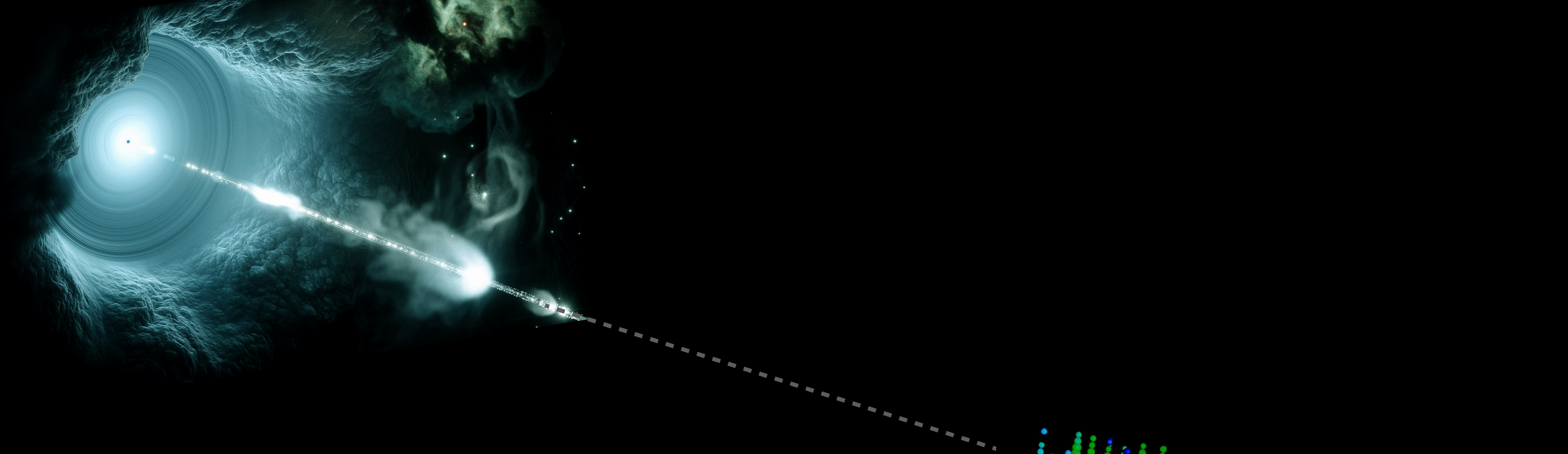
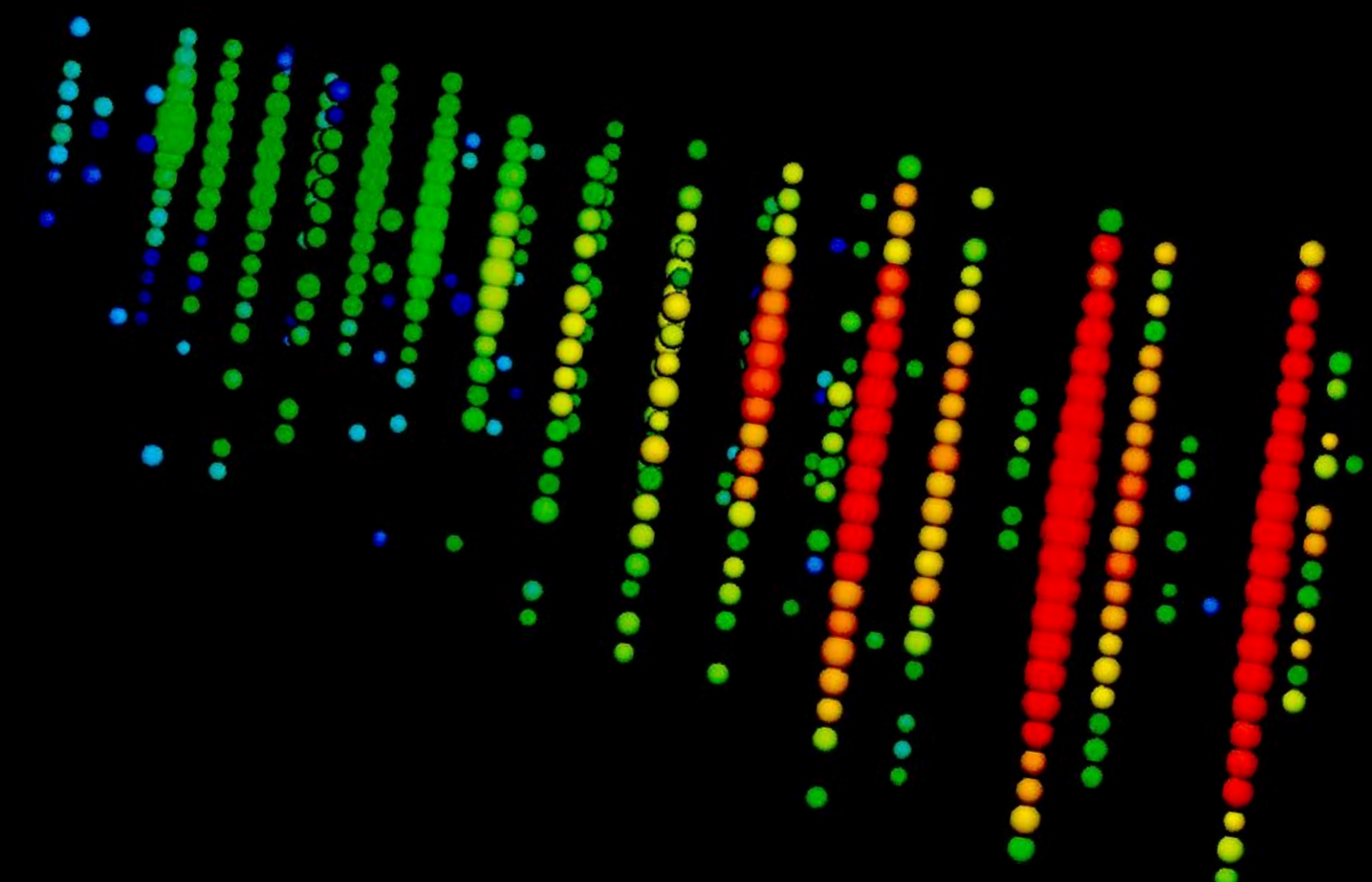




Multimessenger Astroparticle Physics

ISCRA Erice 2026



Foteini Oikonomou

 NTNU

Norwegian University of
Science and Technology

Plan

Thursday: generic source properties

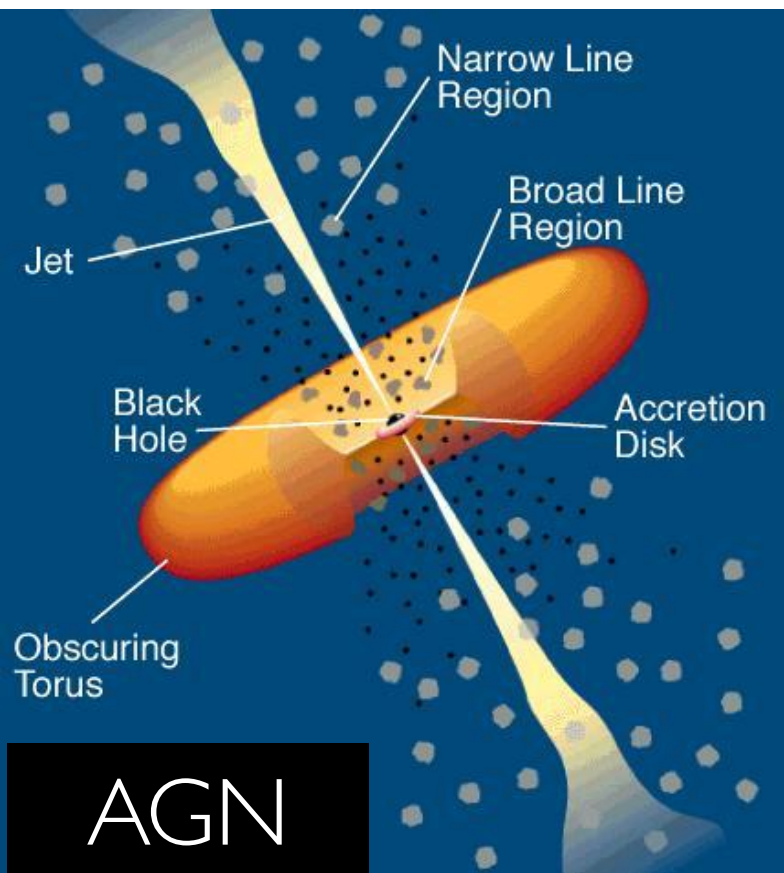
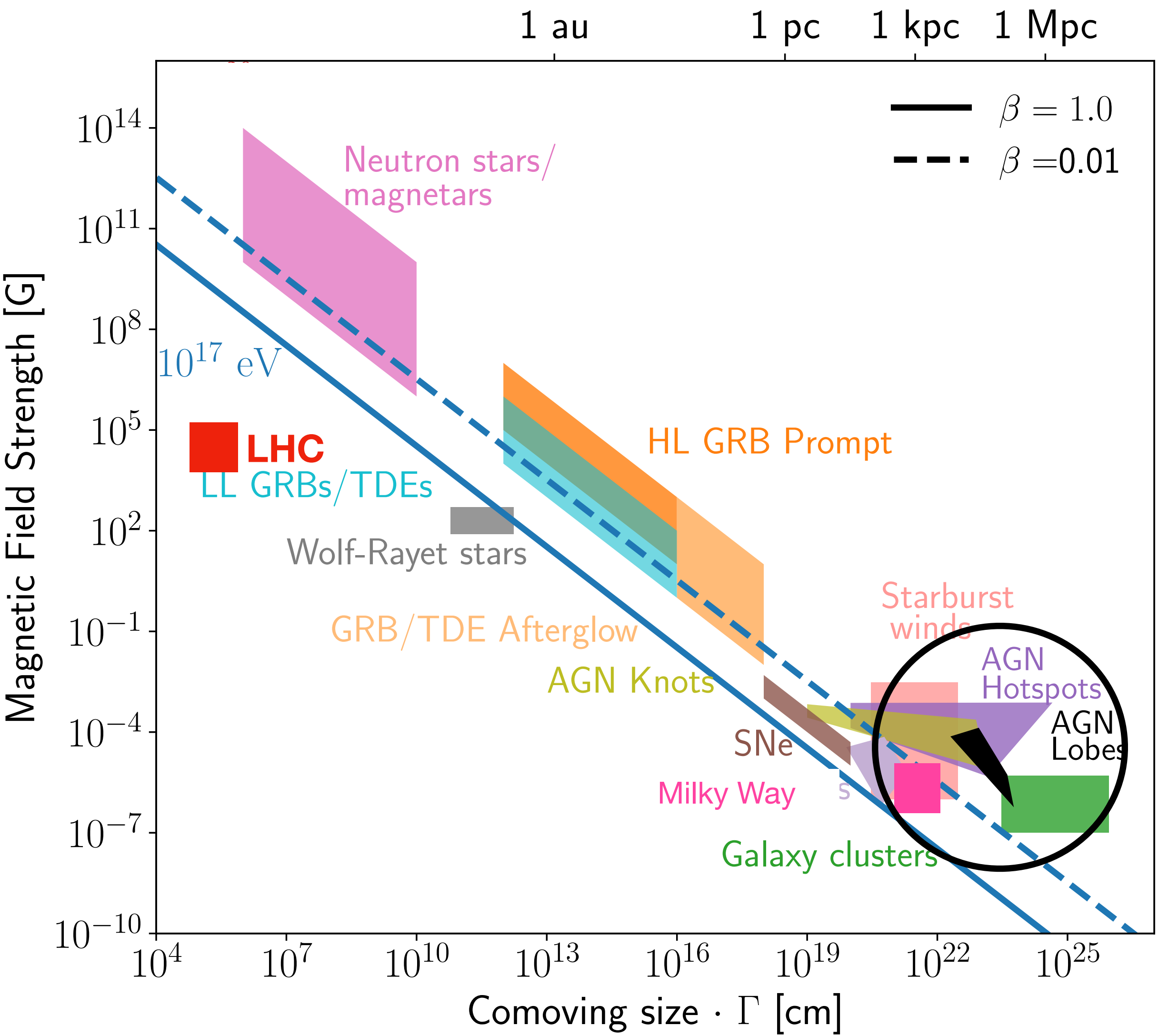
Friday: jetted active galactic nuclei

Today: starburst galaxies, gamma-ray bursts, tidal-disruption events

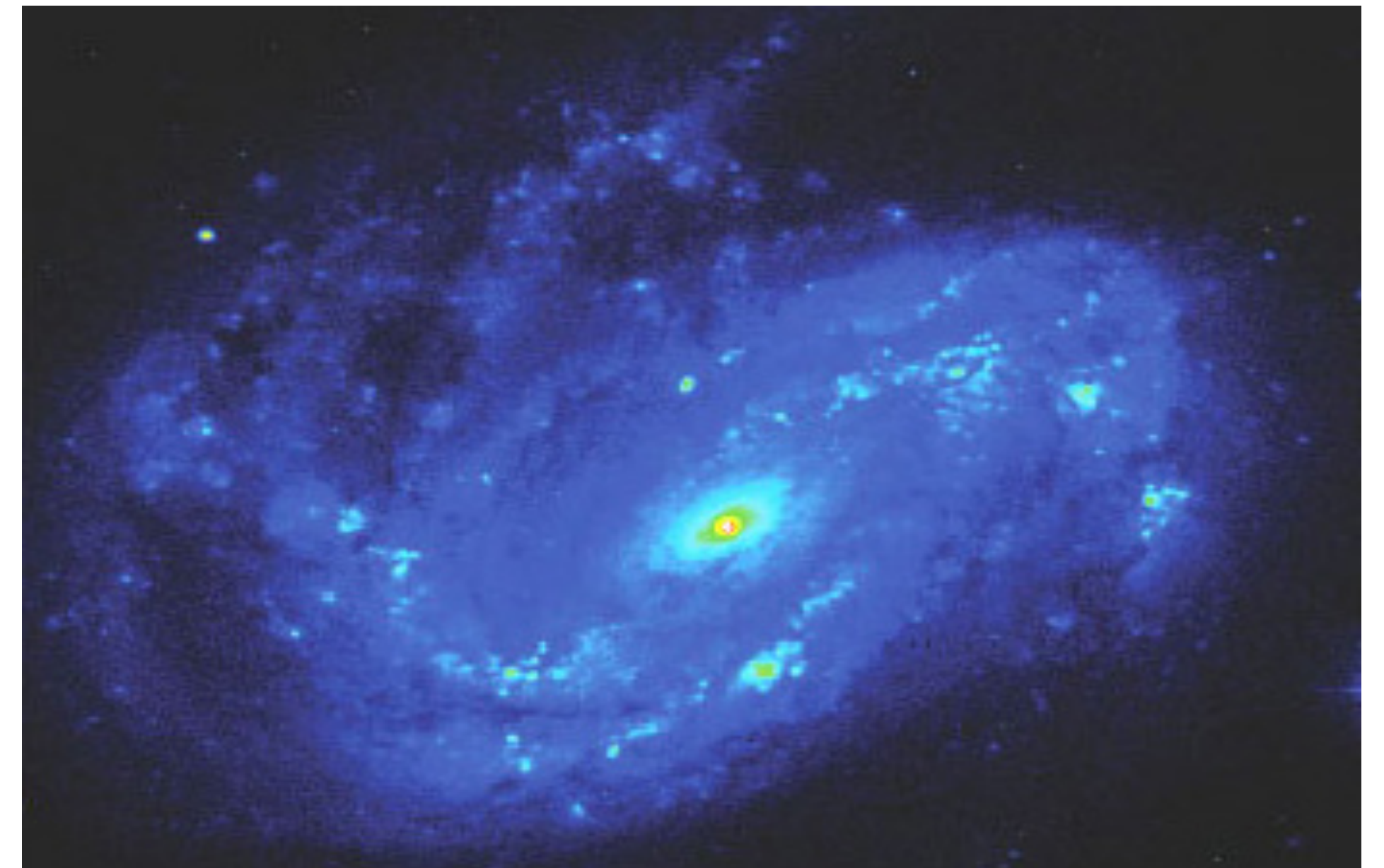
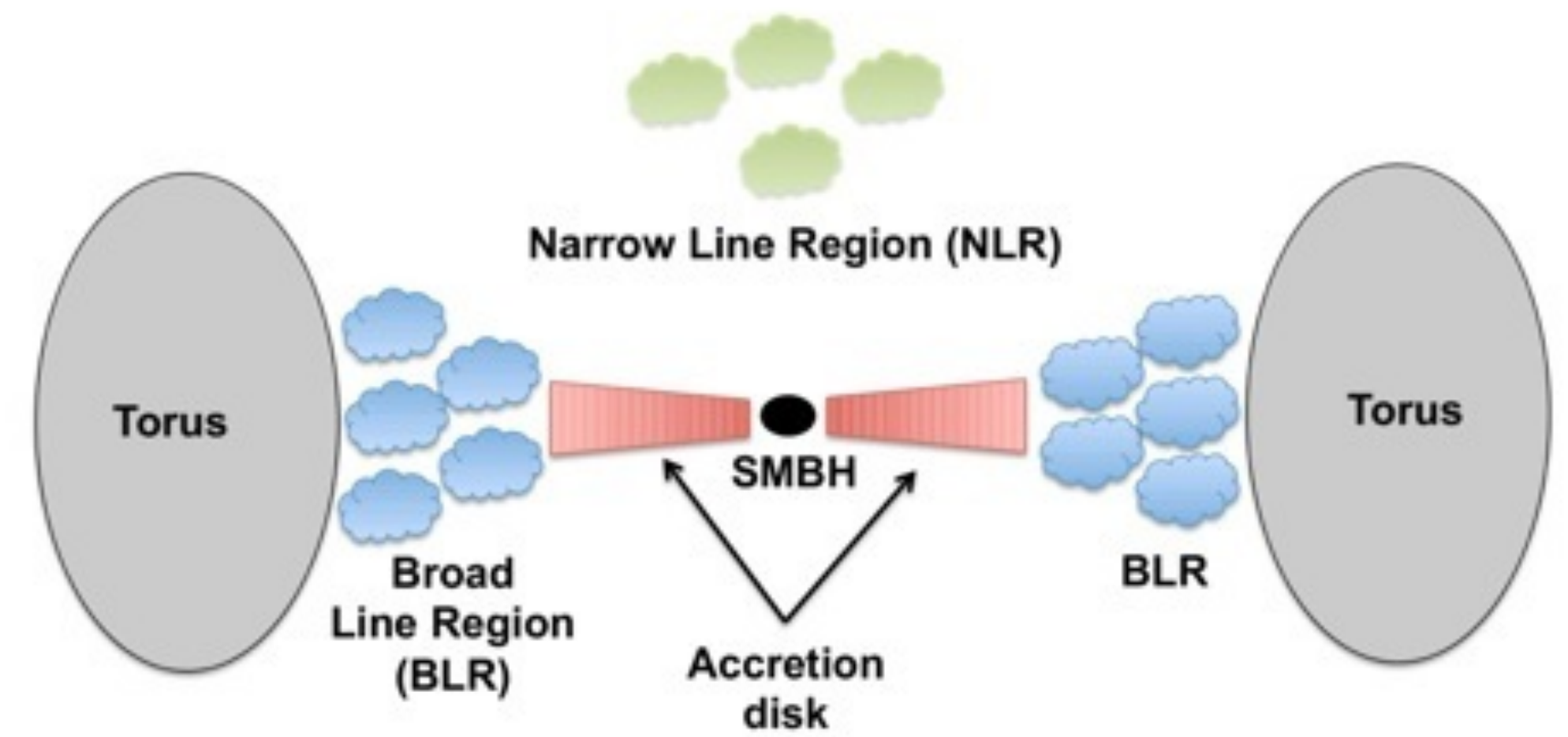
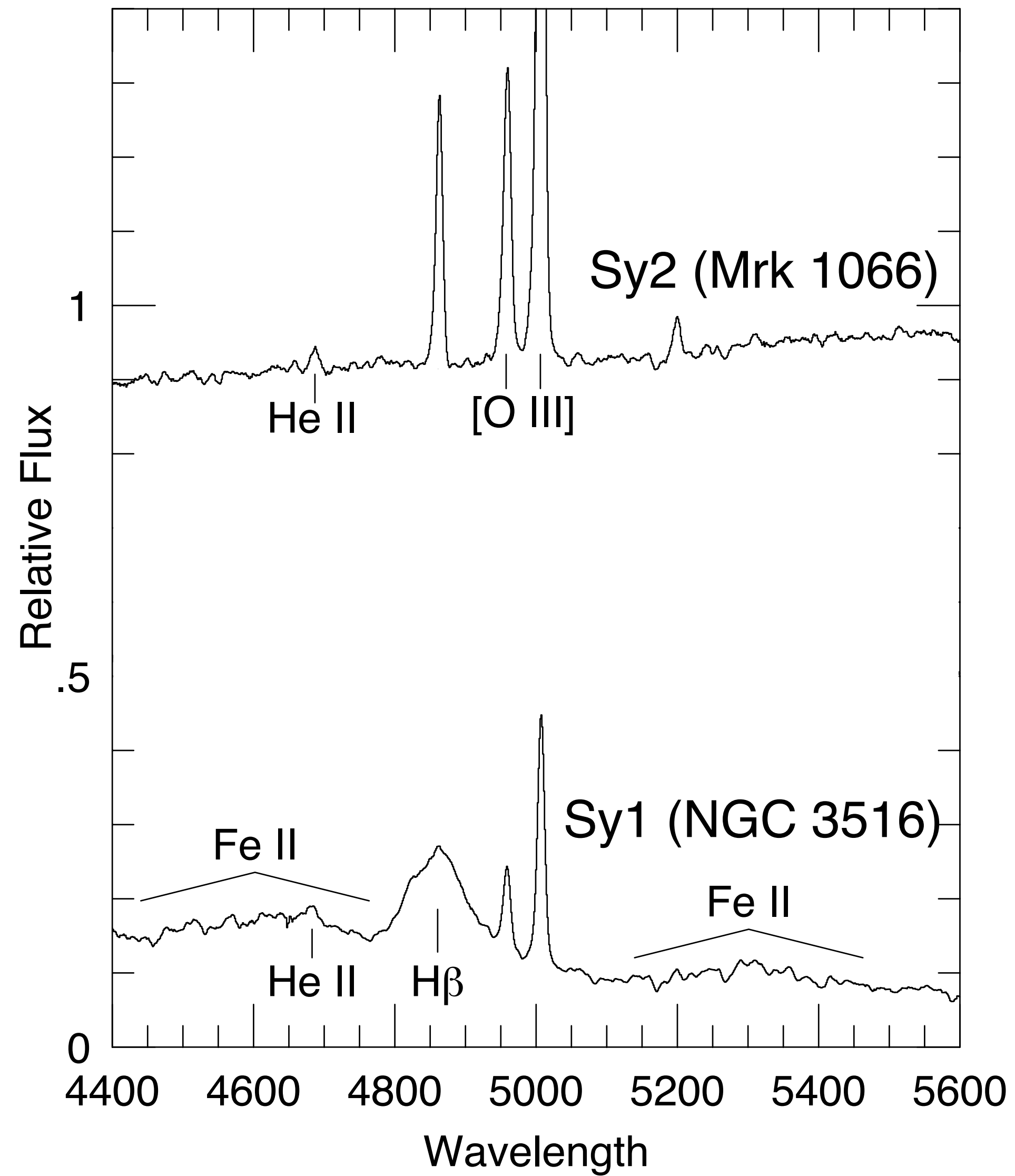
Scorecard

	$E_{\text{max}}^{\text{UHECR}}$	n_{UHECR}	$\dot{\epsilon}_{\text{UHECR}}$	n_{ν}	Stacking UL
BL Lacs	😊	😞	😊	😞	~20%
FSRQs	😊	😞	😊	😞	~20%
FR I	😊	😊	😊	😊	~20%
FR II	😊	😊	😊	😊	~20%
Non-jetted AGN					
Starburst galaxies					
HL GRBs					
LL GRBs					
TDEs					

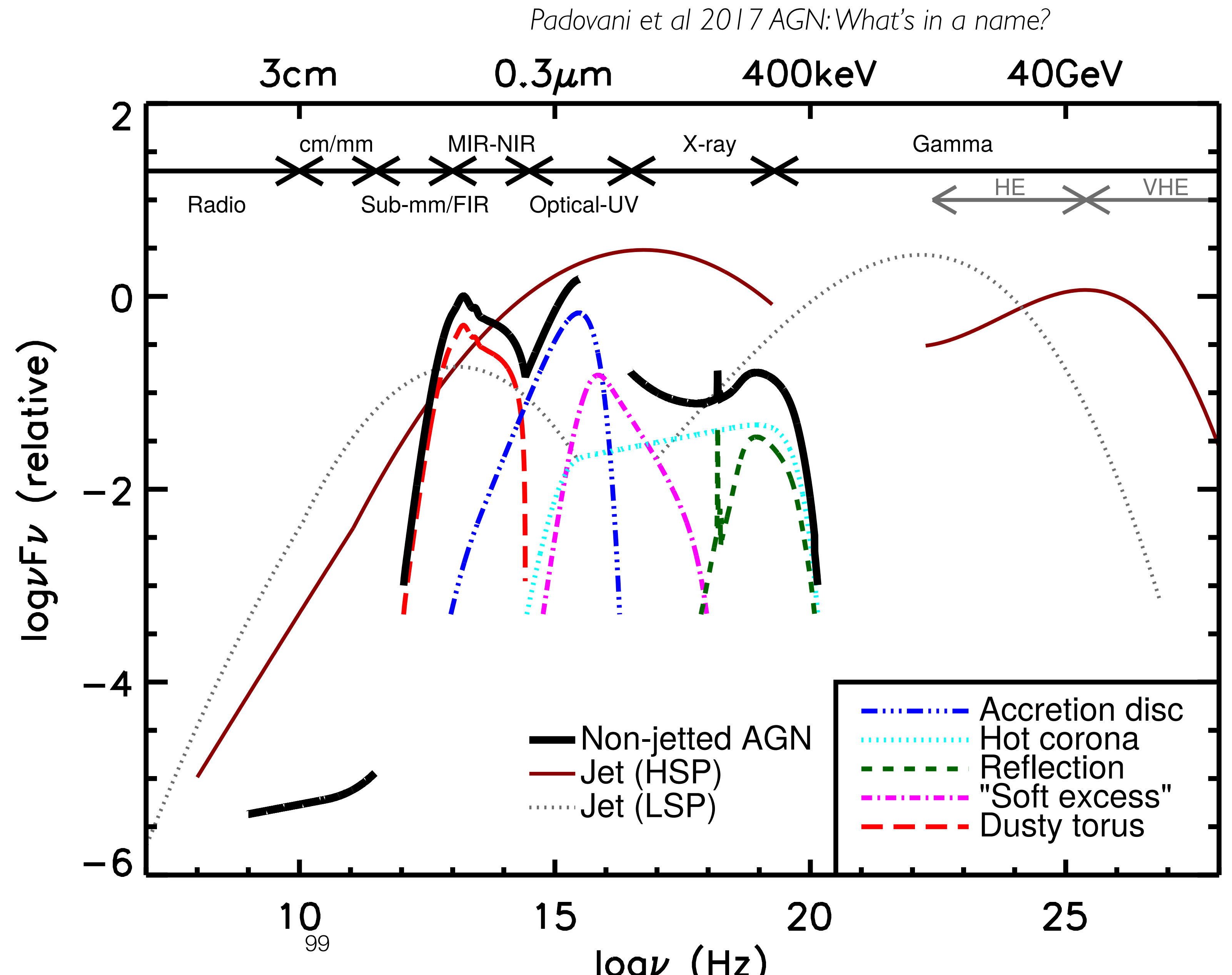
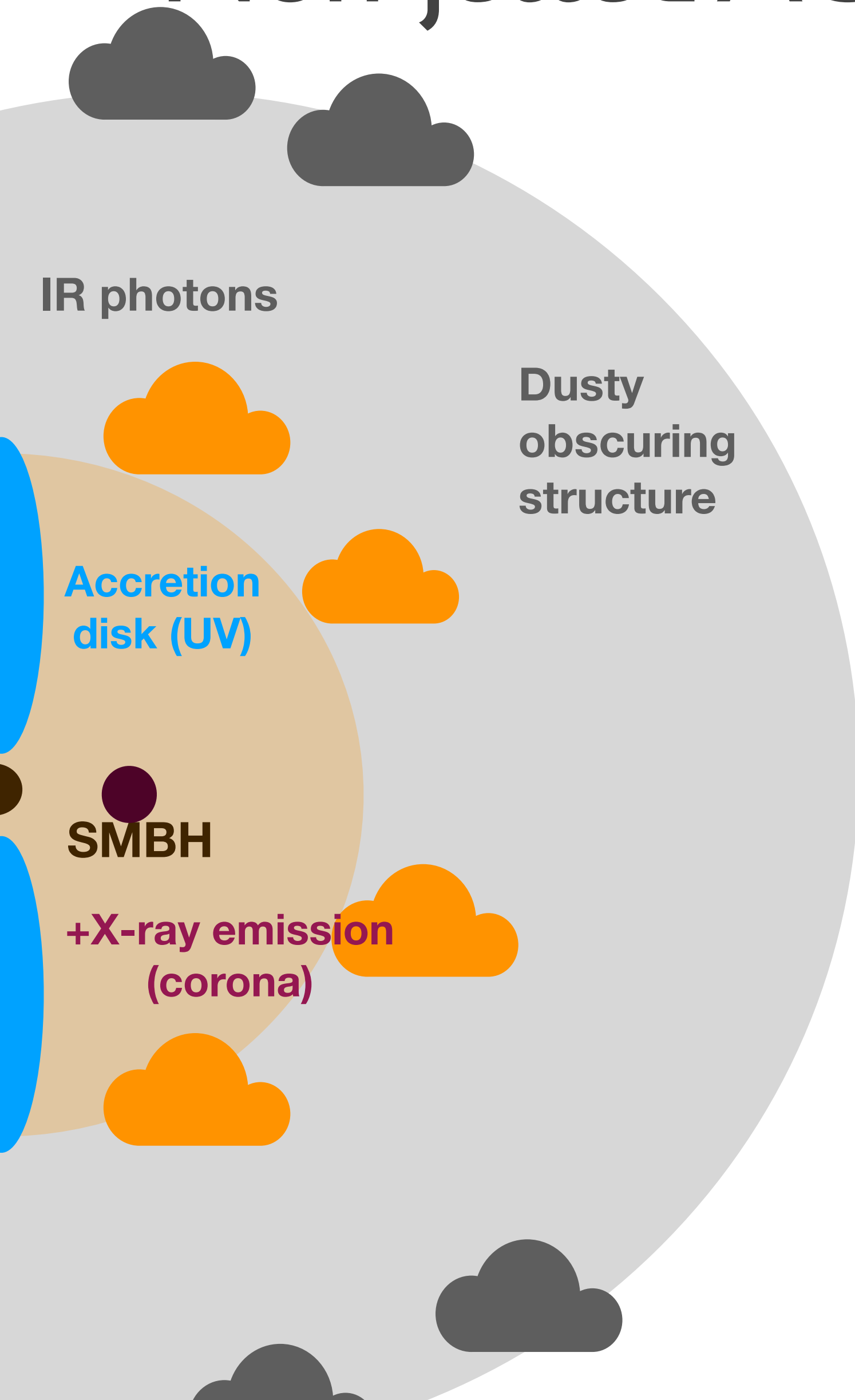
Cosmic-ray accelerators that satisfy the confinement



