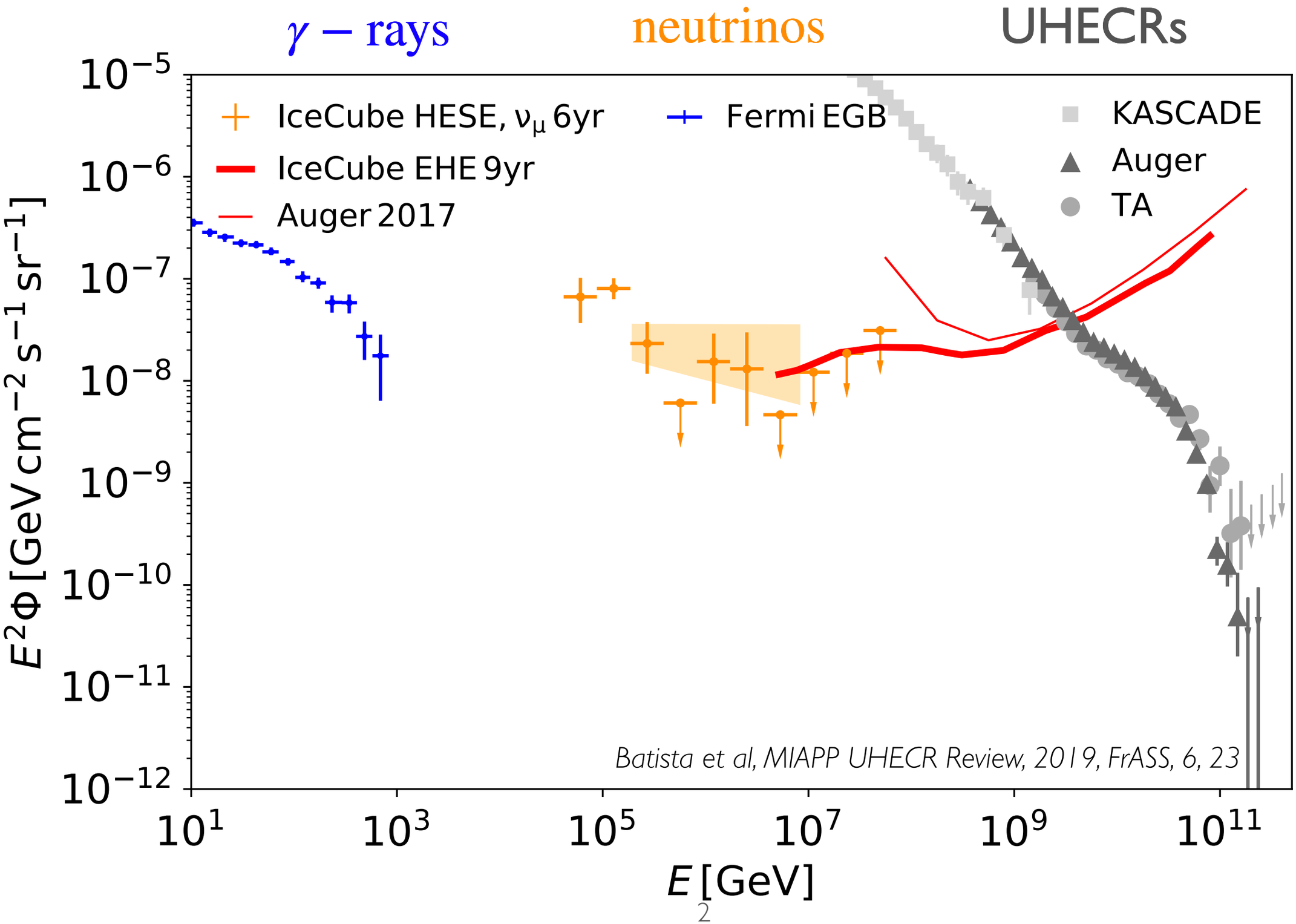
MULTIMESSENGER VIEW

AUGER 20th ANNIVERSARY CELEBRATION

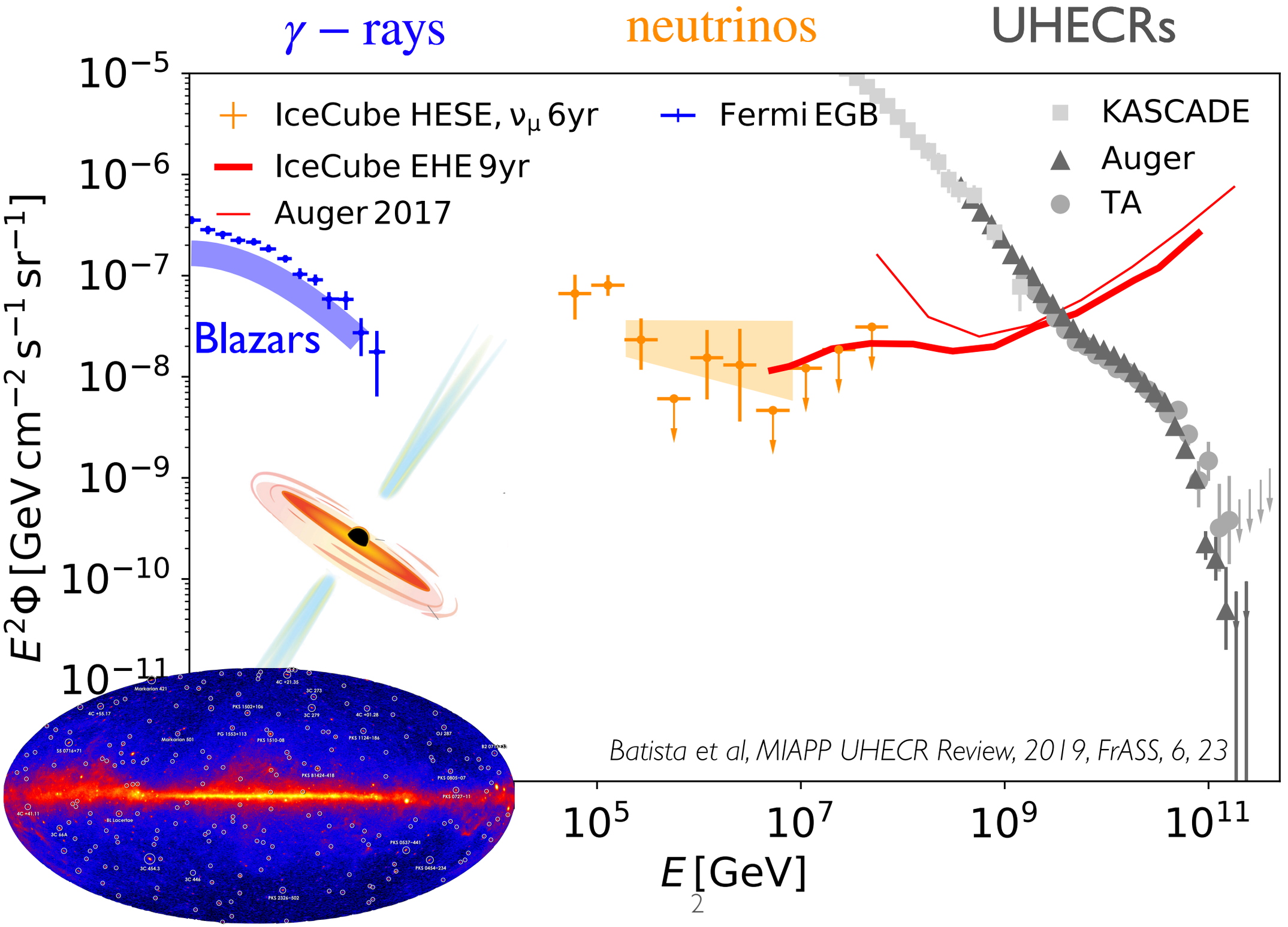
FOTEINI OIKONOMOU, 15 November 2019

SFB 1258 Neutrinos Dark Matter Messengers

High-energy messengers of the non-thermal Universe

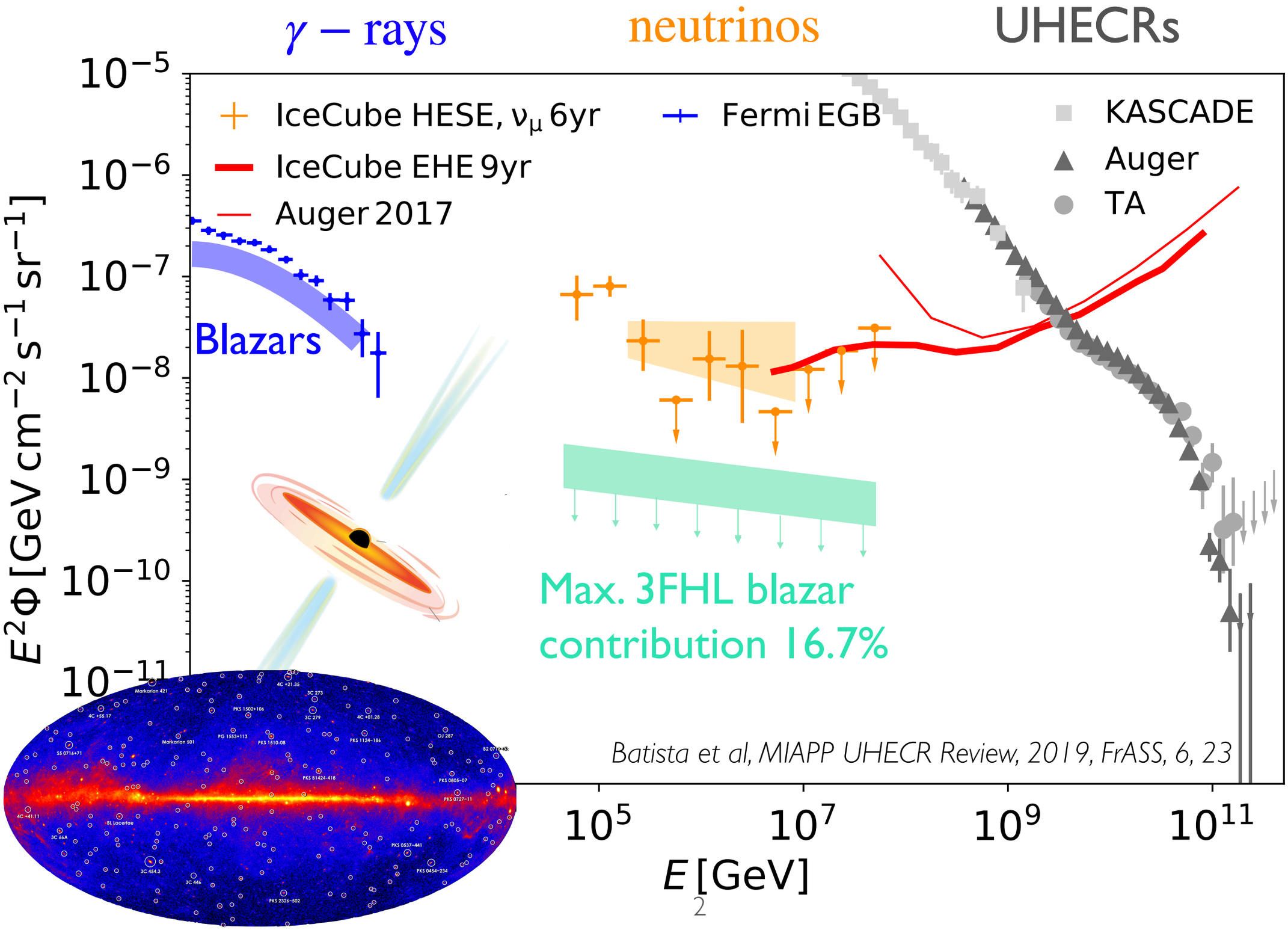


High-energy messengers of the non-thermal Universe

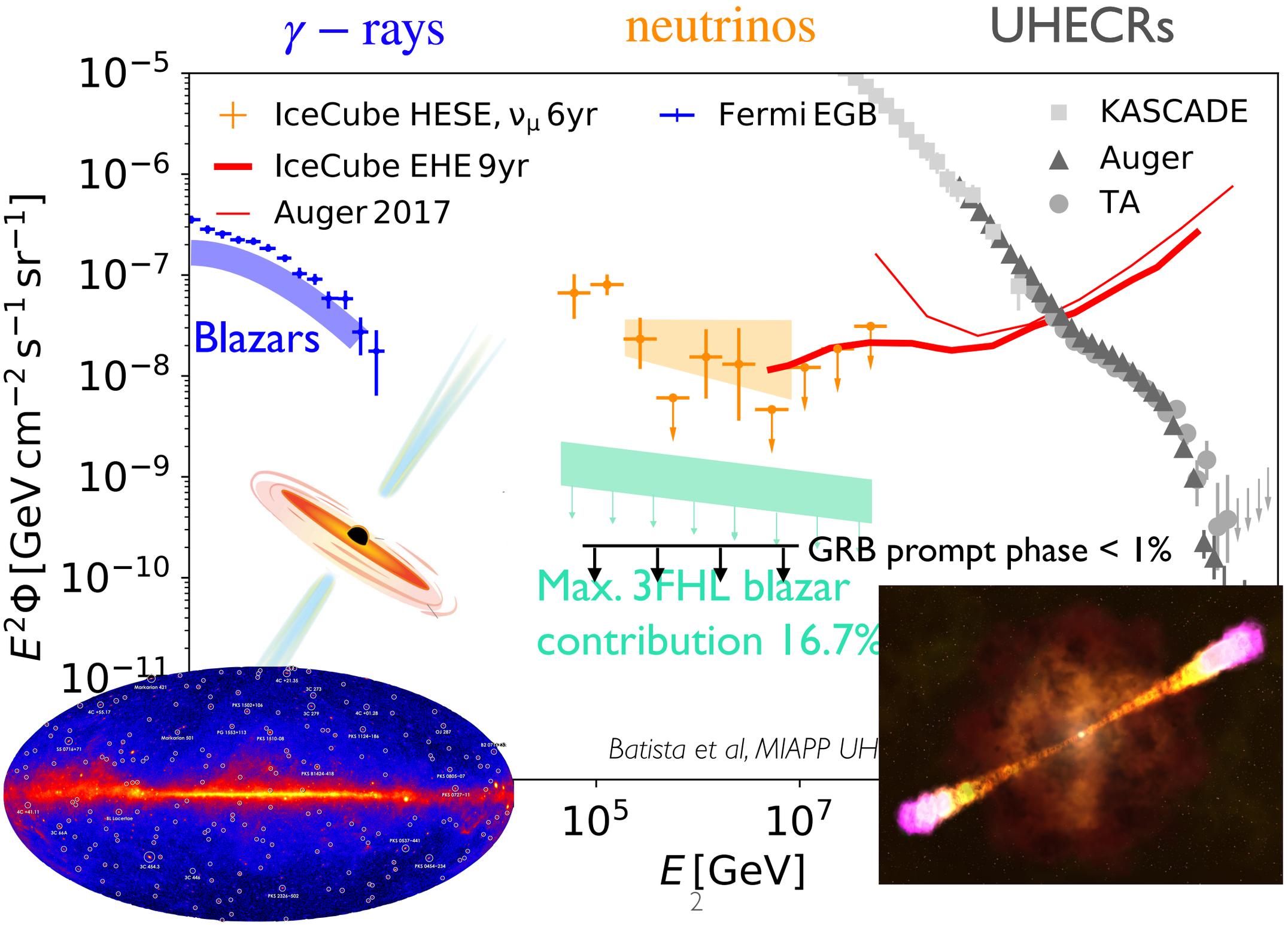


Batista et al, MIAPP UHECR Review, 2019, FrASS, 6, 23

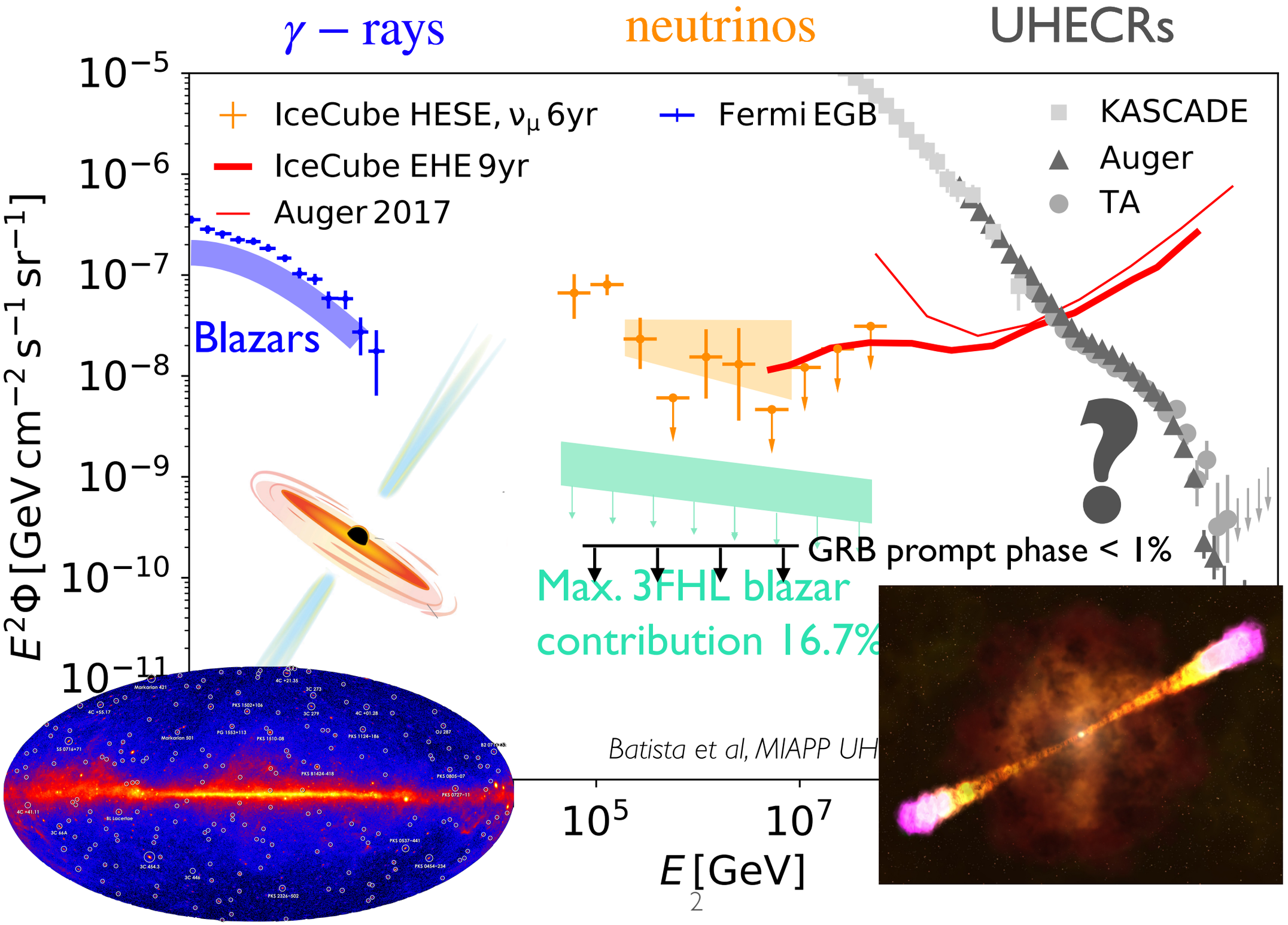
High-energy messengers of the non-thermal Universe



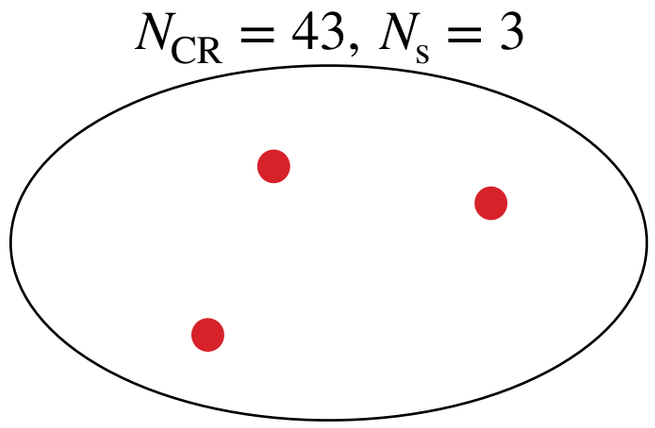
High-energy messengers of the non-thermal Universe



High-energy messengers of the non-thermal Universe



Source number density constraints: UHECRs



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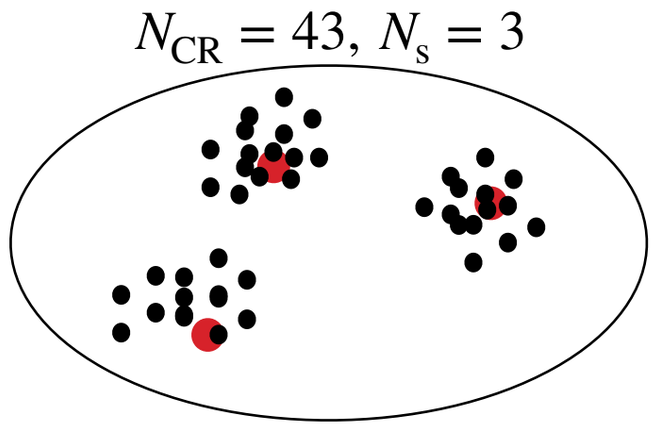
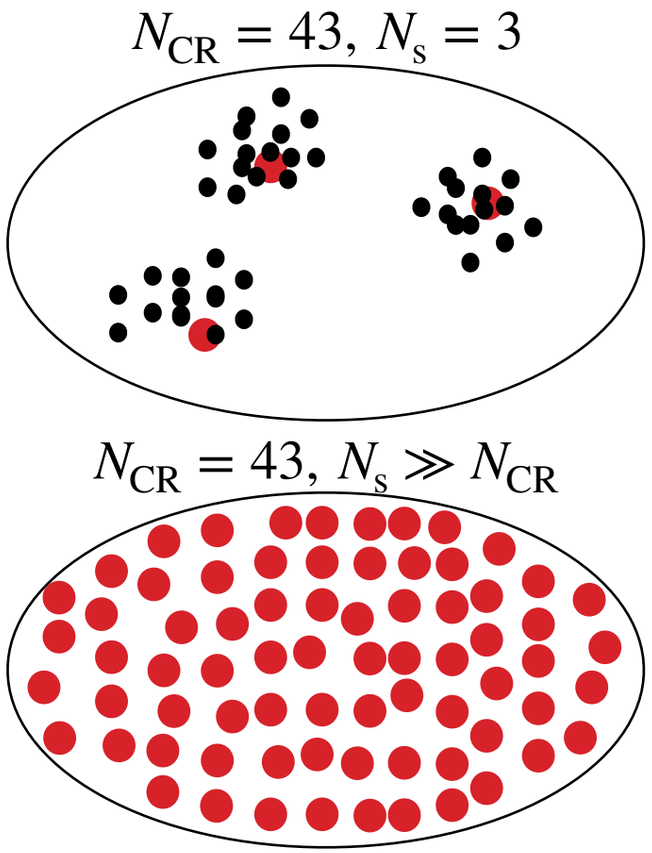
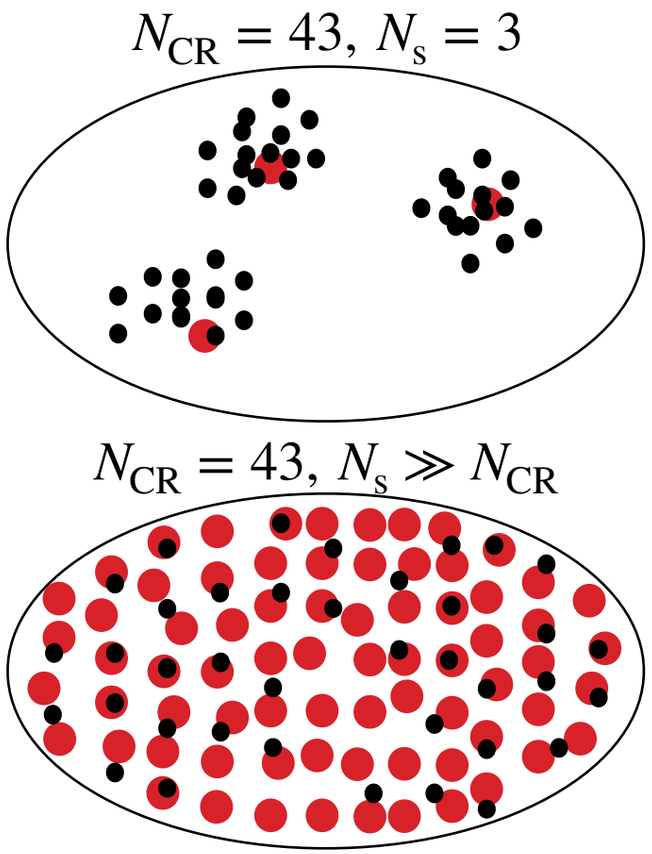


Source number density constraints: UHECRs



Source number density constraints: UHECRs



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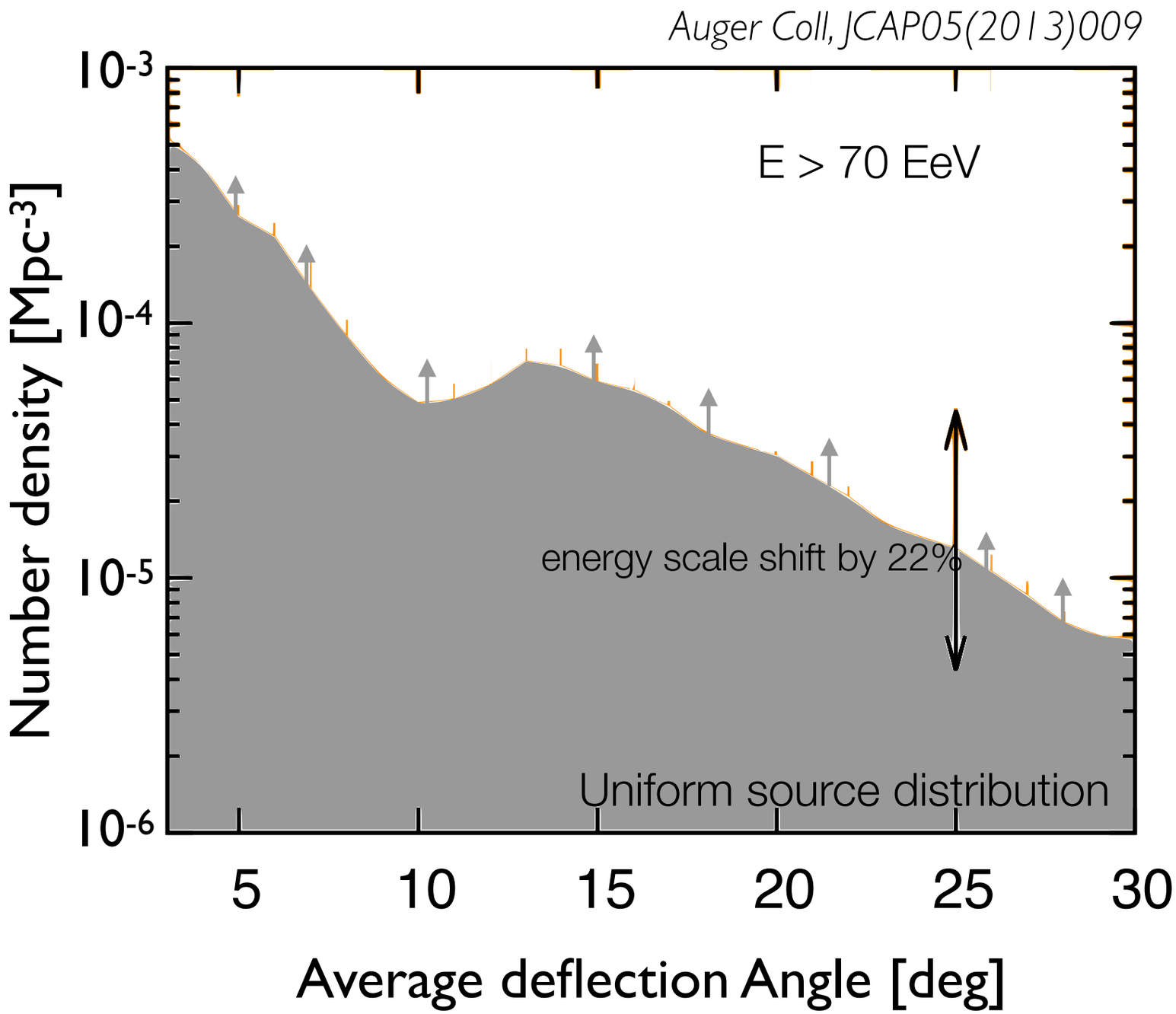
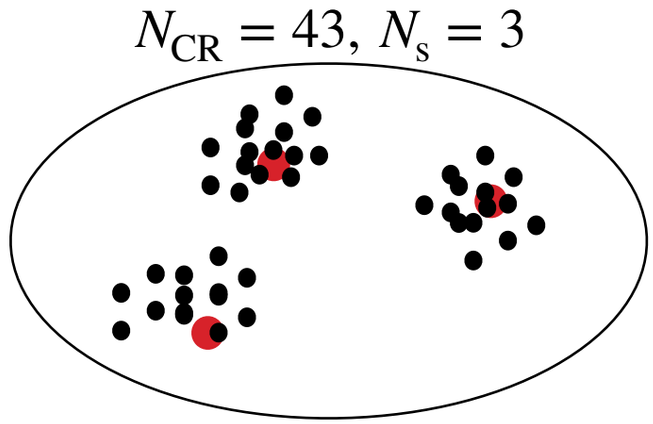
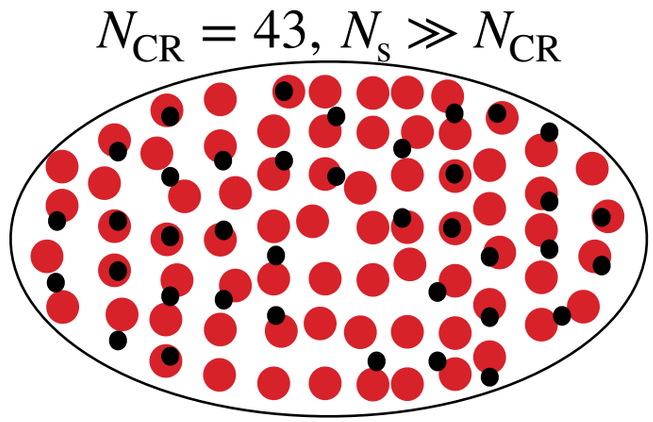






Galaxies - 10^{-2} Mpc^{-3}

Starbursts - 10^{-4} Mpc^{-3}

BL Lacs - 10^{-6} Mpc^{-3}

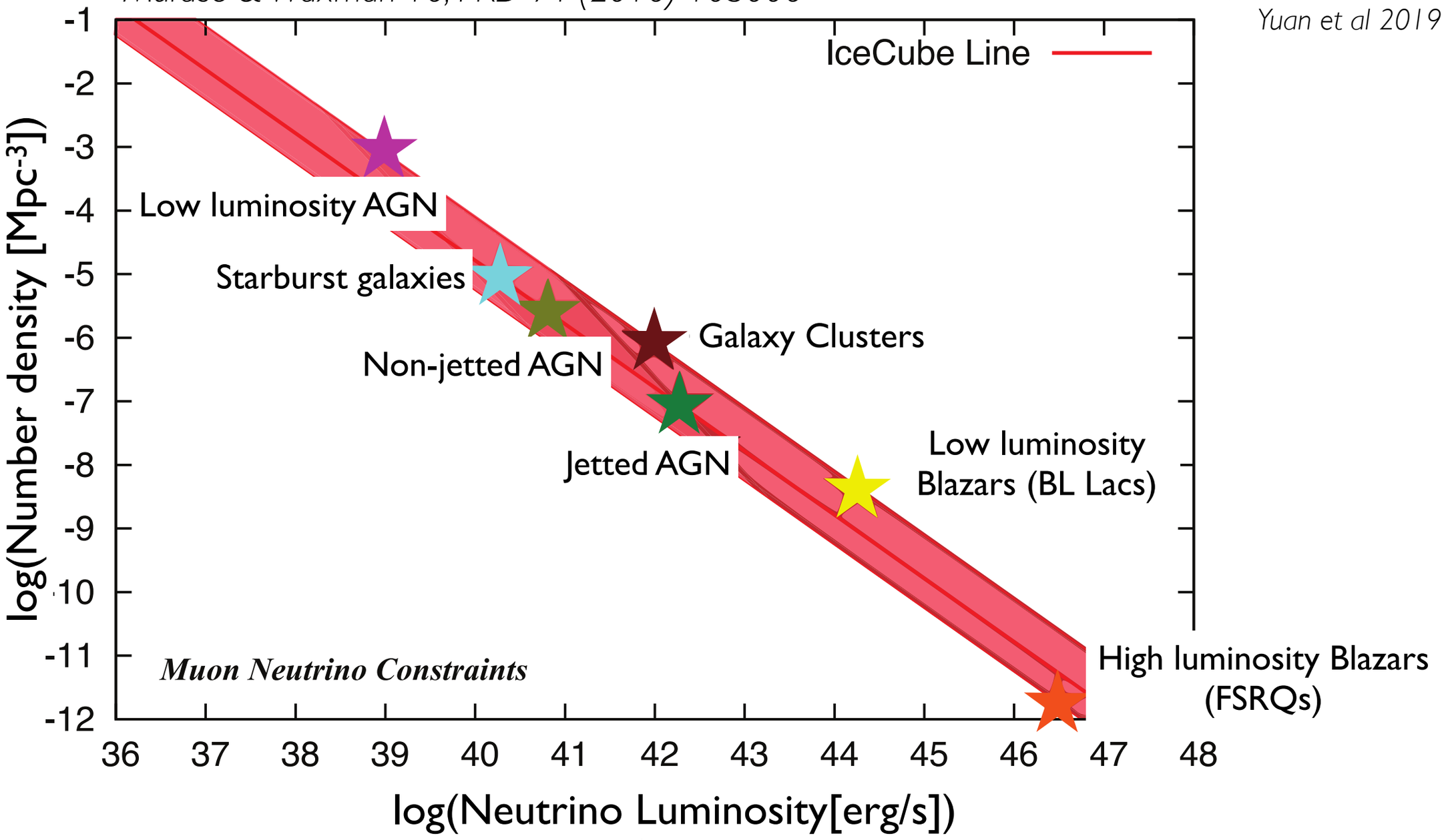
FSRQs - 10^{-9} Mpc^{-3}

as well as Waxman, Fisher, Piran , ApJ 1997
Dubovski, Tinyakov, Tkachev, PRL85(2000)1154
Takami & Sato, Astrop.Phys.30 (2009) 306
FO, Connolly , Thomas, Abdalla, Lahav, Waxman, JCAP05(2013)015

Source number density constraints: Neutrinos

as well as Lipari PRD78(2008)083011
Ahlers & Halzen PRD90(2014)043005
Kowalski 2014,
Murase, FO, Petropoulou ApJ 865 (2018) 124
Neronov & Semikoz 2018,
Ackermann, Ahlers et al. 2019,
Yuan et al 2019

