Did IceCube detect Dark Matter around Blazars?

Andrea Giovanni De Marchi

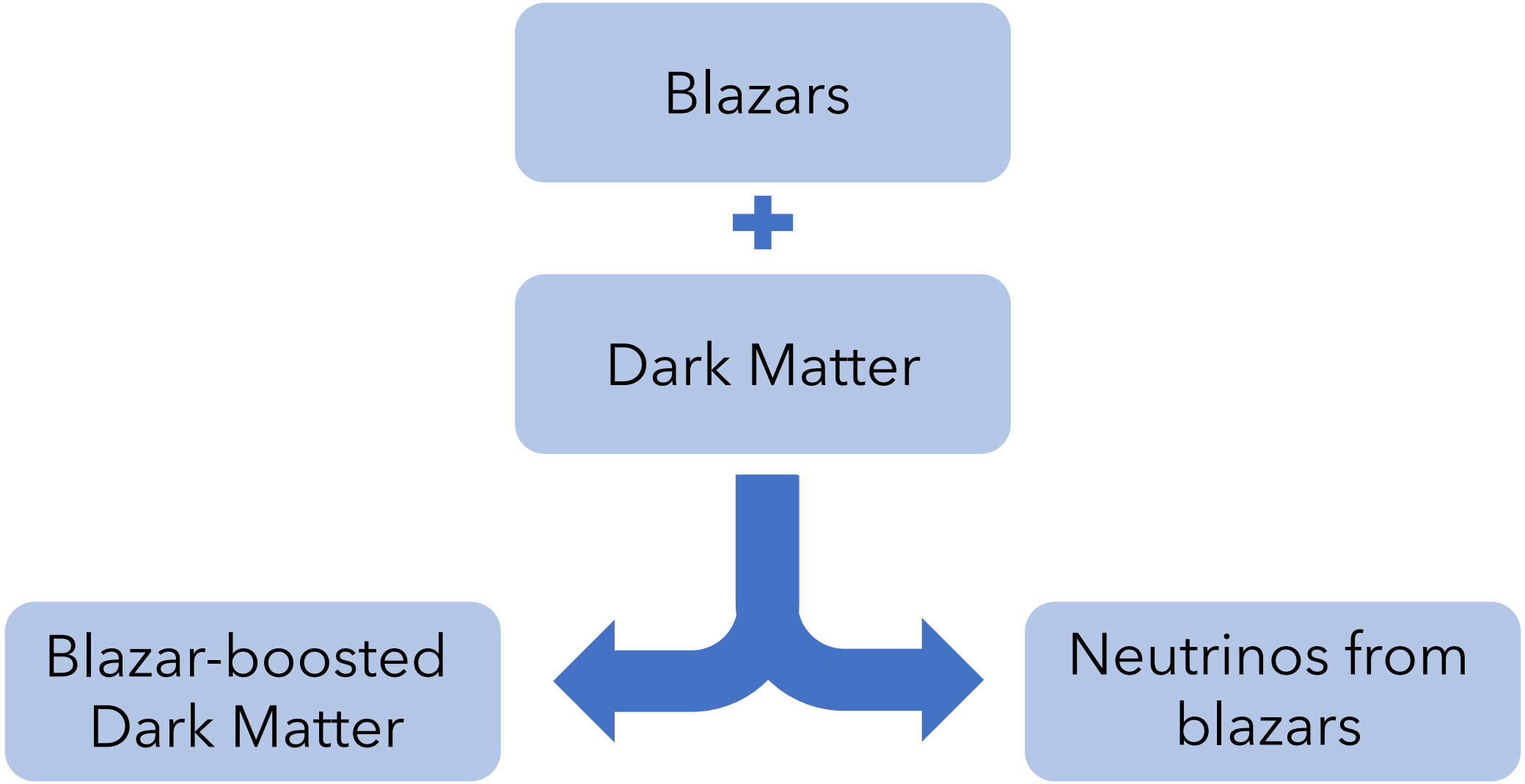
DESY Theory Workshop – Hamburg, 25/09/2025

Based on 2412.07861 AGDM, Granelli, Nava, Sala
2506.06416 AGDM, Granelli, Nava, Sala
2507.12278 AGDM, Granelli, Nava, Sala

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Istituto Nazionale di Fisica Nucleare

Outline

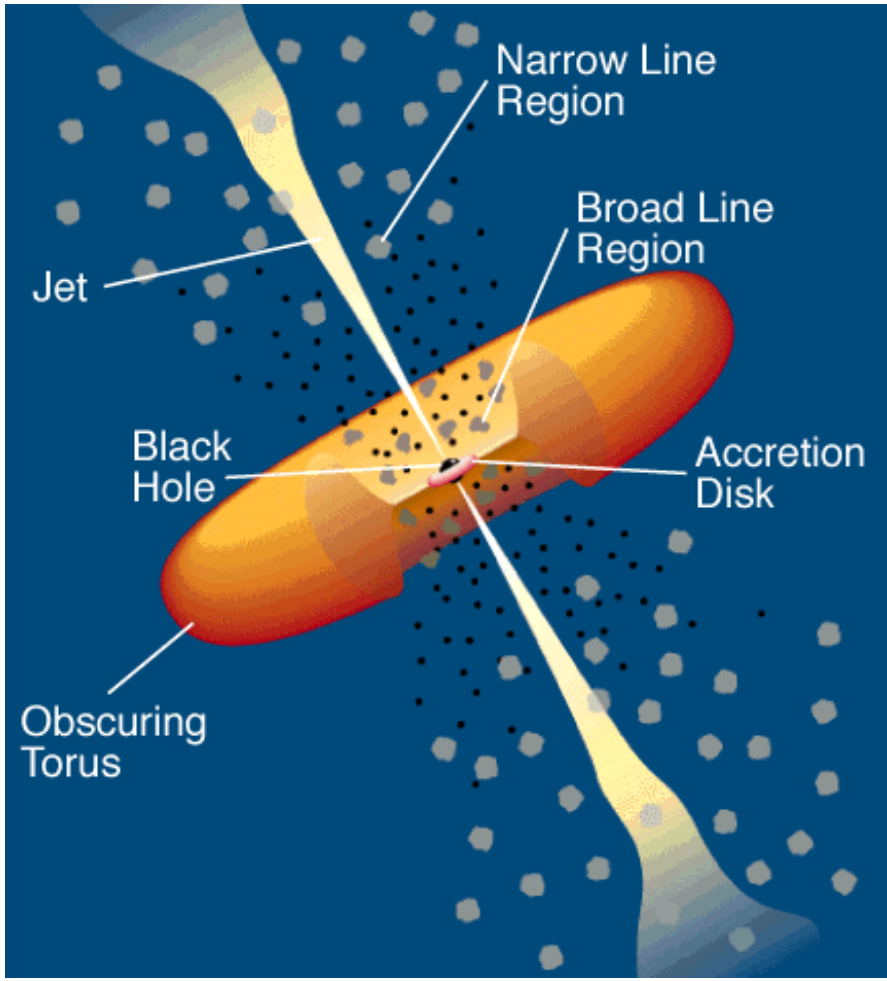

Blazars
+
Dark Matter
Blazar-boosted Dark Matter
Neutrinos from blazars

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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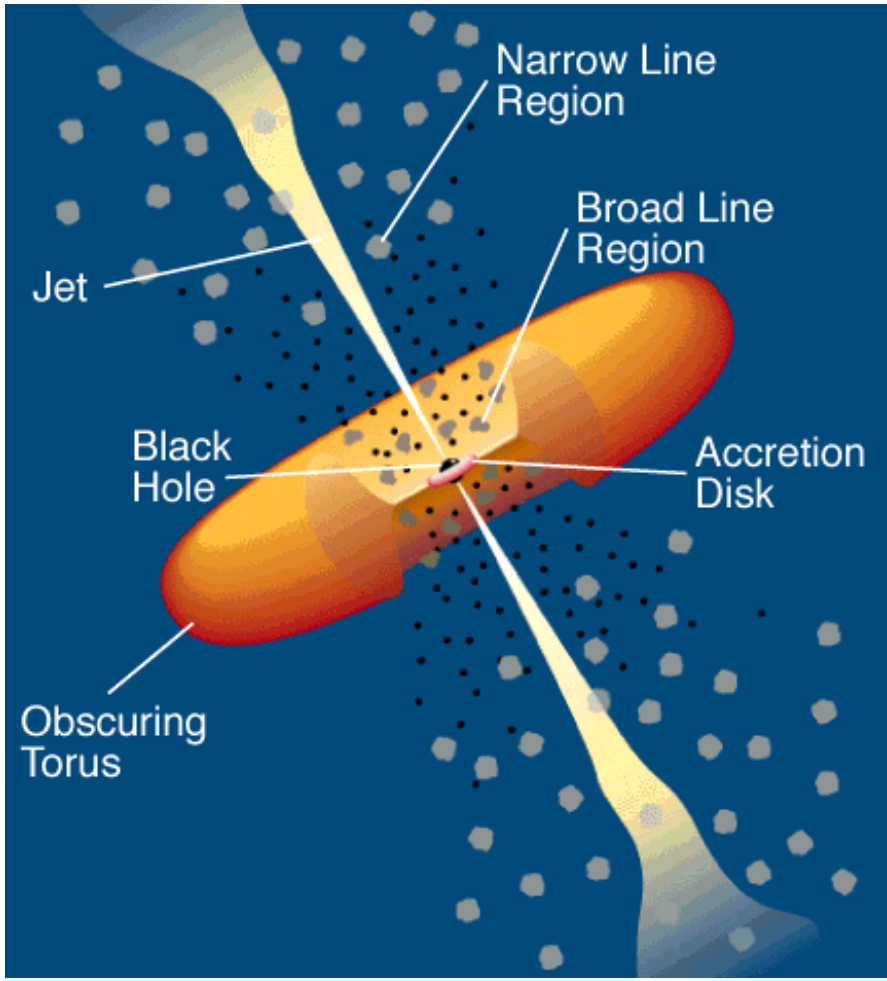

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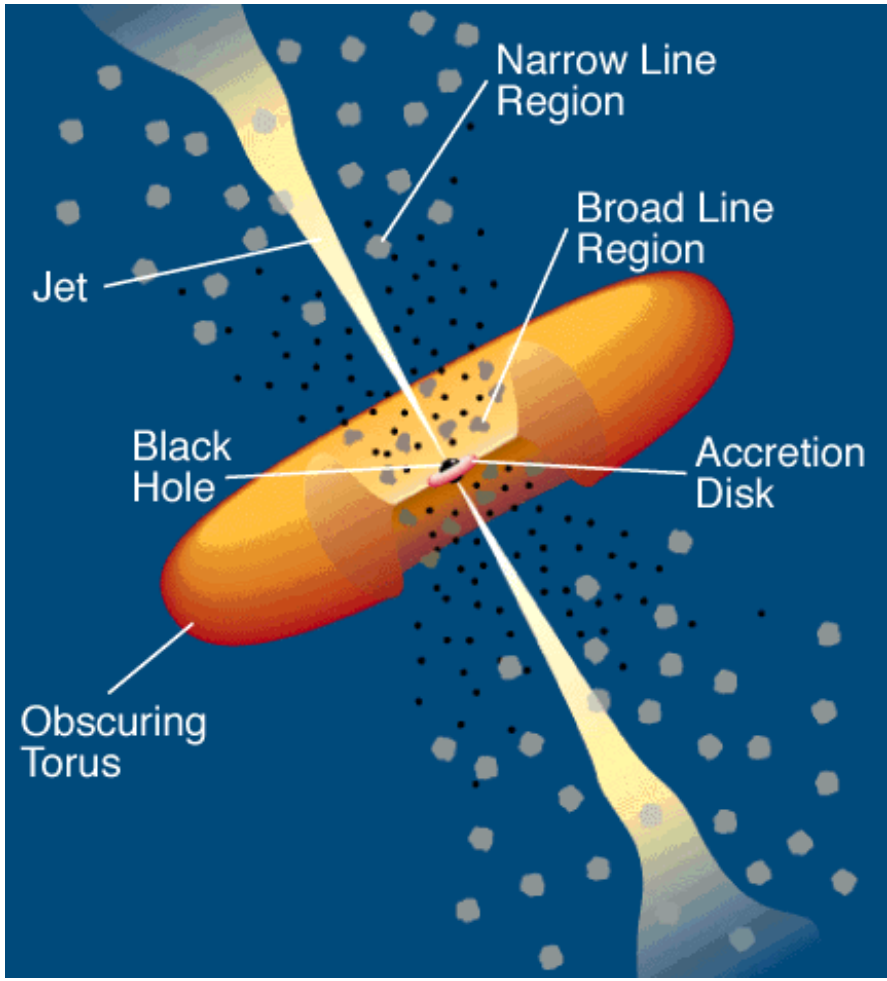
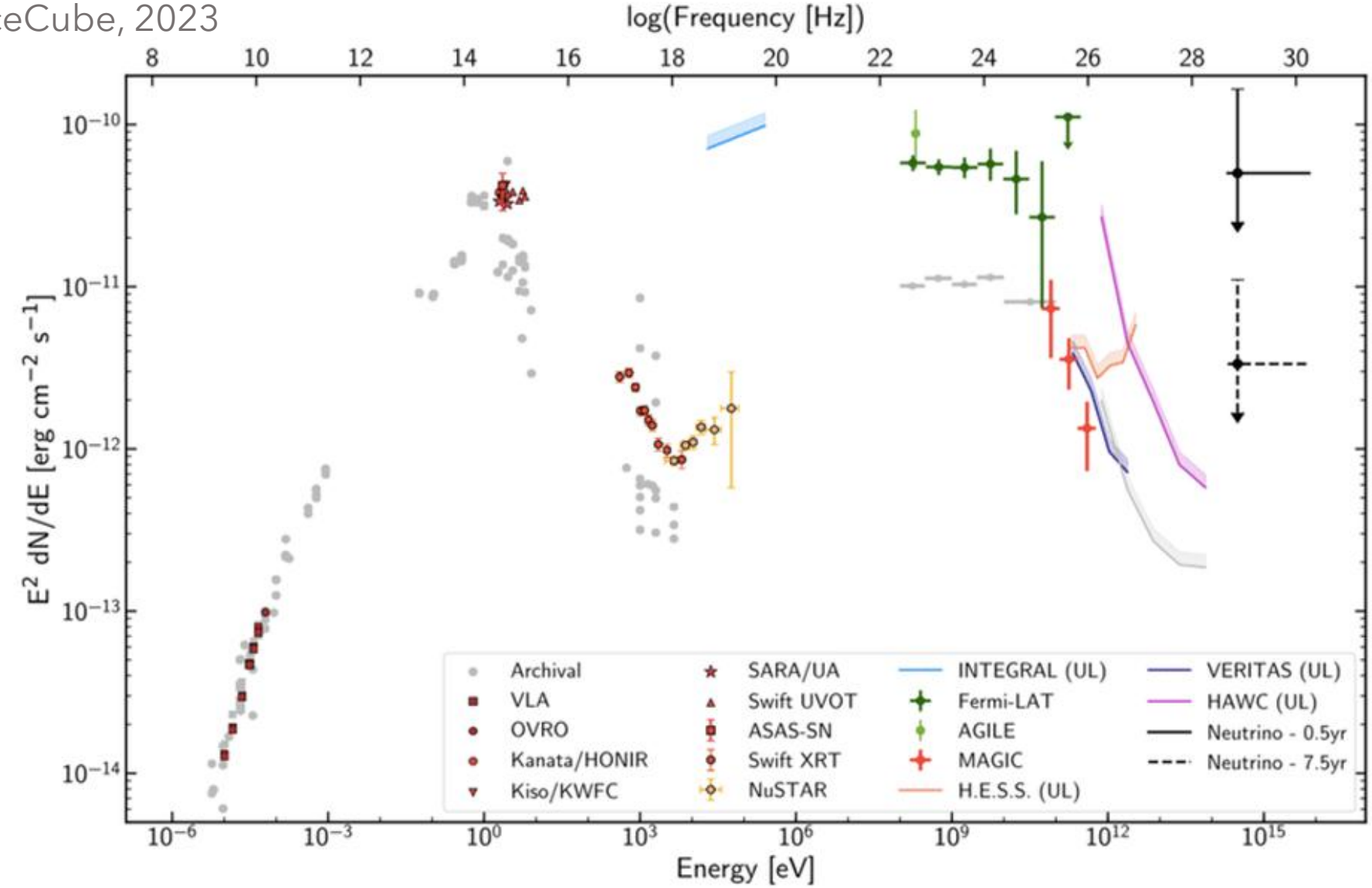
If jet pointed towards Earth: **blazar**