Non-jetted AGN

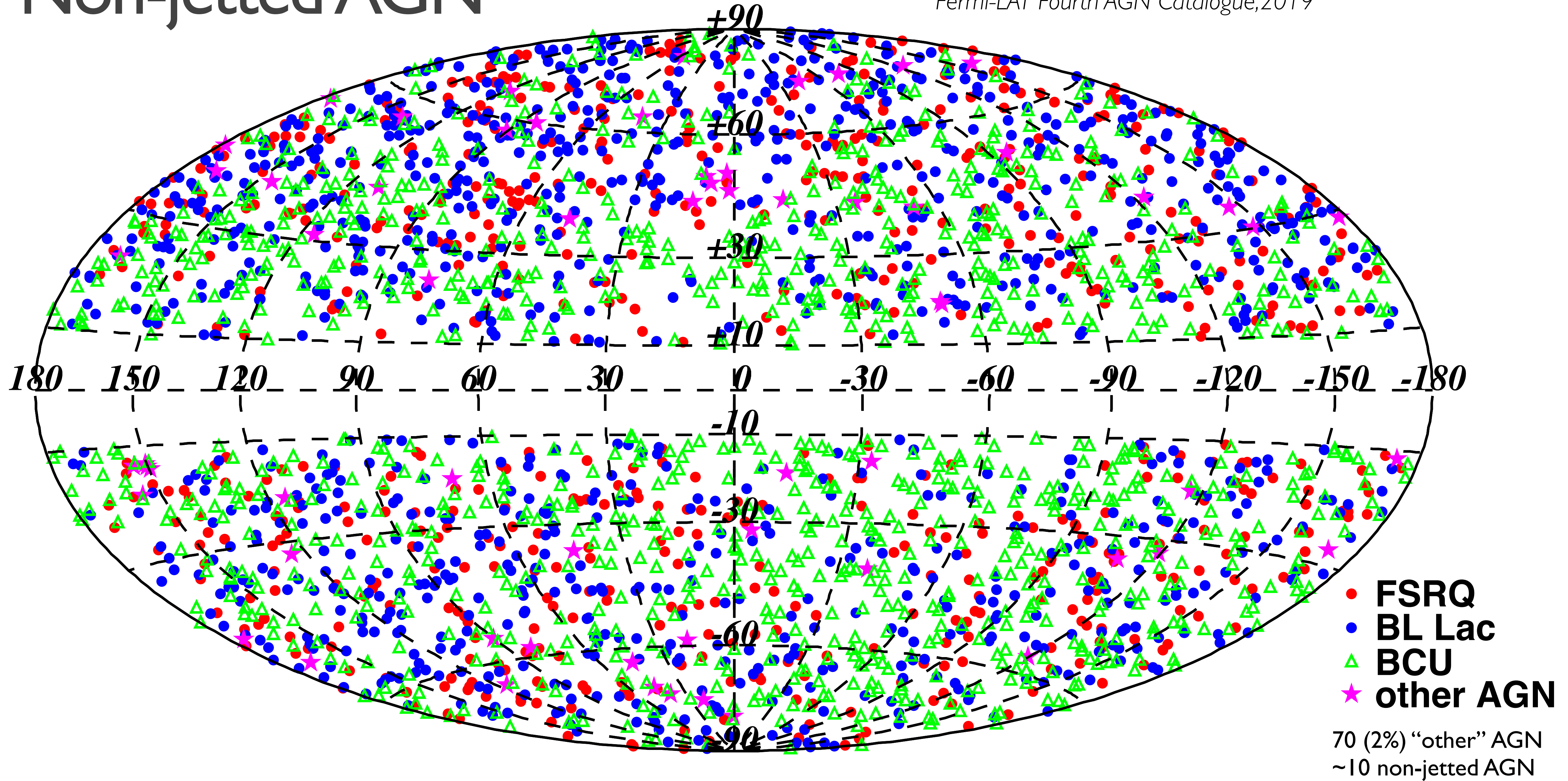


Non-jetted AGN



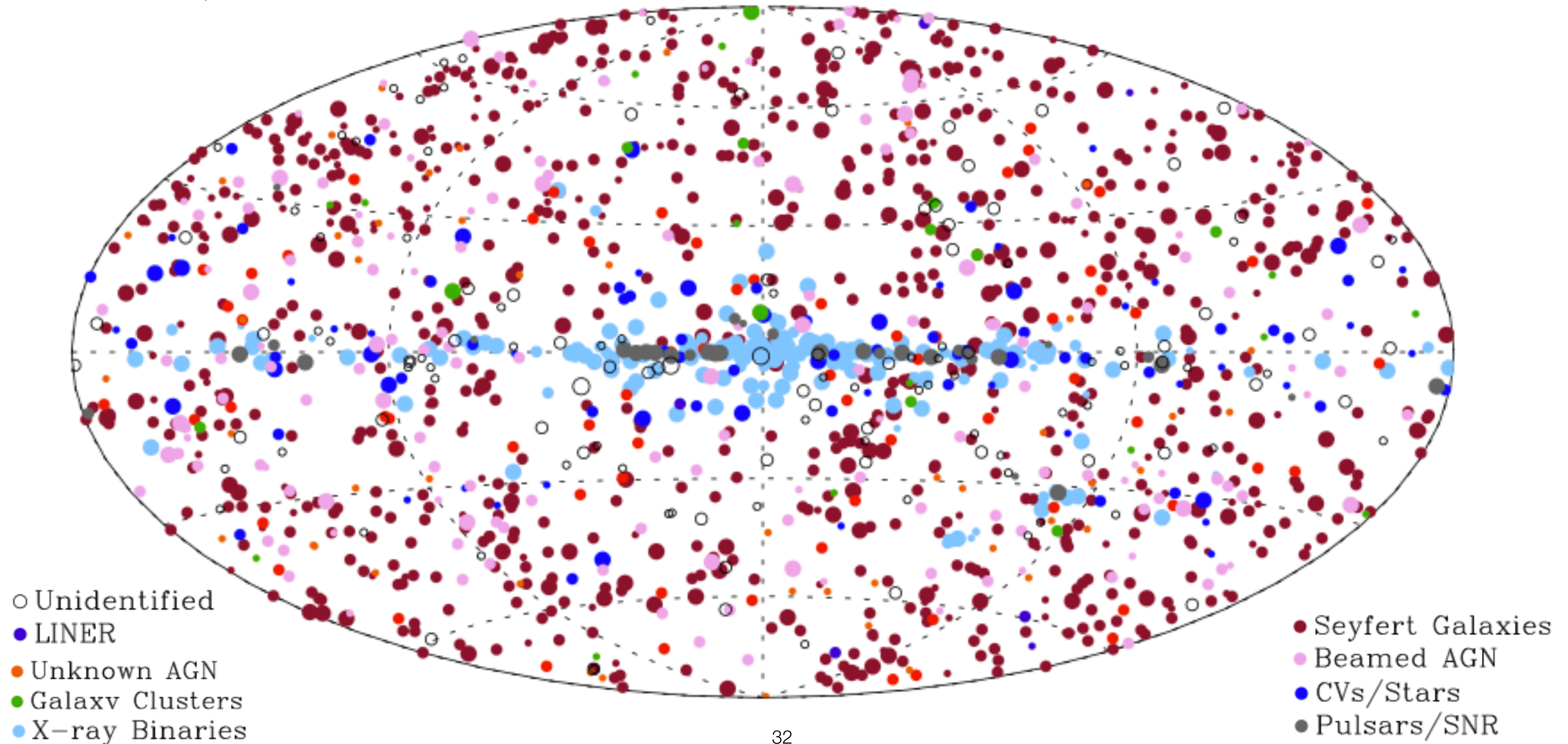
Non-jetted AGN

Fermi-LAT Fourth AGN Catalogue, 2019

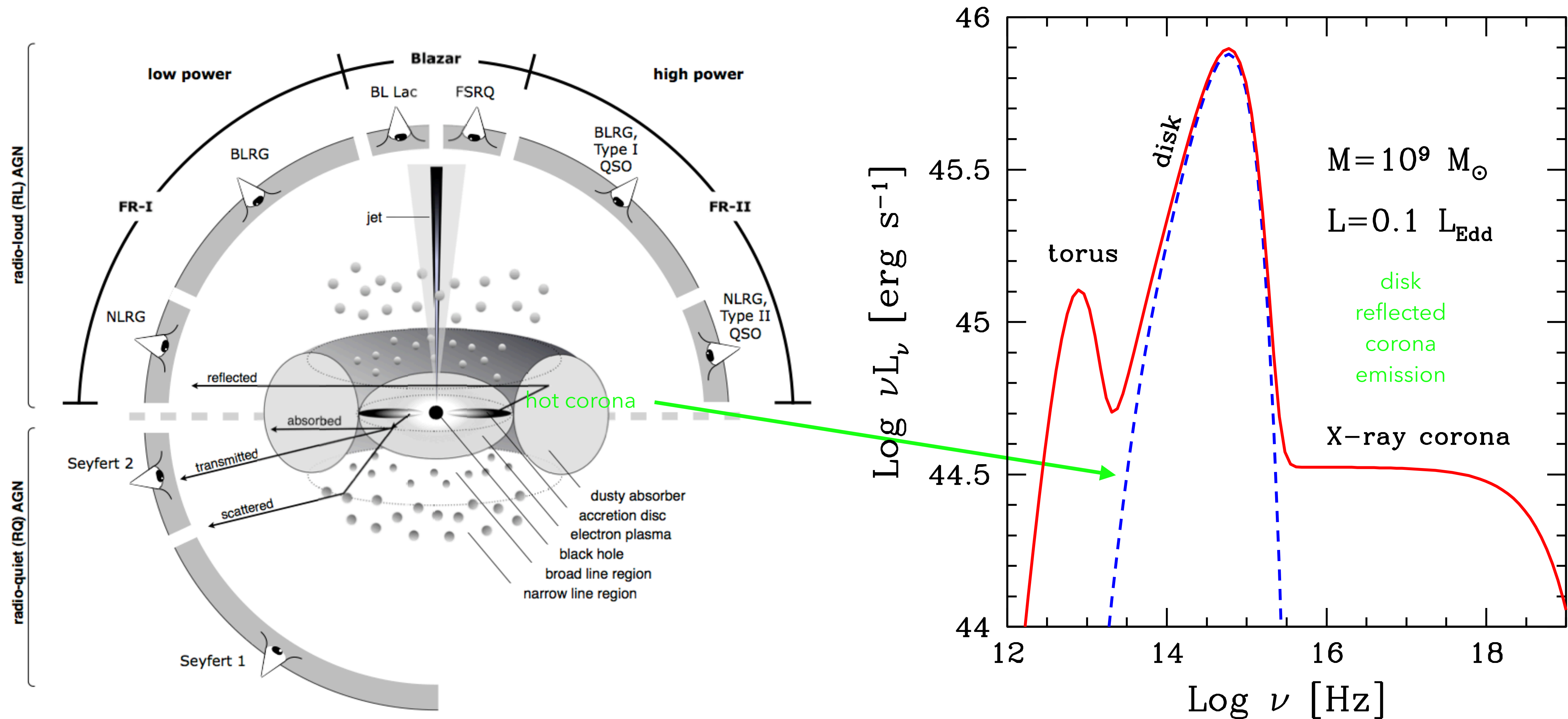


Non-jetted AGN

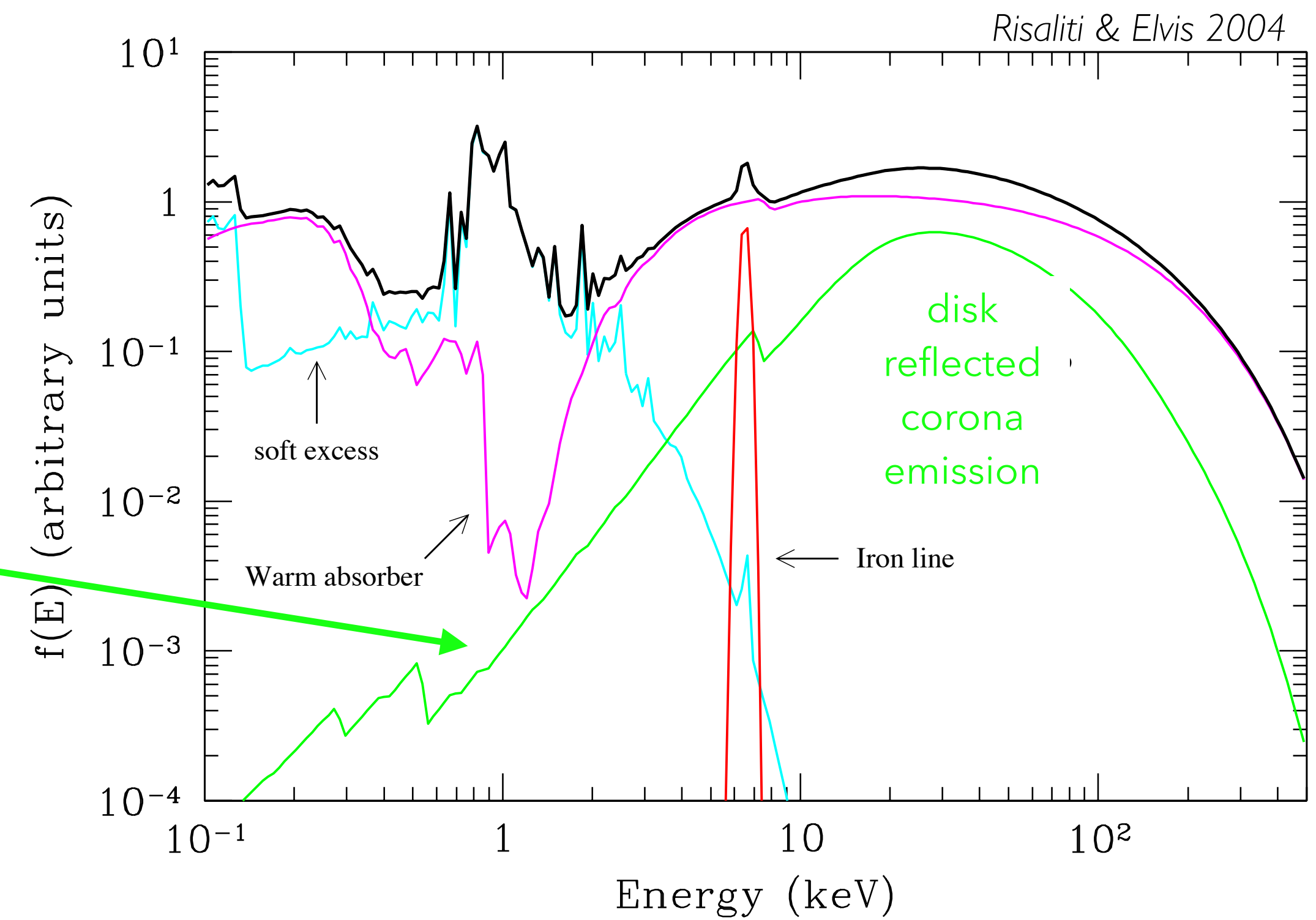
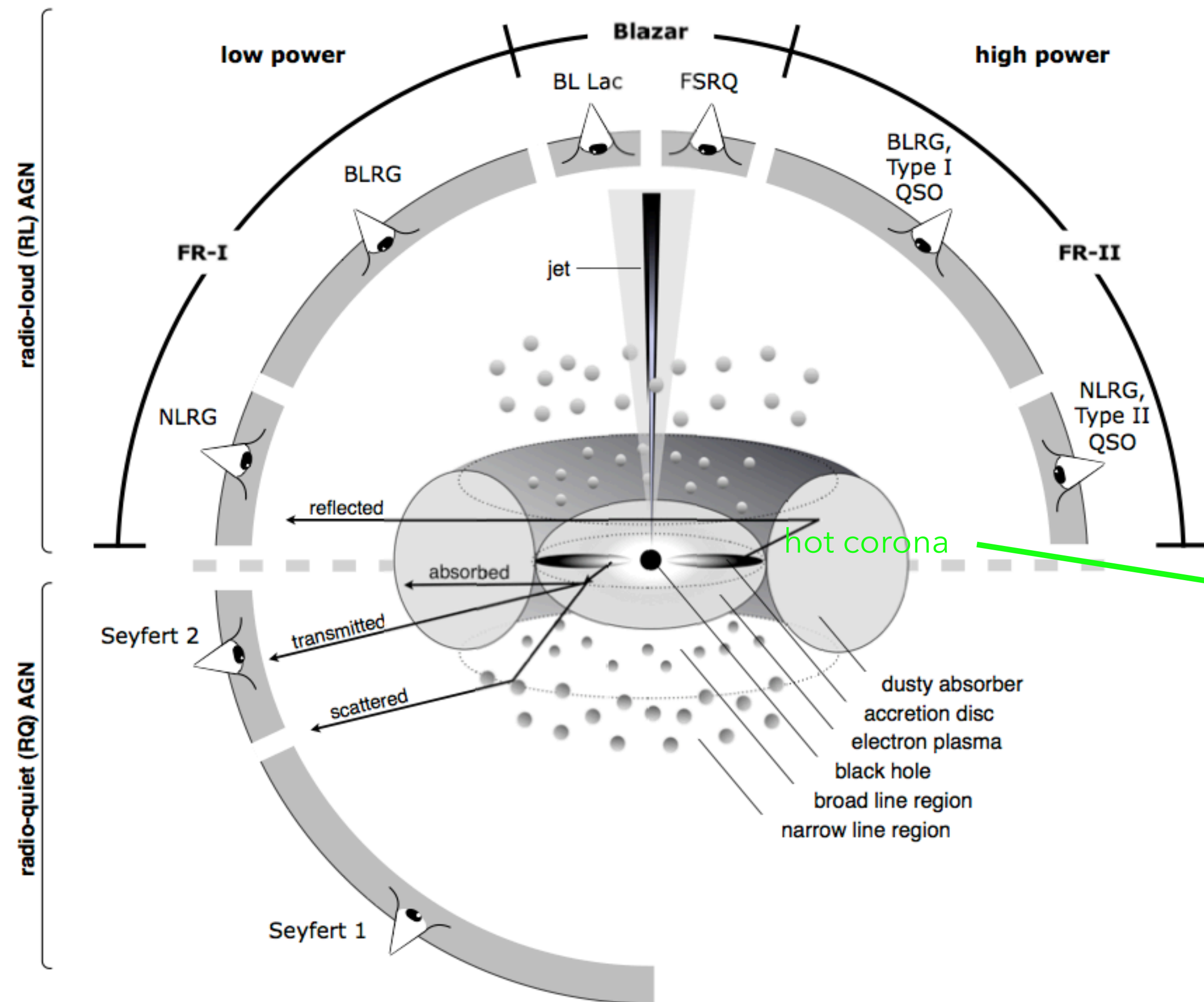
Swift-BAT 105-month hard-X-ray catalogue 2018



X-ray absorbers in AGN



X-ray absorbers in AGN



NALs

$\log[\xi \text{ (erg cm s}^{-1}\text{)}] = 0-1.5$
 $\log[N_{\text{H}} \text{ (cm}^{-2}\text{)}] = 18-20$
Velocity = 100–1,000 km s⁻¹
Distance scale = ~1 pc–1 kpc

WAs

$\log[\xi \text{ (erg cm s}^{-1}\text{)}] = -1-3$
 $\log[N_{\text{H}} \text{ (cm}^{-2}\text{)}] = 21-22.5$
Velocity = 100–2,000 km s⁻¹
Distance scale = 0.1 pc–1 kpc

Observed in ~50% of
Seyfert I

BALs

$\log[\xi \text{ (erg cm s}^{-1}\text{)}] = 0.5-2.5$
 $\log[N_{\text{H}} \text{ (cm}^{-2}\text{)}] = 20-23$
Velocity = 10,000–60,000 km s⁻¹
Distance scale = 0.001 pc–500 pc

UFOs

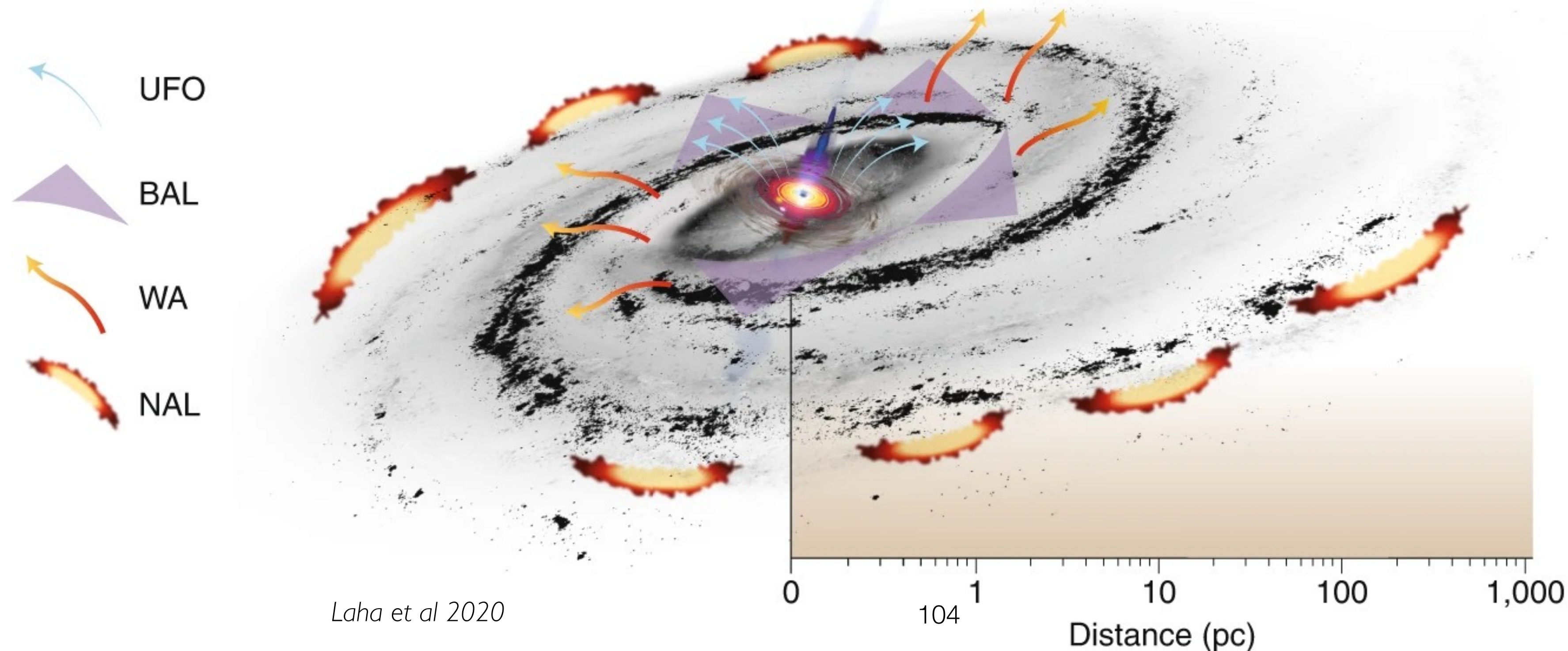
$\log[\xi \text{ (erg cm s}^{-1}\text{)}] = 3-5$
 $\log[N_{\text{H}} \text{ (cm}^{-2}\text{)}] = 22-23.5$
Velocity = 10,000–70,000 km s⁻¹
Distance scale = 0.001 pc–10 pc

Observed in ~40% of
radio loud and radio
quiet AGN

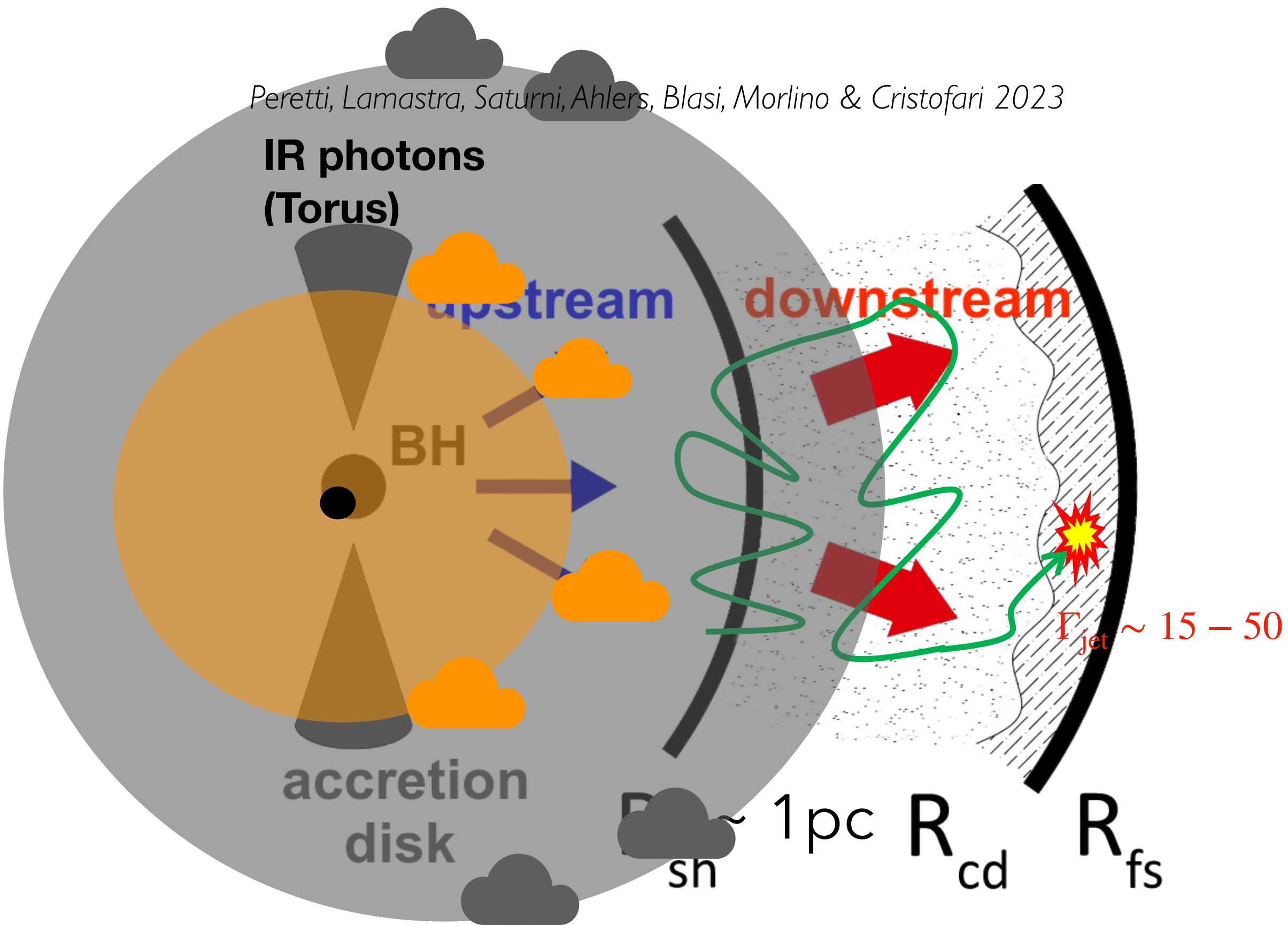
$v \sim 0.03 - 0.3 c$

(Tombesi et al
2010, 2011, 2012, 2014)

Hillas criterion OK!
(but interactions with
IR photons limit max energy)

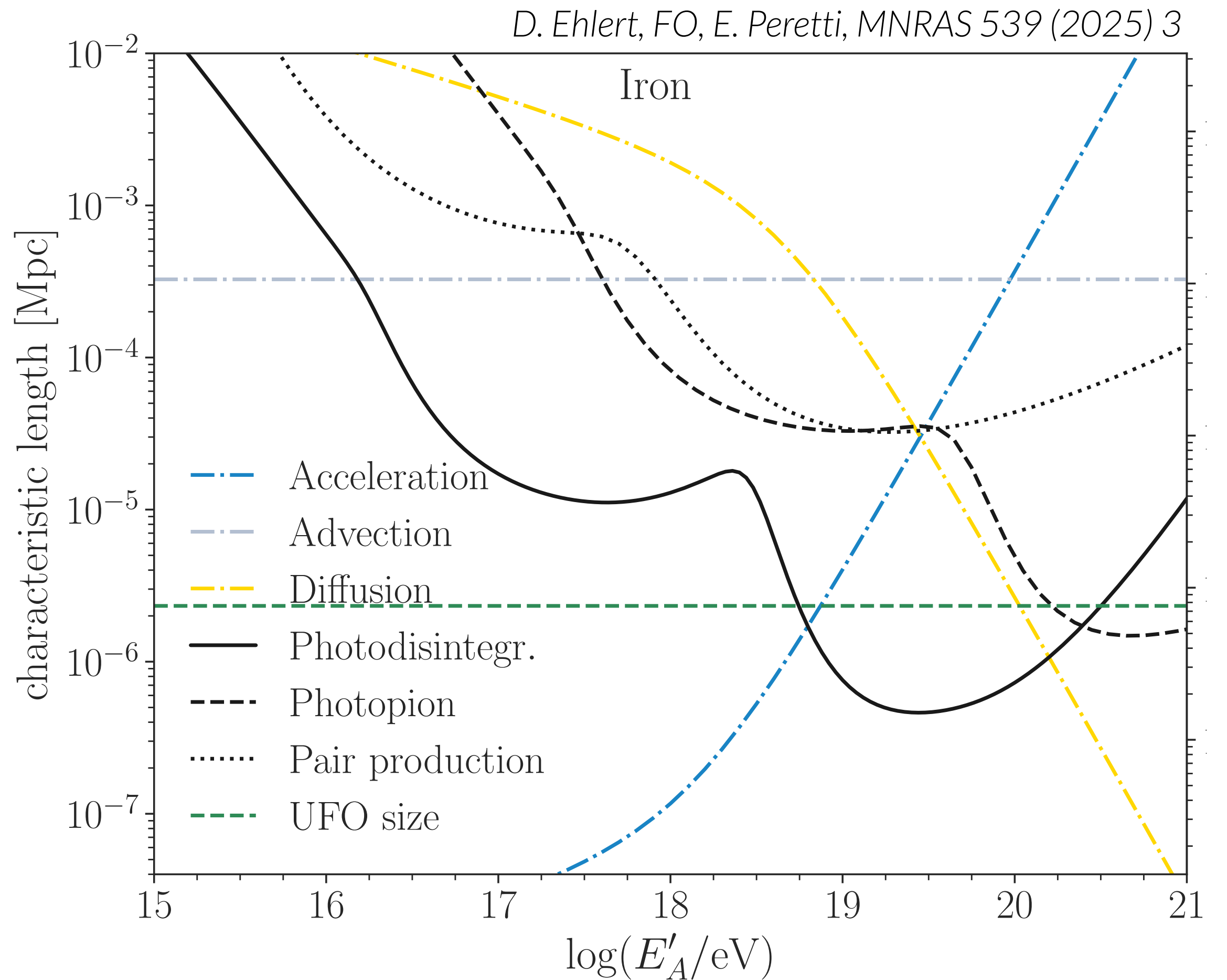


Can UFOs accelerate UHECRs?



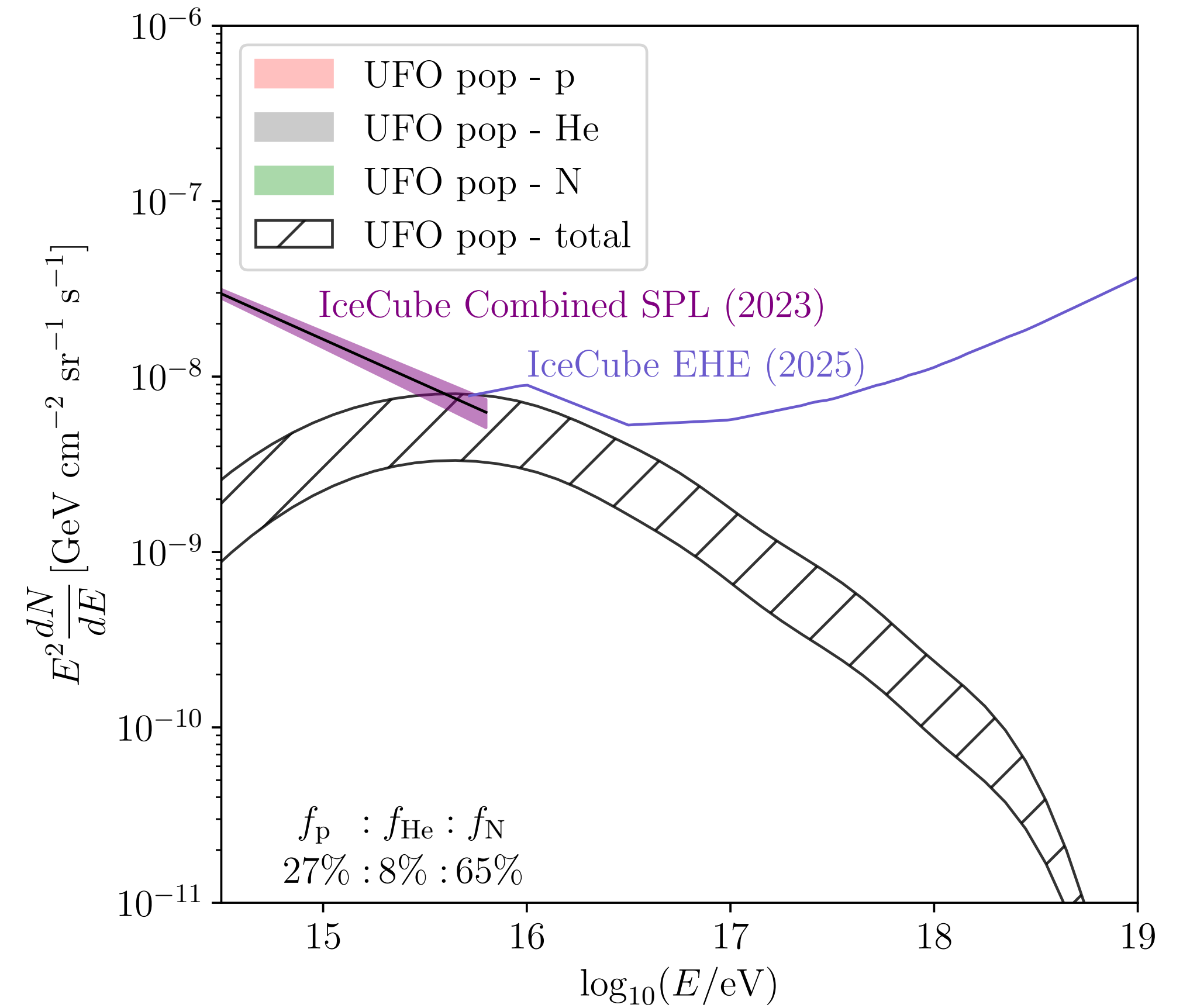
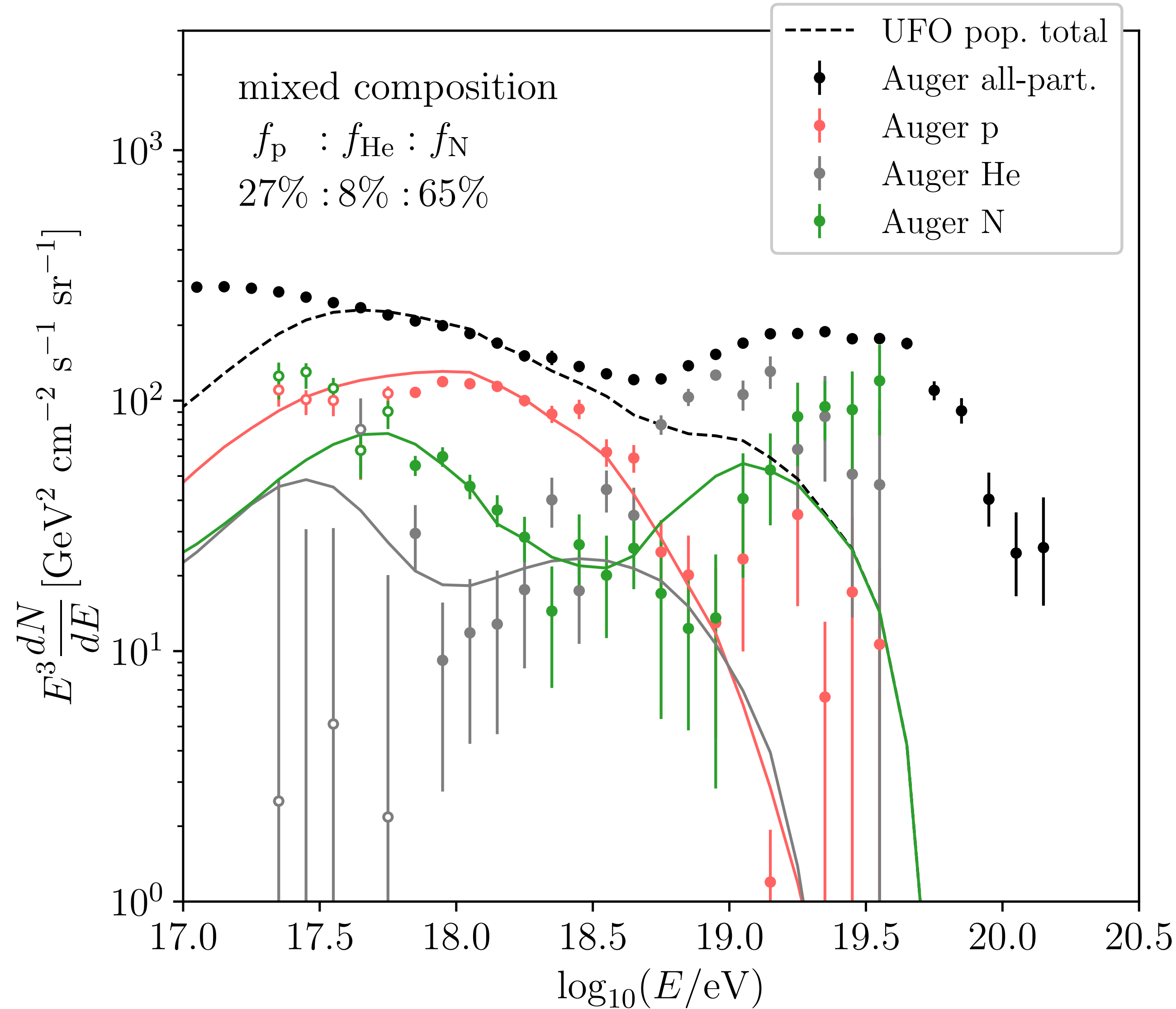
IR torus $L_{IR} \sim 0.5 L_{disk}$

$$R_{IR} \sim 1 \text{ pc} \cdot \left(\frac{L_{disk}}{10^{45} \text{ erg/s}} \right)^{1/2}$$



Can UFOs accelerate UHECRs?

