Did IceCube detect Dark Matter around Blazars?

Andrea Giovanni De Marchi
27/05/2025 PLANCK - Padova

Based on 2412.07861 AGDM, Granelli, Nava, Sala
250X.YYYYY AGDM, Granelli, Nava, Sala
250X.ZZZZZ AGDM, Granelli, Nava, Sala

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Istituto Nazionale di Fisica Nucleare

Outline

Blazars

+

Dark Matter

Blazar-boosted Dark Matter

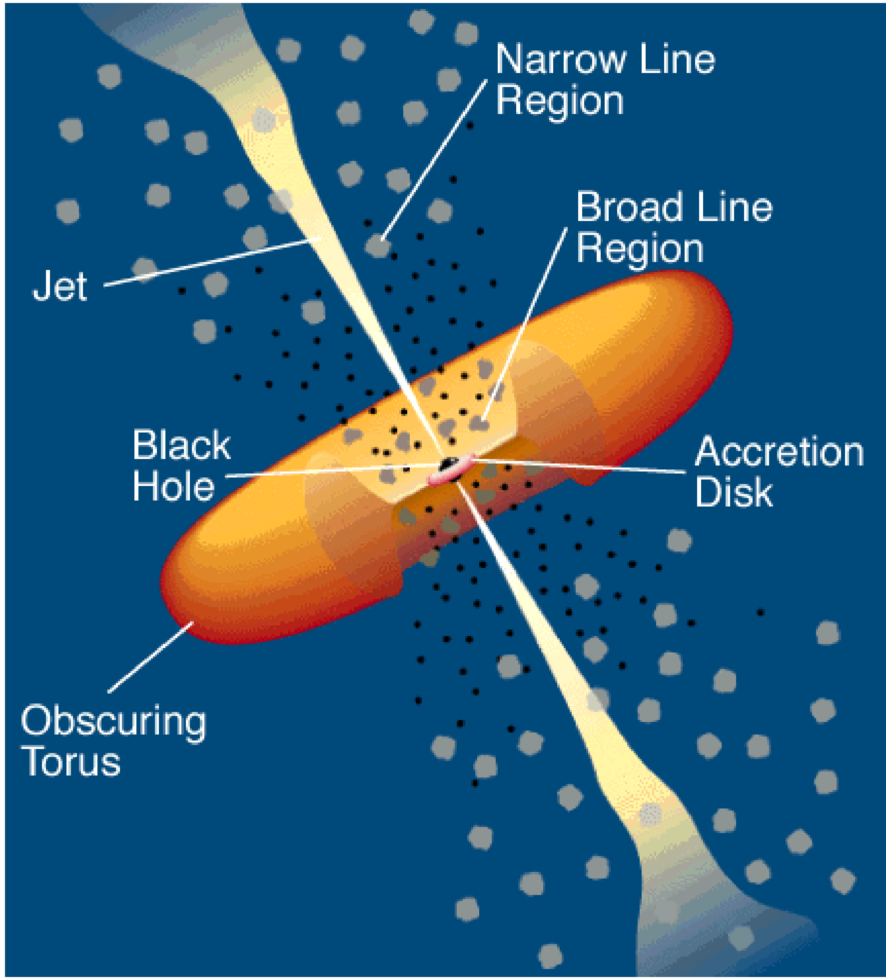
Neutrinos from blazars

I

Blazars

AGNs

Brightest objects in the Universe! Only engine that can power this: accreting supermassive black hole (SMBH)



Urry, Padovani 1995

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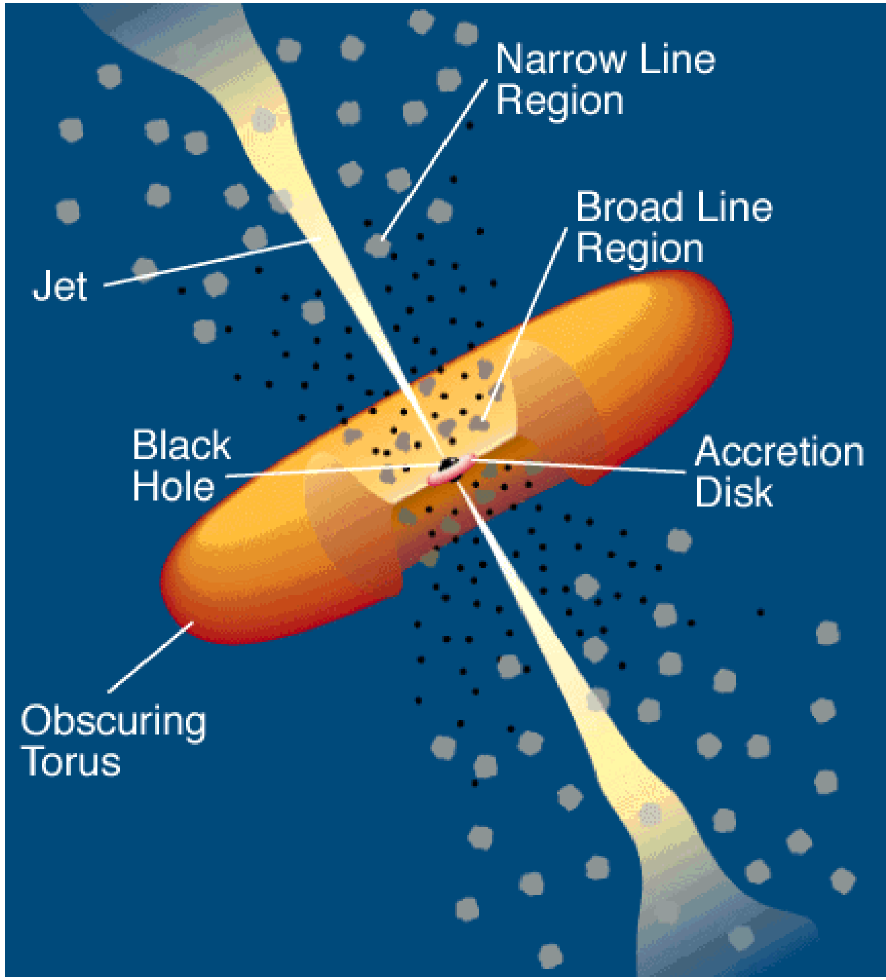
Depending on the angle of line-of-sight wrt to SMBH, you observe different features



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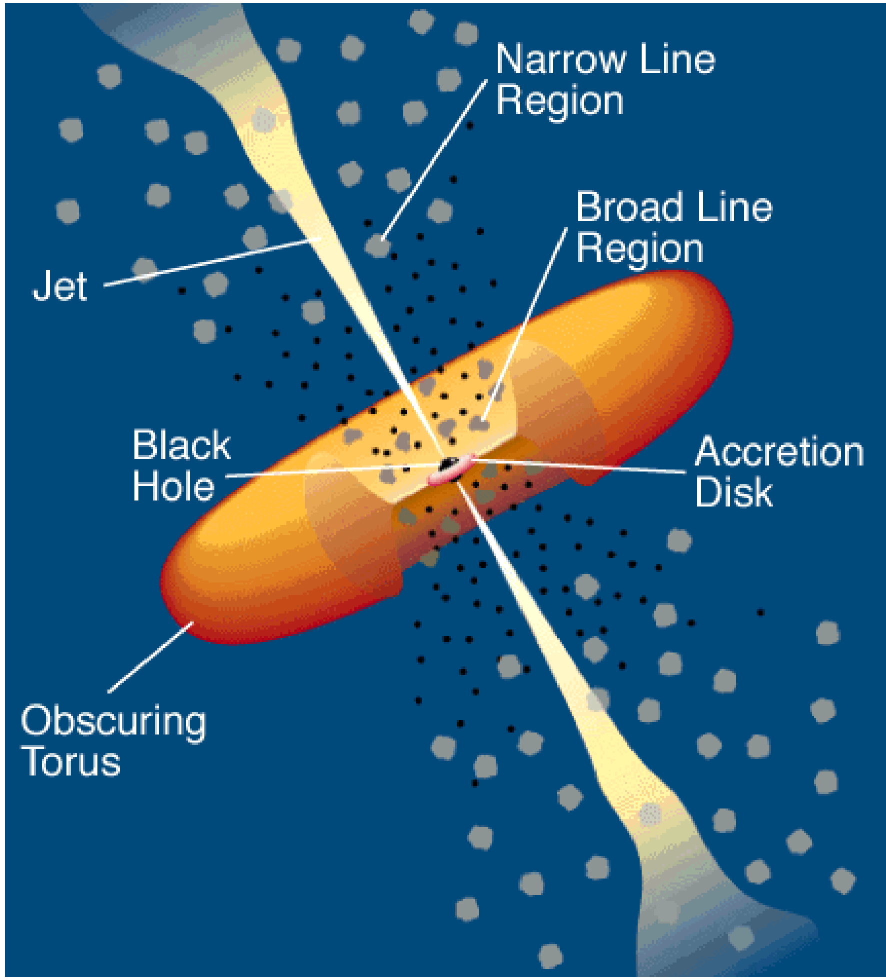
If jet pointed towards Earth: **blazar**



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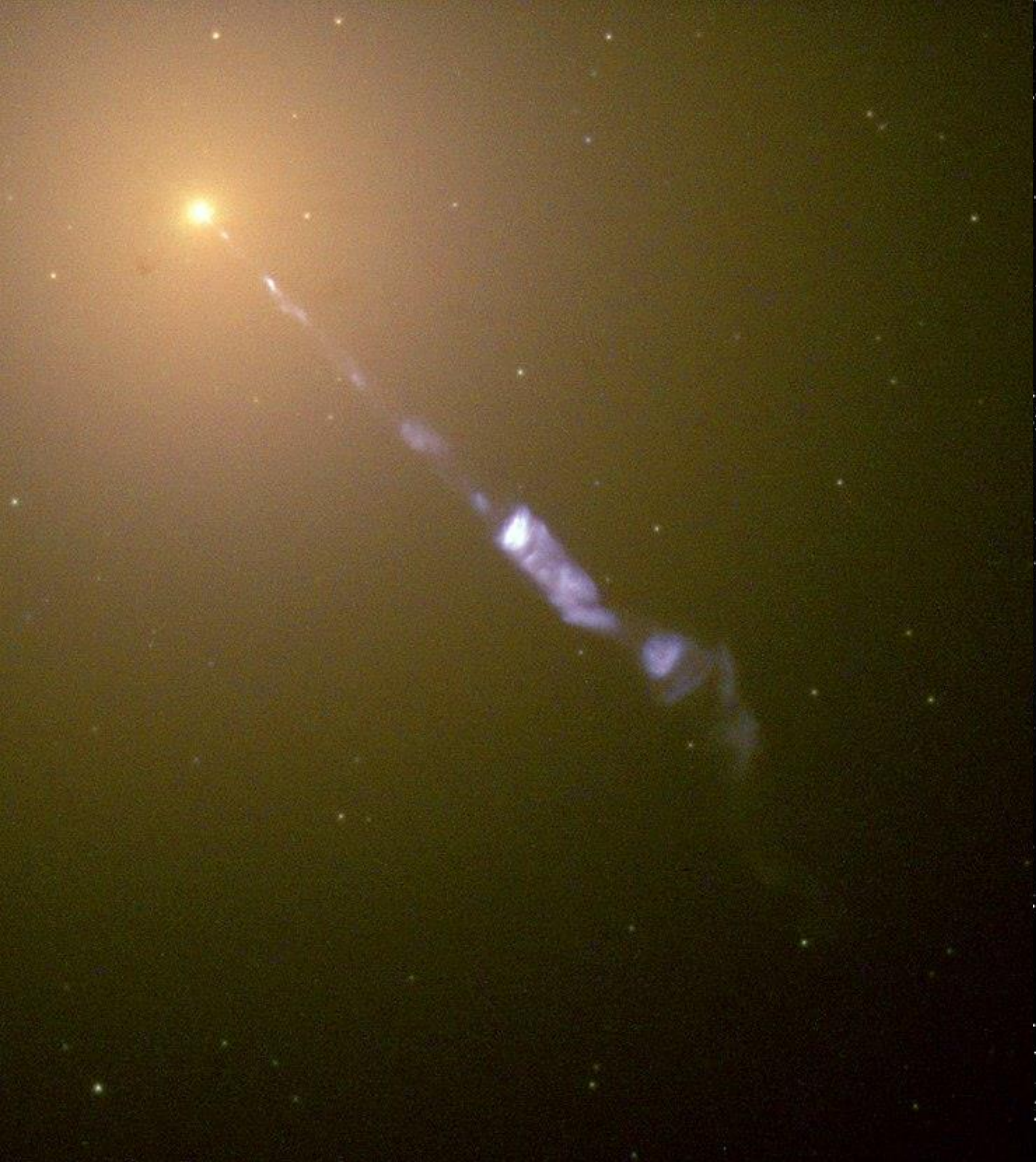
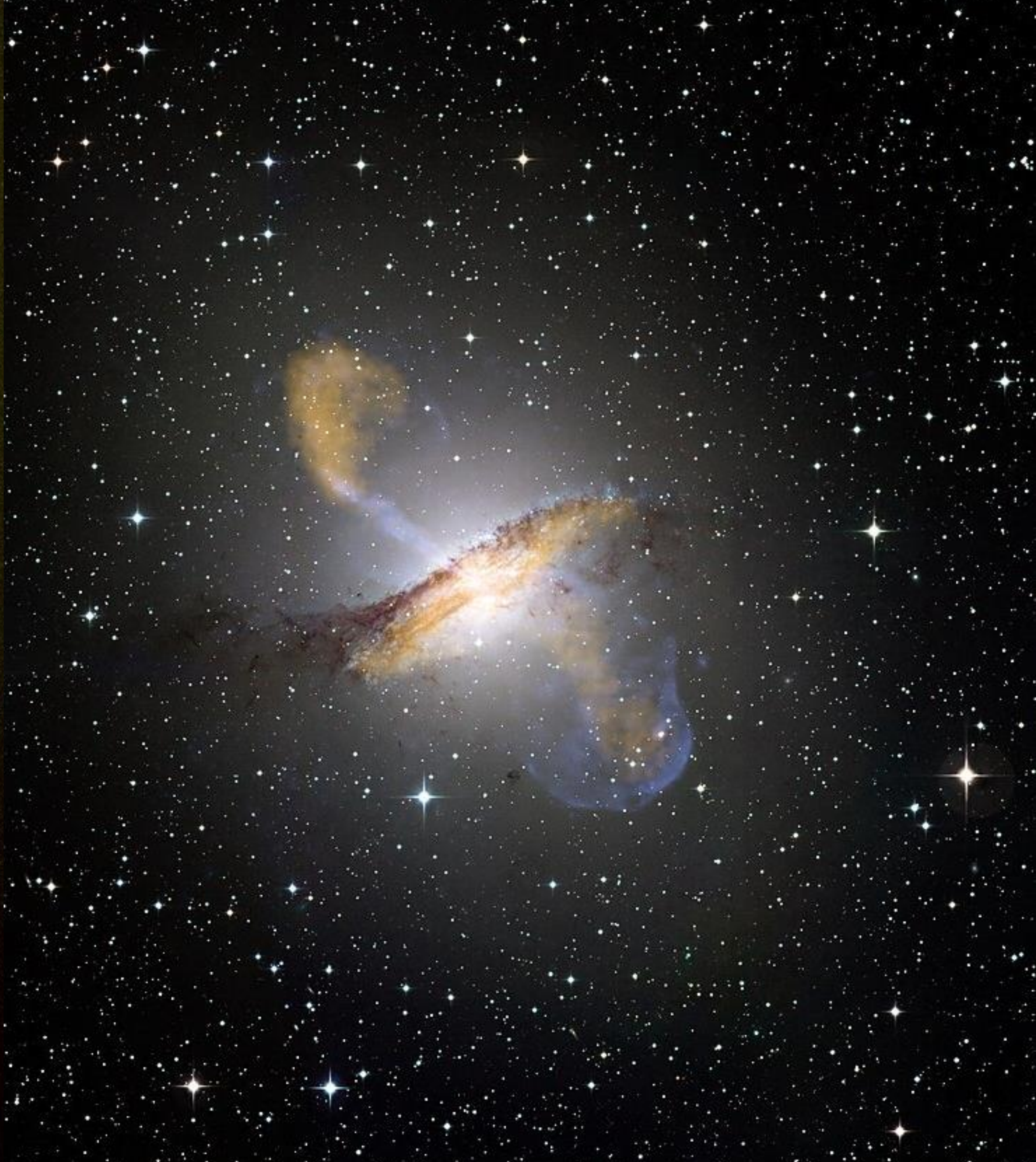
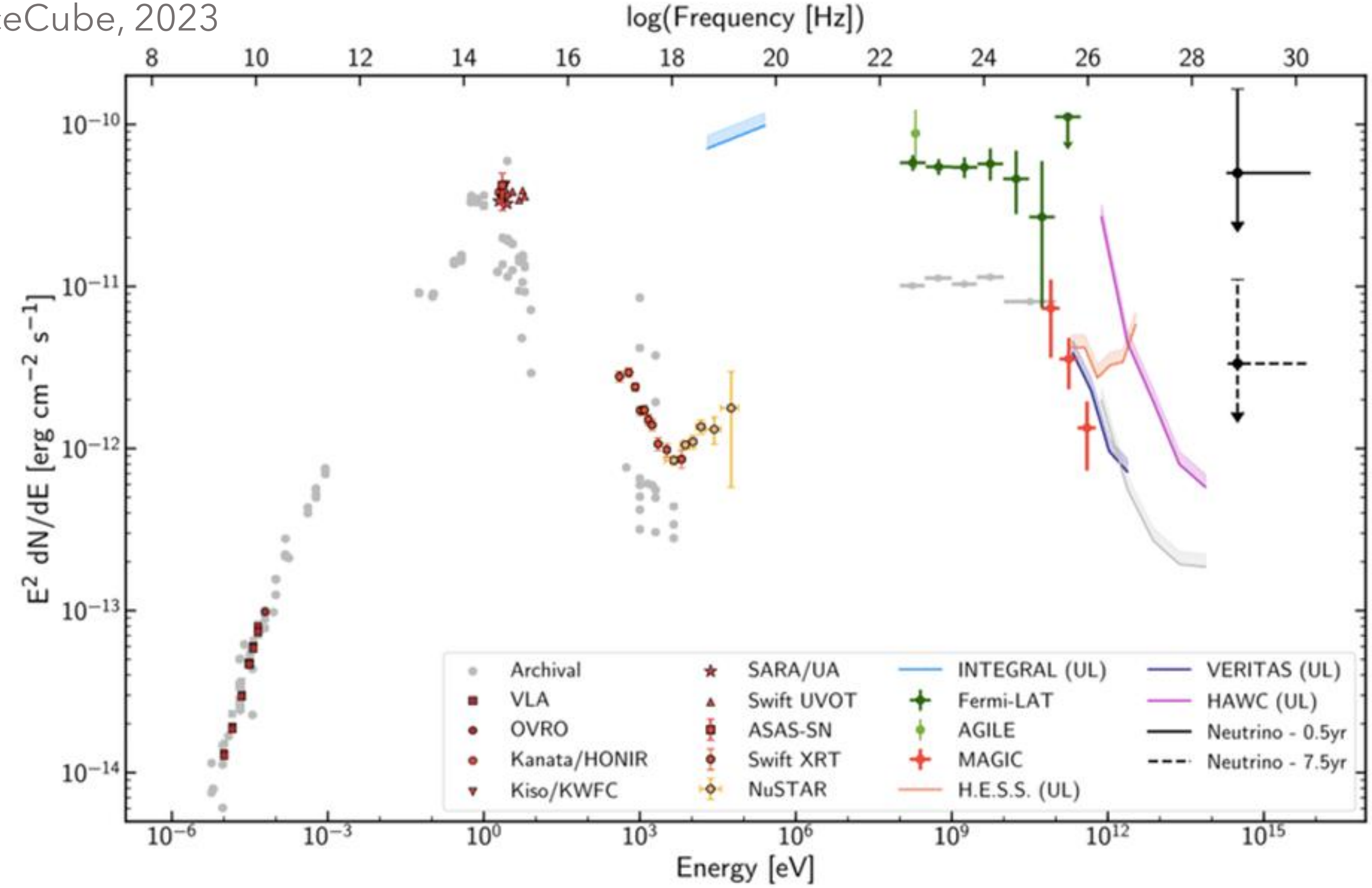
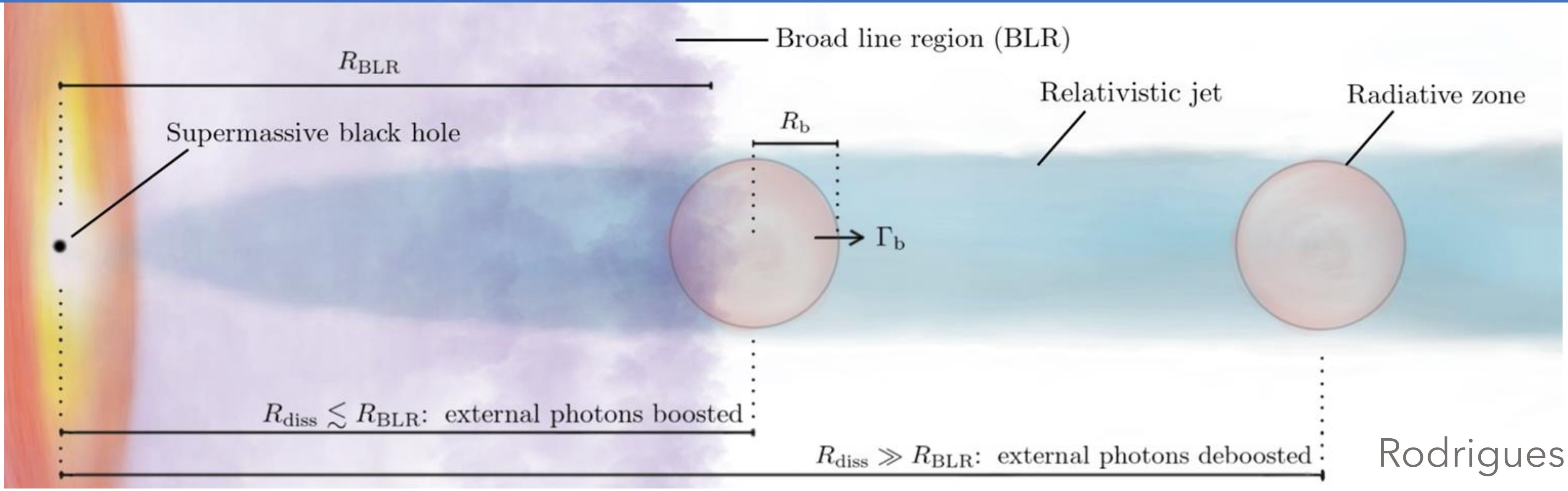