Murase & Waxman 16, PRD 94 (2016) 103006



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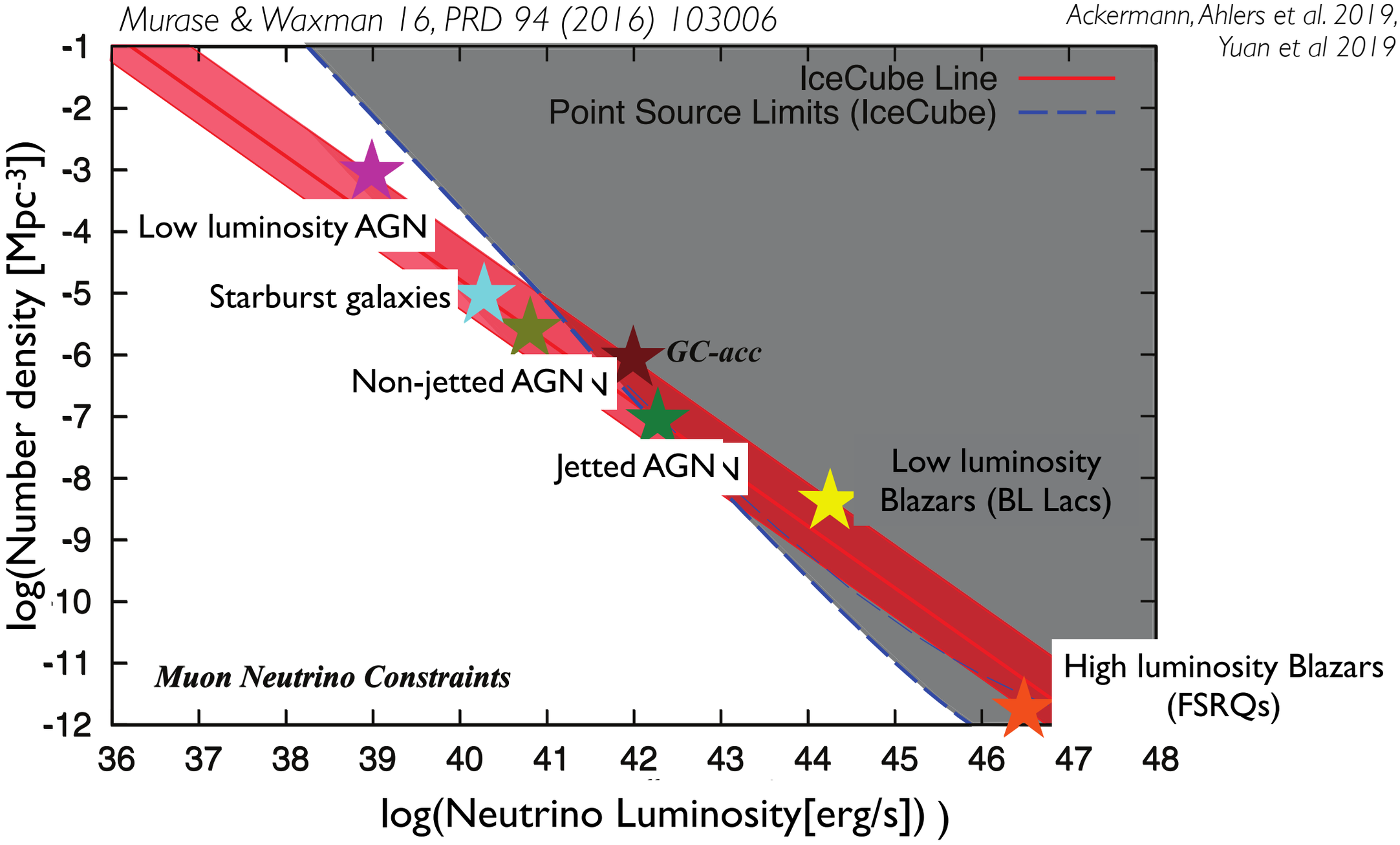

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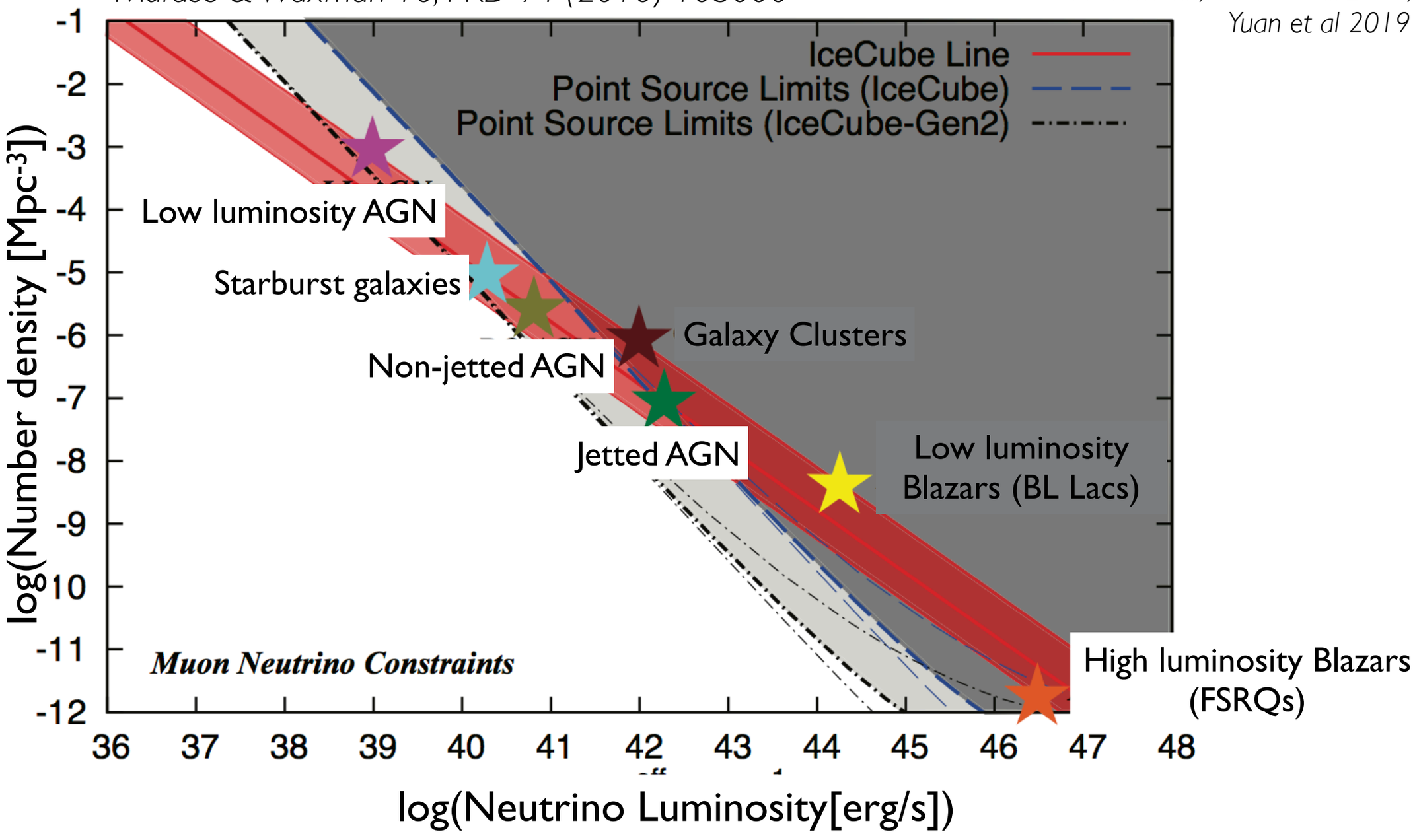
Yuan et al 2019

Murase & Waxman 16, PRD 94 (2016) 103006



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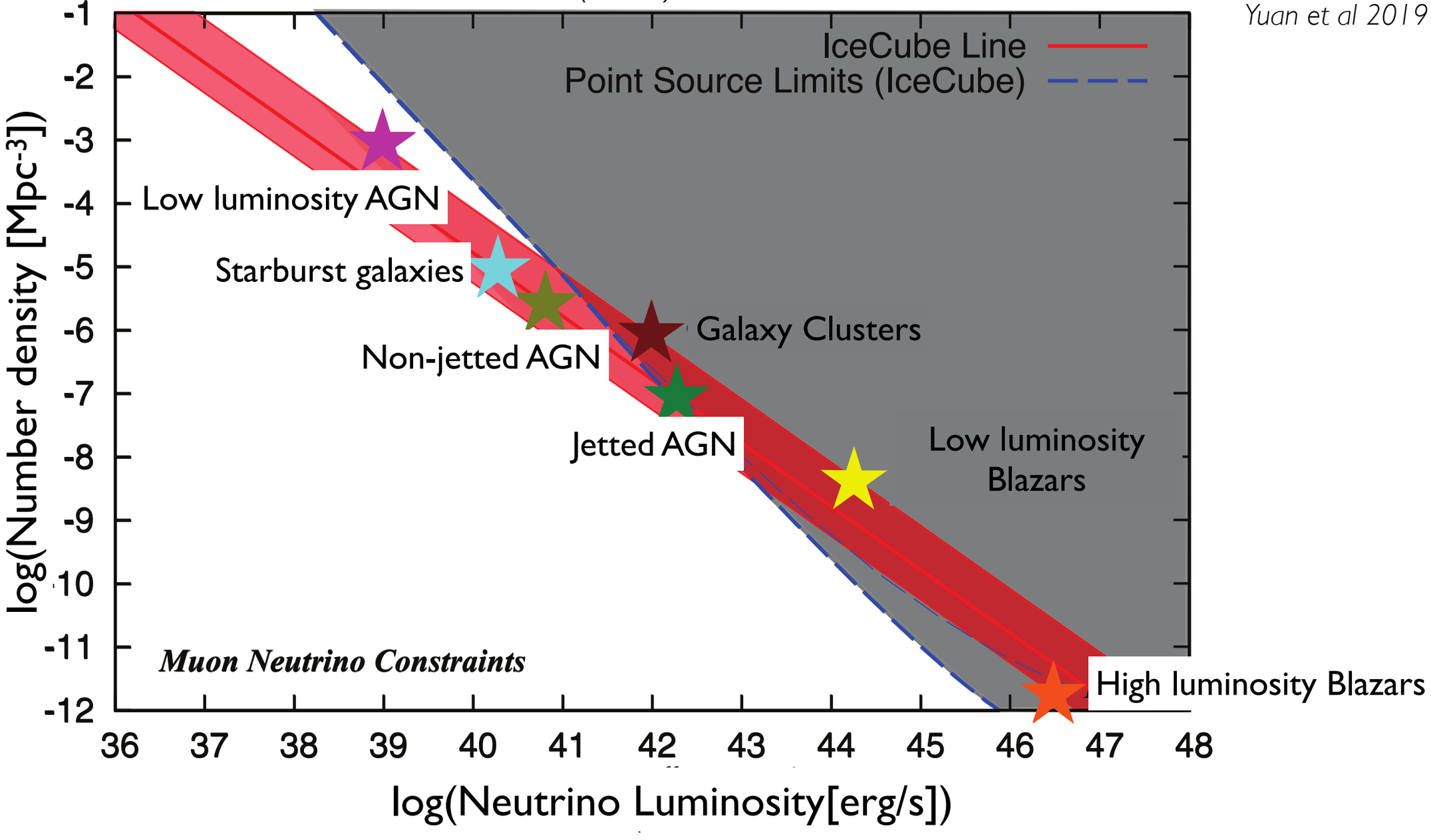
Murase, FO, Petropoulou ApJ 865 (2018) 124
Neronov & Semikoz 2018,
Ackermann, Ahlers et al. 2019,
Yuan et al 2019

Murase & Waxman 16, PRD 94 (2016) 103006



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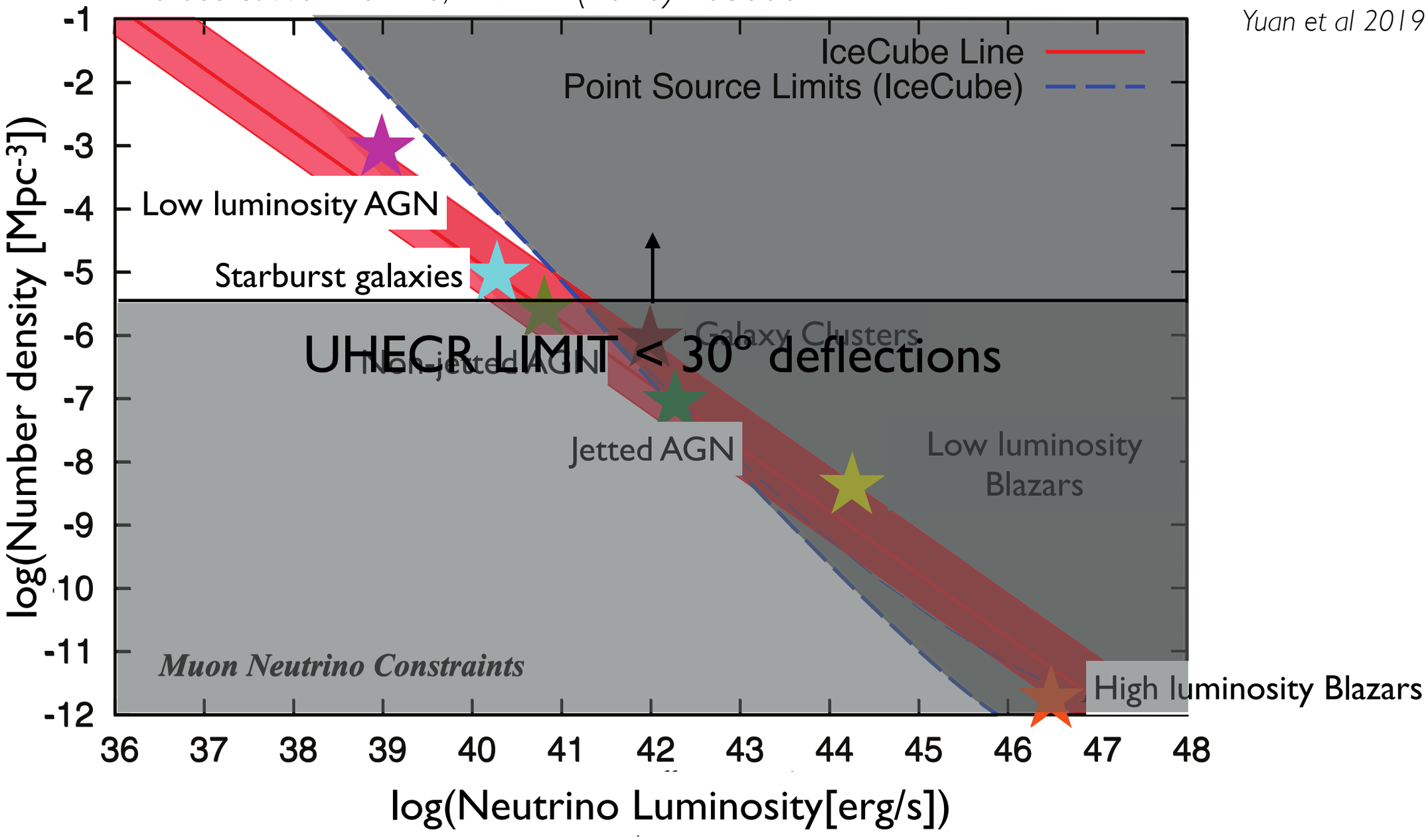
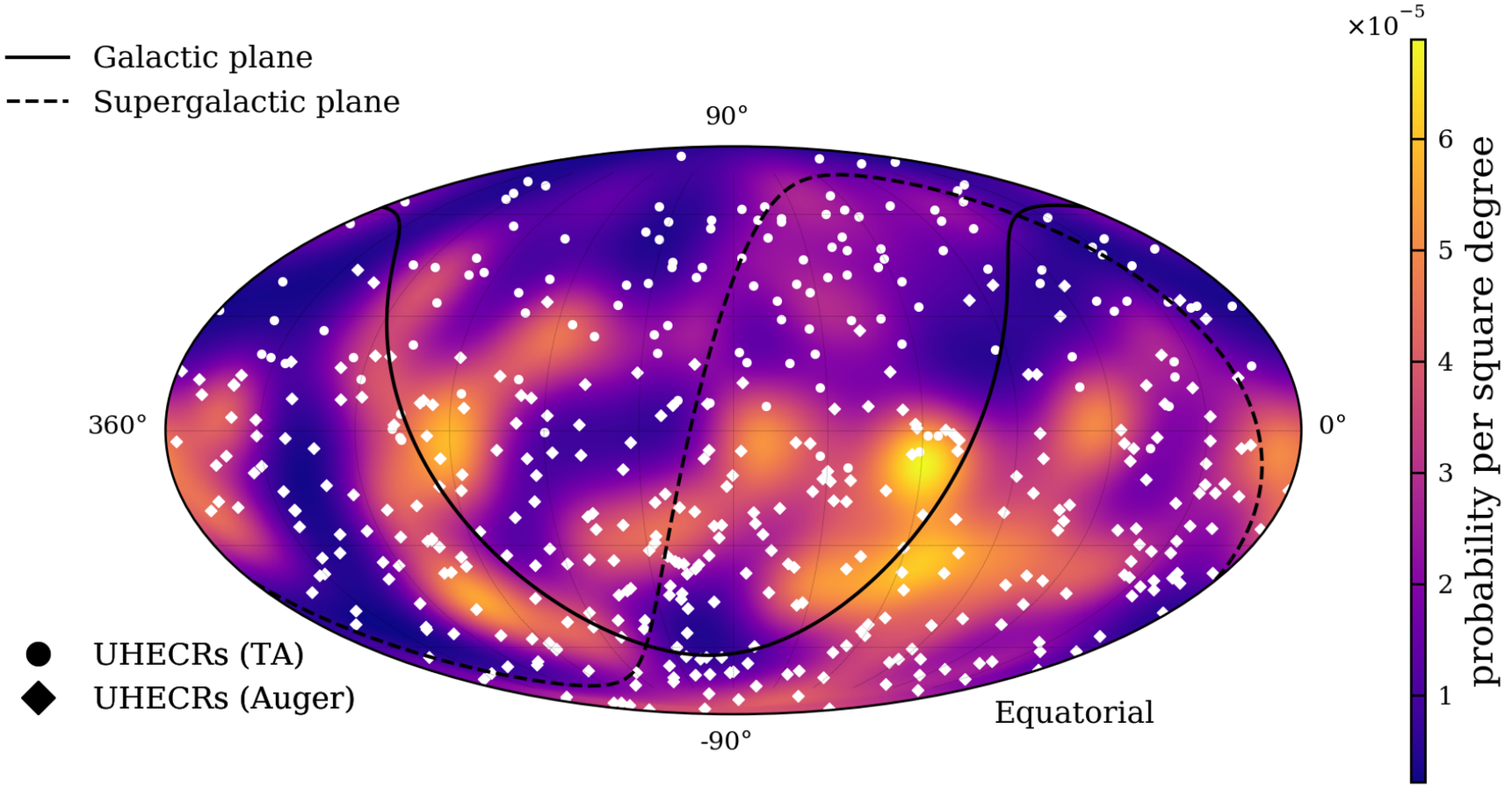
Yuan et al 2019

Murase & Waxman 16, PRD 94 (2016) 103006

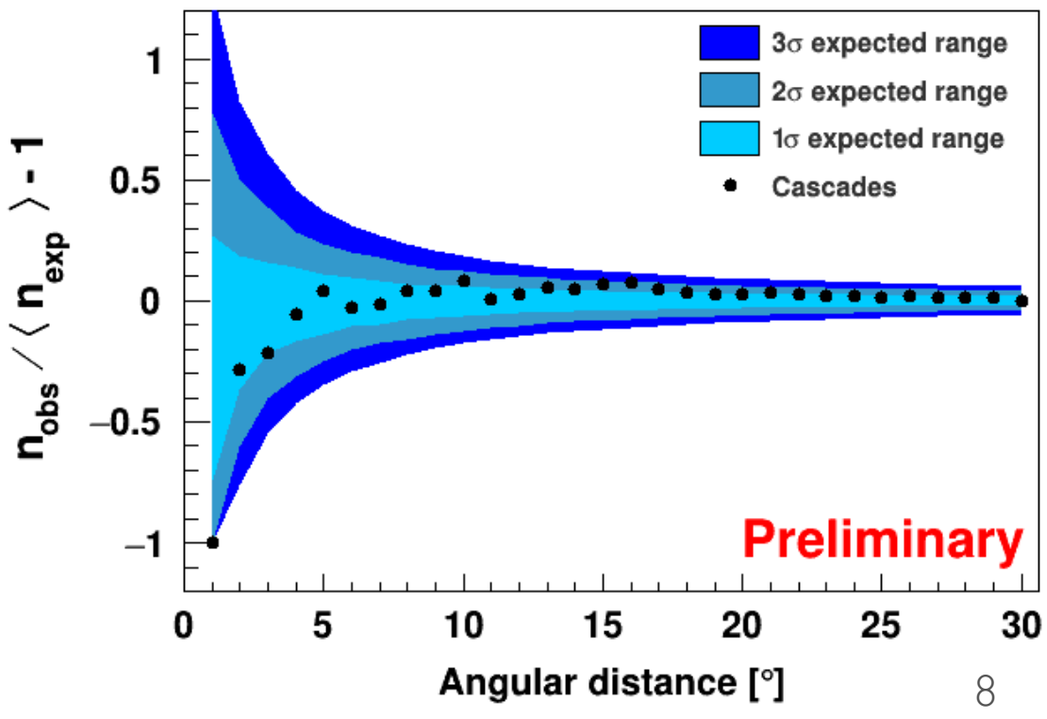


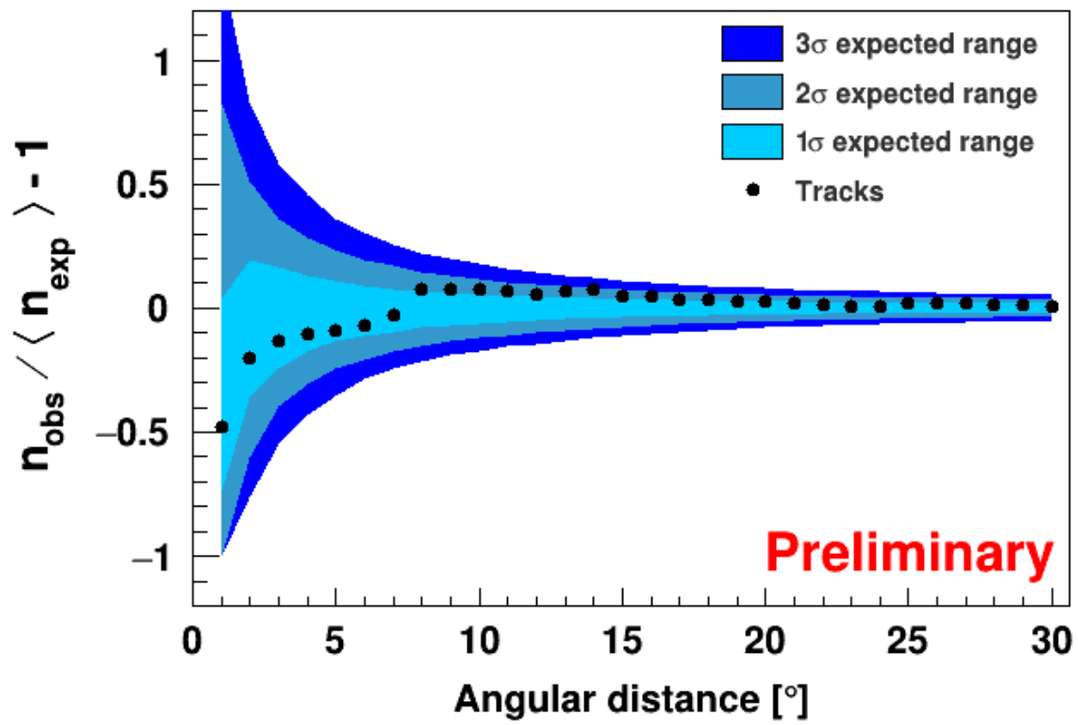
UHECR/Neutrino arrival direction correlations



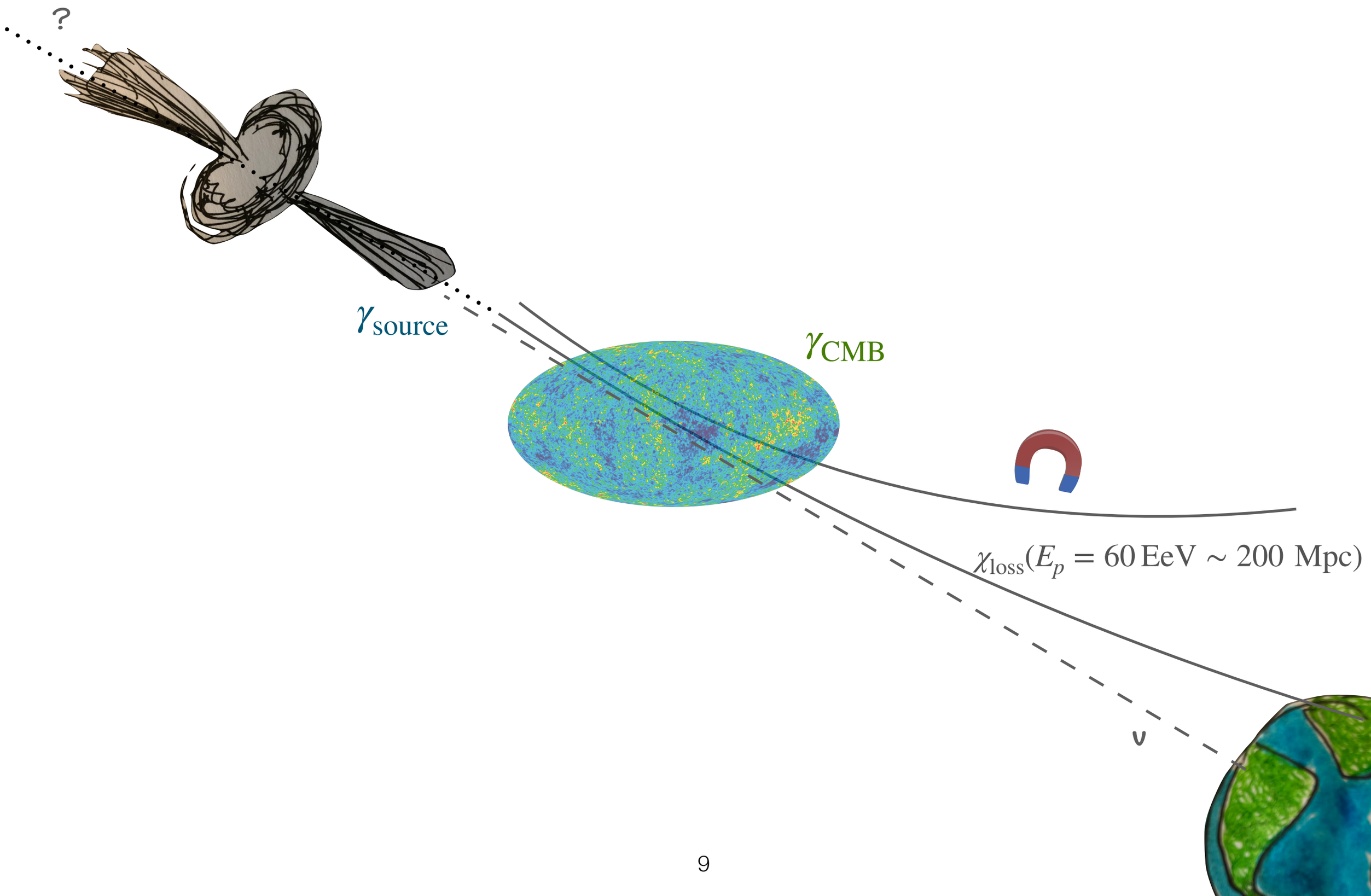
ANTARES, IceCube, Auger, TA Collaborations:
M. G. Aartsen et al., JCAP 1601 (2016) 037
Al Samarai et al, PoS(ICRC2017)961
Caccianiga et. al., EPJ Web Conf., 210 (2019)
Schumacher, L. et al., EPJ Web Conf., 207 (2019)
Barbano et al 2019 PoS(ICRC2019)1177

[see also Resconi, Coenders, Padovani, Giommi, Caccianiga, MNRAS, 468, 1, 2017]

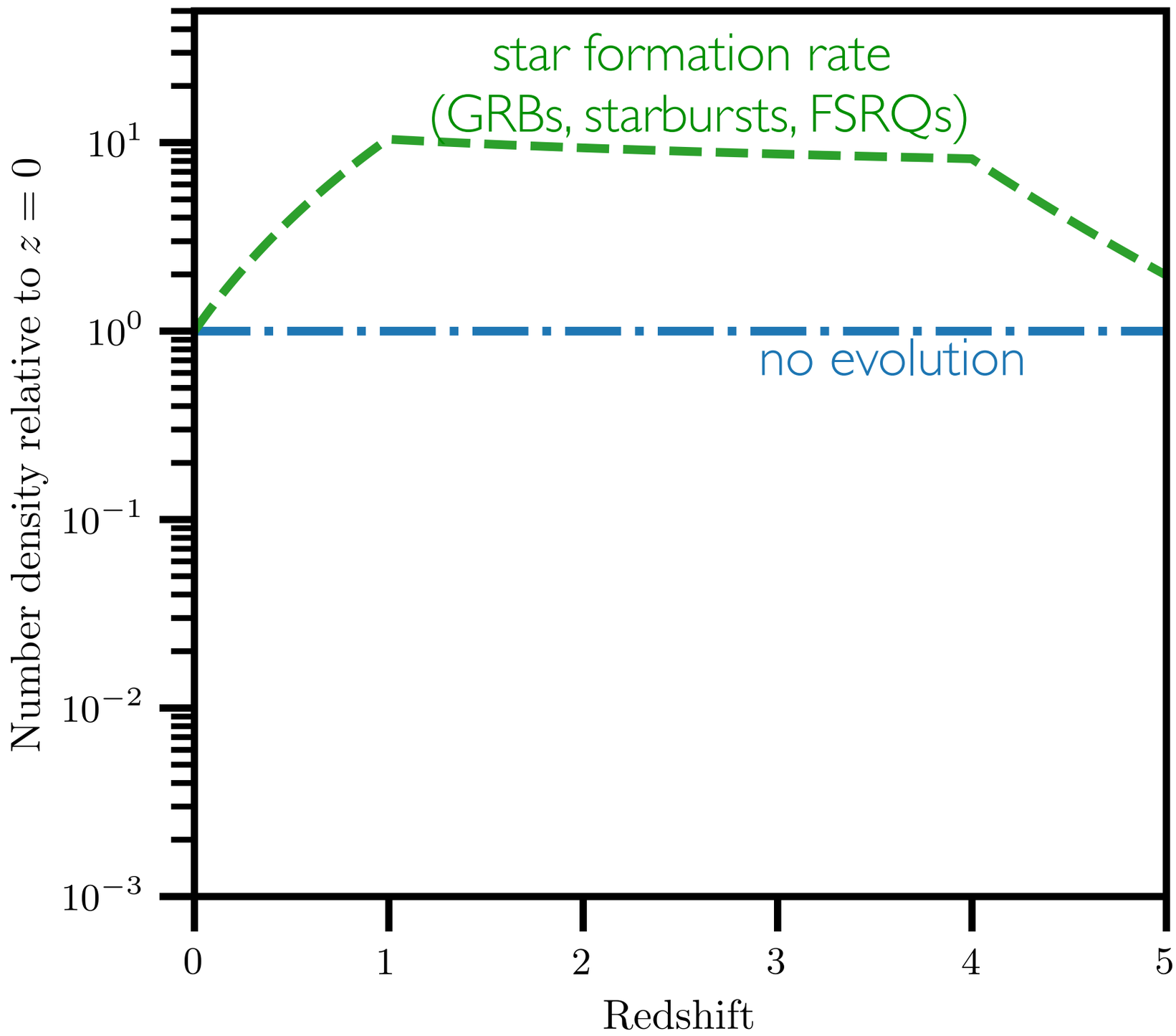




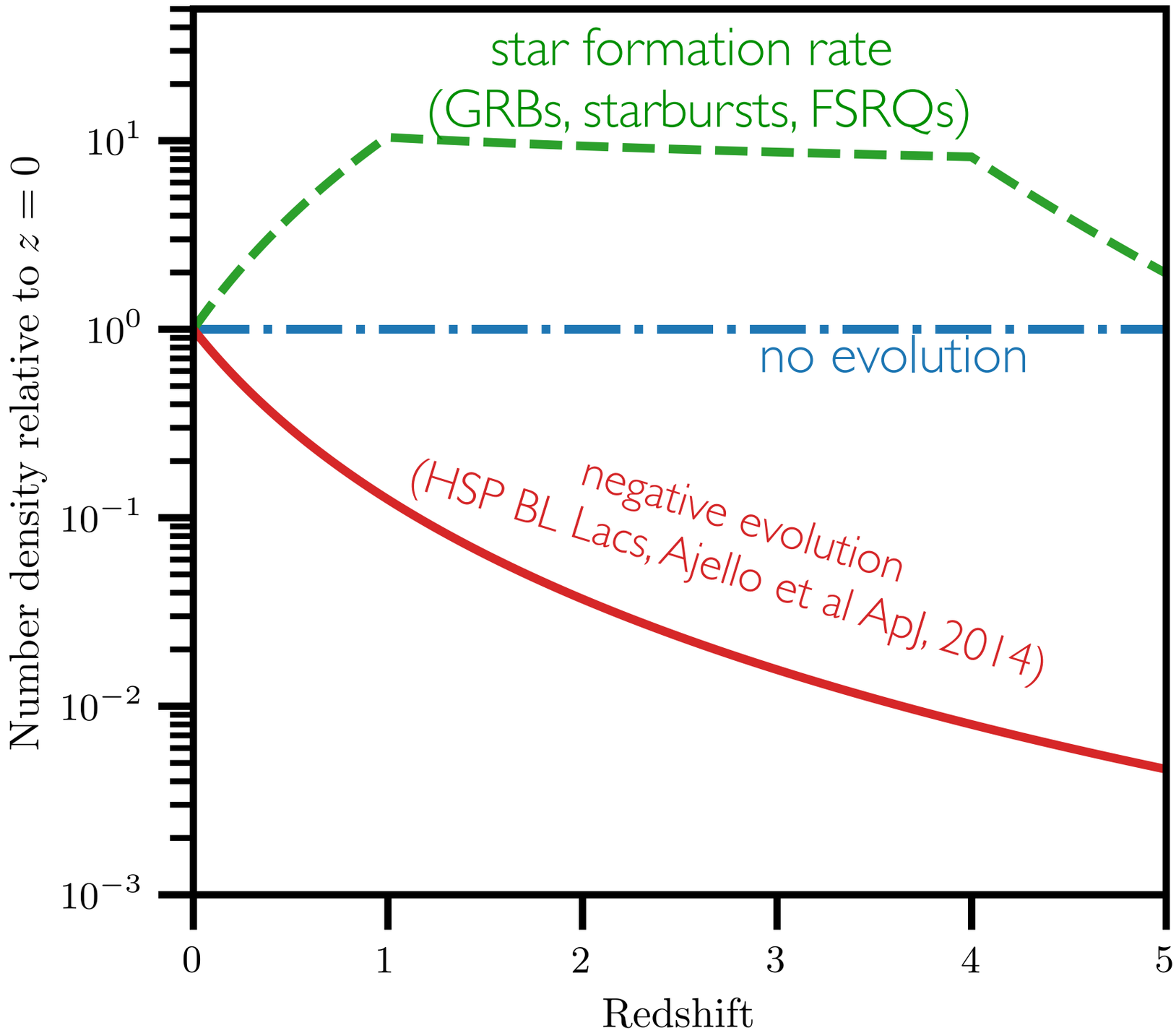
Can neutrino arrival directions trace the origin of UHECRs?