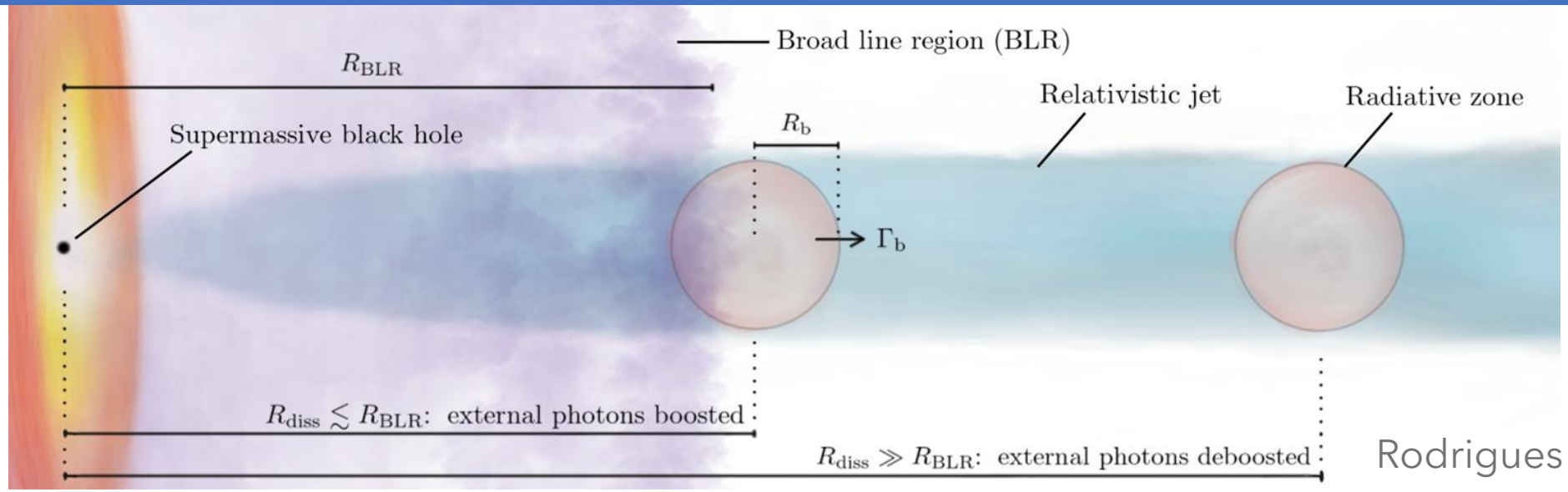
Urry, Padovani 1995

Blazar's spectral energy distribution

Montaruli for IceCube, 2023



How to model a blazar jet

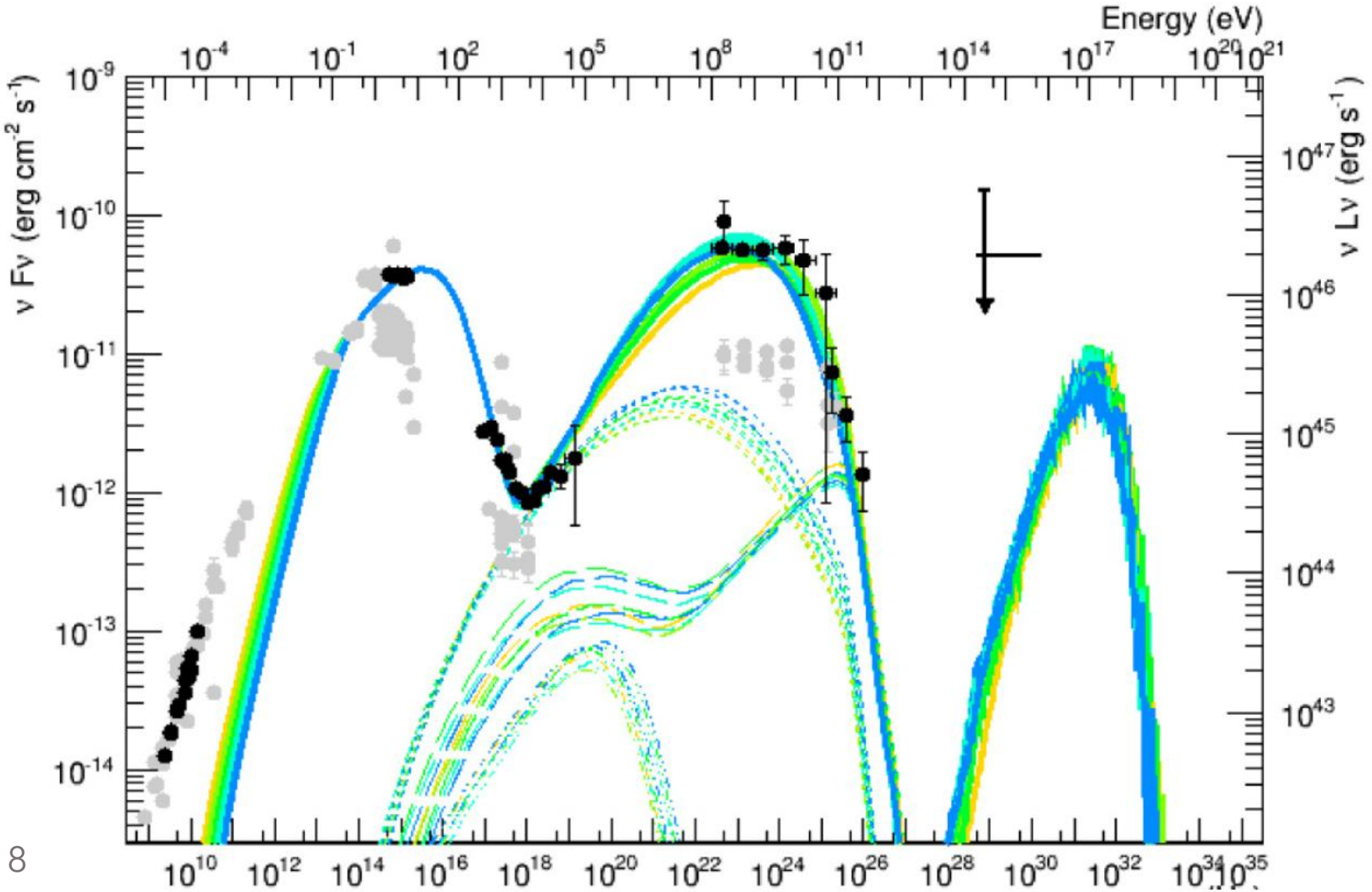


Rodrigues et al, 2023

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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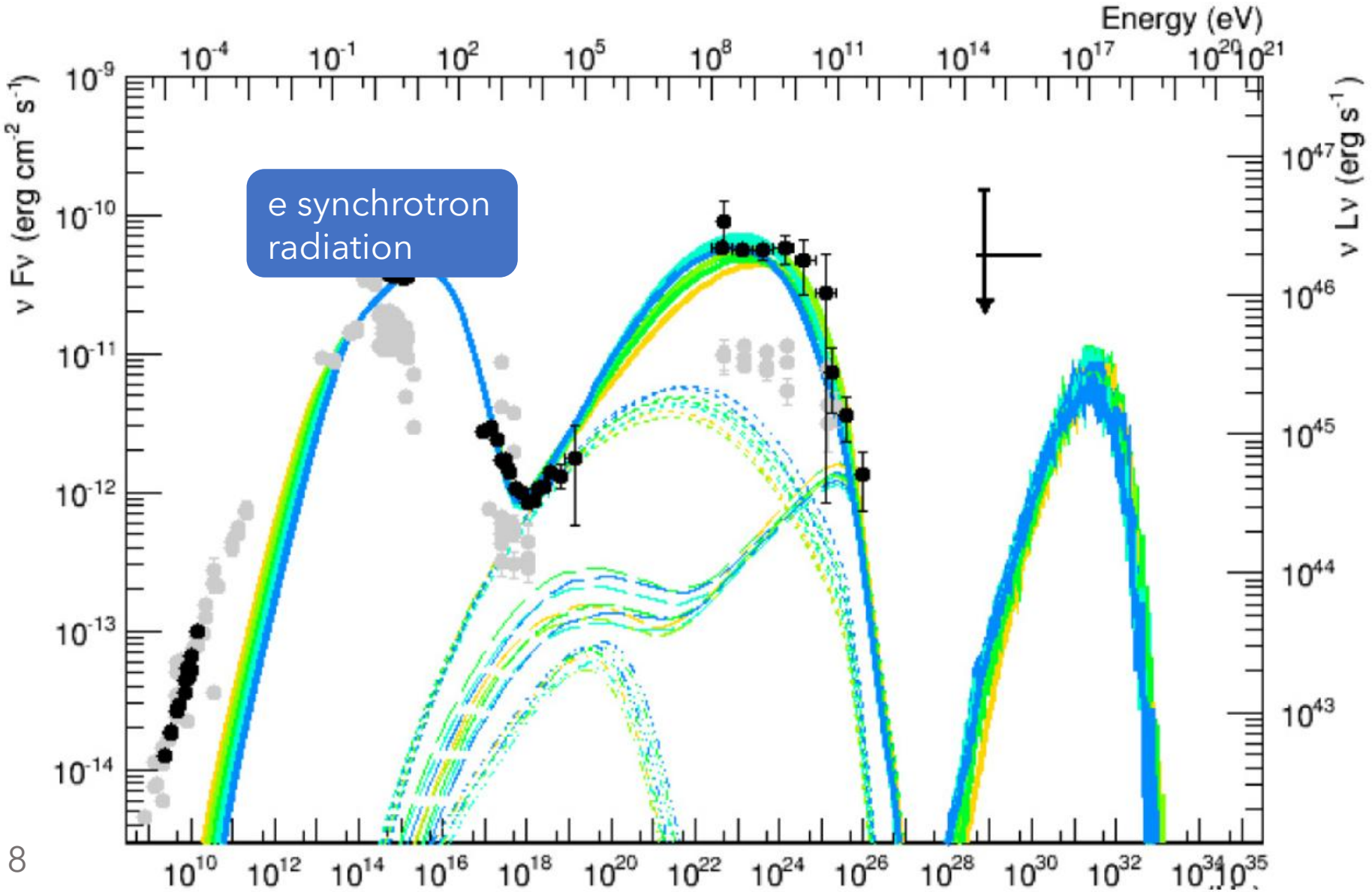