Blazar's spectral energy distribution

Montaruli for IceCube, 2023



How to model a blazar jet

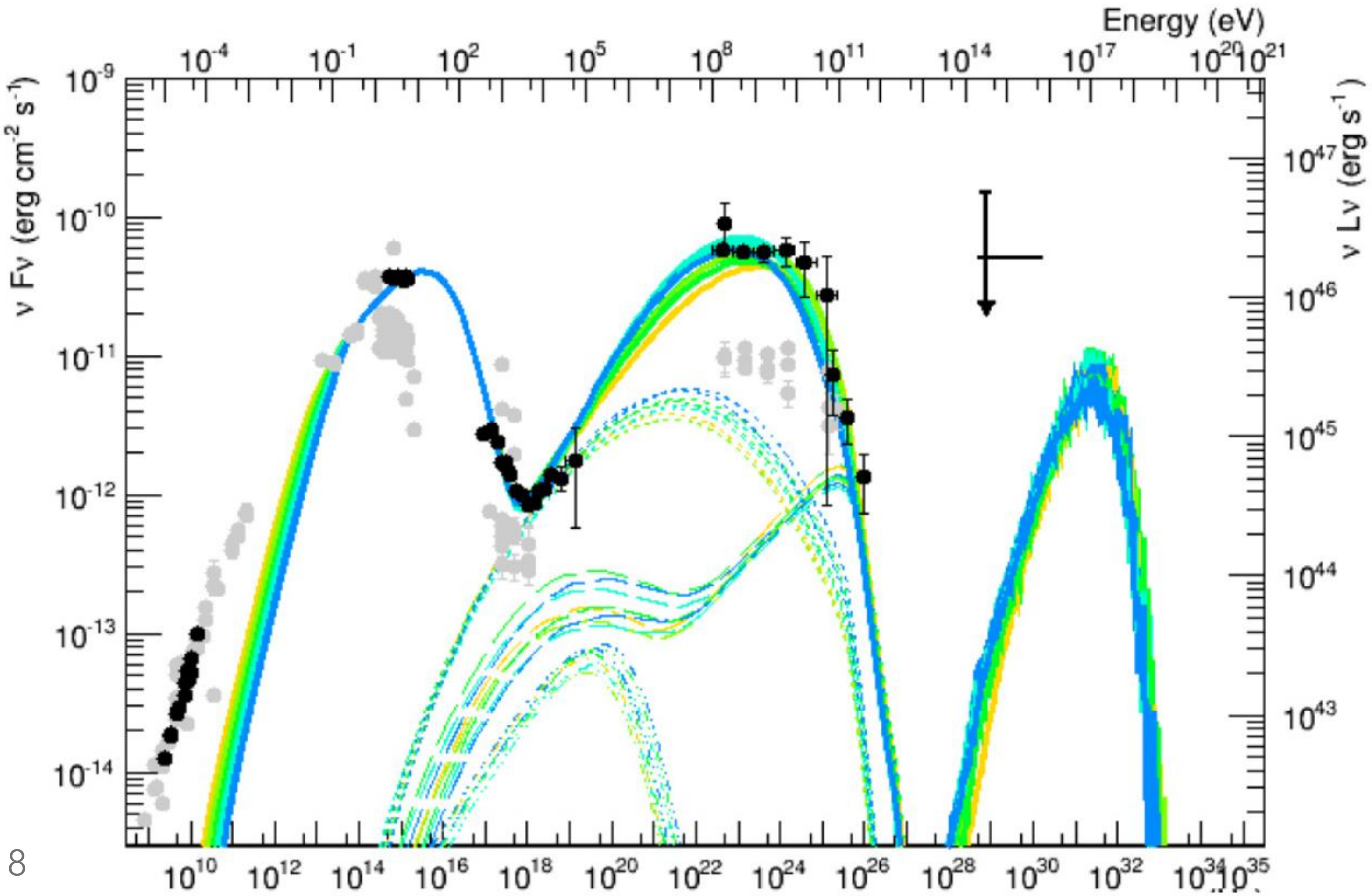


Rodrigues et al, 2023

Blob moving towards Earth with Lorentz factor Γ_B, filled with extremely energetic protons and electrons

\+ ambient photons from accretion disk and the jet

Leptohadronic model



Cerruti et al 2018

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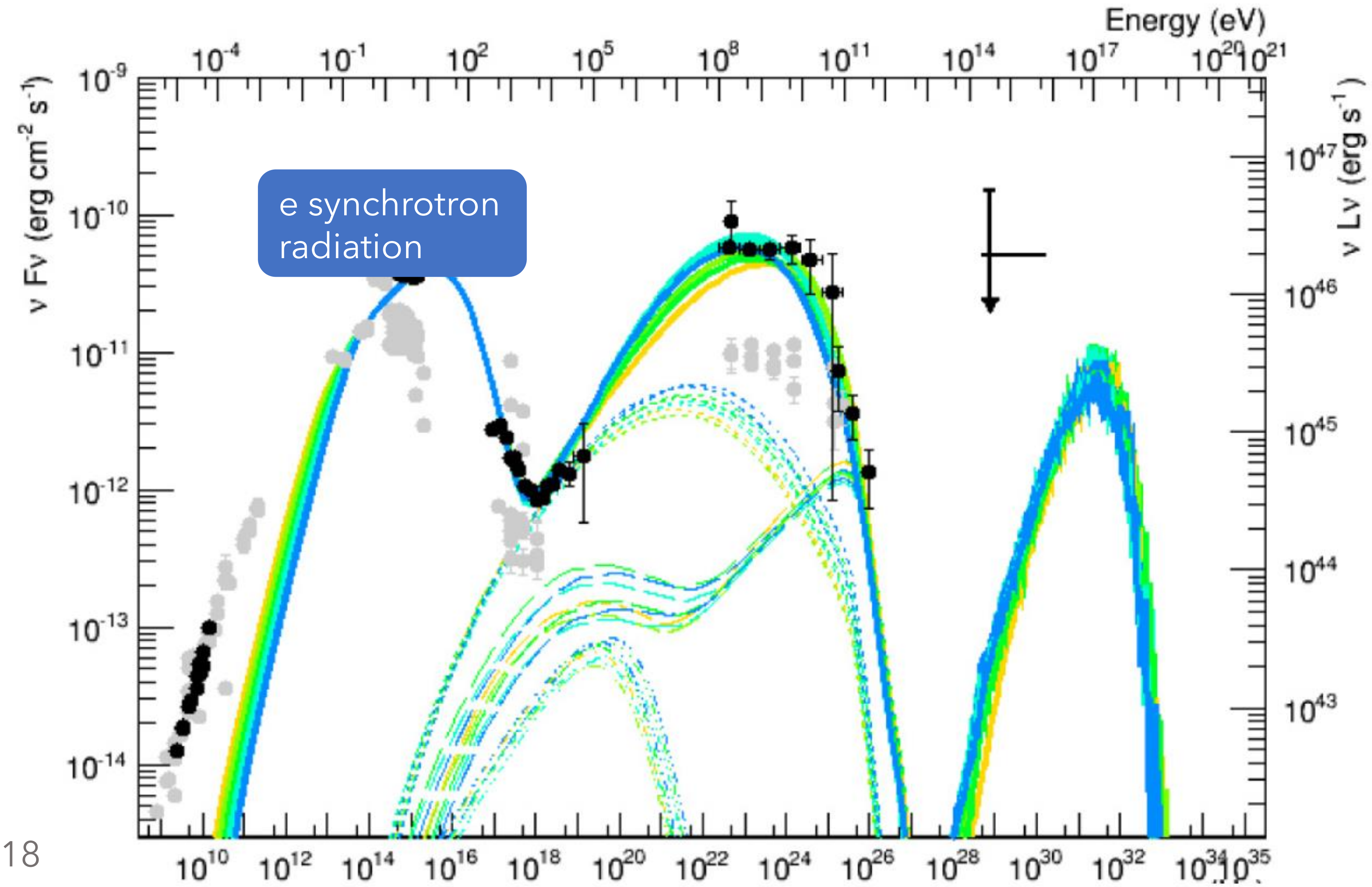

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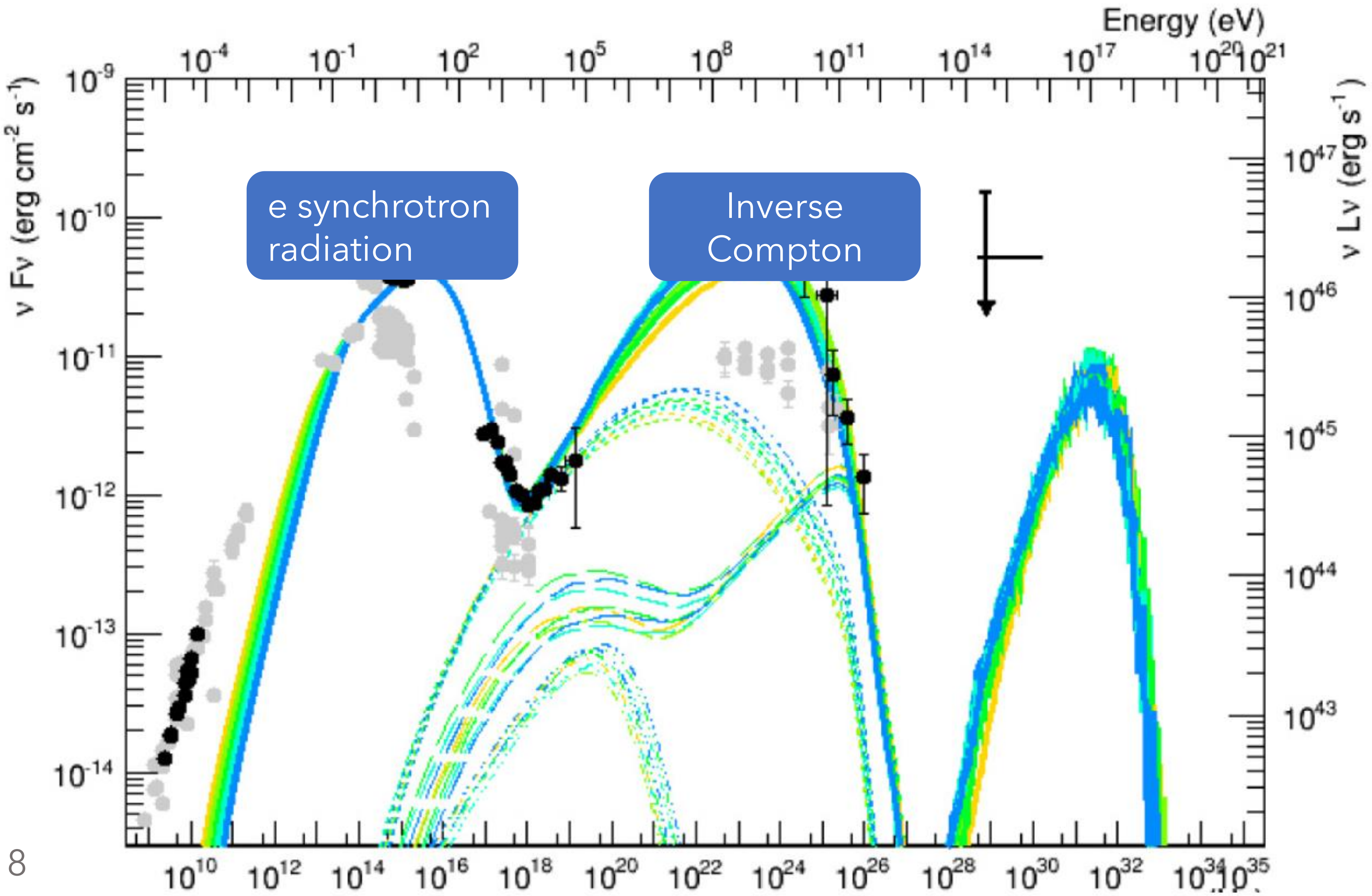

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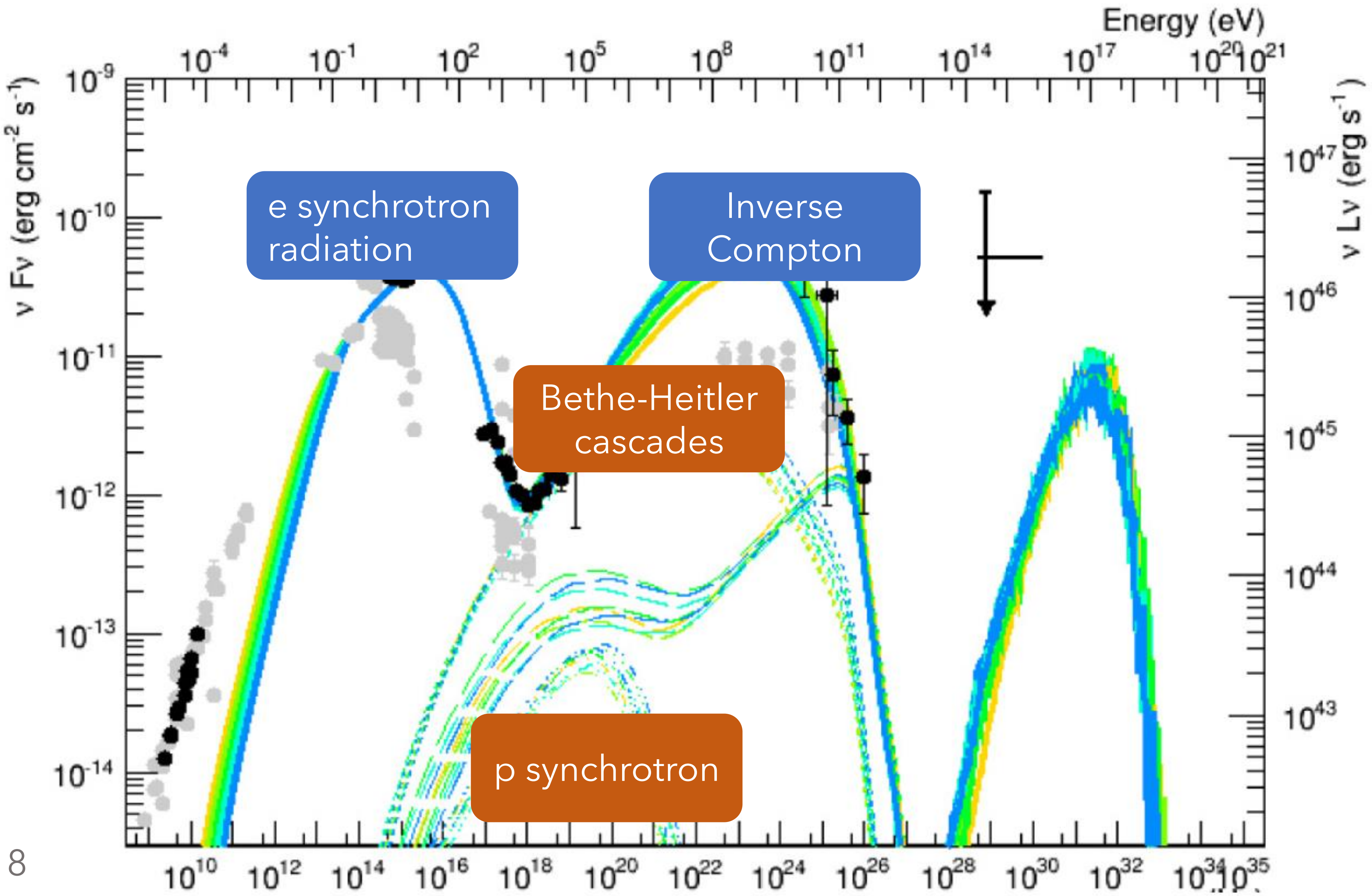

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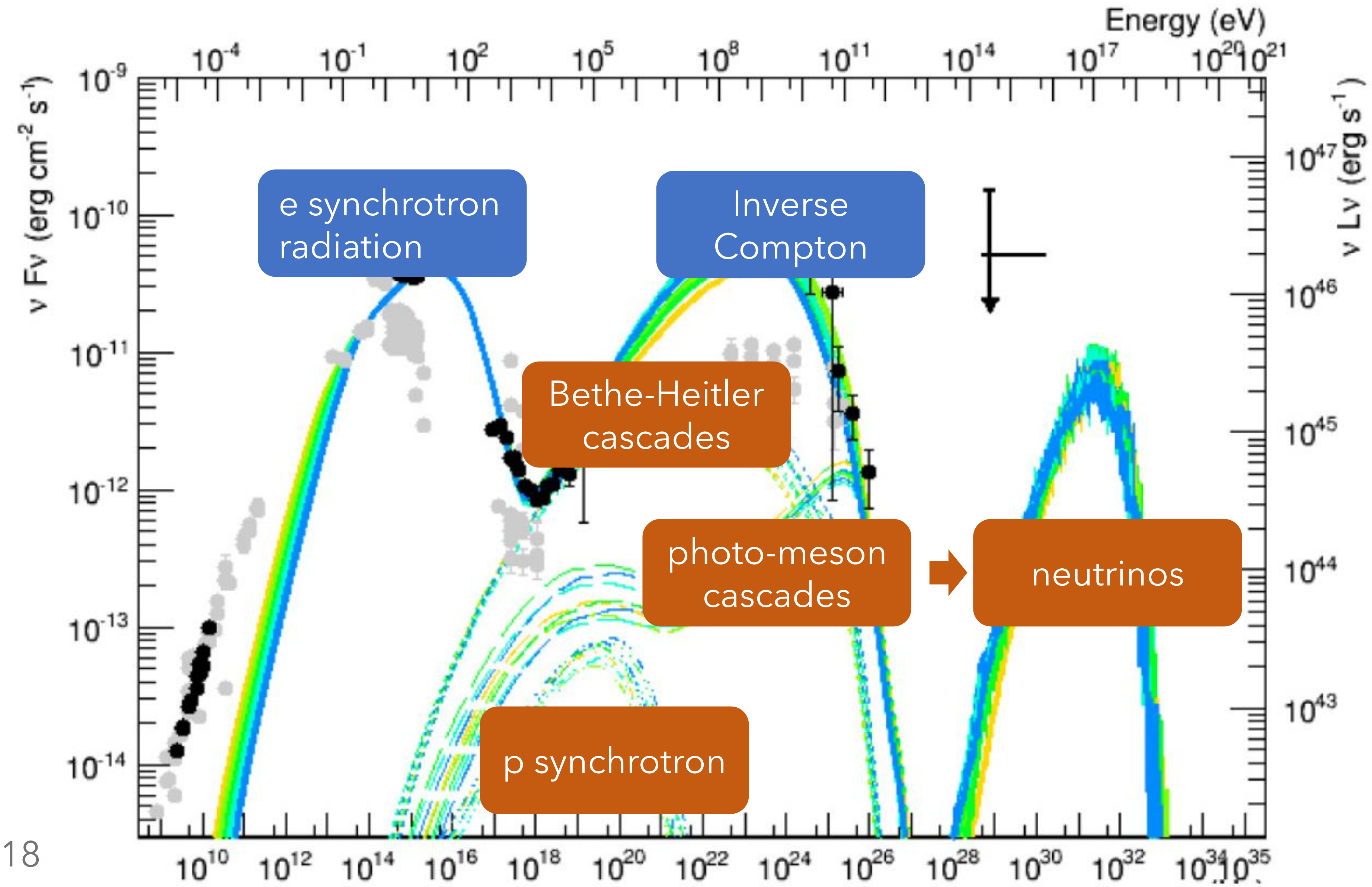

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II

Dark Matter

Why Dark Matter?