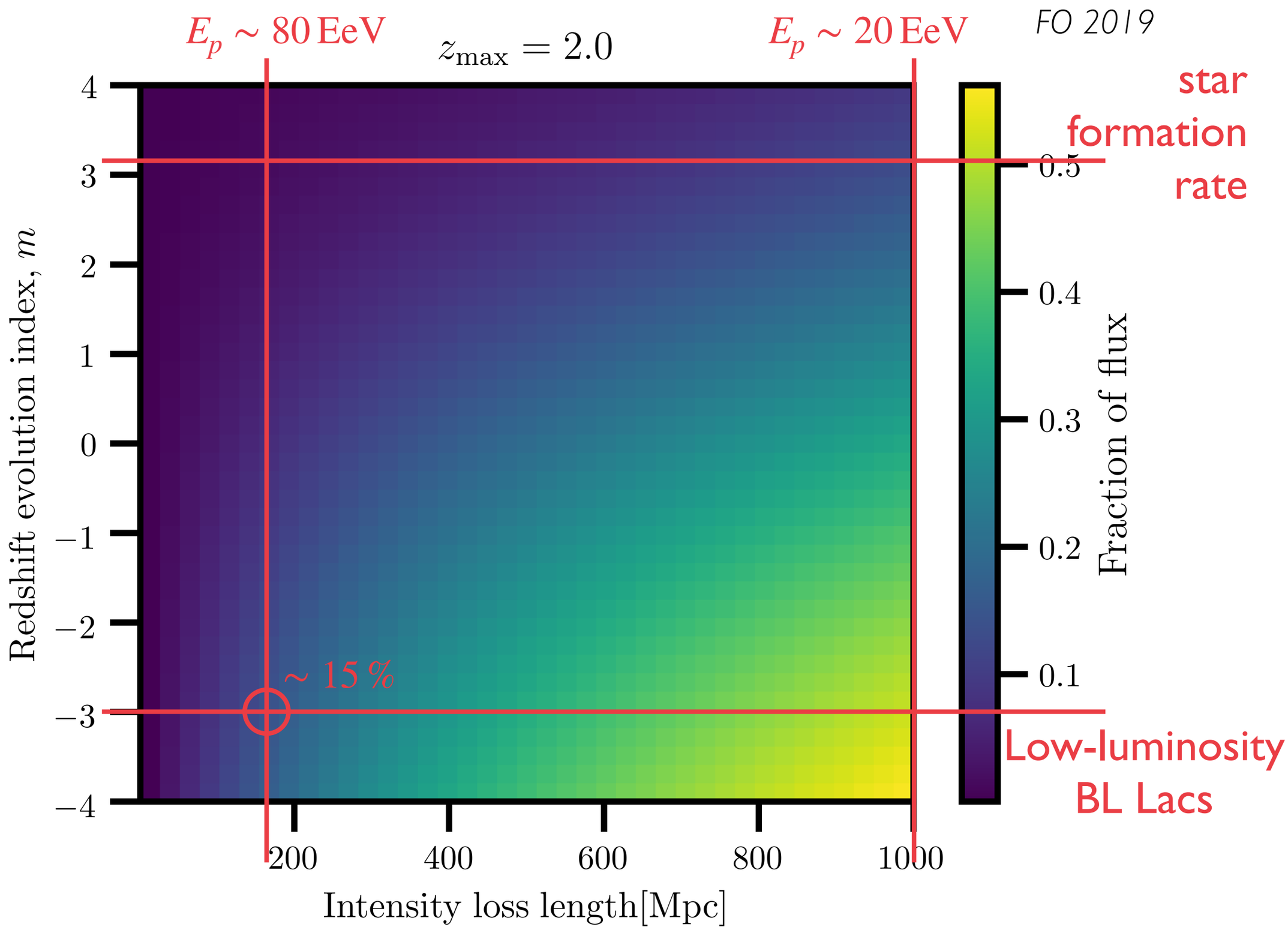
Source redshift evolution



Source redshift evolution

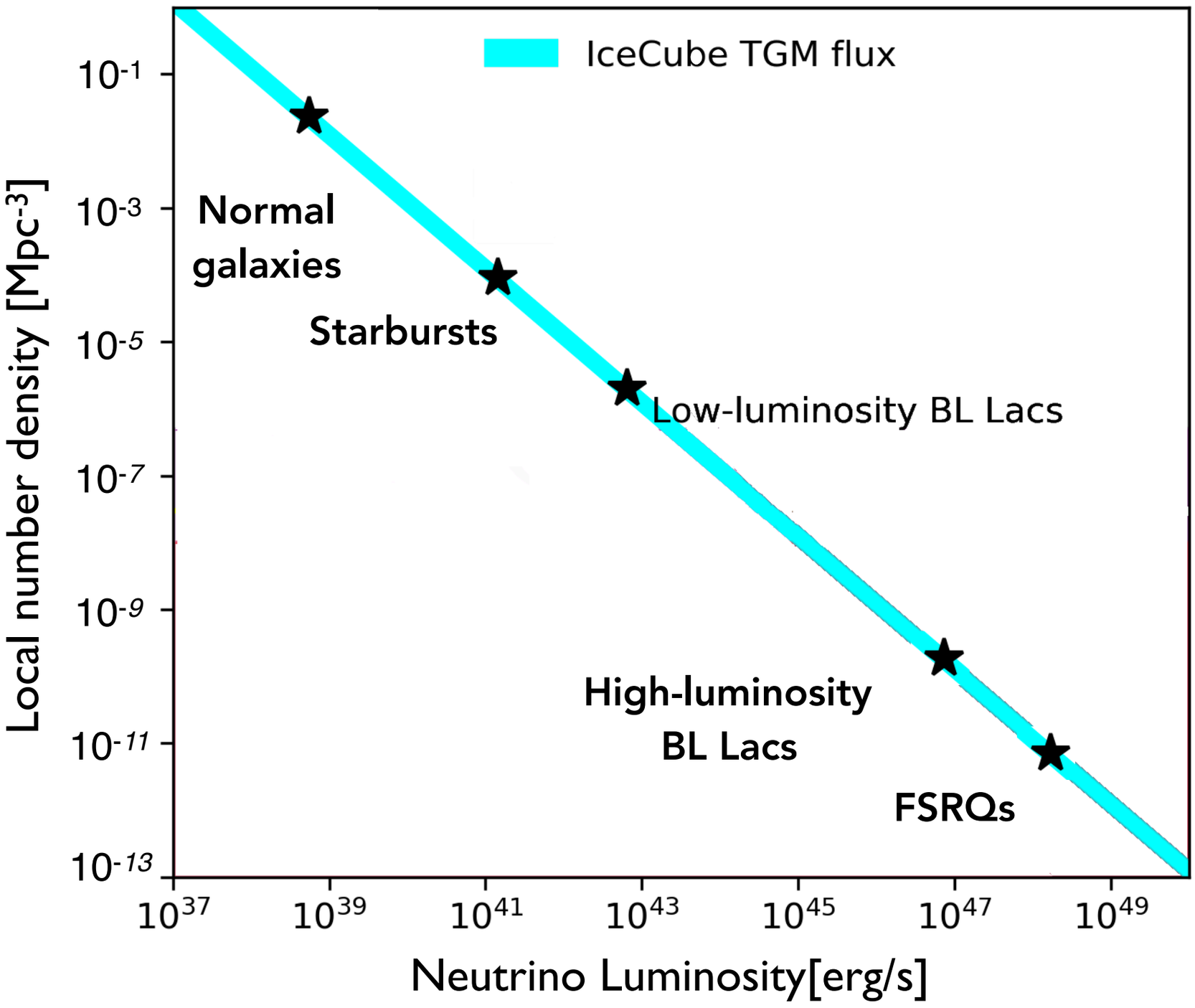


UHECR/Neutrino joint horizon



Can neutrino arrival directions trace the origin of UHECRs?

Palladino, Van Vliet, Winter, Franckowiak,arXiv:1911.05756



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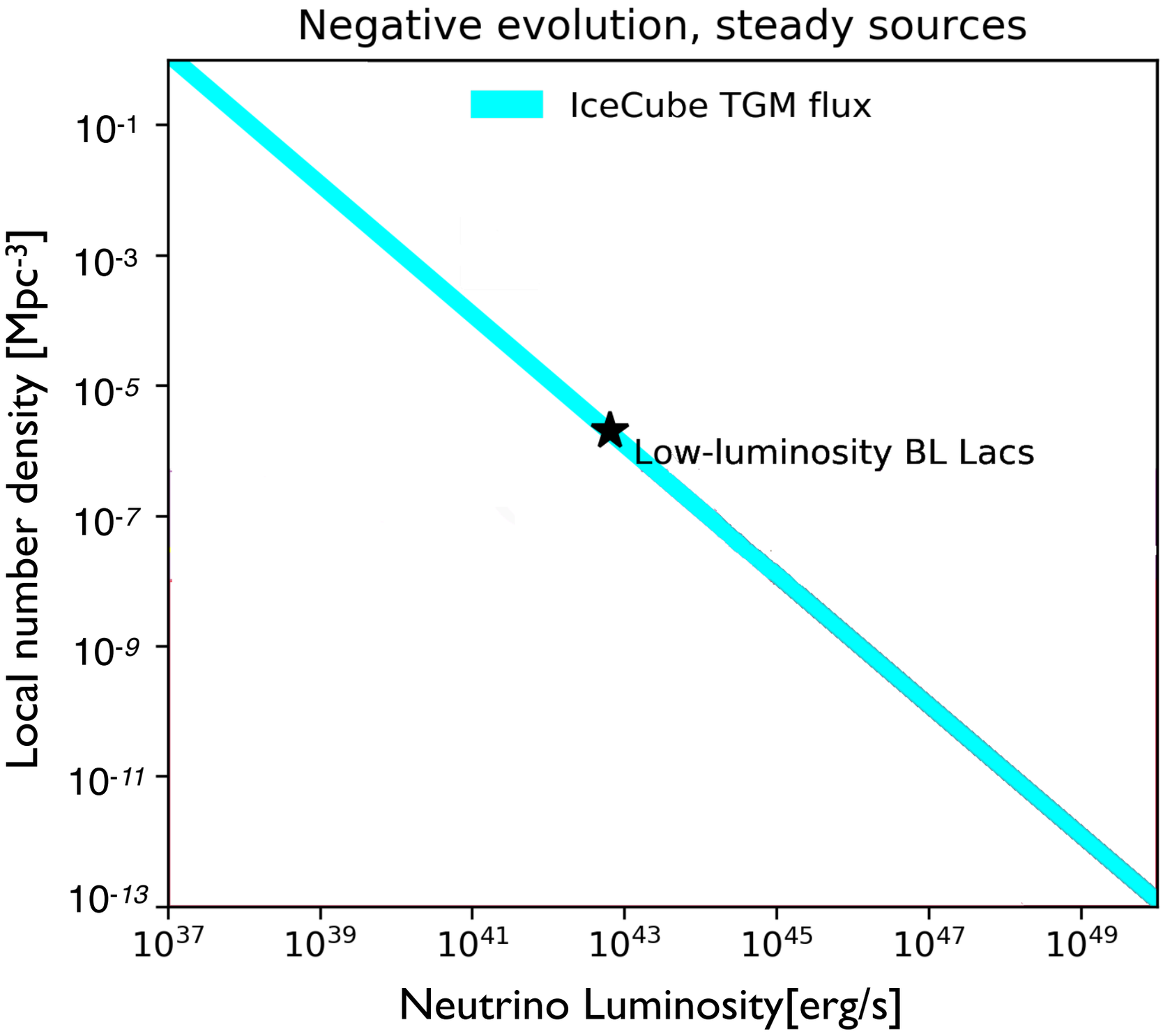

Fit to Auger spectrum, X_{max} and $\sigma(X_{max})$ based on negative evolution scenario of *Alves Batista et al., JCAP 01 (2019) 002*

γ	1.42
$R_{\max}/V$	$10^{18.85}$
f_p	0.07
f_{He}	0.34
f_{N}	0.53
f_{Si}	0.06

Can neutrino arrival directions trace the origin of UHECRs?

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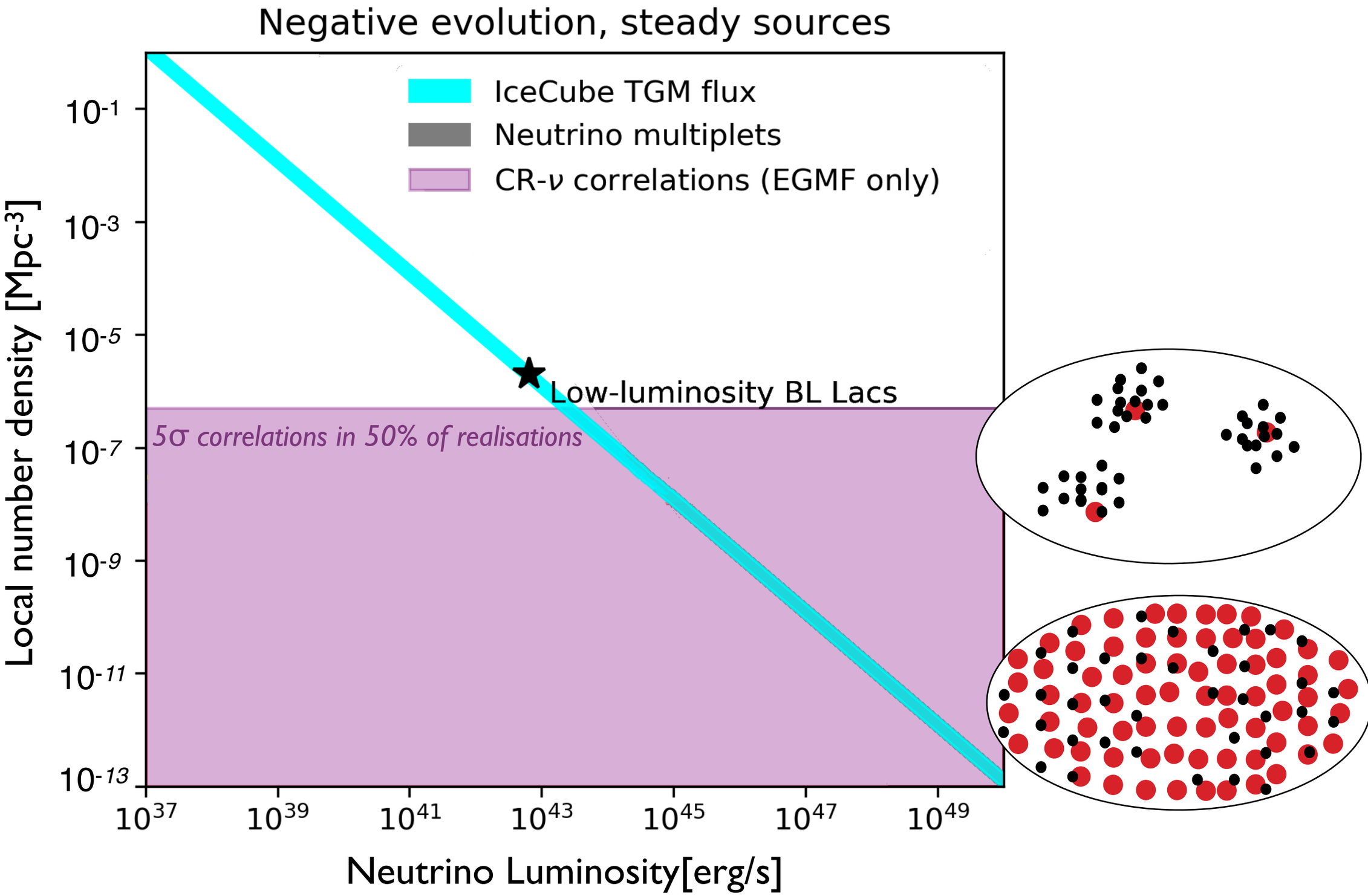

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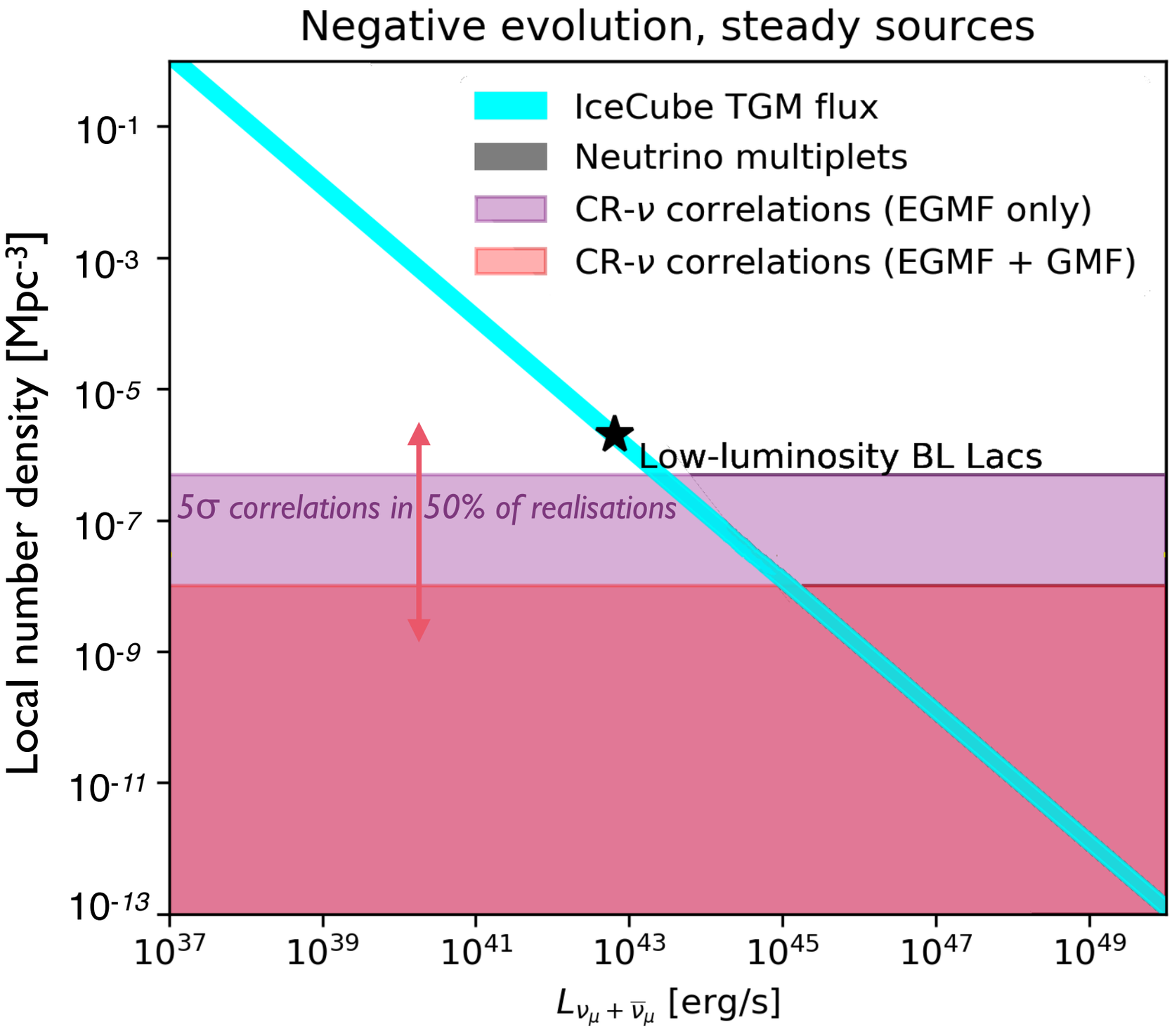
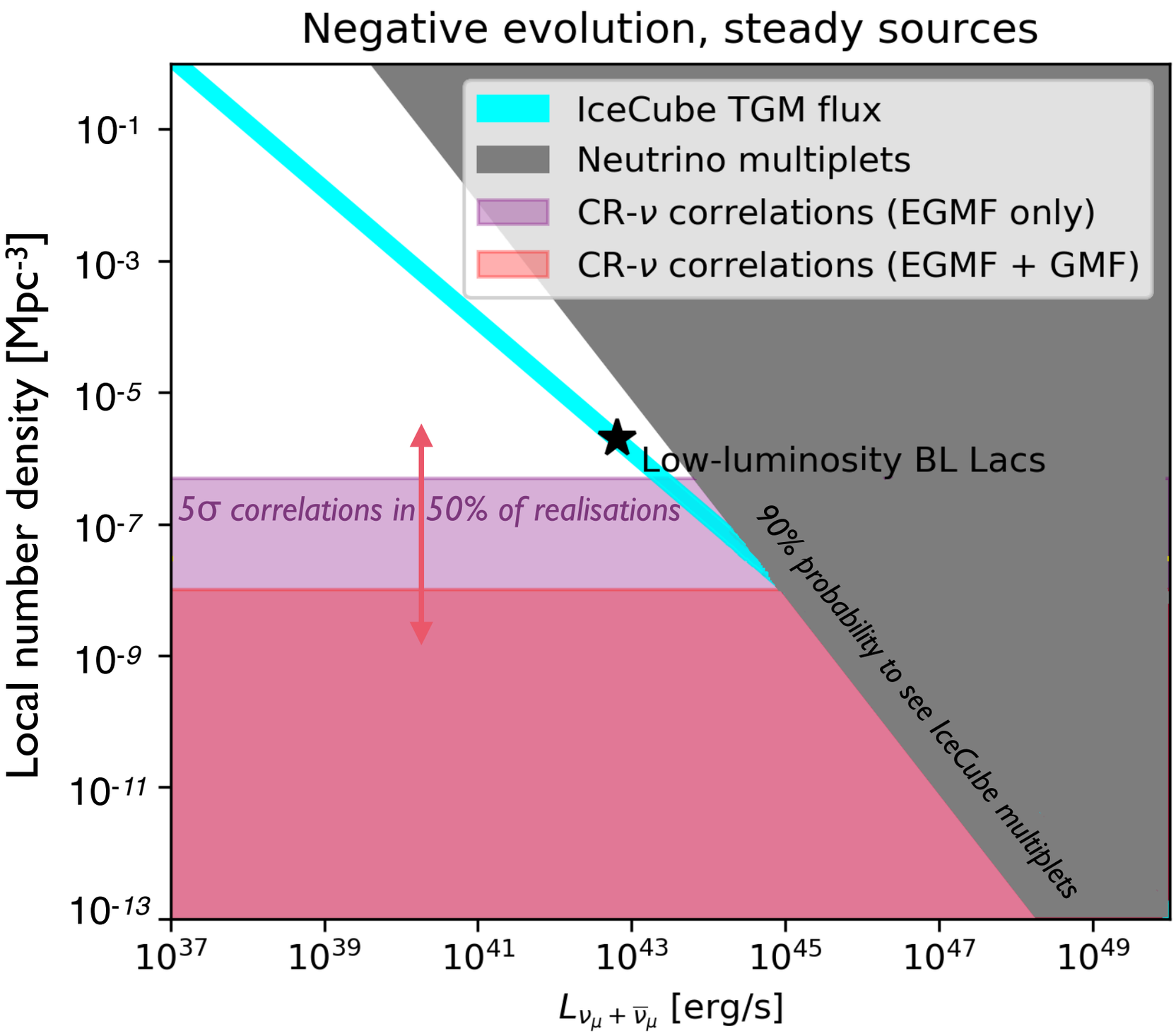


Can neutrino arrival directions trace the origin of UHECRs?

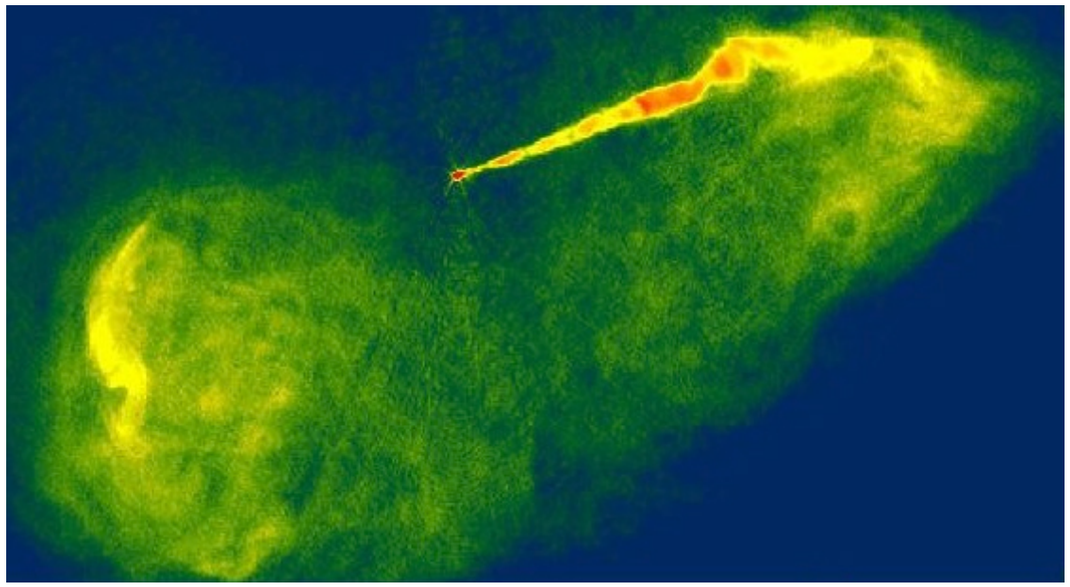
Palladino, Van Vliet, Winter, Franckowiak, arXiv:1911.05756

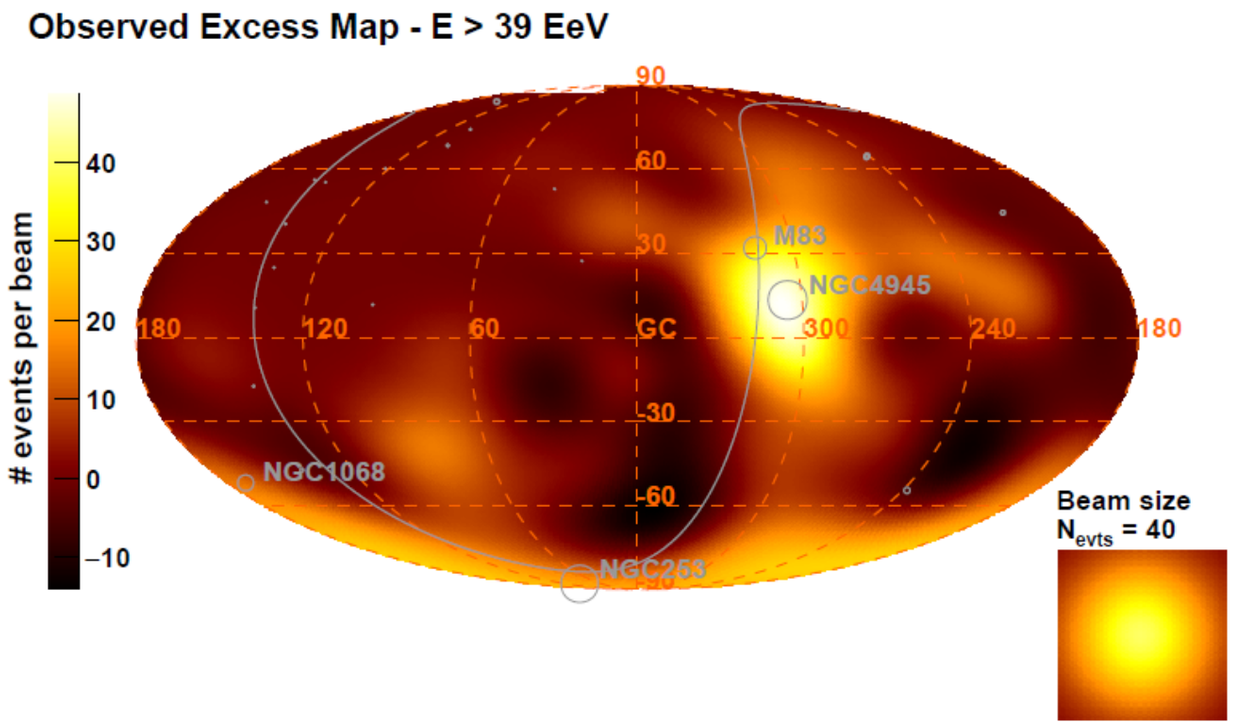


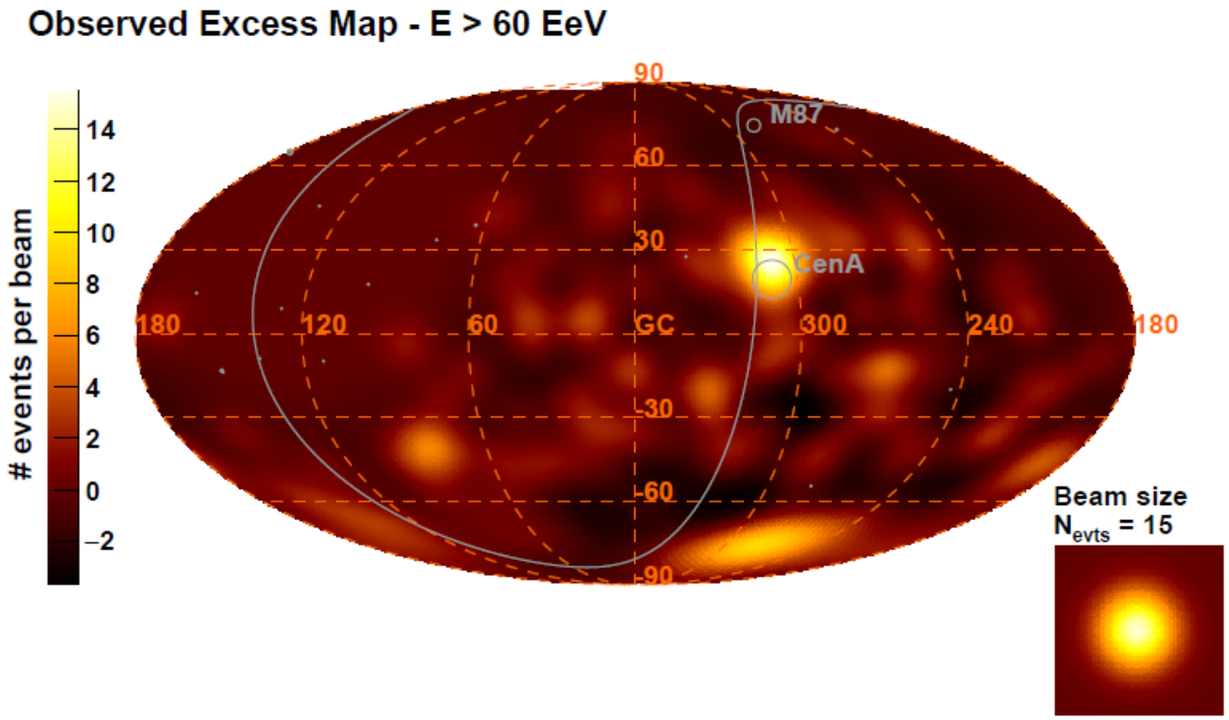
Starbursts vs. AGN: Multimessenger diagnostics

Auger Coll, ApJL, 853, L29, 2018

Caccianiga, L. on behalf of Auger, PoS, ICRC2019, 206

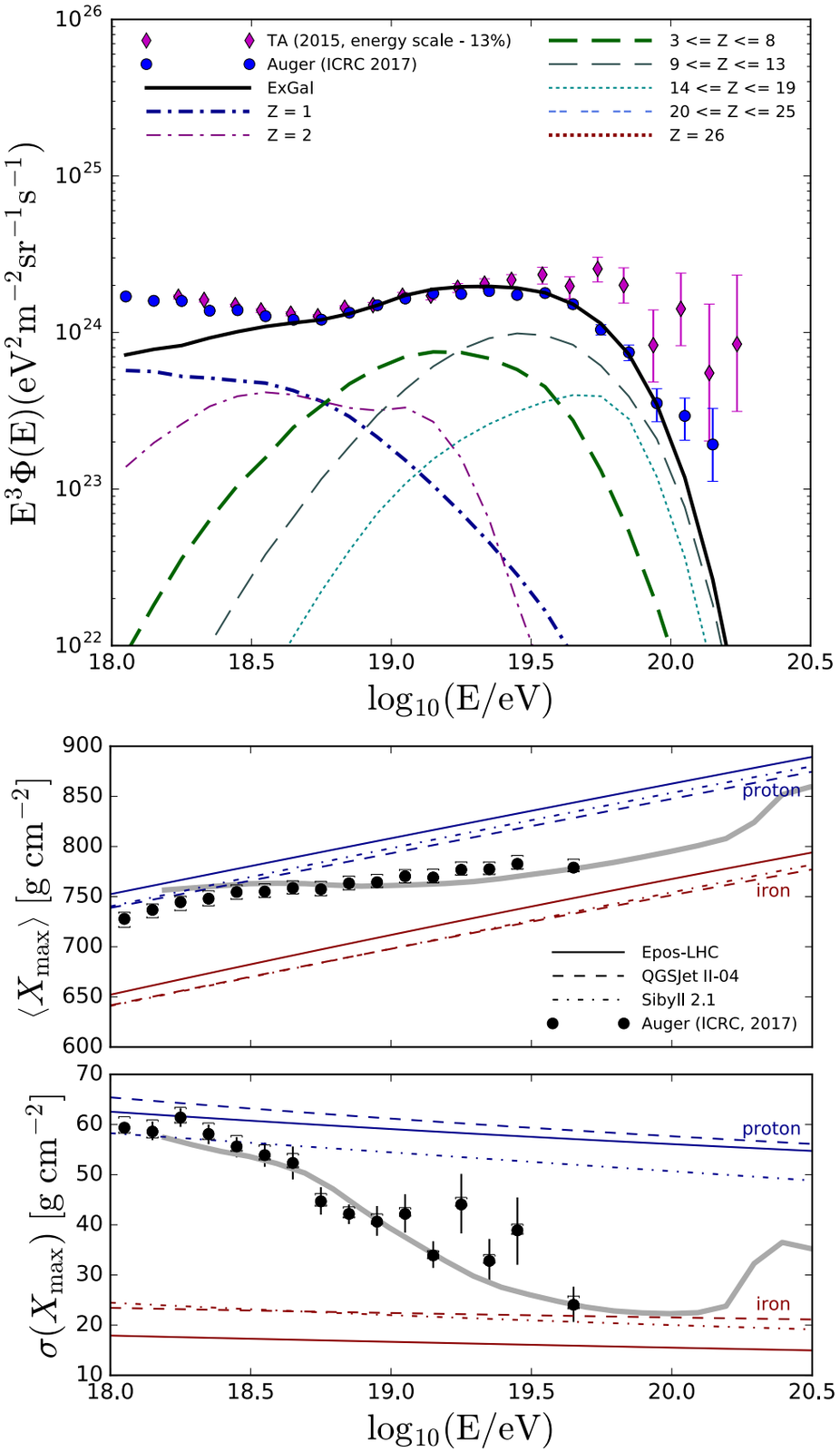




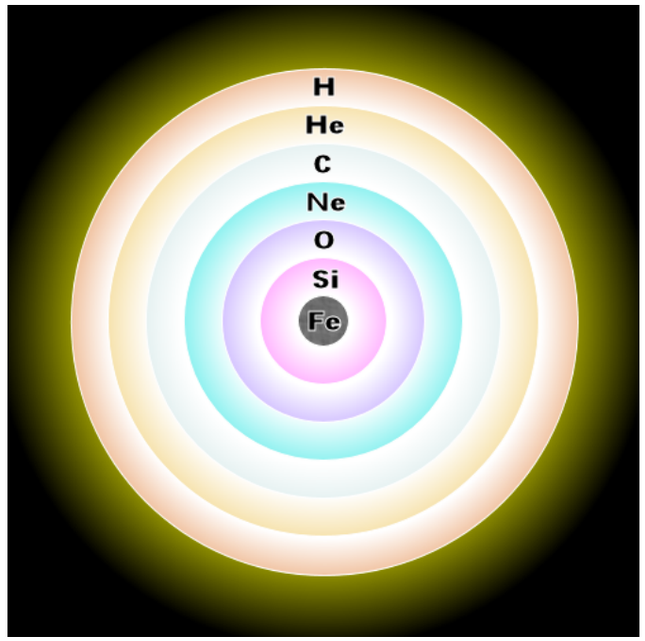


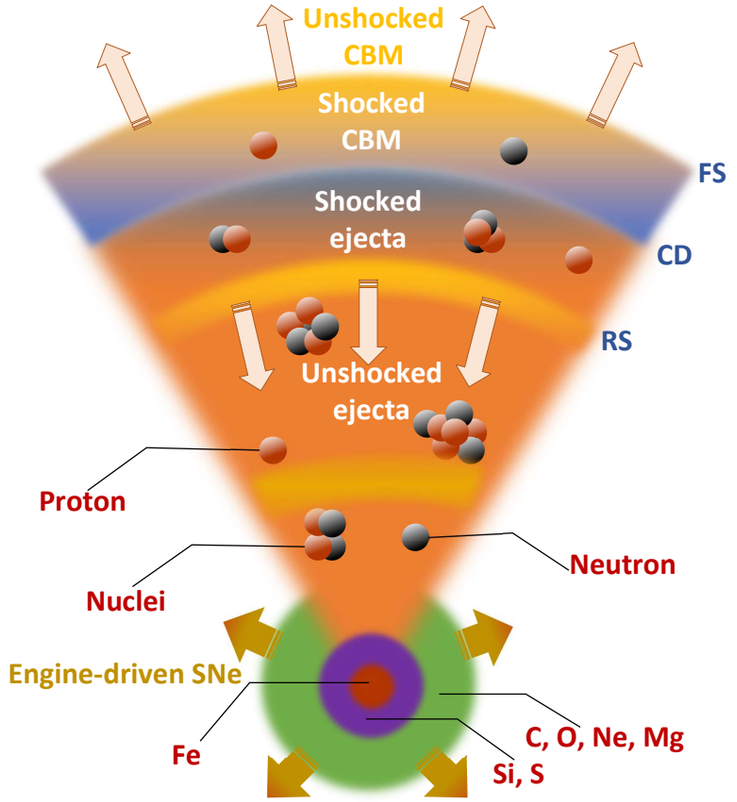
Starbursts vs. AGN: Composition

Zhang et al, PRD 97, 083010 (2018)