D. Ehlert, FO, E. Peretti, MNRAS 539 (2025) 3

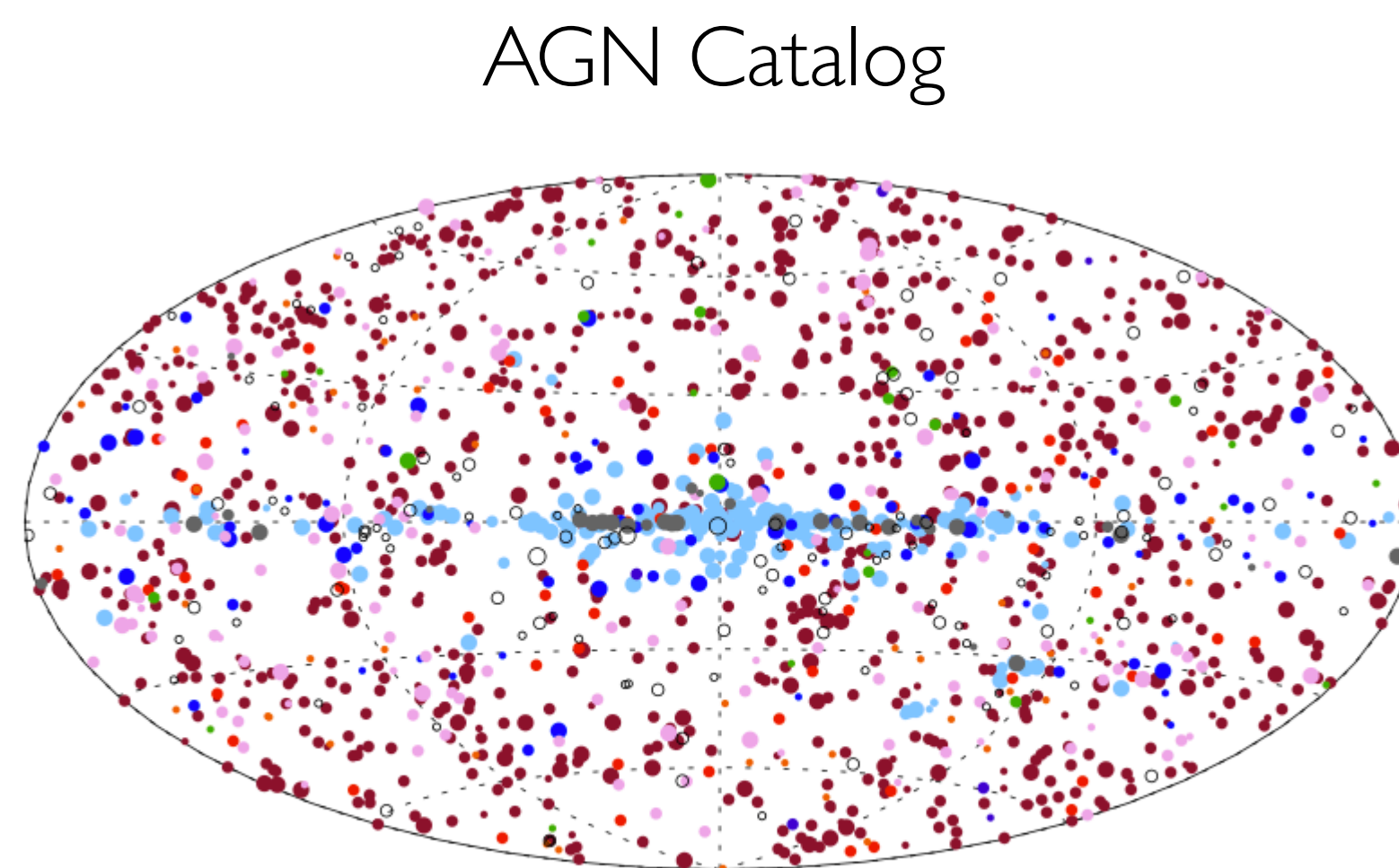


Non-jetted AGN contribution to the cosmic-neutrino flux

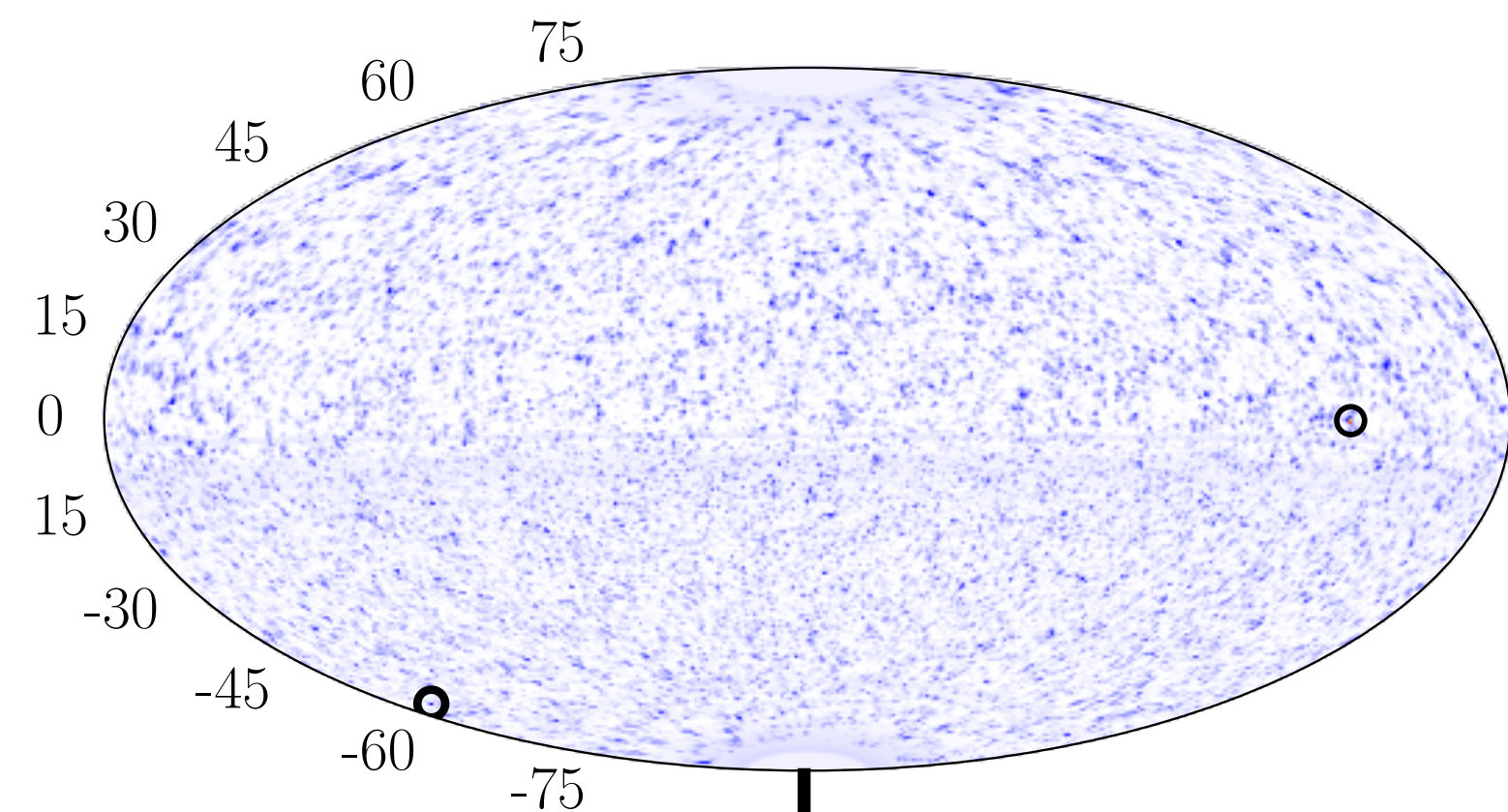
Infrared selected (ALLWISE) AGN with
soft-X-ray weights $\sim 32,249$ AGN

2.6σ excess w.r.t. background
expectations

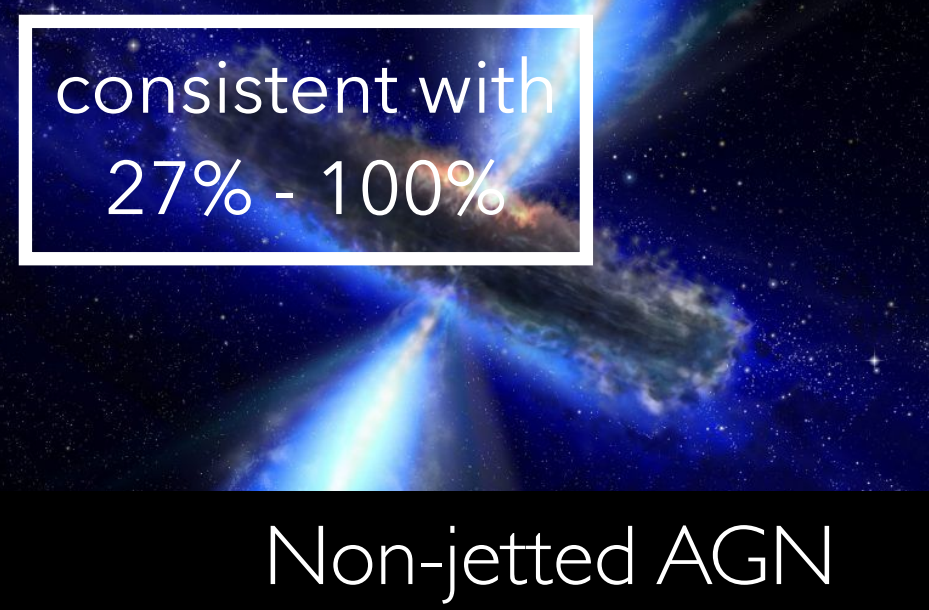
Best-fit spectral index $\frac{dN}{dE} \sim E^{-2}$



IceCube Point-Source Events



could account for 27-100% of diffuse
neutrino flux at 100 TeV

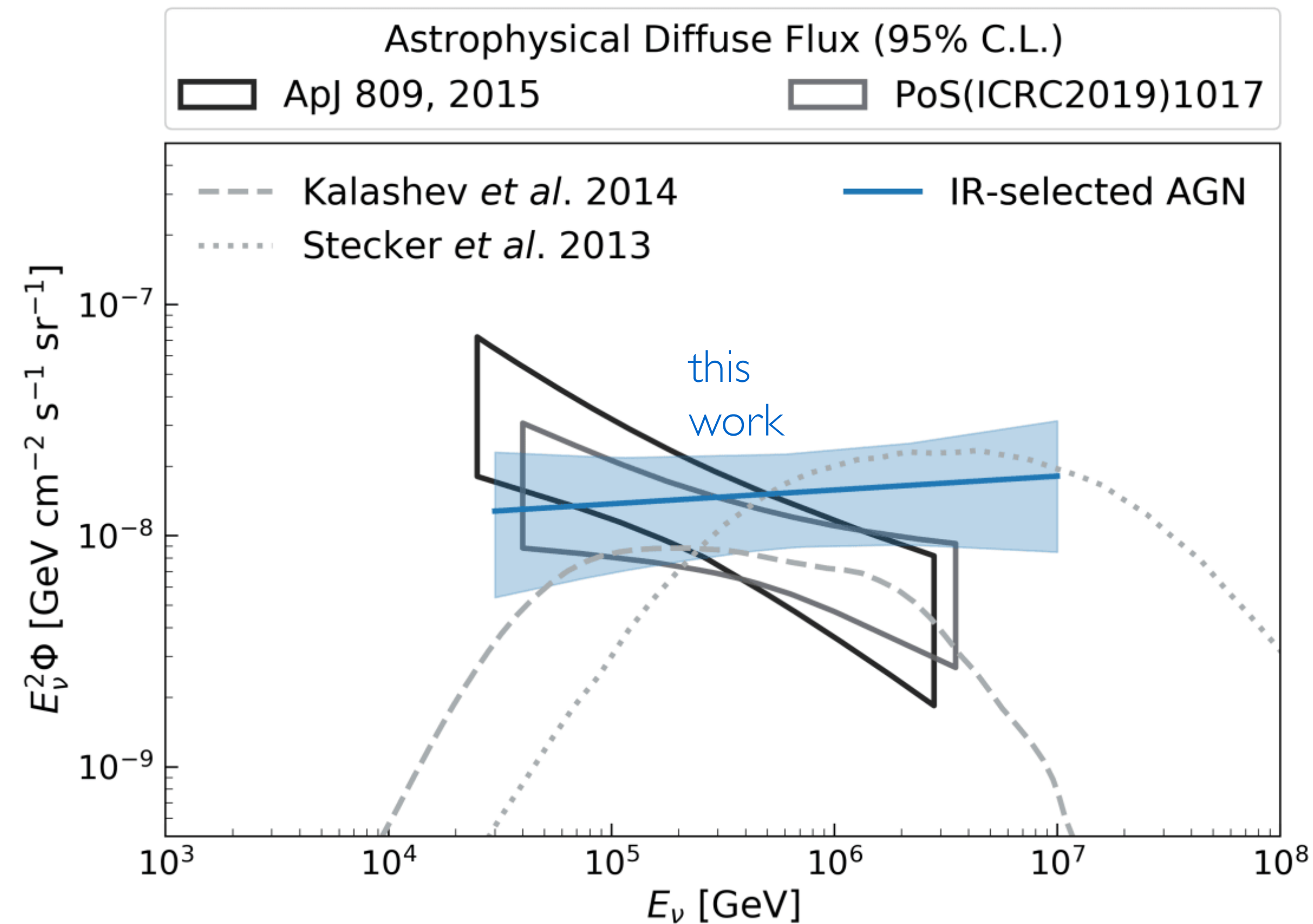


IceCube Coll 2022, PRD

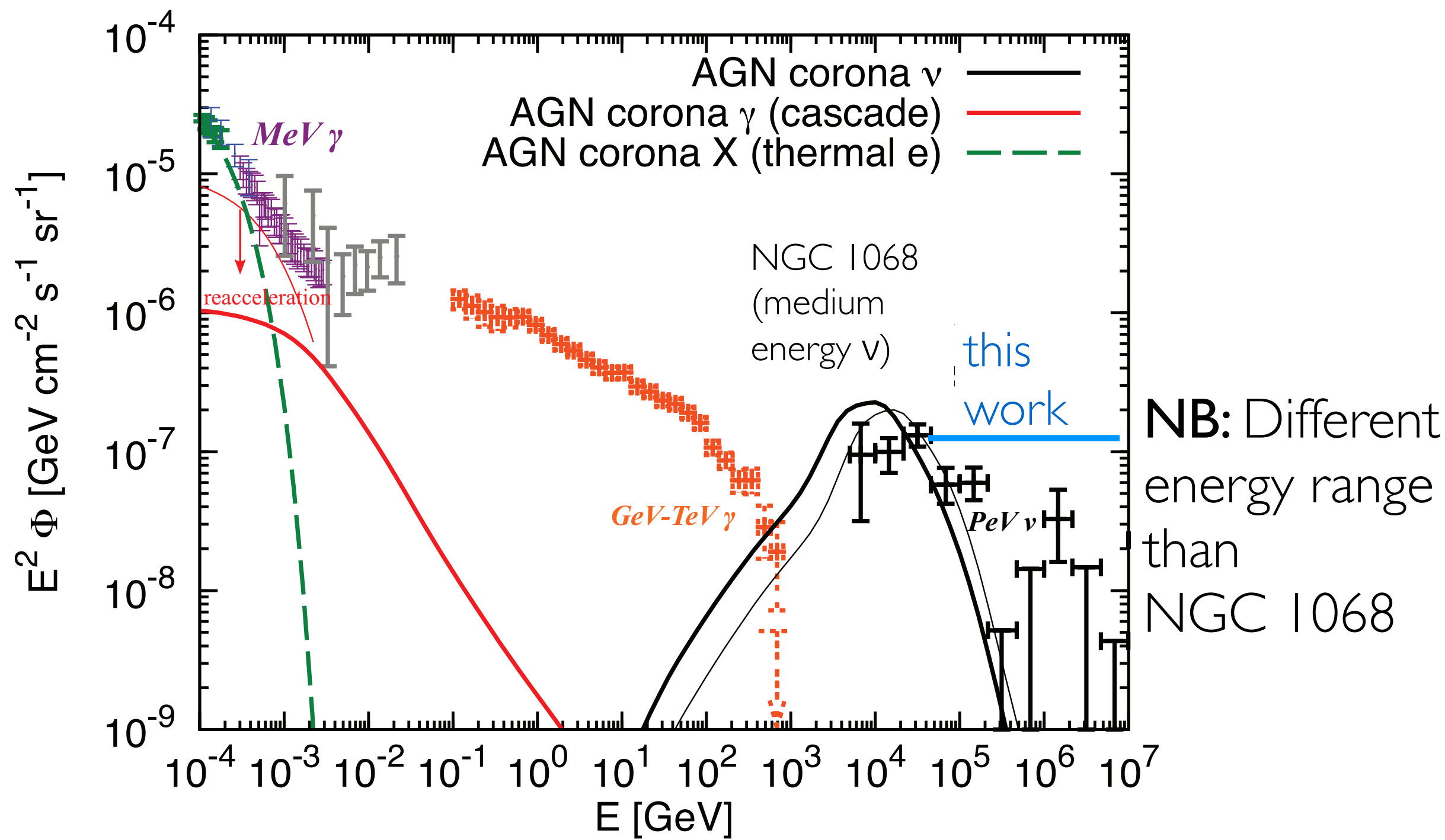
Non-jetted AGN contribution to the cosmic-neutrino flux



Non-jetted AGN



several mechanisms proposed and consistent with this signal
E.g. UFOs (Ehlert, FO, Peretti 2025)



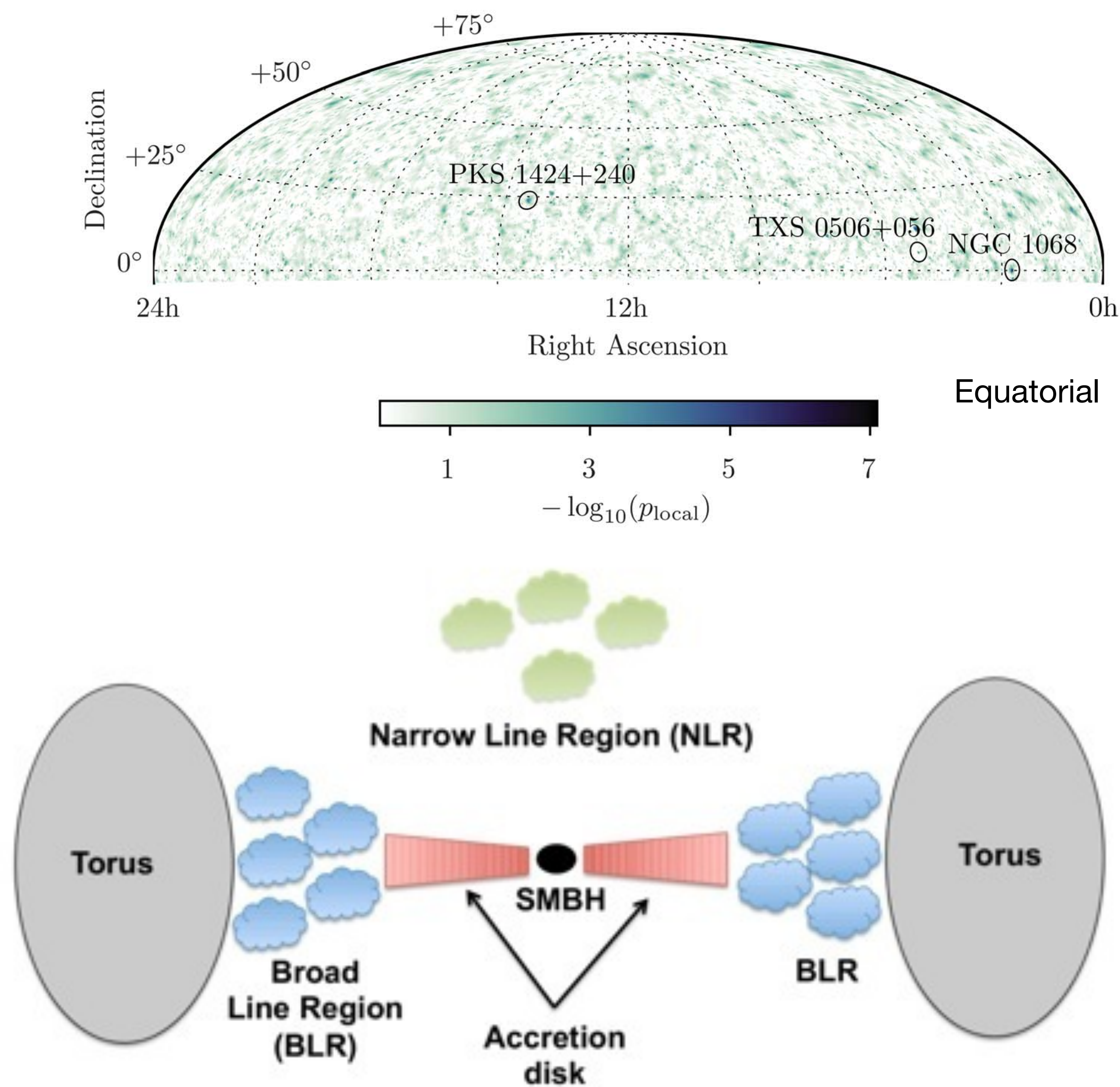
NB: Different energy range than NGC 1068

could account for 27-100% of diffuse neutrino flux at 100 TeV

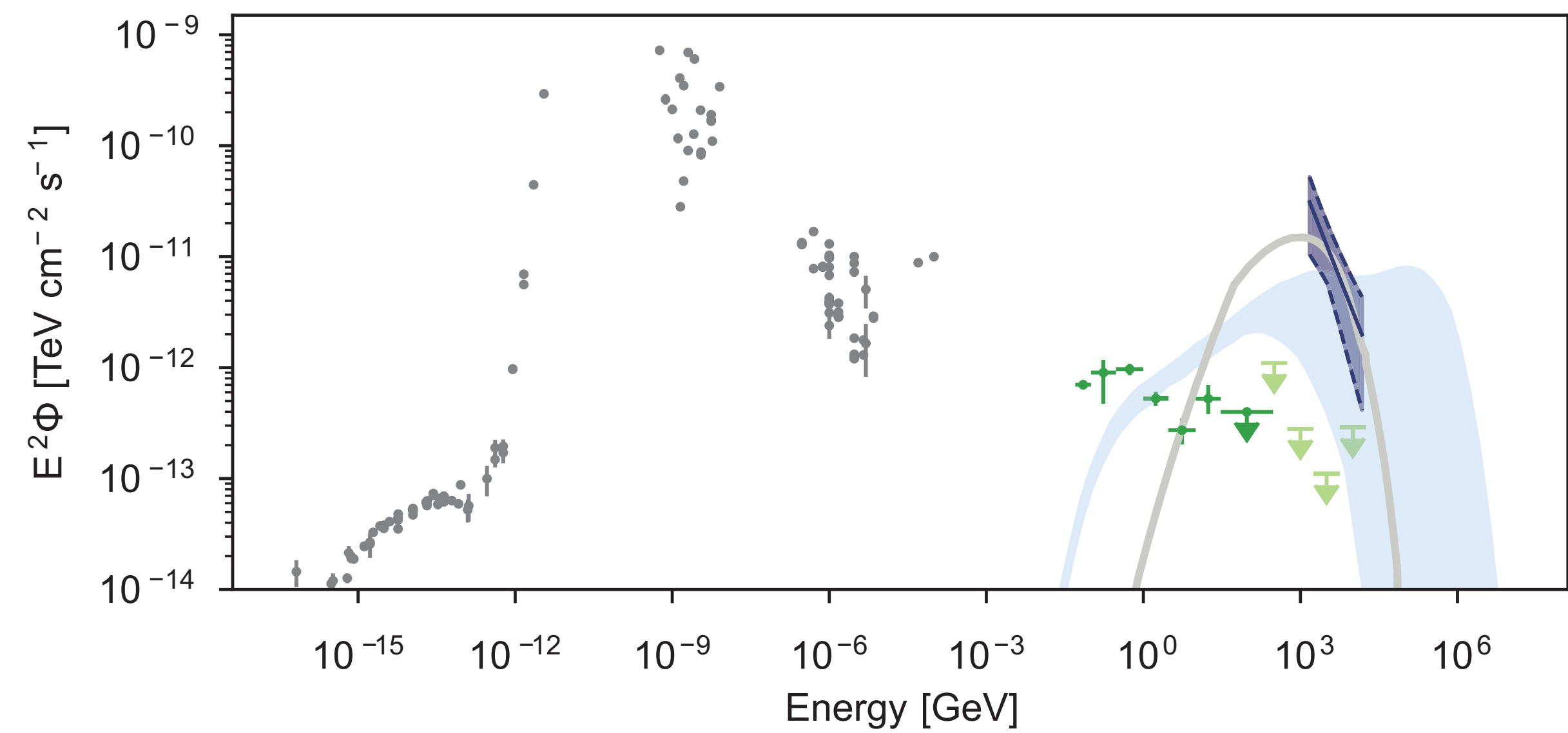
IceCube Coll 2022, PRD

NGC 1068

Icecube Coll 2023 - Science

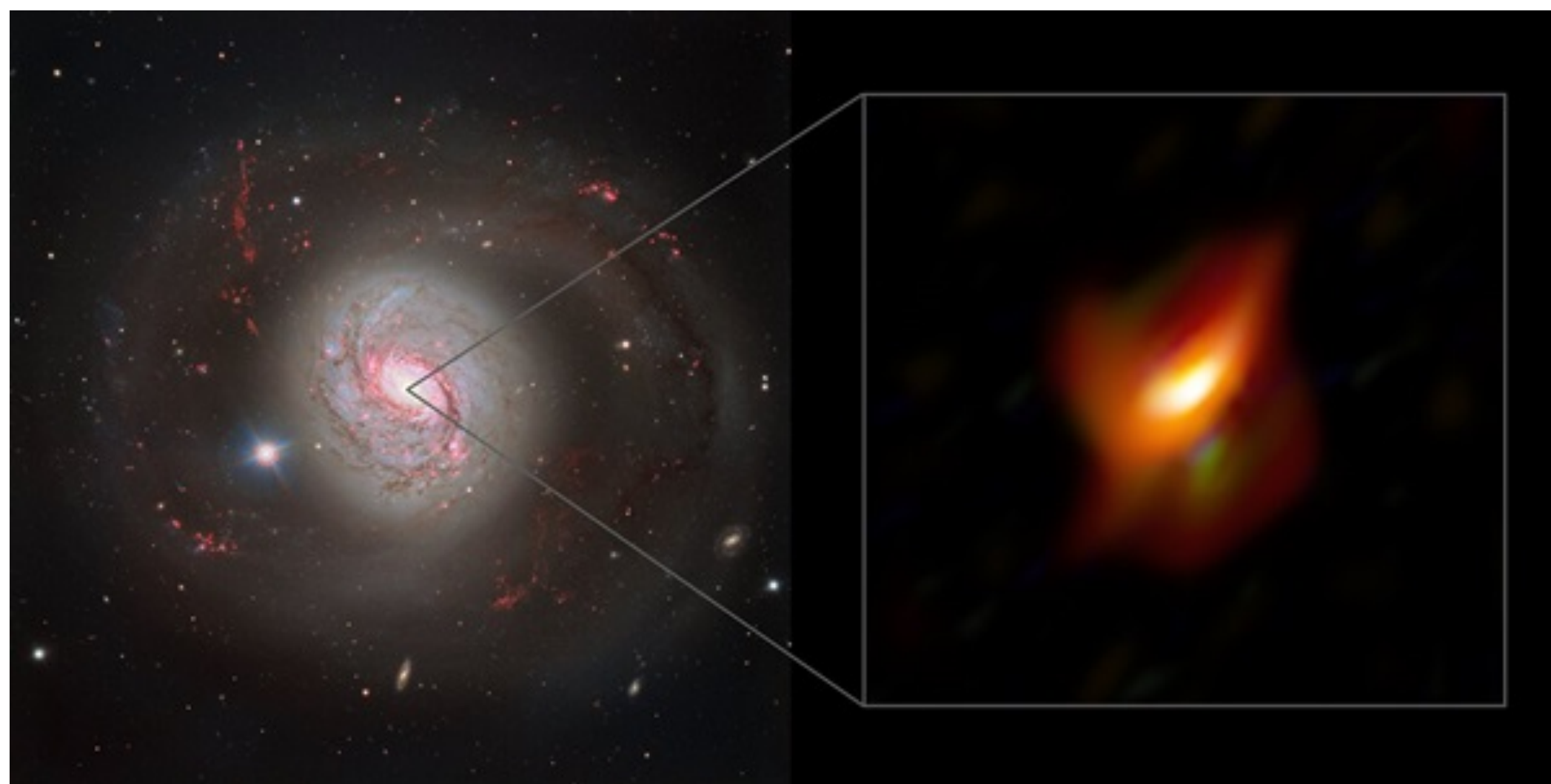


Test type	Pretrial P value, P_{local} (local significance)	Posttrial P value, P_{global} (global significance)
Northern Hemisphere scan	5.0×10^{-8} (5.3σ)	2.2×10^{-2} (2.0σ)
List of candidate sources, single test	1.0×10^{-7} (5.2σ)	1.1×10^{-5} (4.2σ)
List of candidate sources, binomial test	4.6×10^{-6} (4.4σ)	3.4×10^{-4} (3.4σ)



NGC 1068

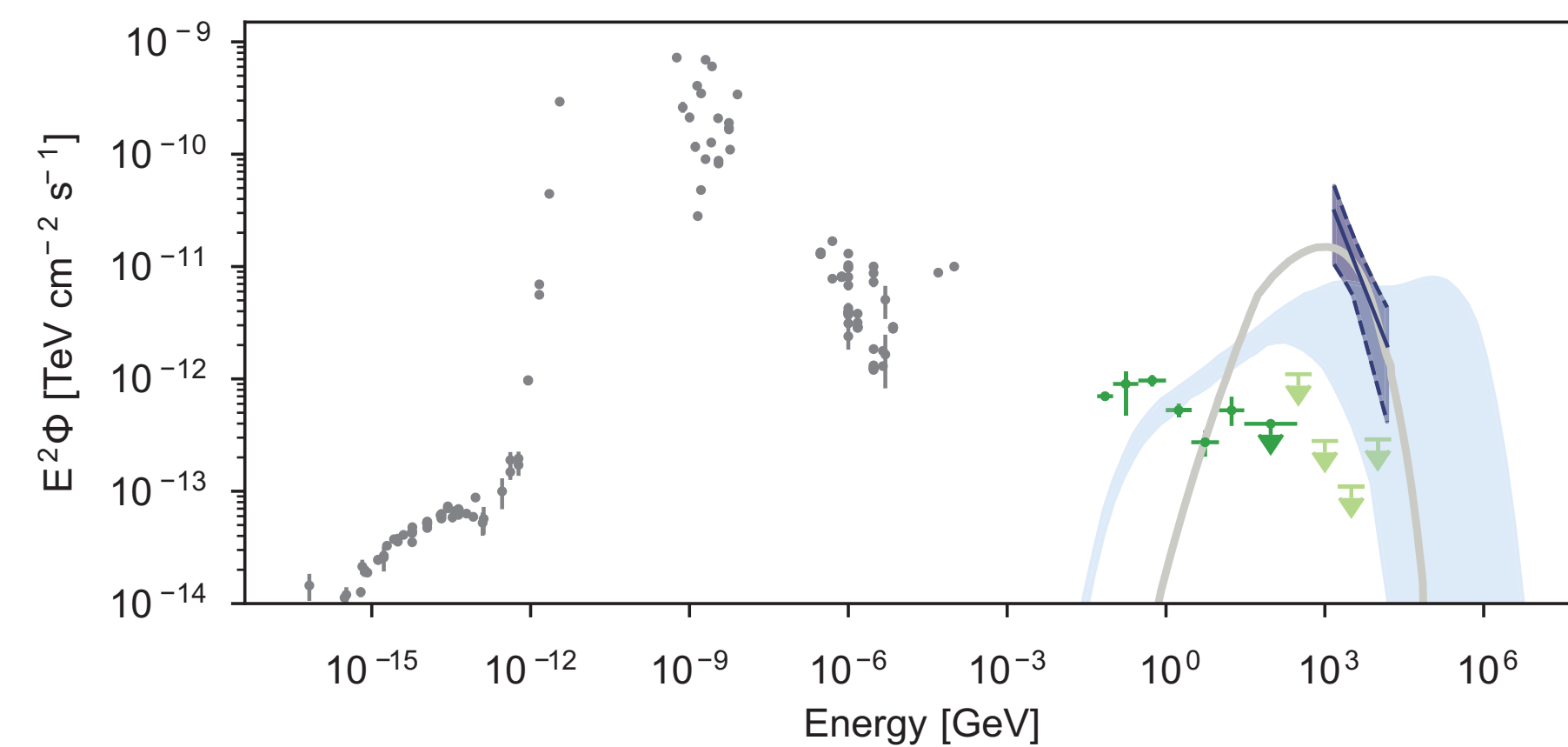
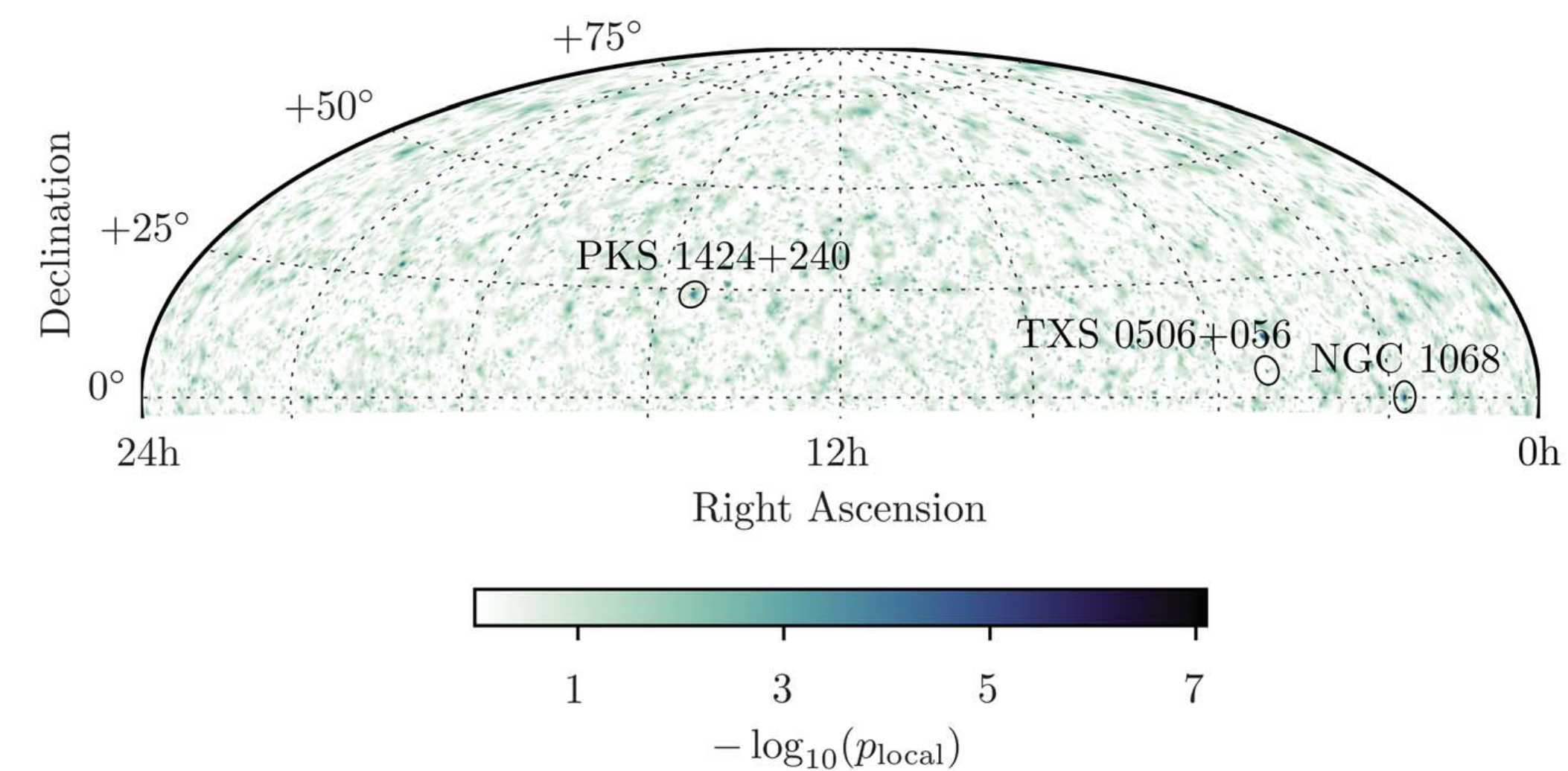
Icecube Coll 2023 - Science