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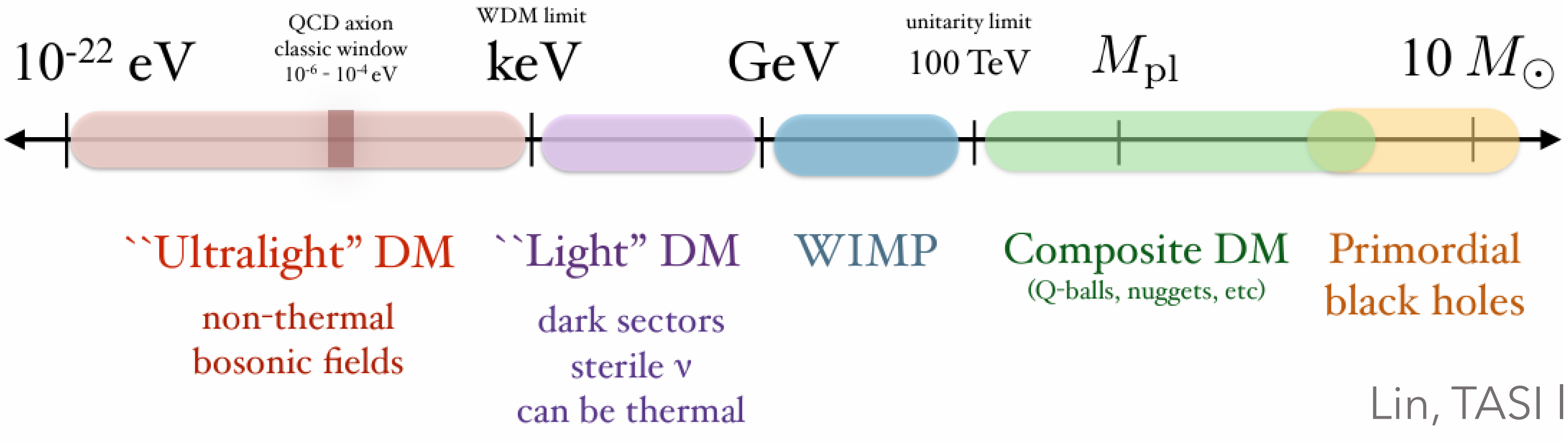
- Somewhere in this mass range:



Lin, TASI lectures 2019

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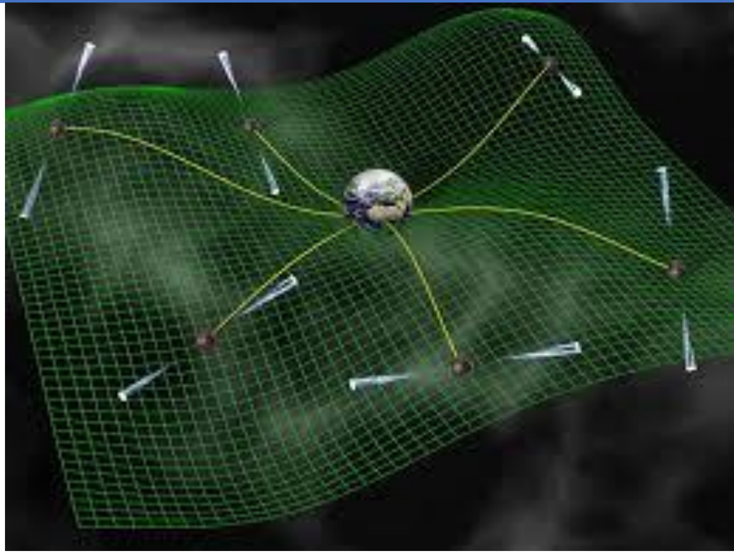

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- PTA signal: sub-GeV dark sector phase transition? [Bringmann+ 2023]

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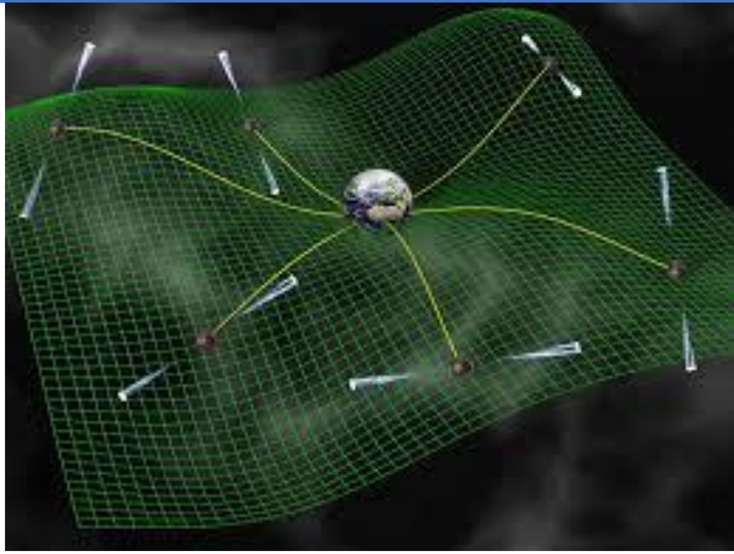
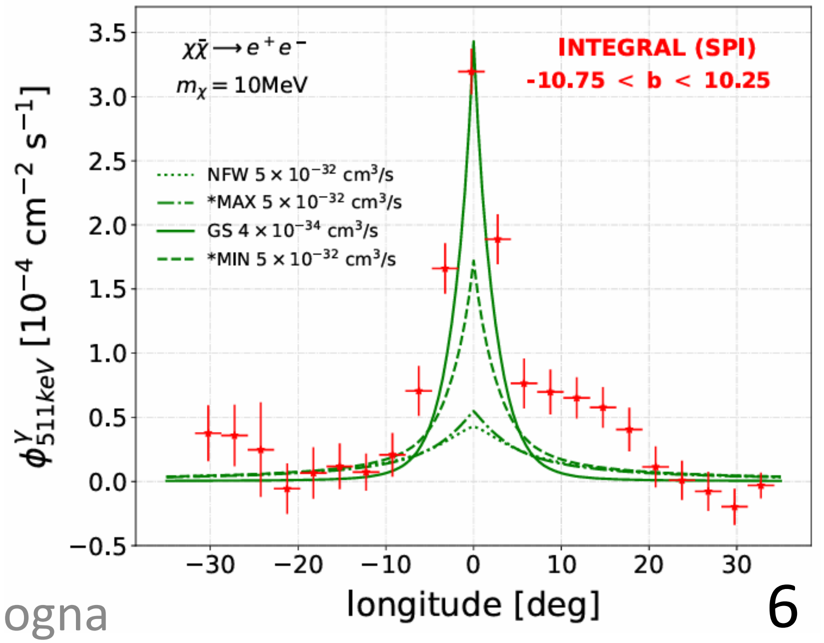
- Standard Model singlets, only portal interactions: allow small couplings and sub-GeV mass
- PTA signal: sub-GeV dark sector phase transition? [Bringmann+ 2023]
- 511 keV line from the galactic centre: annihilating DM? [Boehm+ 2004]





The Gondolo & Silk spike

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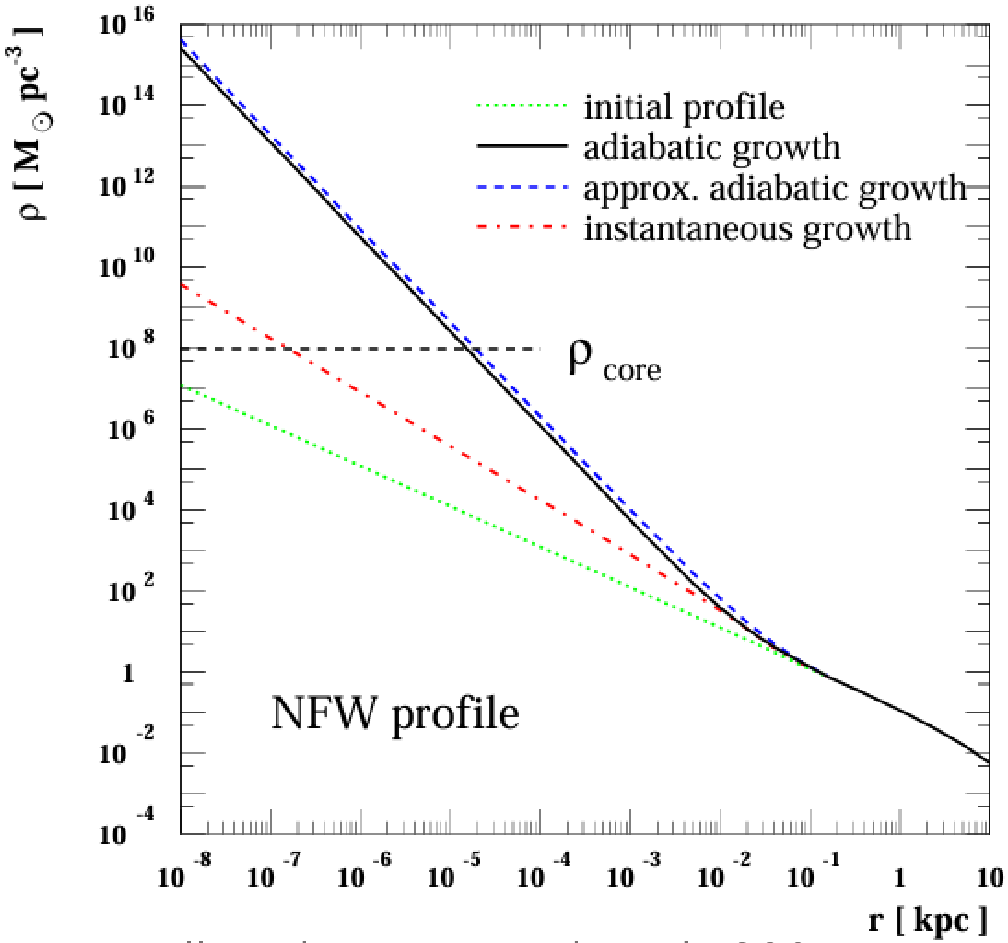
As SMBH grows, it contracts orbit around it, turns $r^{-\gamma}$ into $r^{-(9-2\gamma)/(4-\gamma)}$

[Gondolo, Silk 1999]



Ullio, Zhao, Kamionkowski 2001

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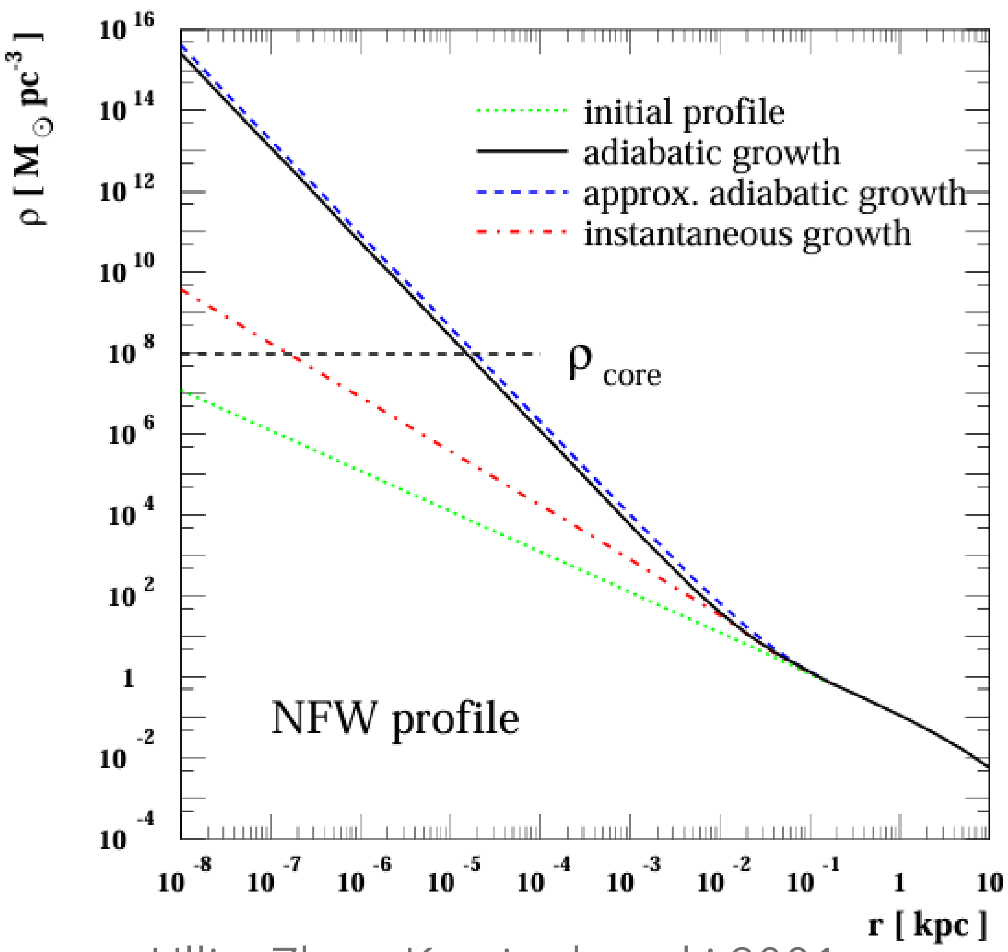

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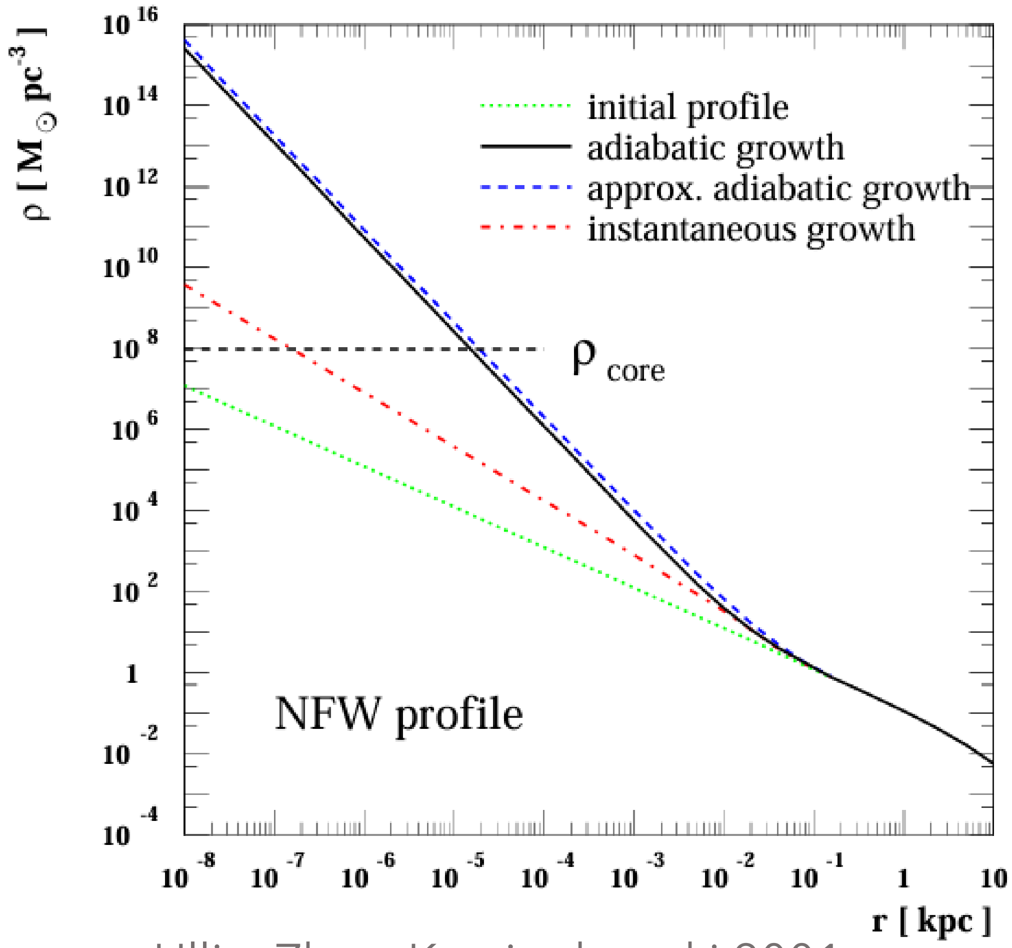
Ideal case, we choose as benchmarks 3000x and 10^6x enchancement



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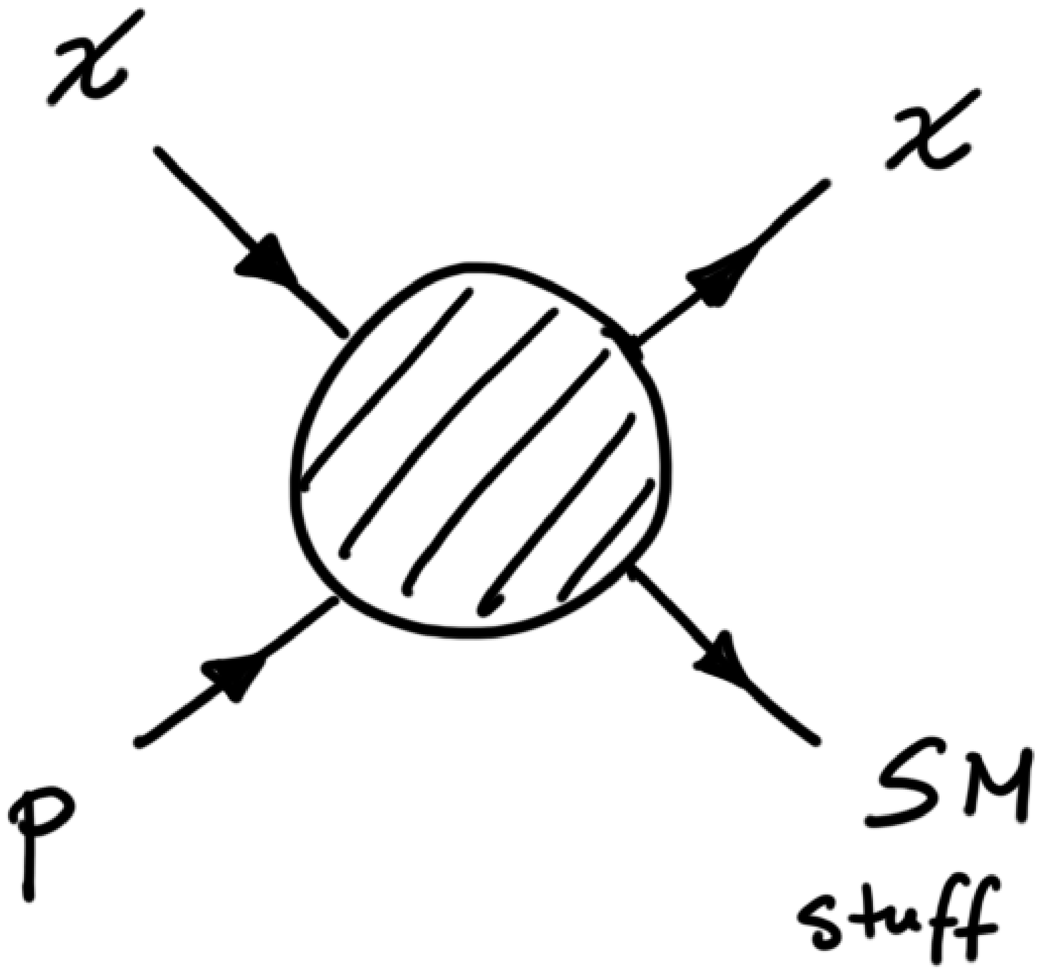
Two complementary signals



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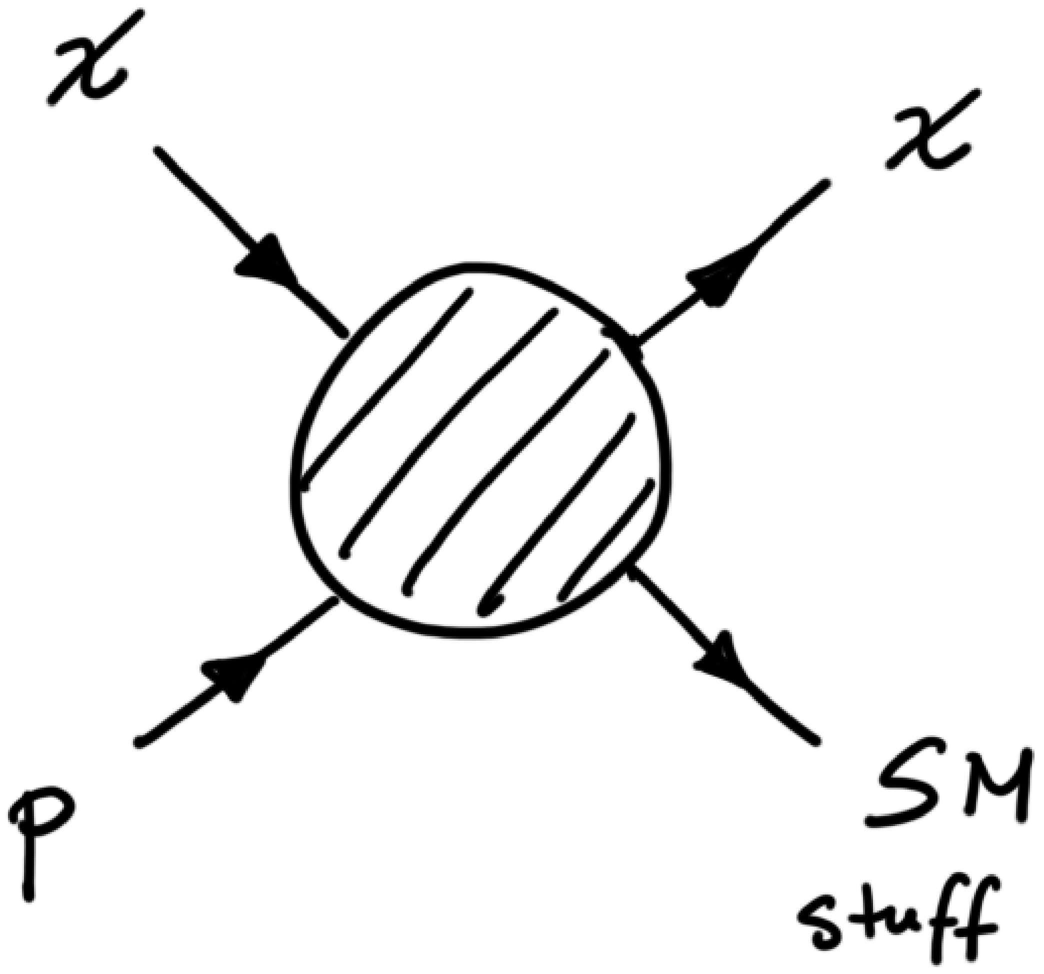