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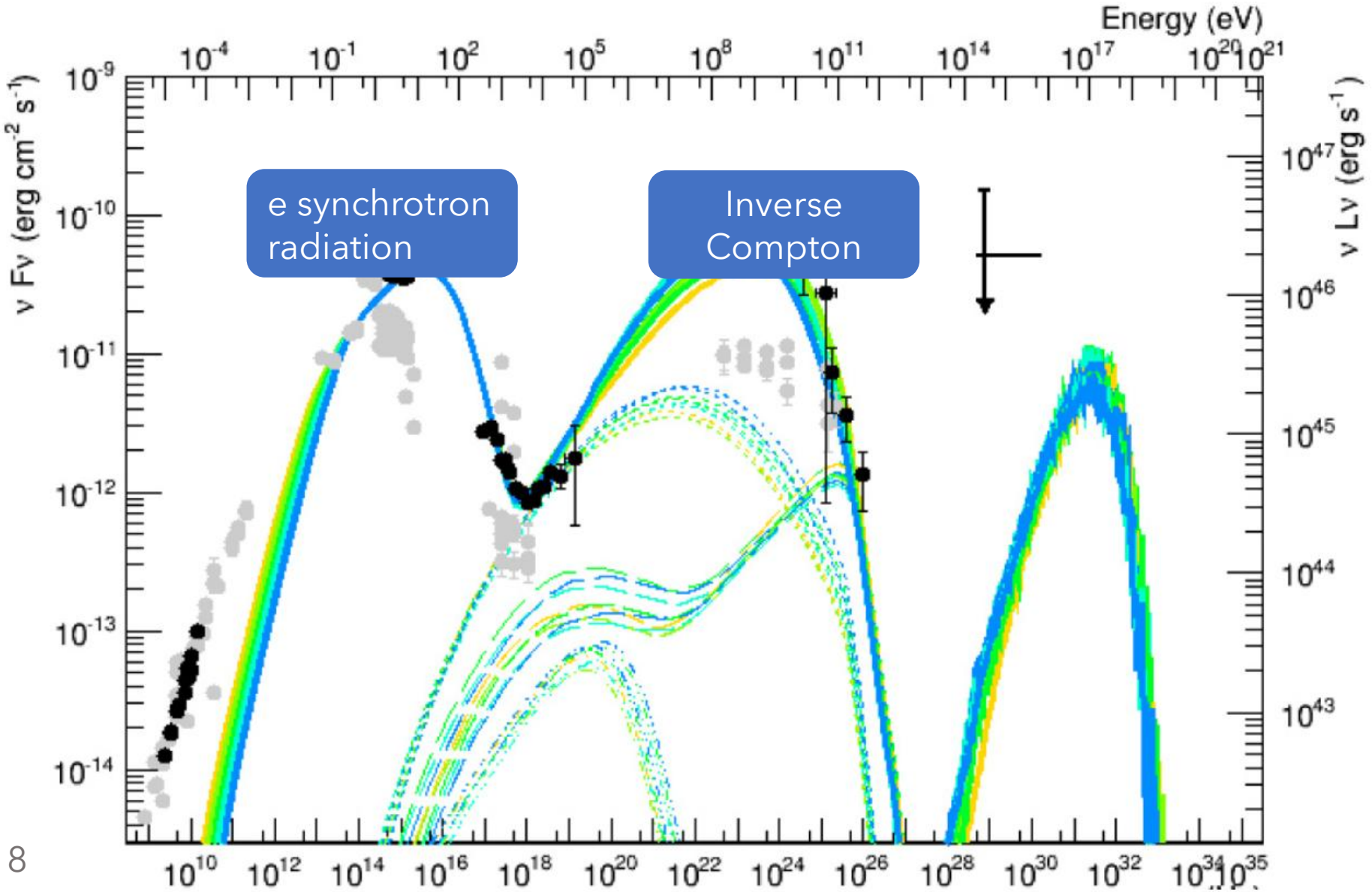

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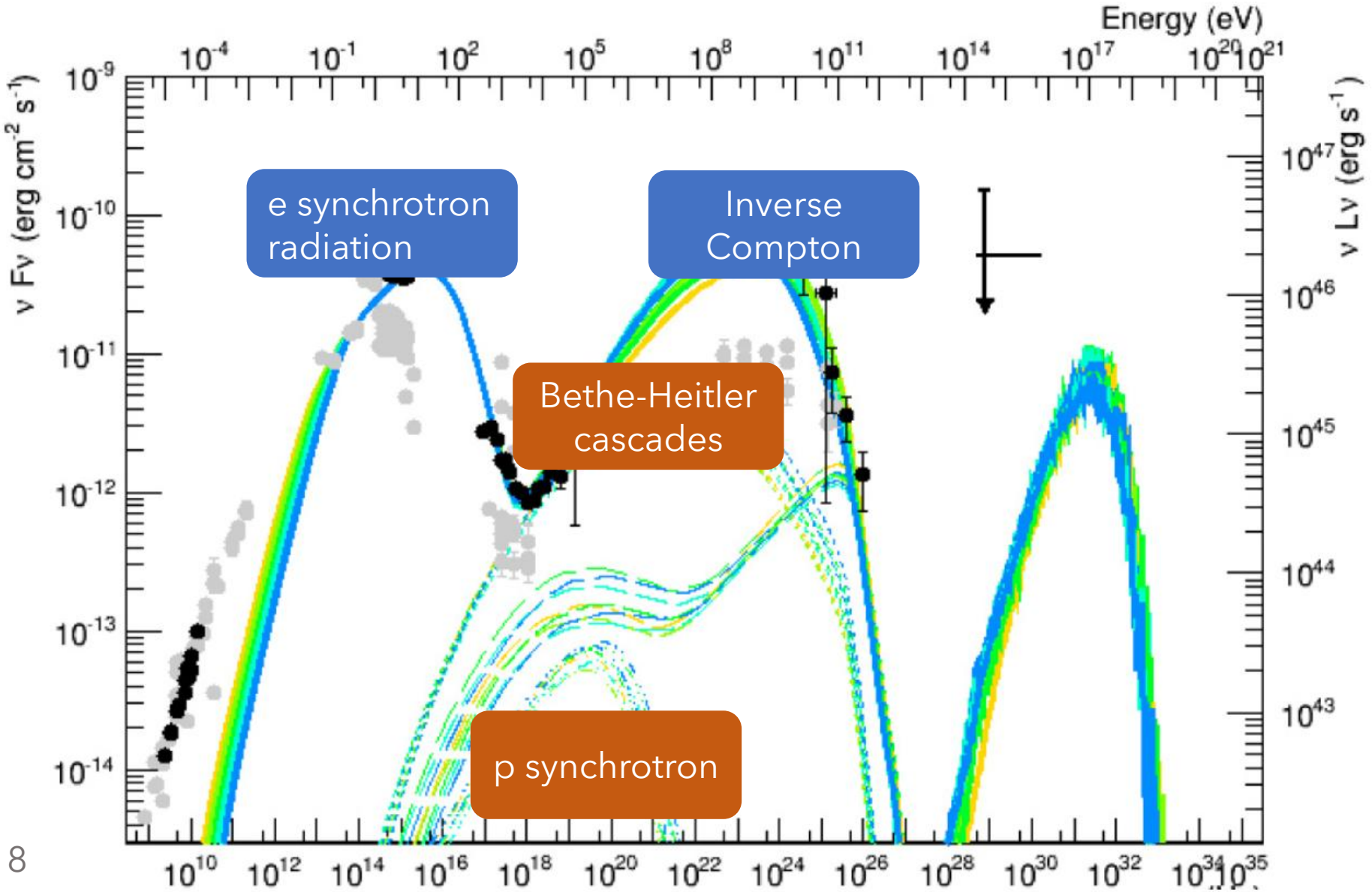

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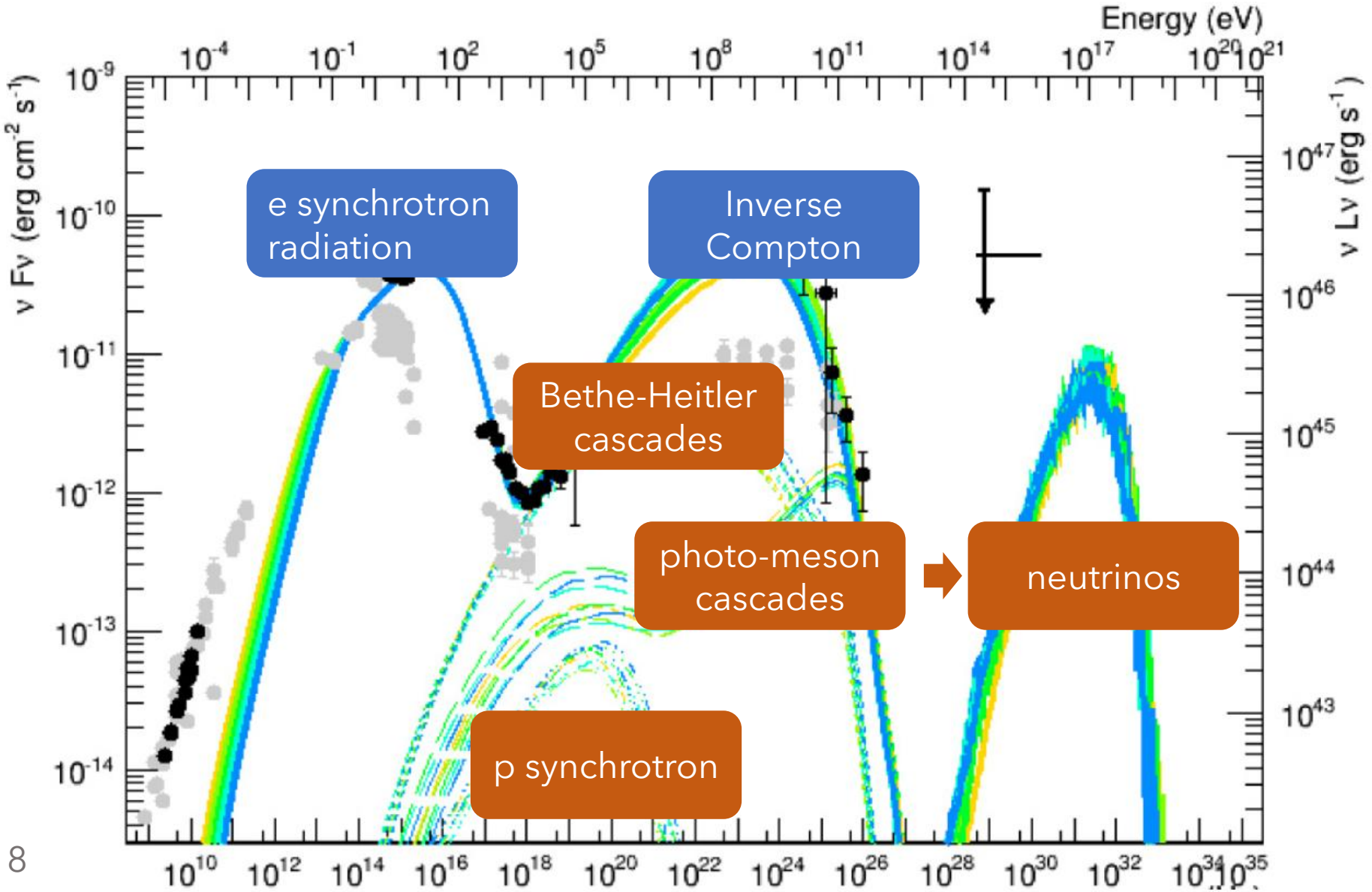

Cerruti et al 2018

II

Dark Matter

Why Dark Matter?

Since the 30s overwhelming evidence for Dark Matter on all scales: rotation curves, galaxy clusters, large scale structure…

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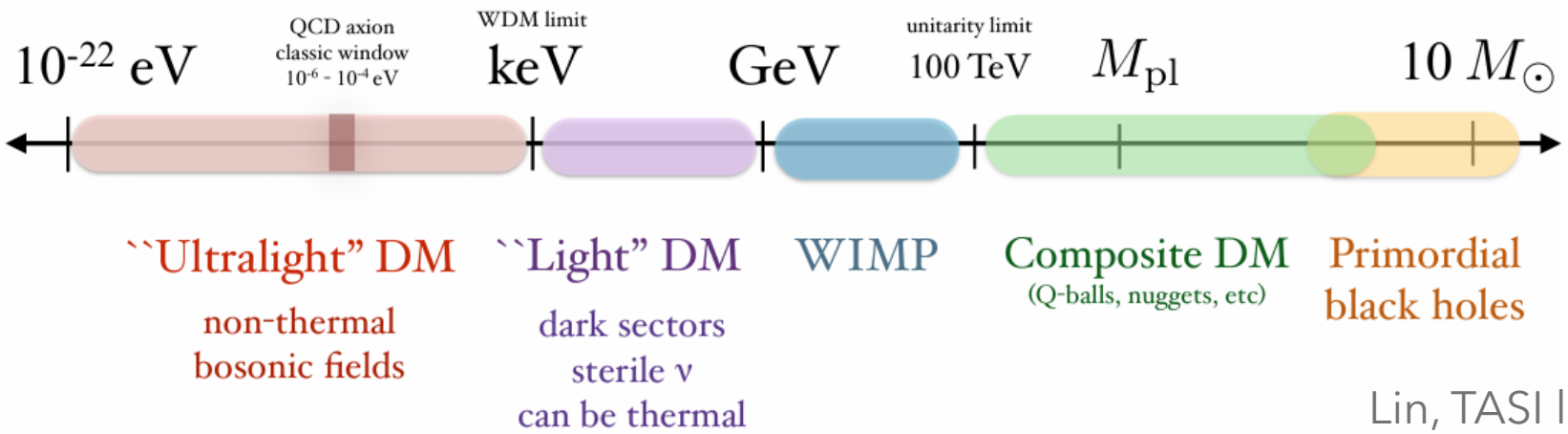

Lin, TASI lectures 2019

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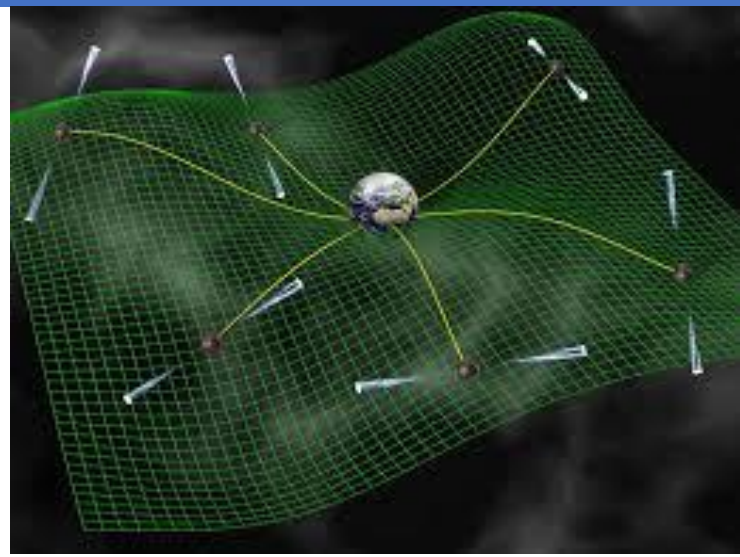