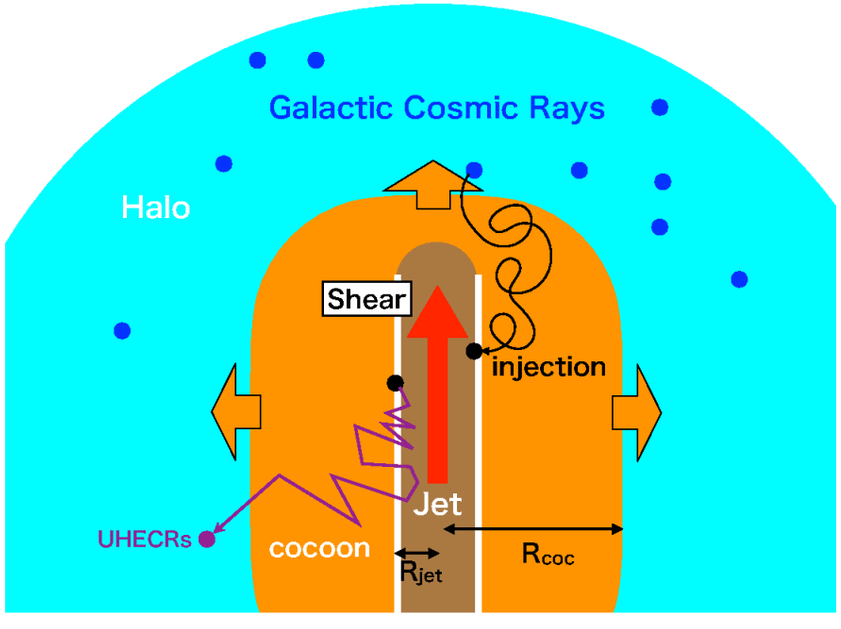


as well as Boncioli et al ApJ 872, 110 (2019)
Zhang & Murase, PRD 100, 103004 (2019)

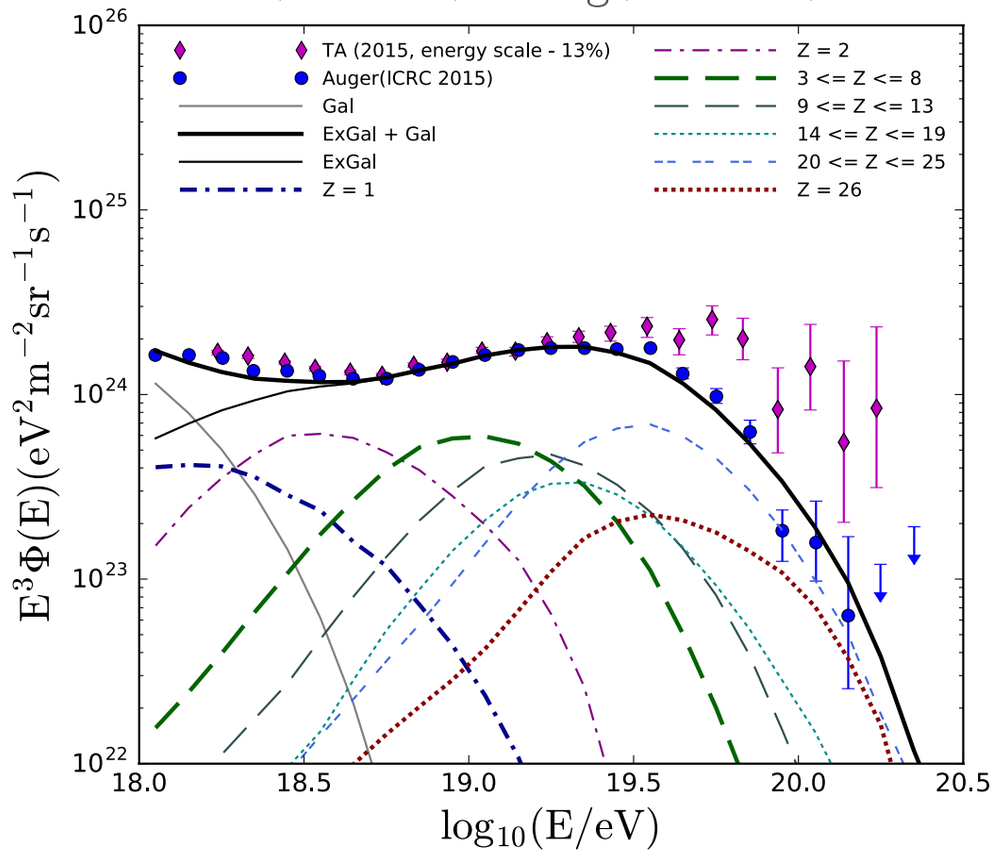




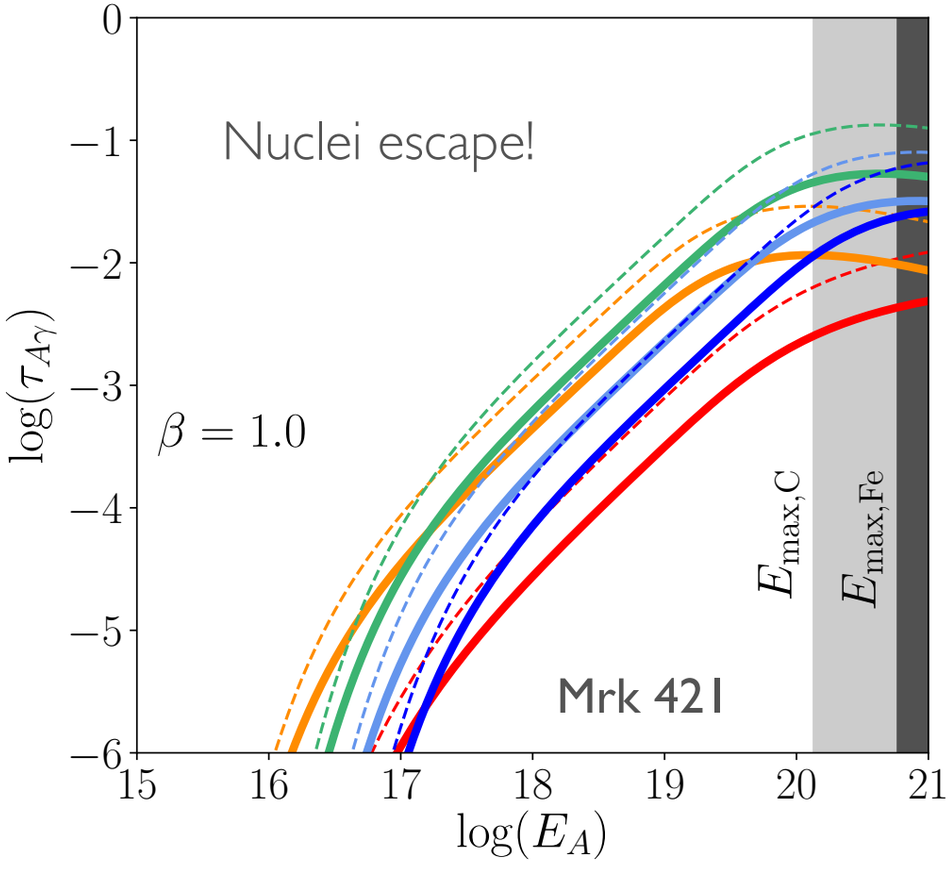
Starbursts vs. AGN: Composition

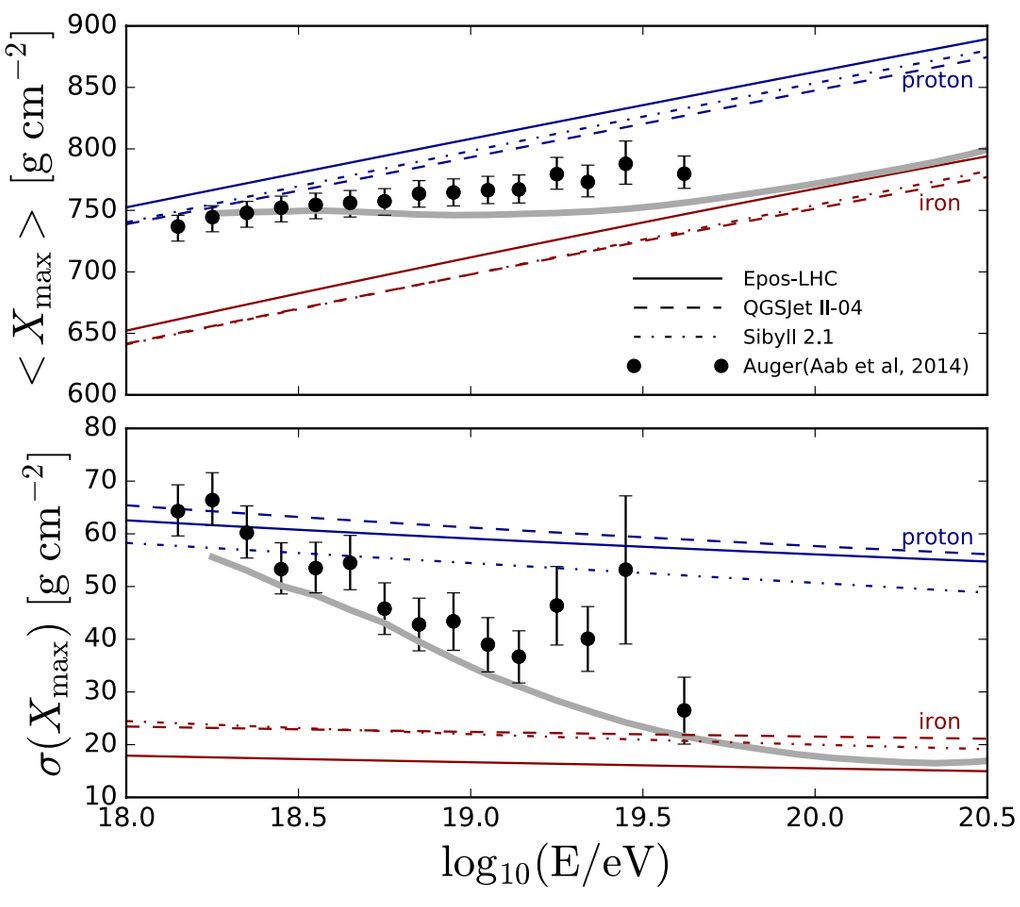


Kimura, Murase, Zhang , PRD 97, 023026, 2018



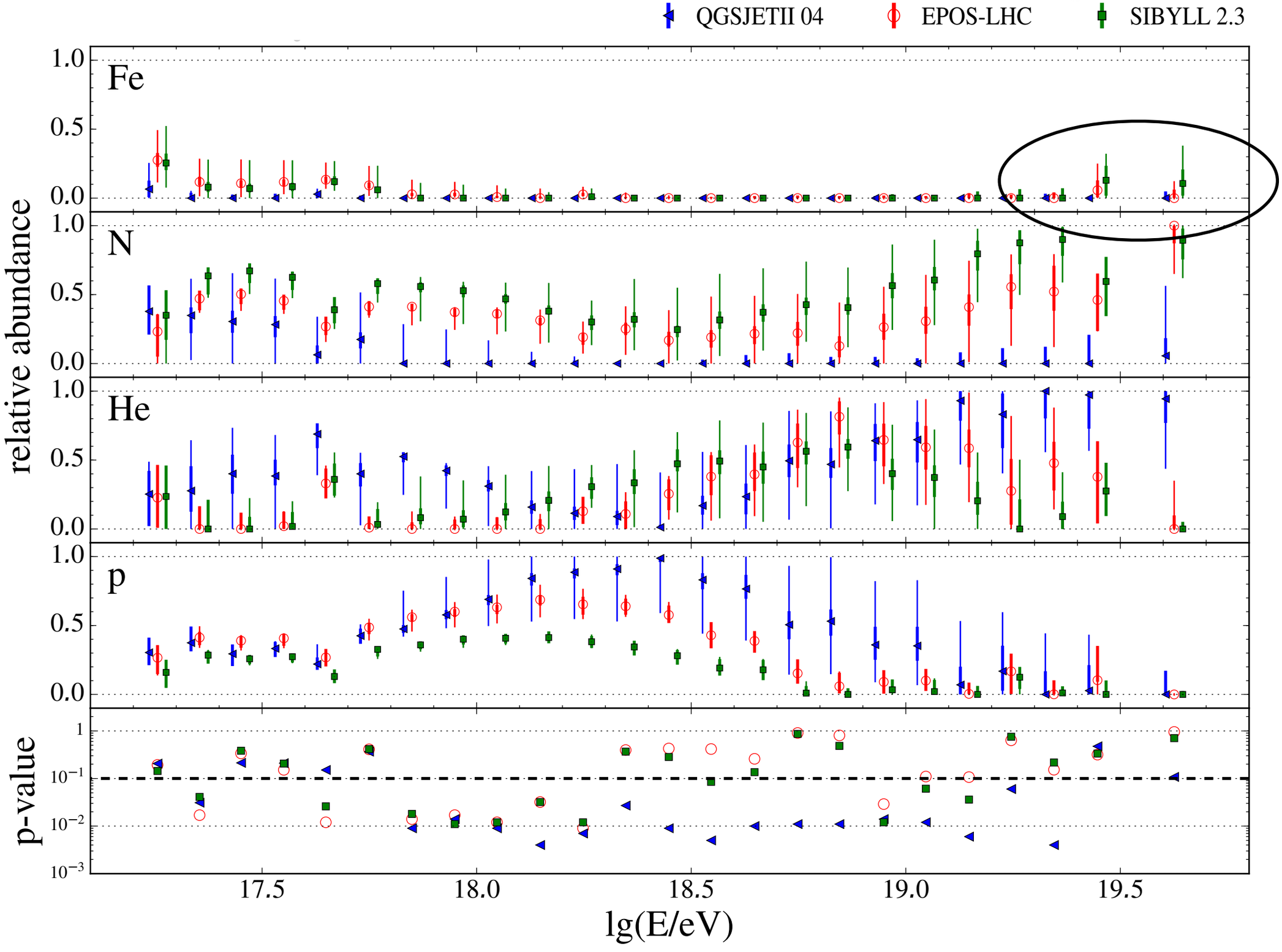
Tavecchio, FO, Righi, MNRAS, 2019, 488, 3





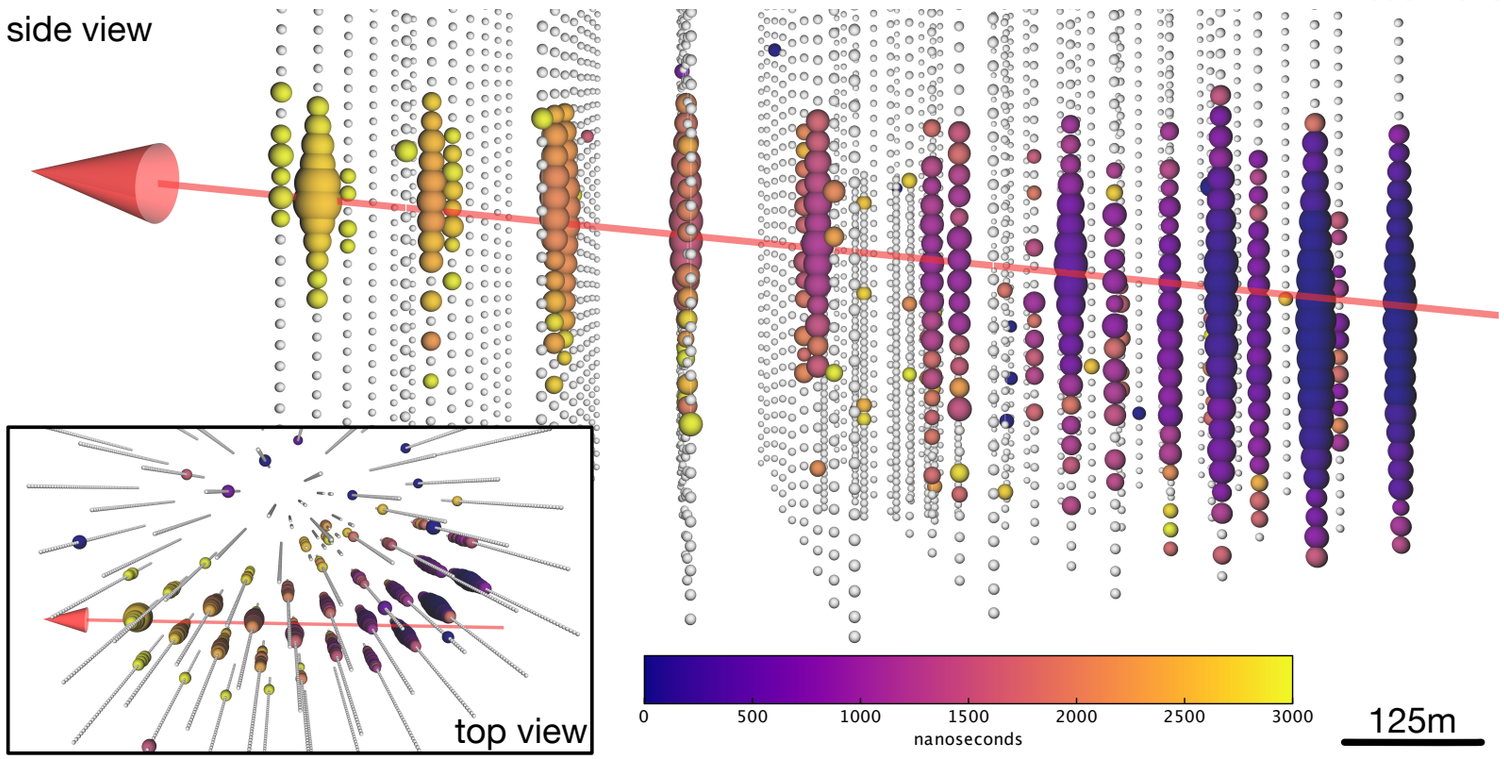
Starbursts vs. AGN: Composition

J. Bellido on behalf of Auger Coll, PoS(ICRC2017)506



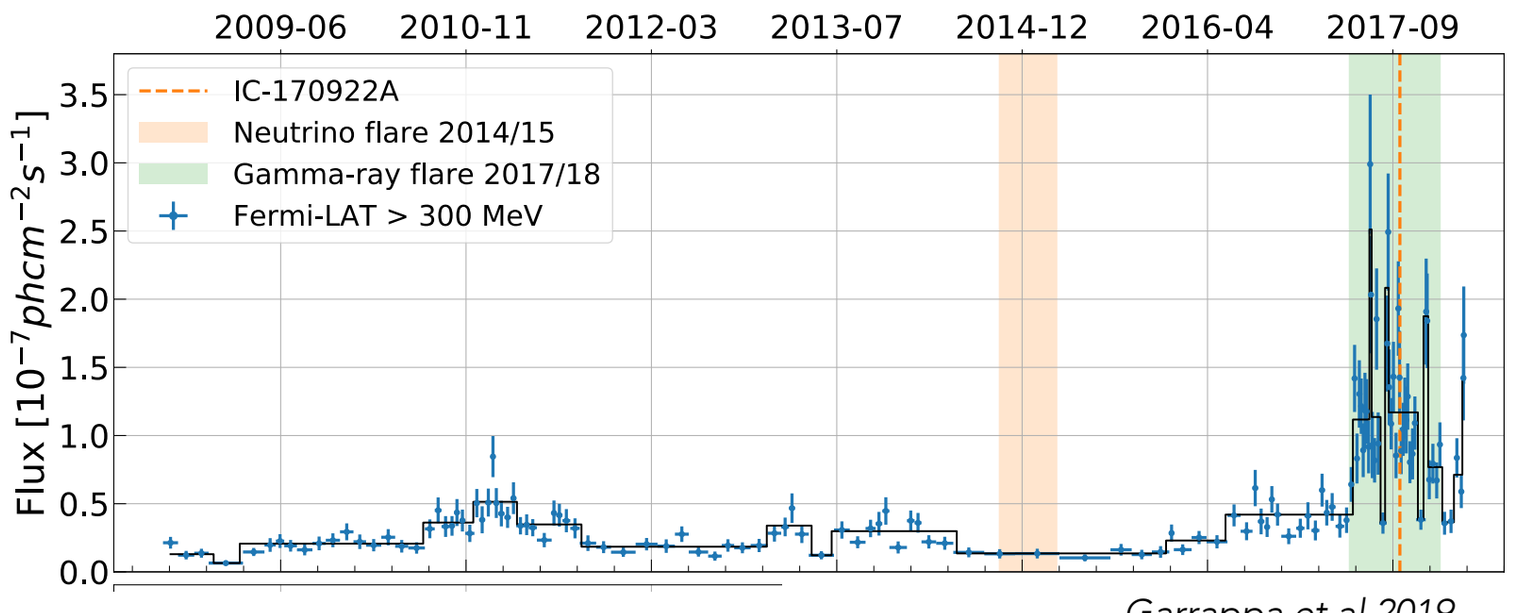
TXS 0506+056 IC170922A

IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/NuSTAR, VERITAS, and VLA/17B-403 teams. Science 361, 2018, MAGIC Coll. Astrophys.J. 863 (2018) L10



Background fluctuation?
Chance probability ~0.3%

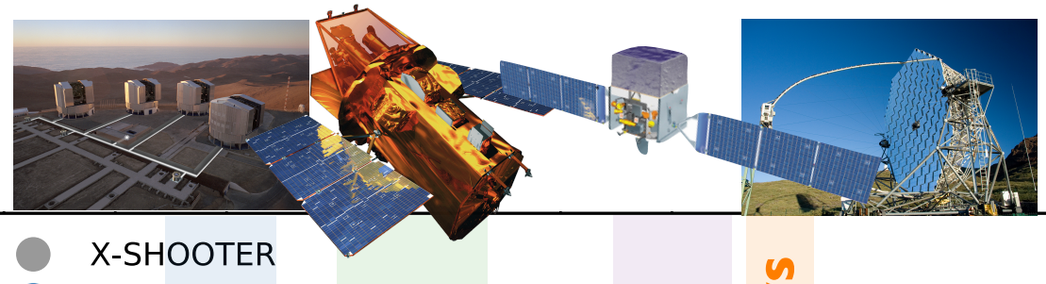
- Blazars can be the brightest point sources despite diffuse constraints
- Flares are ideal times for neutrino detection

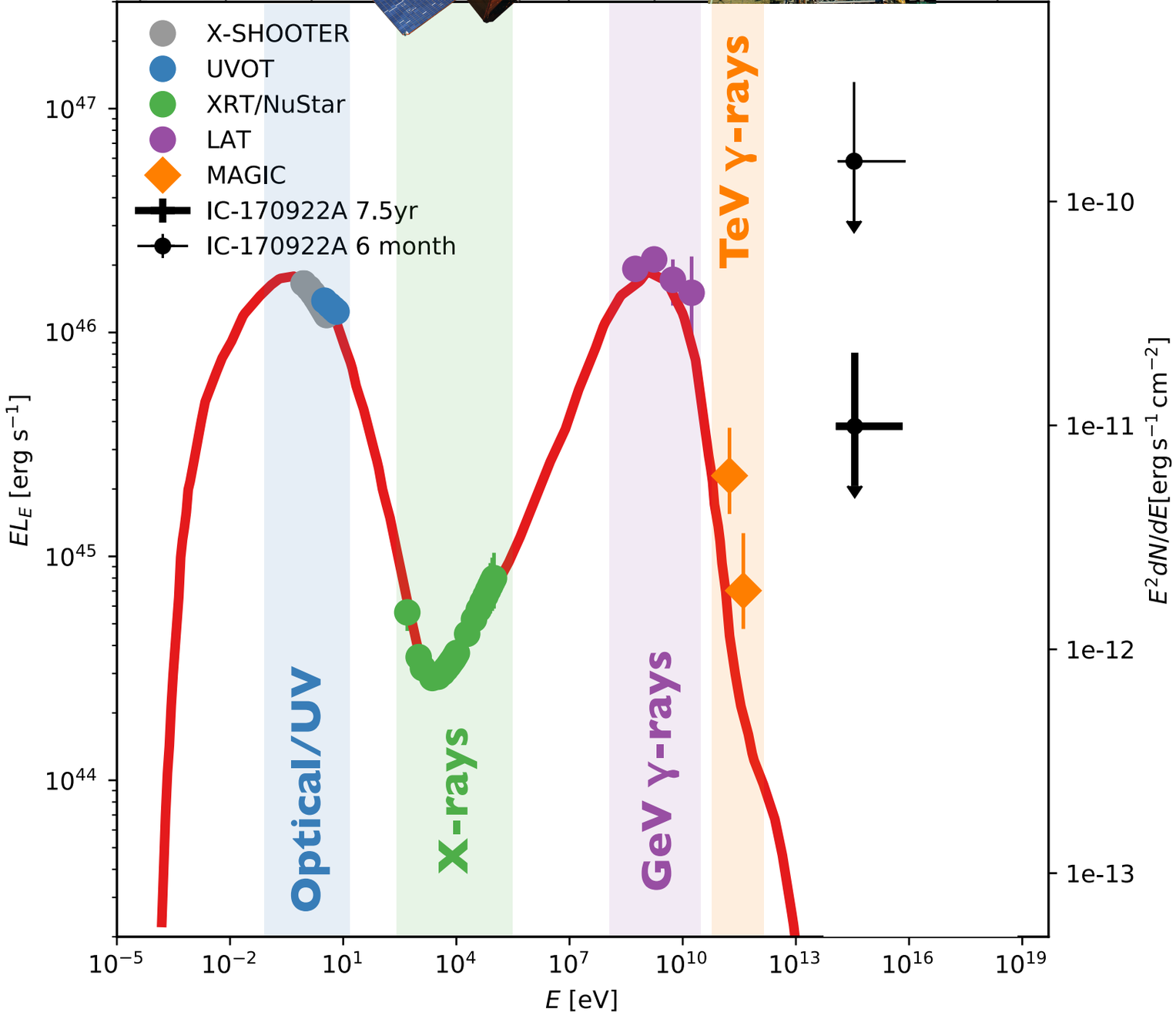


Garrappa et al 2019

TXS 0506+056 in 2017

IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/ NuSTAR, VERITAS, and VLA/ 17B-403 teams. Science 361, 2018, MAGIC Coll. Astrophys.J. 863 (2018) L10

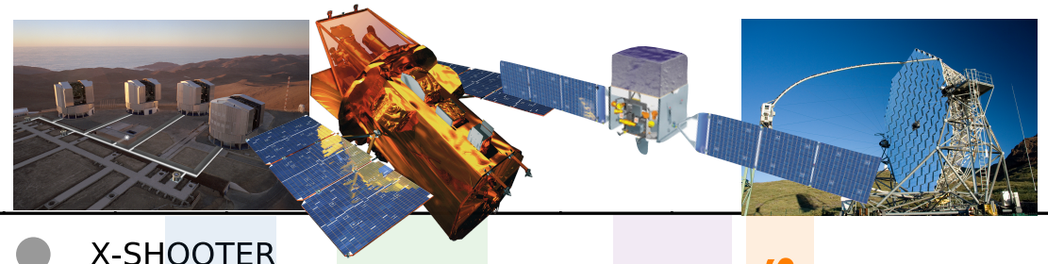


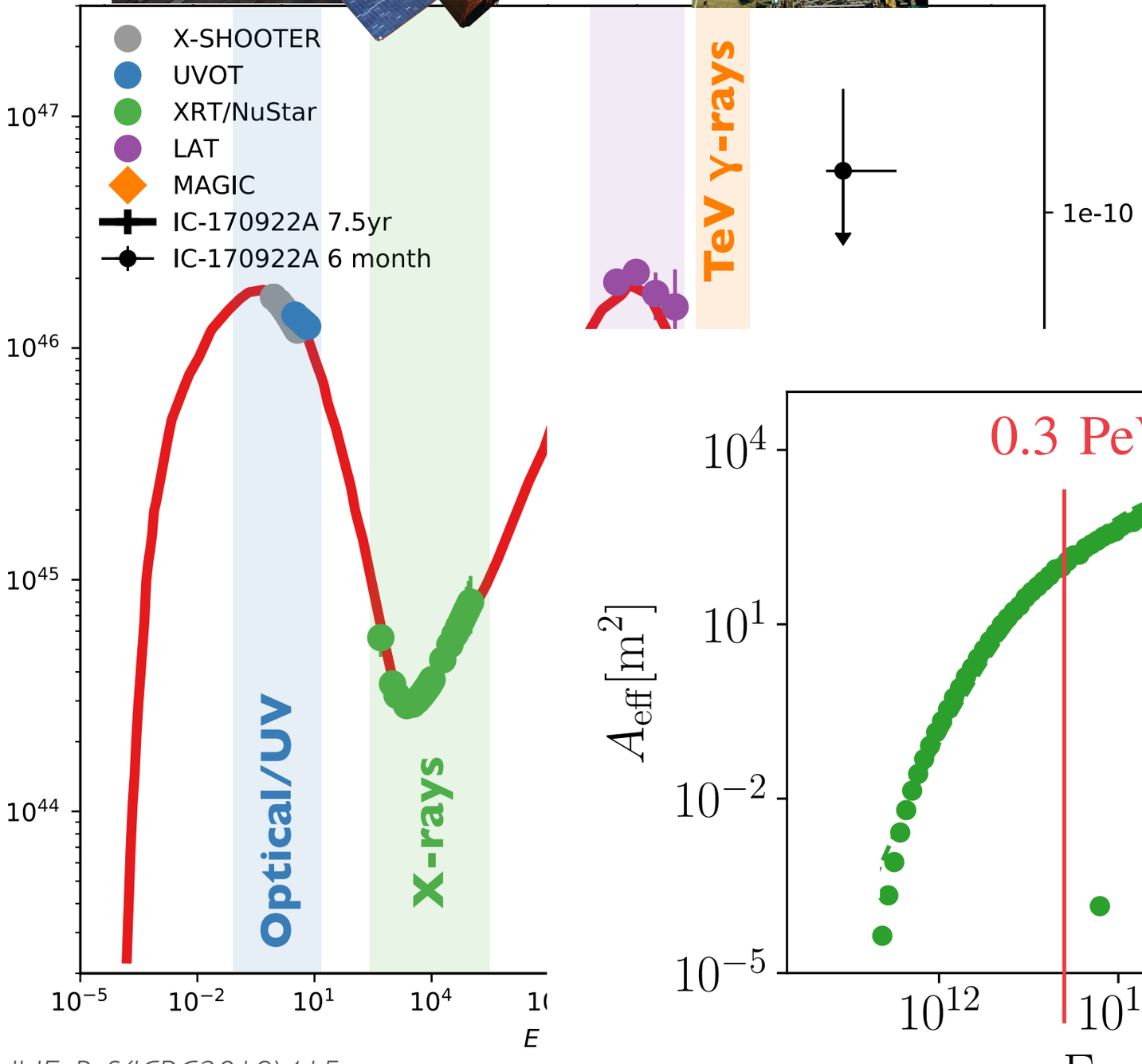


see also Auger upper limit at UHE, PoS(ICRC2019)415

TXS 0506+056 in 2017

IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/ NuSTAR, VERITAS, and VLA/ 17B-403 teams. Science 361, 2018, MAGIC Coll. Astrophys.J. 863 (2018) L10





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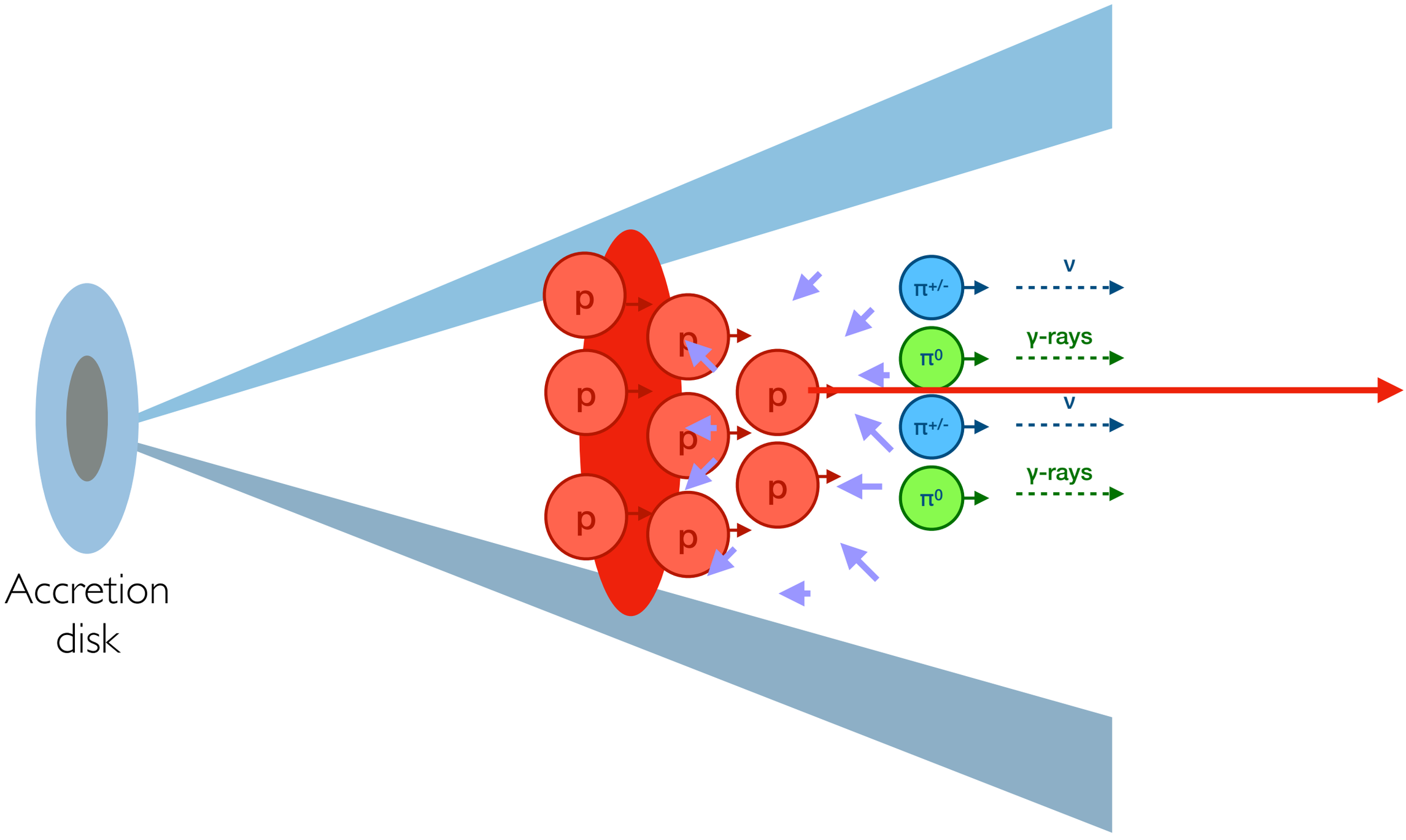
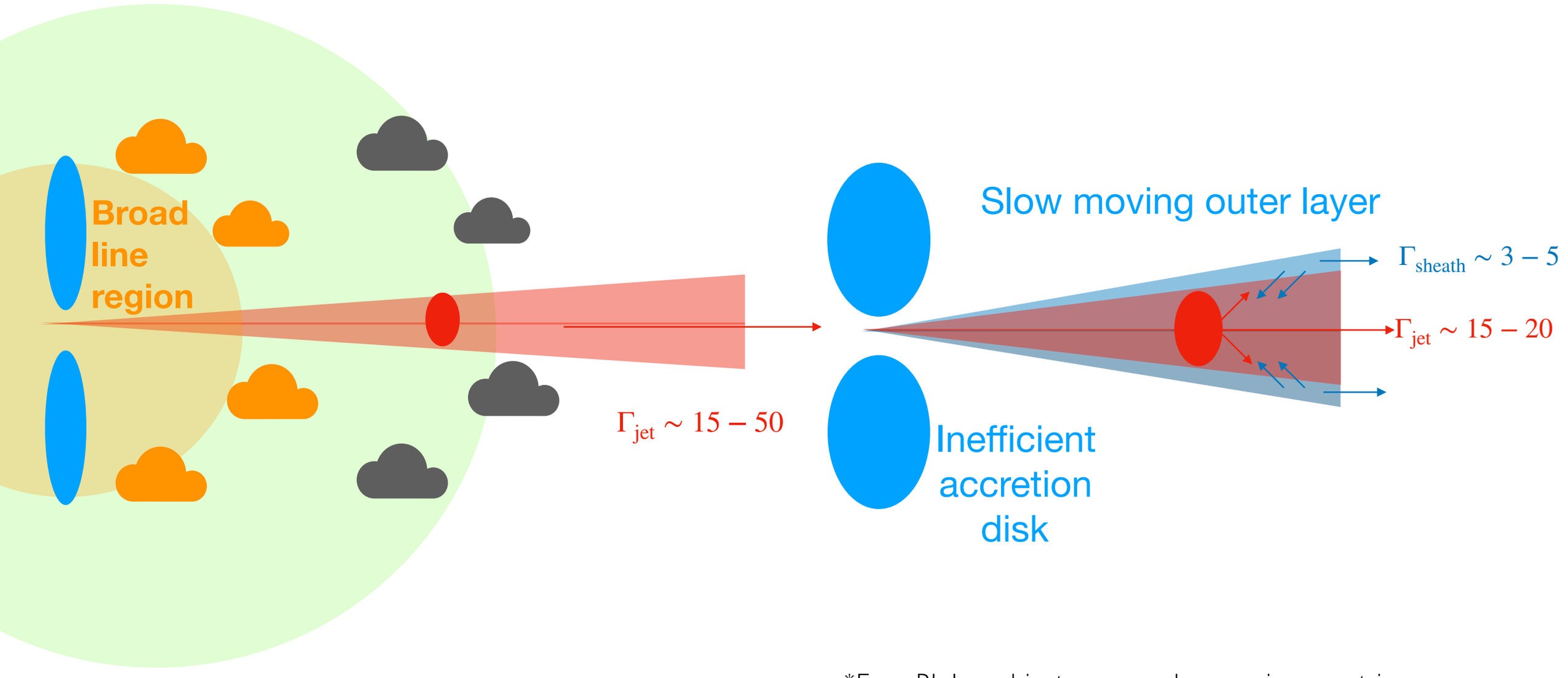
Neutrino production in TXS 0506+056 in 2017



Blazar photon fields

FSRQ

BL Lac



*Despite its optical classification TXS 0506+056 is an FSRQ with an efficient accretion disk!