Blazar-boosted
Dark Matter

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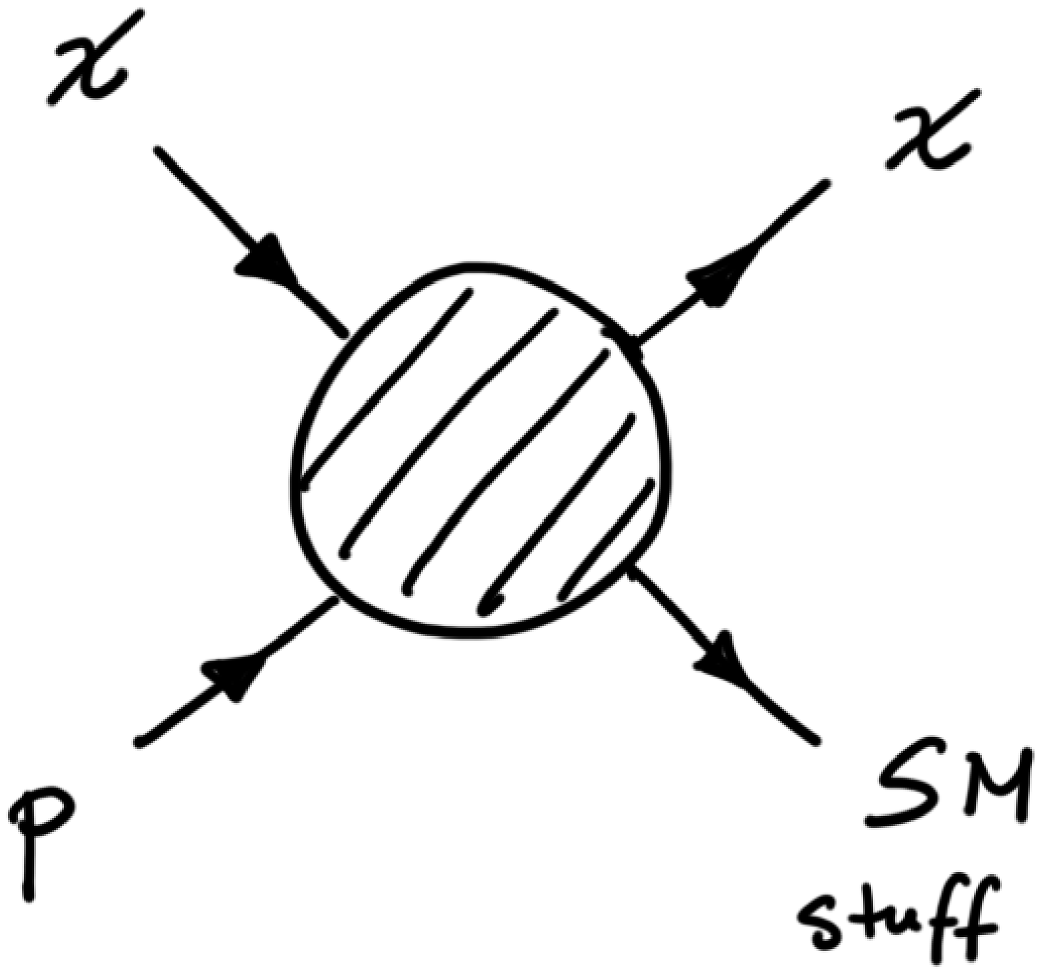

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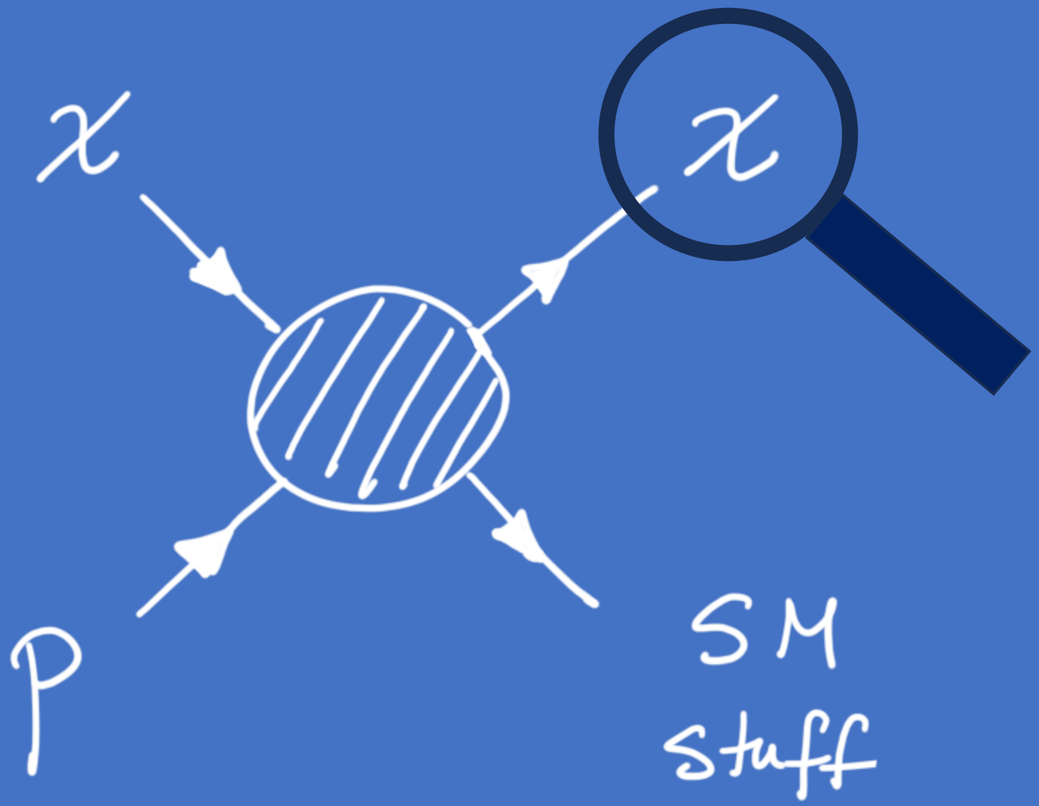


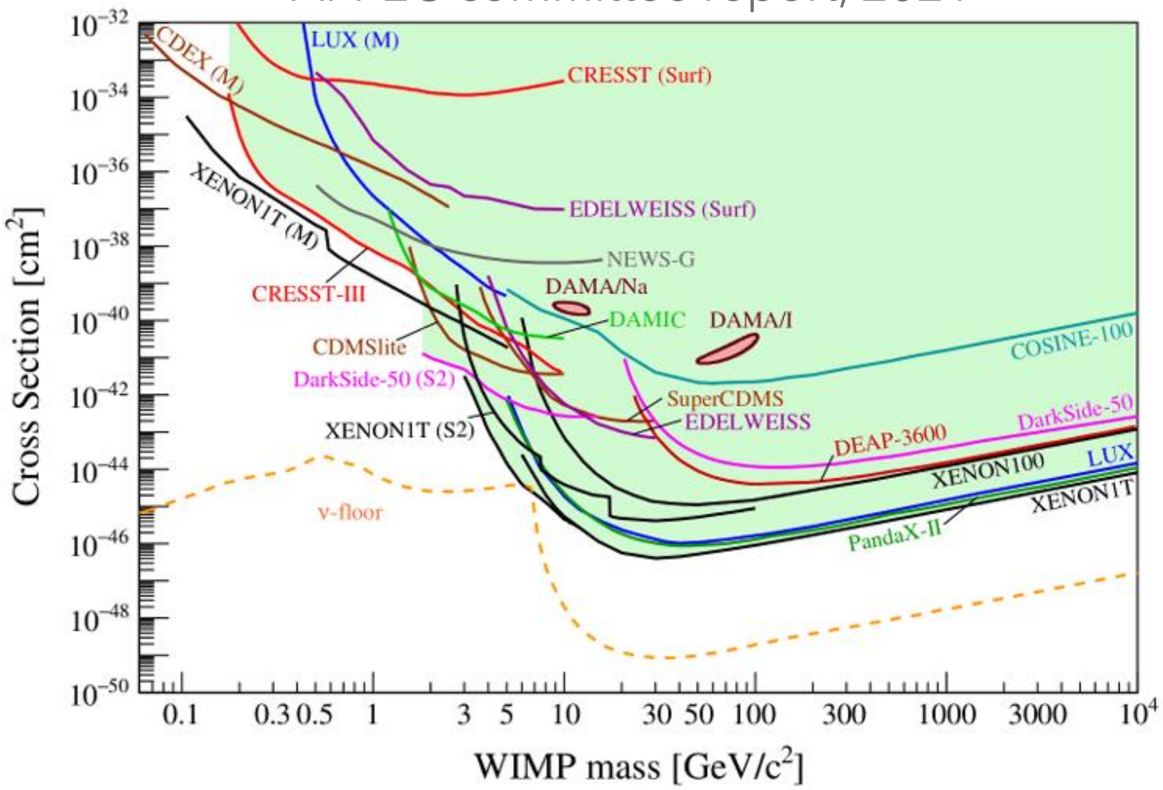
III

Blazar-boosted Dark Matter

Why boosted Dark Matter?

Direct detection loses sentitivity to sub-GeV DM, not enough energy to leave a signal

APPEC committee report, 2021



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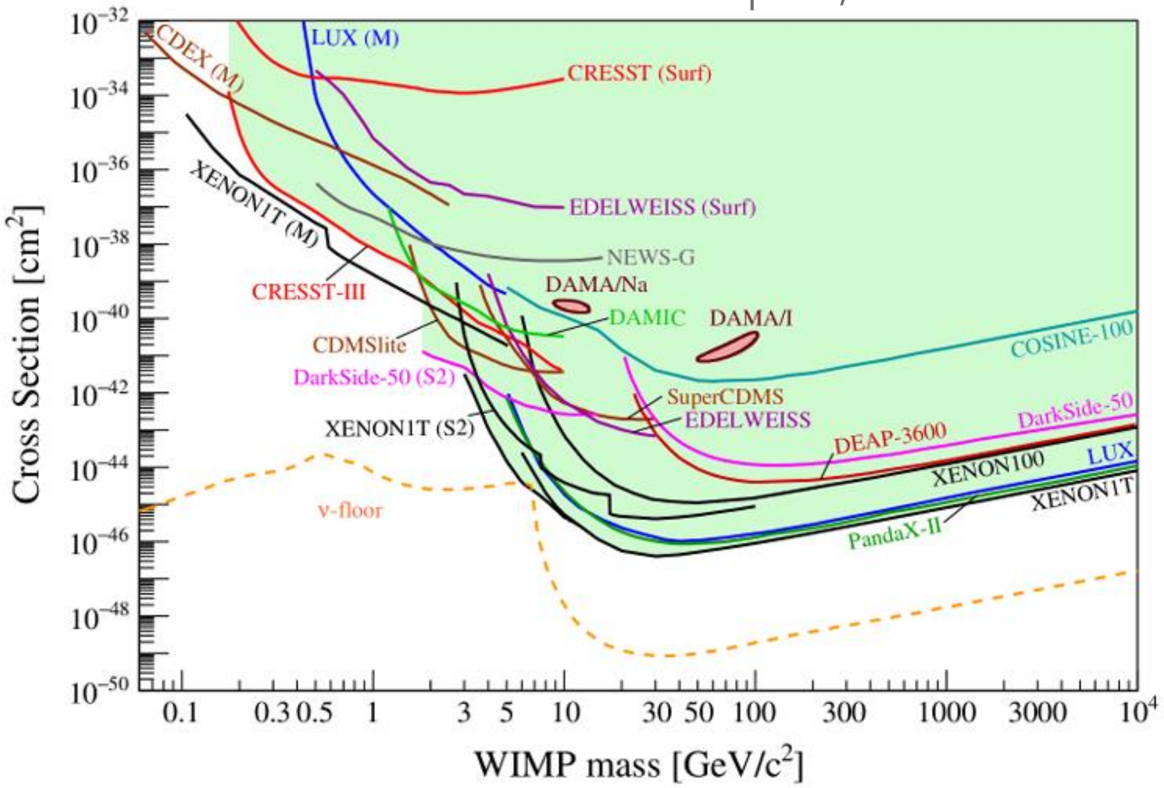

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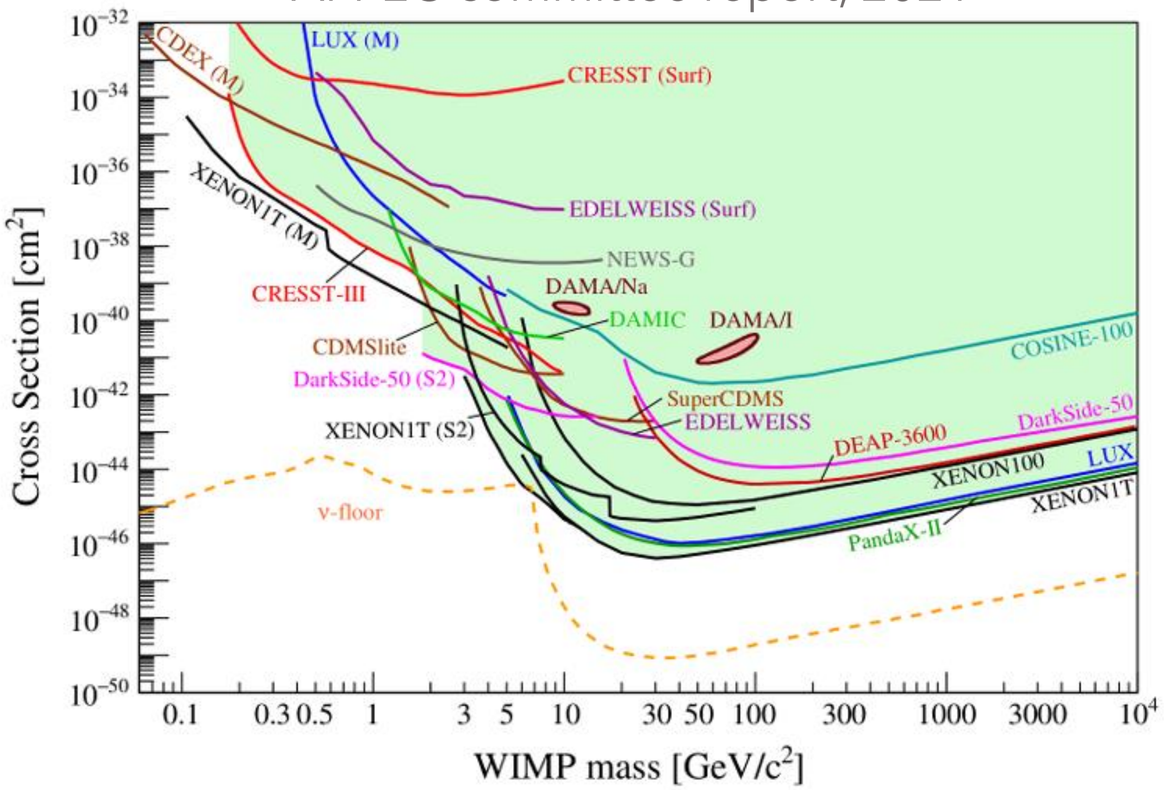

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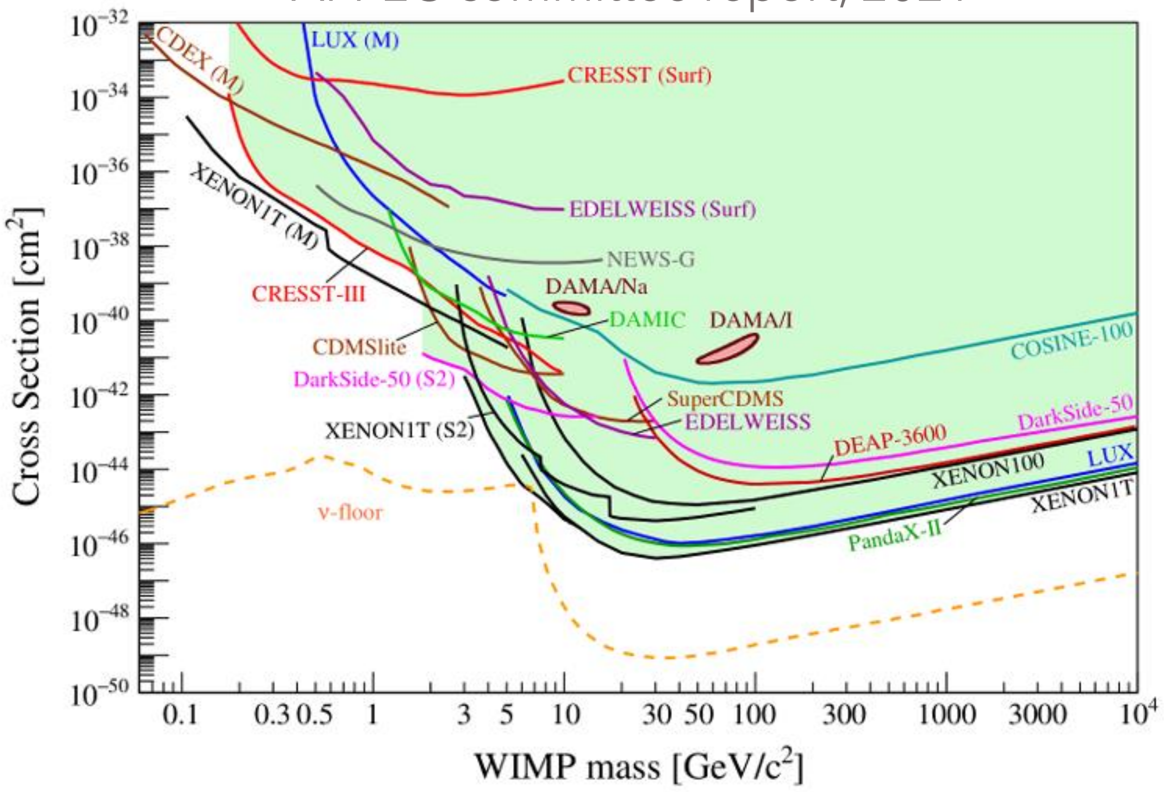

To do better: more cosmic rays, more DM, higher energies… **Blazars!**

[Wang+ 2021]

Our model

We add to the SM a fermion DM and a new massive vector that couples only to quarks

$$\mathcal{L}_{\mathrm{DM}} = g_q\, \overline{q}\, \gamma_\mu\, q\, V^\mu + g_\chi\, \overline{\chi}\, \gamma_\mu\, \chi\, V^\mu + \frac{1}{2} m_V^2\, V^\mu V_\mu$$

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We can compute the flux as

$$\frac{d\Phi_\chi}{dE_\chi} = \frac{\Sigma_{\mathrm{los}}}{m_\chi d_L^2} \int dE_p \frac{d\Gamma}{dE_p\, d\Omega} \frac{d\sigma}{dE_\chi}$$

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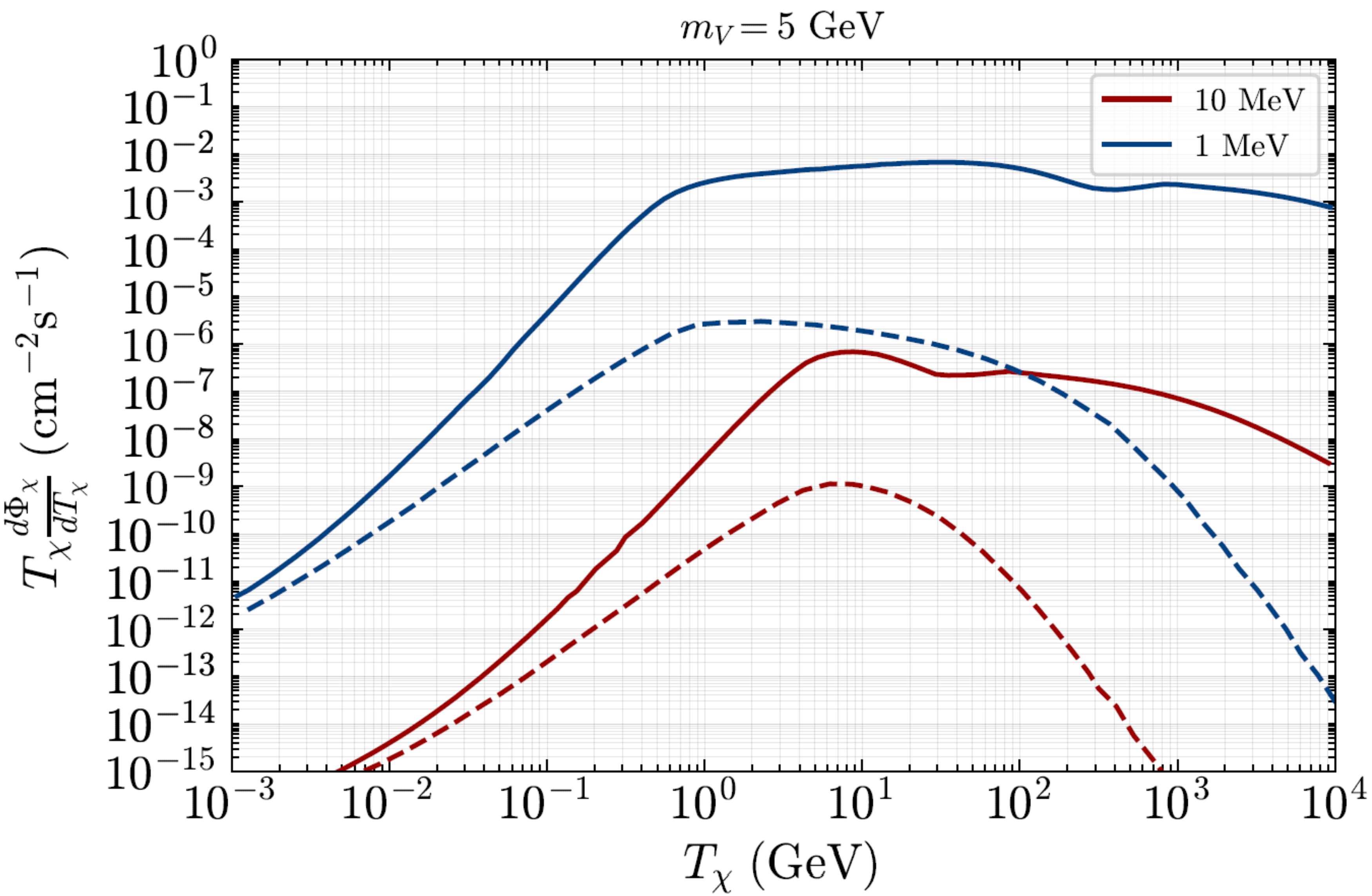
Spike model