Seyfert 2 galaxy with heavily obscured nucleus

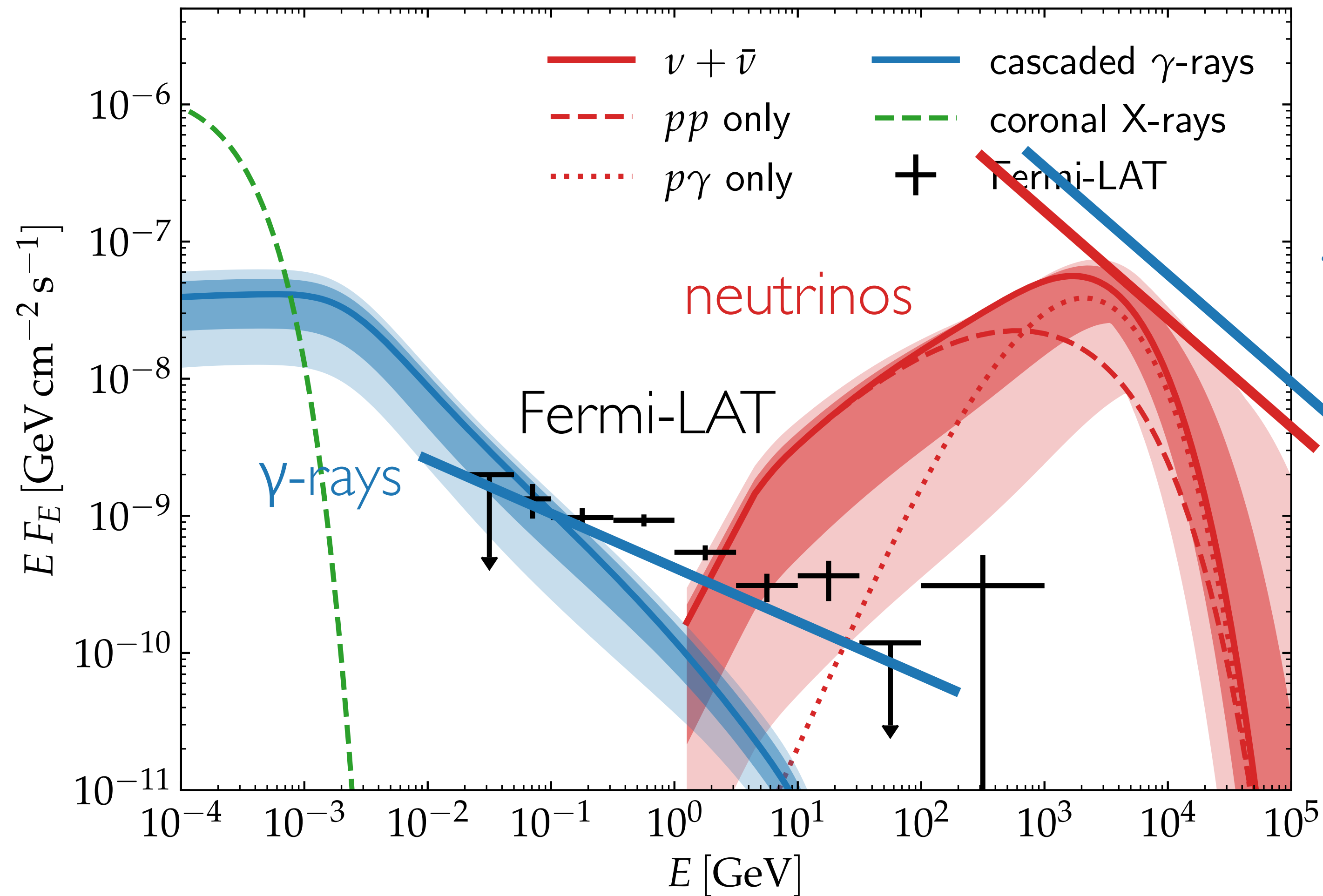
Prototypical nearby Seyfert 2 (14.4 Mpc)

High infrared luminosity: high-level of star formation



Neutrino production in NGC 1068

Saurenhaus, Capel, FO, Buchner, PRD, 2025



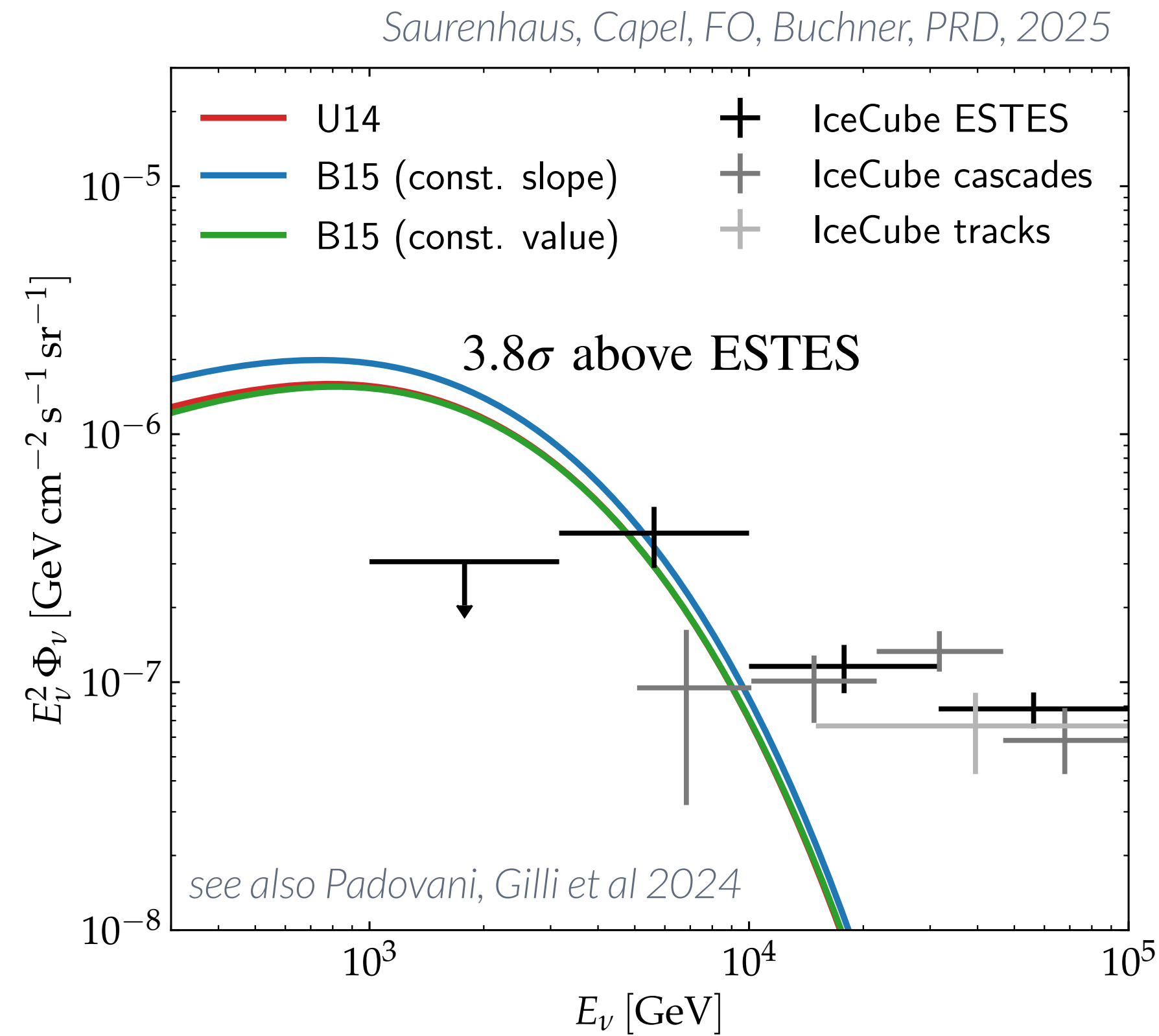
$$\pi^0 \rightarrow \gamma\gamma : \pi^{+/-} \rightarrow \nu_e \nu_\mu \bar{\nu}_\mu$$

$$E_\gamma \Phi_\gamma|_{E_\gamma = 2E_\nu} \approx E_\nu \Phi_\nu$$

$$R_{\text{neutrinos}} \leq 5R_{\text{Sw}}$$

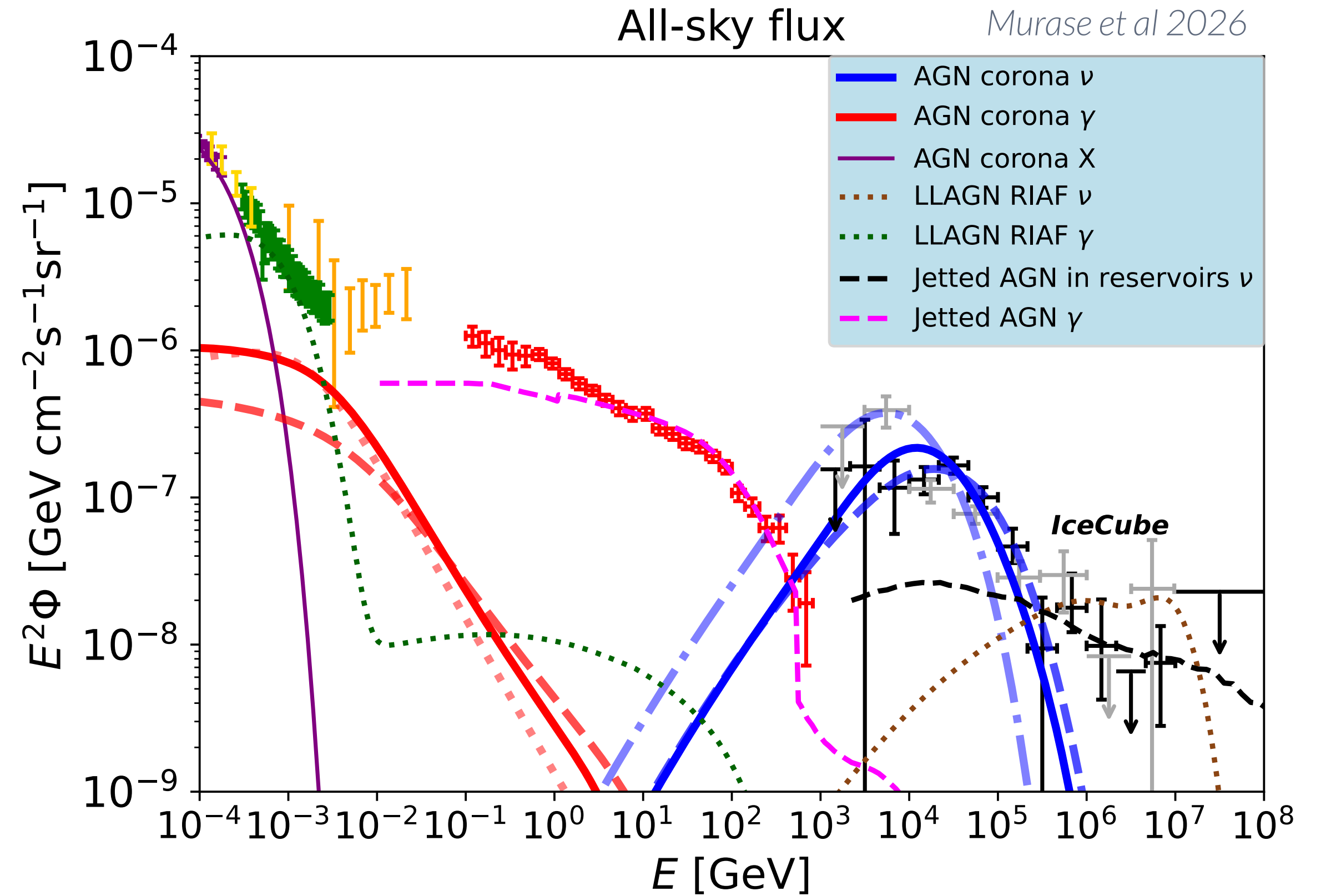
Murase 2022, Halzen 2023,
newer Fermi-LAT analysis:
Murase 2024, Das et al 2024,
Saurenhaus et al 2025

Neutrino production in AGN Coronae



Population model based on Murase et al 2020 PRL
(updated gamma-ray, neutrino observations)

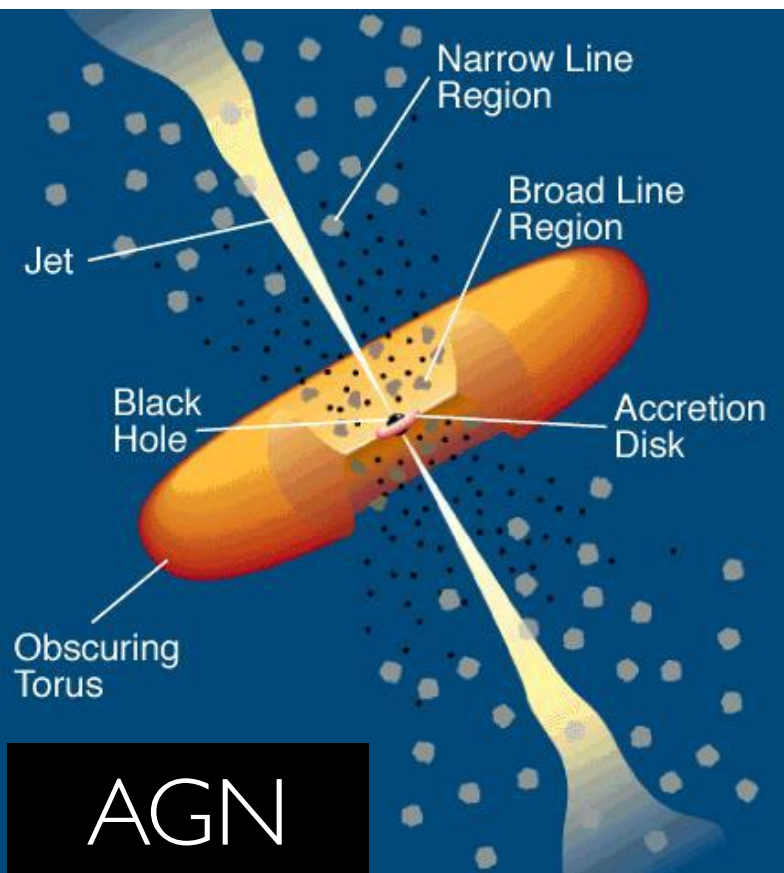
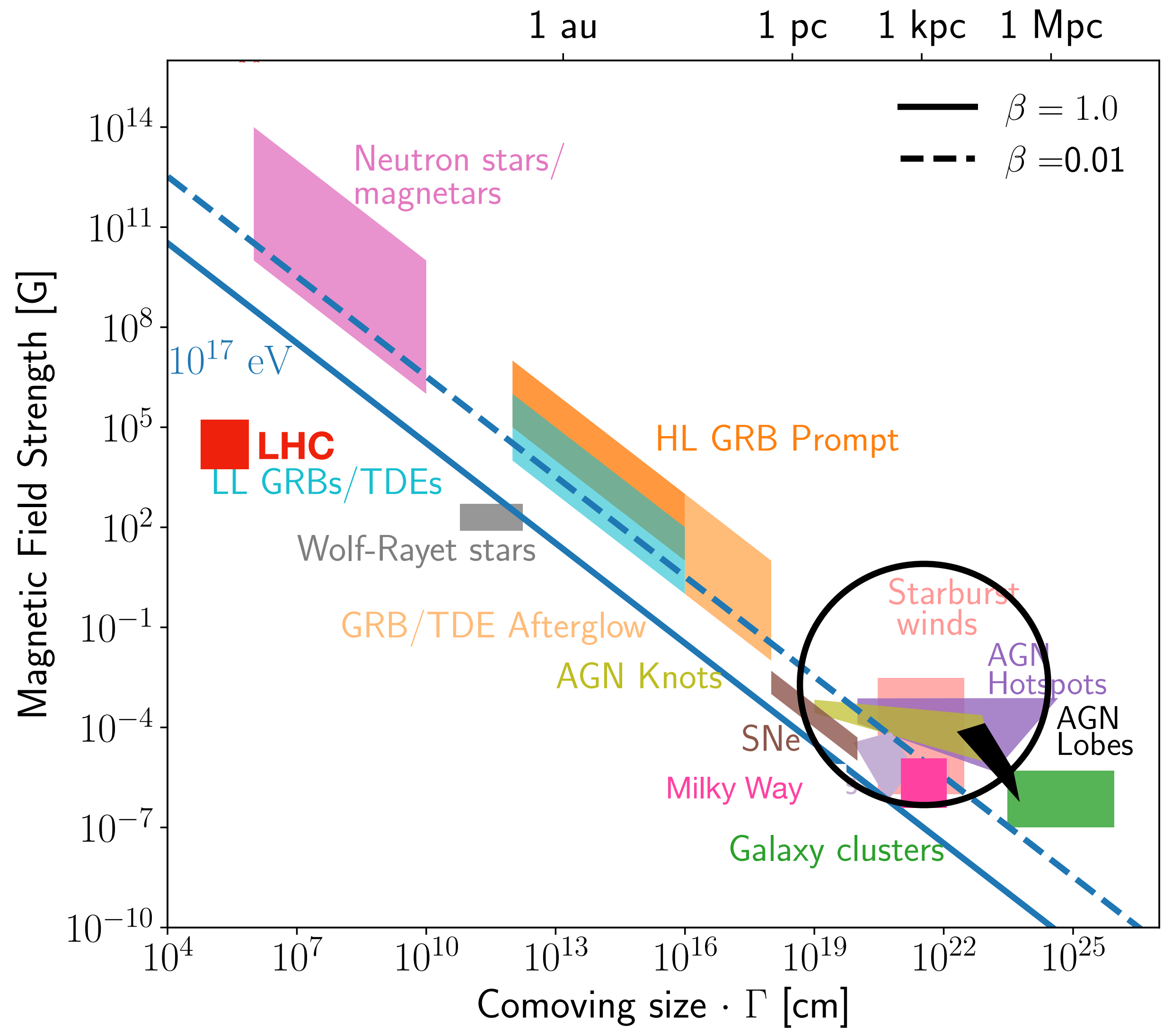
$$L_\nu \propto L_X^{0.7}$$



Scorecard

	$E_{\text{max}}^{\text{UHECR}}$	n_{UHECR}	$\dot{\epsilon}_{\text{UHECR}}$	n_{ν}	Stacking UL
BL Lacs	😊	😞	😊	😞	$\lesssim 20\%$
FSRQs	😊	😞	😊	😞	$\lesssim 20\%$
FR I	😊	😊	😊	😊	$\lesssim 20\%$
FR II	😊	😊	😊	😊	$\lesssim 20\%$
Non-jetted AGN UFOs	😐	😊	😊	😊	$\lesssim 100\%$
Non-jetted AGN Corona	😞	😊	😊	😊	$\lesssim 100\%$
Starburst galaxies					
HL GRBs					
LL GRBs					
Pulsars					
TDEs					

Cosmic-ray accelerators that satisfy the confinement req (10¹⁷ eV)



Starburst galaxies

High star-formation rate ($> 100 \times$ Milky Way)

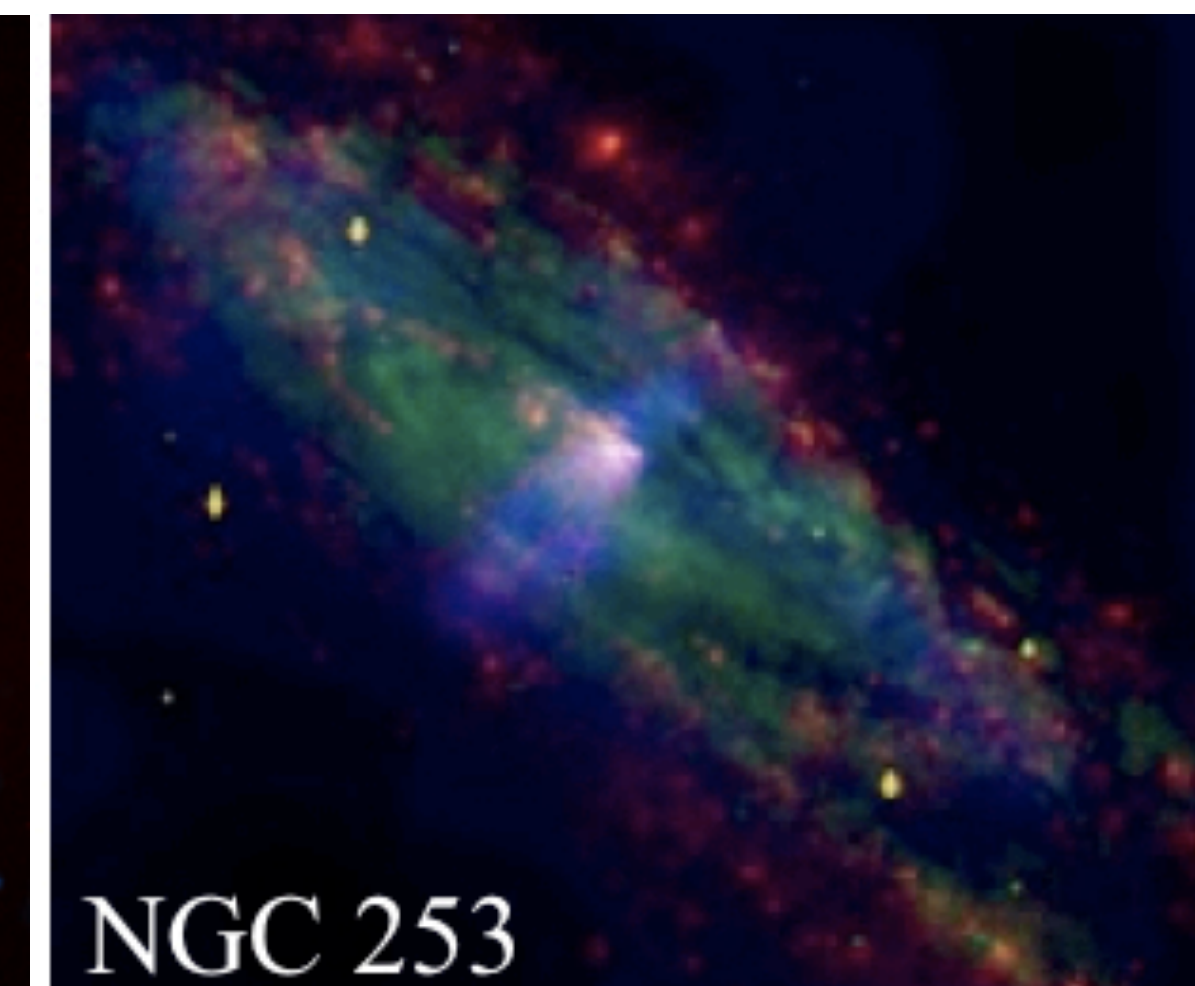
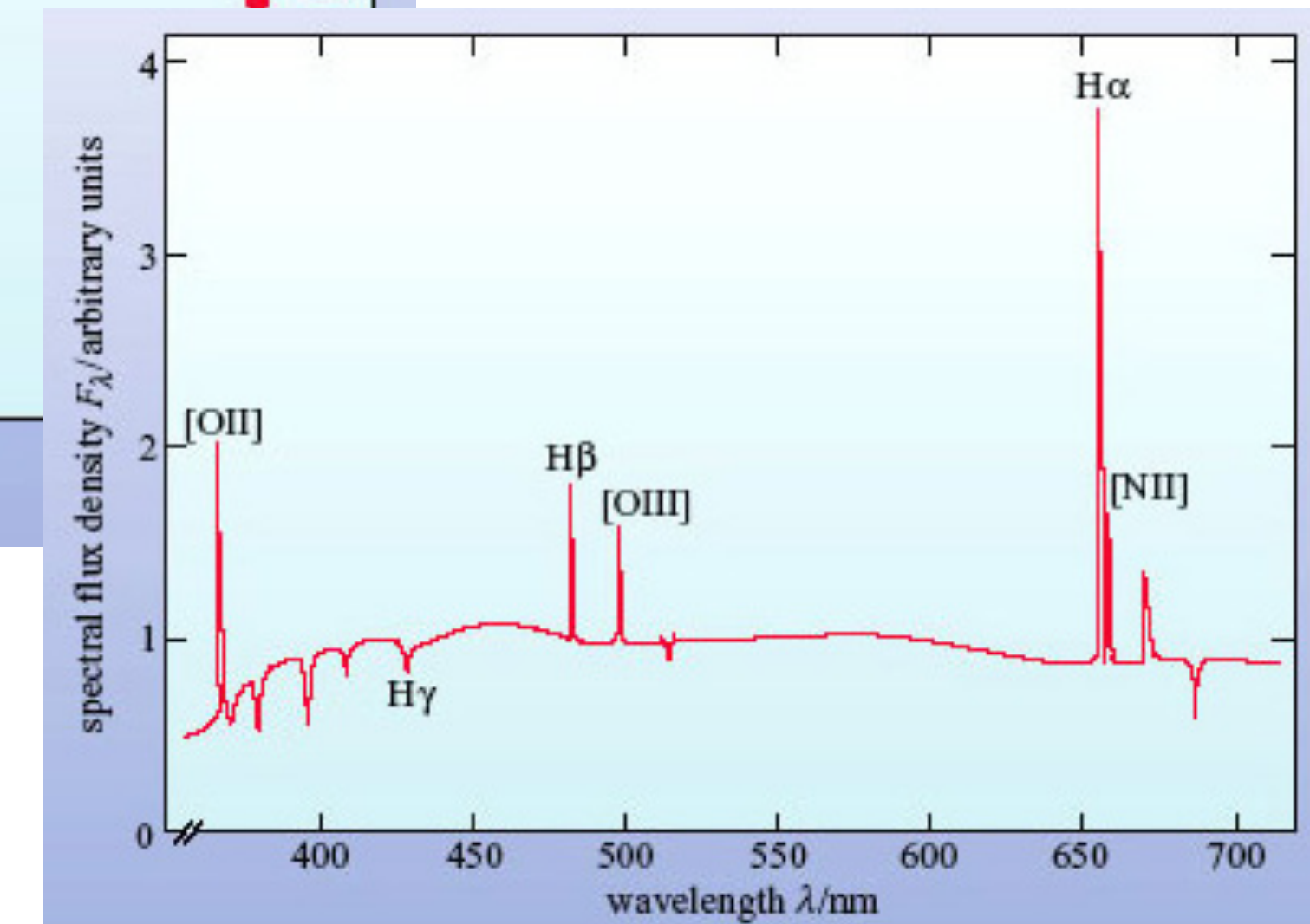
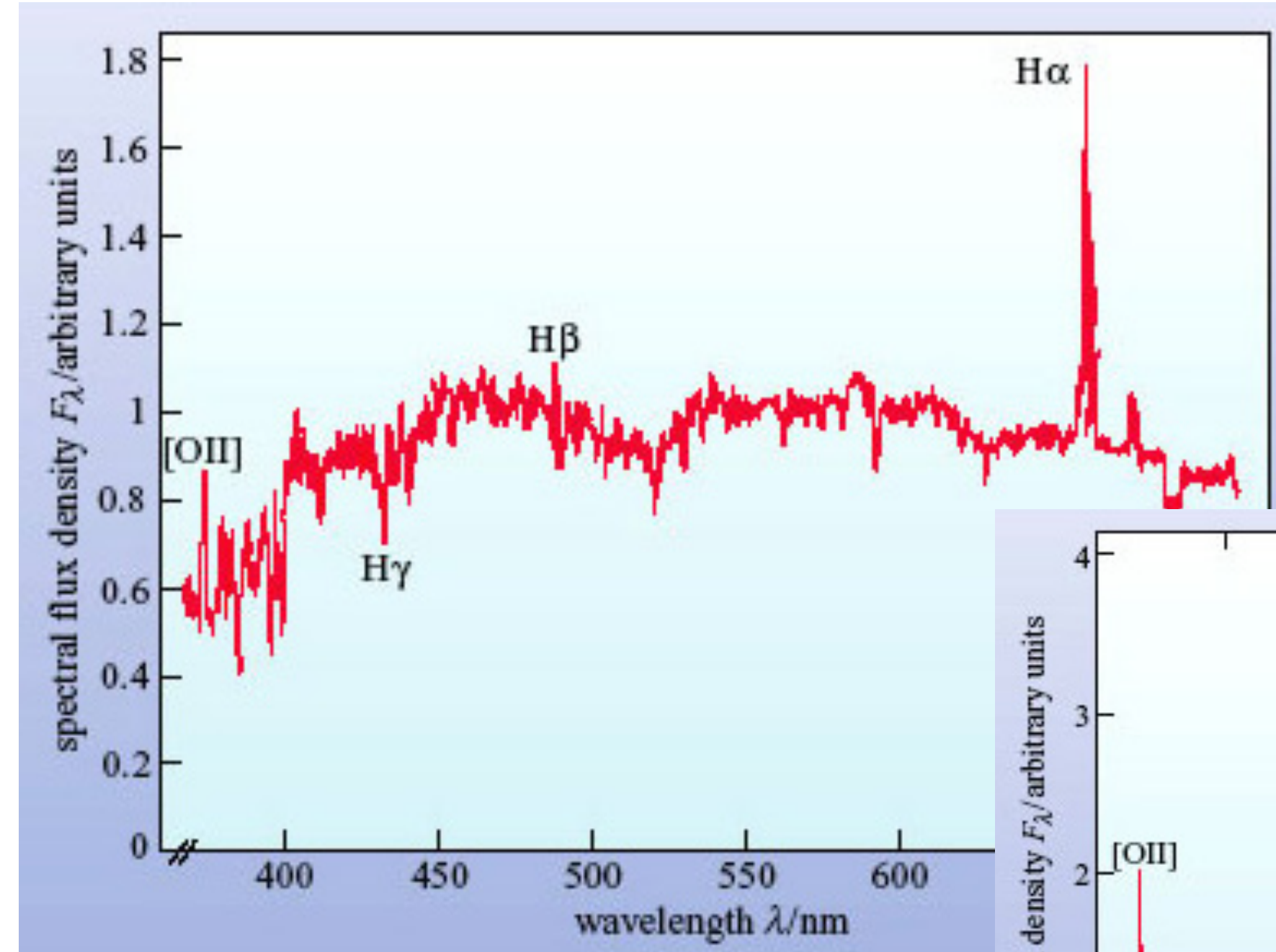
Starburst episodes are short-lived ($< 10^8$ yrs)

Centrally driven strong outflows (“superwinds”)

Column densities $\Sigma_g > 0.1 \text{ g/cm}^2$ and magnetic fields
 $B \sim 1 \text{ mG}$ (cf $\Sigma_g \approx 0.003 \text{ g/cm}^2$, $B \sim 5 \mu\text{G}$ in the Milky way)

TeV gamma-ray detections from NGC 253 ($\sim 3 \text{ Mpc}$) &
M82 ($\sim 4 \text{ Mpc}$) - consistent with point like at VHE

And a handful more in GeV gamma-rays (NGC4945, ¹¹⁵
NGC1068, Circinus, Arp 220)



UHECRs from starburst galaxies?