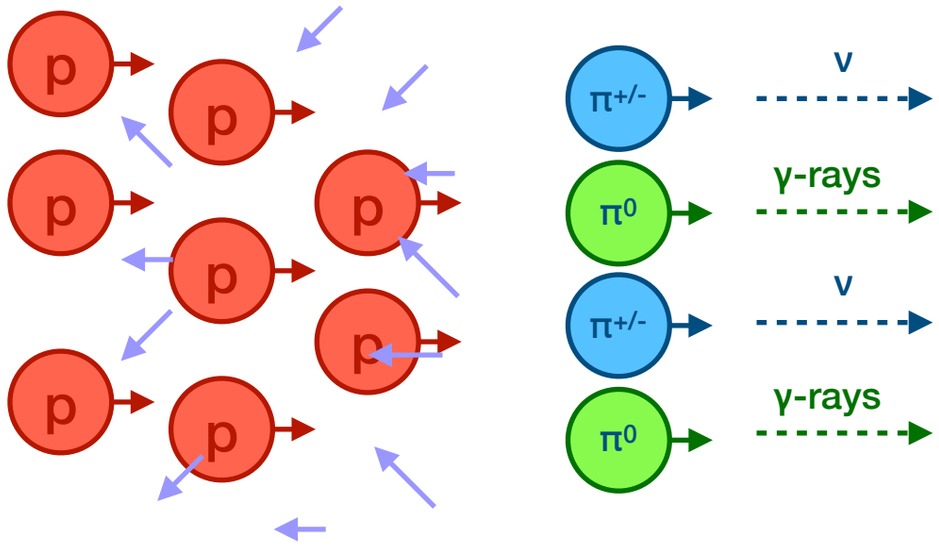
see *Padovani, FO Petropoulou et al, MNRASL 484 (2019)*

*Even BL Lac objects can produce copious neutrinos if they have a slow moving outer layer which there is evidence for

Ghisellini, Tavecchio, Chiaberge 2005
Tavecchio & Ghisellini 2014

Neutrino production in TXS 0506+056 in 2017

Murase, FO, Petropoulou ApJ 865 (2018) 124
FO, Murase, Petropoulou EpJ Conf 210 (2019) 03006



Padovani, FO Petropoulou et al, MNRASL 484 (2019)
Gao et al, 2019, Nat. Astron., 3, 88
MAGIC Coll 2018, ApJ, 863, L10
Cerruti et al, 2019 MNRAS, 483, L12
Reimer et al 2019 ApJ 881, 46
Rodrigues et al, 2019 ApJ, 874, L29

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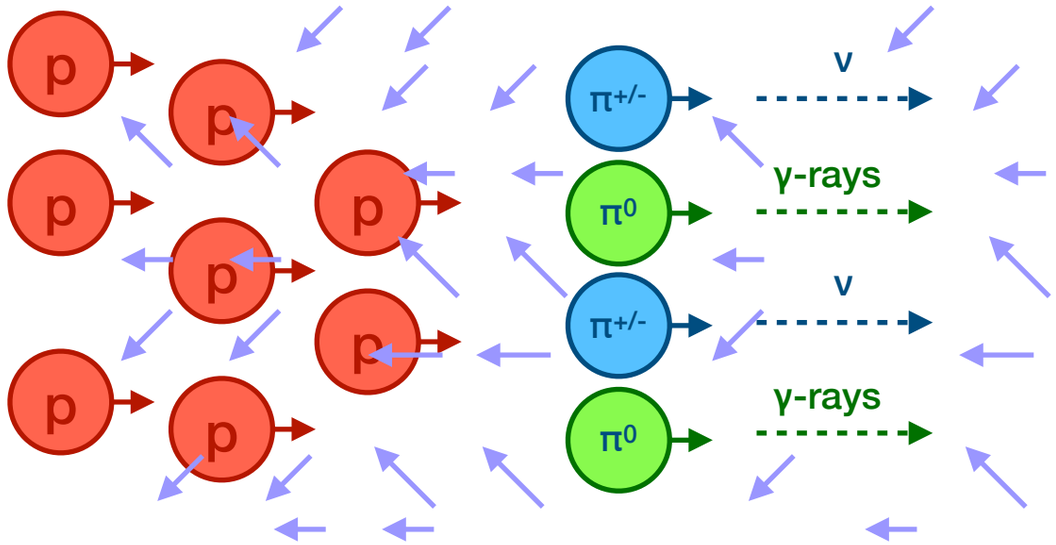

Padovani, FO Petropoulou et al, MNRASL 484 (2019)
Gao et al, 2019, Nat. Astron., 3, 88
MAGIC Coll 2018, ApJ, 863, L10
Cerruti et al, 2019 MNRAS, 483, L12
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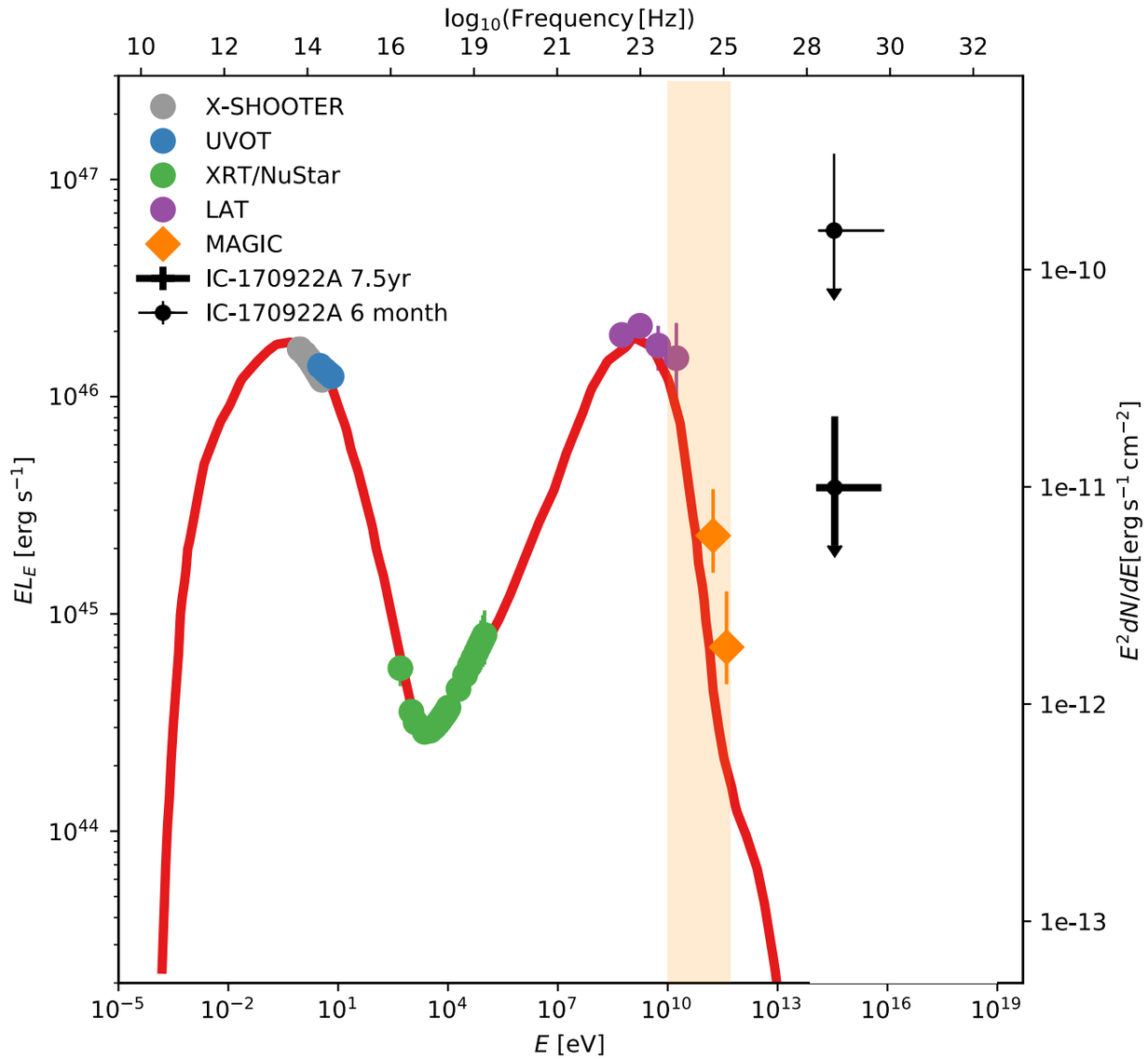
Neutrino production in TXS 0506+056 in 2017

Murase, FO, Petropoulou ApJ 865 (2018) 124
FO, Murase, Petropoulou EpJ Conf 210 (2019) 03006

1 . $\tau_{\gamma\gamma}(10-100\,\mathrm{GeV}) \lesssim 1$



Padovani, FO Petropoulou et al, MNRASL 484 (2019)
Gao et al, 2019, Nat. Astron., 3, 88
MAGIC Coll 2018, ApJ, 863, L10
Cerruti et al, 2019 MNRAS, 483, L12
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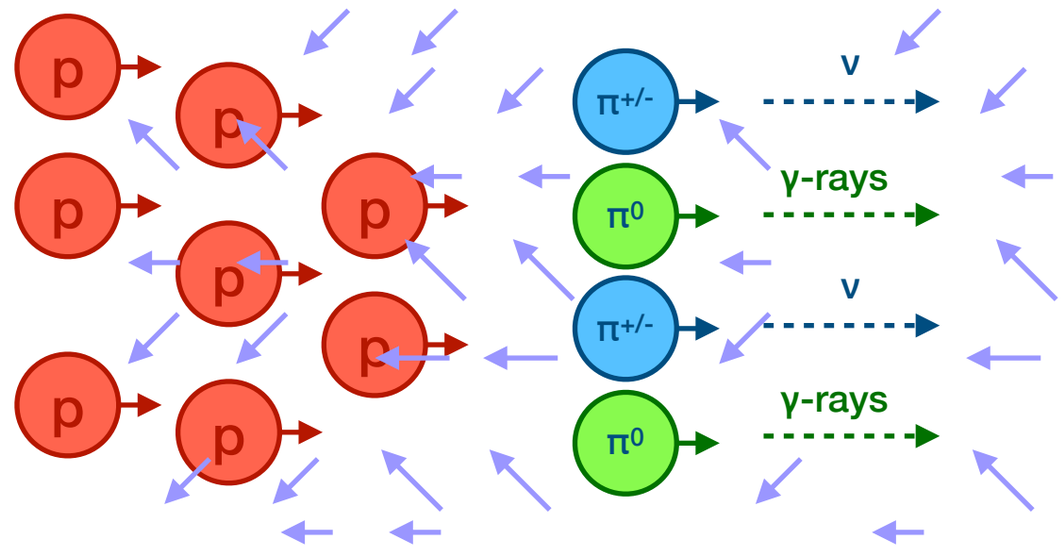
Rodrigues et al, 2019 ApJ, 874, L29



At energy,

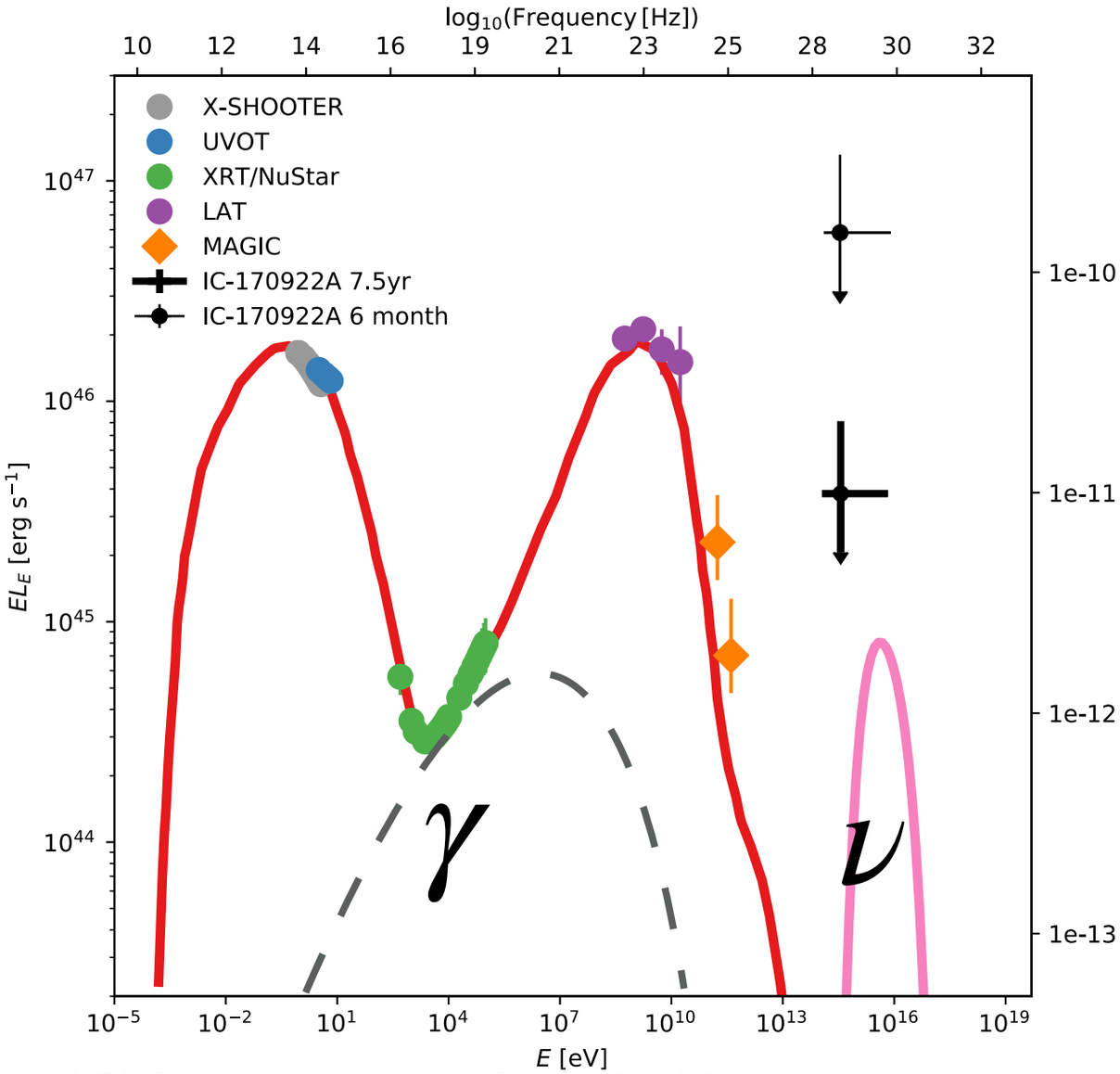
$$E'_\gamma \sim 15\ \mathrm{GeV}\left(\frac{E'_p}{6\ \mathrm{PeV}}\right) \sim 15\ \mathrm{GeV}\left(\frac{E'_\nu}{300\ \mathrm{TeV}}\right)$$

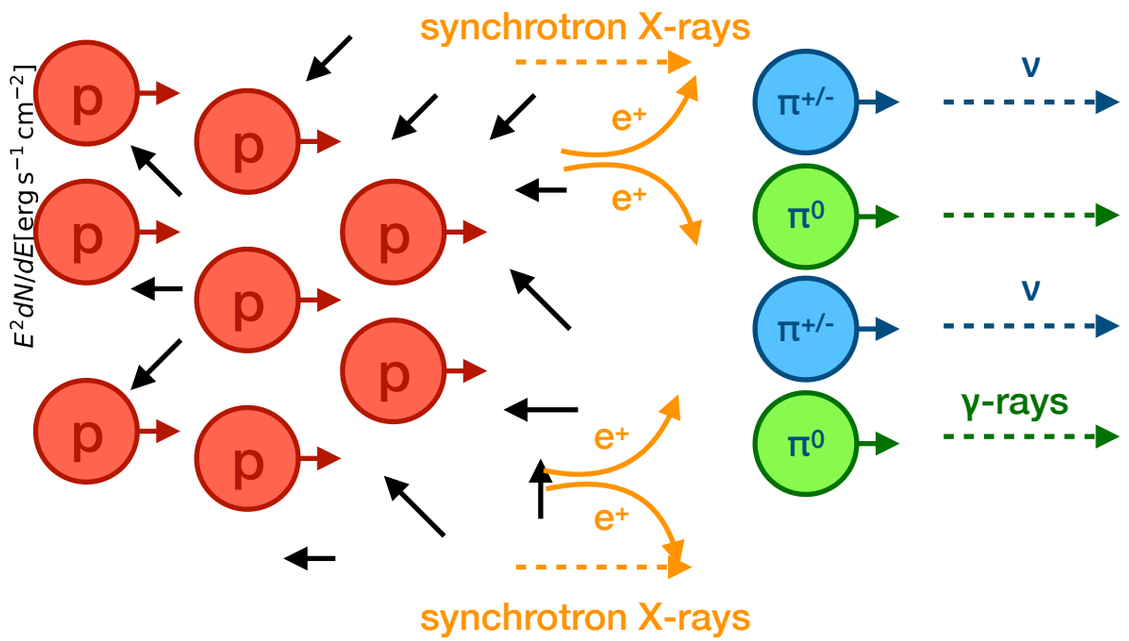
$$\tau_{\gamma\gamma}(E'_\gamma) \approx 10^3 \tau_{p\gamma}(E'_p)$$

Neutrino production in TXS 0506+056 in 2017

Murase, FO, Petropoulou ApJ 865 (2018) 124
FO, Murase, Petropoulou EpJ Conf 210 (2019) 03006

2. $p_{\rm PeV} + \gamma \rightarrow p + e^+ + e^- \rightarrow$ cascade that peaks in keV band





Padovani, FO Petropoulou et al, MNRASL 484 (2019)
Gao et al, 2019, Nat. Astron., 3, 88
MAGIC Coll 2018, ApJ, 863, L10
Cerruti et al, 2019 MNRAS, 483, L12
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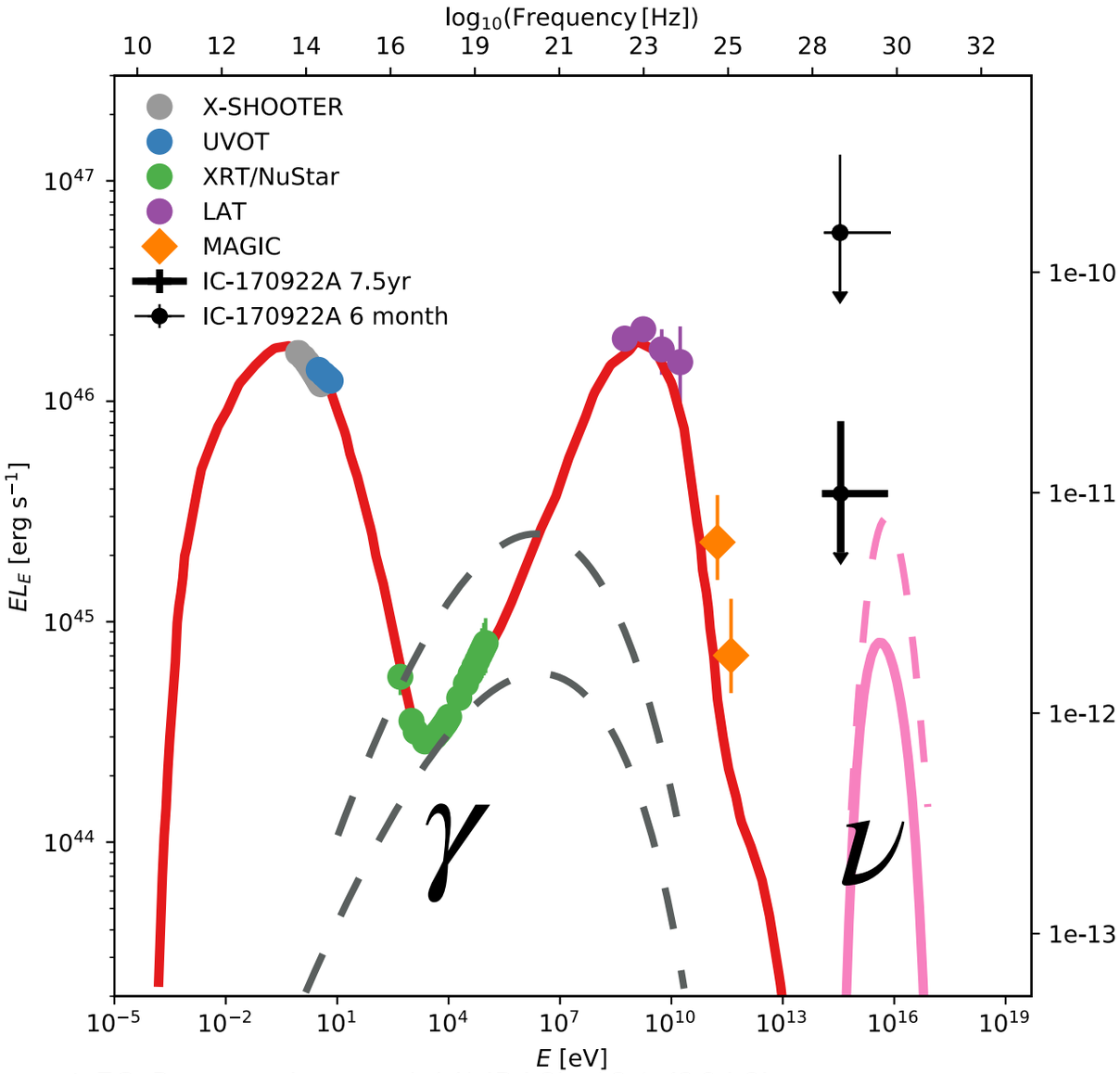
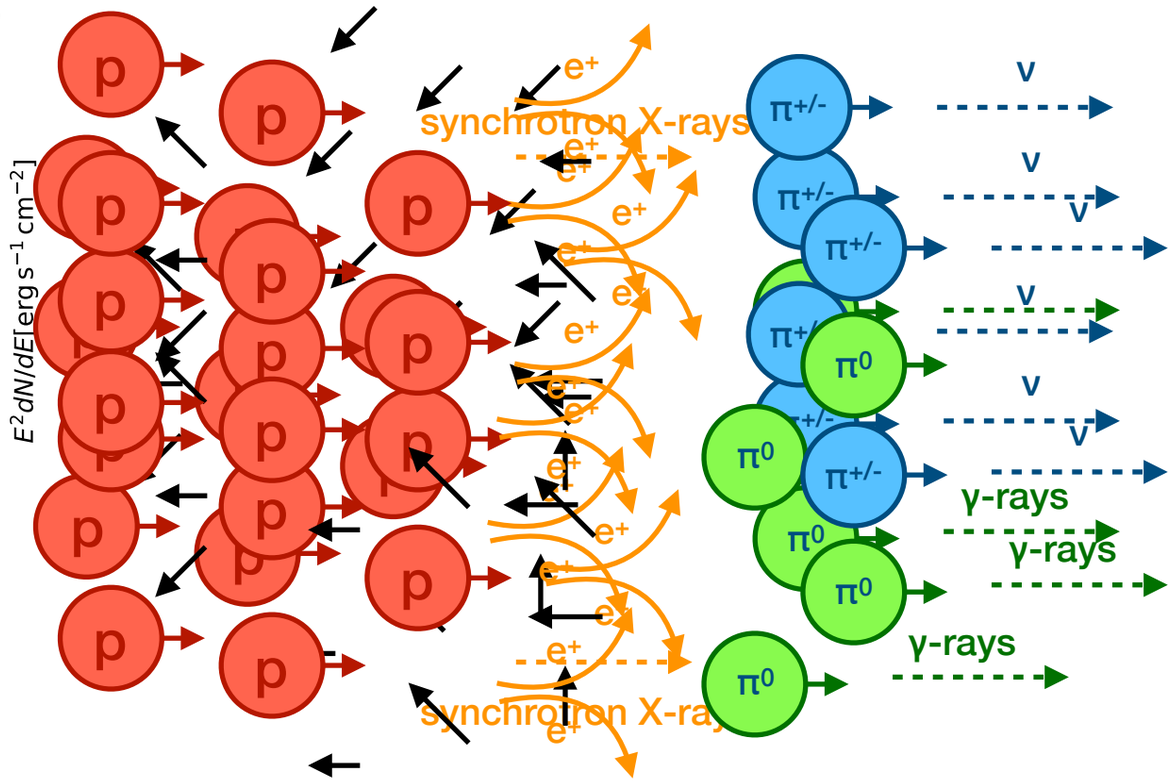
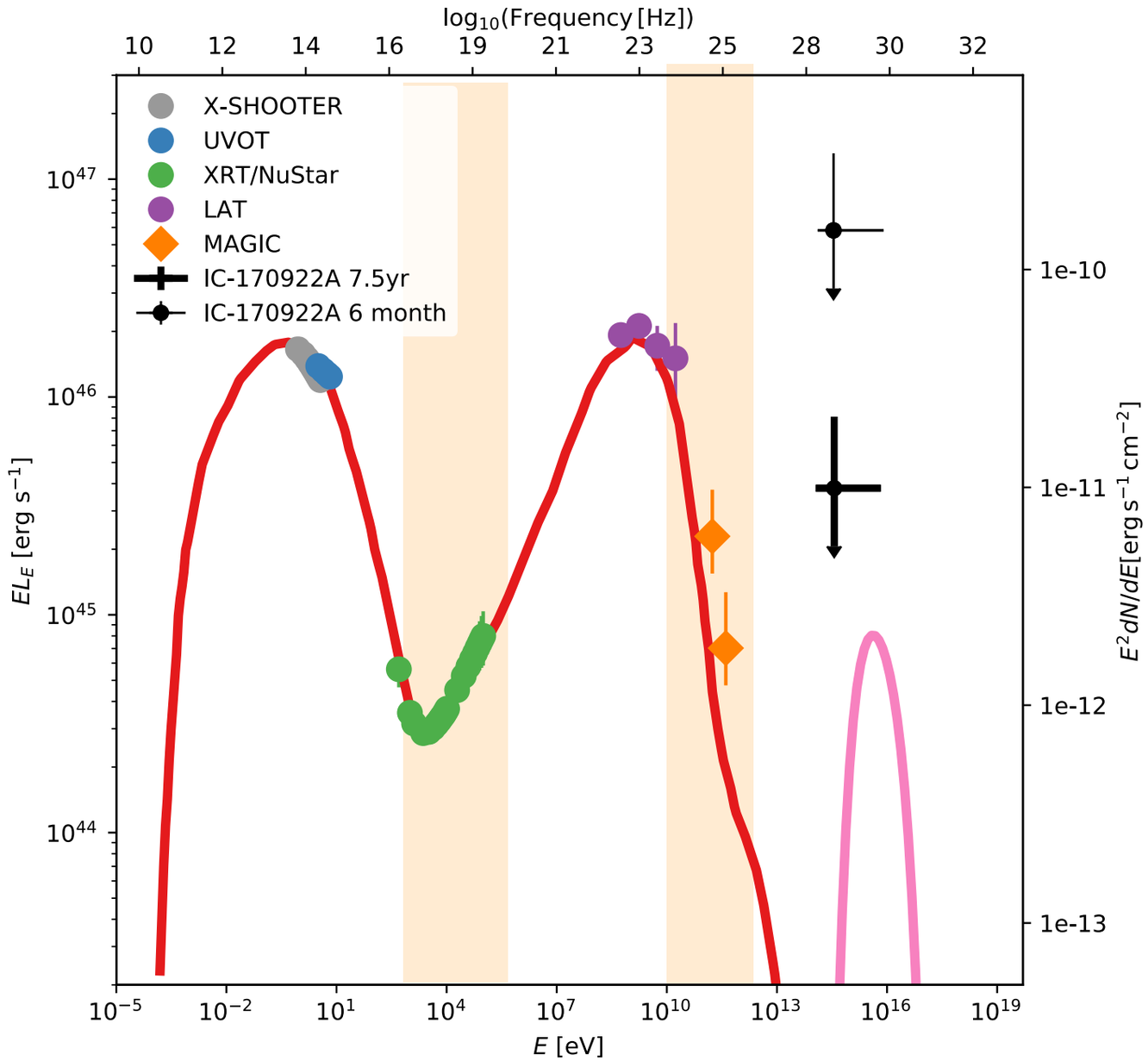




Padovani, FO Petropoulou et al, MNRASL 484 (2019)
Gao et al, 2019, Nat. Astron., 3, 88
MAGIC Coll 2018, ApJ, 863, L10
Cerruti et al, 2019 MNRAS, 483, L12
Reimer et al 2019 ApJ 881, 46
Rodrigues et al, 2019 ApJ, 874, L29

Neutrino production in TXS 0506+056 in 2017

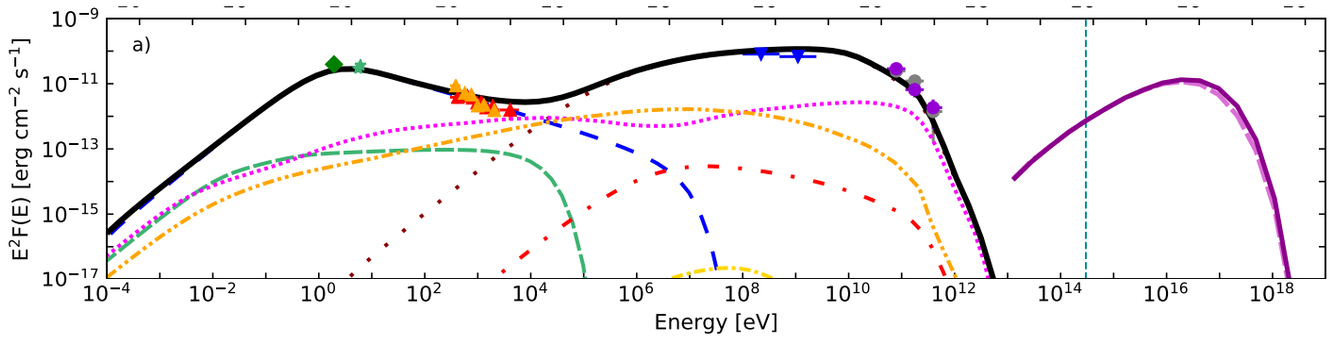


$$N_{\nu_\mu} \lesssim 0.01/6 \text{ months}^{\star}$$

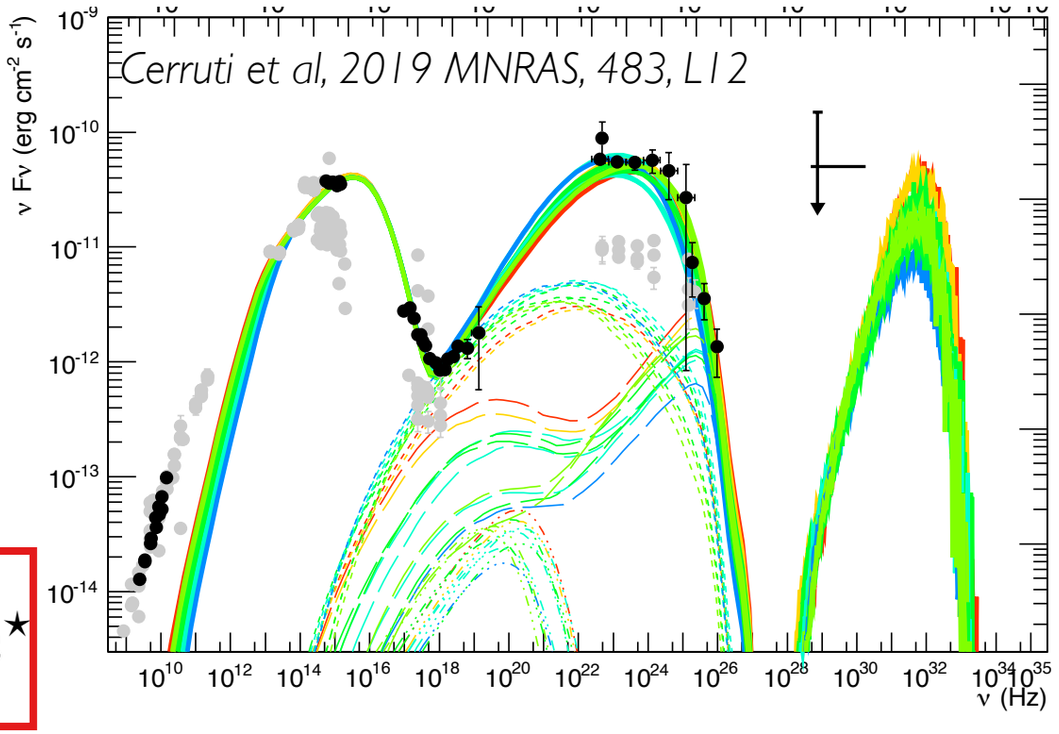
*(*ok due to Eddington bias, Strotjohann et al 2019)*