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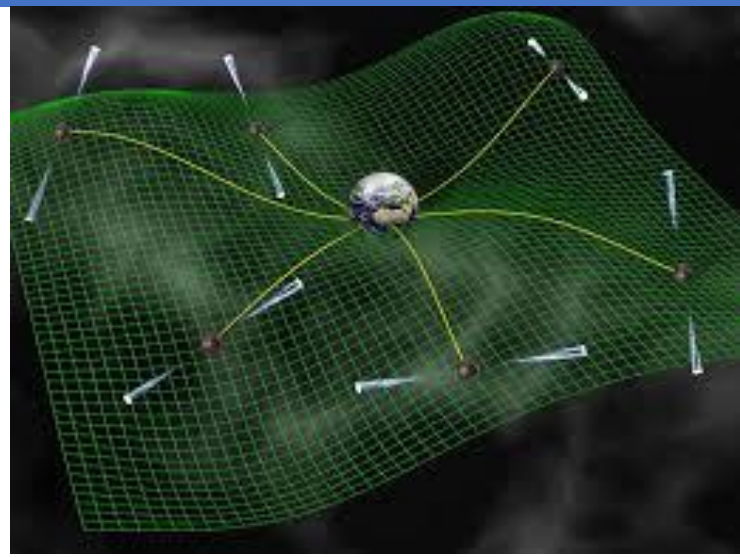
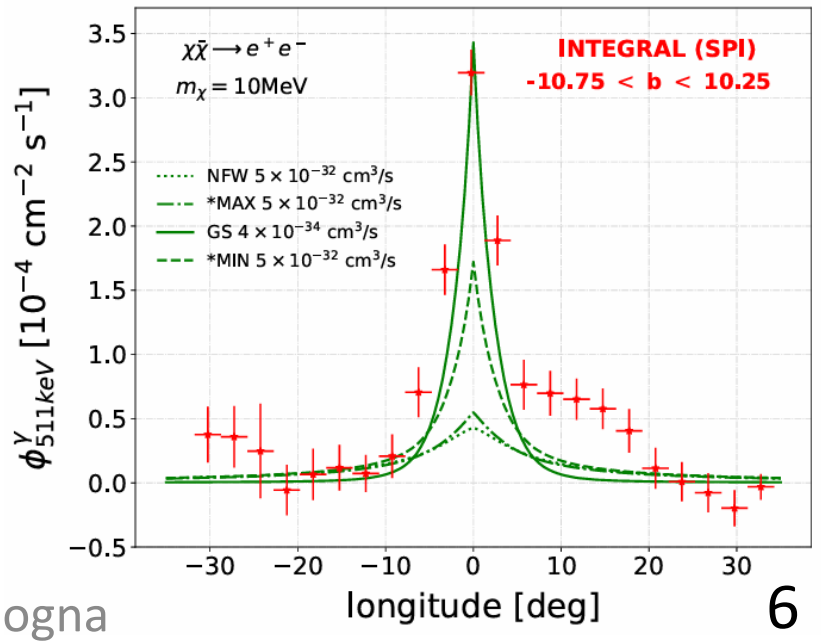
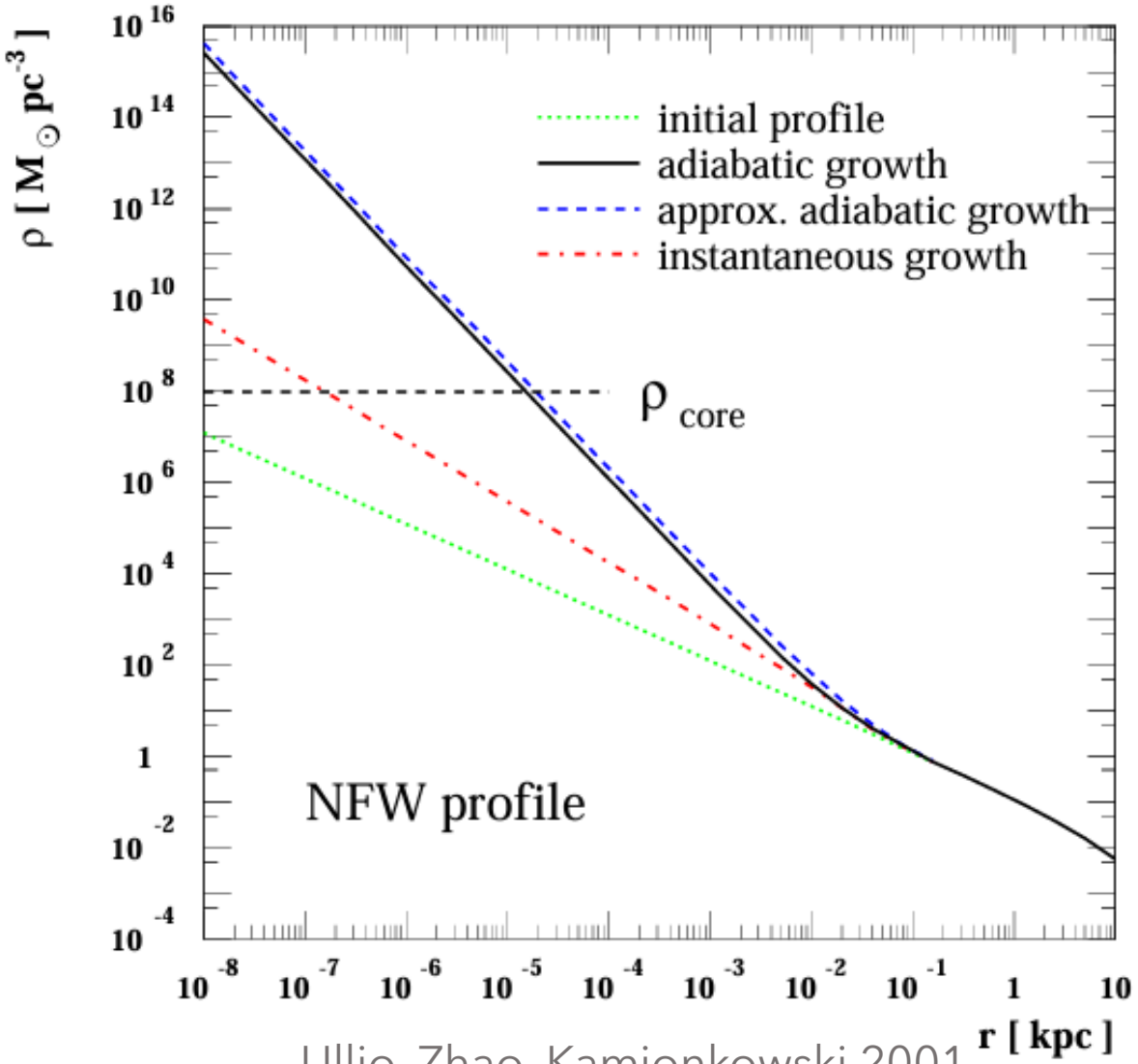
- 511 keV line from the galactic centre: annihilating DM? [Boehm+ 2004]





The Gondolo & Silk spike

Dark Matter around SMBH accumulates into spikes by adiabatic contraction [Gondolo, Silk 1999]



Ullio, Zhao, Kamionkowski 2001

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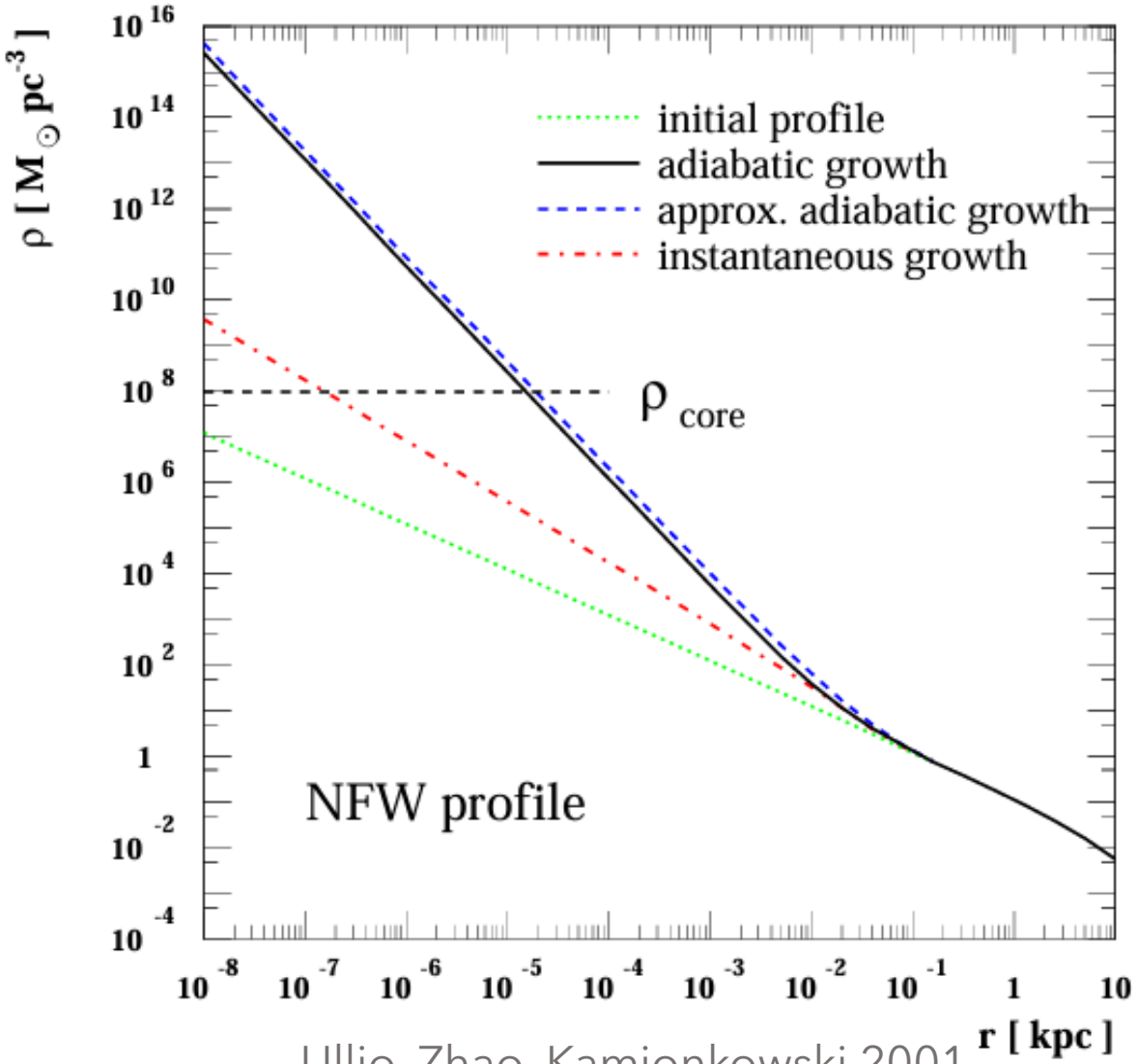
For $\Sigma_{\mathrm{los}} = \int_{r_{\mathrm{min}}}^{r\mathrm{max}} dr\, \rho(r)$, up to 8-9 orders of magnitude more than NFW



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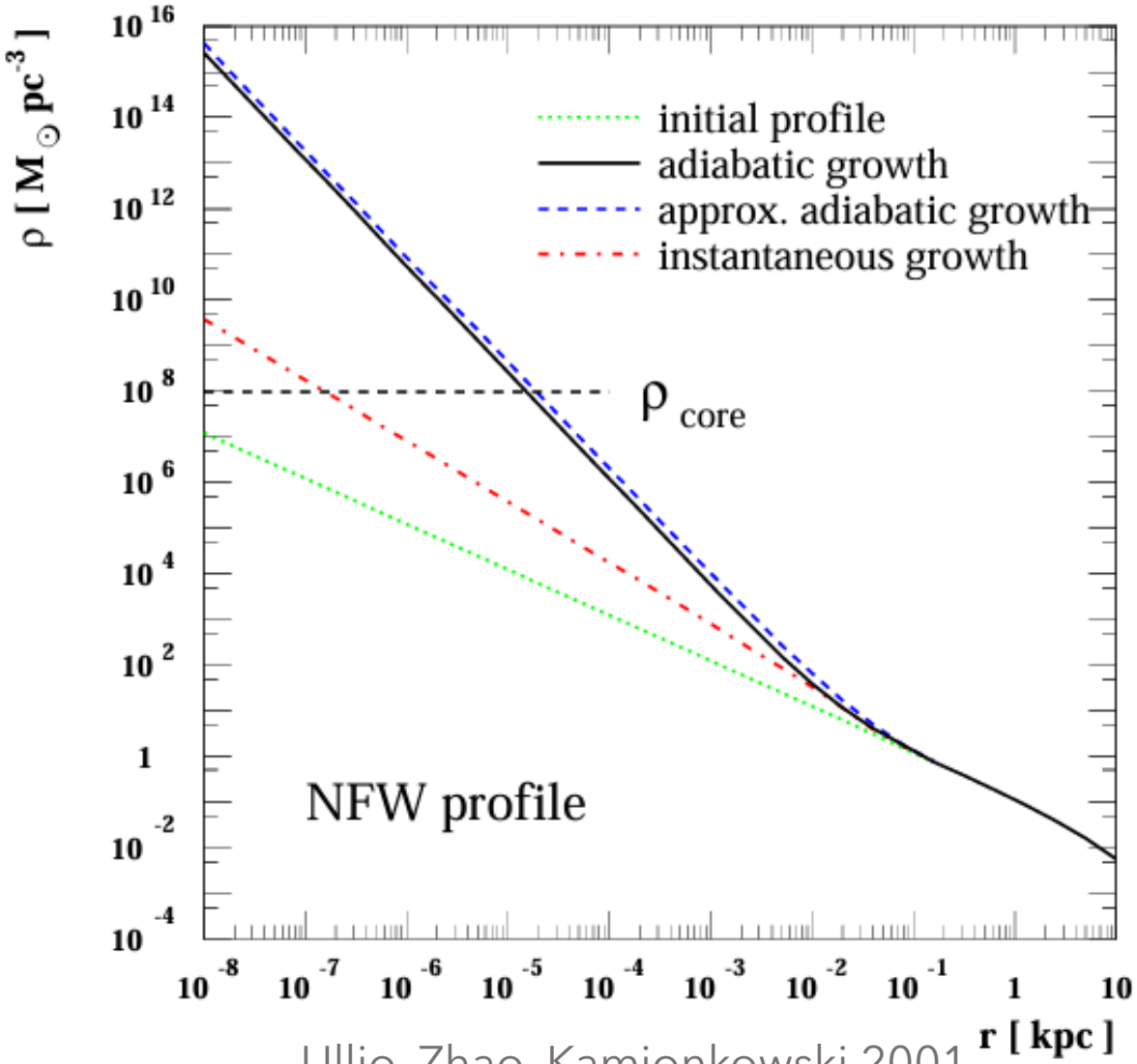
Ideal case, we choose as benchmarks 3000x and 10^6x enchancement