Lovelace 1976, Waxman 1995, 2001, Blandford 2000,
Lemoine & Waxman 2009, Farrar & Gruzinov 2009

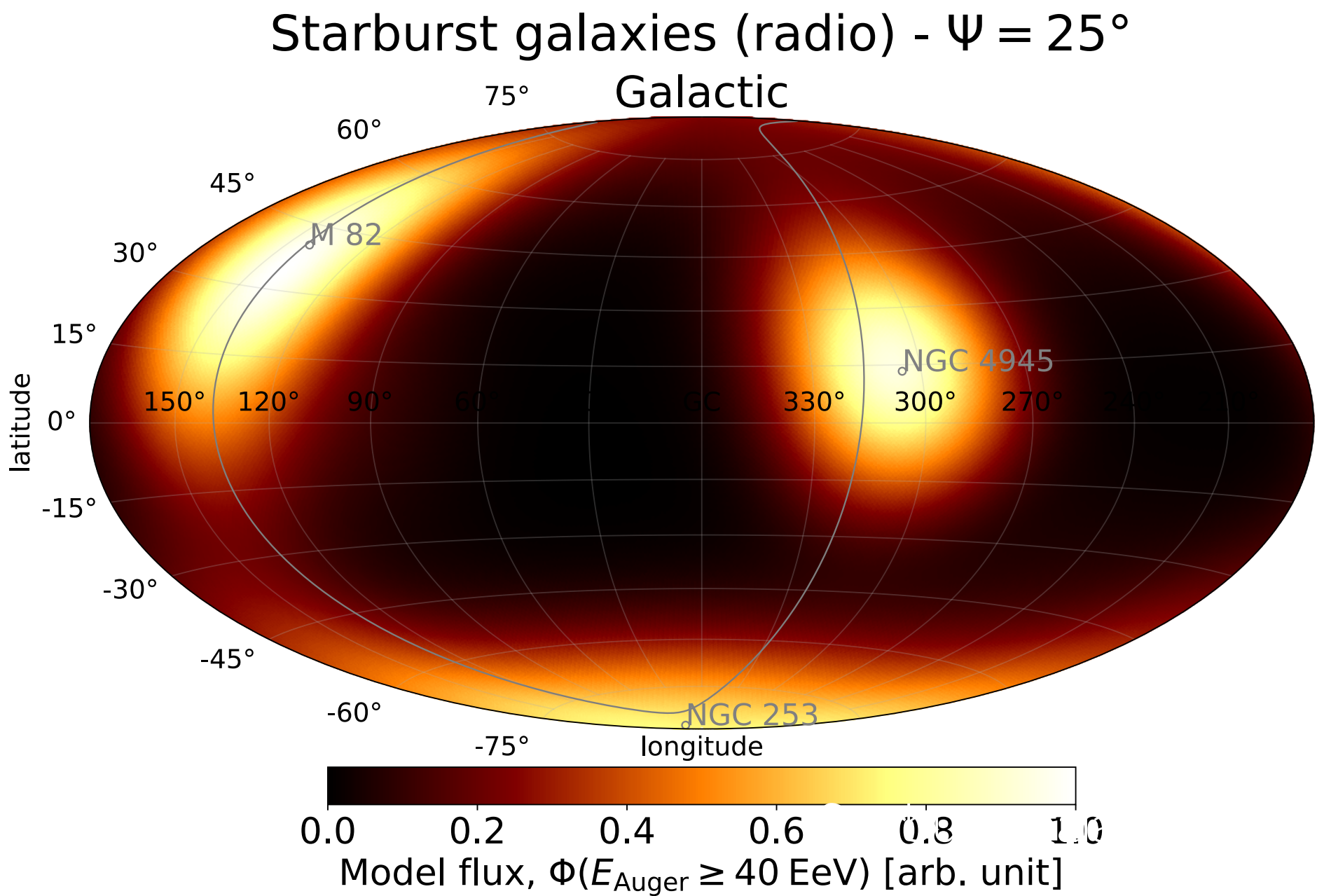
Auger Coll, ApJL, 853, L29, 2018, Auger Coll 2022, ApJ 935 (2022) 2, 170

$$U_{\text{rad}} \gtrsim U_B$$

$$L \gtrsim L_B \sim \frac{U_B \cdot \text{Volume}}{t} \sim B^2 R^2 \beta c$$

$$L_{\text{min}} \sim 10^{45} \text{ erg/s} \cdot \left(\frac{E}{10^{20} \text{ eV}}\right)^2 \left(\frac{Z}{10}\right)^{-2} \left(\frac{u}{10^{-3} c}\right)^{-1}$$

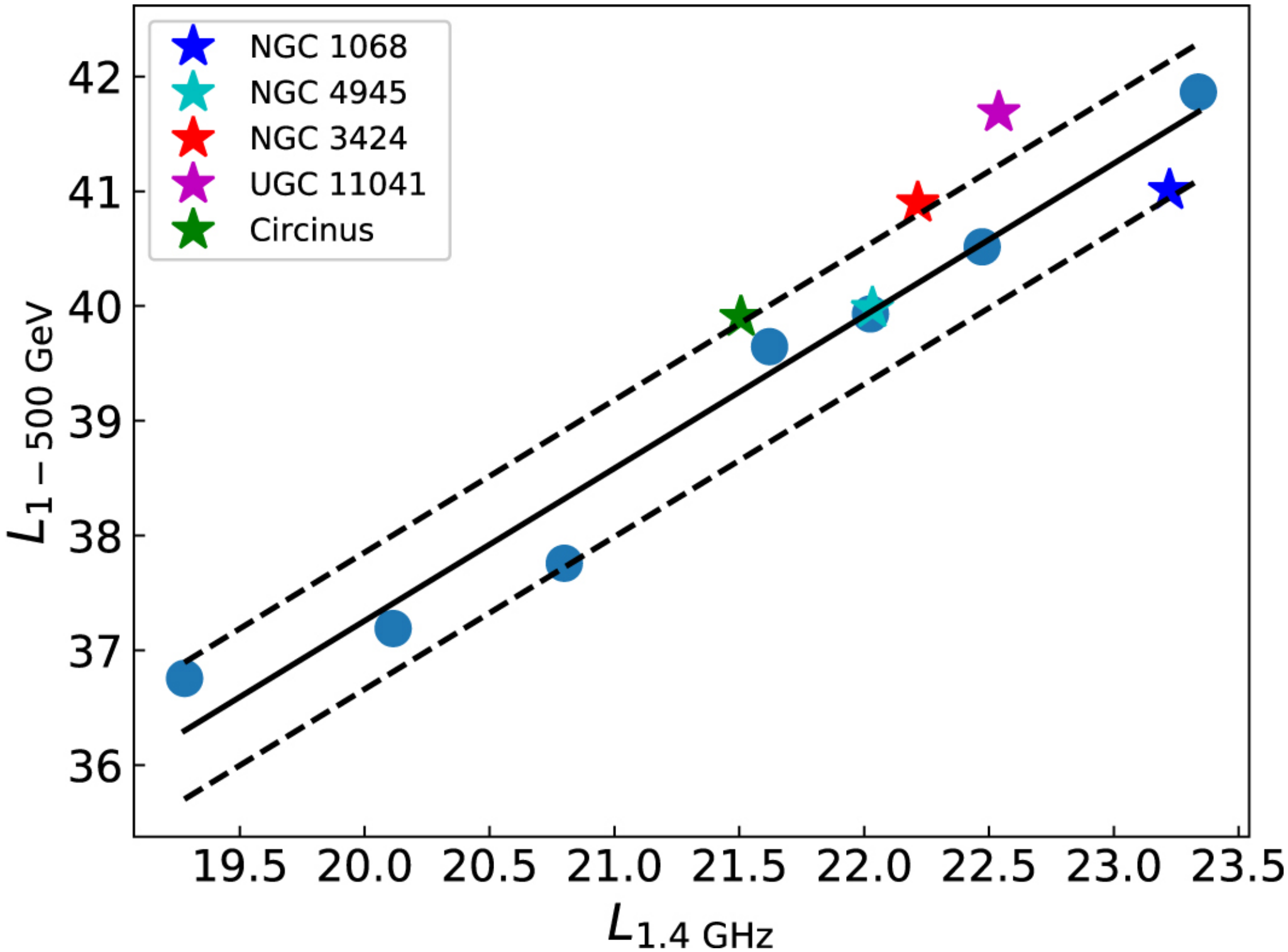
Peng et al 2019



Starburst galaxies (radio flux weights)
Correlation could be related to lightcents

$E \geq 28 \text{ EeV}$, Flux fraction (GRBs etc)

post-trial significance: 4.2σ



Neutrino production in proton-proton interactions

Gas reservoirs (Starburst galaxies, Galaxy Clusters...)

$$p + p \rightarrow p + p + N\pi^+ + N\pi^- + N\pi^0$$

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

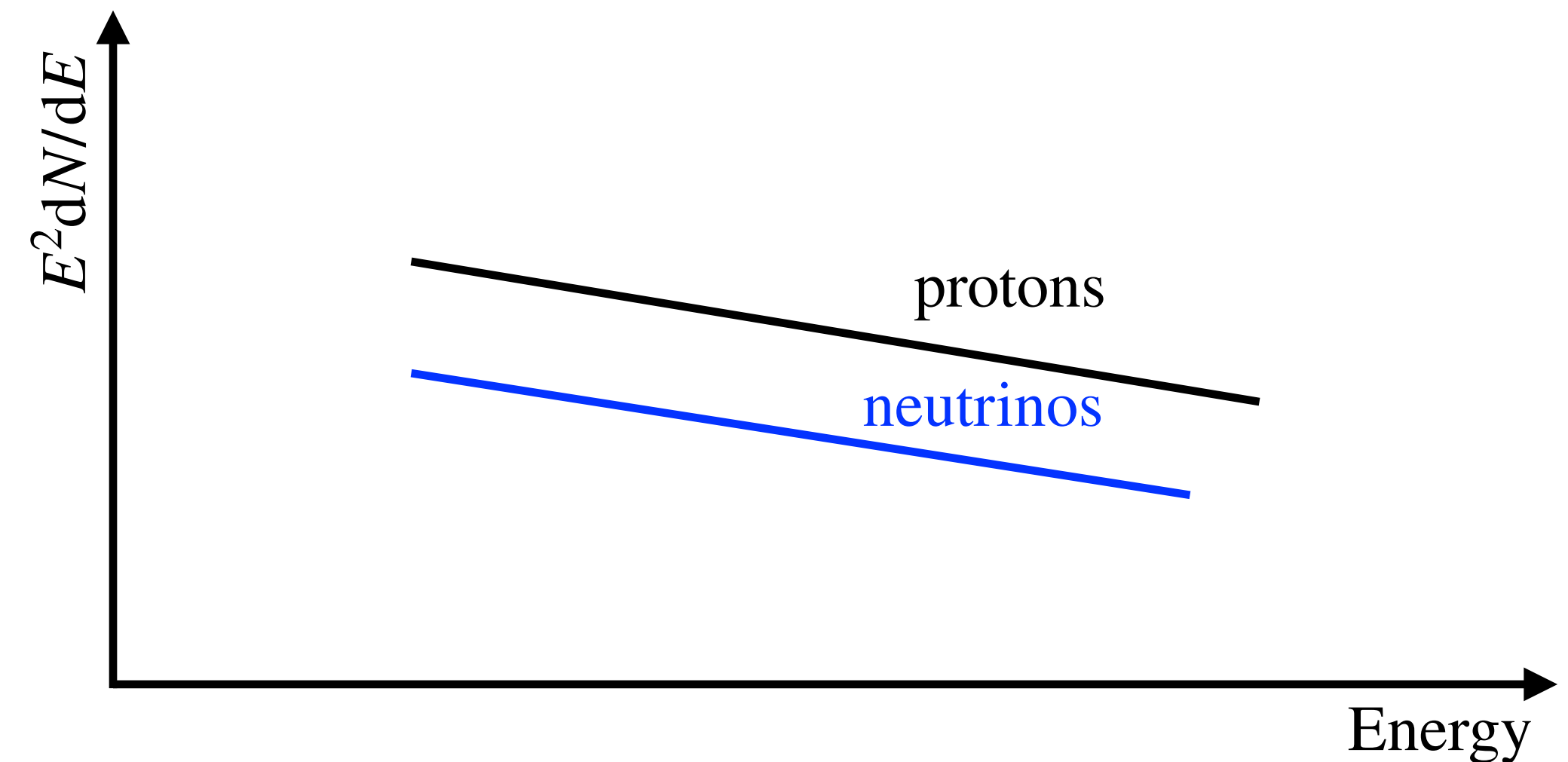
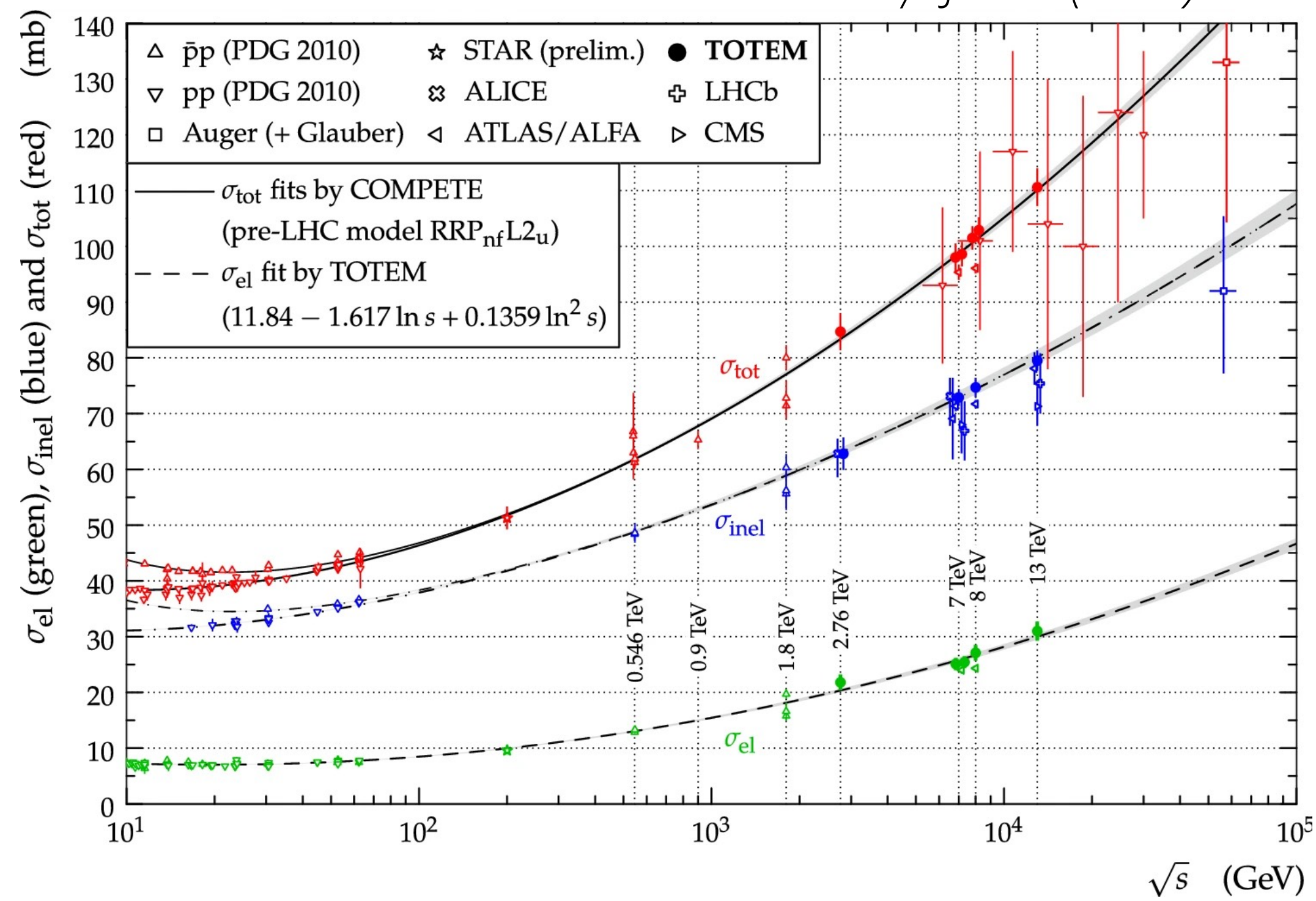
Since interaction length $\lambda(E) \propto 1/\sigma(E) \approx \text{const.}$
and meson production spectra

$$f(E_\pi, E_p) \approx f(E_\pi/E_p)$$

For $dN/dE \sim E_p^{-\gamma}$

$$dN/dE_\nu \sim dN/dE_\pi \sim E_p^{-\gamma}$$

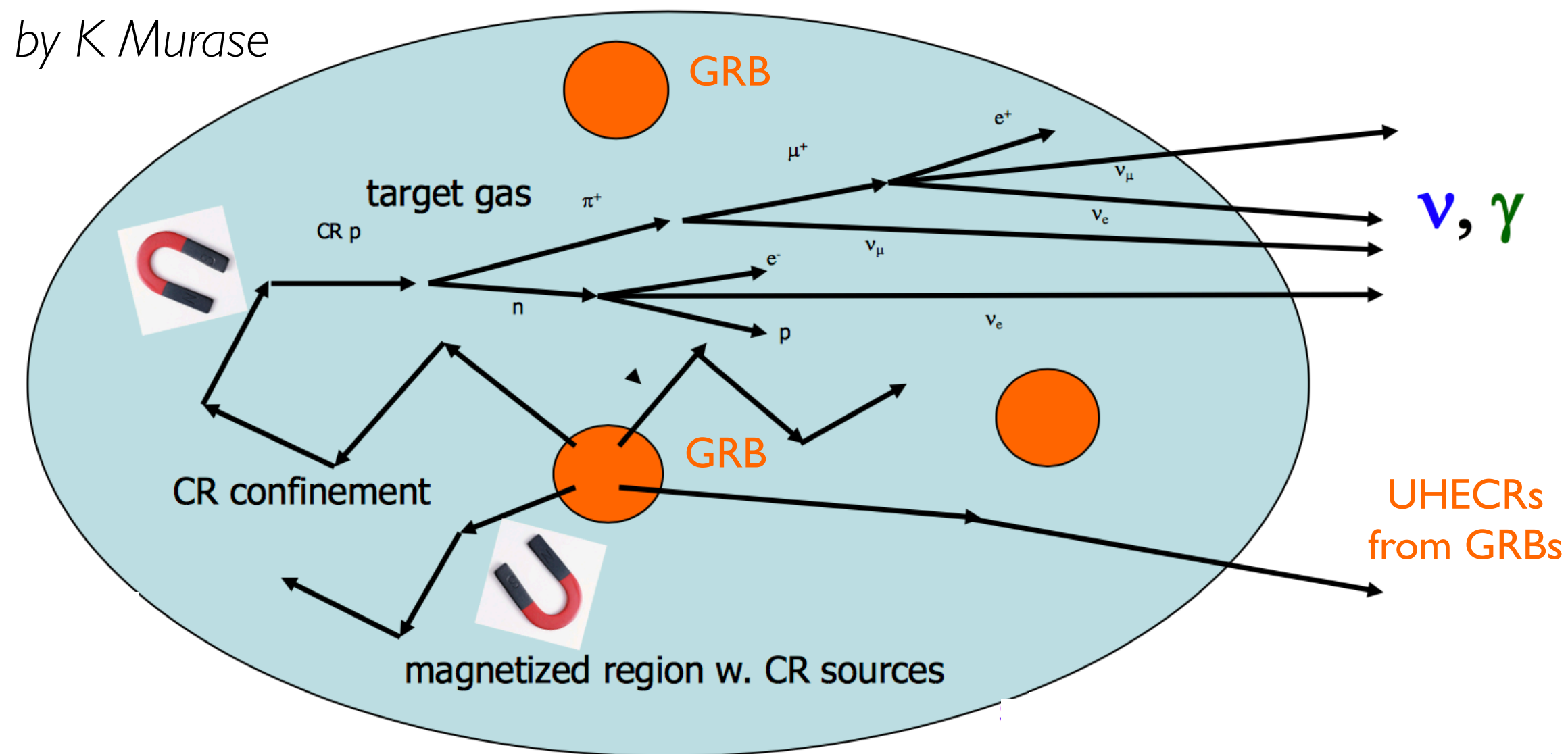
TOTEM Coll. Eur.Phys.J.C 79 (2019) 103



Neutrinos from starburst galaxies: Reservoir model

Loeb, Waxman

sketch by K Murase



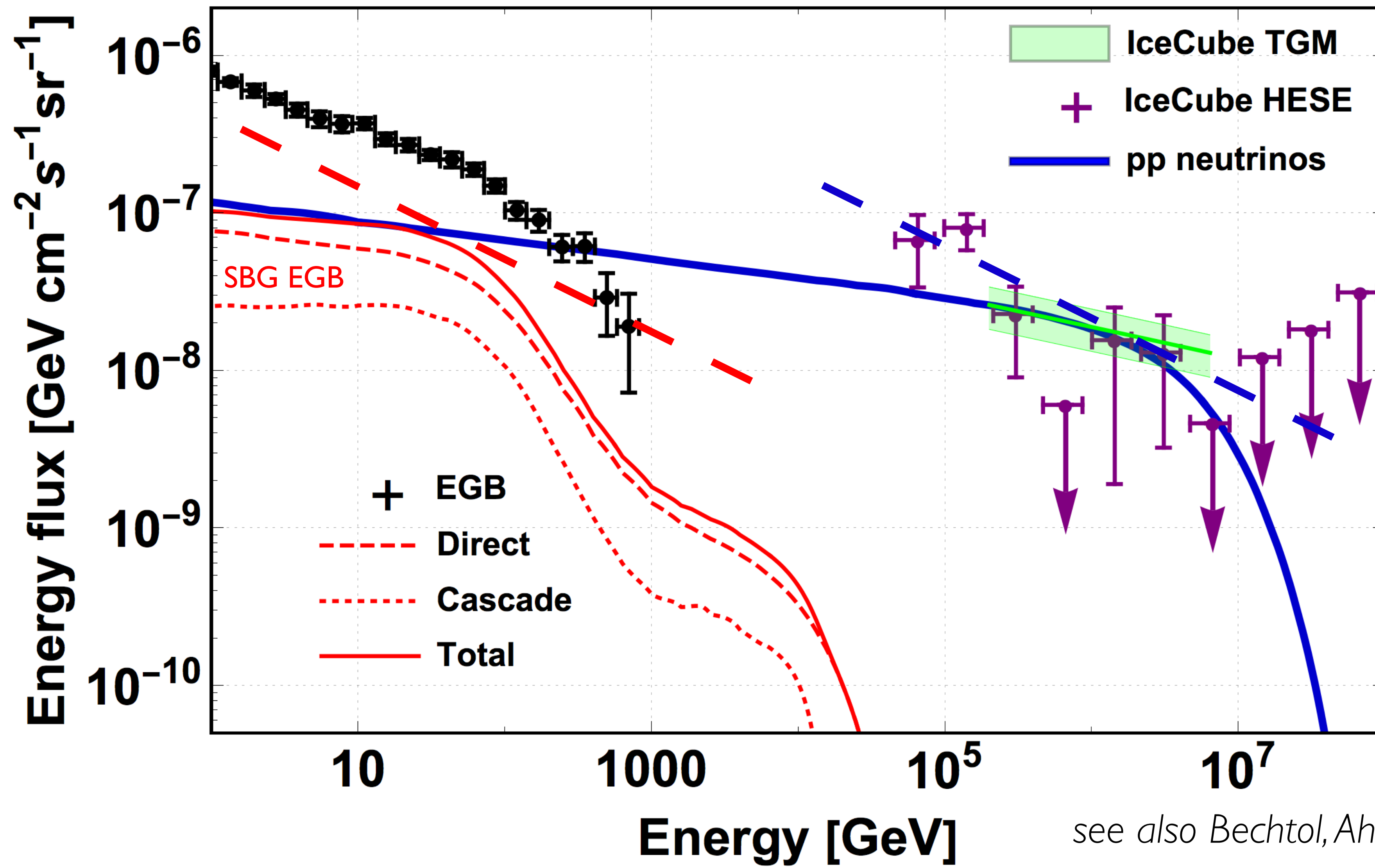
High gas density, high B environment

The highest energy cosmic rays escape (observed)

Lower energy CRs lose all their energy in pp interactions

Neutrinos from starburst galaxies

Palladino et al 2019

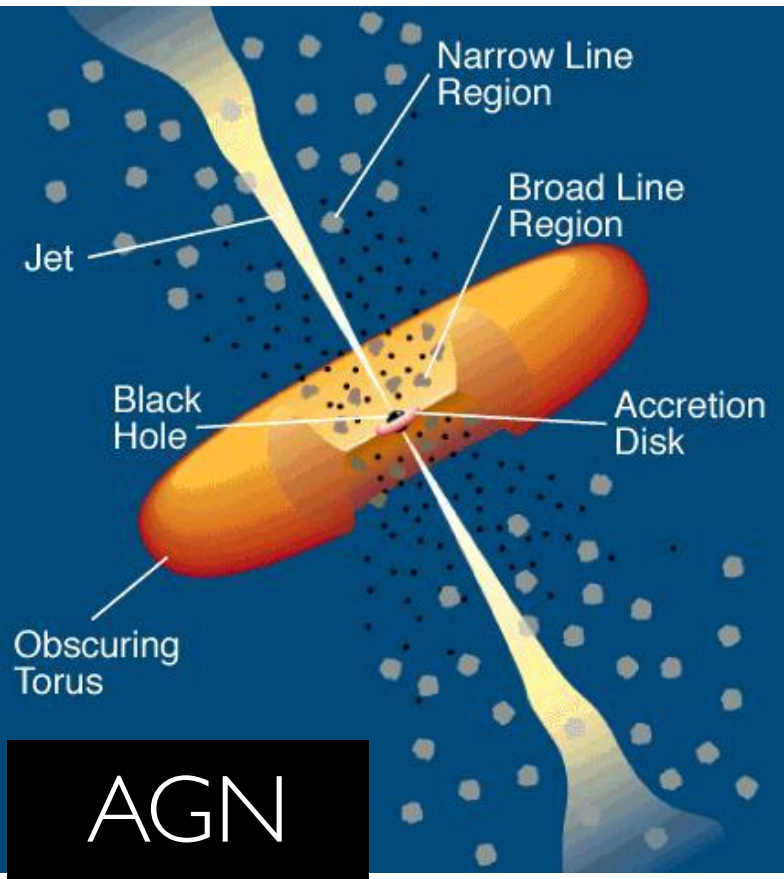
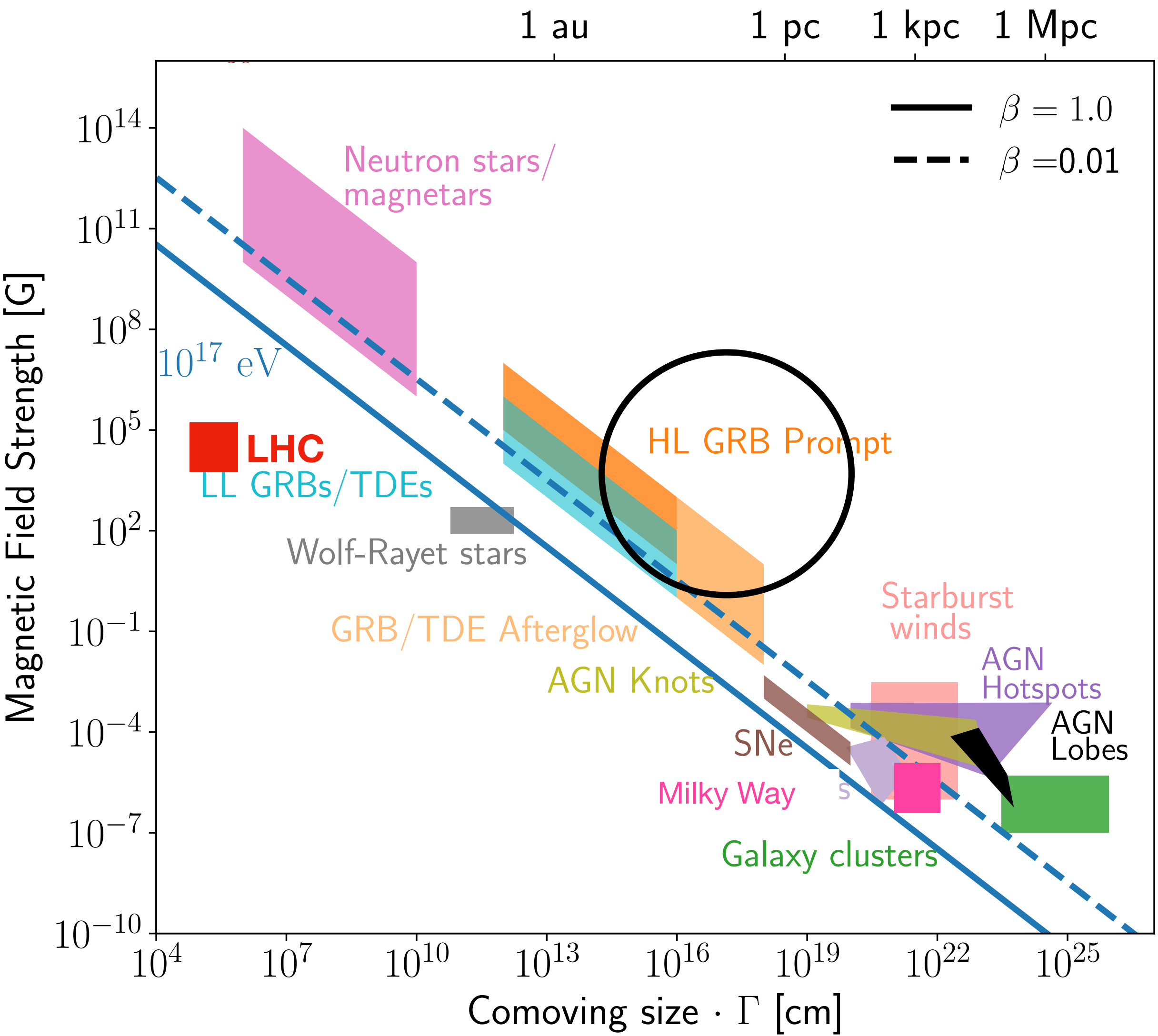


see also Bechtol, Ahlers et al 2015

Scorecard

	$E_{\text{max}}^{\text{UHECR}}$	n_{UHECR}	$\dot{\epsilon}_{\text{UHECR}}$	n_{ν}	Stacking UL	
BL Lacs	😄	😞	😄	😞	$\lesssim 20\%$	
FSRQs	😄	😞	😄	😞	$\lesssim 20\%$	
FR I	😄	😄	😄	😄	$\lesssim 20\%$	
FR II	😄	😄	😄	😄	$\lesssim 20\%$	
Non-jetted AGN	😐	😄	😄	😄	$\lesssim 100\%$	*(but problems at medium E)
Starburst galaxies	😞	😄	😄	😄	$\lesssim 100\%$	
HL GRBs						
LL GRBs						
TDEs						

Cosmic-ray accelerators that satisfy the confinement req (10¹⁷ eV)



Gamma-ray bursts

Discovered serendipitously in 1967

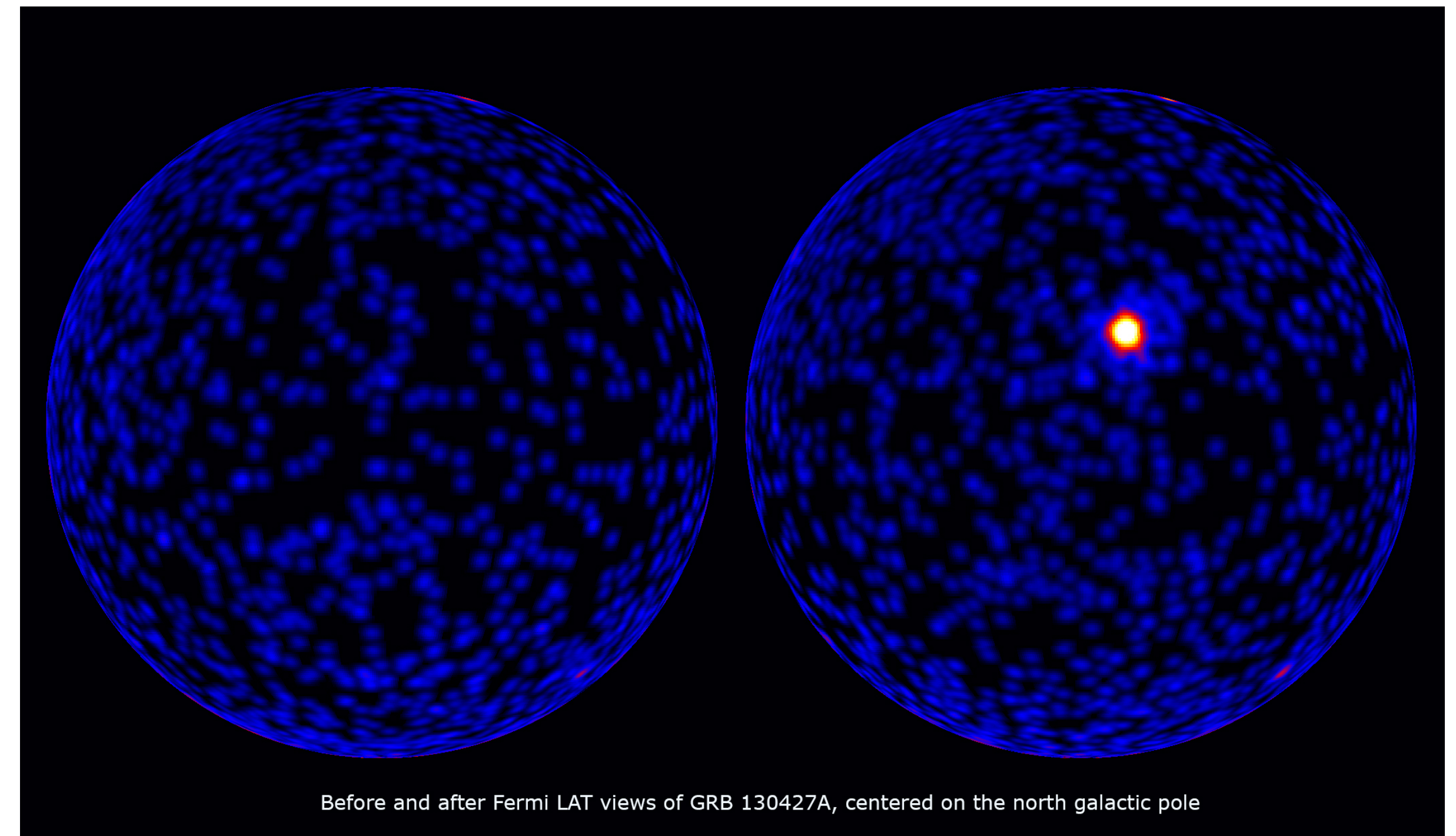
Intense short flashes of light peaking in the 10 keV - 1 MeV range

Isotropic equivalent energy release $\sim 10^{52}$ - 10^{55} erg (cf $< 10^{49}$ erg/s in AGN)

Rate $\sim$ 1000 year occur in the Universe

Short (0.3 second) and long (50 second) bursts - Two distinct populations

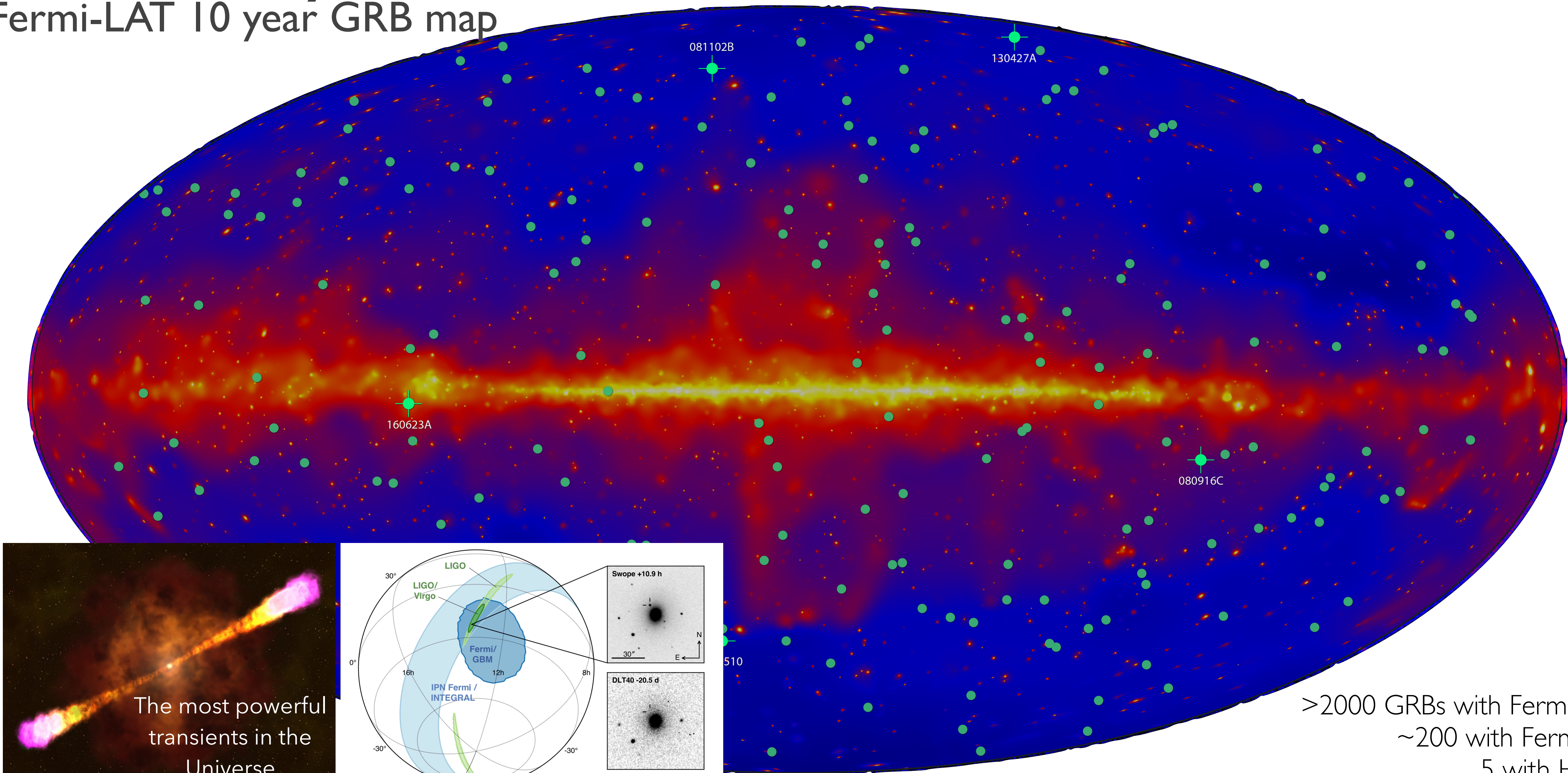
“Afterglow” fading emission for hours to months