Jet model

Particle physics model

Boosted DM flux



Sounds good, but…

Bounds on mediator from meson decays:

- If $m_V \lesssim 300\ \mathrm{MeV}$ bounds from $K \to \pi + \mathrm{inv}$
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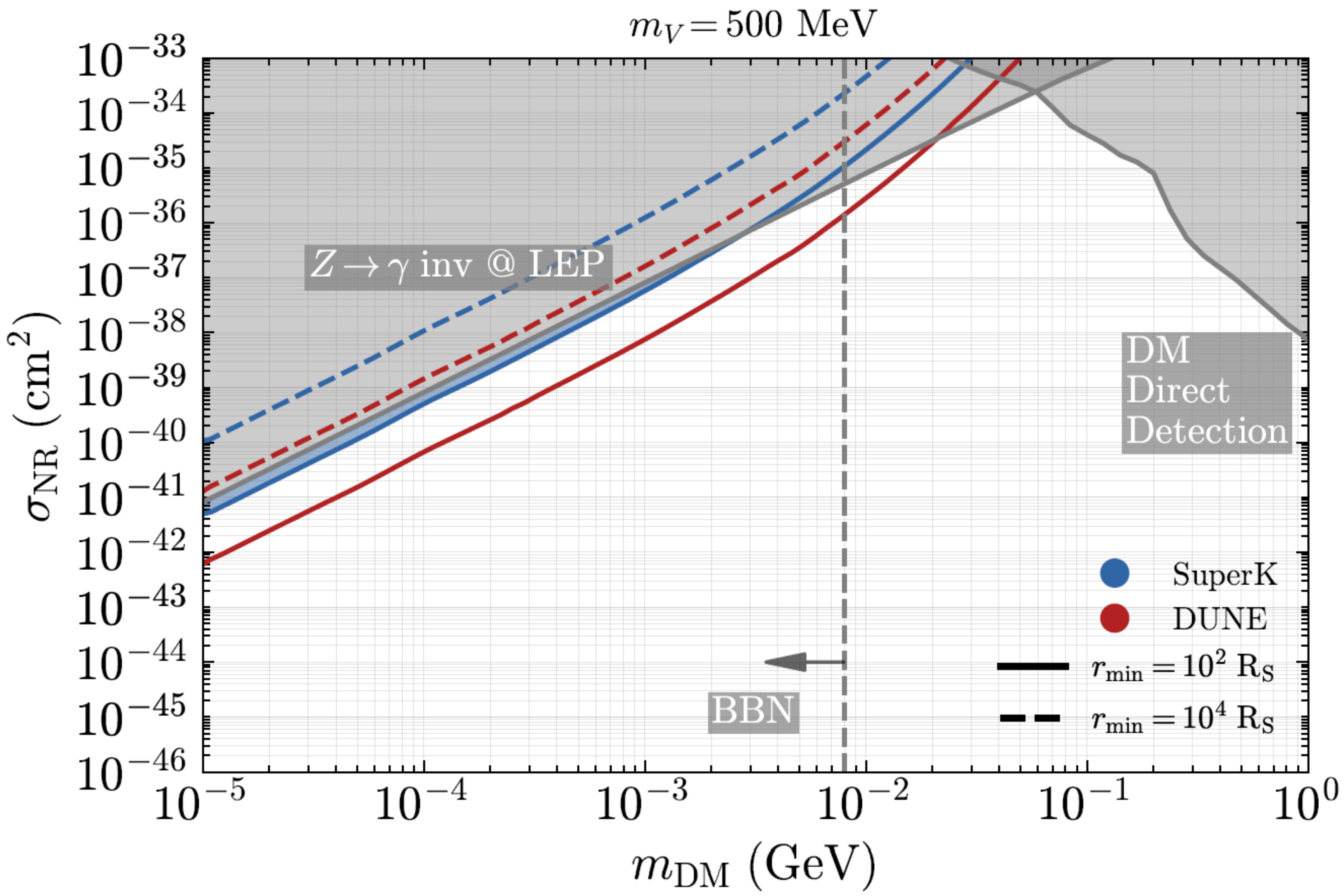
Strongest bound is UV model dependent, avoidable in other UV completions

Constraints



IV

Neutrinos from blazars

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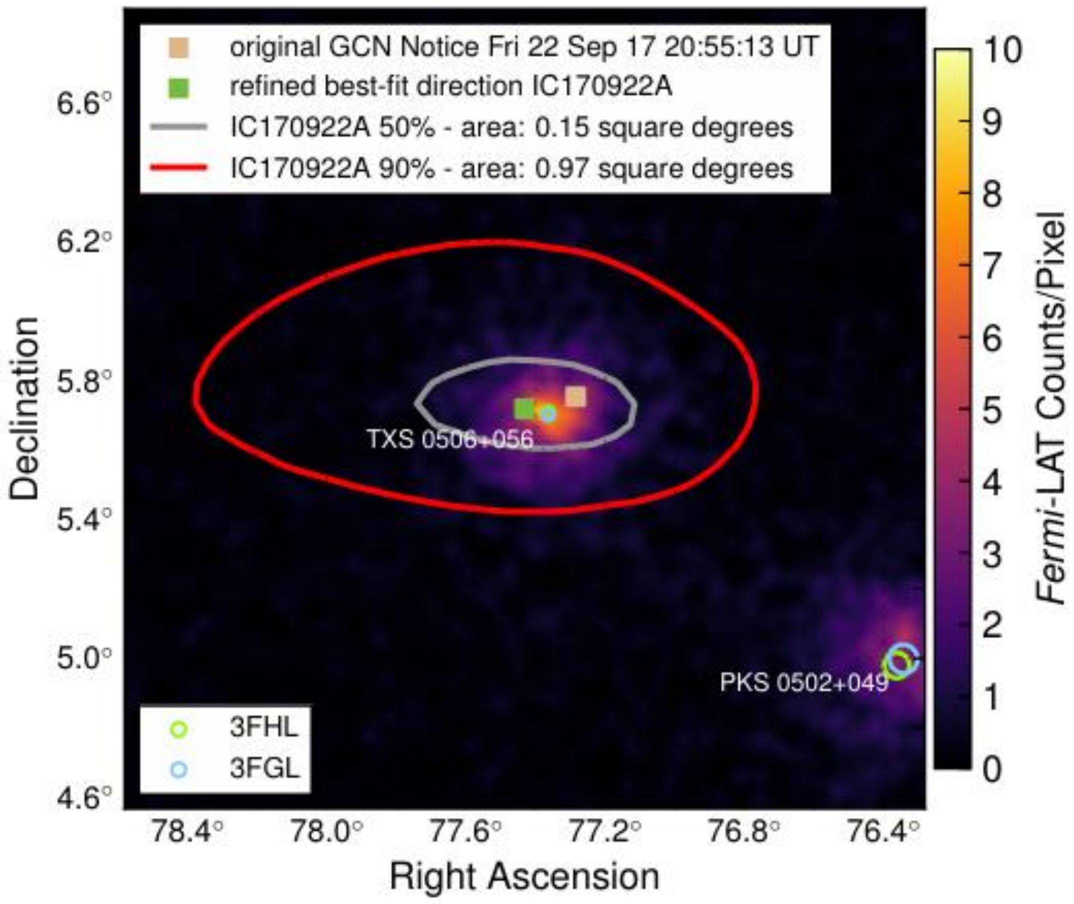
2017: IceCube detects ~ 300 TeV ν

First associated to astro source: blazar TXS 0506+056

(A)



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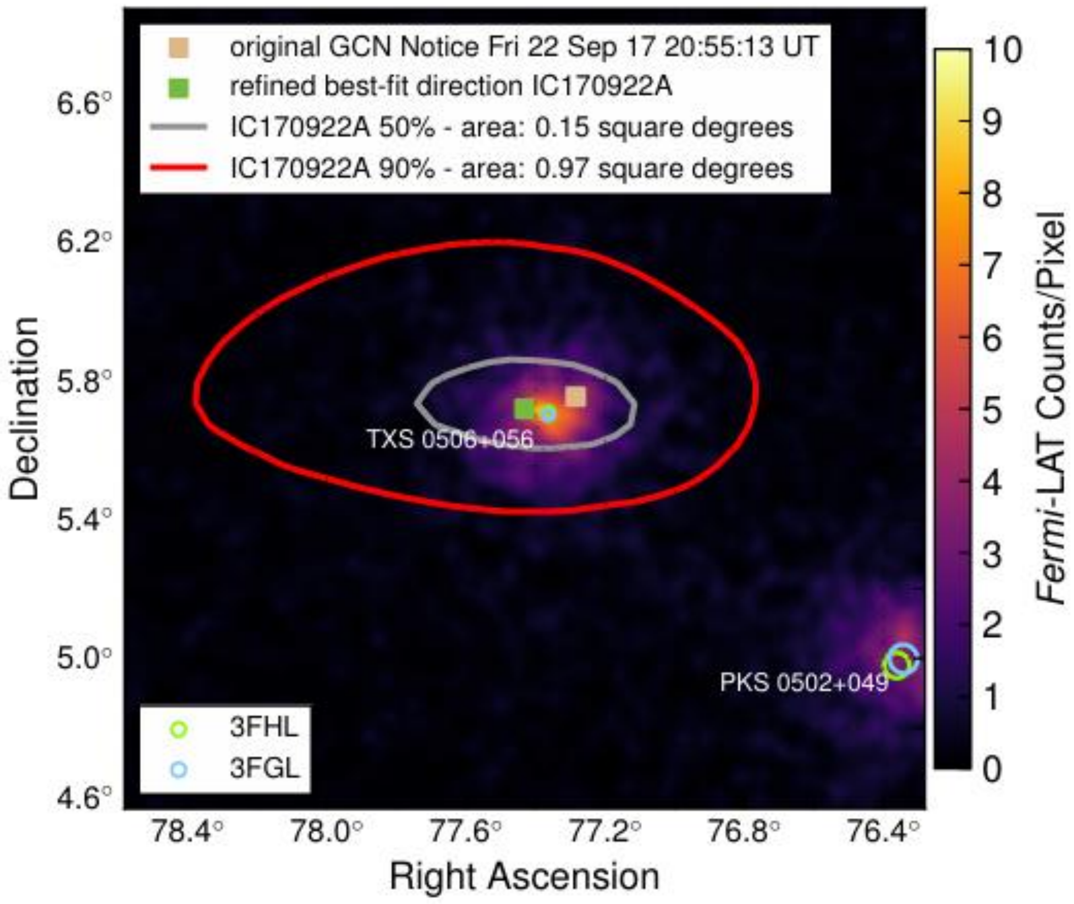

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Many others blazar associations:

Blazars are HE neutrino sources!

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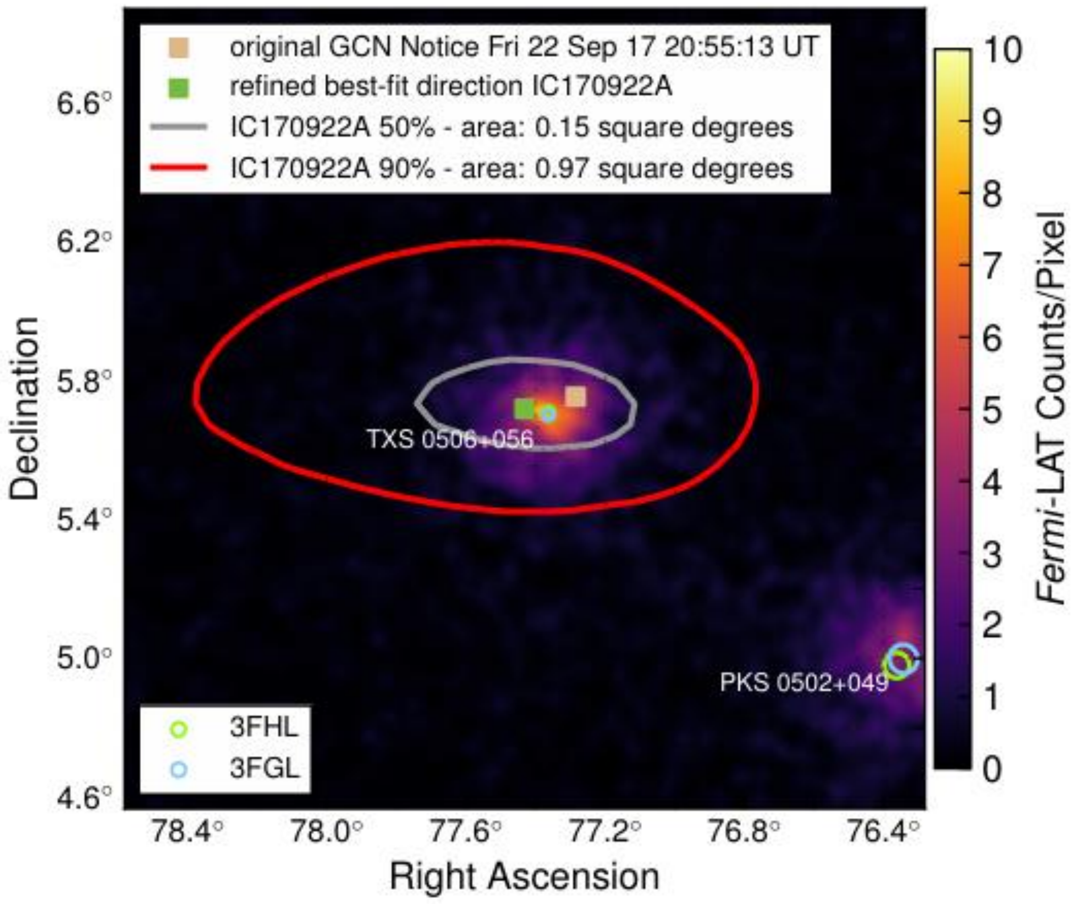
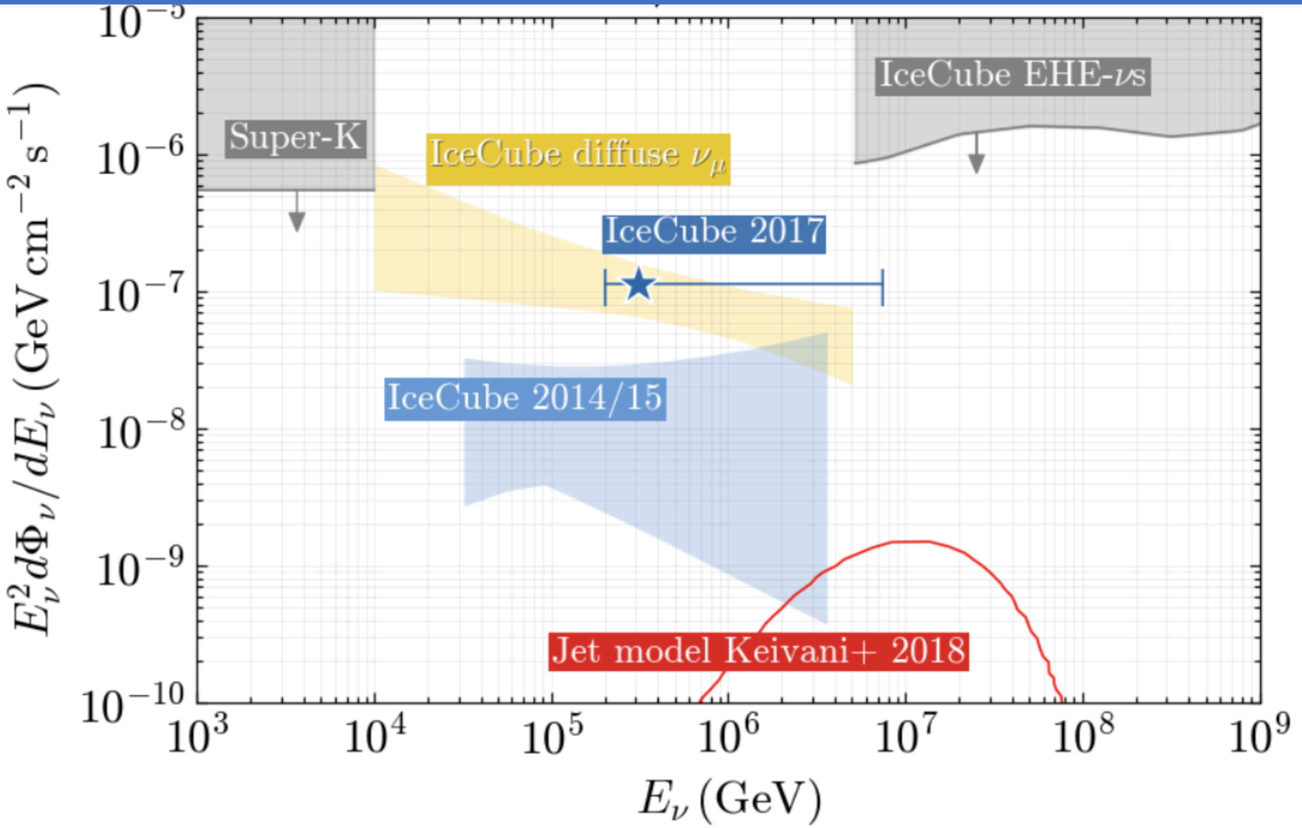


But… hard to explain

Astro models underpredict neutrino flux



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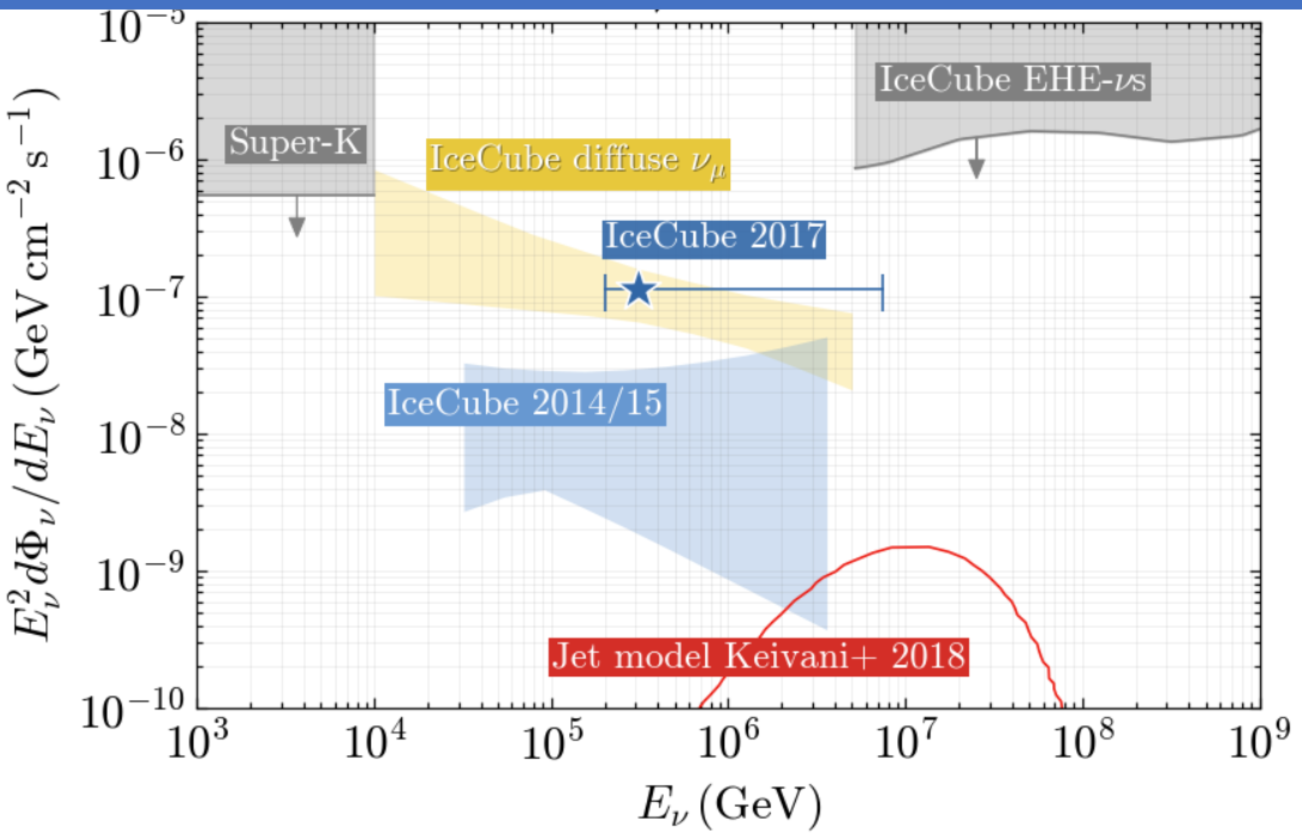