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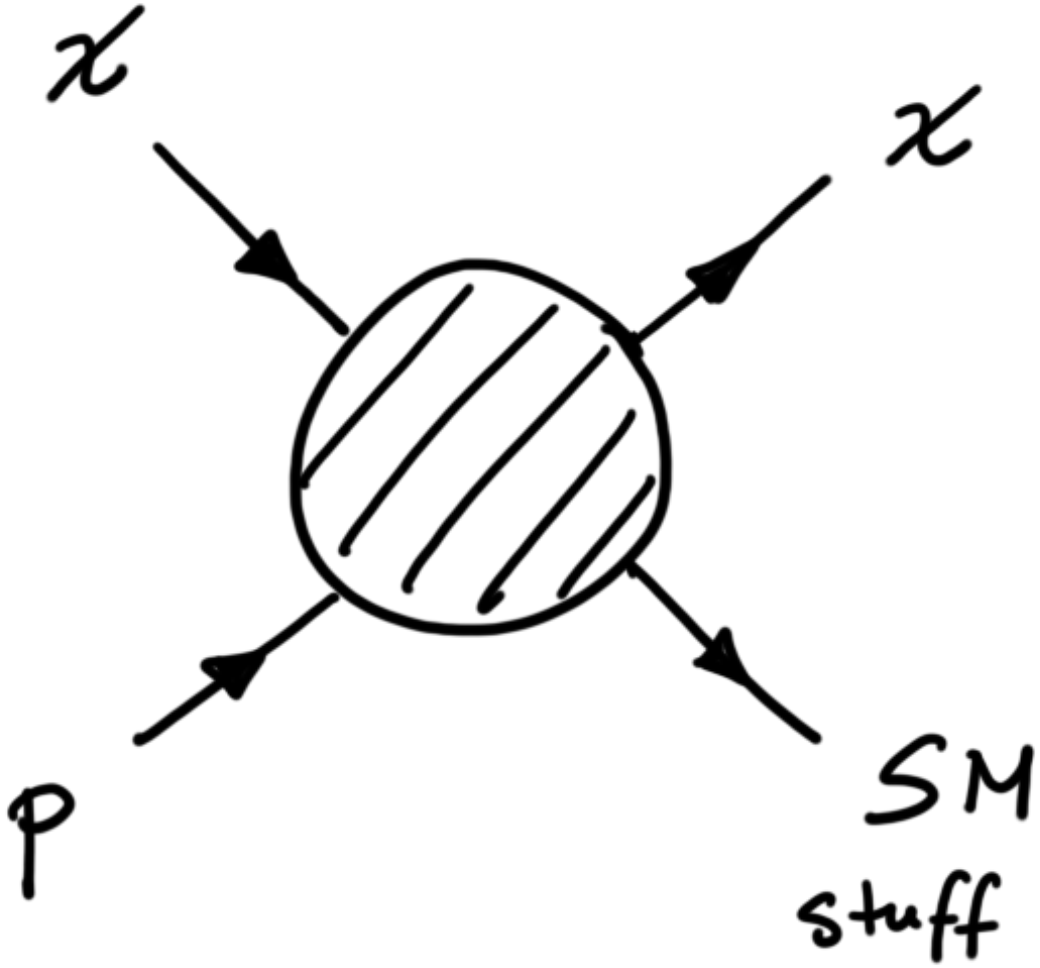
Two complementary signals



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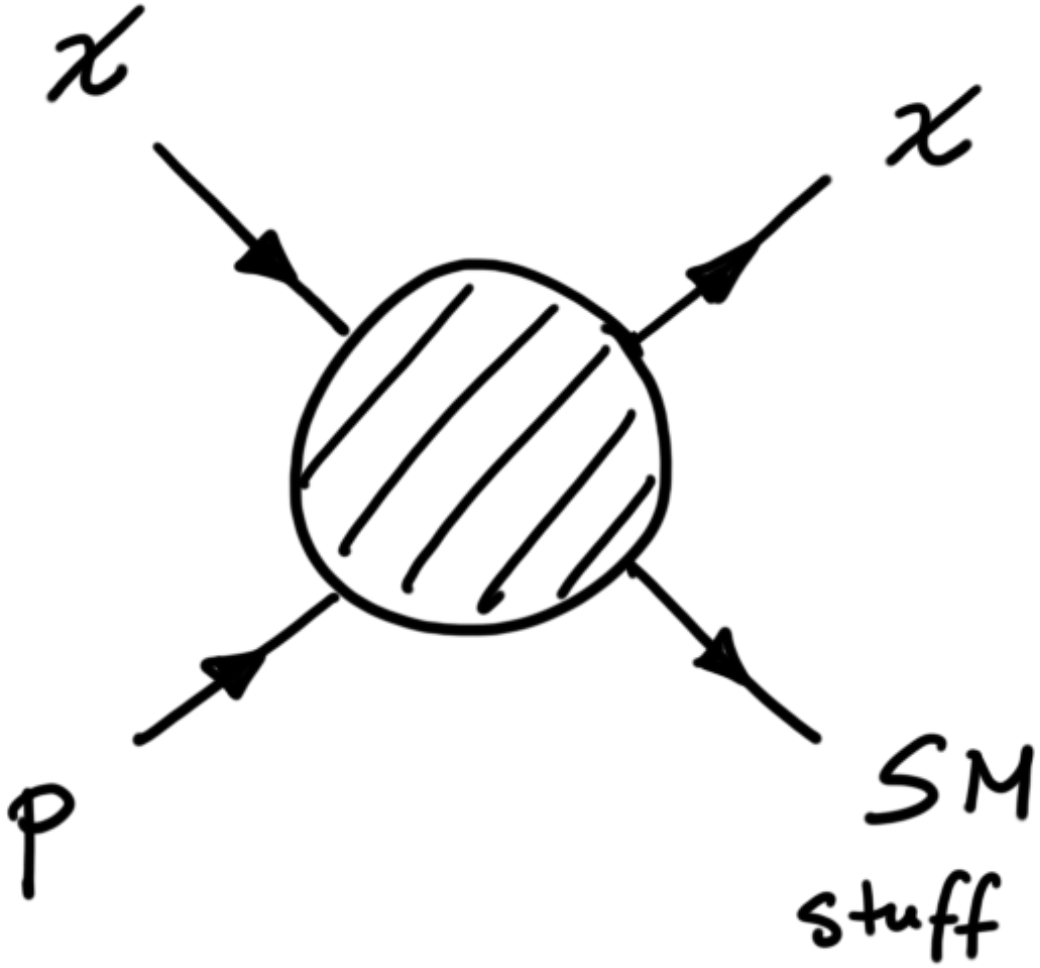

Blazar-boosted
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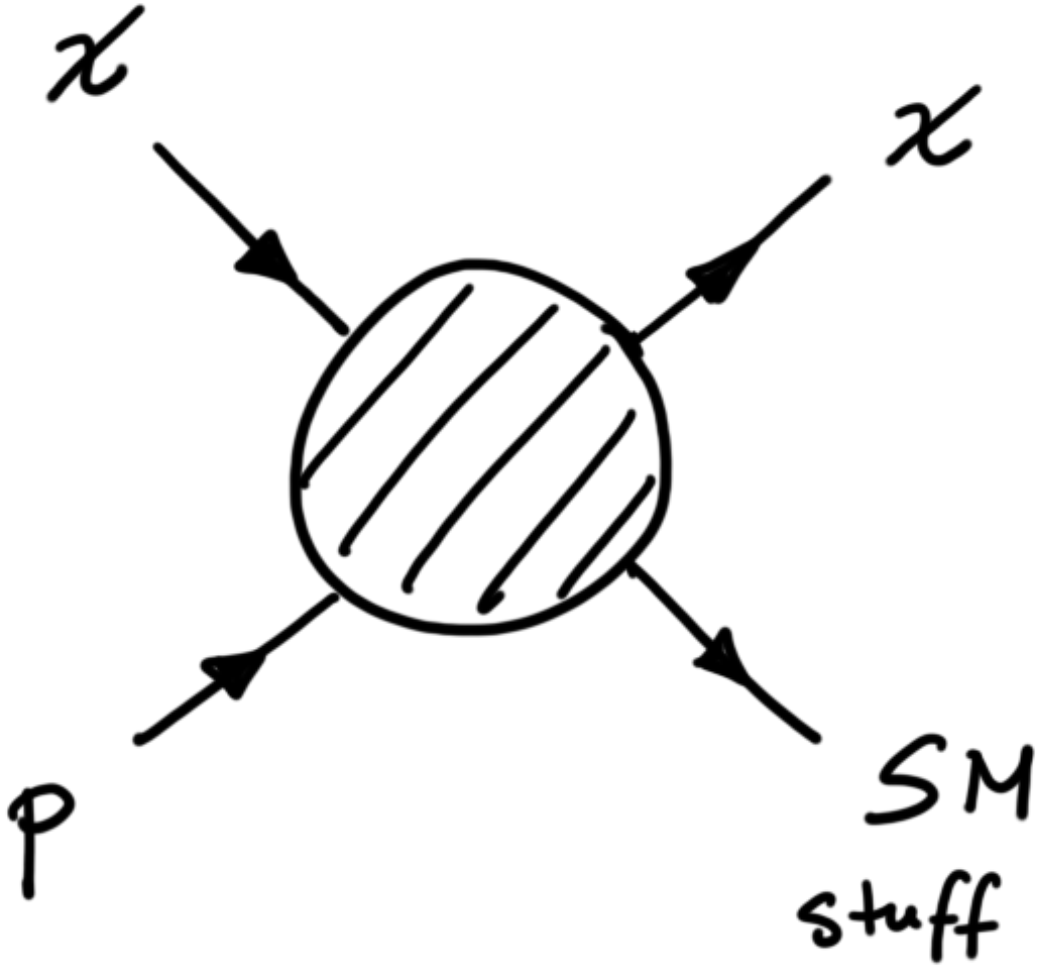
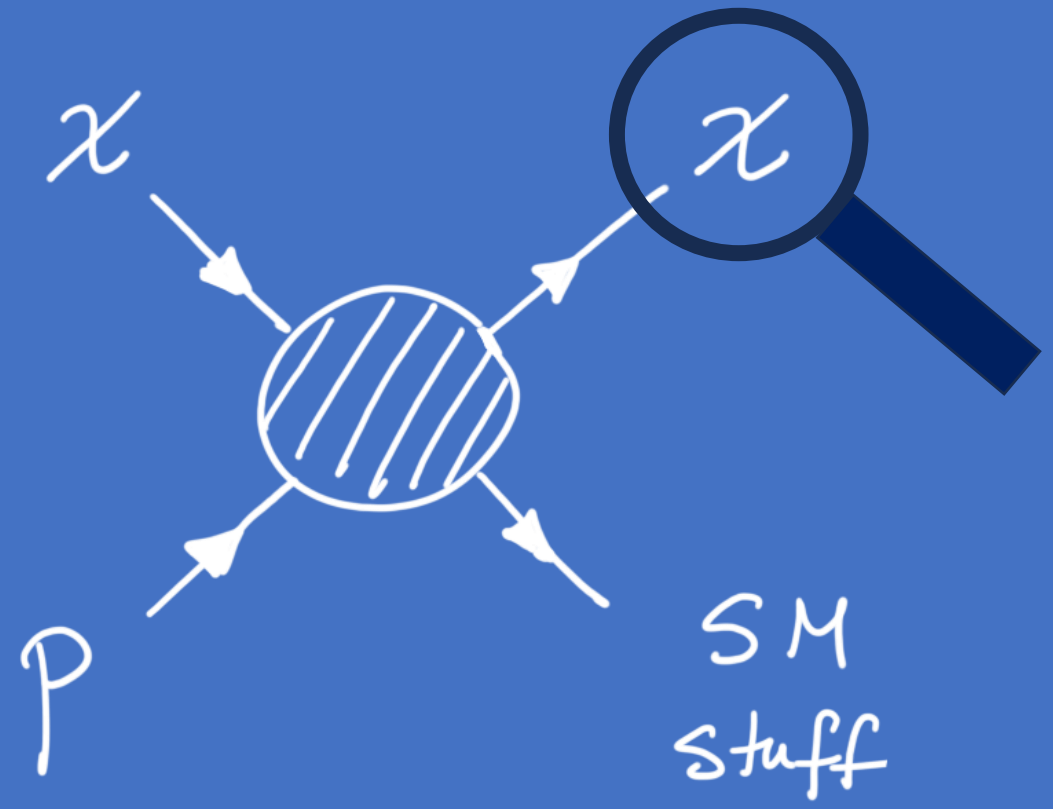