Gamma-ray bursts

Fermi-LAT 10 year GRB map

Fermi-LAT 2nd GRB Catalogue, 2019



Binary neutron star mergers: GW170817

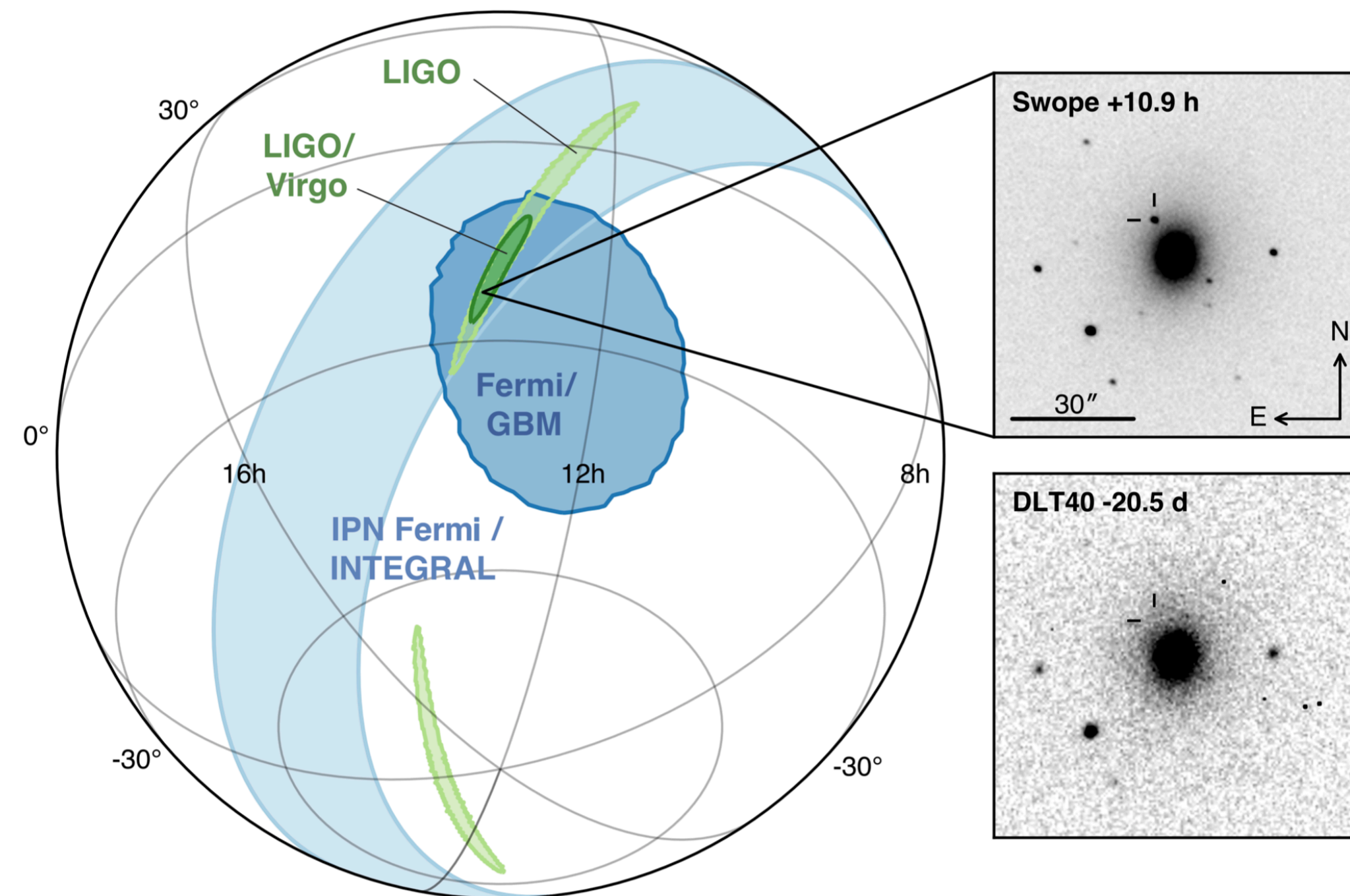
On August 17th, 2017 LIGO and Virgo reported the detection of GWs from the coalescence of a binary neutron star system

Fermi GBM independently detected the sGRB GRB170817A, 1.7s later

An extensive observational campaign localised SGRB in the early type NGC 4993, at $d \sim 40$ Mpc

GW170817 and GRB170817A confirm binary neutron stars as progenitors of SGRBs ($p_{\text{chance}} \sim 10^{-8}$)

*LIGO, Virgo, Fermi Coll+ many others,
Astrophys.J. 848 (2017) no.2, L12*



UHECR maximum energy

Very high Lorentz factors, $\Gamma = 100-1000$

Highly magnetised expanding jet

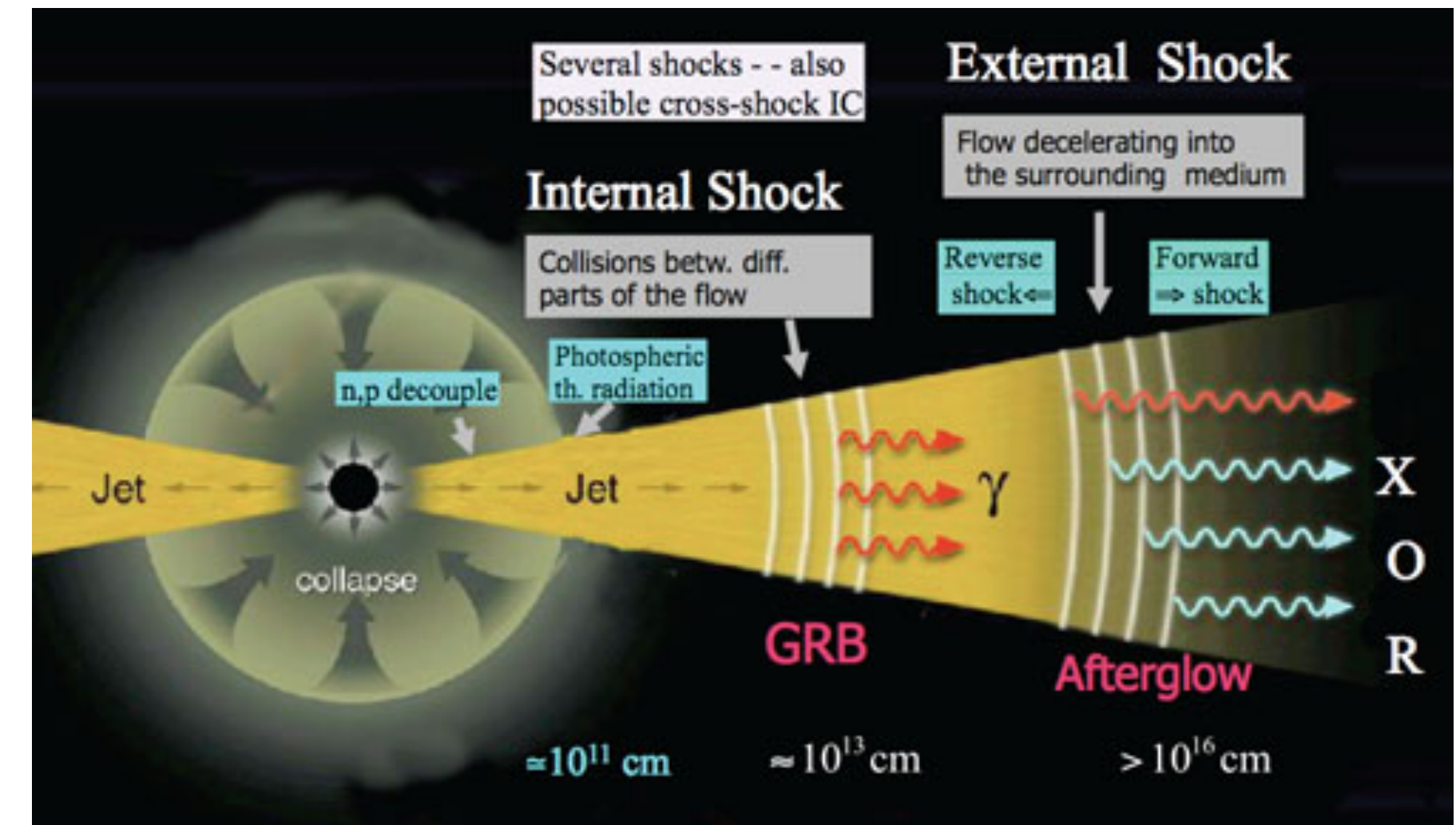
$$B'_{\text{eq}} = \frac{1}{\Gamma R} \sqrt{\frac{2L_{\text{iso}}}{c}} \approx 3 \times 10^5 \text{ G} \left(\frac{L_{\text{iso}}}{10^{52} \text{ erg s}^{-1}} \right)^{1/2} \left(\frac{\Gamma}{300} \right)^{-1} \left(\frac{R}{10^{13} \text{ cm}} \right)^{-1}$$

$$E_{\text{max}} = ZeB'_{\text{eq}} \Gamma R' \simeq ZeB'_{\text{eq}} R = \frac{Ze}{\Gamma} \sqrt{\frac{2L_{\text{iso}}}{c}} \approx 8 \times 10^{20} \text{ eV} \cdot Z \left(\frac{L_{\text{iso}}}{10^{52} \text{ erg s}^{-1}} \right)^{1/2} \left(\frac{\Gamma}{300} \right)^{-1}$$

Waxman 1995, Vietri 1995

Maximum energy OK for protons

Nuclei survival in GRB photon fields?



UHECRs from GRBs?

GRB rate:

$$\rho \approx 10^{-9} - 10^{-8} \text{ Mpc}^{-3} \text{ year}^{-1}$$

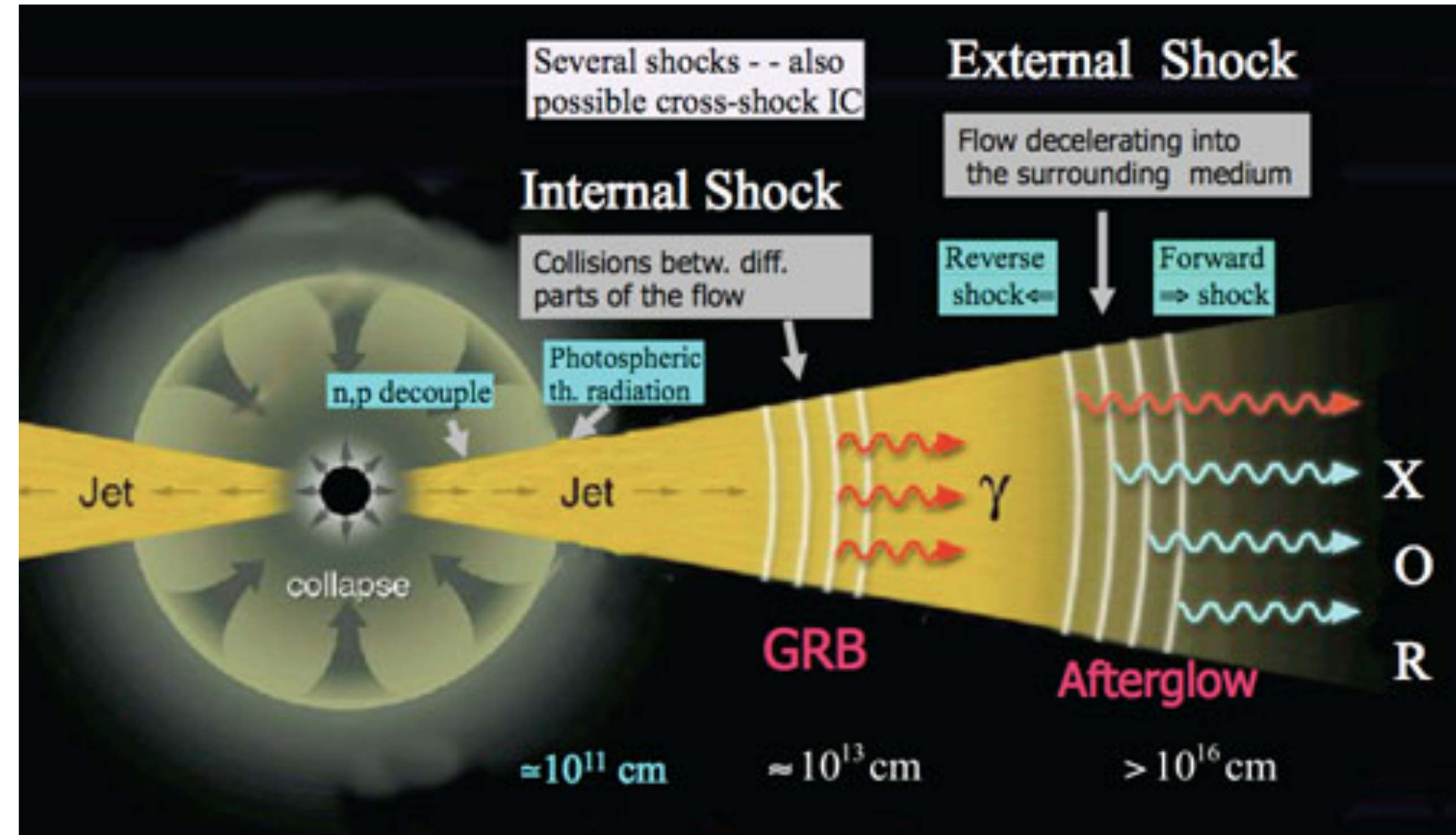
The apparent number density is:

$$n_{\text{eff,GRB}} \sim \delta t \cdot \rho$$

And we inferred $n_{\text{UHECR}} \gtrsim 10^{-5} \text{ Mpc}^{-3}$

Thus GRBs may just about satisfy the number density constraint for $B_{\text{EGMF}} \gtrsim 0.1 \text{ nG}$

$$\delta t_{\text{delay}} = 1.5 \times 10^3 \text{ yr} \cdot \left(\frac{D}{100 \text{ Mpc}} \right)^2 \left(\frac{E}{10^{20} \text{ eV}} \right)^{-2} \left(\frac{\lambda_{\text{coh}}}{1 \text{ Mpc}} \right) \left(\frac{B}{0.1 \text{ nG}} \right)^2$$

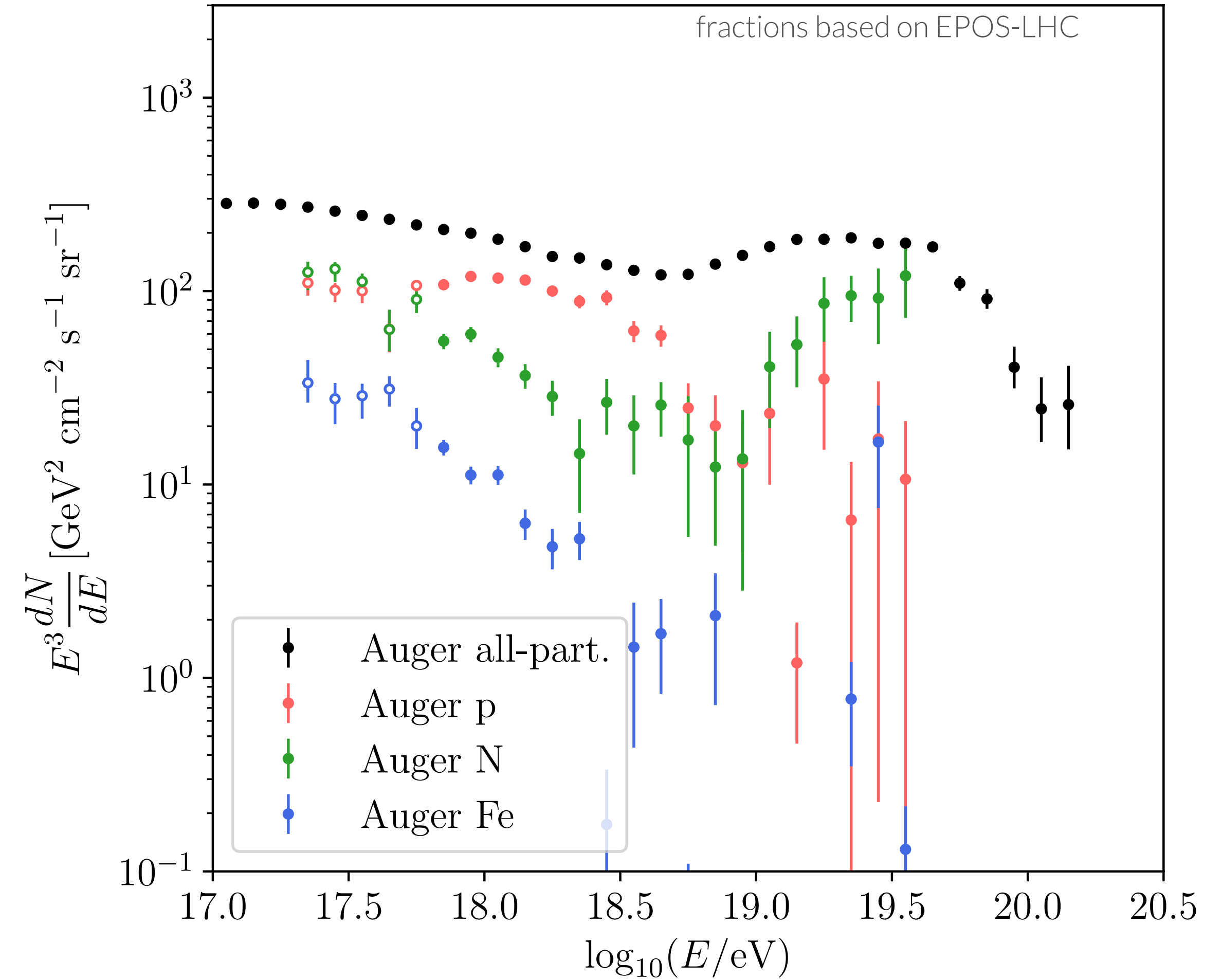
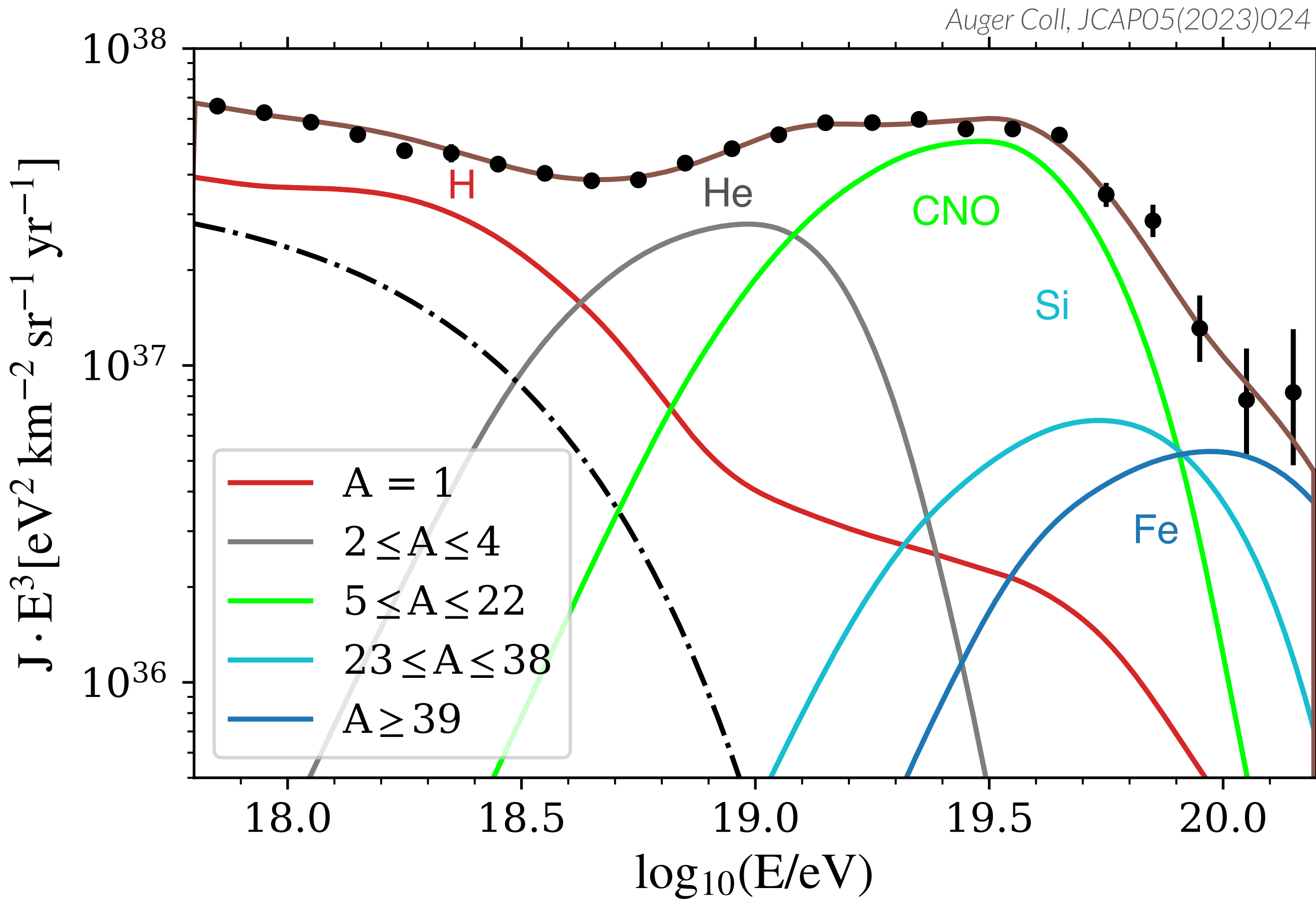


UHECR Spectrum and Composition Observables

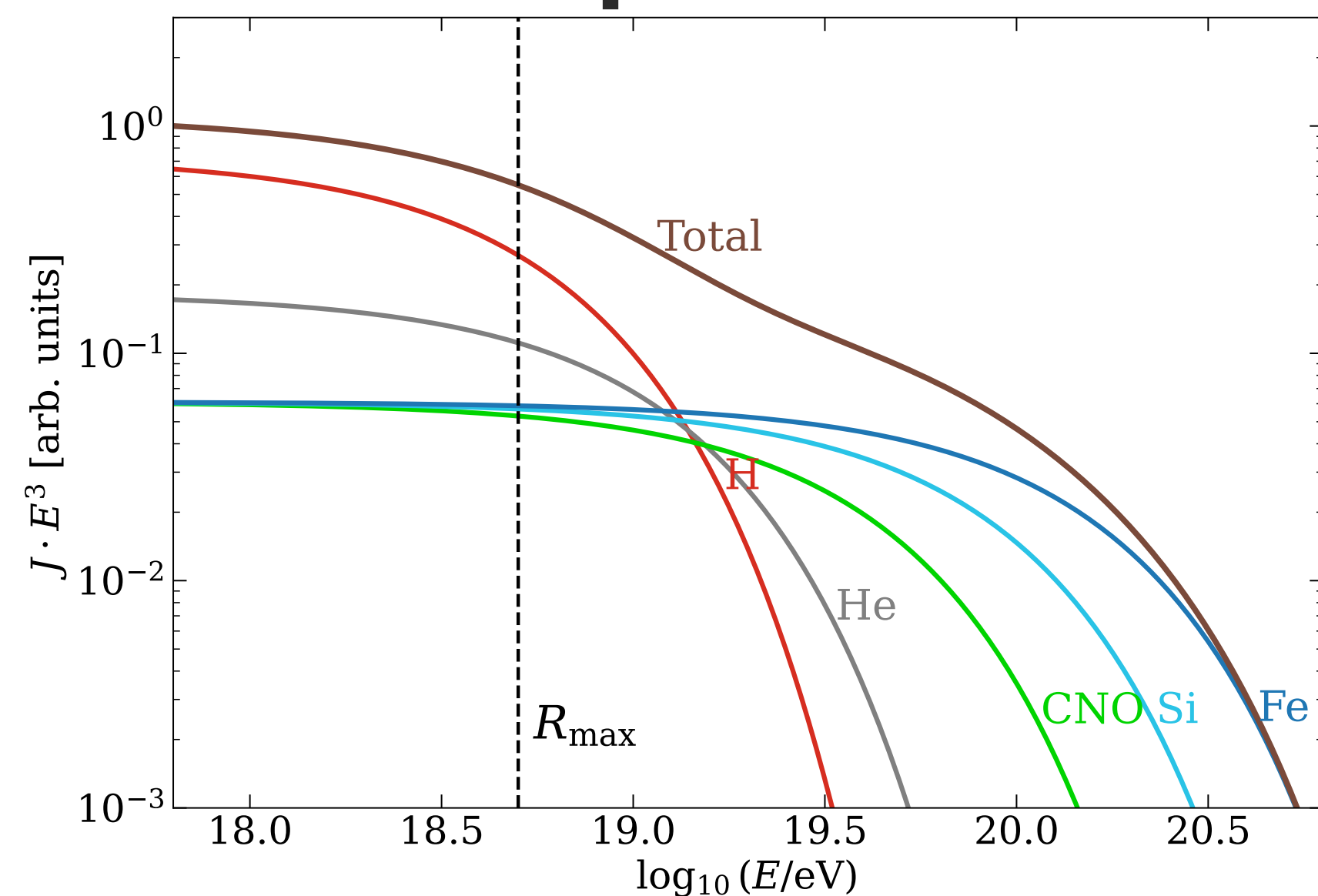
Auger Coll, PRL, 125, 121106, 2020

Tkachenko for Auger Coll, PoS(ICRC2023)438

Auger Coll, PRL, 134, 021001, 2024

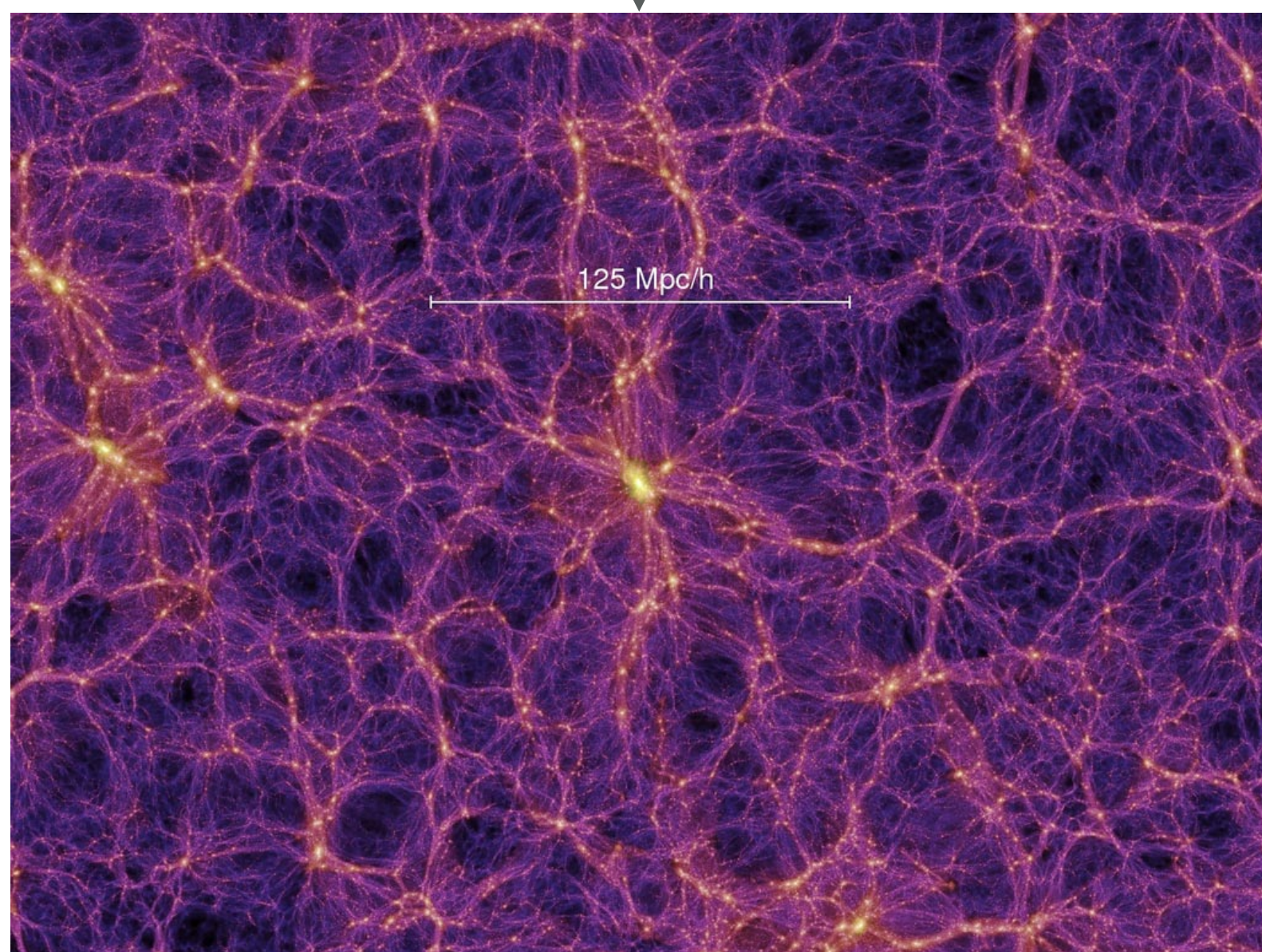


UHECR Spectrum and Composition Observables

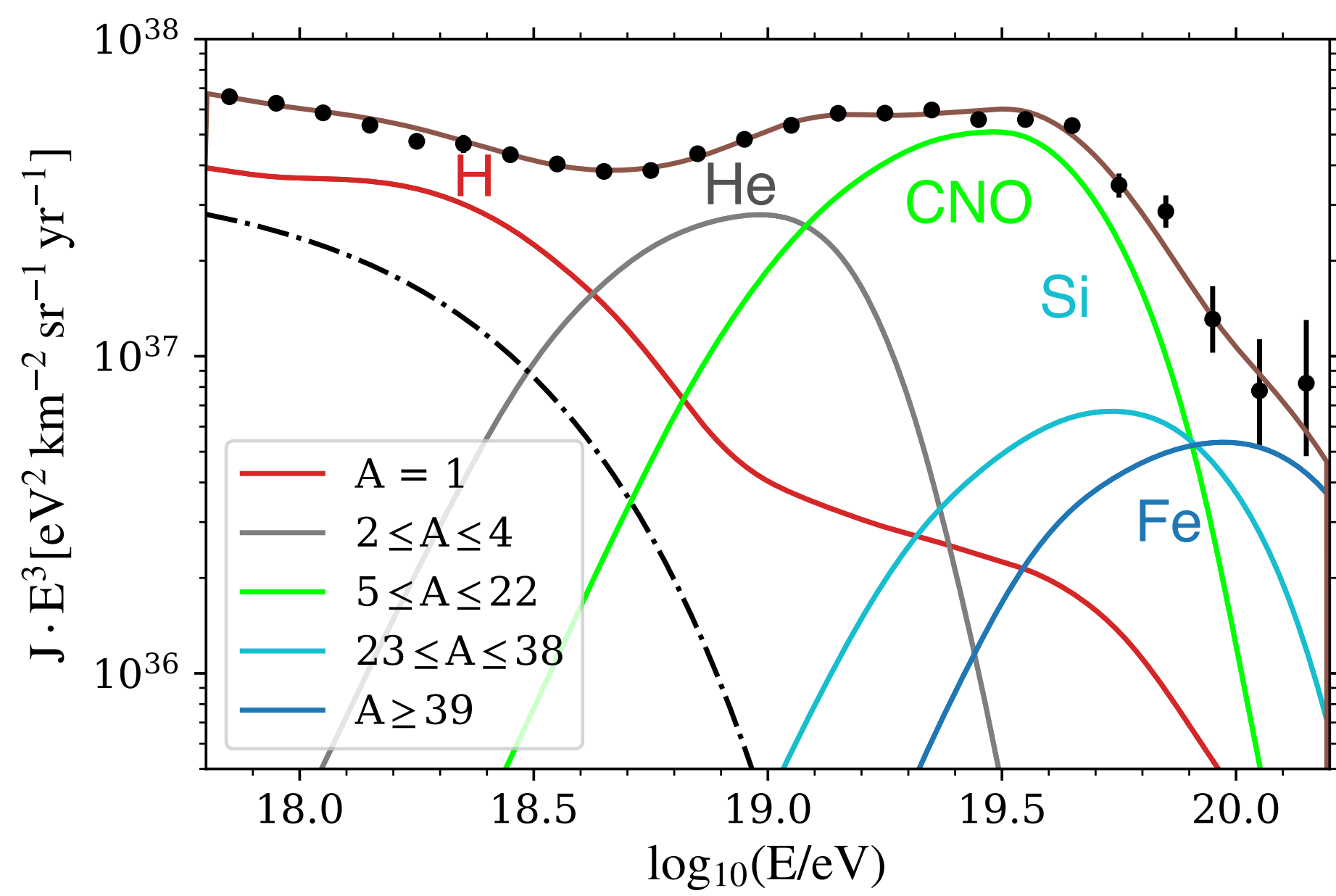


Each source characterised by:

- R_{max}
- Spectral index
- Composition

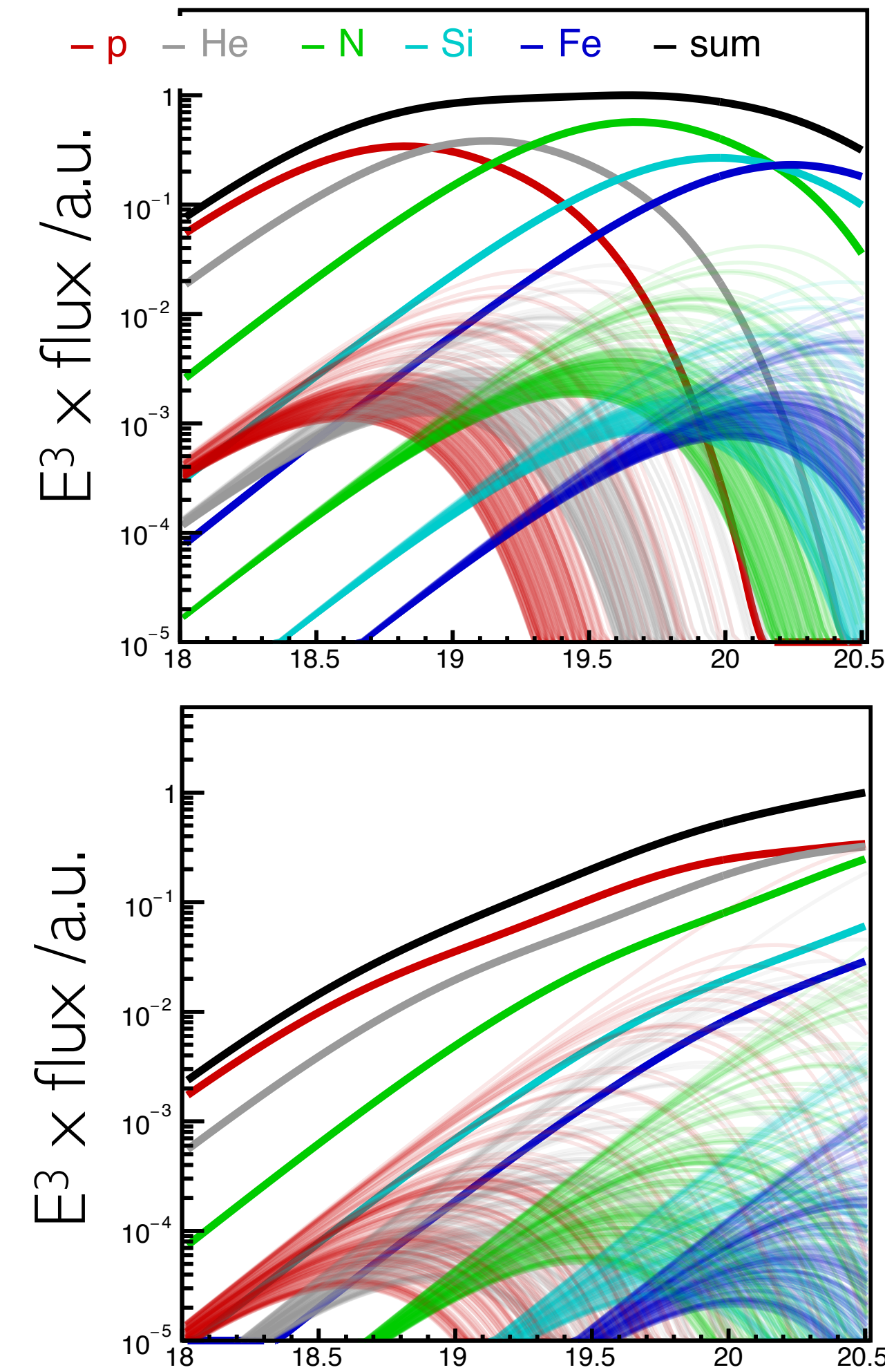
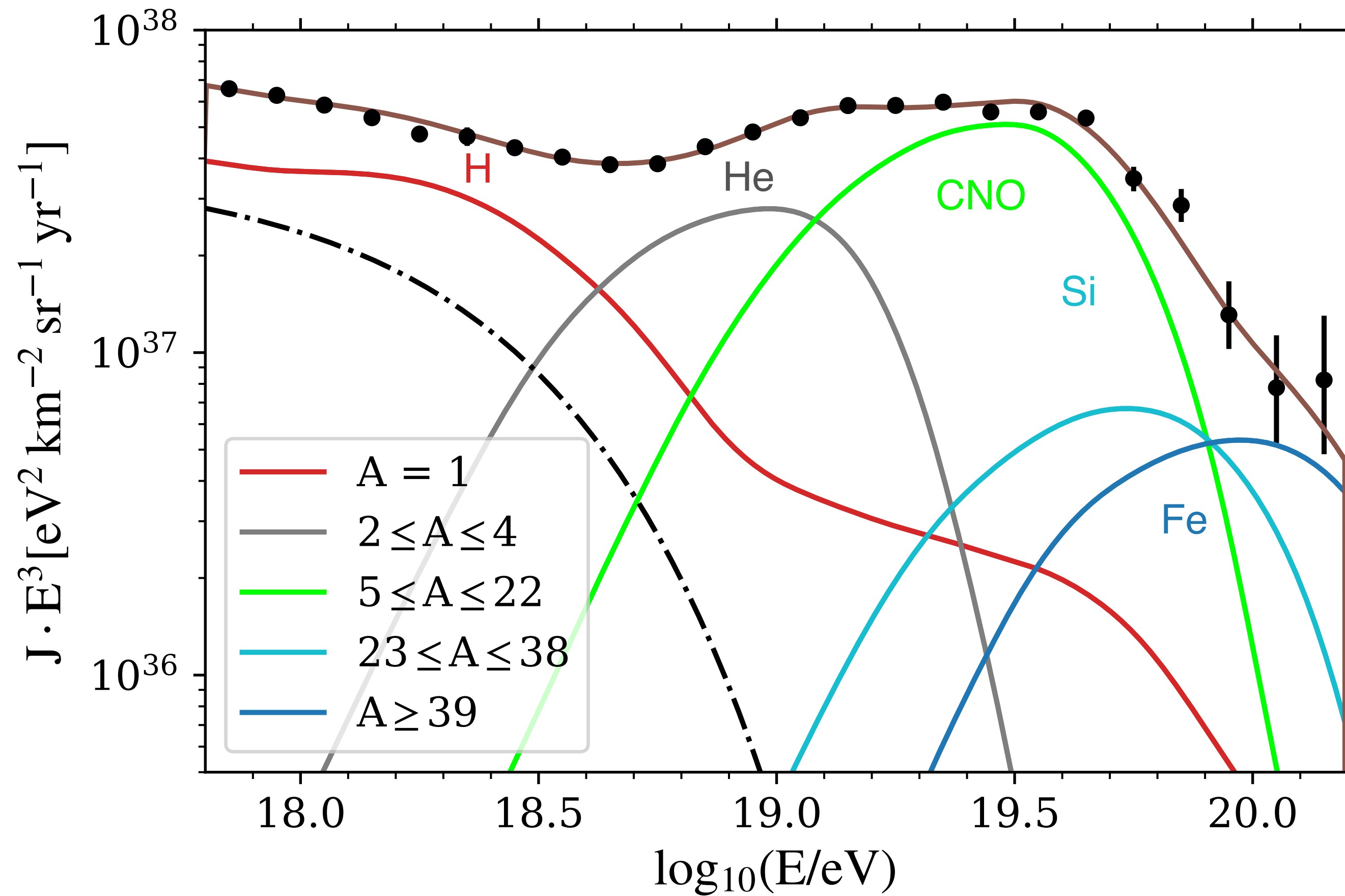


particle
transport

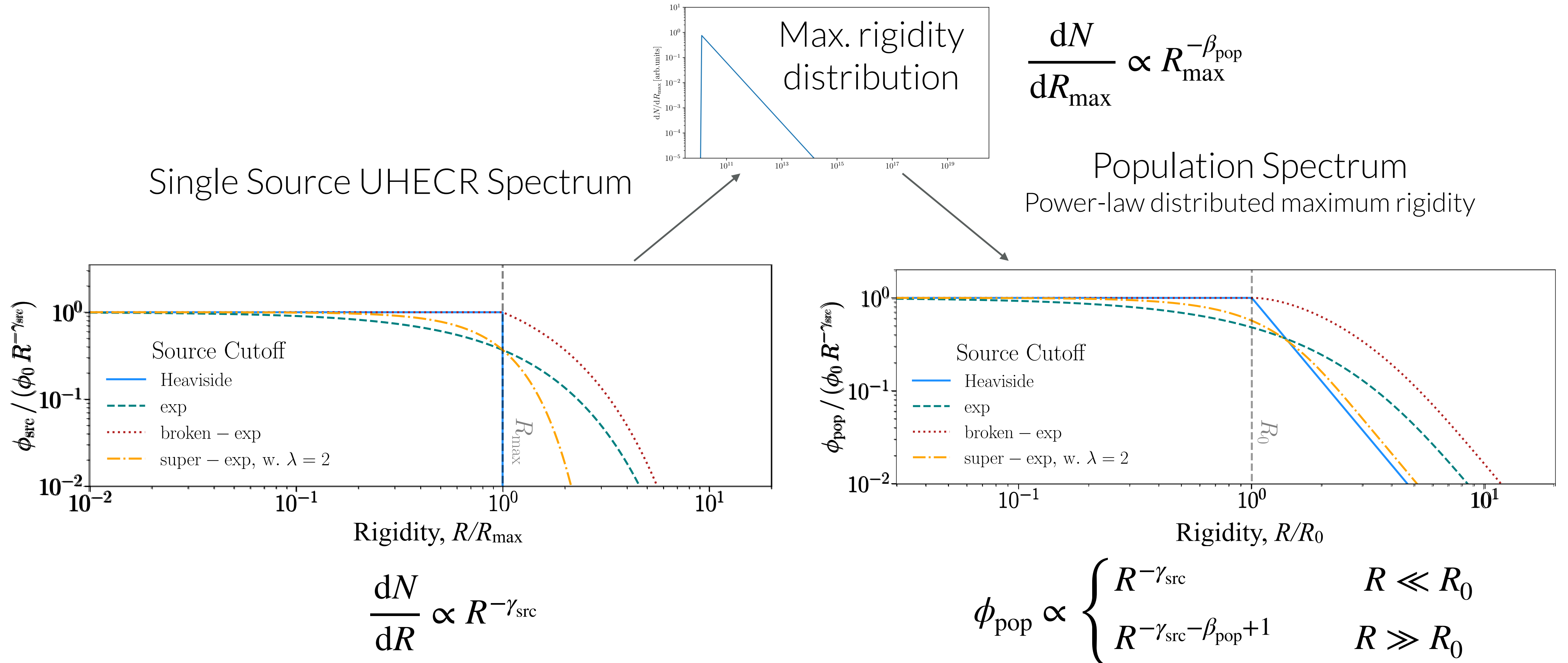


From identical sources to a population

D. Ehlert, FO, M. Unger, PRD 107 (2023) 10



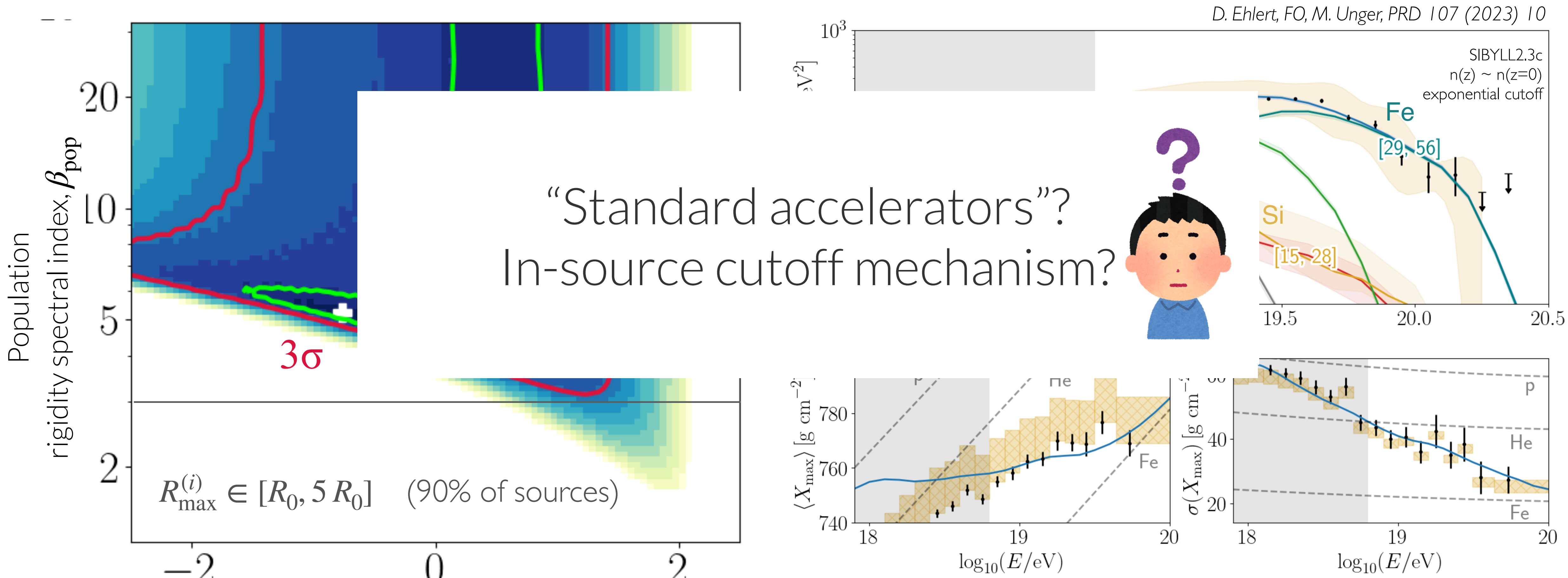
From identical sources to a population



Broken exponential, e.g. Auger Combined Fit (Aab et al 2017)

Super exponential in case of DSA with synchrotron losses with $dN/dR \propto \exp - R^\lambda, \lambda = 2$ e.g. Zirakasvili & Aharonian 2007

A curious maximum rigidity distribution



Inv **Conclusion #2:** UHECR sources are few or near-identical E_{max}

spectral index, β_{src}

131

αK

αK_{max}

UHECRs from GRBs?

GRB rate:

$$\rho \approx 10^{-9} - 10^{-8} \text{ Mpc}^{-3} \text{ year}^{-1}$$

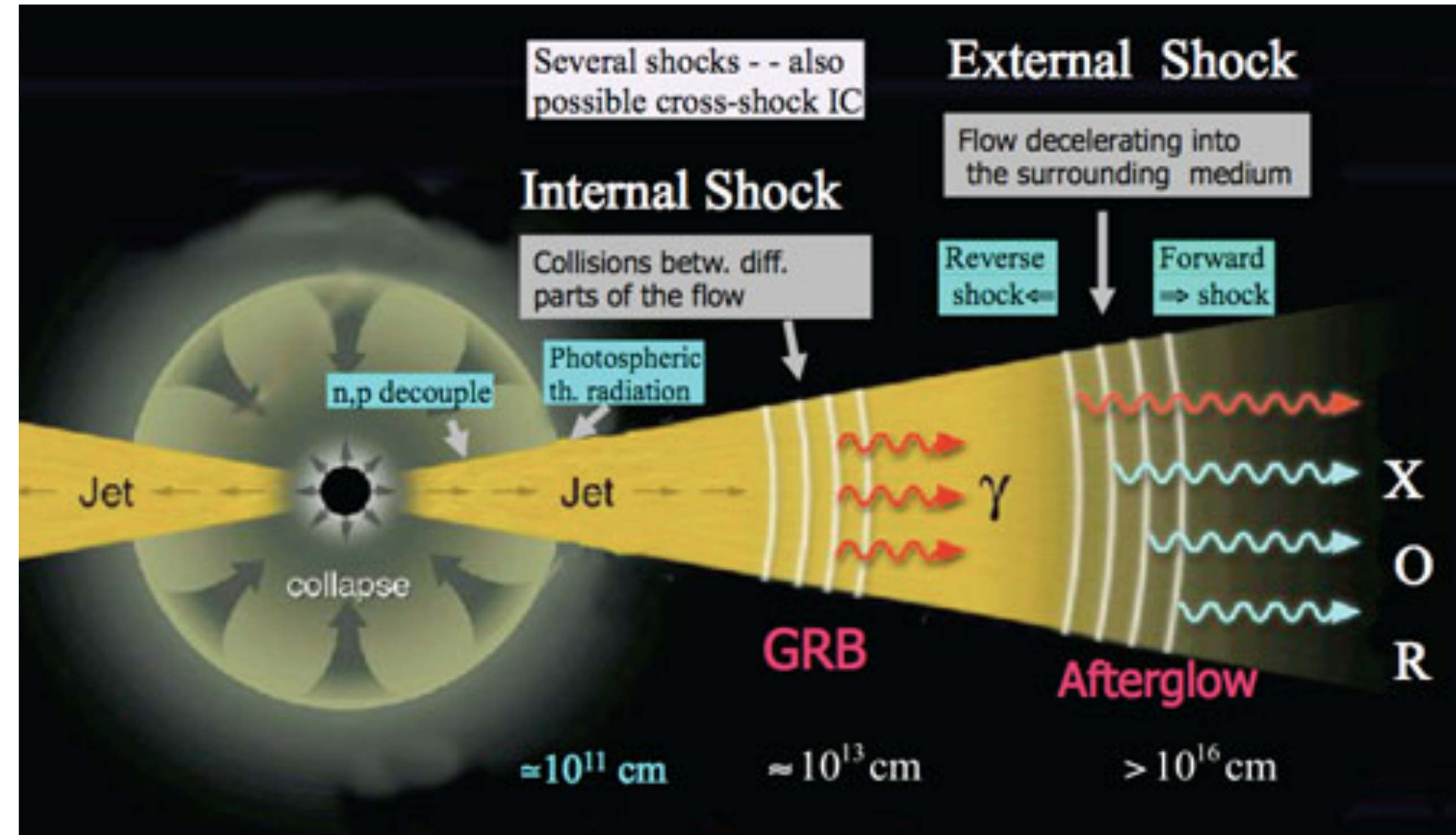
The apparent number density is:

$$n_{\text{eff,GRB}} \sim \delta t \cdot \rho$$

And we inferred $n_{\text{UHECR}} \gtrsim 10^{-5} \text{ Mpc}^{-3}$

Thus GRBs may just about satisfy the number density constraint for $B_{\text{EGMF}} \sim 0.1 \text{ nG}$

$$\delta t_{\text{delay}} \approx 1.5 \times 10^3 \text{ yr} \cdot \left(\frac{D}{100 \text{ Mpc}} \right)^2 \left(\frac{E}{10^{20} \text{ eV}} \right)^{-2} \left(\frac{\lambda_{\text{coh}}}{1 \text{ Mpc}} \right) \left(\frac{B}{0.1 \text{ nG}} \right)^2$$



Neutrino production in GRBs

Ample photon fields

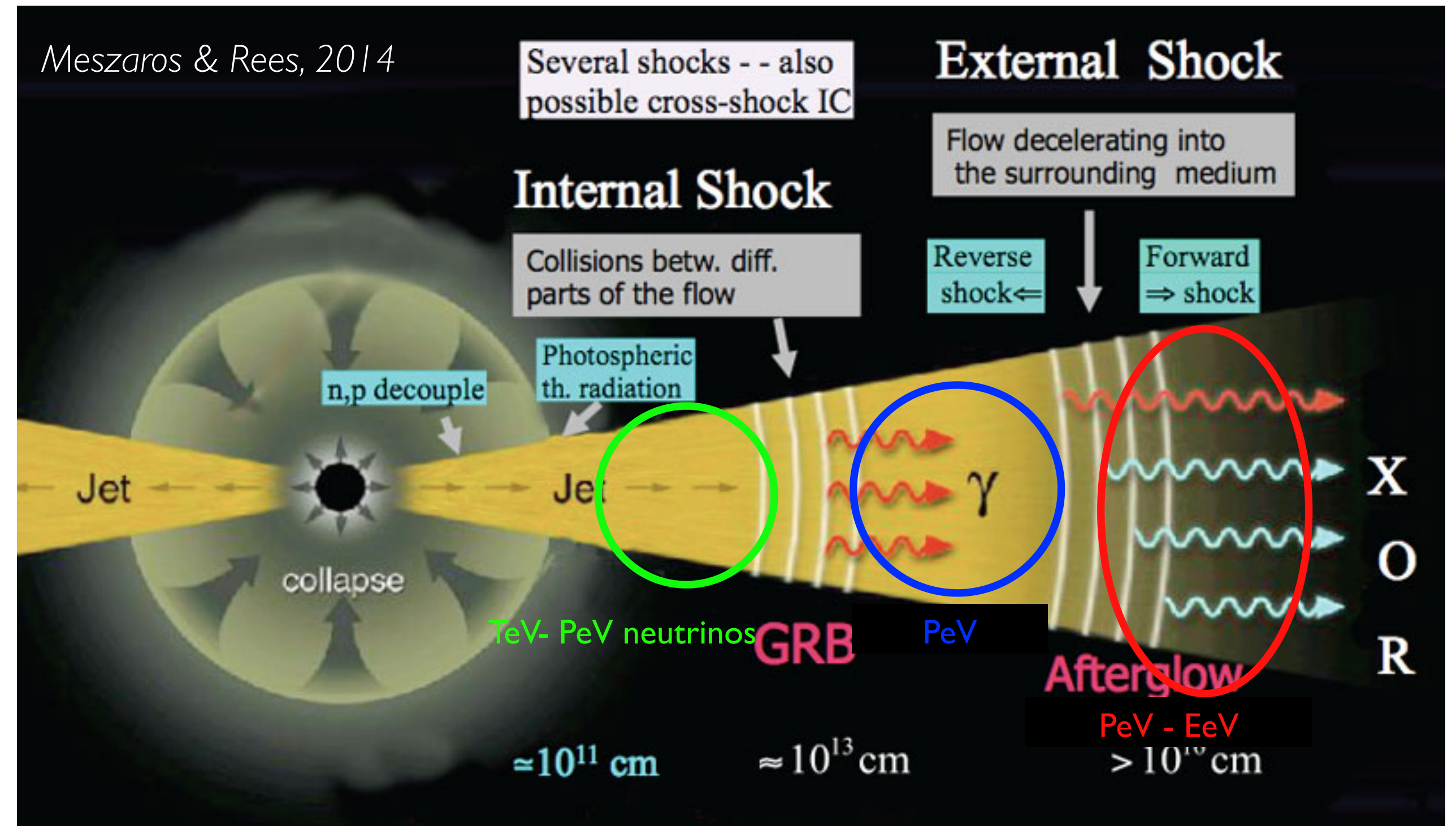
$$p + \gamma_{\text{jet}} \rightarrow n/p + \pi^+/\pi^0$$

$$E_p E_\gamma \gtrsim \frac{m_\Delta^2}{4} \left(\frac{\Gamma}{1+z} \right)^2 = 0.16 \text{ GeV} \left(\frac{\Gamma}{1+z} \right)^2$$

$$E_\nu \geq 8 \text{ GeV} \left(\frac{\Gamma}{1+z} \right)^2 \left(\frac{E_\gamma}{\text{MeV}} \right)^{-1}$$

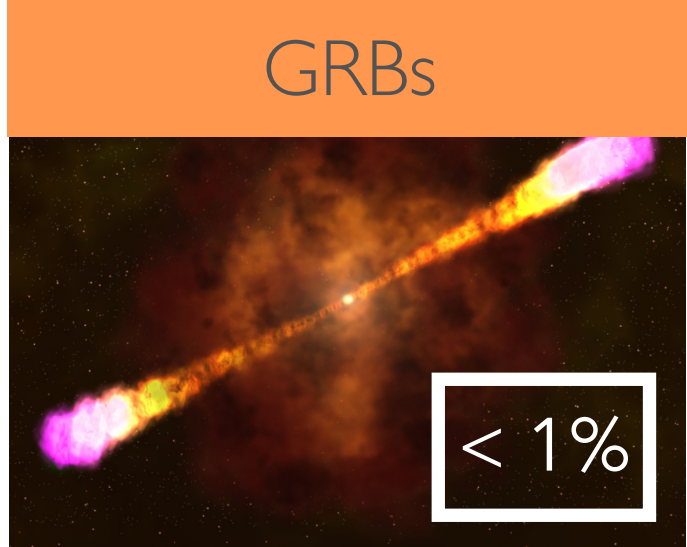
e.g. prompt emission,

$$z = 1, \Gamma^2 = 10^5, E_\gamma \sim 250 \text{ keV} \rightarrow E_\nu \sim \text{PeV}$$



> 100 publications on theoretical expectations:
see e.g. review "Neutrinos from GRBs" (Kimura 2022)

GRB contribution to the cosmic-neutrino flux



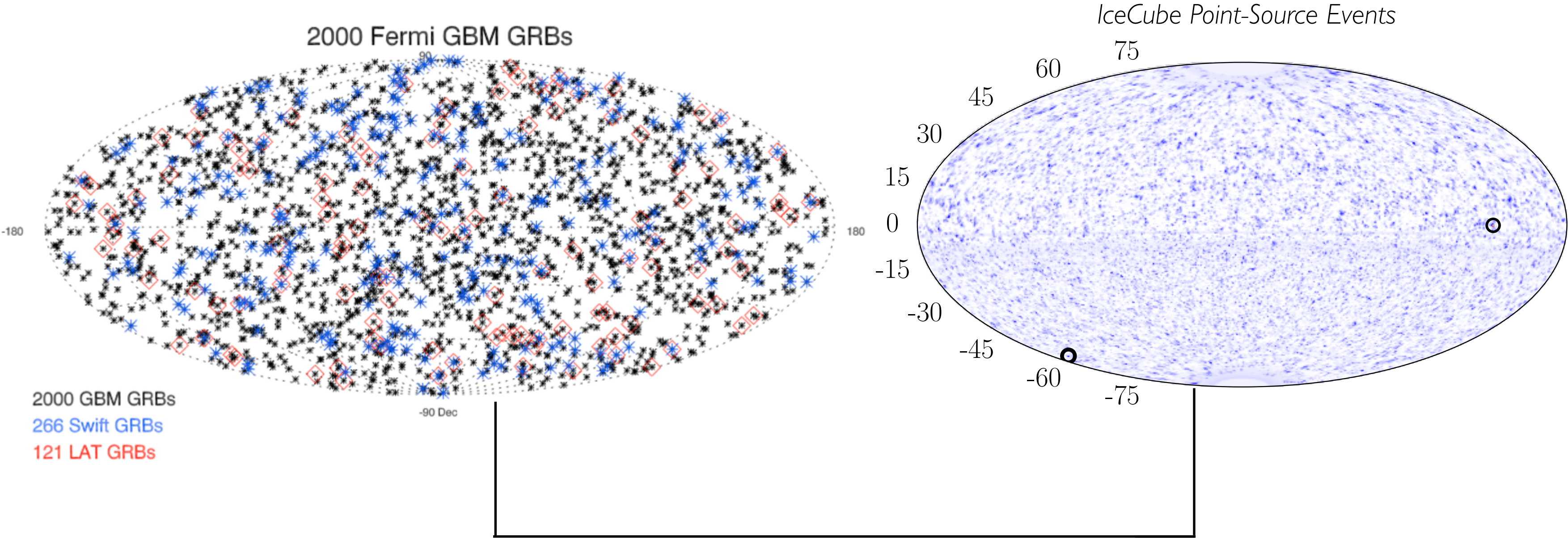
GRBs

NS/NS Mergers



Stacked search for
neutrinos coincident with
prompt GRB emission.

2091 GRBs



IceCube Coll, ApJ 843 (2017) 112
IceCube Coll., Fermi GBM Coll, ApJ 939 (2022) 2
+strong limits from GRB221009A (the ``BOAT'')
IceCube Coll ApJL 946 L26 (2023)
ANTARES Coll MNRAS 469 906 (2017)

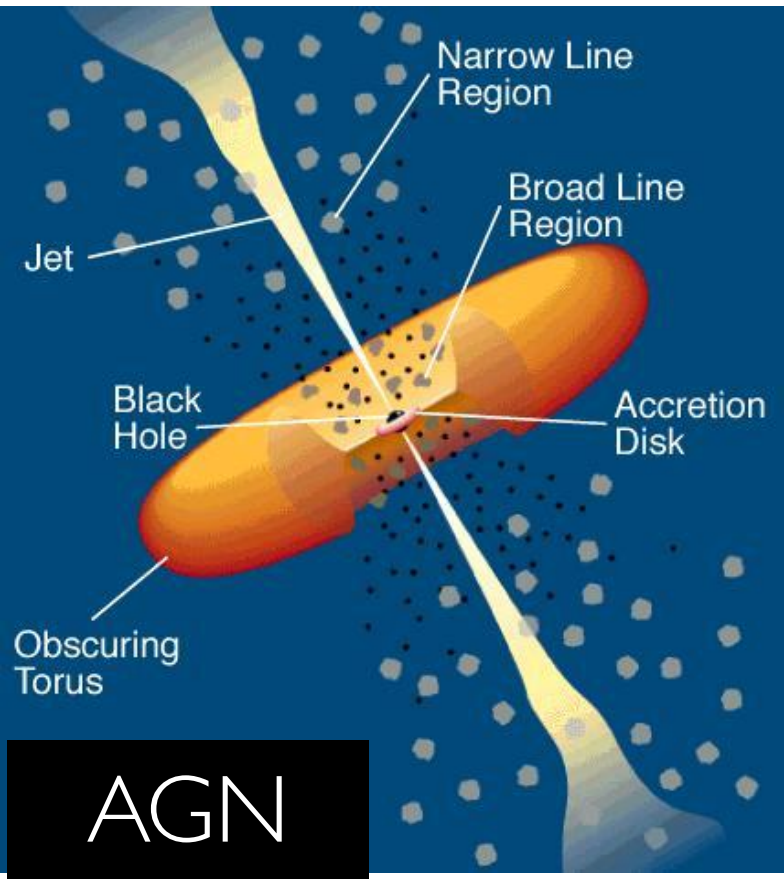
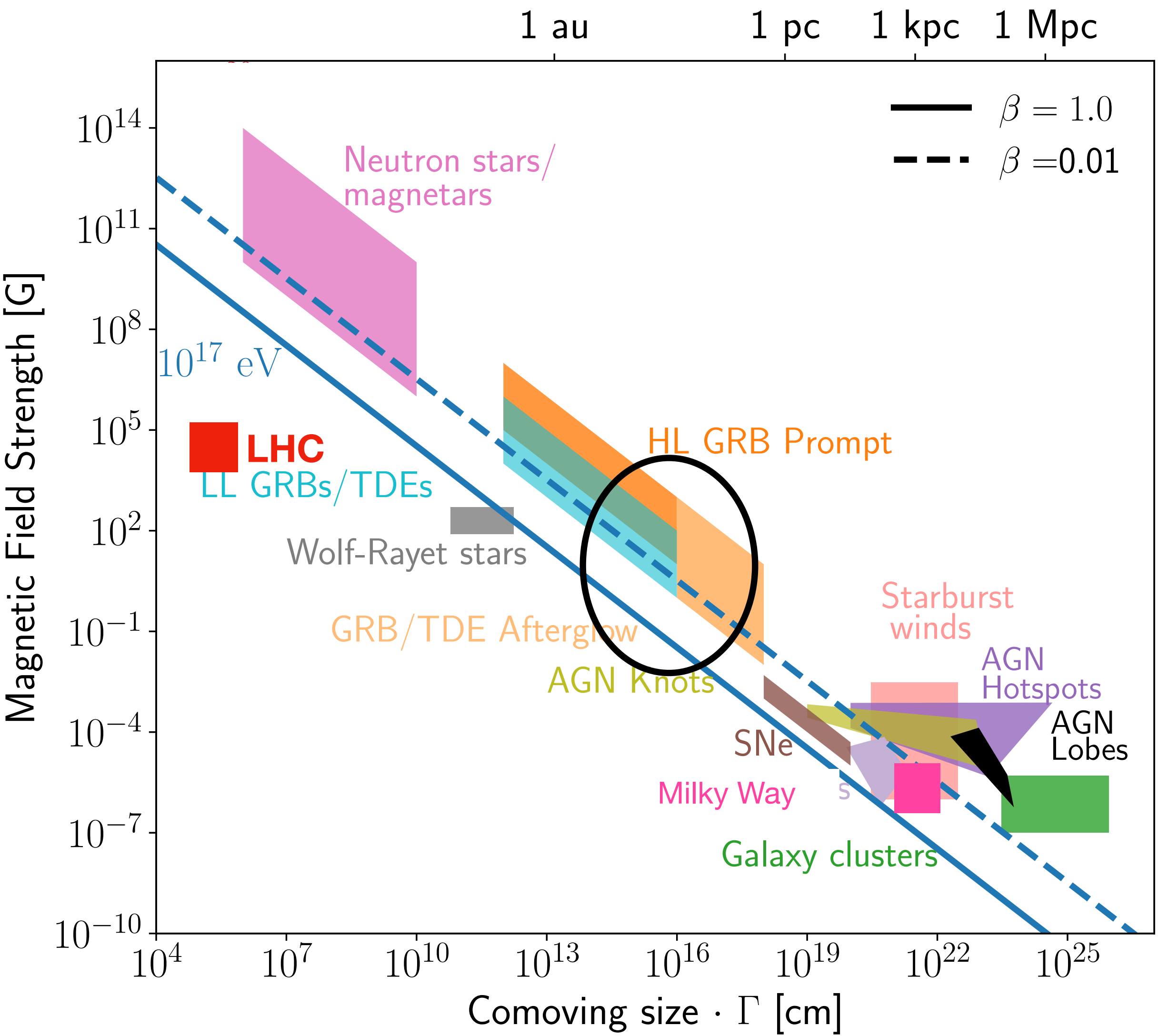
Prompt ($\Delta T_{\text{prompt}} \sim 1-100\text{s}$): < 1% diffuse neutrino flux

Precursor/Afterglow ($\Delta T_{\text{afterglow}} \pm 14\text{d}$): < 24% diffuse neutrino flux

Scorecard

	$E_{\text{max}}^{\text{UHECR}}$	n_{UHECR}	$\dot{\epsilon}_{\text{UHECR}}$	n_{ν}	Stacking UL
BL Lacs	😄	😞	😄	😞	$\lesssim 20\%$
FSRQs	😄	😞	😄	😞	$\lesssim 20\%$
FR I	😄	😄	😄	😄	$\lesssim 20\%$
FR II	😄	😄	😄	😄	$\lesssim 20\%$
Non-jetted AGN	😐	😄	😄	😄	$\lesssim 100\%$
Starburst galaxies	😞	😄	😄	😄	$\lesssim 100\%$
GRBs	😄	😐	😐	😐	$\lesssim 1\%$
TDEs					

Cosmic-ray accelerators that satisfy the confinement req (10¹⁷ eV)