Neutrino production in TXS 0506+056 in 2017

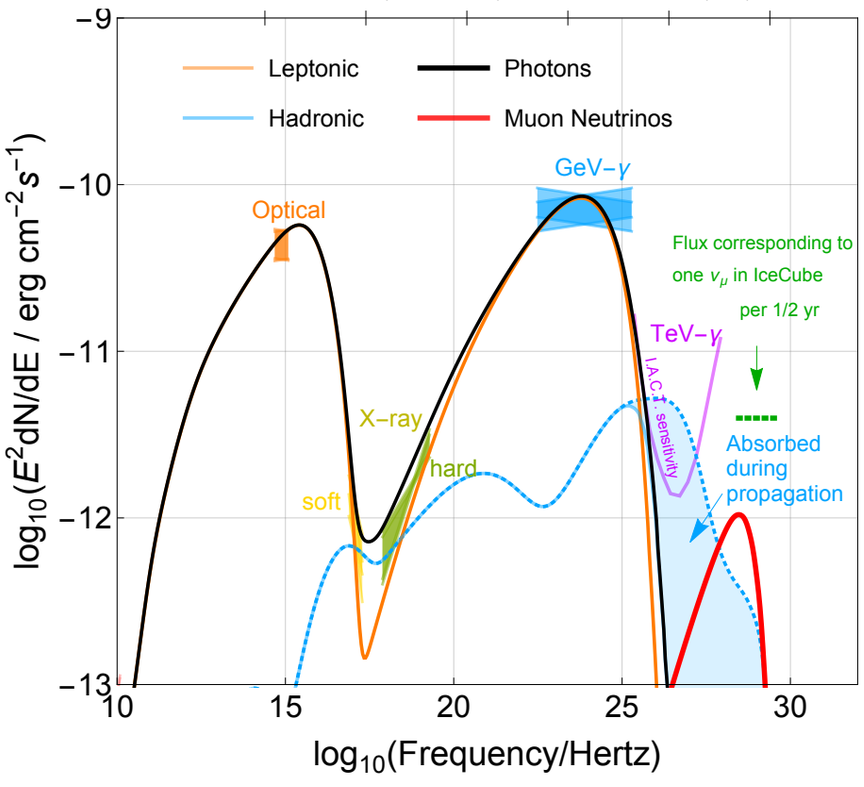
MAGIC Coll 2018, ApJ, 863, L10



Cerruti et al, 2019 MNRAS, 483, L12

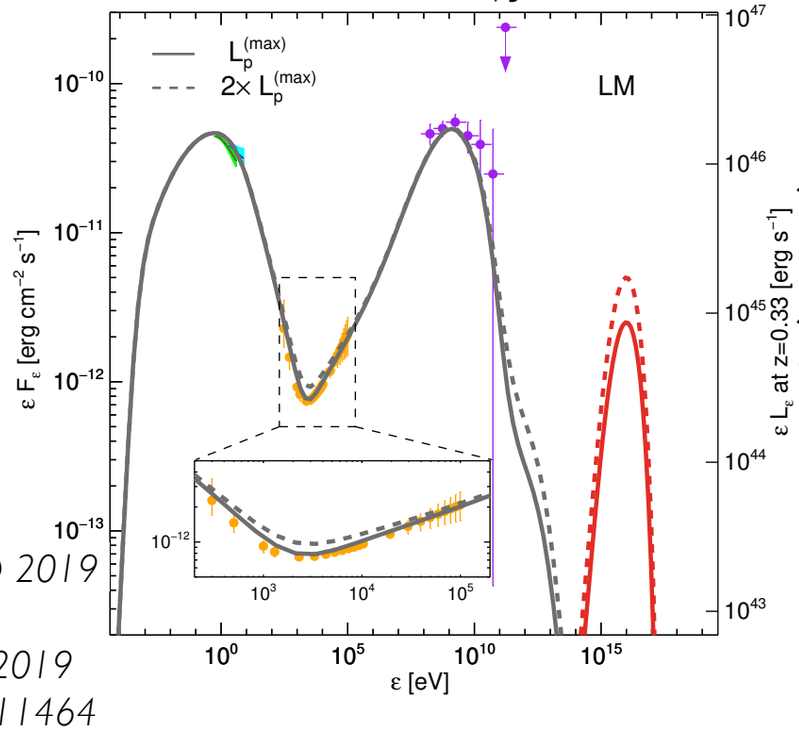


Gao et al, 2019, Nat. Astron., 3, 88

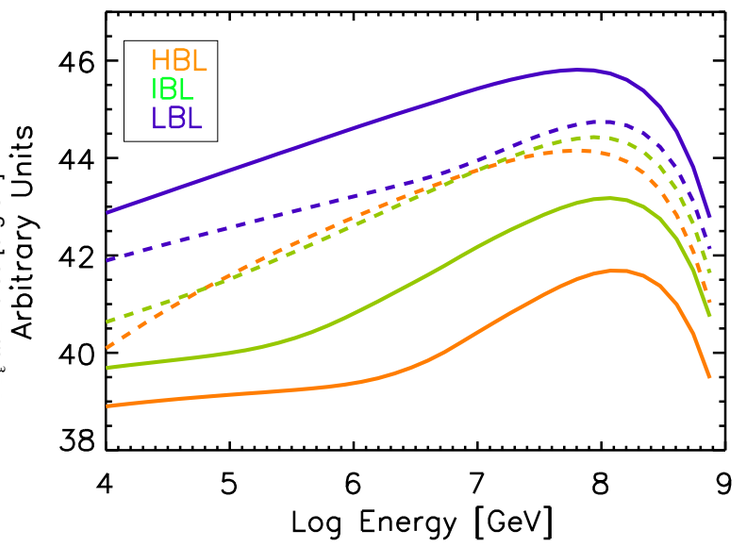


$$N_{\nu_\mu} \lesssim 0.01/6 \text{ months}^{\star}$$

Keivani et al. 2018, ApJ, 864, 84



Righi et al, MNRAS, 483, L127



Other more exotic options

hadro-nuclear interactions: *Liu, Wang, Xue, Taylor et al, PRD 2019*

stellar disruption: *Wang, Liu et al, arXiv:1809.00601*

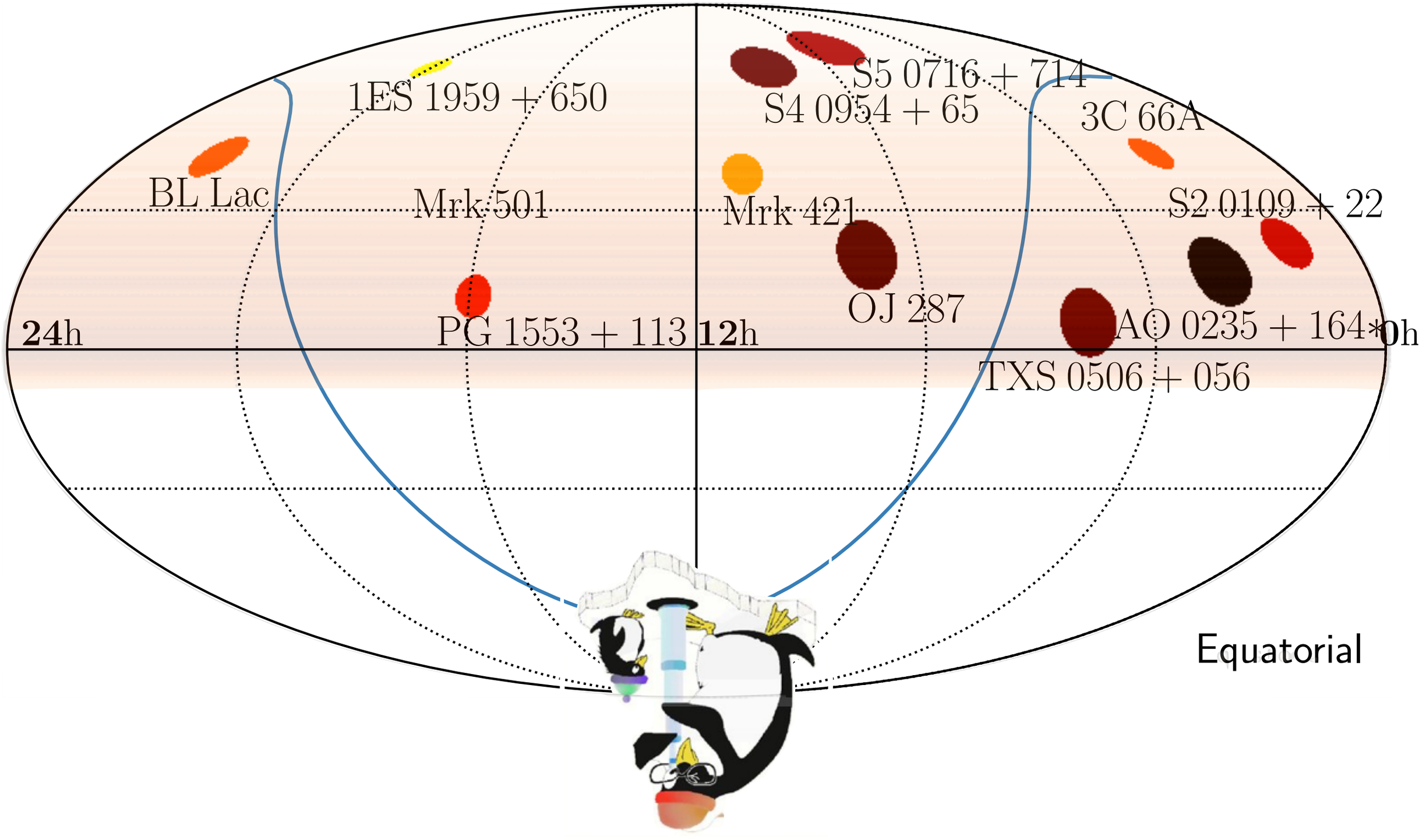
multiple zones: *Xue, Liu, Petropoulou, Oikonomou et al. ApJ 2019*

neutron beam: *Zhang, Petropoulou, Murase, FO, arXiv:1910.11464*

curved/double jet: *Britzen, Fendt, Böttcher et al, A&A 2019*

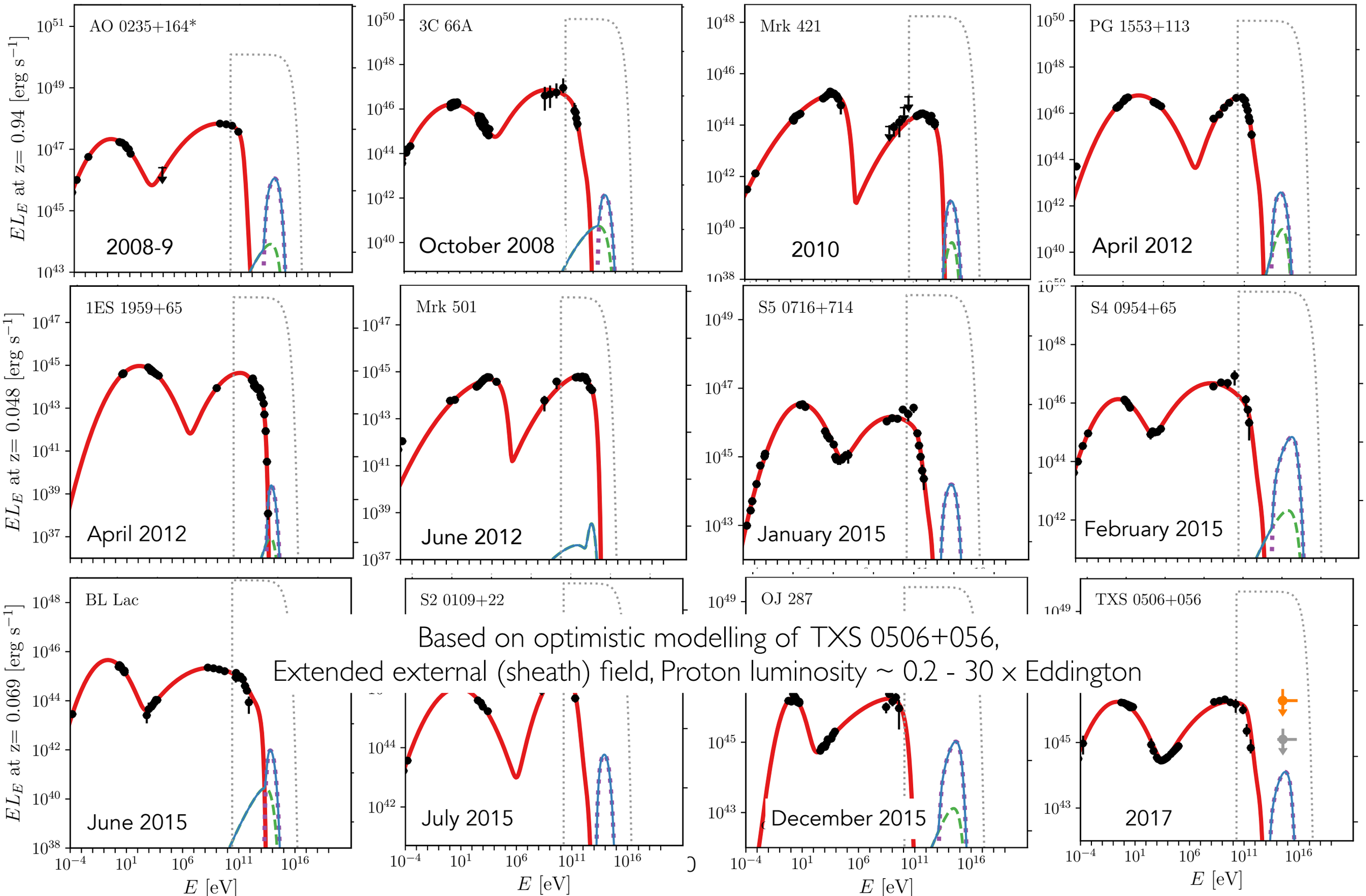
High-energy neutrinos from other blazar flares?

FO, Murase, Padovani, Resconi, Mészáros, MNRAS, 23, 2019



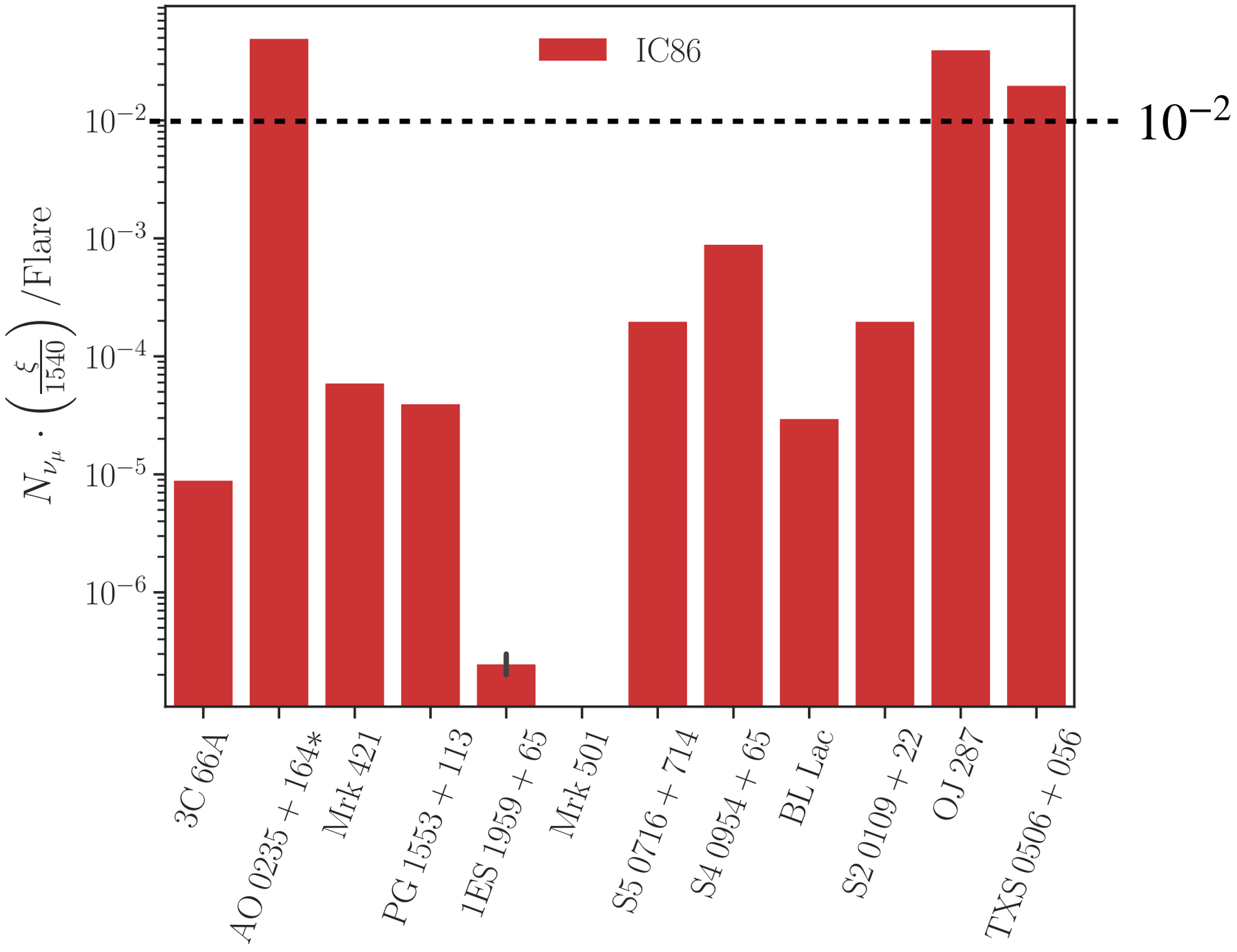
Optimistic scenario based on 2017 flare of TXS 0506+056

FO, Murase, Padovani, Resconi, Mészáros, MNRAS, 23, 2019

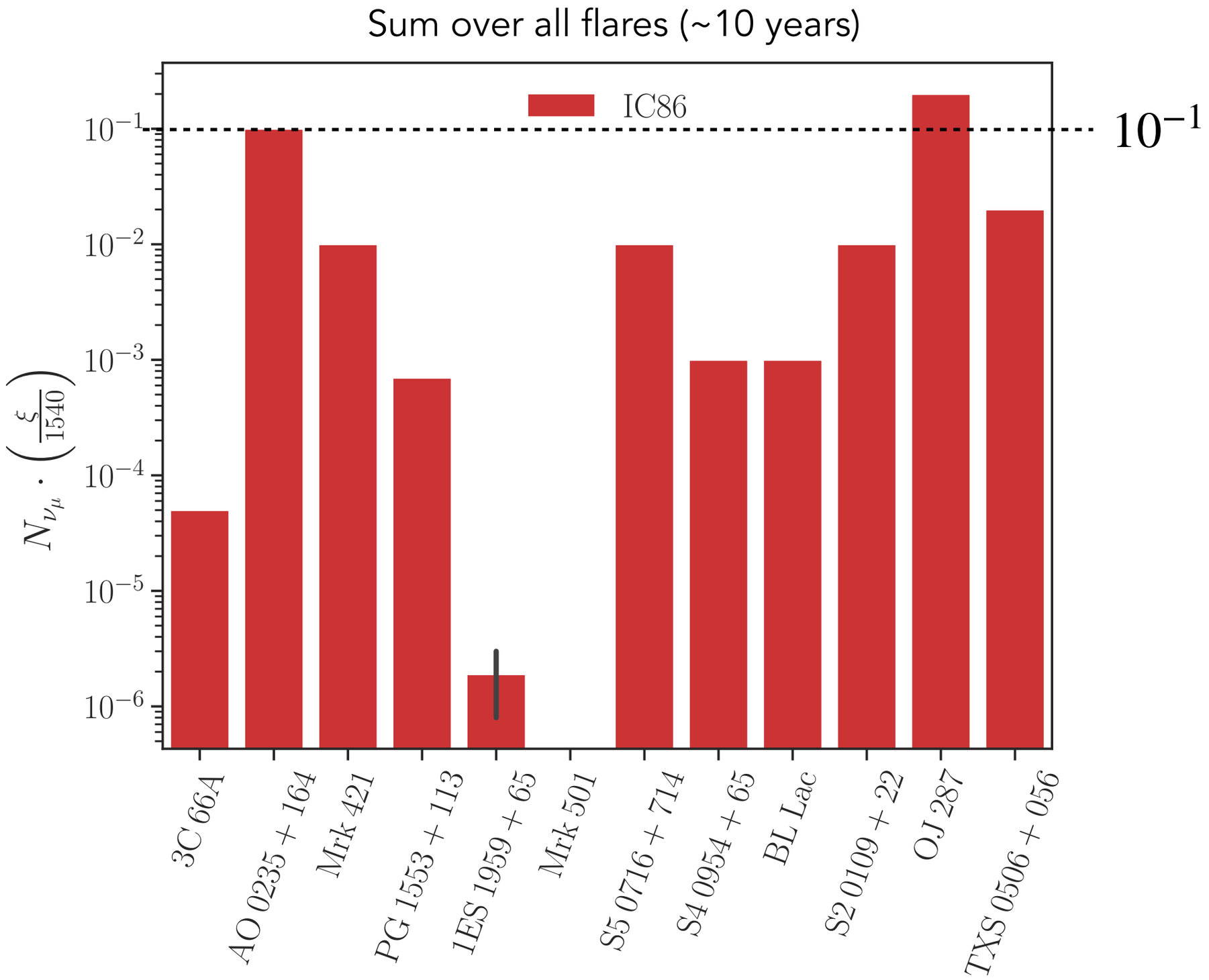


Based on optimistic modelling of TXS 0506+056,
Extended external (sheath) field, Proton luminosity ~ 0.2 - 30 x Eddington

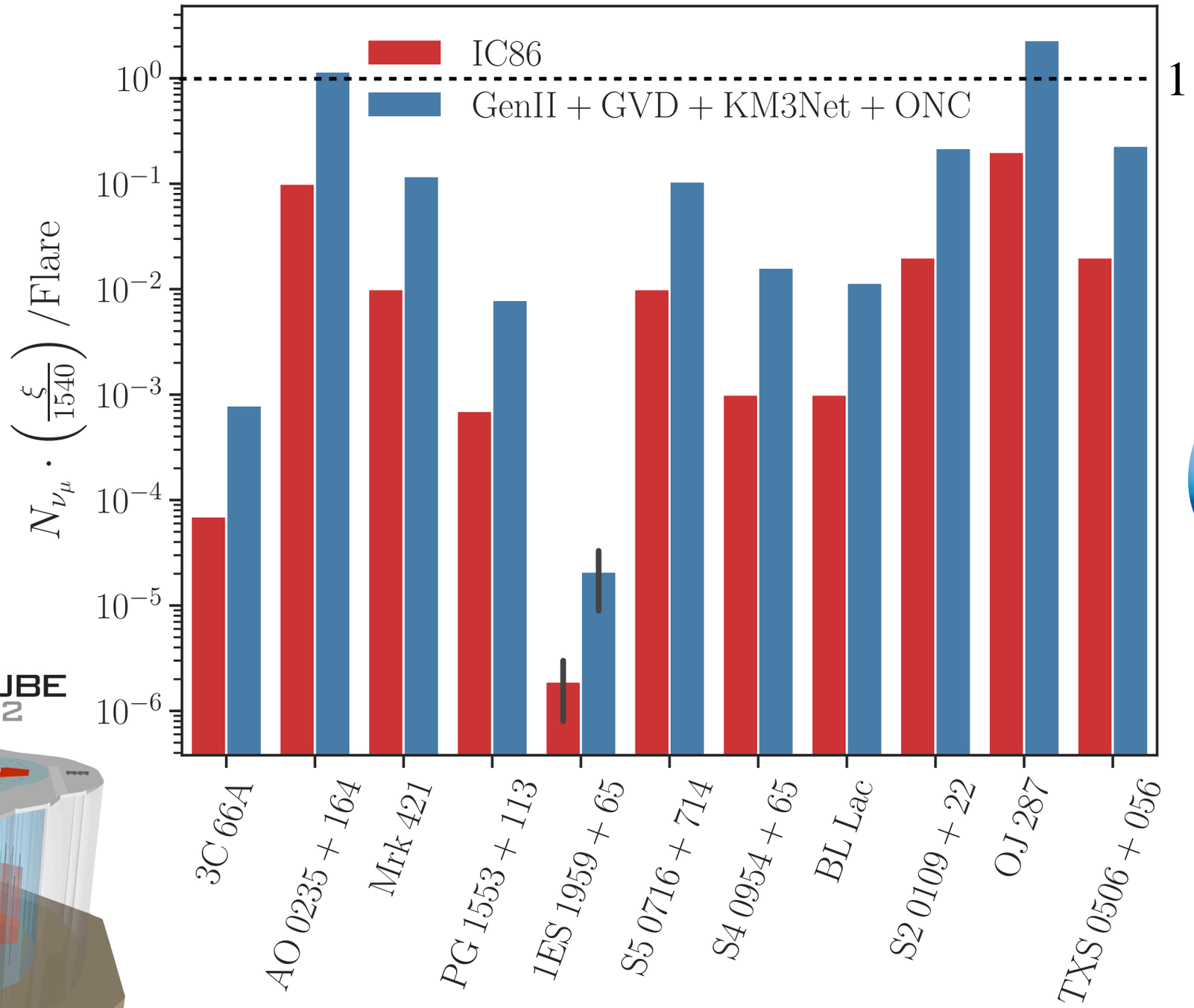
Expected neutrino signal in optimistic case

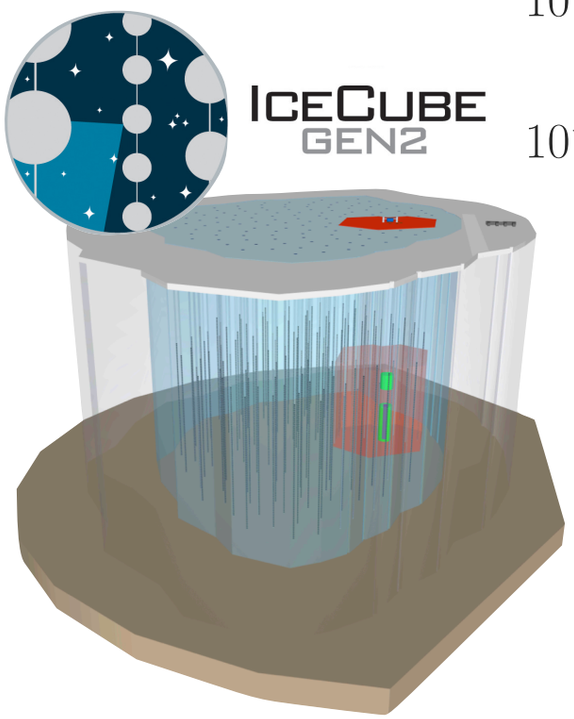


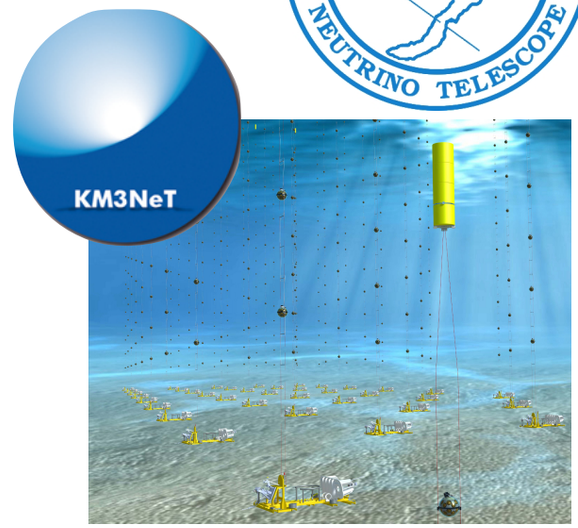
Expected neutrino signal in optimistic case



Expected neutrino signal with next generation detectors







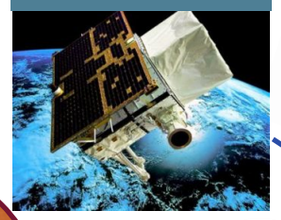
Waiting for the next multimessenger alerts!

Ayalla-Solares et al (inc FO) Astropart.Phys. 114 (2020) 68

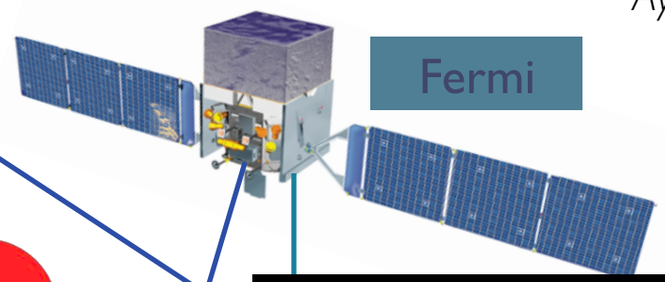
Nordin et al A&A 631, A147 (2019)

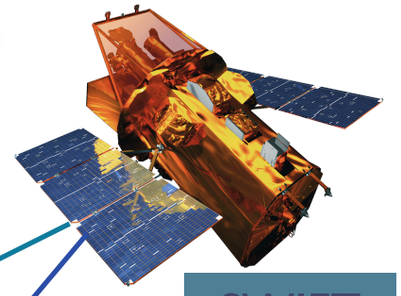
Antares

AGILE



Fermi



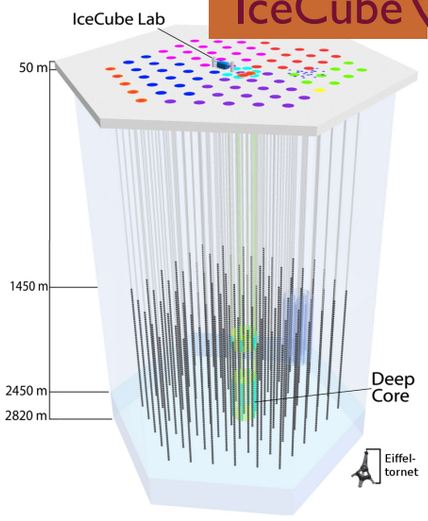


SWIFT

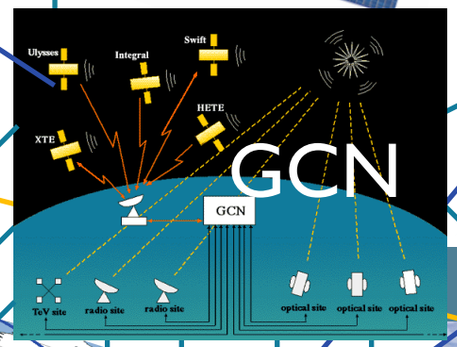
MAGIC

ν

IceCube

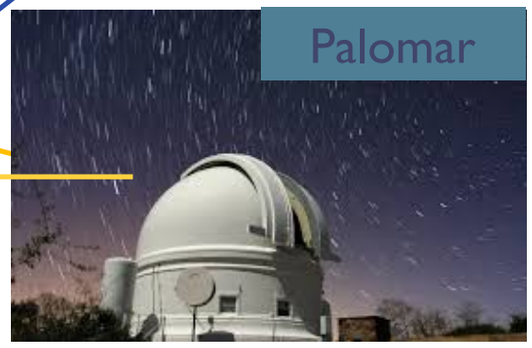


AMPEL

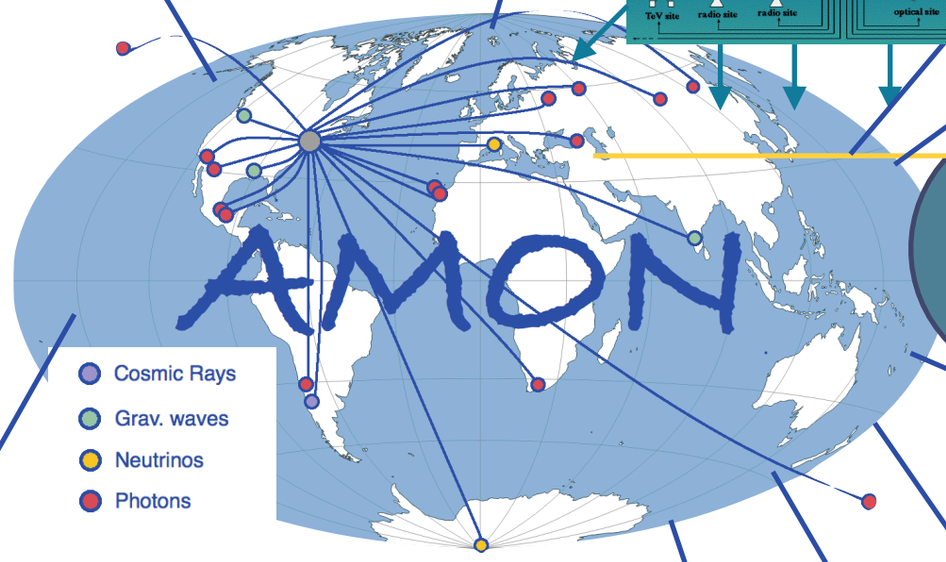


HAWC

Palomar



AMON



Cosmic Rays
Grav. waves
Neutrinos
Photons

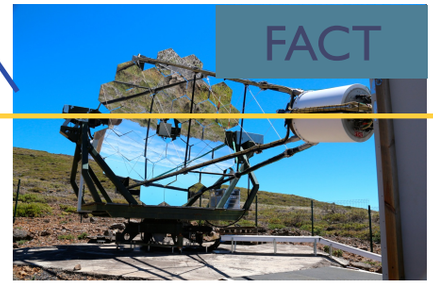
Y

H.E.S.S

LIGO

GW

CR



FACT

VLT

VIRGO

Telescope Array

AUGER

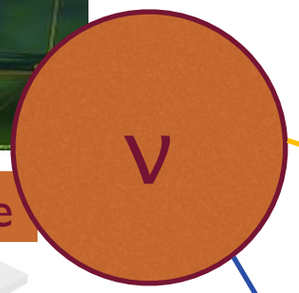
VERITAS

LCOGT

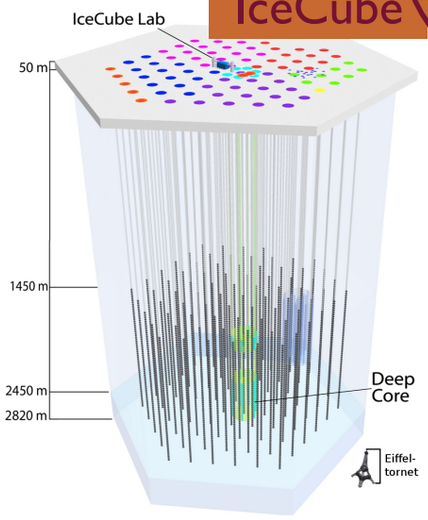
Waiting for the next multi messenger alerts!