Blazar-boosted Dark Matter

Neutrinos from blazars



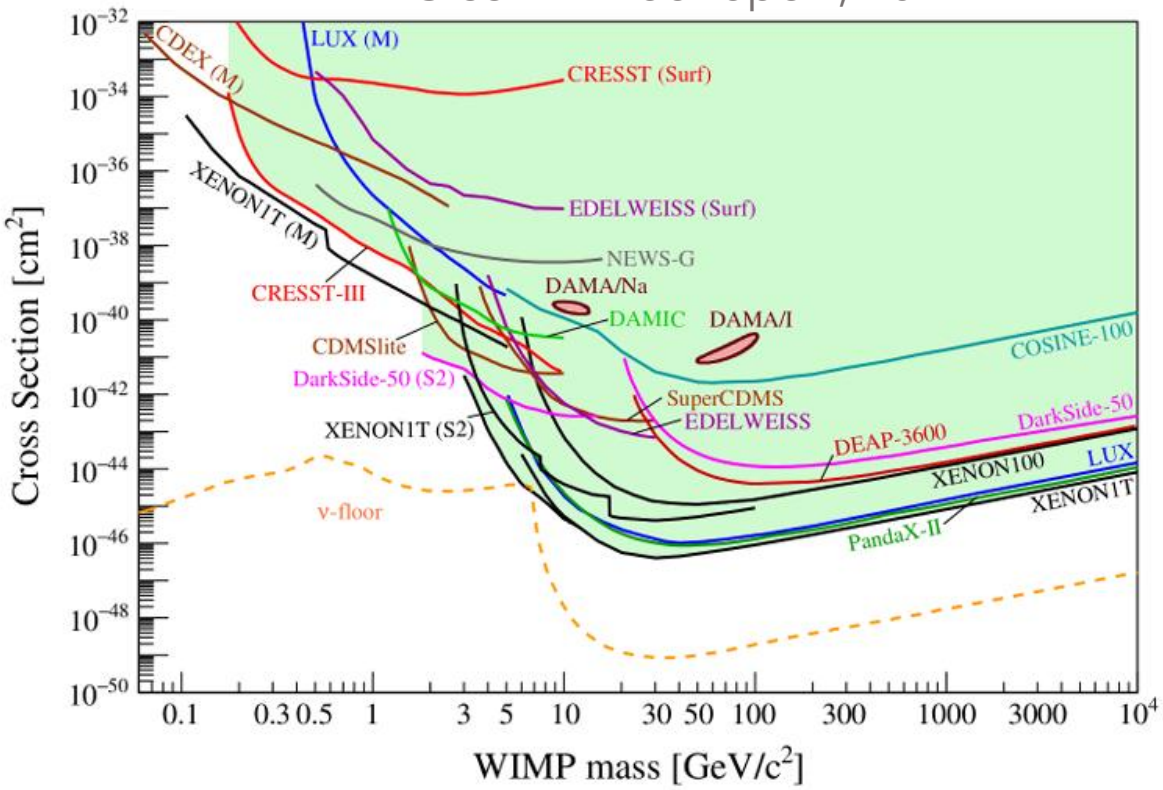
III

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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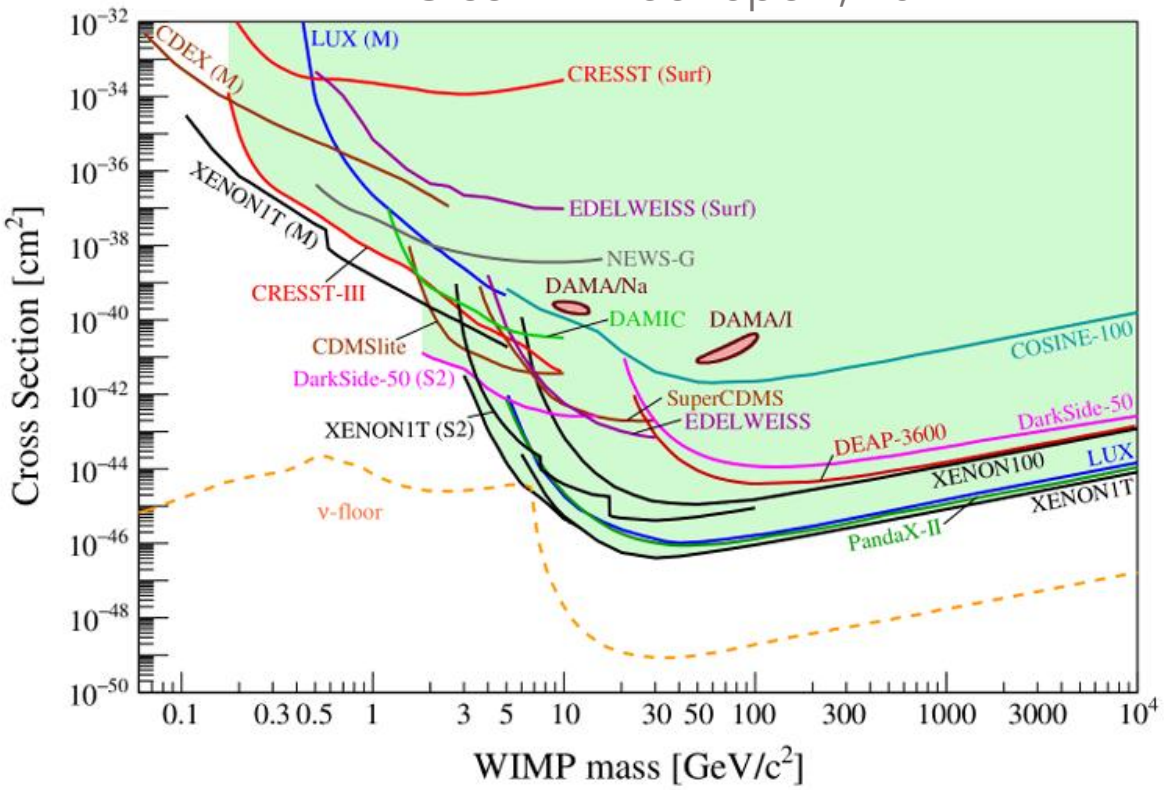

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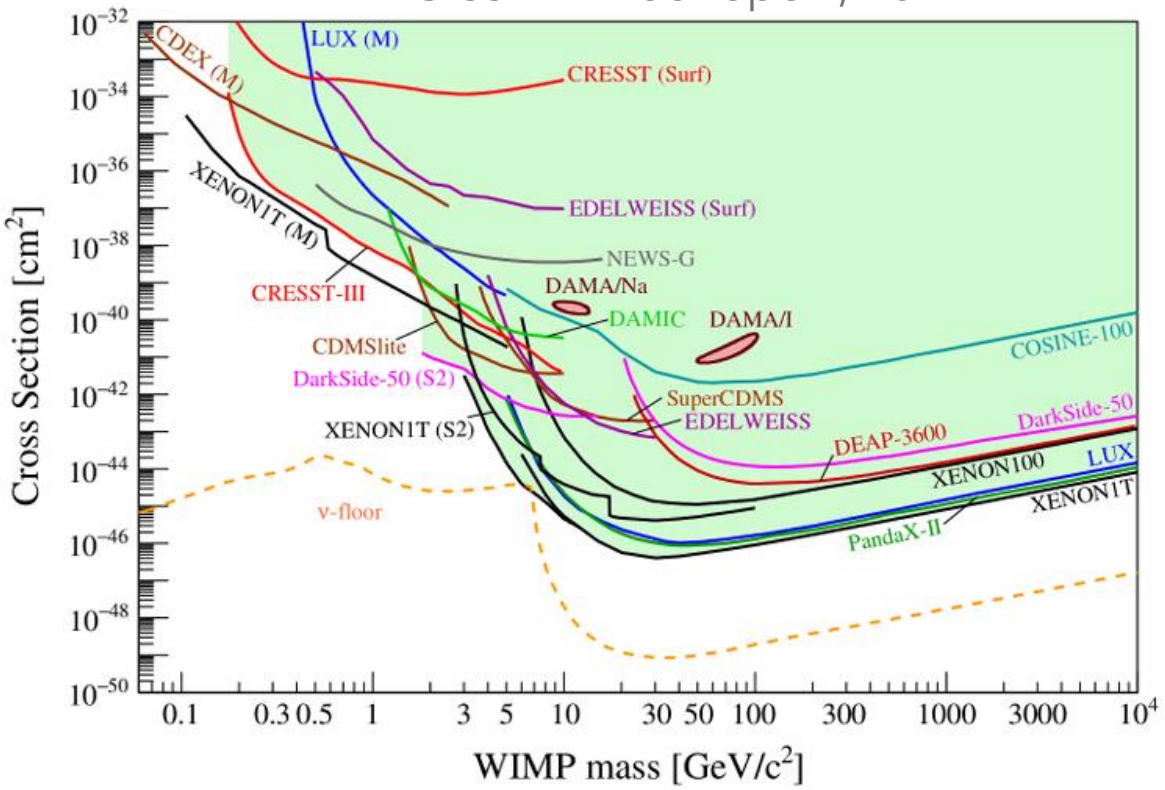

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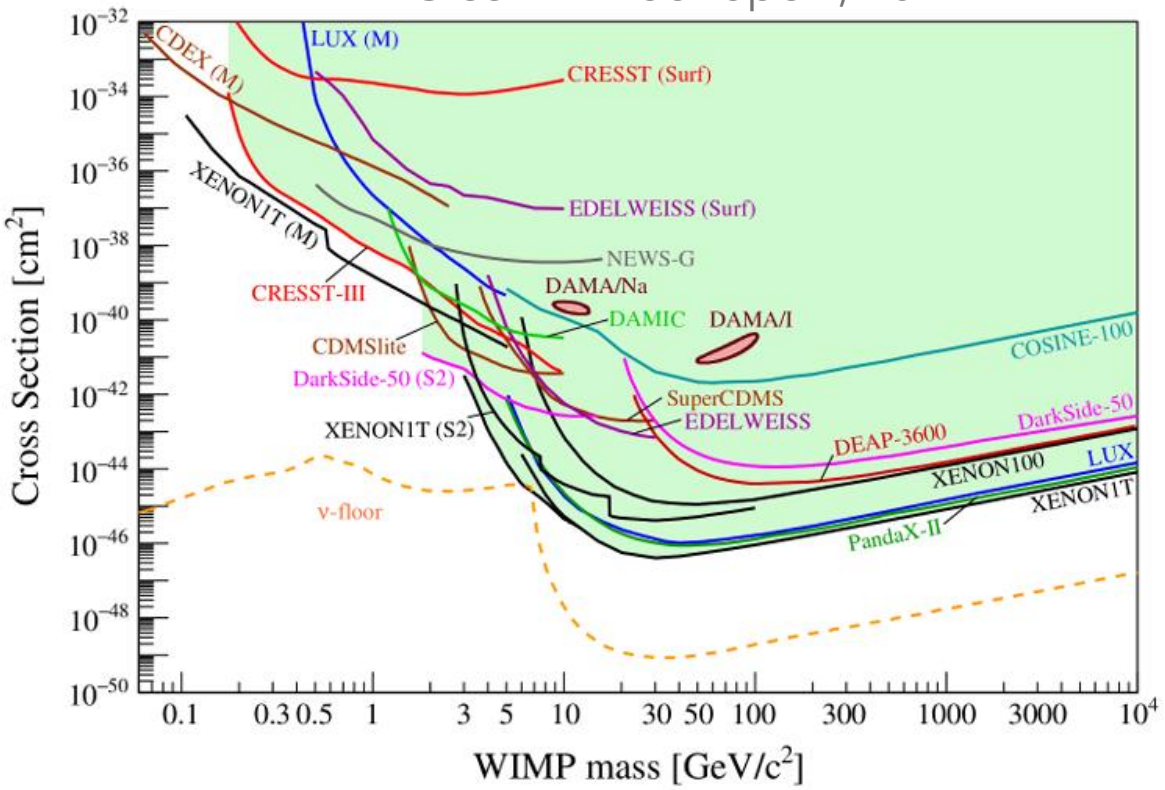

To do better: more cosmic rays, more DM, higher energies… **Blazars!**

[Wang+ 2021]

Our model

We add to the SM a fermion DM and a new massive vector that couples only to quarks (2506.06416, 2507.12278 for other Lorentz structures)

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

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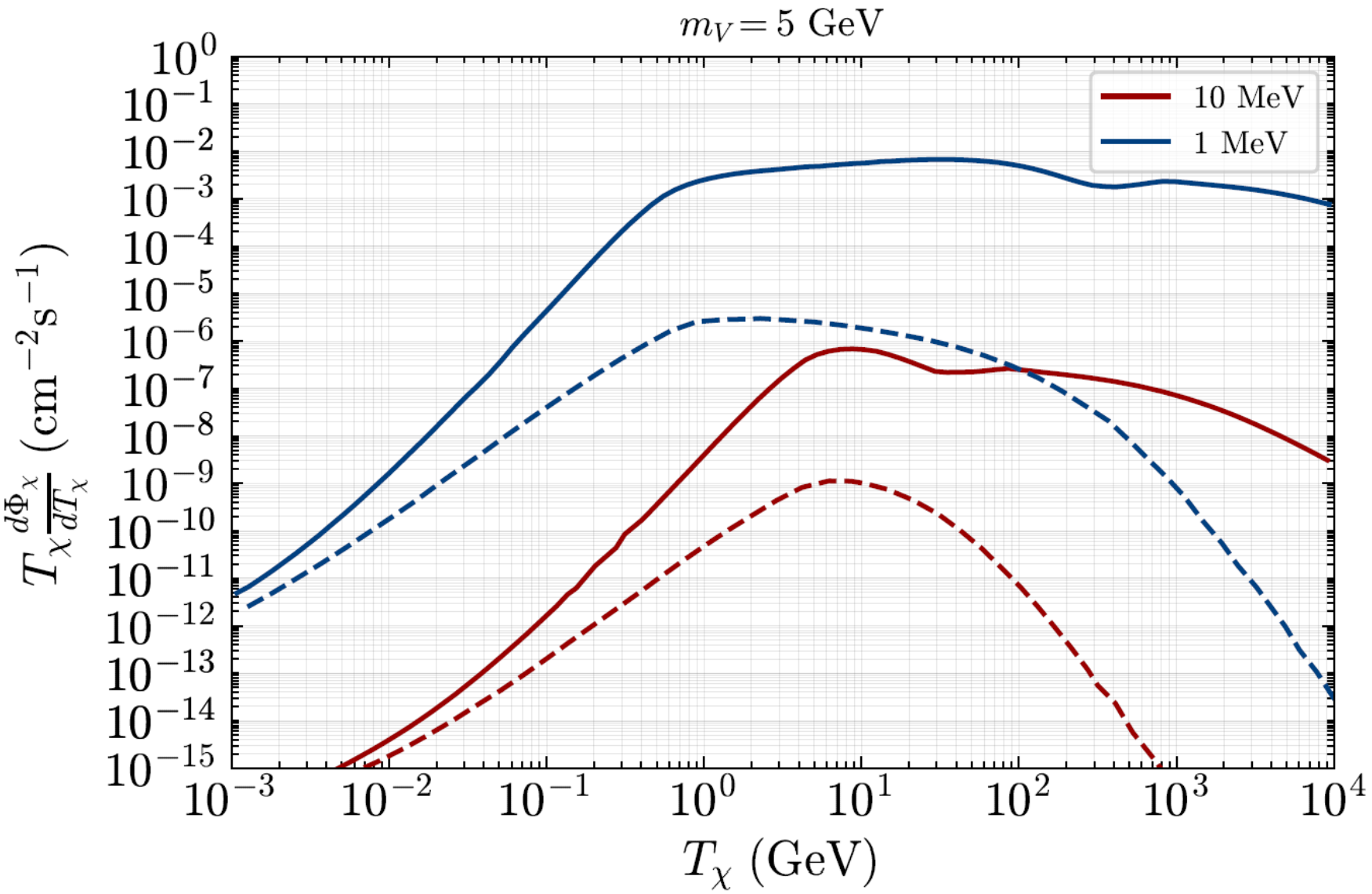
Spike model