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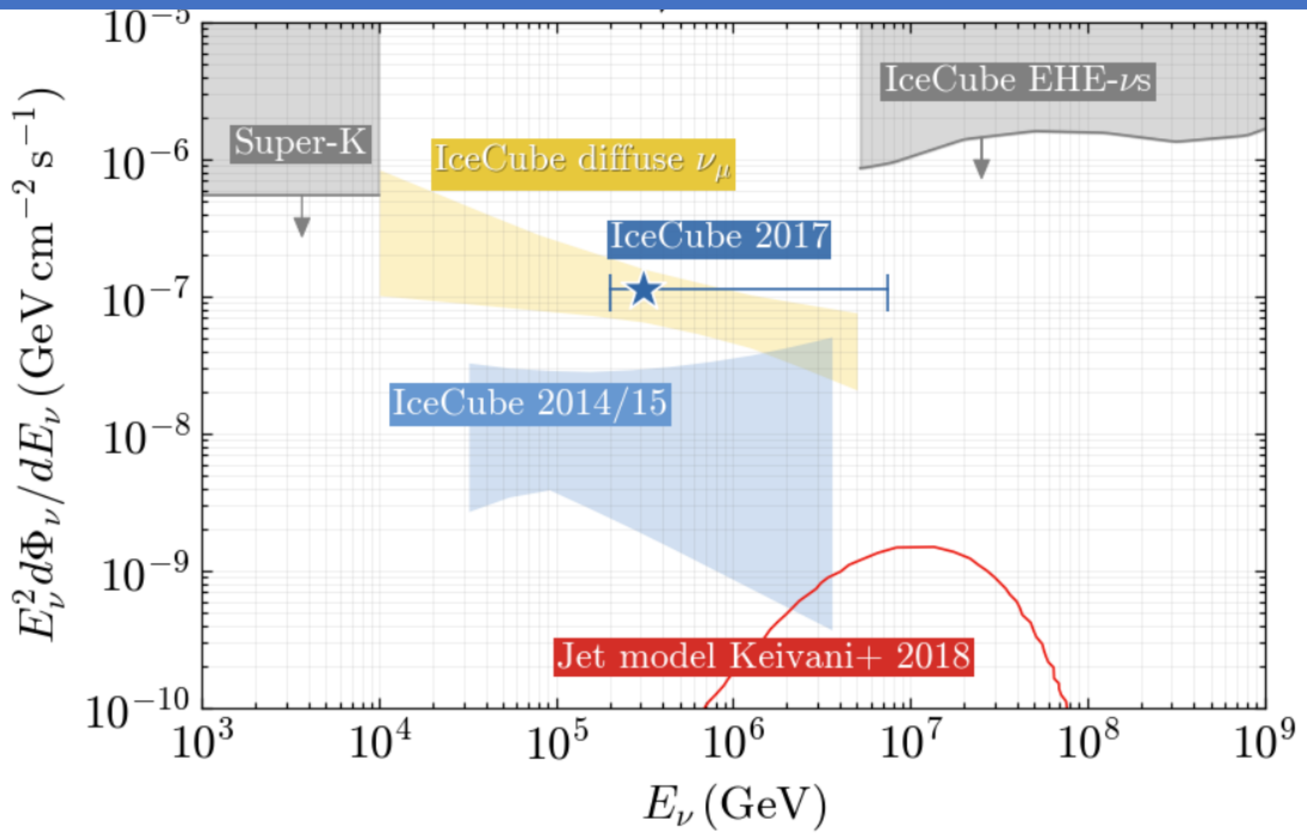

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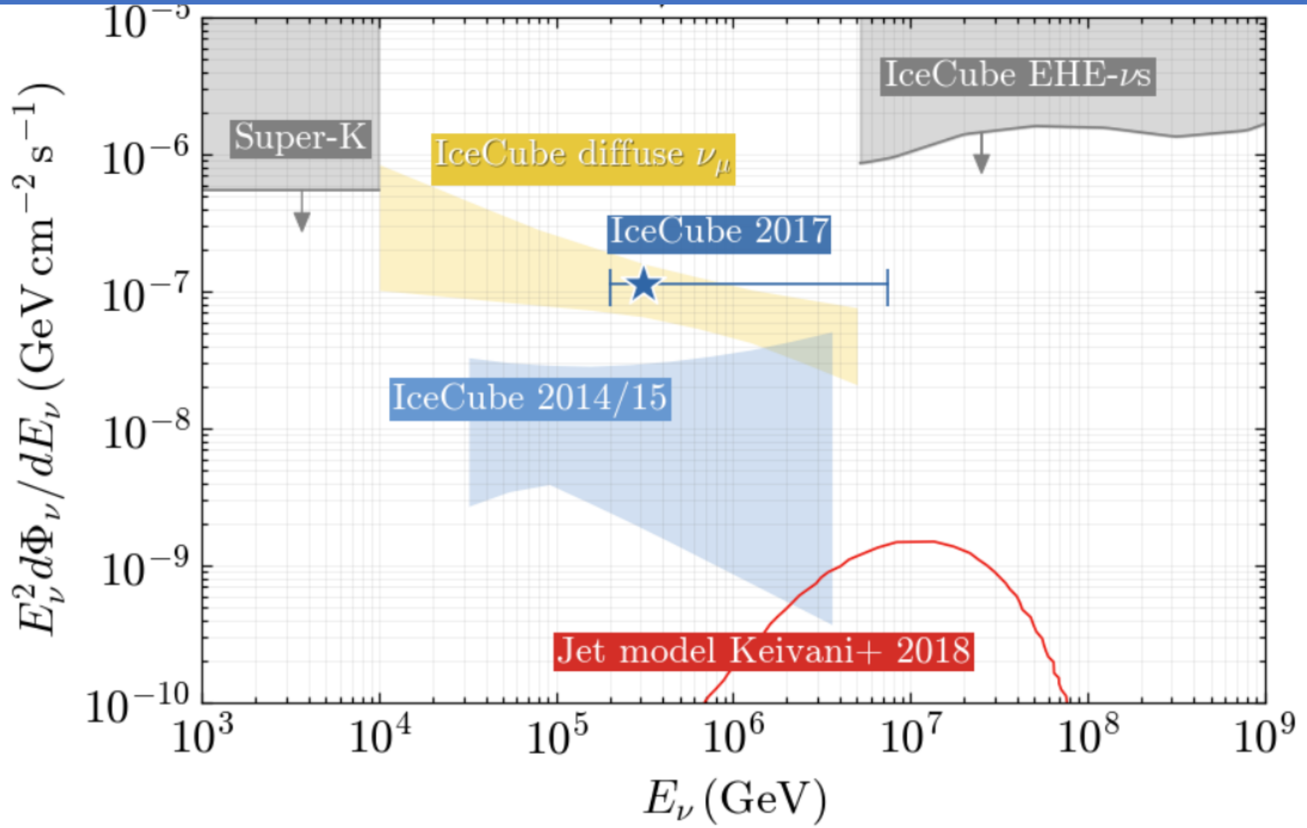
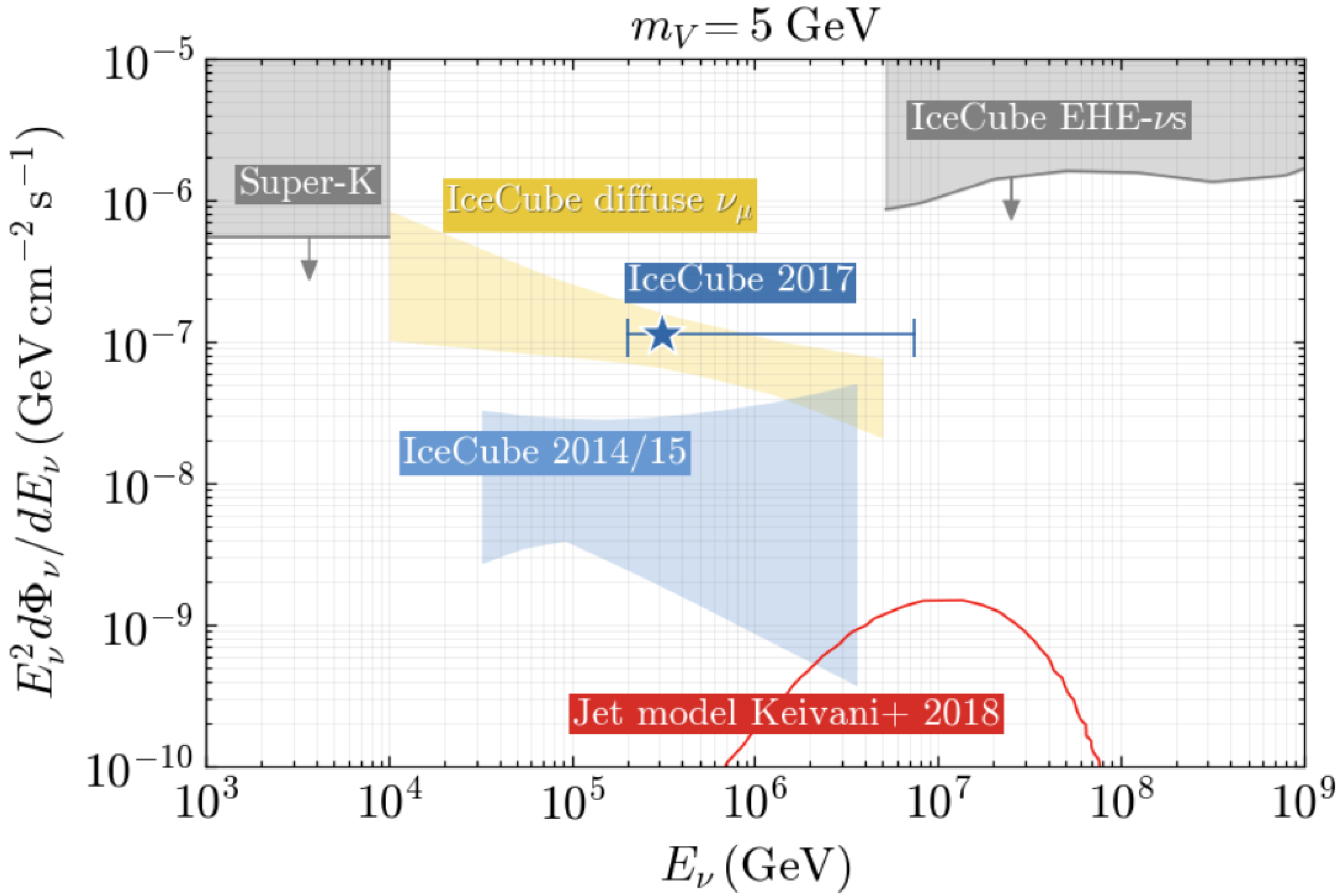


We can compute the flux (using MadGraph + Pythia) as:

$$\frac{d\Phi_\nu}{dE_\nu} = \frac{\Sigma_{\mathrm{los}}}{m_\chi d_L^2} \int dE_p \left.\frac{d\Gamma_p}{dE_p d\Omega}\right|_{\mathrm{los}} \sigma_{\mathrm{DIS}} < \frac{dN_\nu}{dE_\nu} >$$

What we get



$m_V = 5$ GeV
Super-K
IceCube EHE-νs
IceCube diffuse ν_μ
IceCube 2017
IceCube 2014/15
Jet model Keivani+ 2018
$E_\nu^2 d\Phi_\nu/dE_\nu\,(\mathrm{GeV\,cm^{-2}\,s^{-1}})$
$E_\nu\,(\mathrm{GeV})$
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^3
10^4
10^5
10^6
10^7
10^8
10^9

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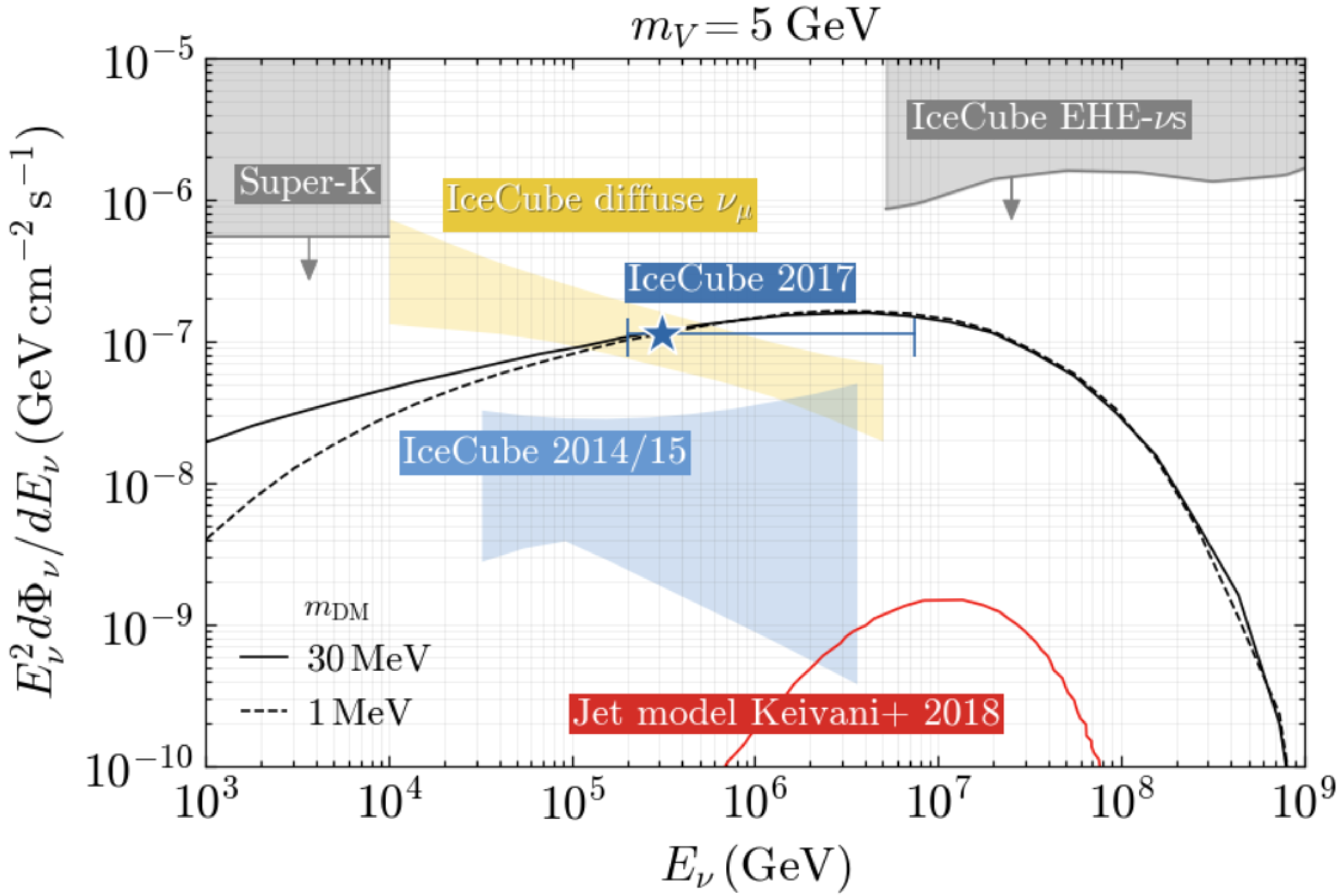

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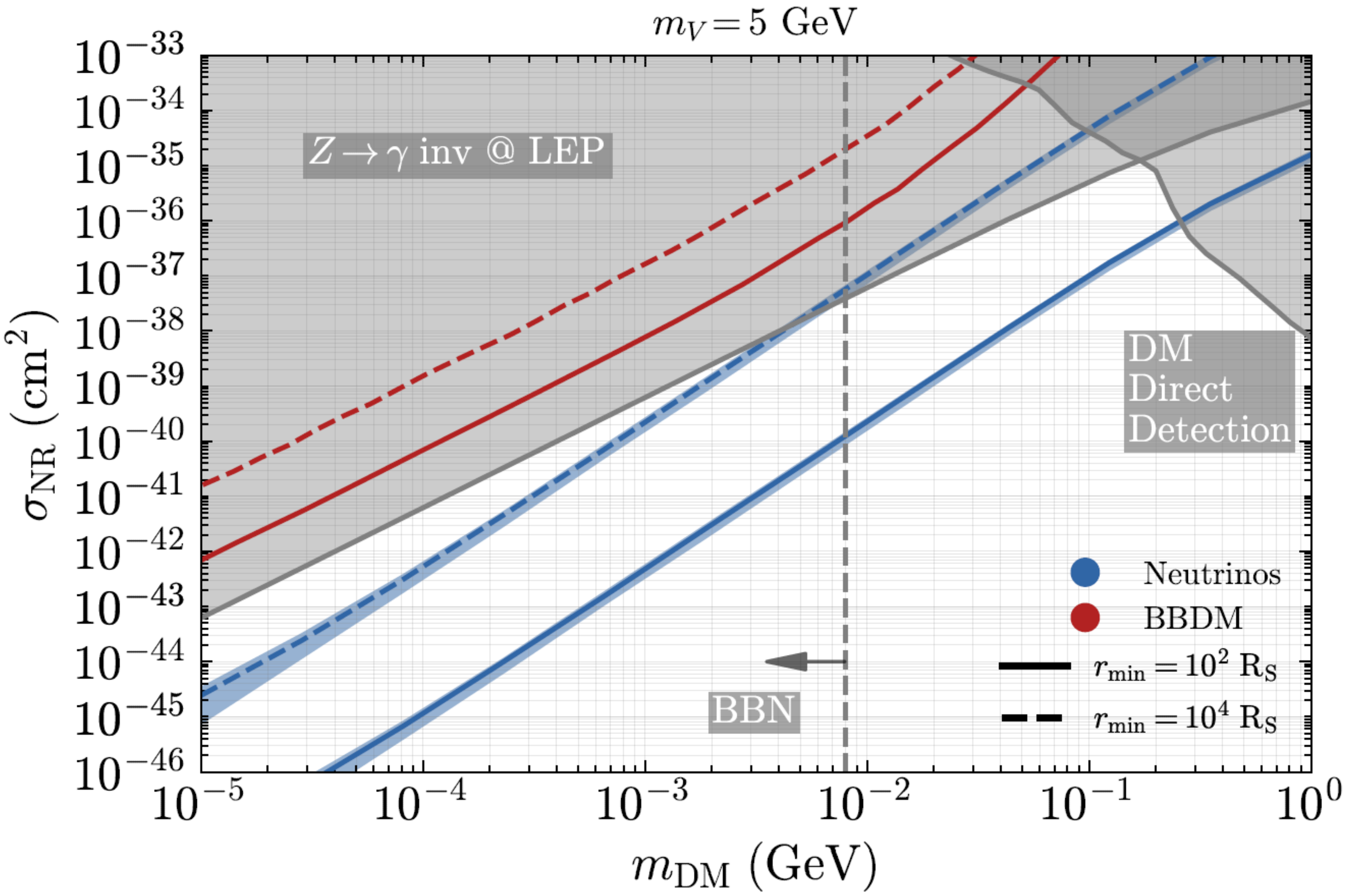
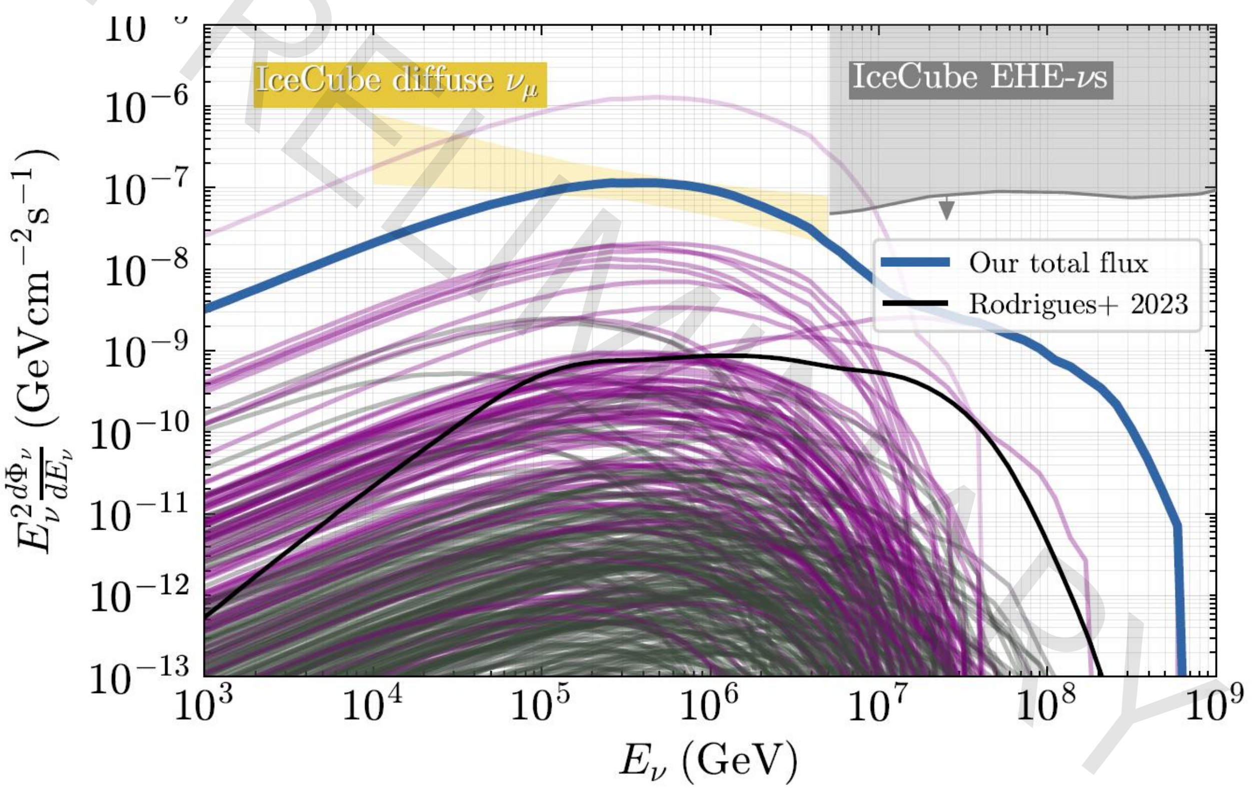
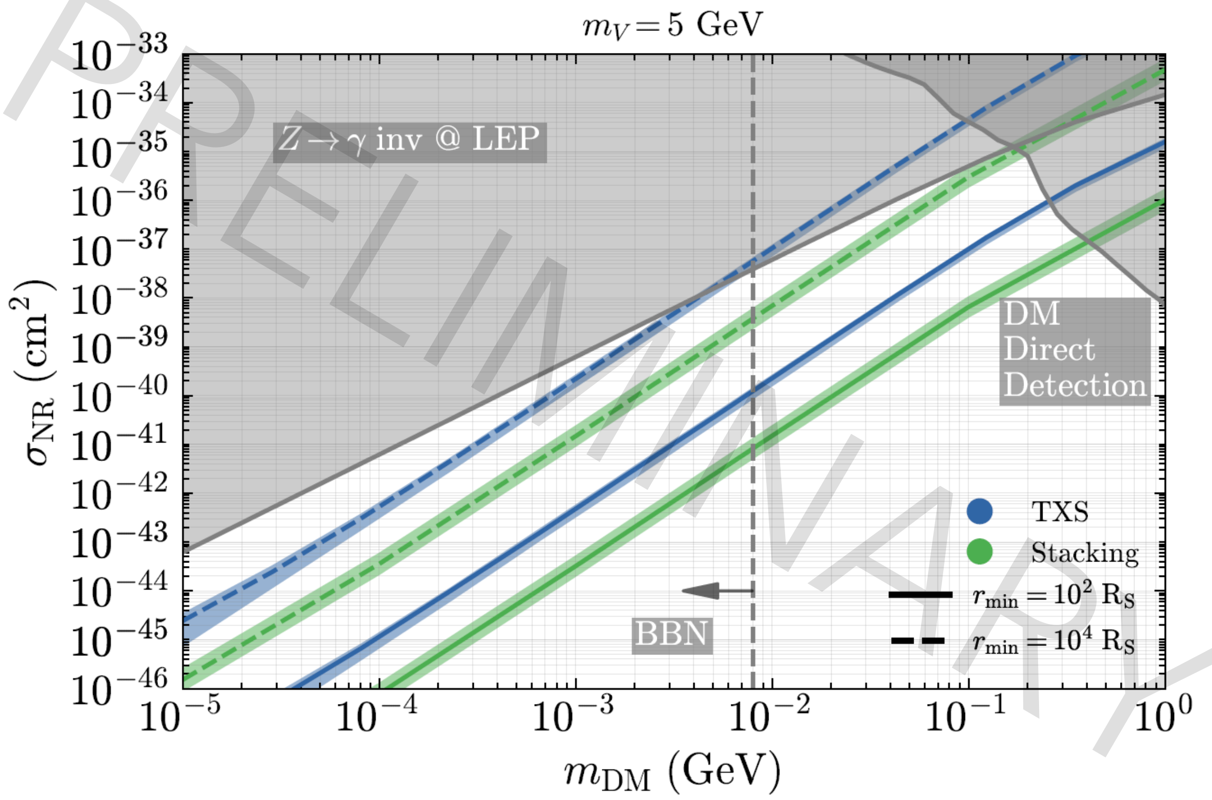
$m_{\rm DM}$
30 MeV
1 MeV
$E_\nu^2 d\Phi_\nu/dE_\nu$ (GeV cm^{-2} s^{-1})
E_ν (GeV)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Available parameter space