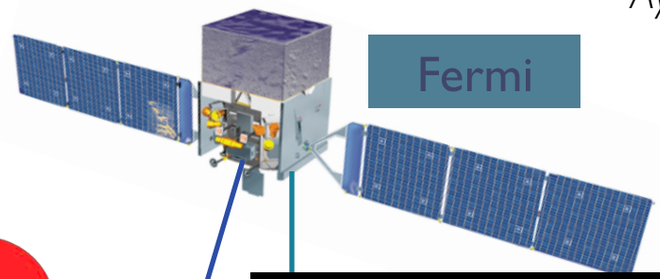
Ayalla-Solares et al (inc FO) Astropart.Phys. 114 (2020) 68

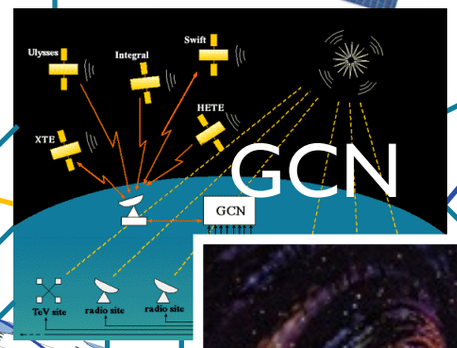
Nordin et al A&A 631, A147 (2019)

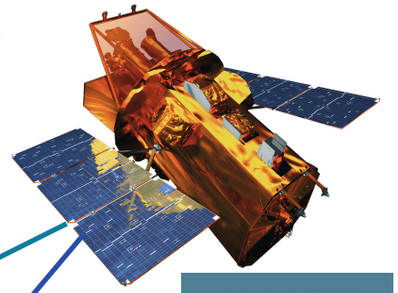


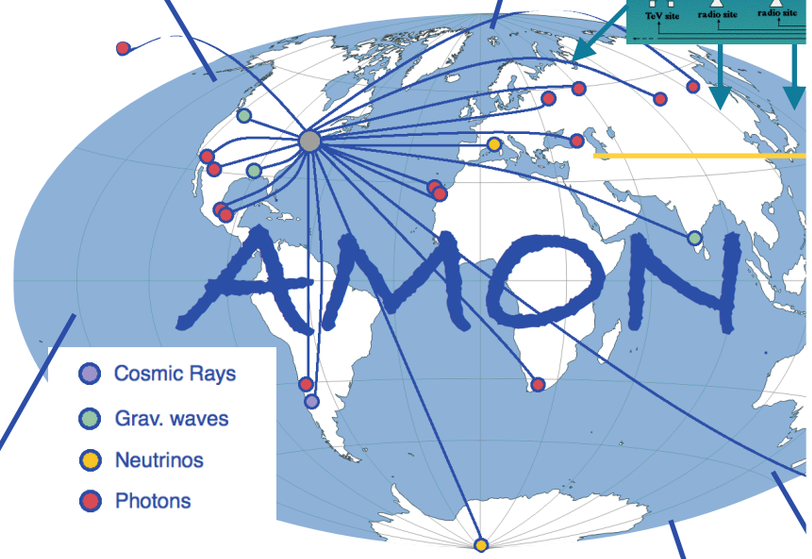
IceCube

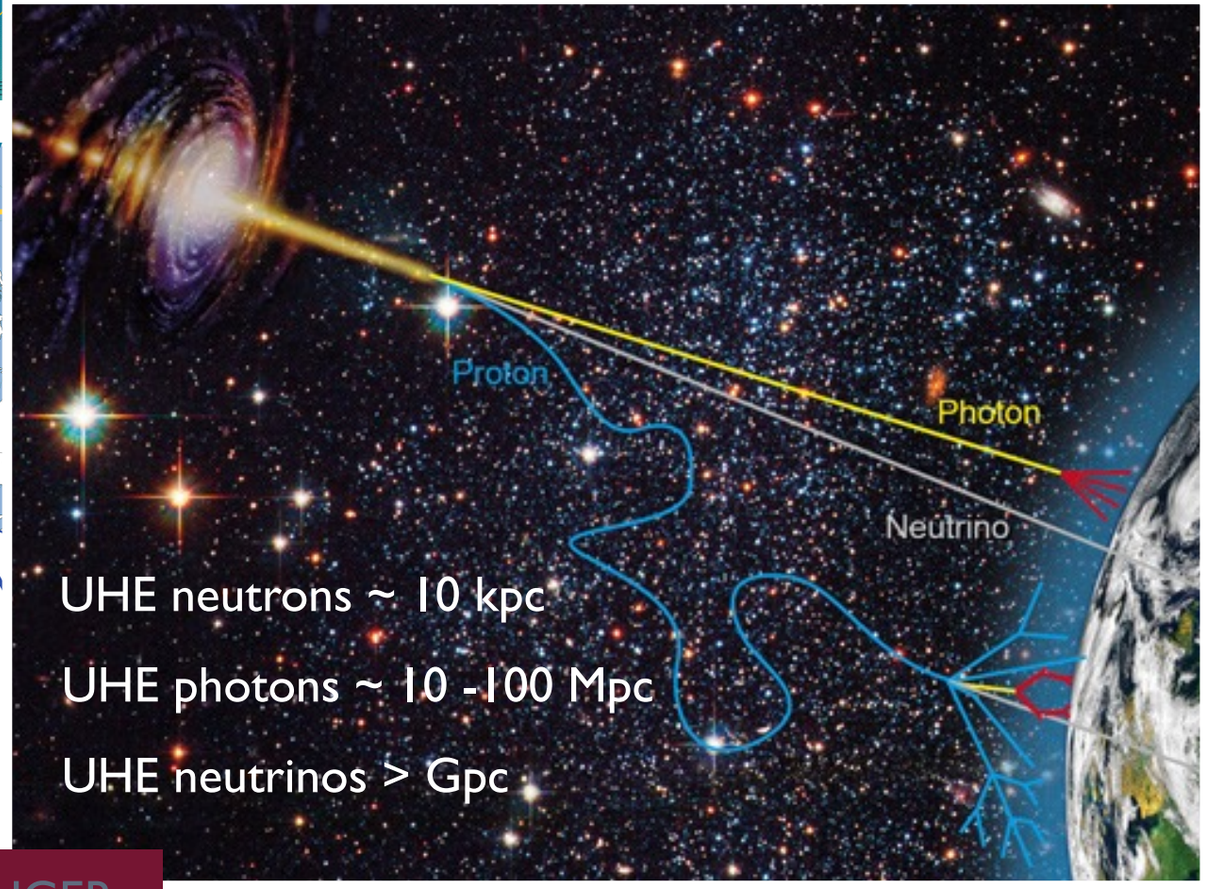






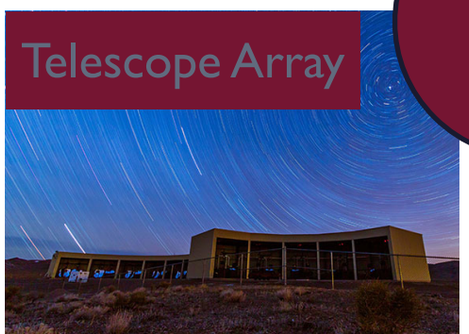




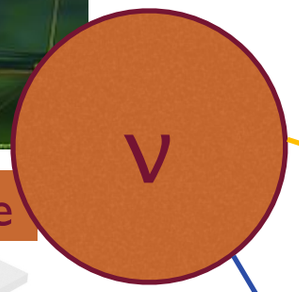


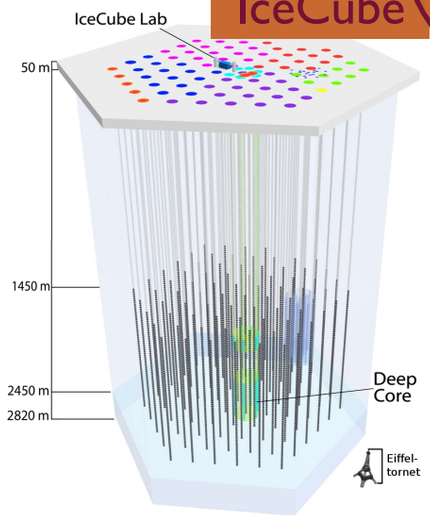
GW

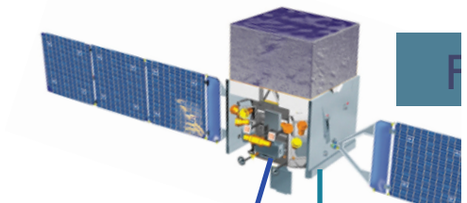
CR

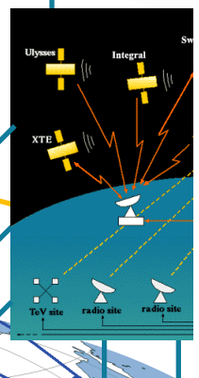


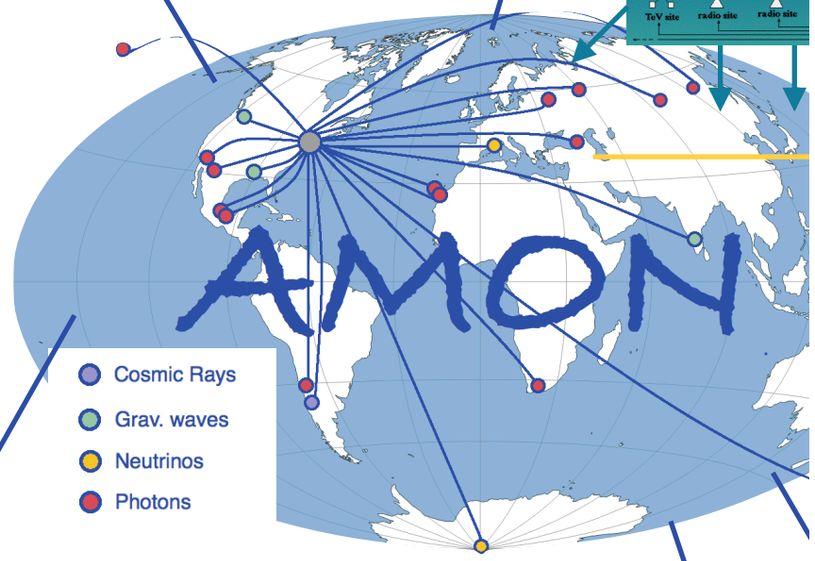
Waiting for the next multi messenger alerts!



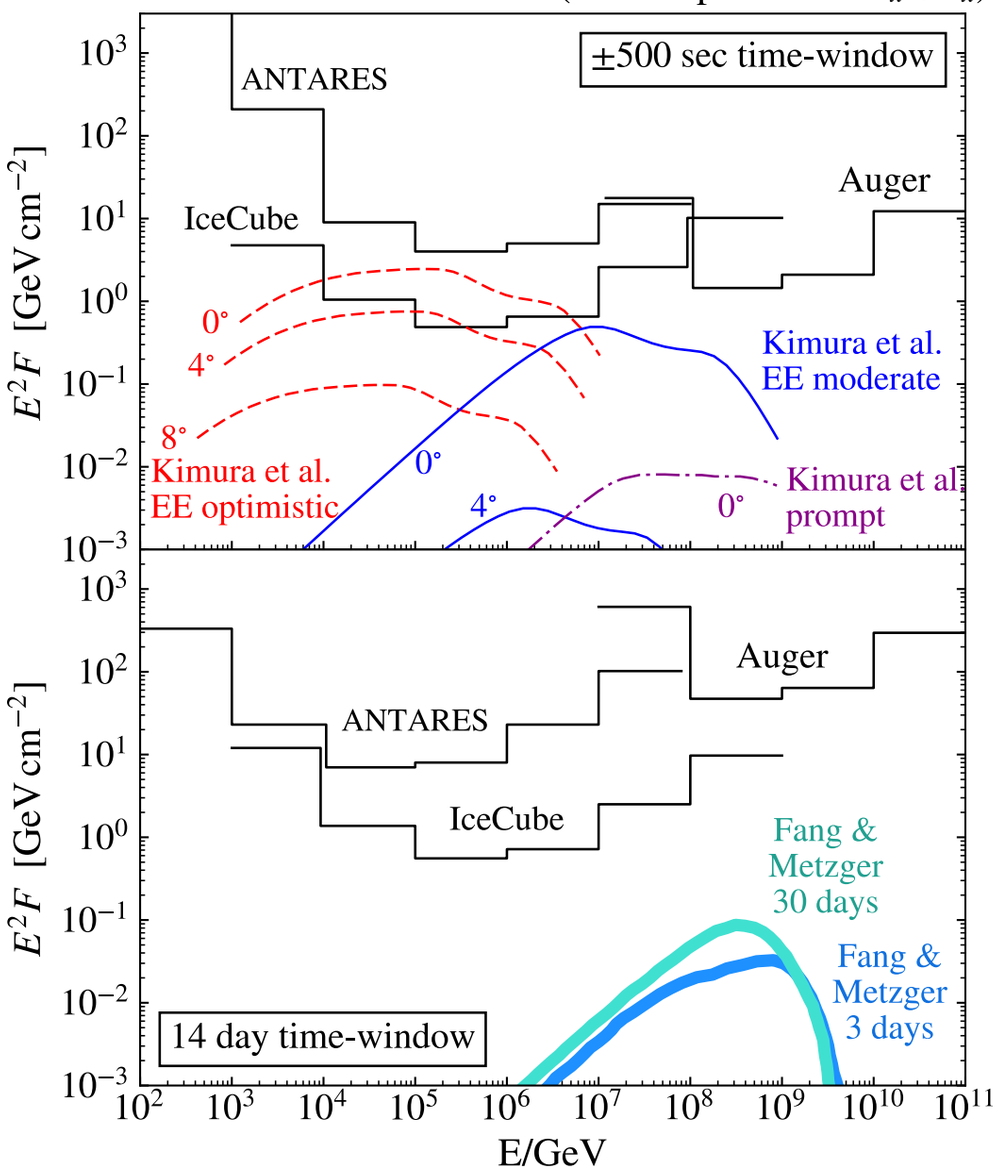








GW170817 Neutrino limits (fluence per flavor: $\nu_x + \bar{\nu}_x$)



ANTARES, IceCube, and Auger Coll, ApJ. 850, L35 (2017)

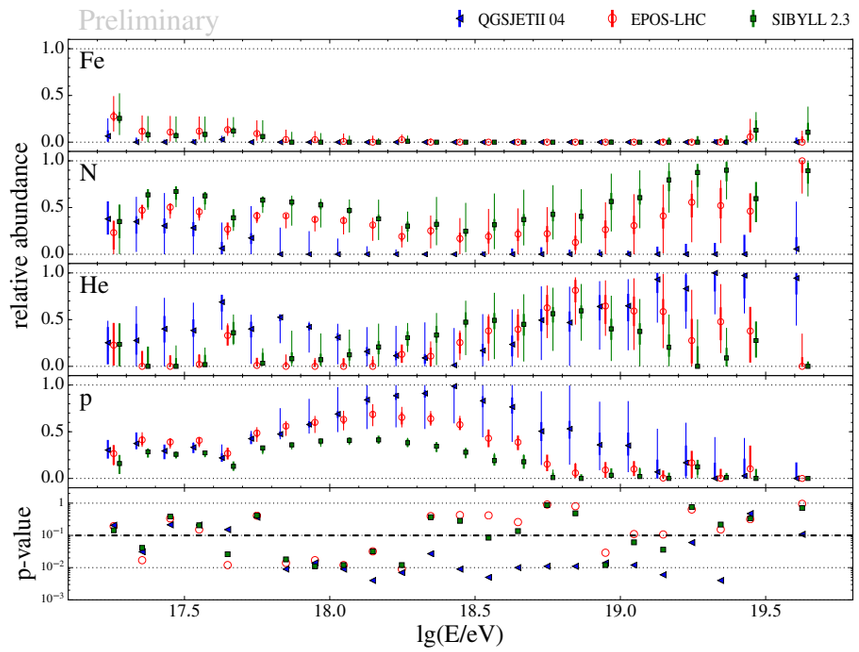
020) 68

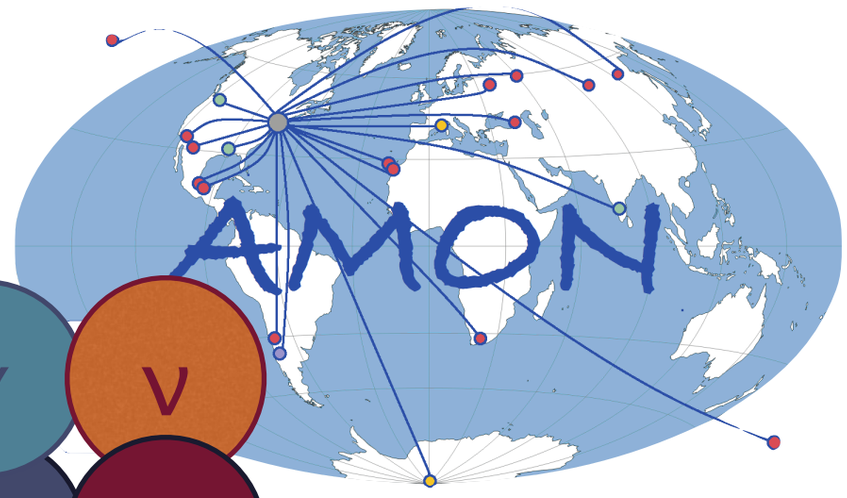
(2019)

Outlook

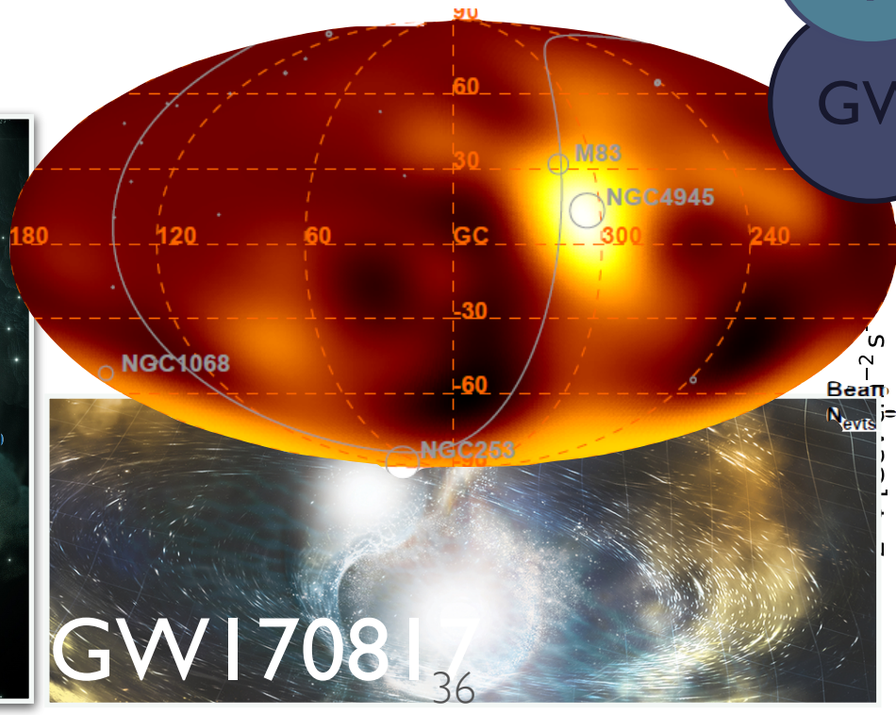
AugerPrime can

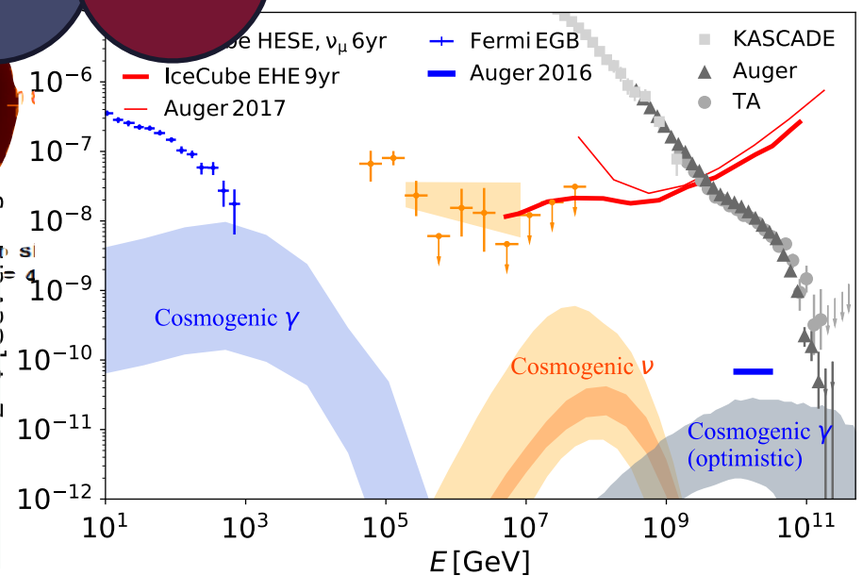
- allow number density determination, correlations with neutrinos, source associations (light component)
- distinguish between AGN and SBGs/GRBs (iron fraction)
- identify UHE sources by temporal/spatial associations with signal from other instruments (neutral particles)





Looking forward to the next multimessenger events!

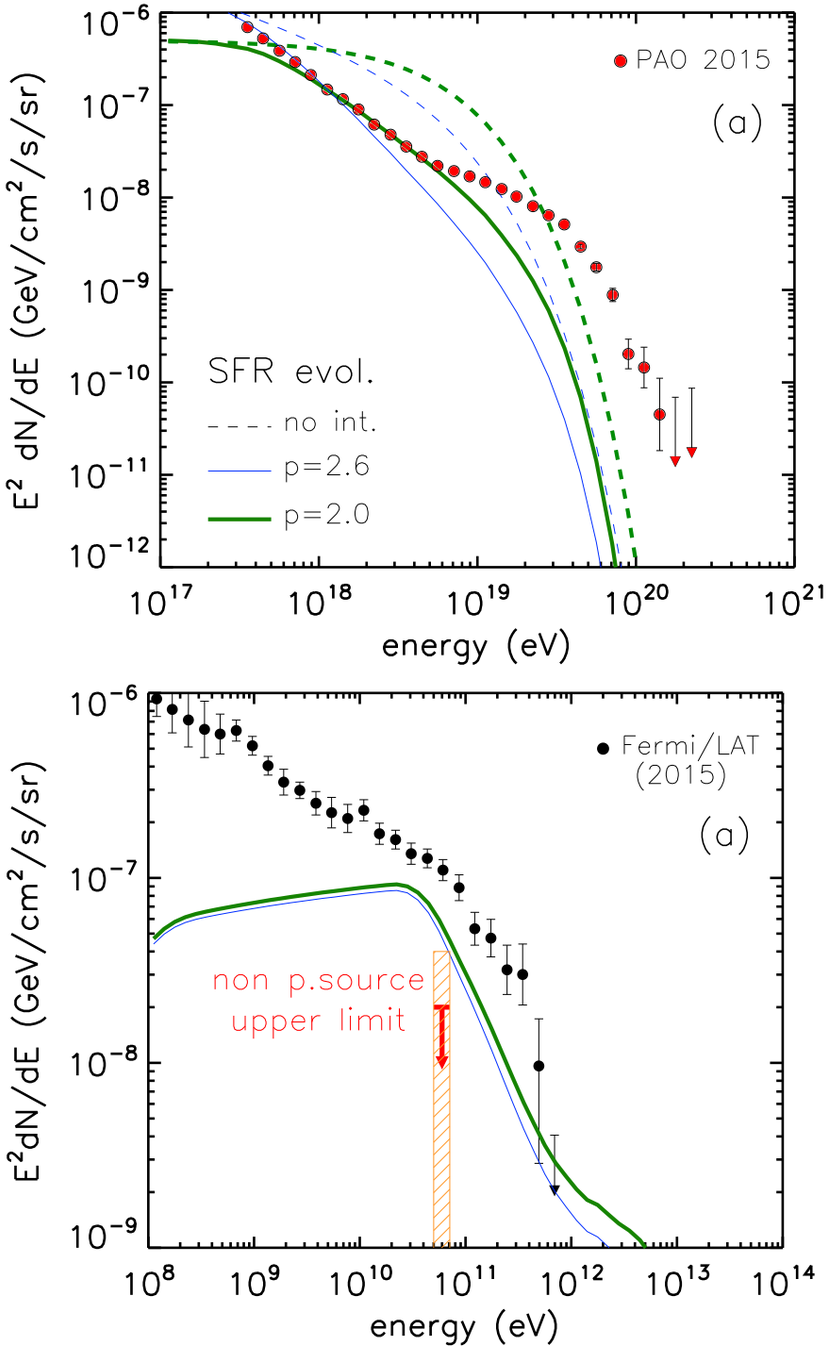


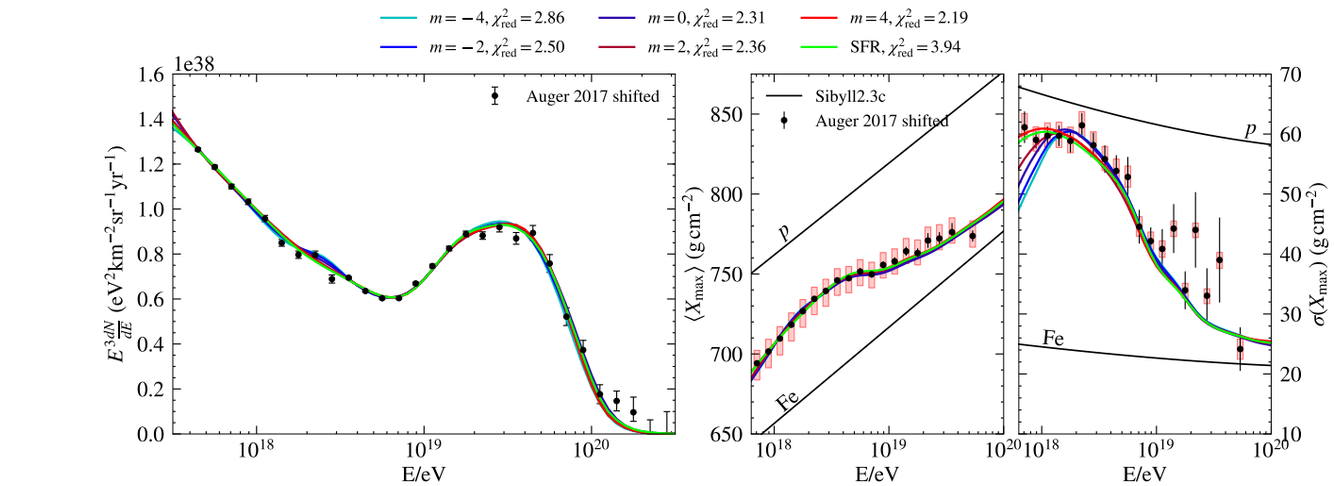


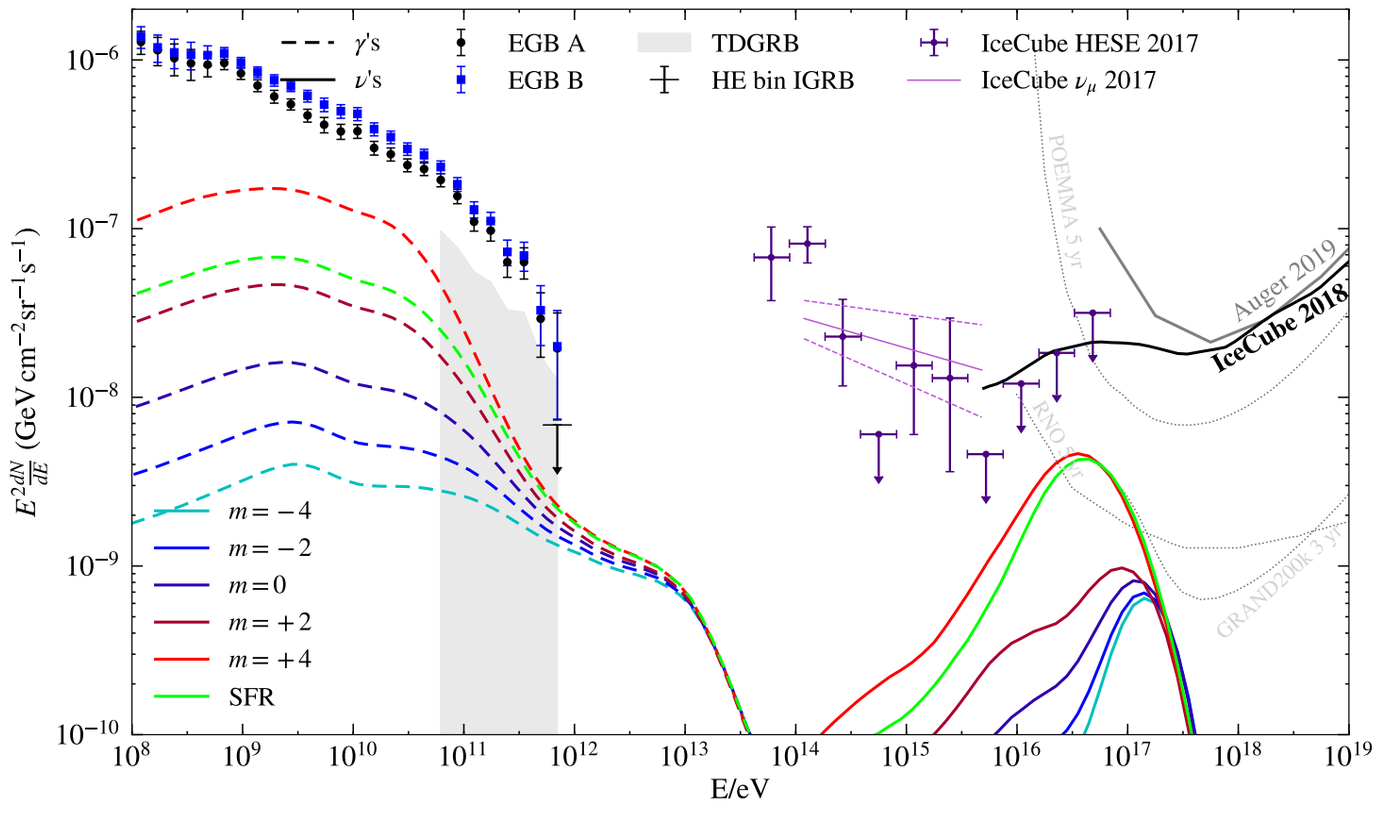
Back-up

Indication of UHECR negative source evolution?

Liu et al., PRD94, 043008 (2016)



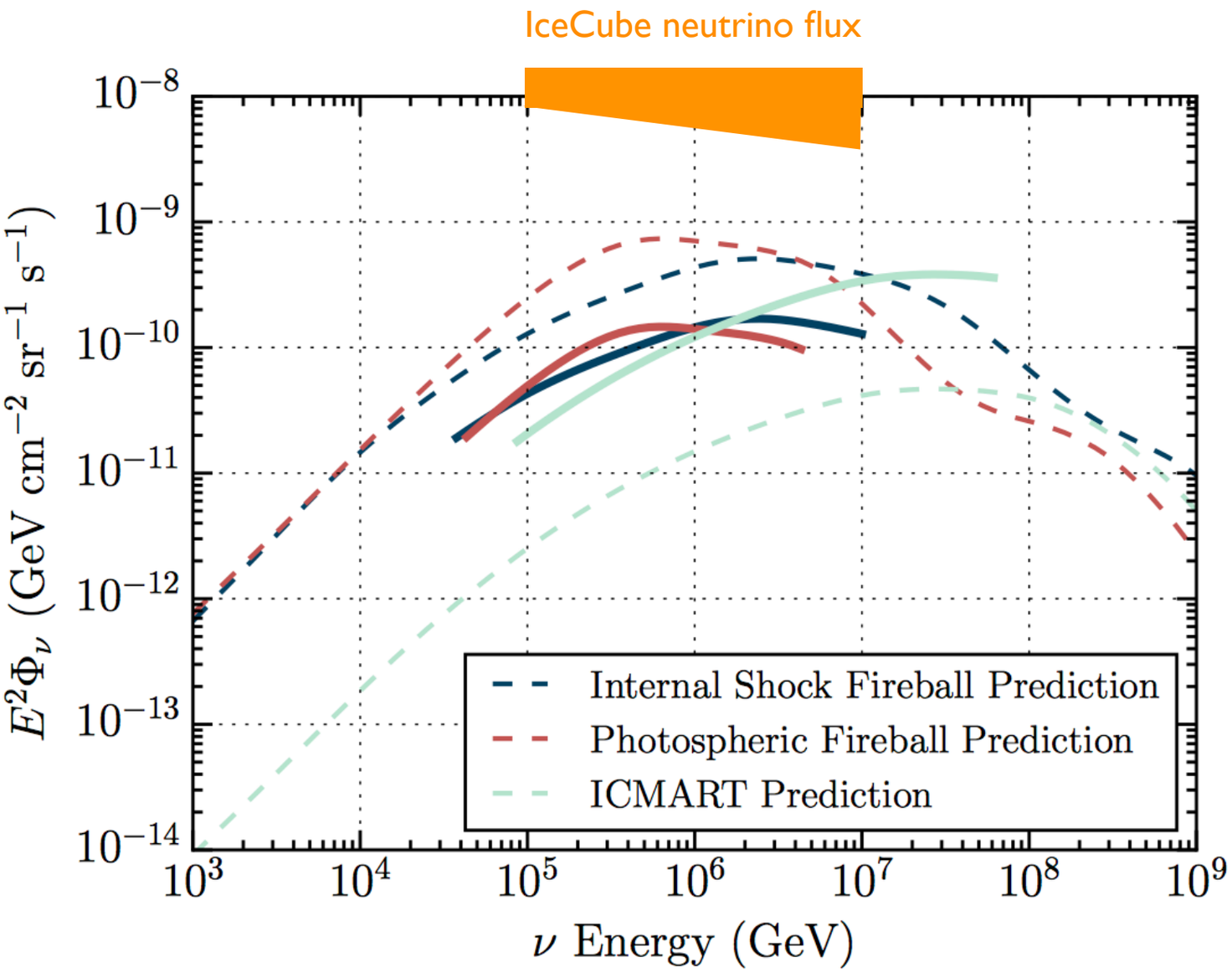


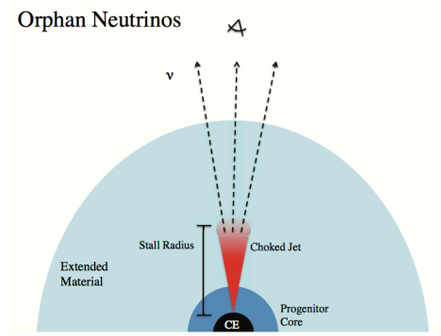


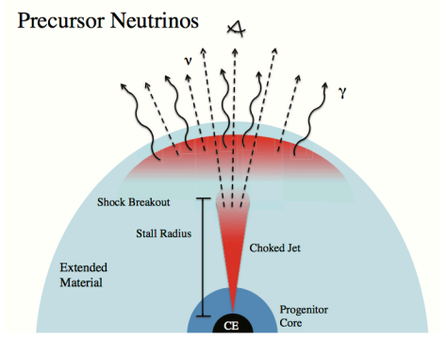
but see e.g. Supanitsky, PRD94, 063002 (2016)
Van Vliet, EpJ Web Conf. 135 (2017)

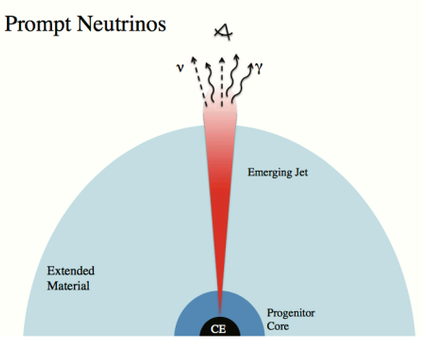
see also J. Heinze et al., ApJ 825, 122 (2016) [neutrinos]