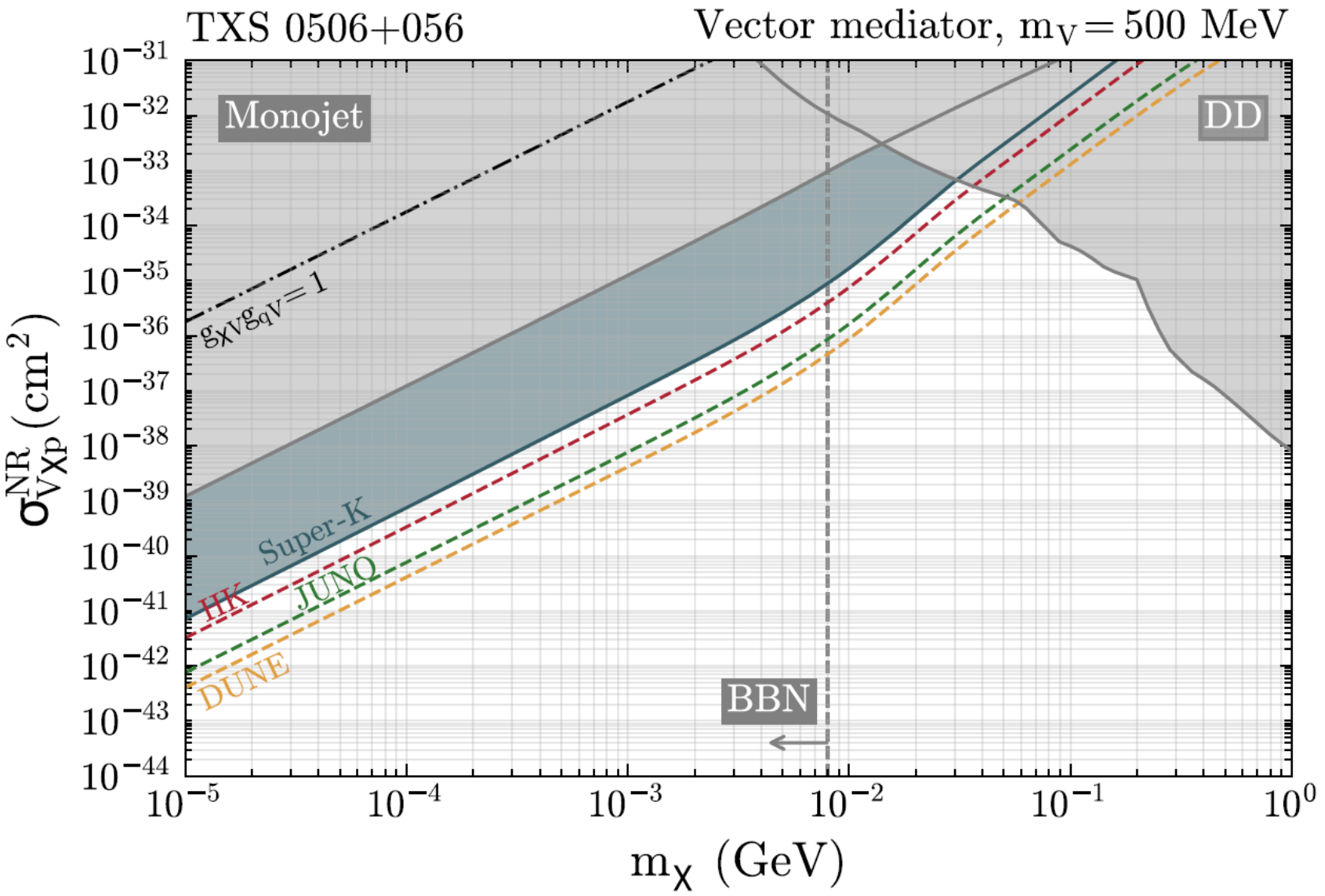
Jet model

Particle physics model

Boosted DM flux



Constraints



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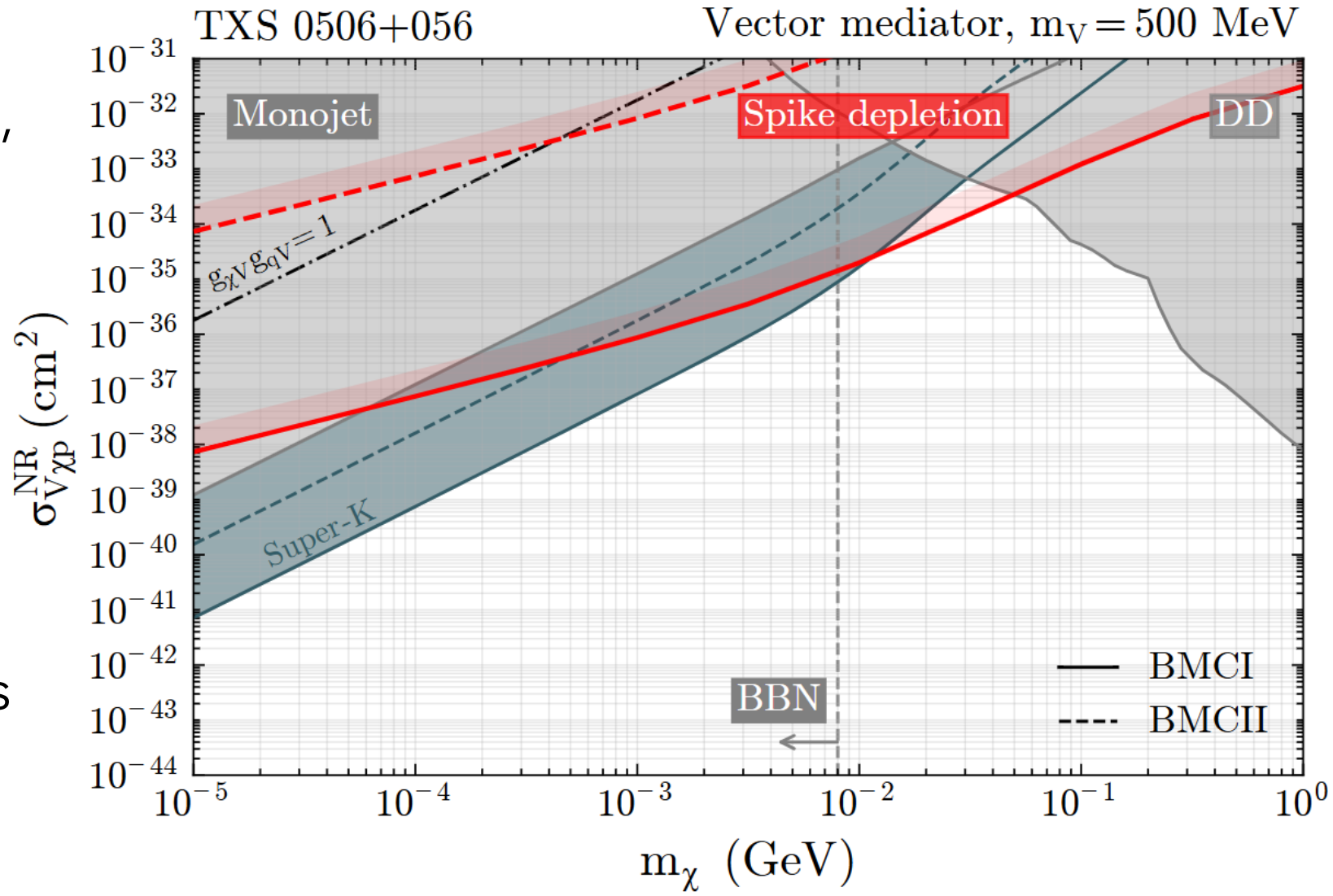
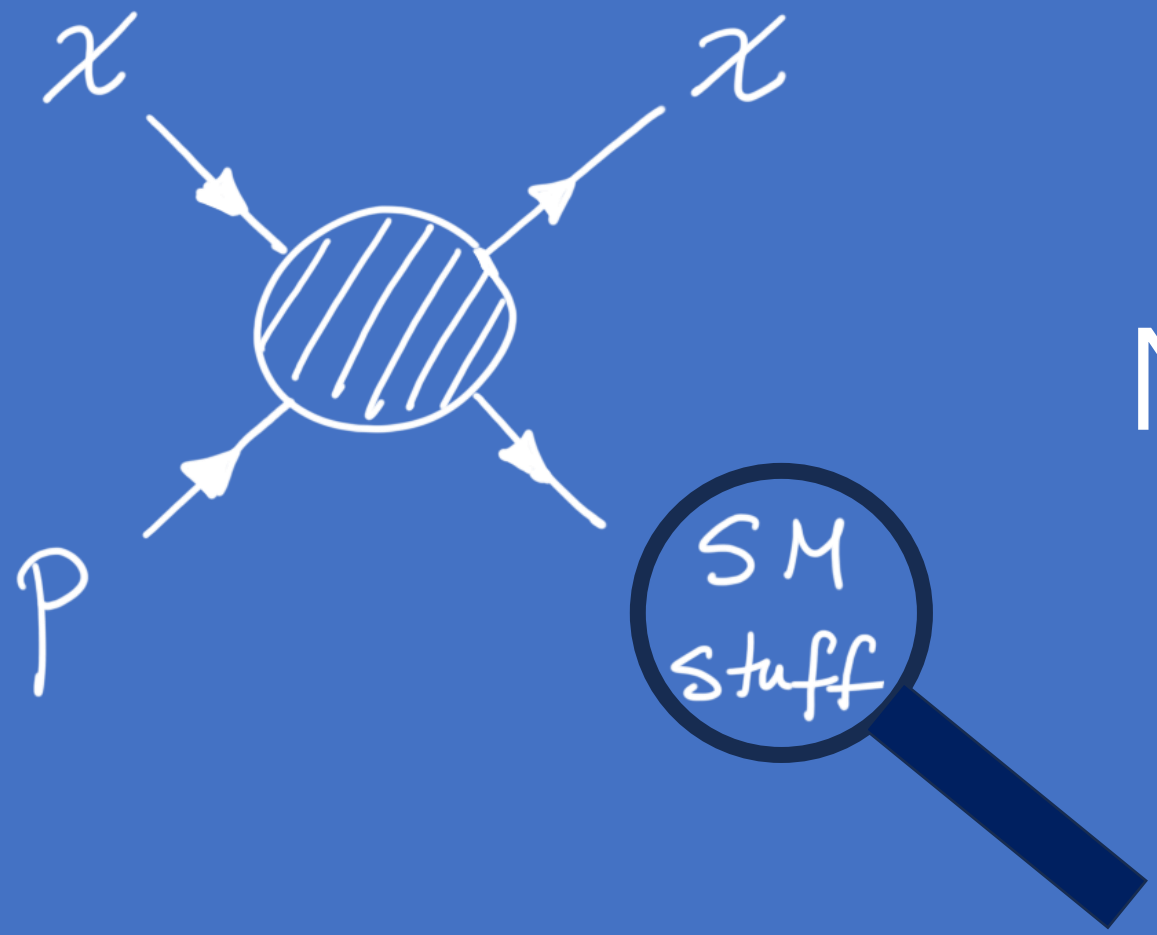
- If depletion is faster than accretion, over time the spike disappears
- Too large cross sections are inconsistent with spike





IV

Neutrinos from blazars

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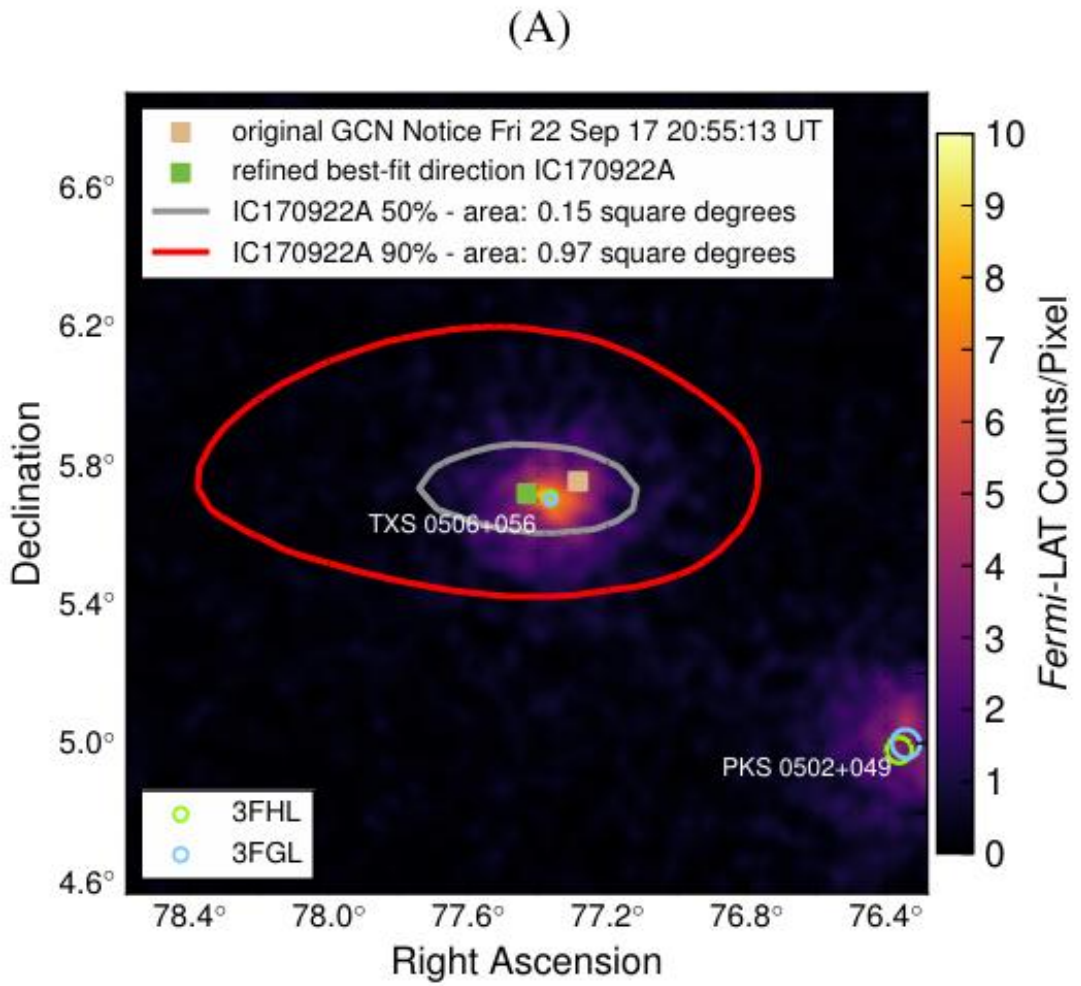
2017: IceCube detects ~ 300 TeV ν