Not a fluke: blazar catalogue

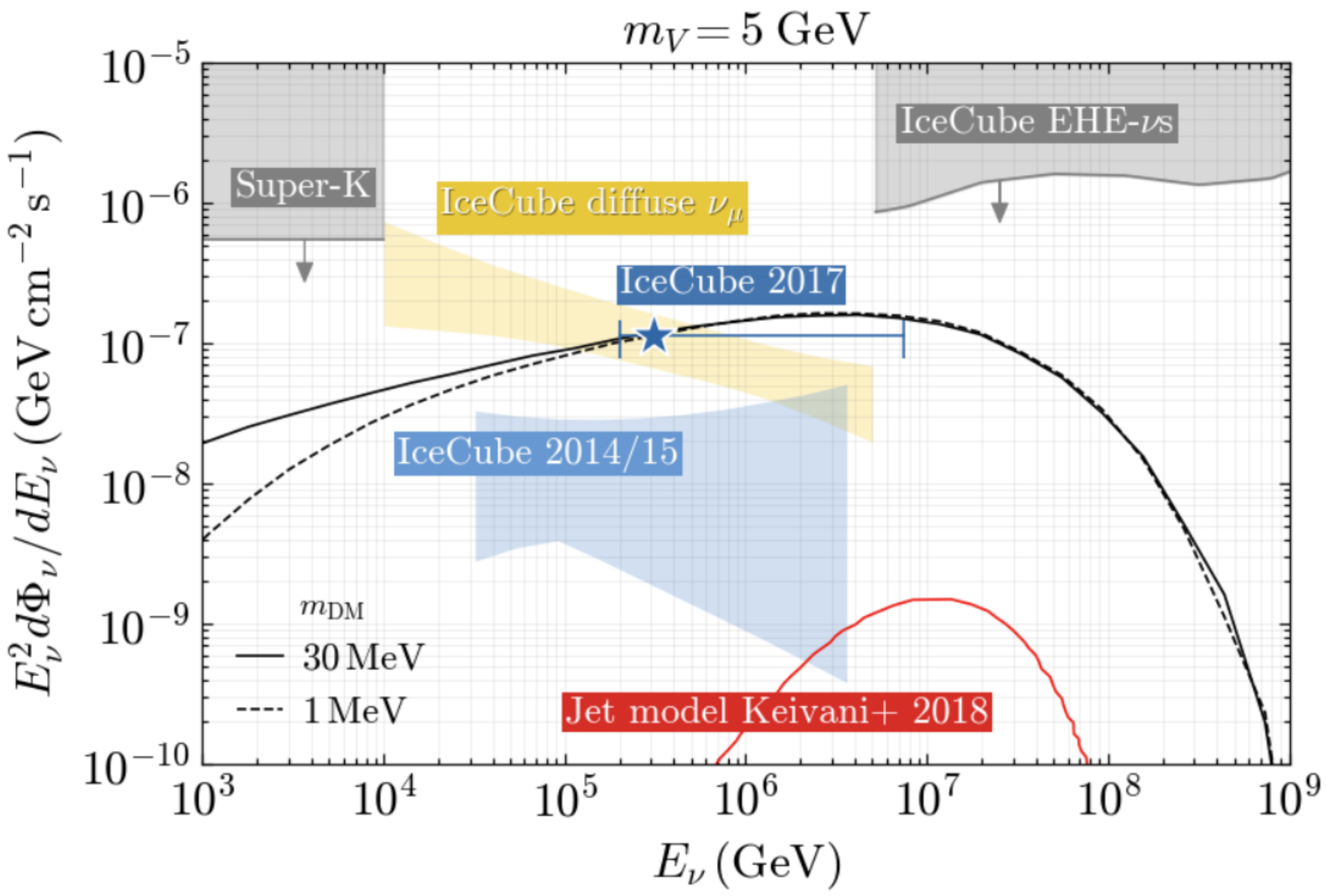




Diffuse neutrino flux correlates to blazar skymap above 100 TeV? [Buson+ 2022]

Key takeaways

- We can probe very small $\sigma_{p\chi}$ via BBDM



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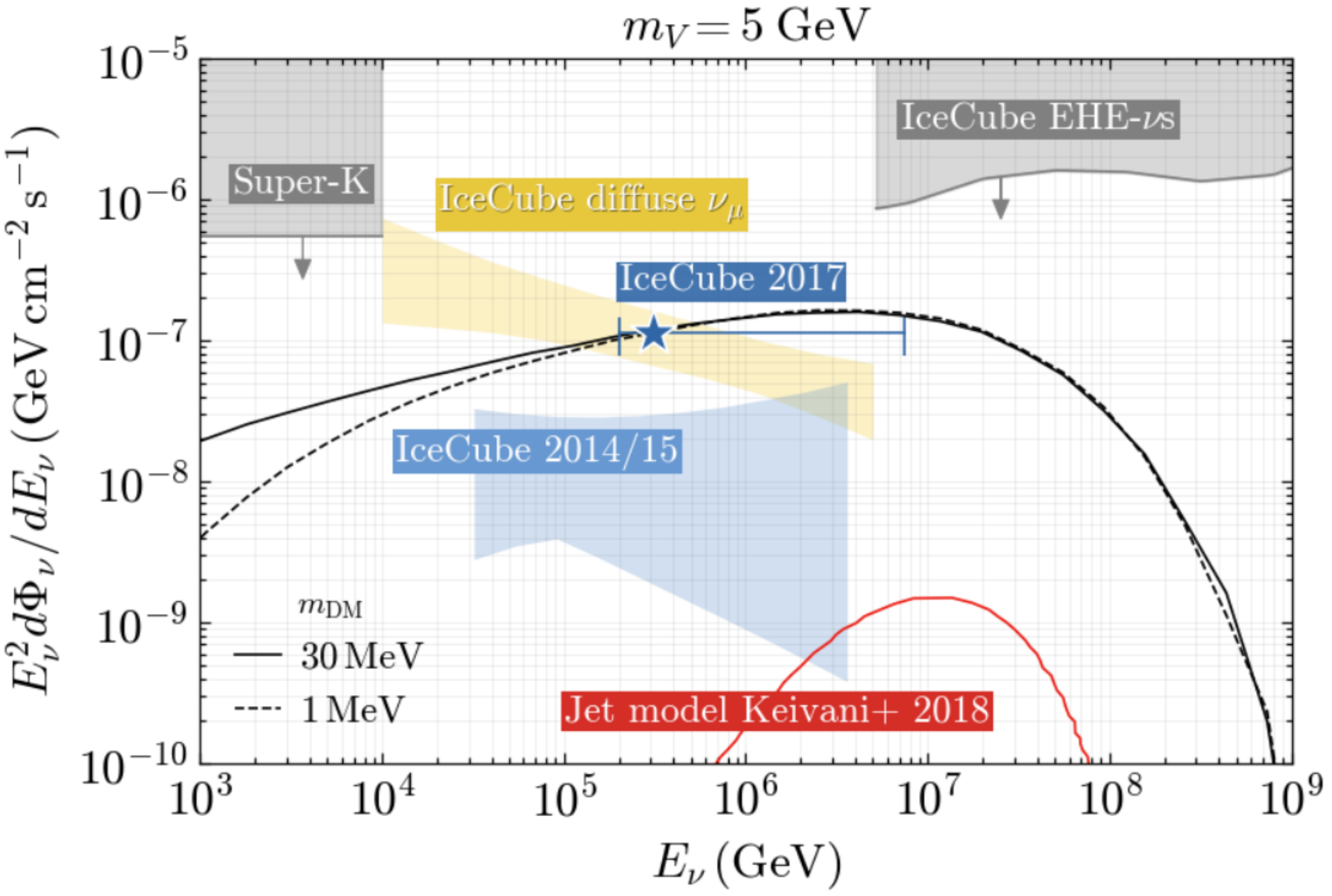

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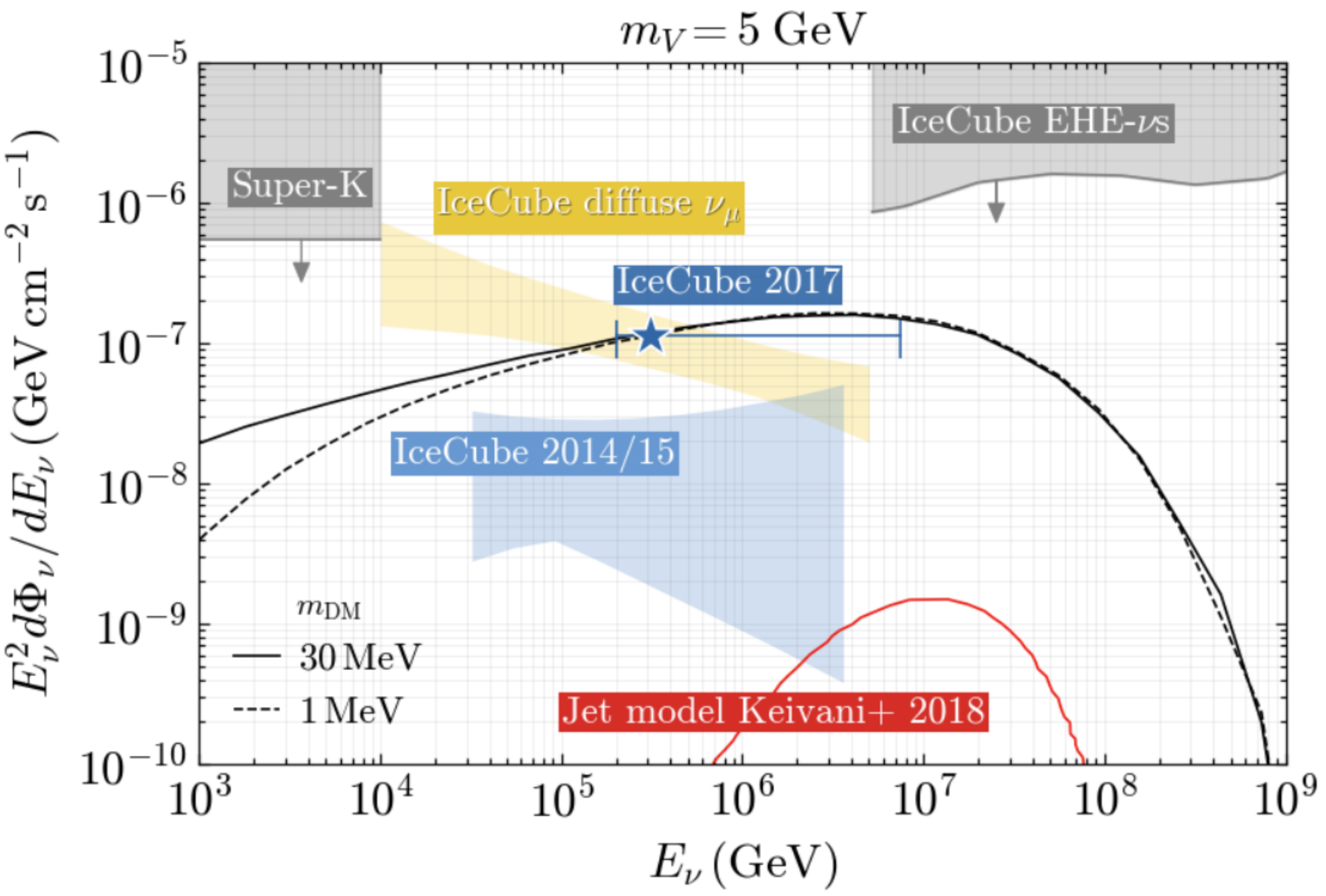

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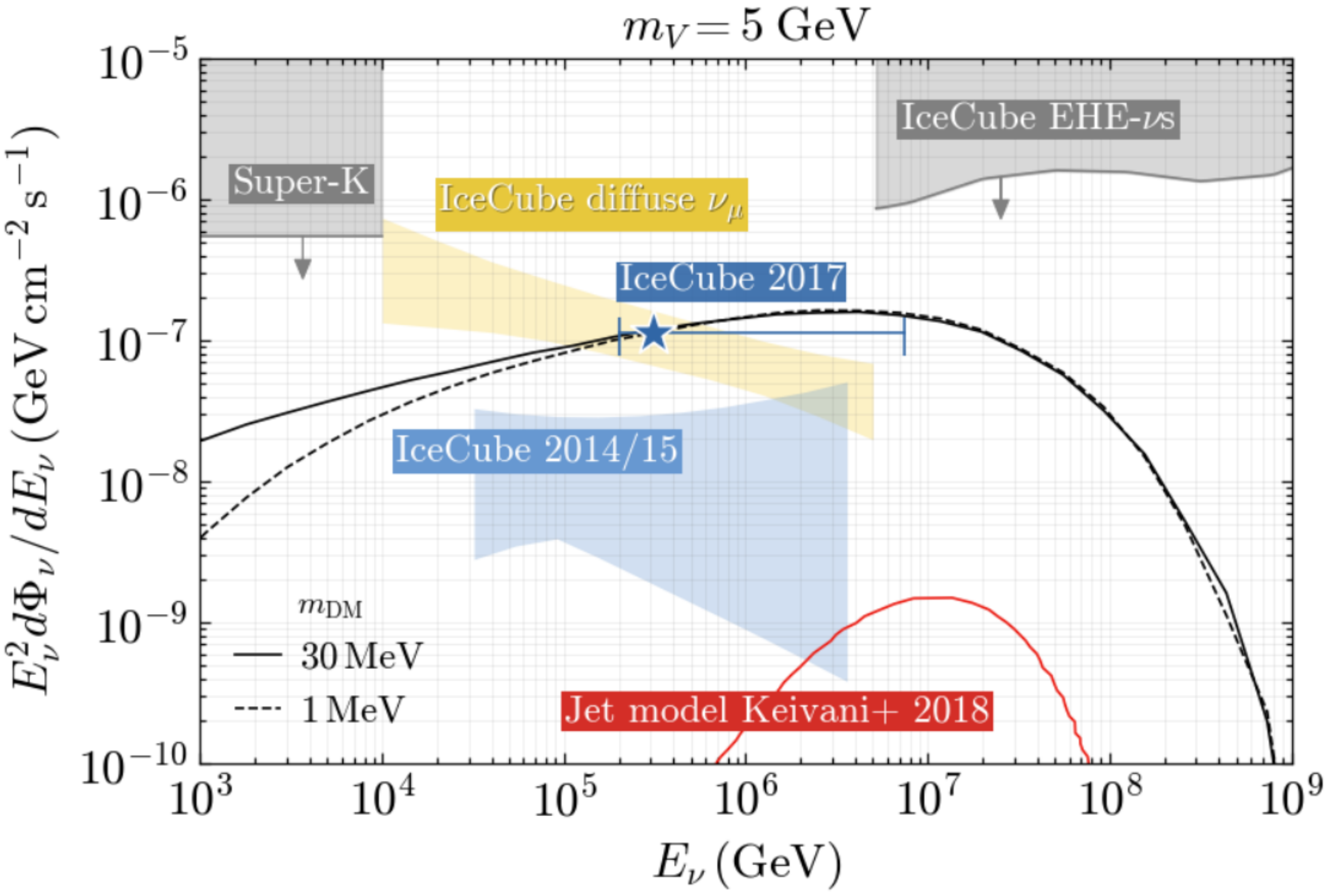
- Can explain neutrino emissions from blazars



Did IceCube detect Dark Matter around blazars?