GRB limits from IceCube







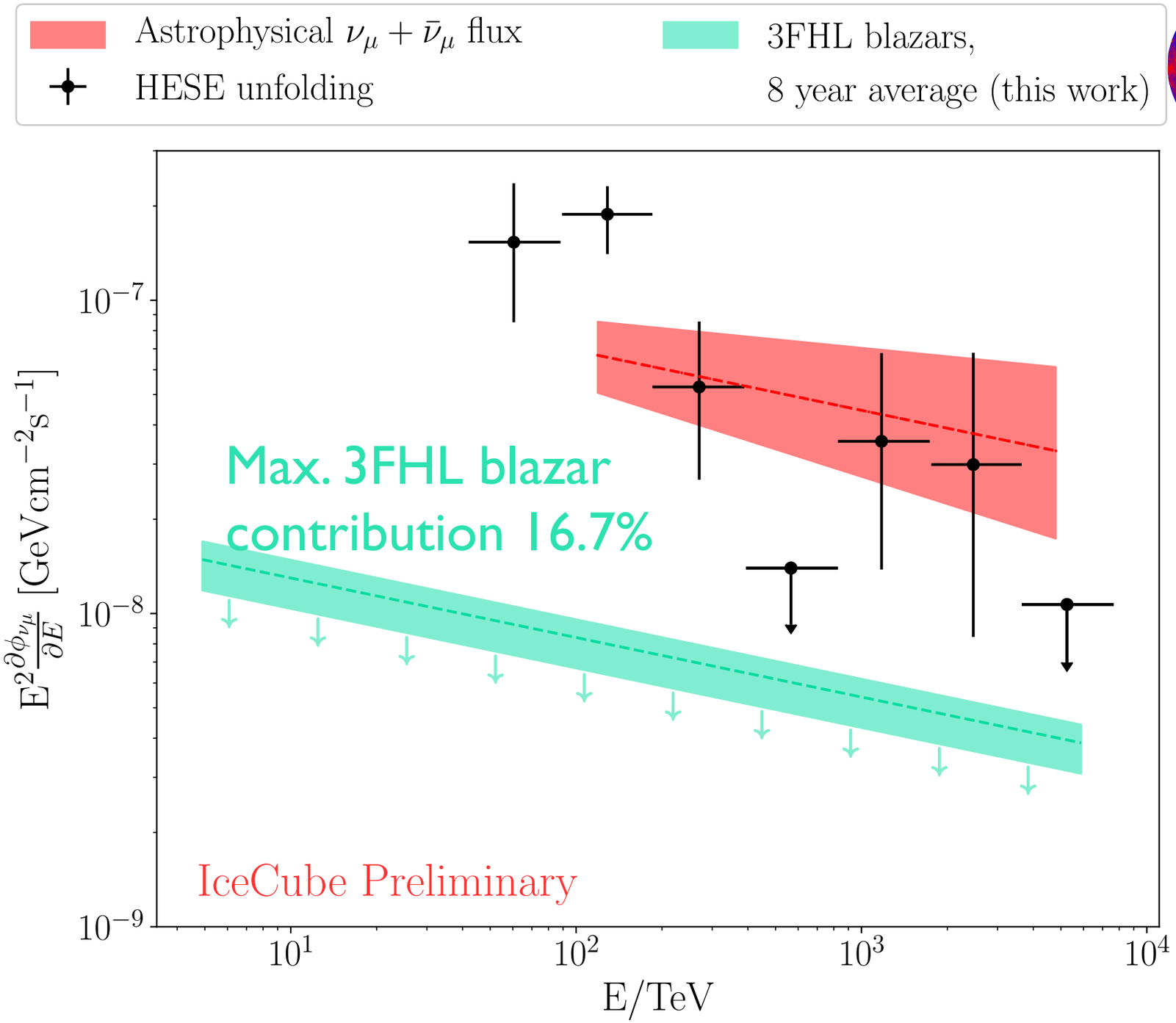


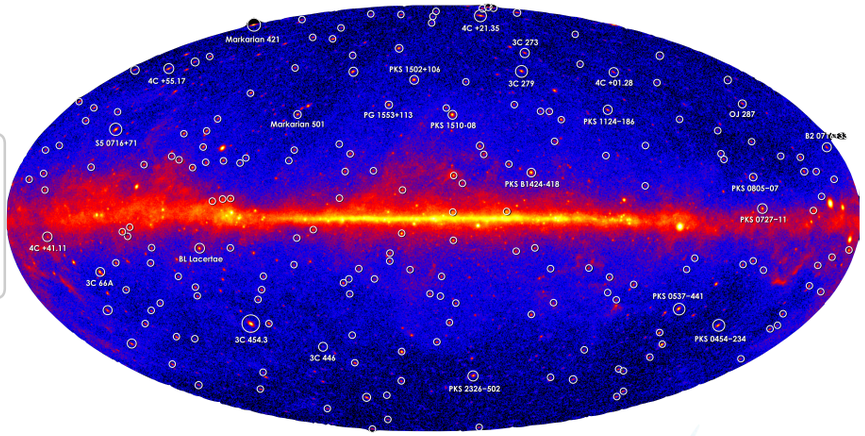
1172 GRBs
Search consistent with background only
Prompt GRBs produce < 1% of IceCube flux

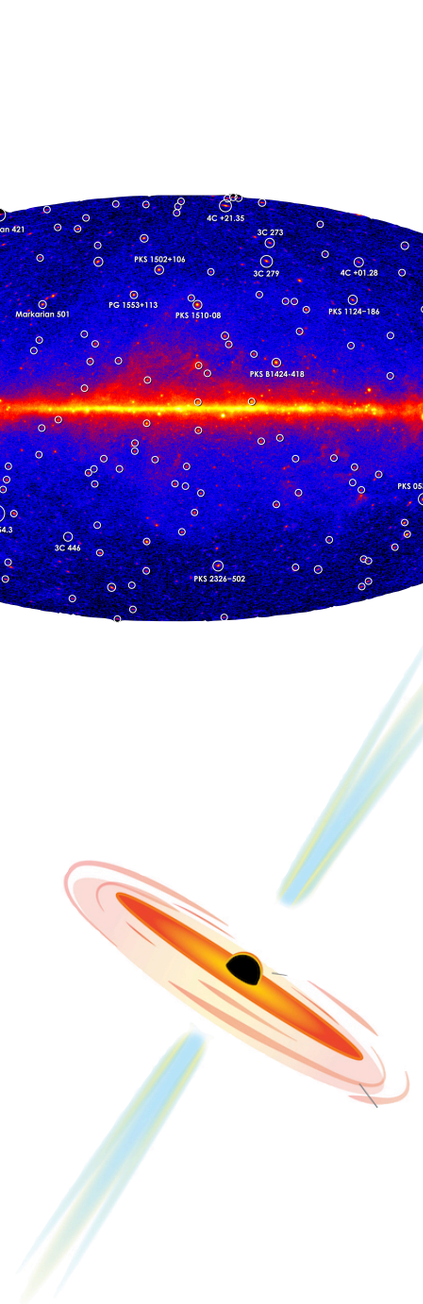
LL-GRBs, afterglow, precursors not constrained
(e.g. Senno et al, Phys.Rev. D93 (2016) no.8, 083003
Kimura et al, ApJ. 848 (2017) no.1, L4

Blazar limits from IceCube

IceCube Coll PoS (ICRC 2019) 916





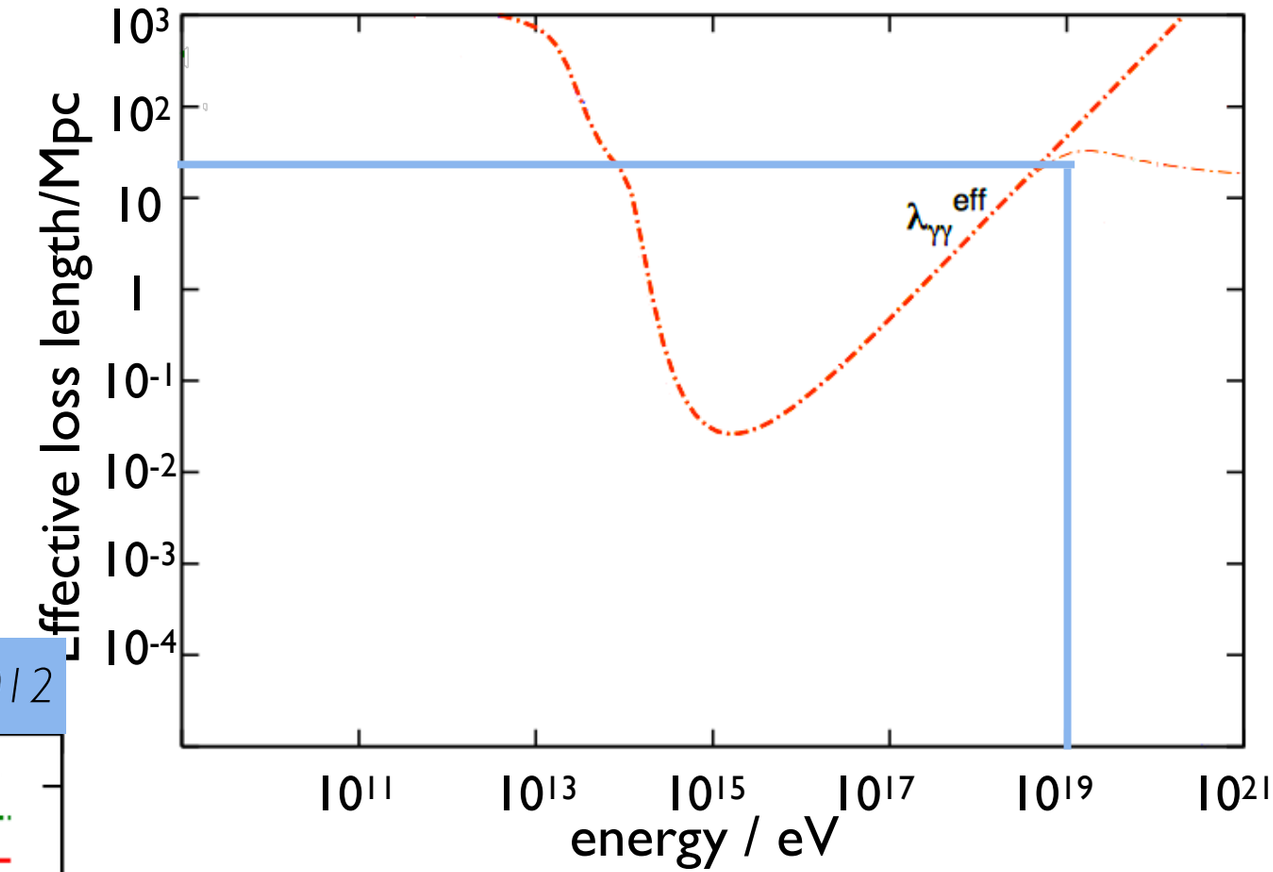


UHE Photons

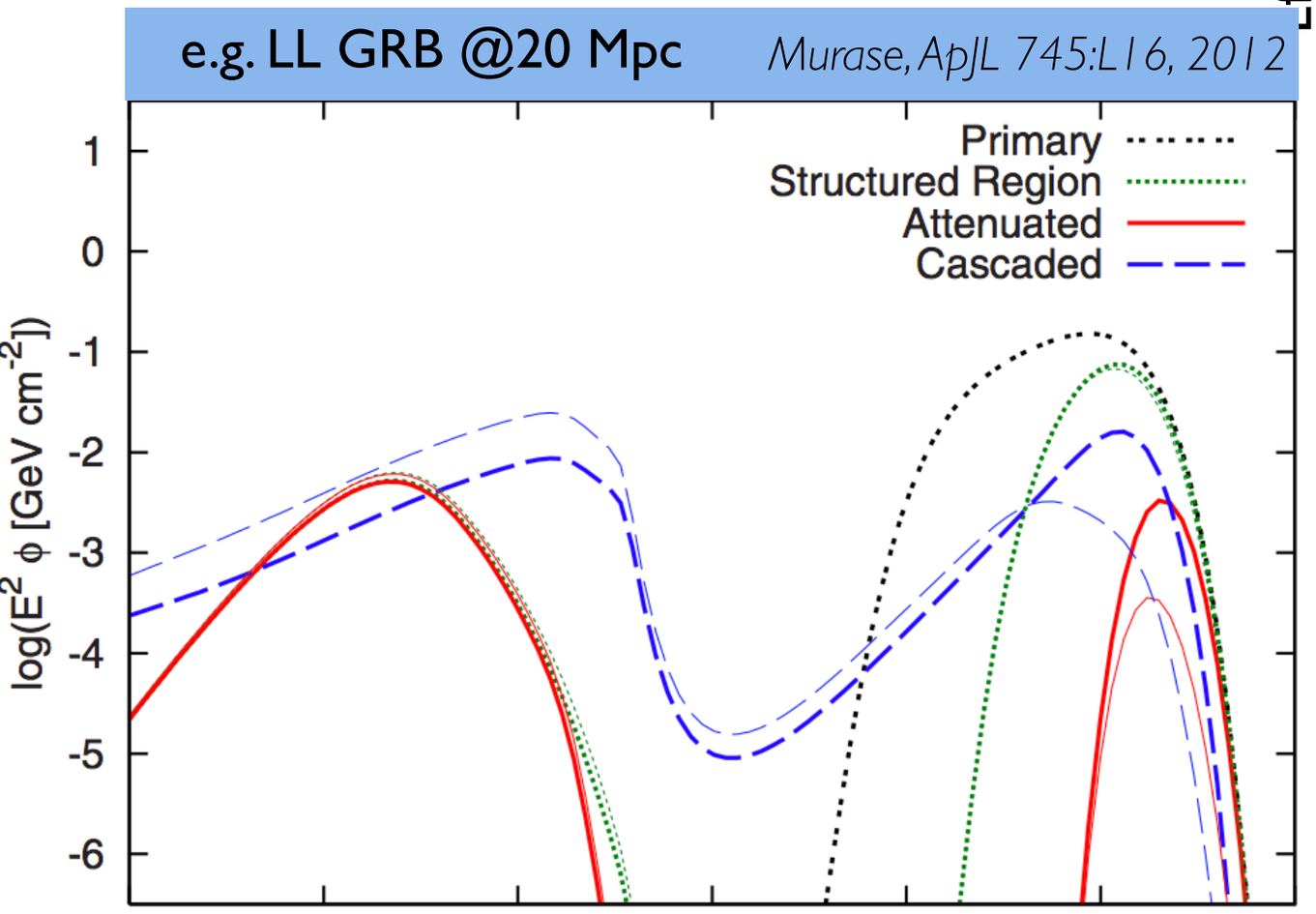
$\gamma \longrightarrow e \longrightarrow \gamma \ldots$ (Stecker 73, Gould&Rephaeli 78)

Effective photon loss length @10^{20}eV~10-100 Mpc

Murase, ApJL 745:L16, 2012



e.g. LL GRB @20 Mpc *Murase, ApJL 745:L16, 2012*

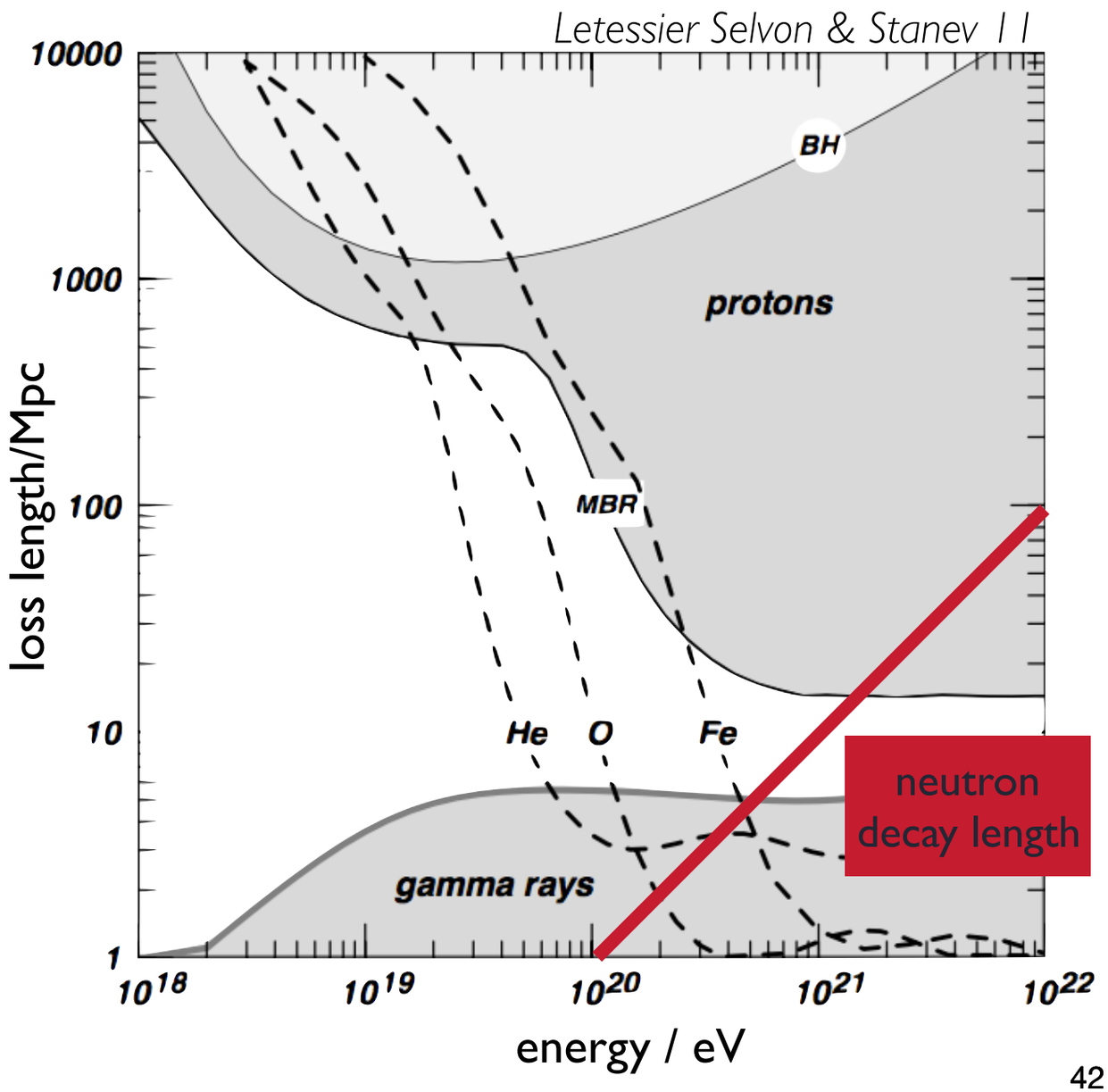


UHE Neutrons

Can they reach us?

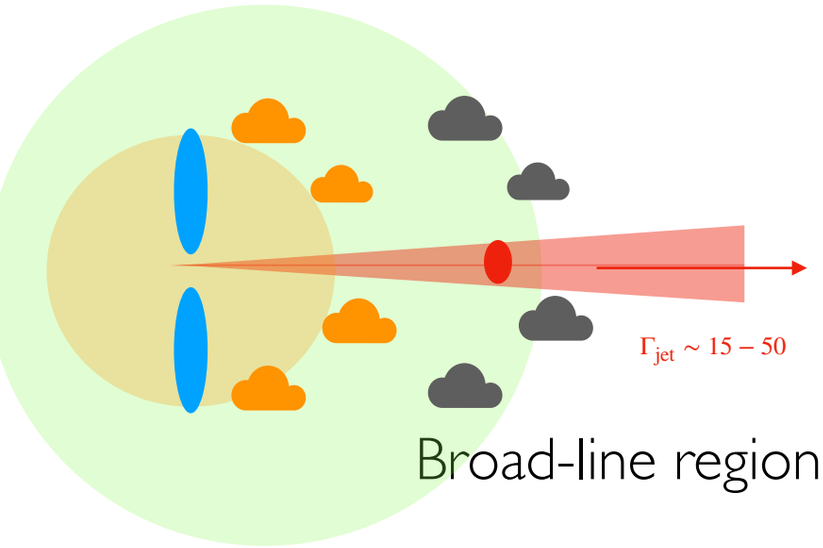
$L_n \sim c \cdot \tau_n \cdot \gamma_n \sim 9\ (E_n/1\ \mathrm{EeV})$ kpc

[c.f. Milky Way radius ~ 8 kpc]

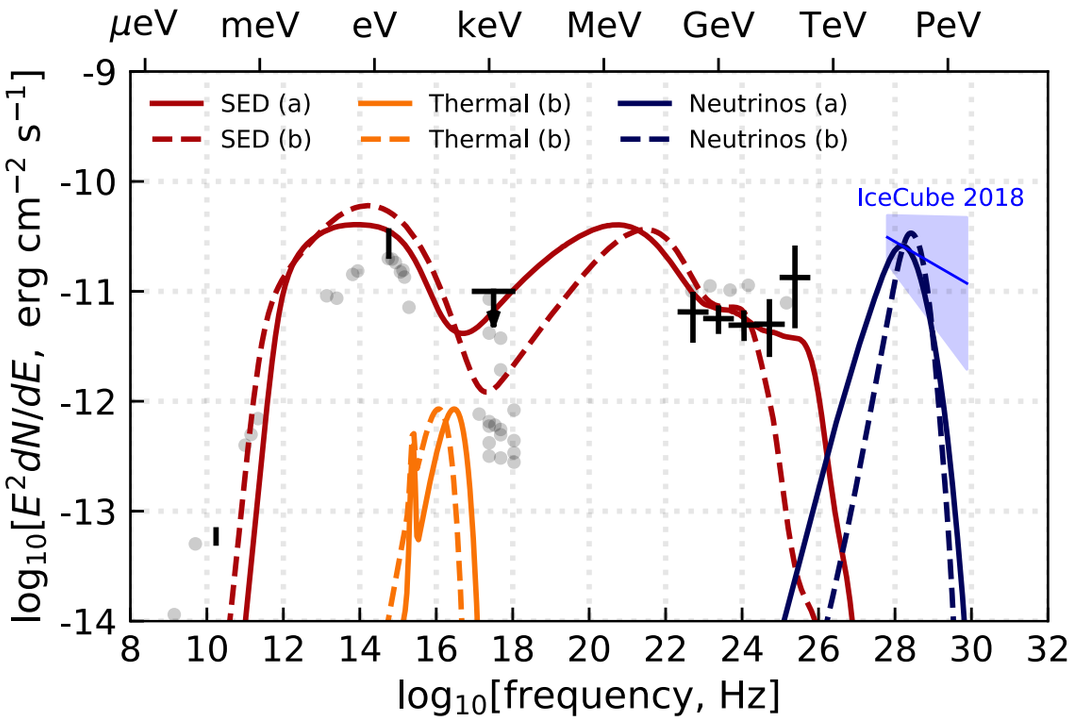


Neutrino production in TXS 0506+056 in 2014-15

Rodrigues, Gao, Fedynitch, Palladino, Winter ApjL 2019,
Reimer, Böttcher, Buson ApJ 2019

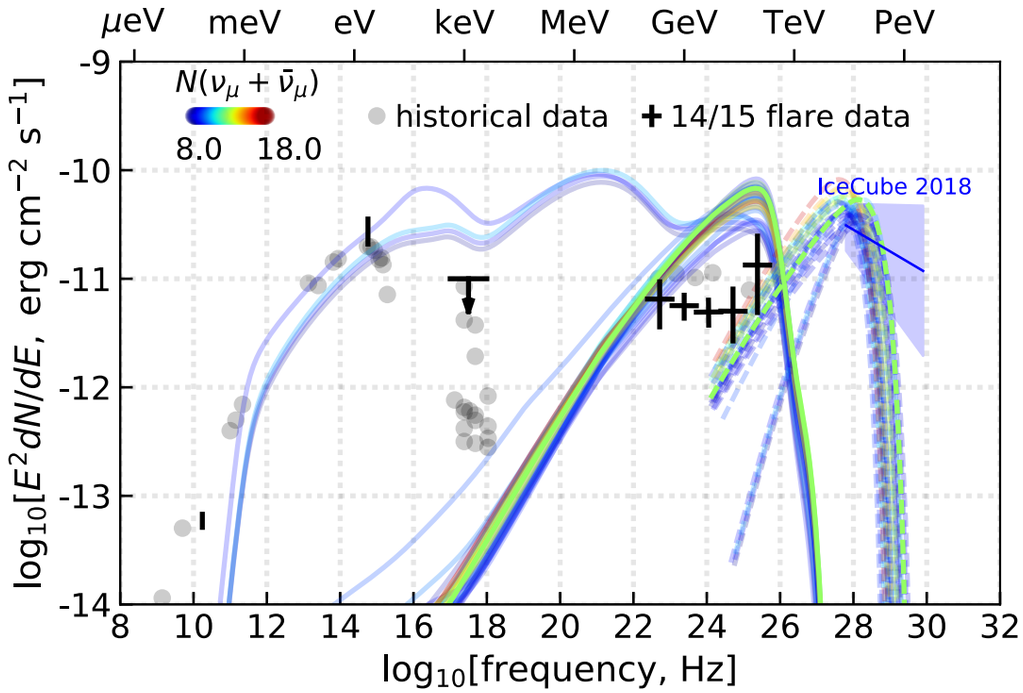


Broad-line region model



$N_{\nu_\mu} \leq 4.9$

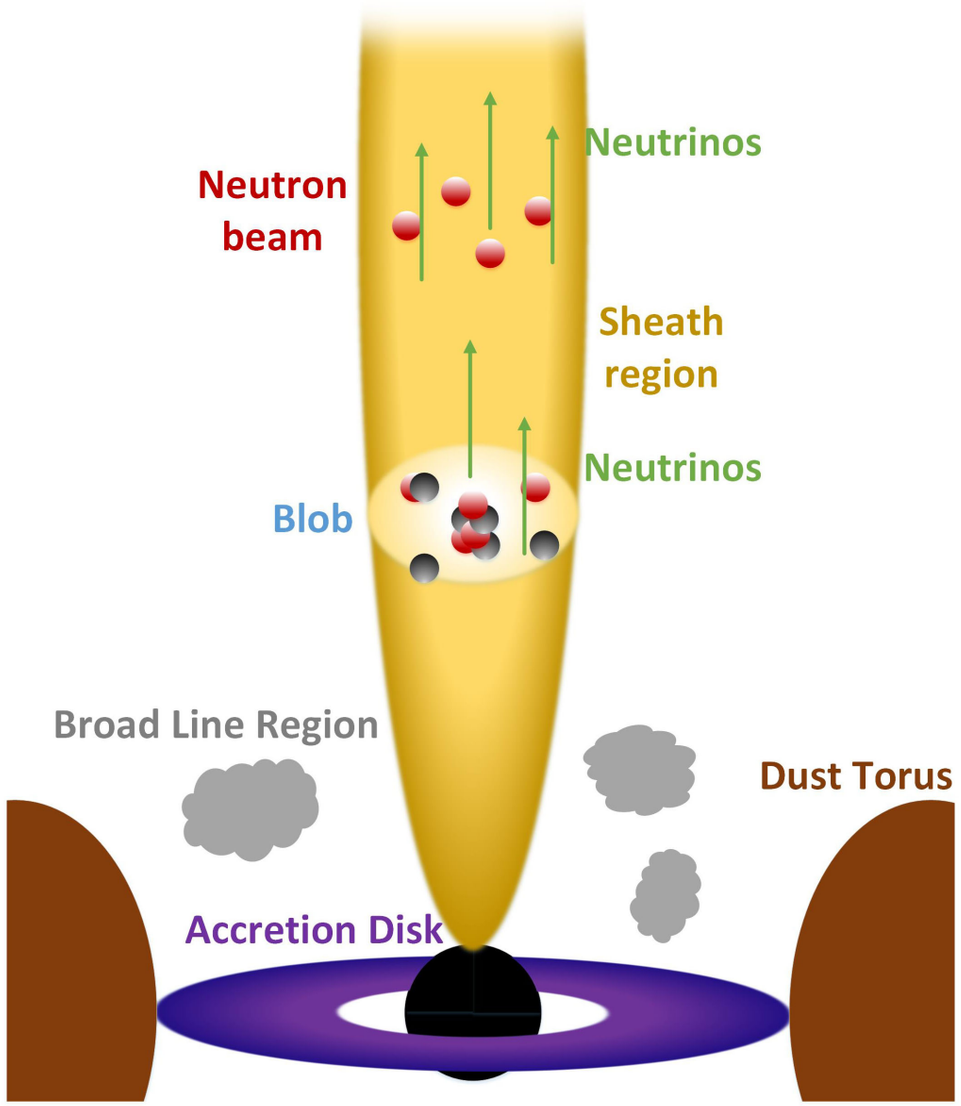
Overshoots SED

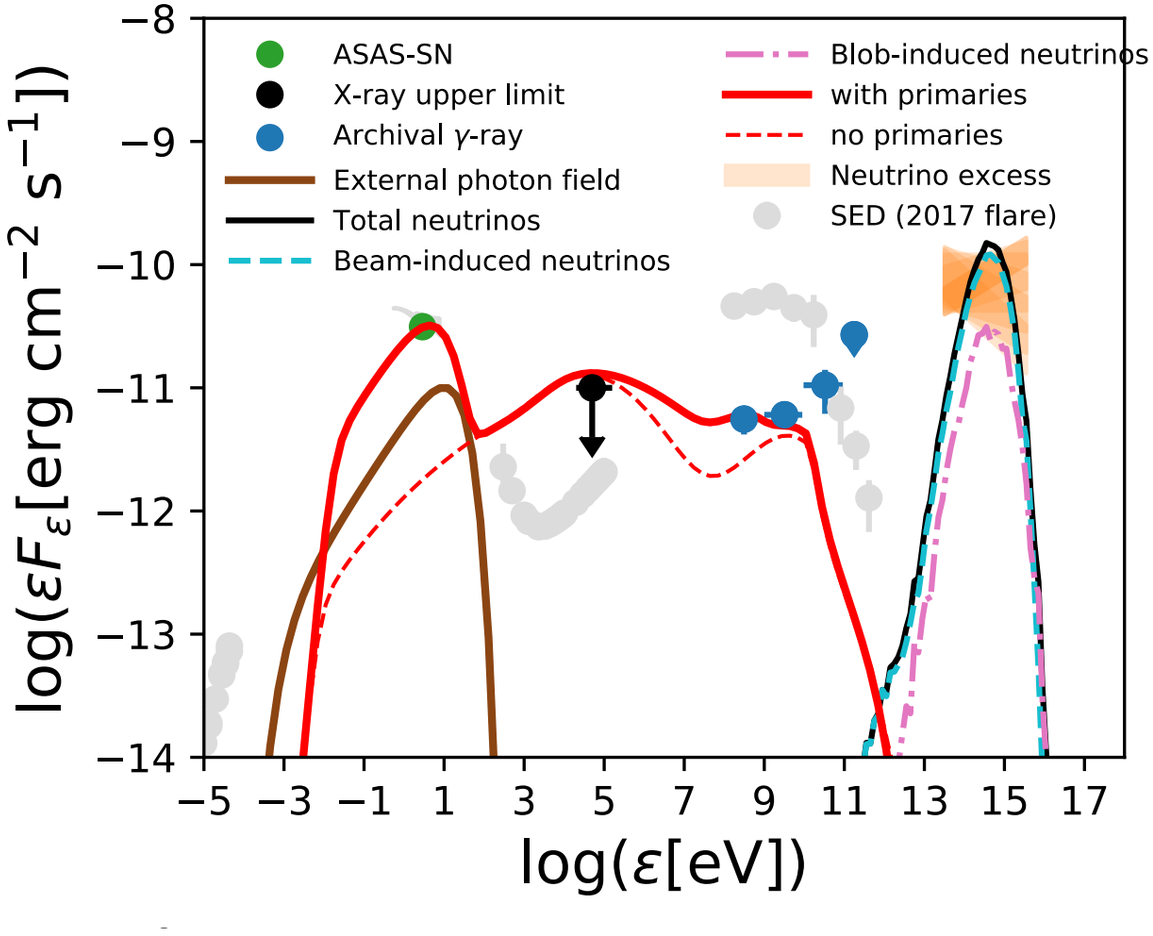


$N_{\nu_\mu} = 13.2$

Neutrino production in TXS 0506+056 in the neutral beam model

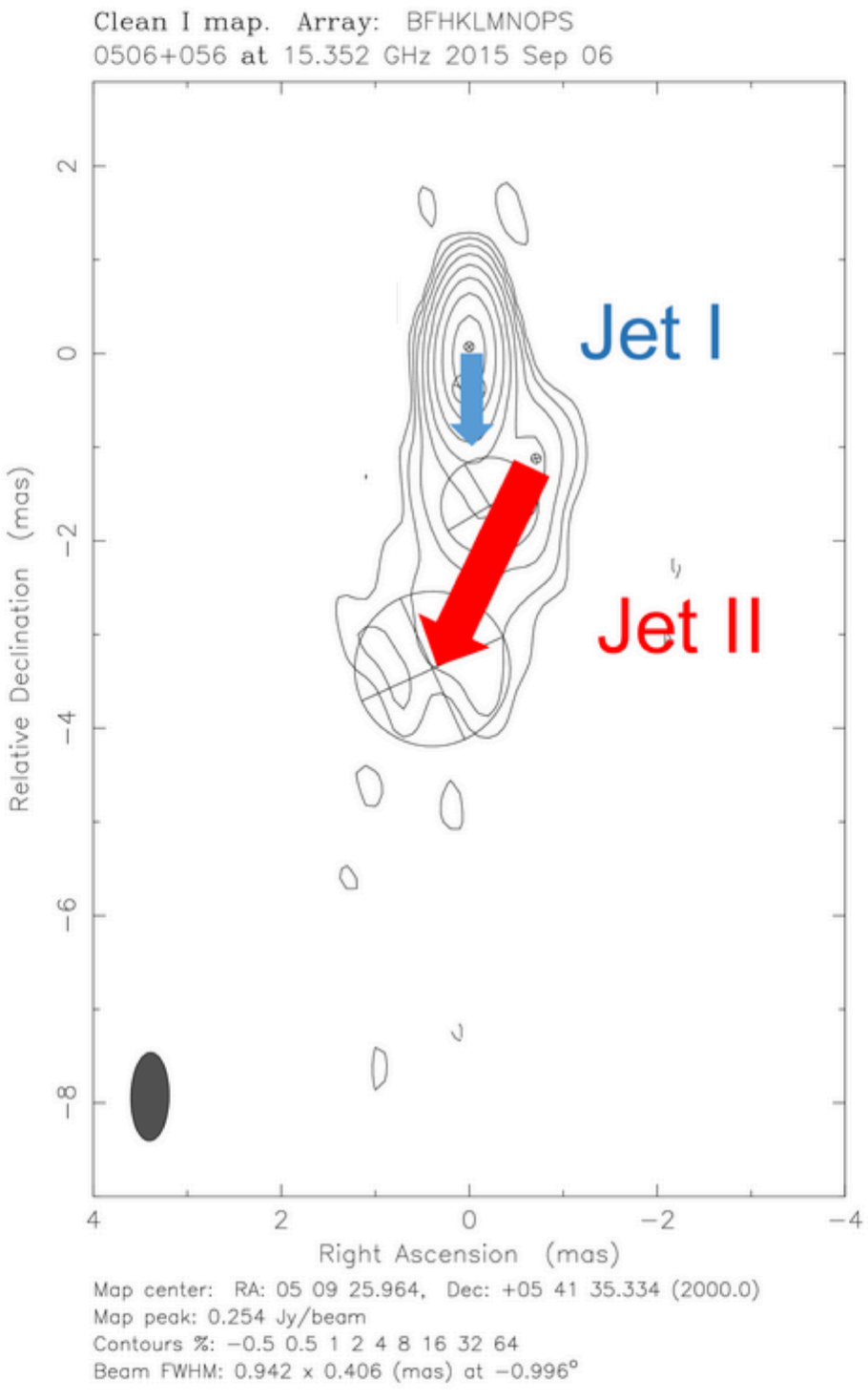
Zhang, Petropoulou, Murase, FO, arXiv:1910.11464



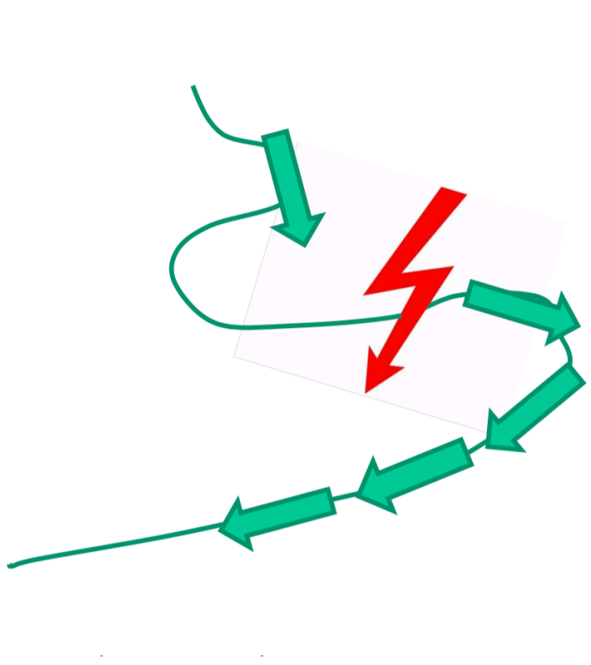


Is TXS 0506+056 a normal blazar?

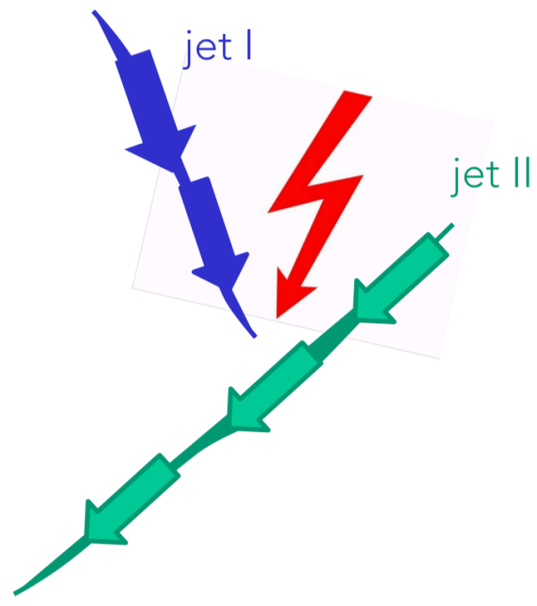
Britzen, Fendt, Böttcher et al, A&A, 2019



Possible models of jet collision



Strongly curved jet



Jet-jet collision