Tidal disruption events

SMBHs are orbited by star clusters

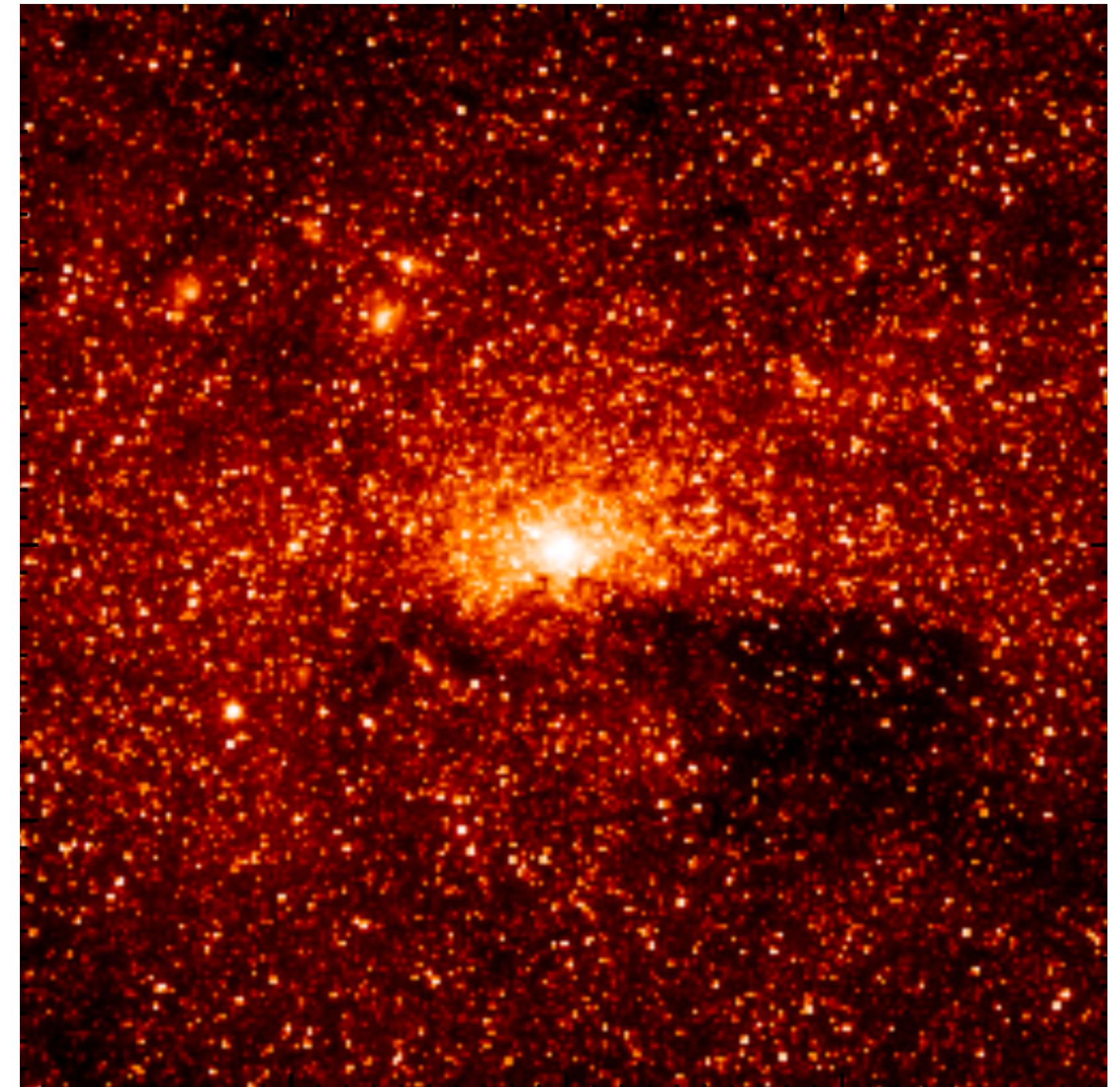
Millions of stars in random orbits

Tidal forces may deform, or tear into pieces a star

One TDE in 10^4 - 10^9 years per SMBH

For tidal forces to be relevant they must be stronger than the star's self gravity

$$\frac{GM_{\text{SMBH}}R_{\star}}{R_t^3} = \frac{GM_{\star}}{R_{\star}^2}$$



Tidal disruption events

$$\frac{GM_{\text{SMBH}}R_{\star}}{R_t^3} = \frac{GM_{\star}}{R_{\star}^2}$$

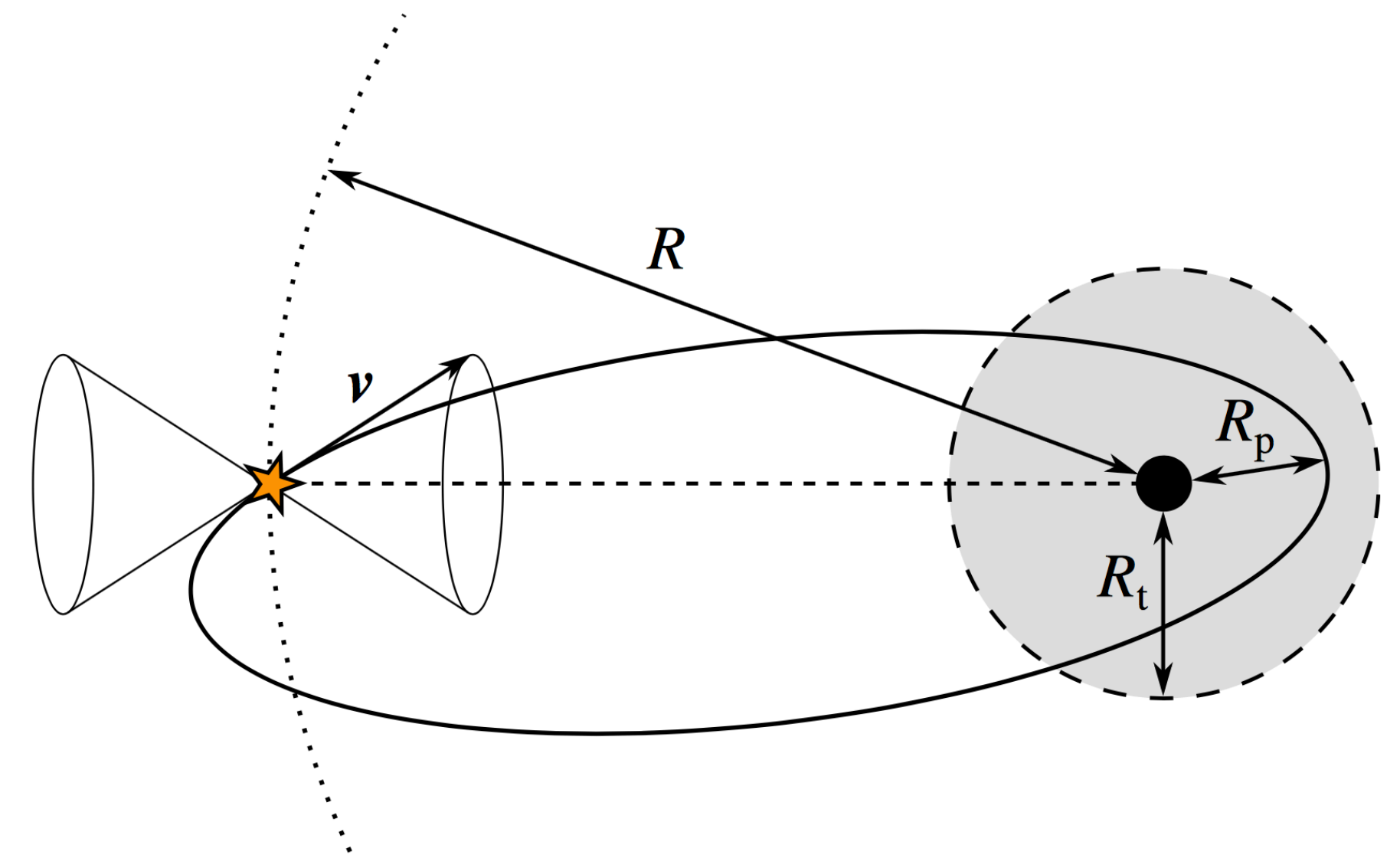
For tidal disruption to occur $R_p < R_t$

R_t must be outside the event horizon for visible TDE

The Schwarzschild radius is

$$M_{\text{SMBH}} \leq M_{\star}^{-1/2} \left(\frac{c^2 R_{\star}}{2G} \right)^{3/2} \approx 10^8 M_{\odot} \left(\frac{R_{\star}}{R_{\odot}} \right)^{3/2} \left(\frac{M_{\star}}{M_{\odot}} \right)^{-1/2}$$

For $R_t > r_s$



Tidal disruption events

Flare of electromagnetic radiation at high peak luminosity (X-rays)

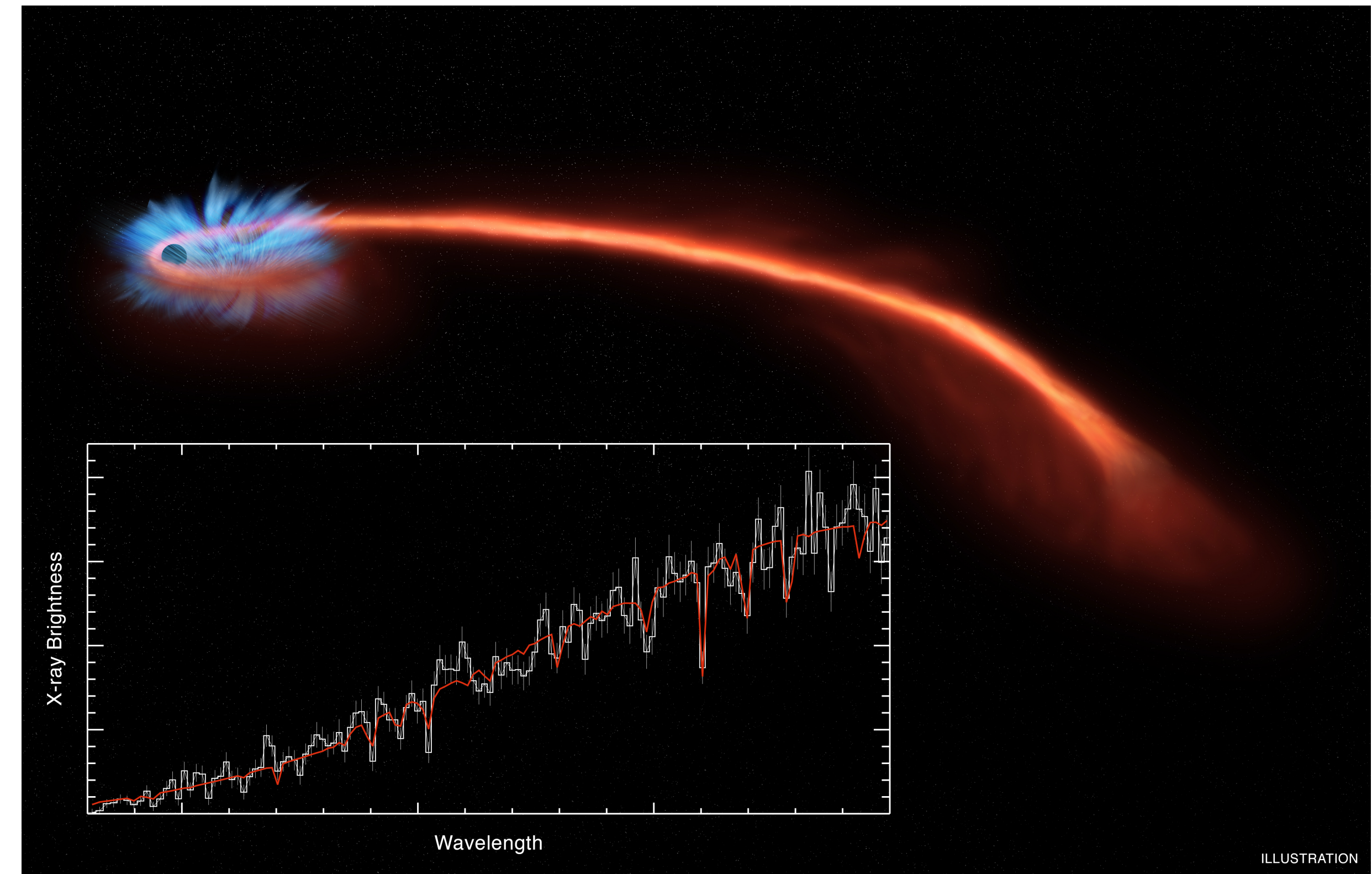
Located in the core of an otherwise quiescent, inactive galaxy

Extreme flares can host a relativistic hadronic jet

Typically 50% of the star's mass expected to stay bound to the SMBH and be ultimately accreted

~100 candidate TDEs observed so far, 3 with jets (hard X-ray spectrum)

Timescale of months to years



Swift J1644+57

Test case, Swift J1644+57, jetted TDE observed in ``blazar'' mode

Observed for ~ 600 days, in a small quiescent galaxy in the Draco constellation at $z = 0.35$

$$E_{\text{max}} \sim 10^{20} \text{ eV } Z \frac{BR}{3 \times 10^{17} \text{ G cm}} \frac{\Gamma}{10}$$



Swift J1644+57

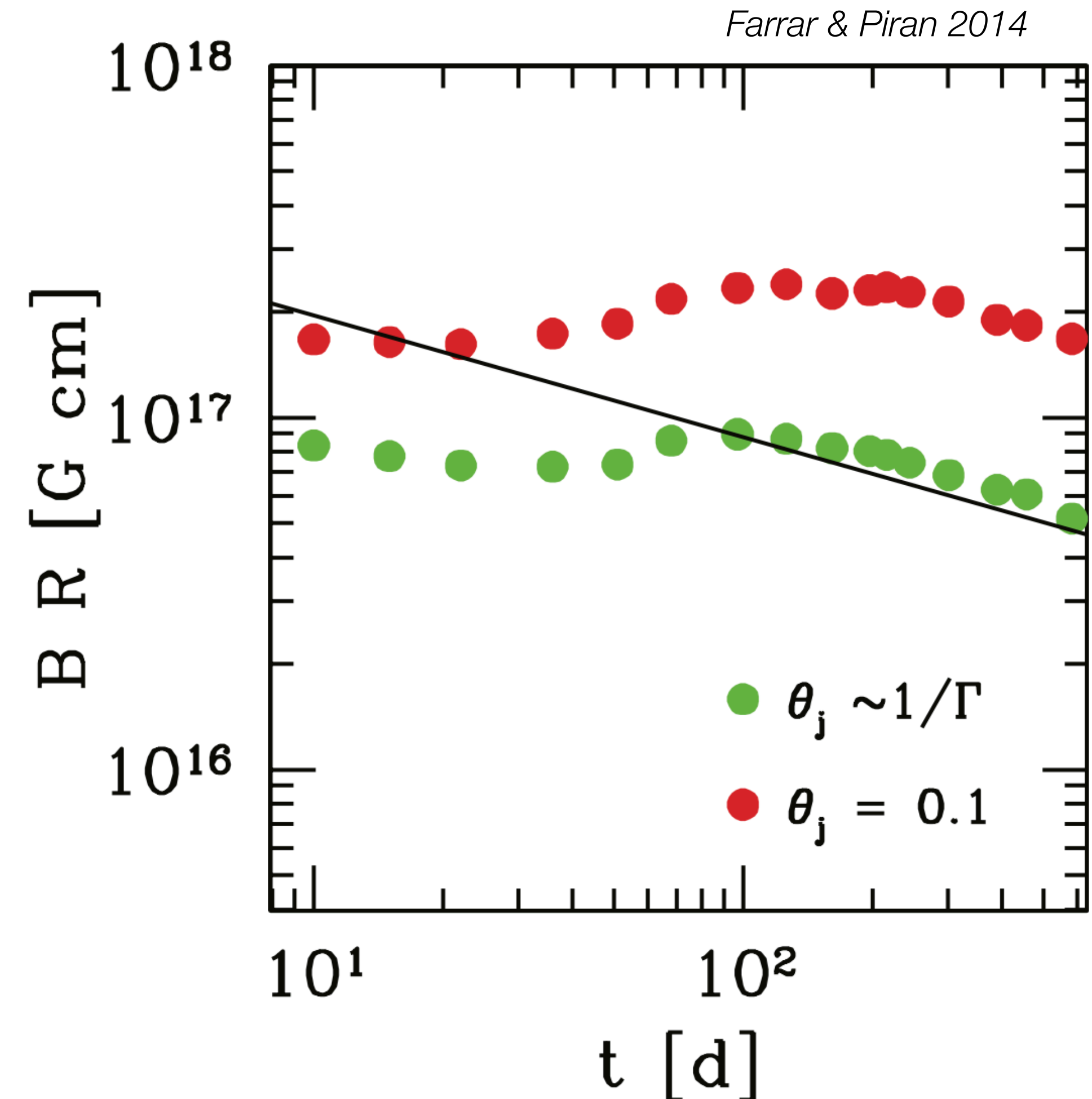
Test case, Swift J1644+57, jetted TDE observed in ``blazar'' mode

Observed for ~ 600 days, in a small quiescent galaxy in the Draco constellation at $z = 0.35$

$$E_{\max} \sim 10^{20} \text{ eV } Z \frac{BR}{3 \times 10^{17} \text{ G cm}} \frac{\Gamma}{10}$$

For Swift J1644+57 from radio observations in the outer jet (but dependent on assumed opening angle of jet)

$$BR \gtrsim 1 - 3 \times 10^{17} \text{ G cm}$$



Can TDEs be the main sources of UHECRs?

The “apparent” source number density must satisfy the observational bound, with δt the spread in arrival times

$$n_{\text{eff}} \sim \delta t \cdot \rho$$

From Auger

$$n_{\text{UHECR}} \gtrsim 2 \times 10^{-5} \text{ Mpc}^{-3}$$

The observed rate of jetted TDEs

$$\rho \approx 10^{-11} - 10^{-10} \text{ Mpc}^{-3} \text{ year}^{-1}$$

TDEs can satisfy the number density requirement if

$$\delta t_{\text{delay}} \approx 10^5 \text{ yr} \cdot \left(\frac{D}{100 \text{ Mpc}} \right)^2 \left(\frac{E}{10^{20} \text{ eV}} \right)^{-2} \left(\frac{\lambda_{\text{coh}}}{1 \text{ Mpc}} \right) \left(\frac{B}{1 \text{ nG}} \right)^2$$

Neutrinos from TDEs?

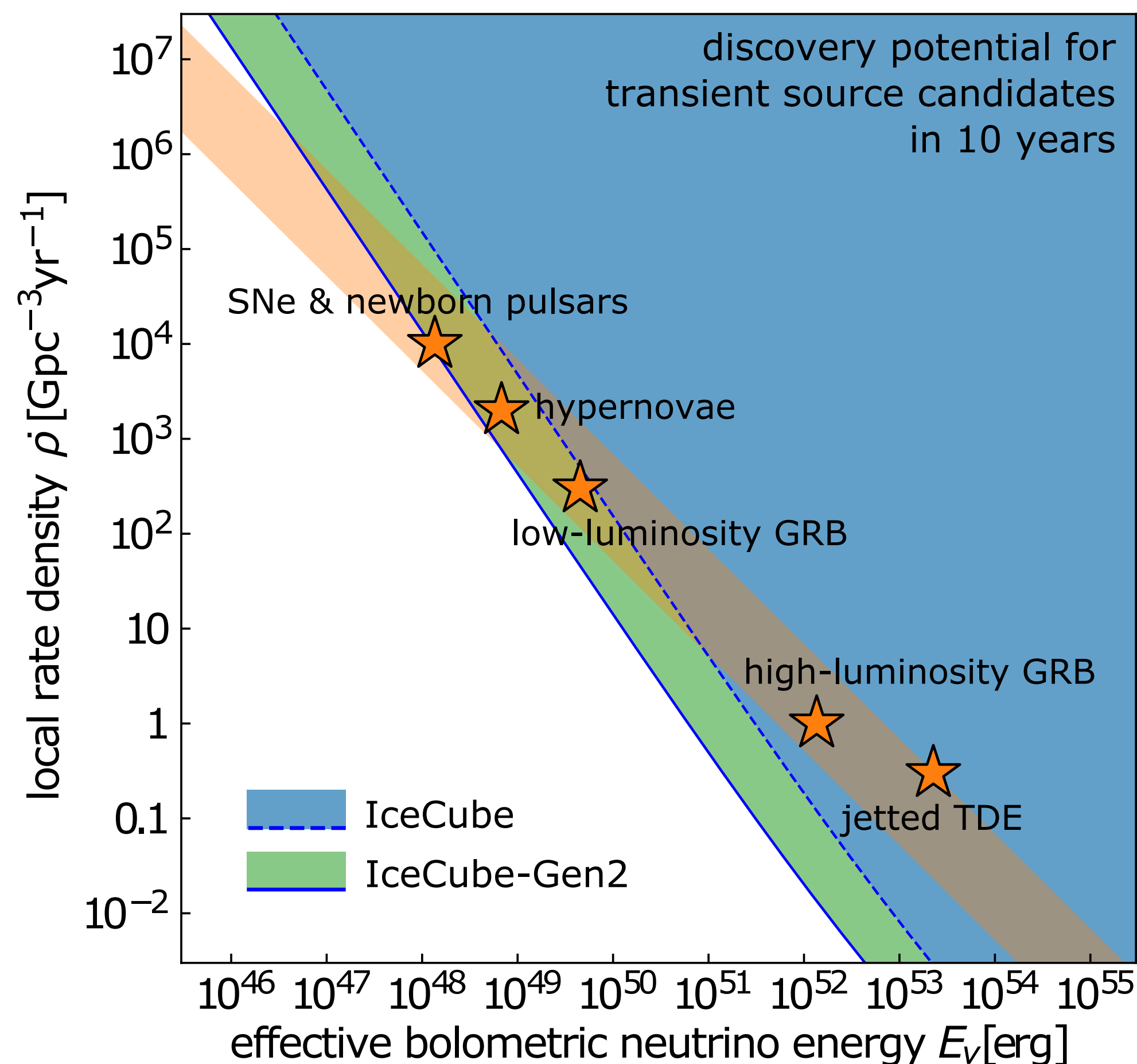
Photopion interactions in the jet (conditions similar to AGN/GRB)

One problem is that jetted TDEs are very rare

$n = 10^{-11} \text{ Mpc}^3$ cf GRBs, $n = 10^{-9} \text{ Mpc}^3$

Non-jetted TDEs 10 -100 times more numerous, but not clear if (where?) they accelerate 10^{17} eV protons

Stacking limits from IceCube (jetted TDEs $< 1\%$, non-jetted $< 26\%$)

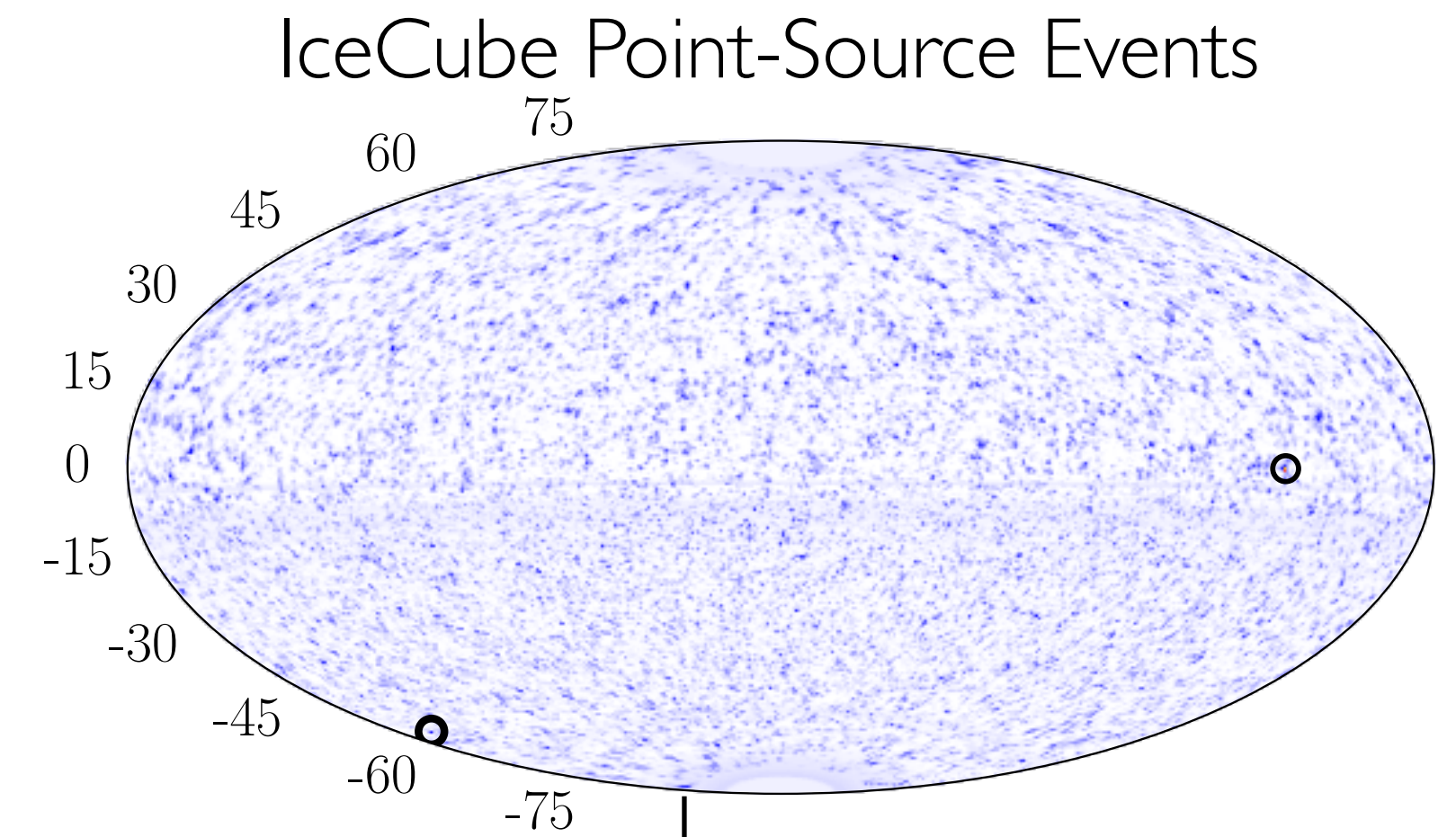
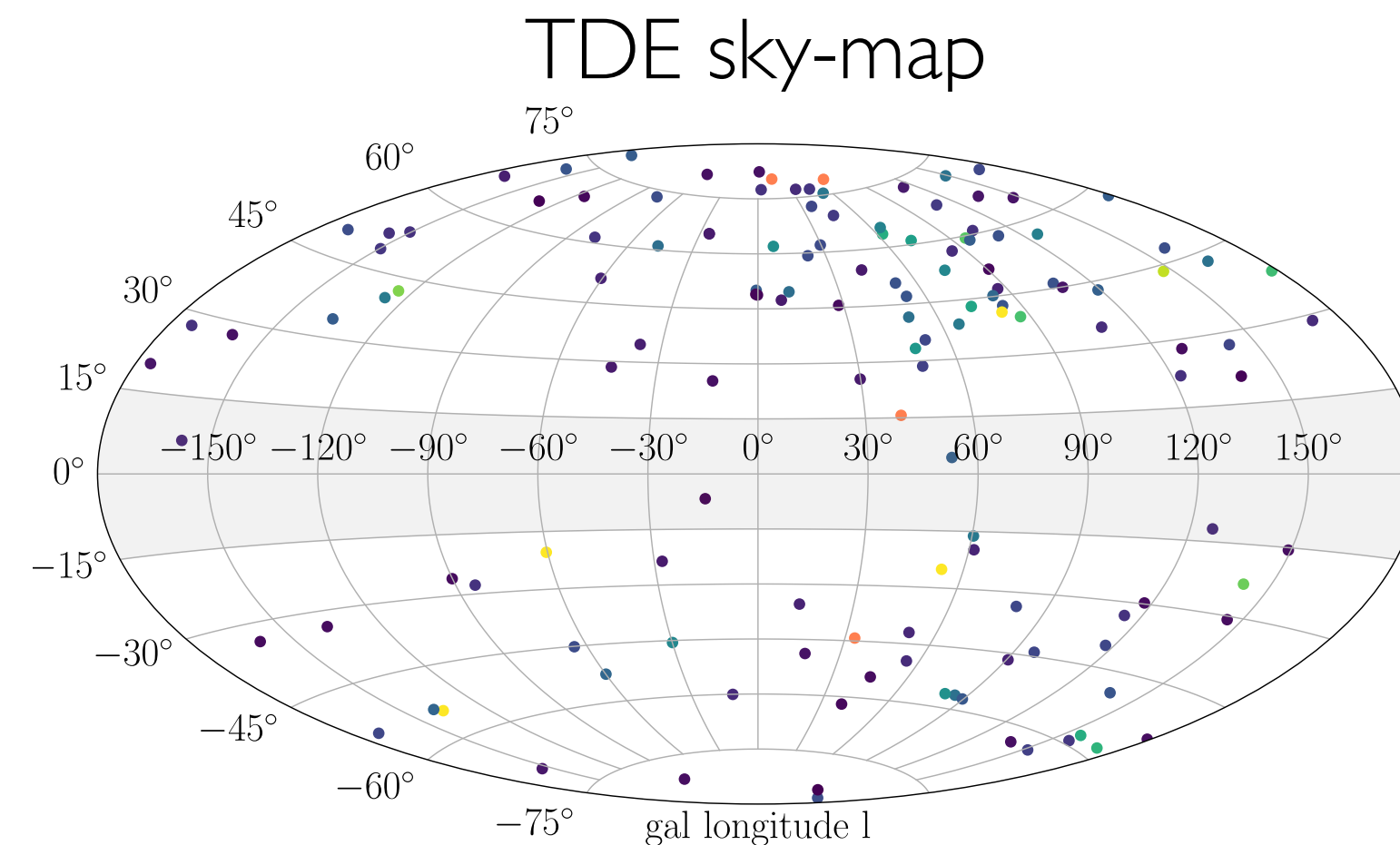


TDE contribution to the cosmic-neutrino flux



3 jetted TDEs
40 non-jetted TDEs (mixture
of X-ray / UV / optical TDEs)

Updated search in 2022 ZTF
TDEs with neoWISE flare
(``dust echo") Y. Necker TeVPA
2022 - No excess



IceCube Coll PoS ICRC 2019
Necker et al 2022 (ASAS-SN Coll)
Stein et al 2022 (ZTF Coll)

Jetted TDEs: < 3% diffuse neutrino flux

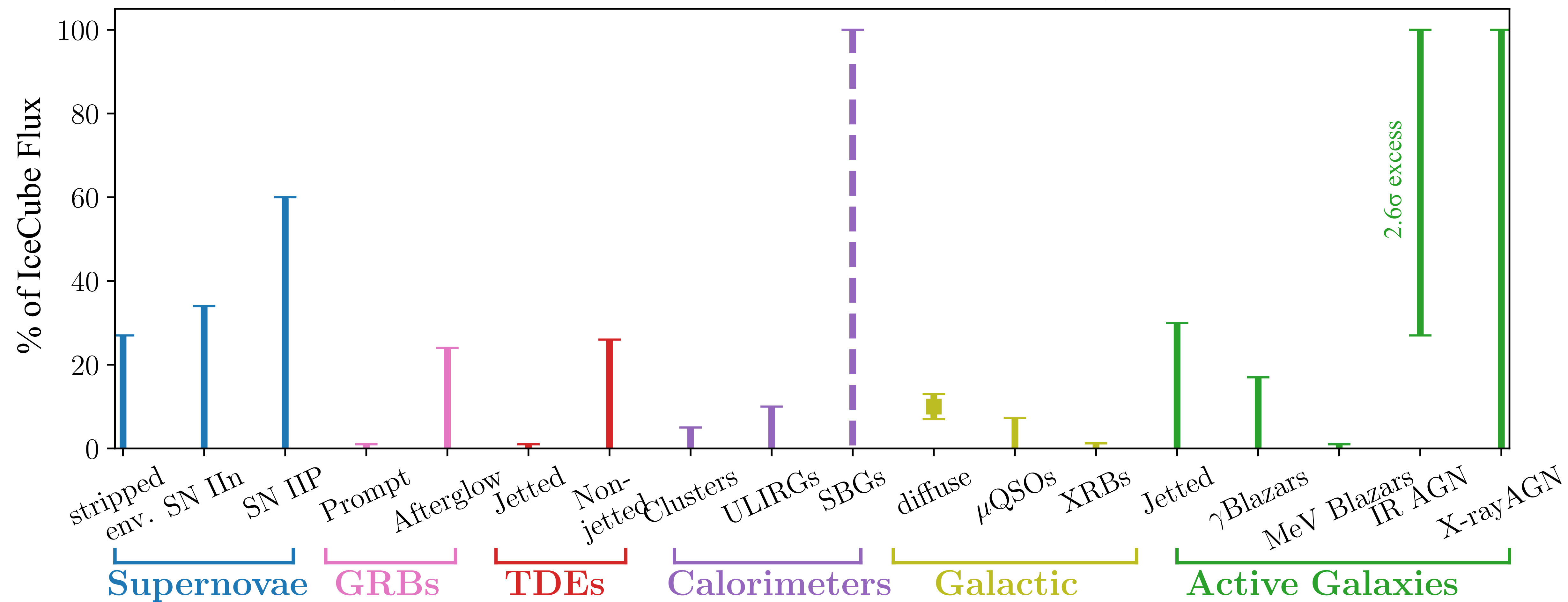
Non-jetted < 26%

Scorecard

	$E_{\text{max}}^{\text{UHECR}}$	n_{UHECR}	$\dot{\epsilon}_{\text{UHECR}}$	n_{ν}	Stacking UL
BL Lacs	😊	😞	😊	😞	$\lesssim 20\%$
FSRQs	😊	😞	😊	😞	$\lesssim 20\%$
FR I	😊	😊	😊	😊	$\lesssim 20\%$
FR II	😊	😊	😊	😊	$\lesssim 20\%$
Non-jetted AGN	😐	😊	😊	😊	$\lesssim 100\%$
Starburst galaxies	😞	😊	😊	😊	$\lesssim 100\%$
GRBs	😊	😐	😐	😞	$\lesssim 1\%$
Jetted TDEs	😊	😞	😞	😞	$\lesssim 3\%$

The current neutrino source landscape: Stacking upper limits

plot from FO PoS ICRC2021 (2022) 030, based on numerous IceCube analyses, see [arXiv:2201.05623](https://arxiv.org/abs/2201.05623) for references



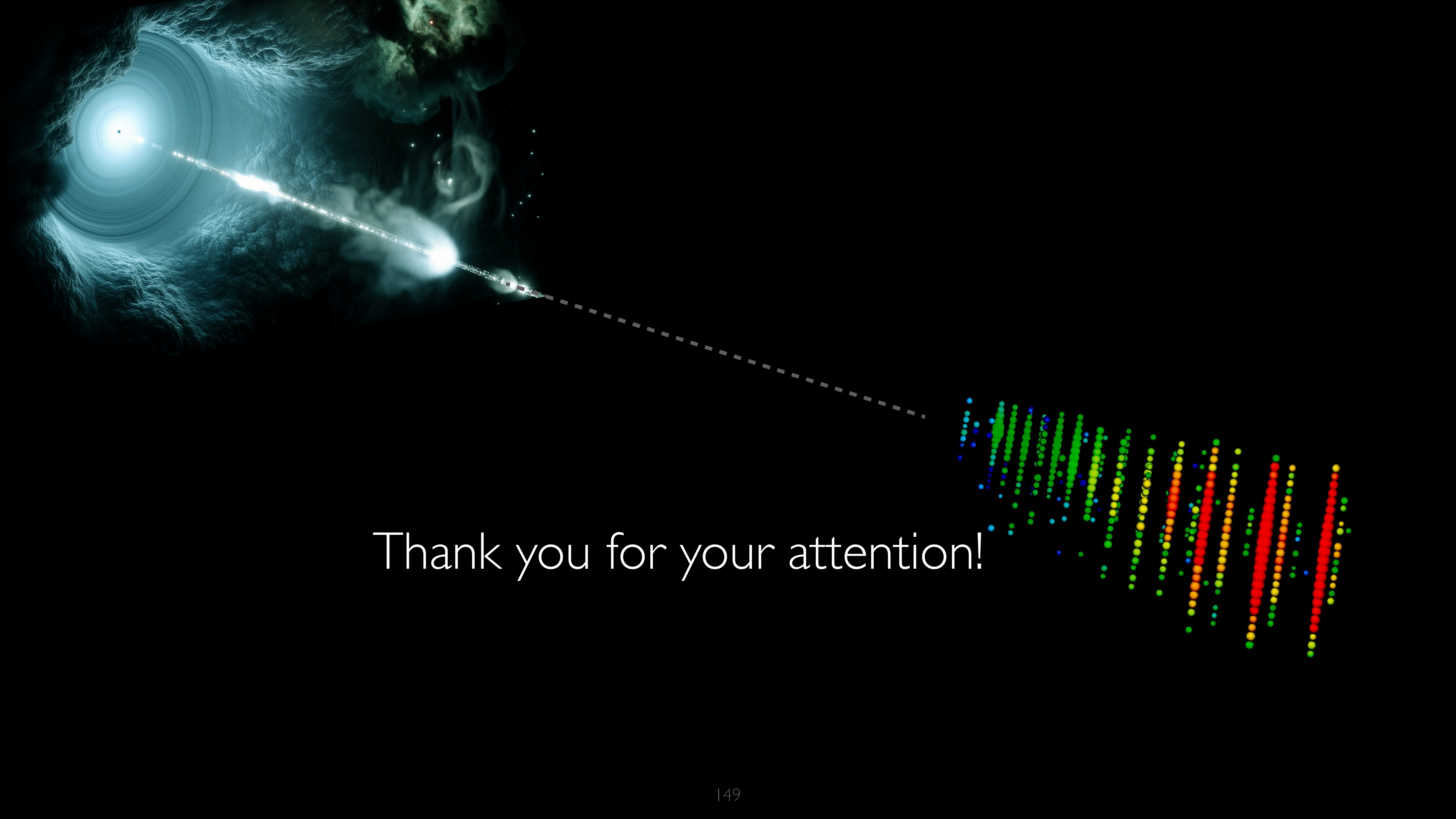
Scorecard

	$E_{\text{max}}^{\text{UHECR}}$	n_{UHECR}	$\dot{\epsilon}_{\text{UHECR}}$	n_{ν}	Stacking UL
BL Lacs					$\lesssim 20\%$
FSRQs					$\lesssim 20\%$
FR I					$\lesssim 20\%$
FR II					$\lesssim 20\%$
AGN Winds					$\lesssim 100\%$
AGN Coronae					$\lesssim 100\%$
Starburst galaxies					$\lesssim 100\%$
GRBs					$\lesssim 1\%$
Jetted TDEs					$\lesssim 3\%$

*(but problems at
medium E)

Votes

	UHECR Sources?	HE neutrino sources?
	Before/After	Before/After
Jetted AGN	9/1	5/2
Non-jetted AGN	2/2	6/15
Starbursts	5/5	2/10
GRBs	13/15	9/5
TDEs	2/0	1/0
Not on slides		BNS: 1



Thank you for your attention!