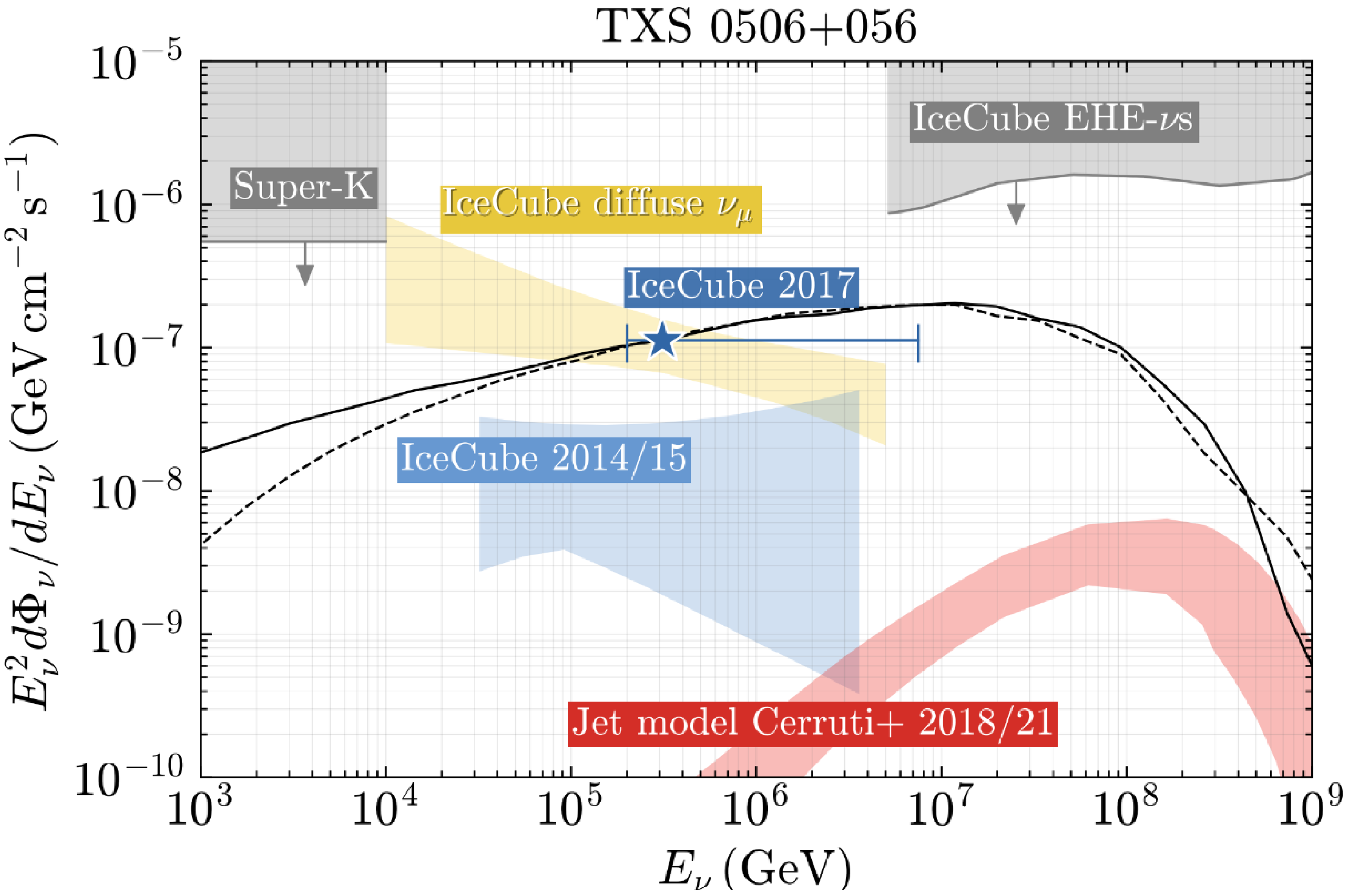
To do:

- What about gamma rays? Does this mess up the leptohadronic fit?
- Is the spike normalization reasonable?
- Understanding the diffuse neutrino background… could this mechanism explain it?
- Large astro uncertainties… can we quantify them somehow?
- Only LO computation, but NLO processes with initial gluon contribute a lot (large gluon pdf) + hadronic resonances

Thank you!

Backup

Different jet model

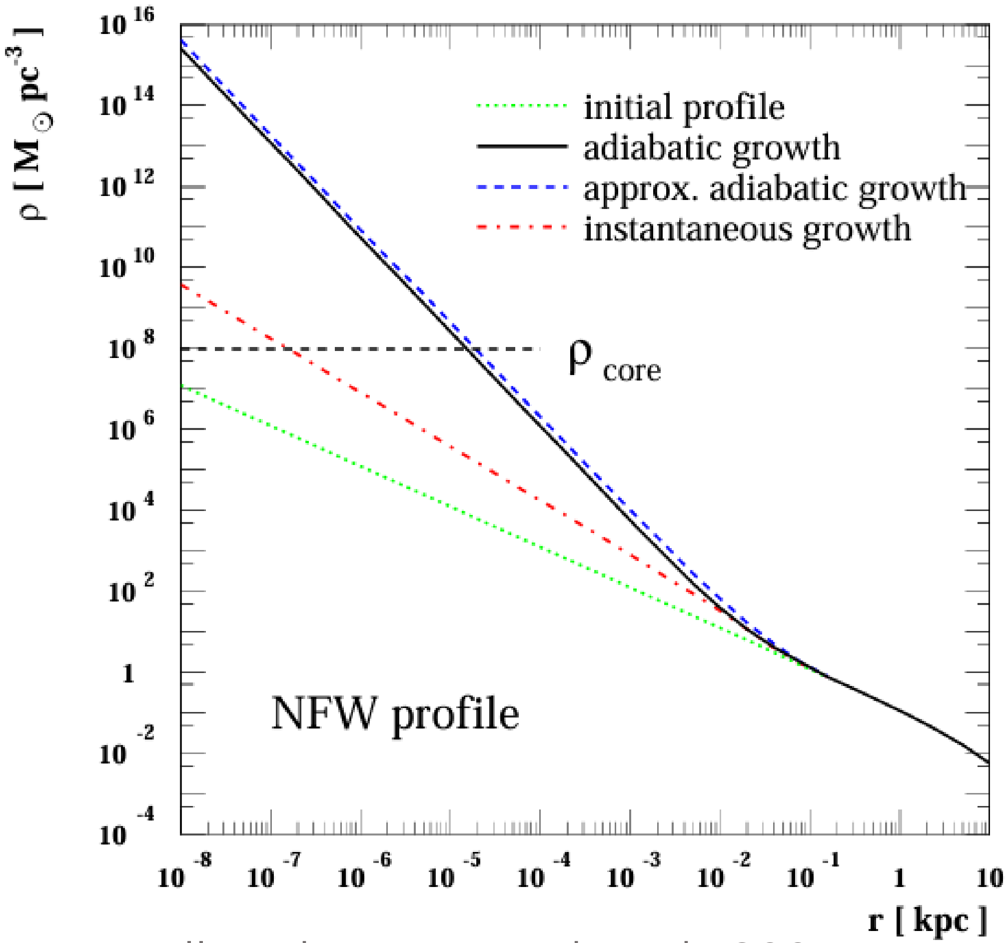


The Gondolo & Silk spike

Dark Matter around SMBH in the center of galaxies accumulates into spikes

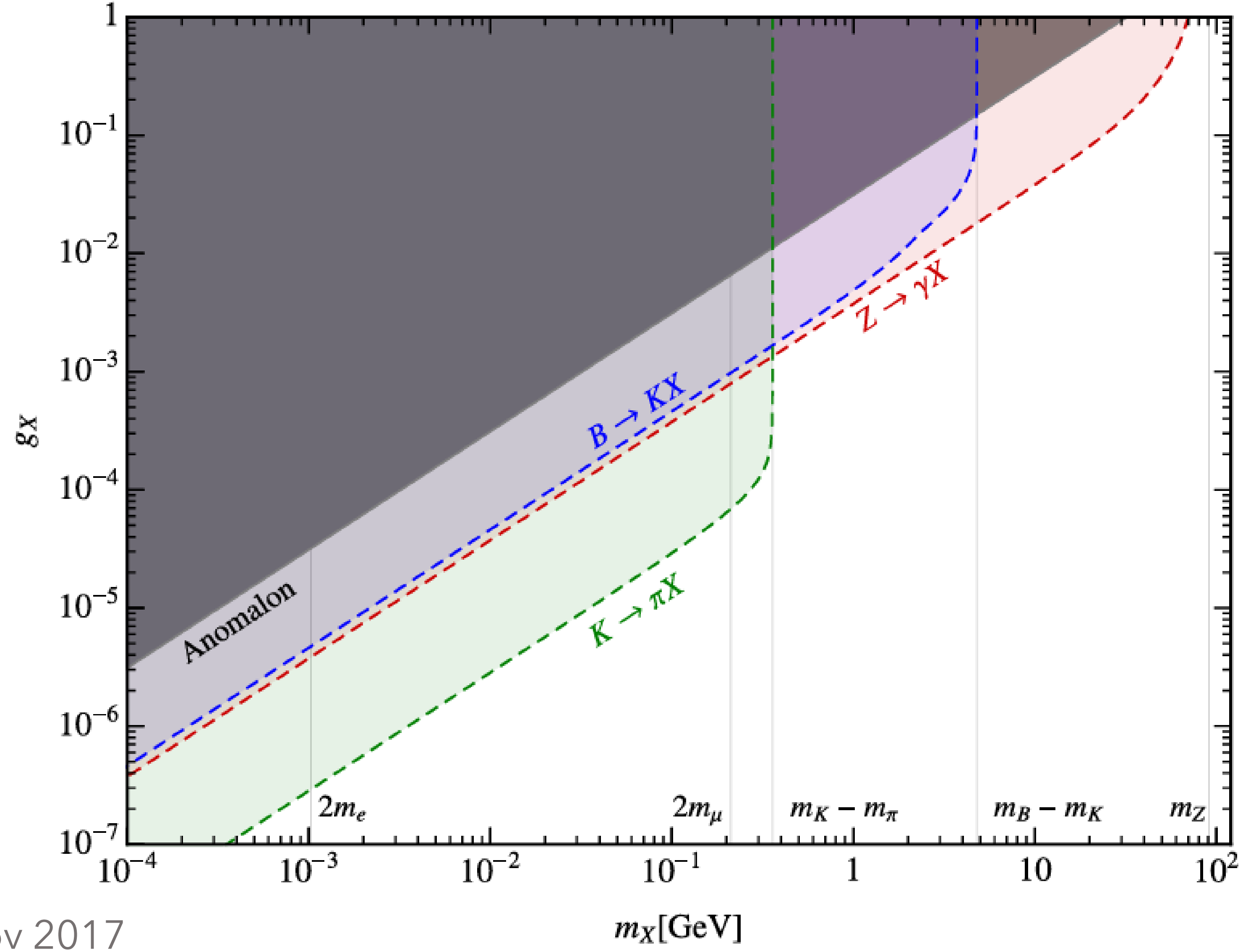
As SMBH grows, it contracts orbit around it, turns $r^{-\gamma}$ into $r^{-(9-2\gamma)/(4-\gamma)}$
[Gondolo, Silk 1999]

For $\Sigma_{\rm los} = \int_{r_{\rm min}}^{r_{\rm max}} dr\, \rho(r)$, up to 8-9 orders of magnitude more than NFW ($\Sigma_{\rm los}^{\rm NFW} \approx 10^{23}$ GeV cm^{-2})



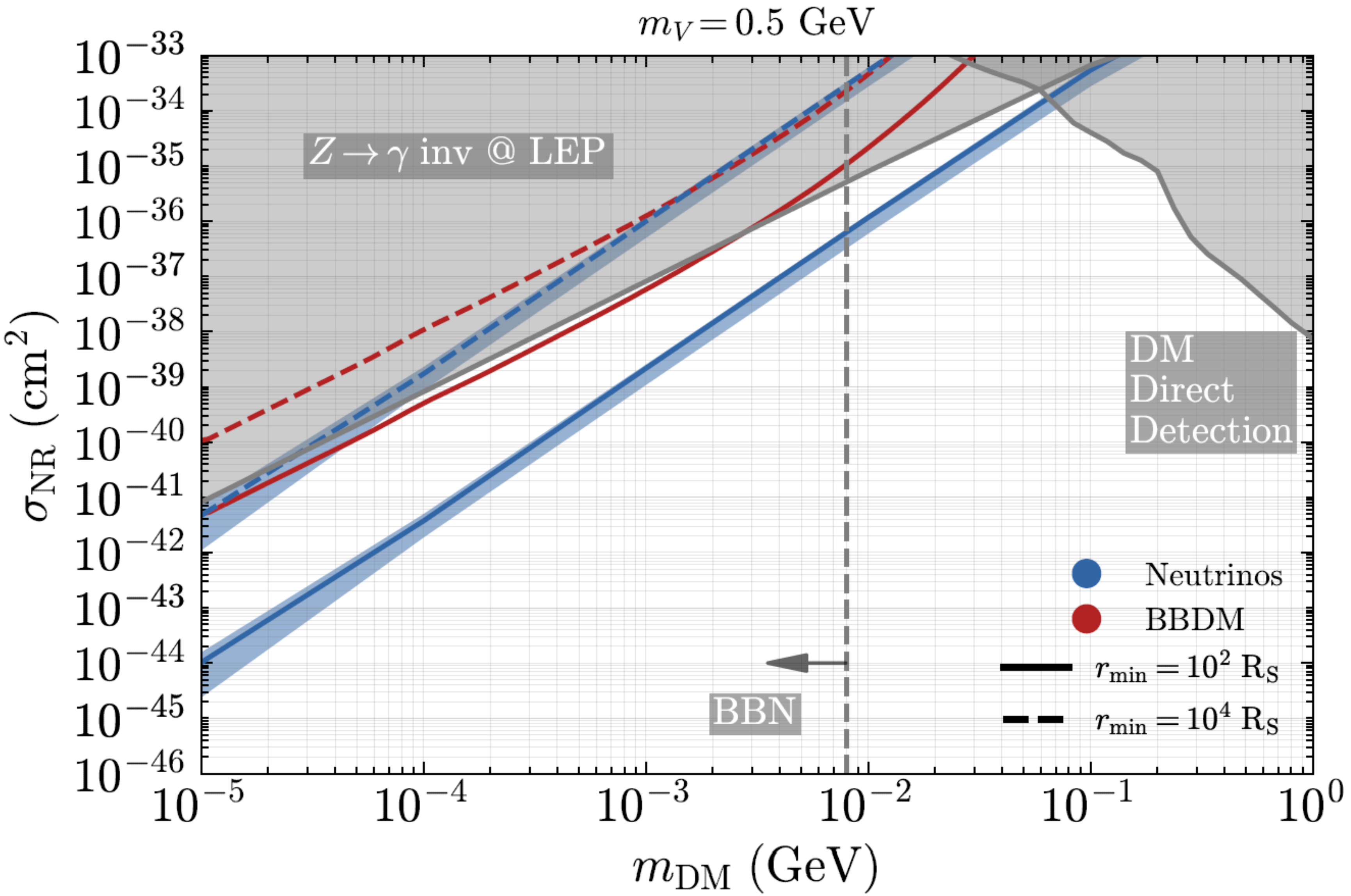
Ullio, Zhao, Kamionkowski 2001

UV completion bounds

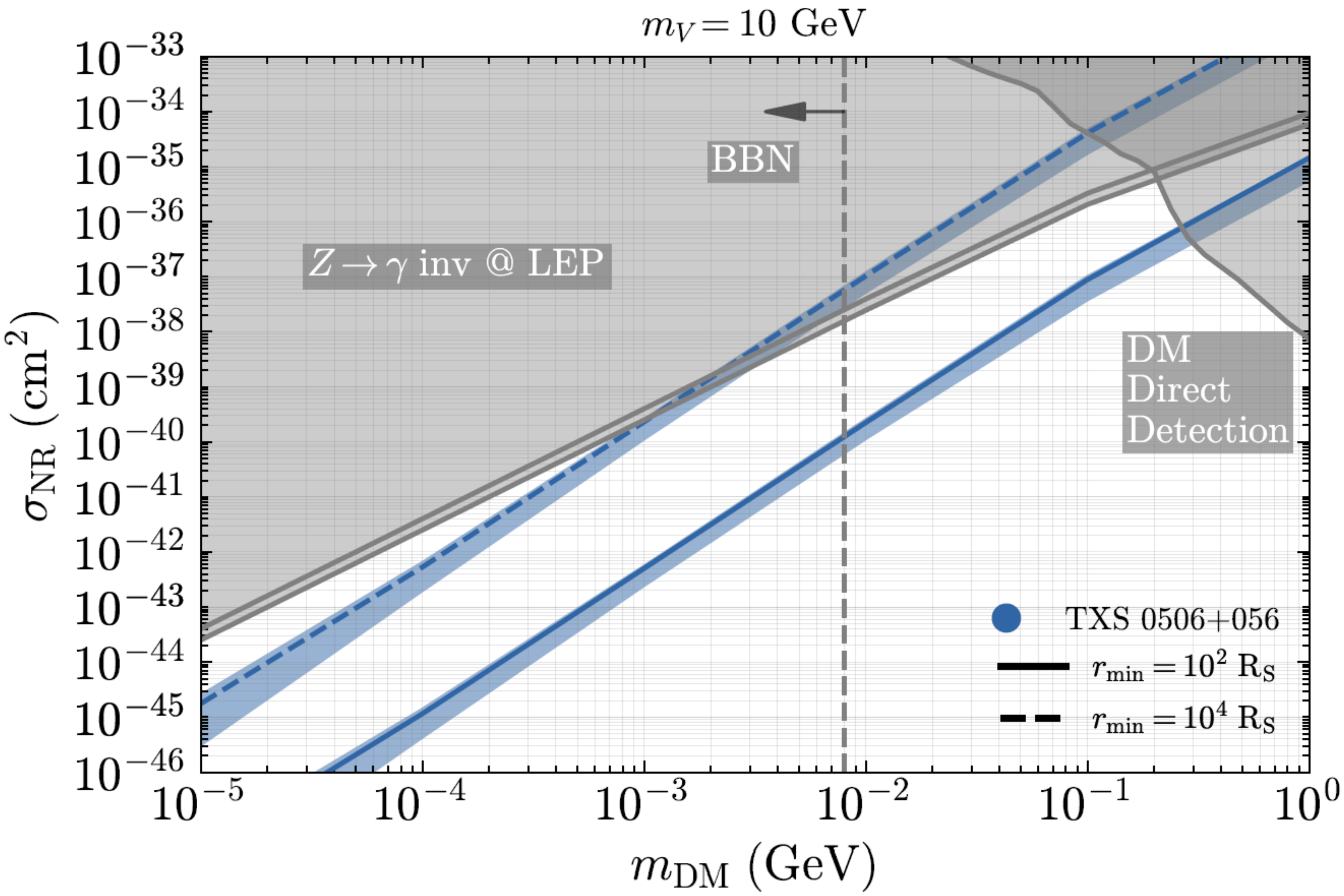


Dror, Lasenby, Pospelov 2017

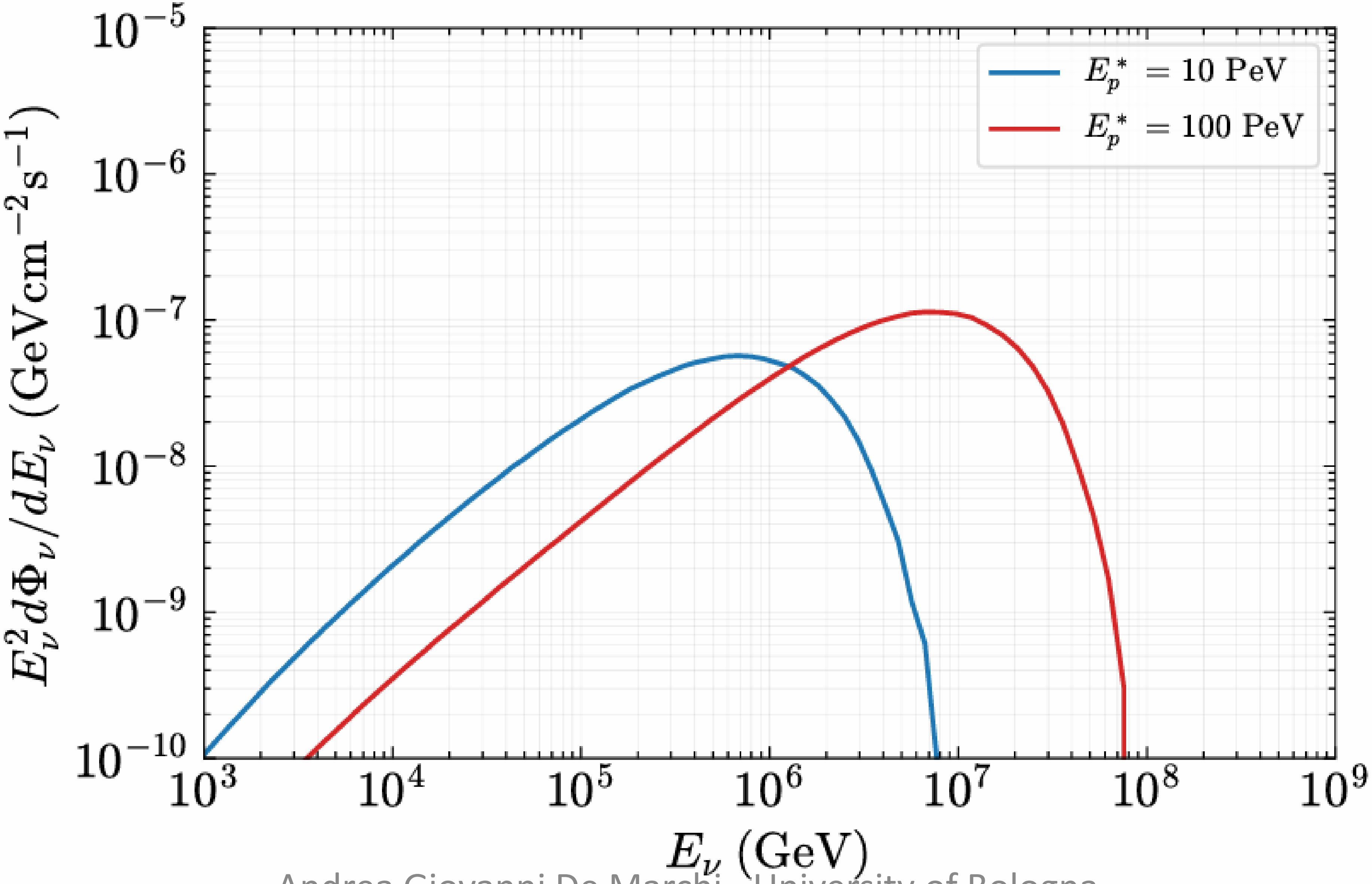
Available parameter space (0.5GeV)



Available parameter space (10 GeV)



Monochromatic



A bit of history

In 1950s, discovery of radio-sources associated to optical star-like sources, with unusual emission lines and color.

Classified as **Quasi-stellar radio sources (Quasars)**

In 1963 first spectrum of 3C273 (Schmidt): Hydrogen lines with z = 0.158, cosmological distance!

Not stars, brighter than entire galaxies!

$$L \sim 10^{13}\, L_\odot$$

Steidel, NASA/ESA, 1996