First associated to astro source: blazar TXS 0506+056



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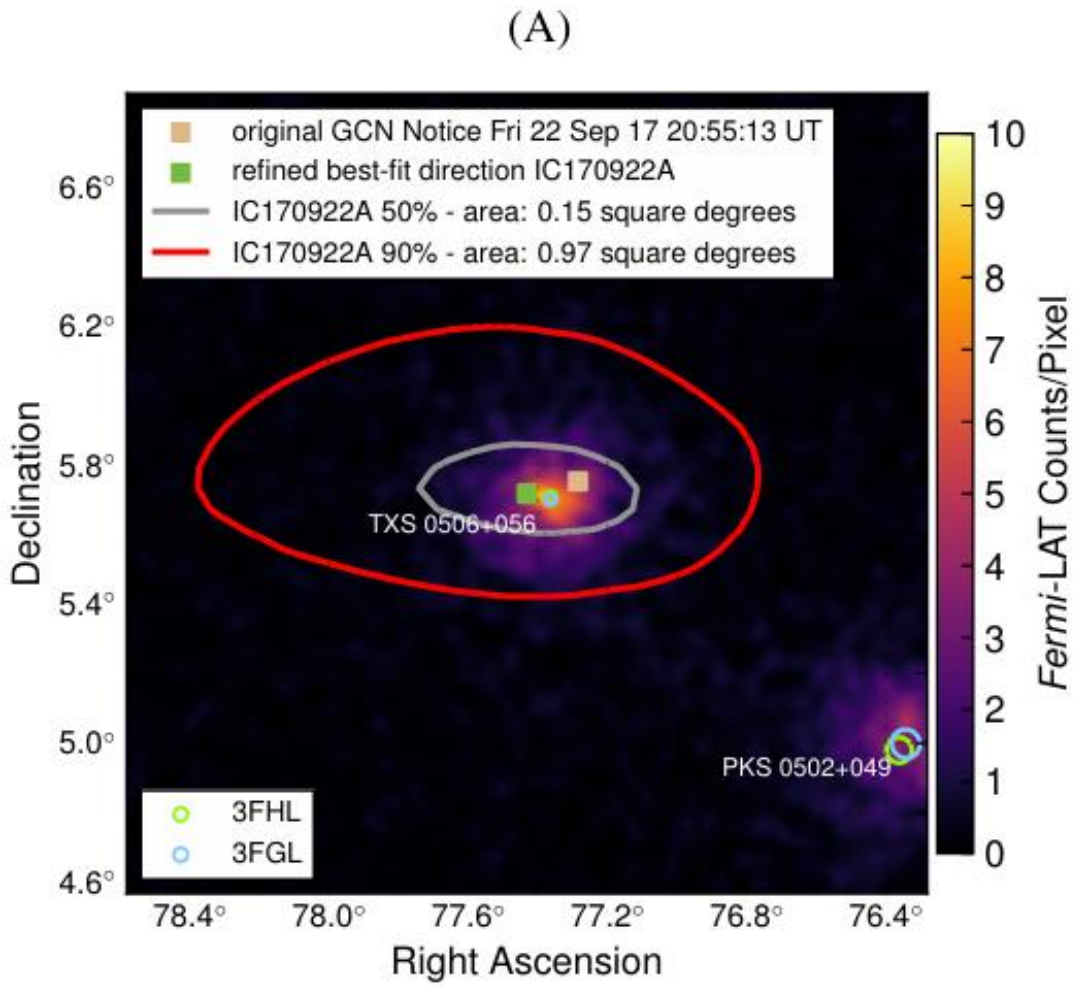

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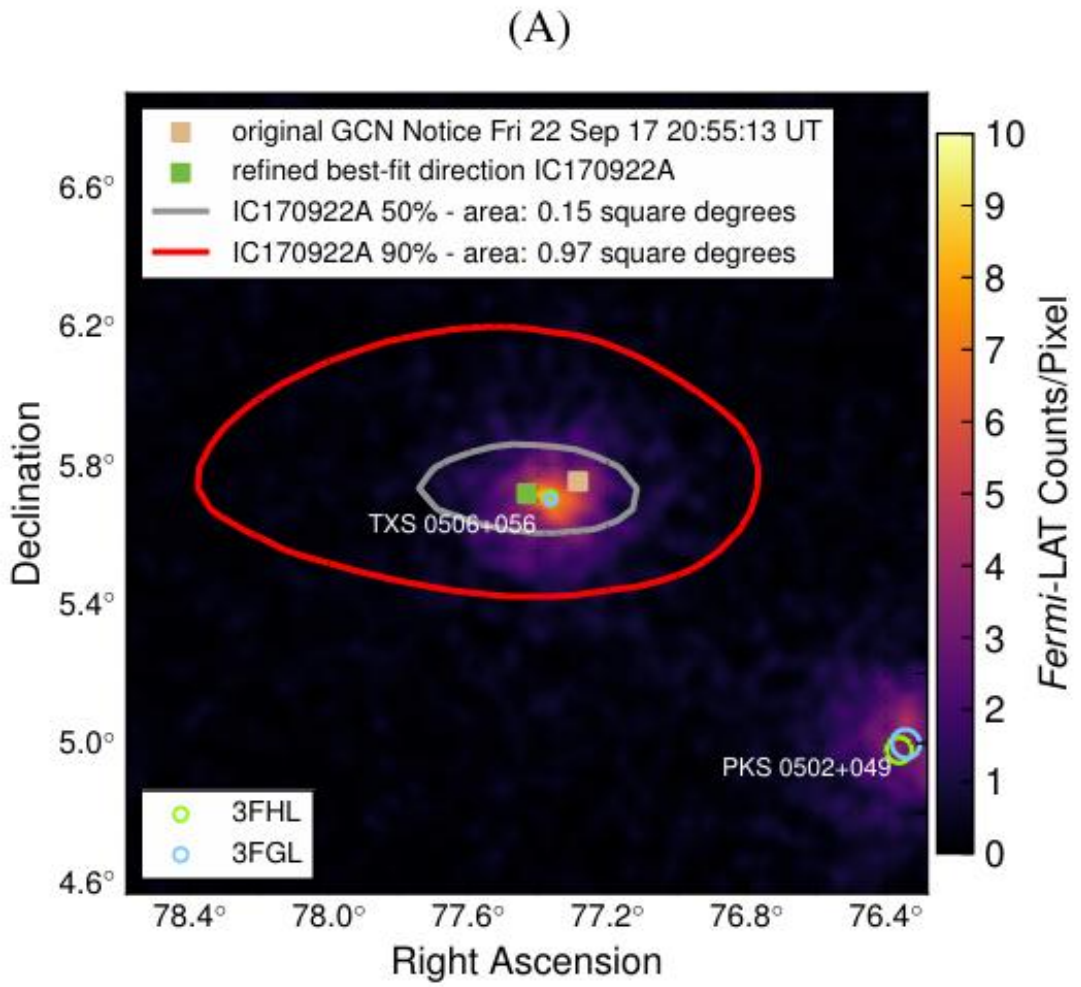
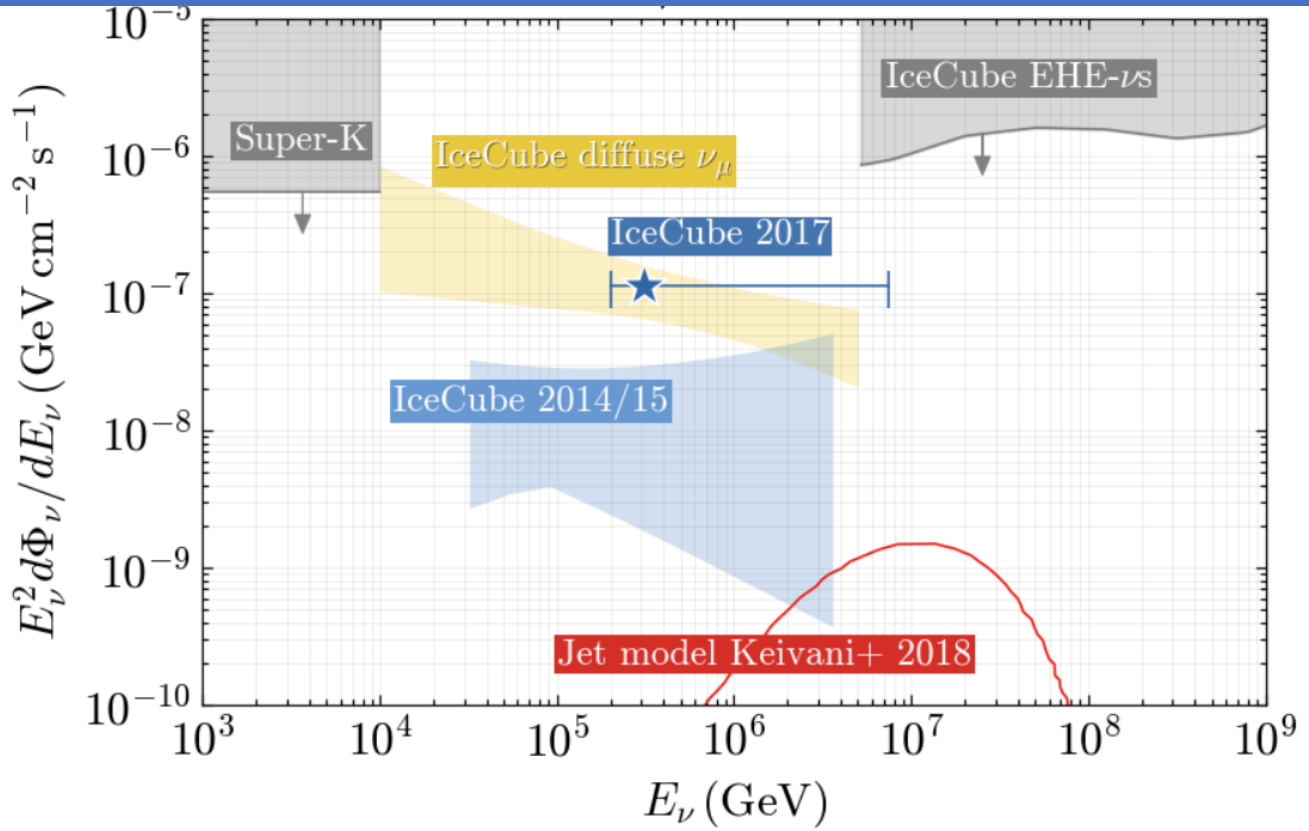
Many others blazar associations:

Blazars are HE neutrino sources!



But… hard to explain

Astro models underpredict neutrino flux



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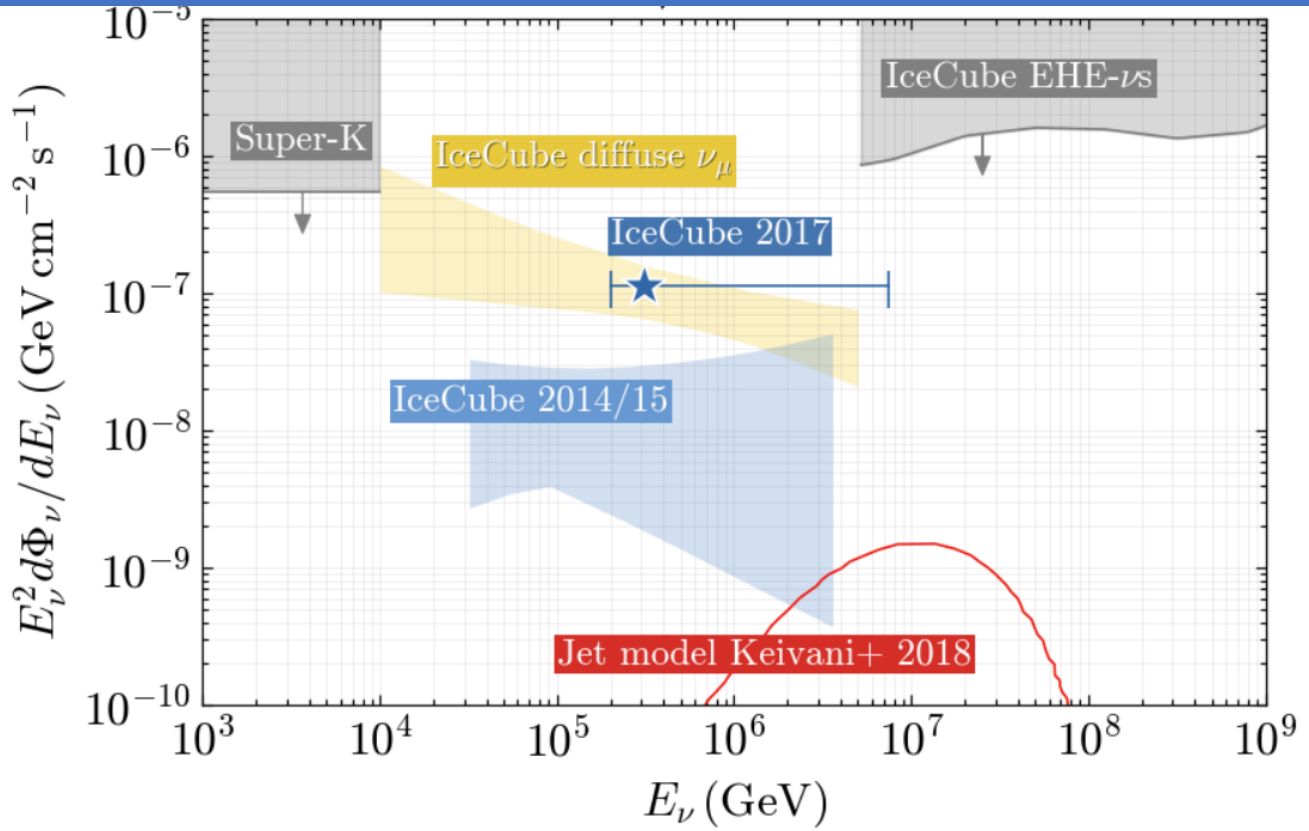

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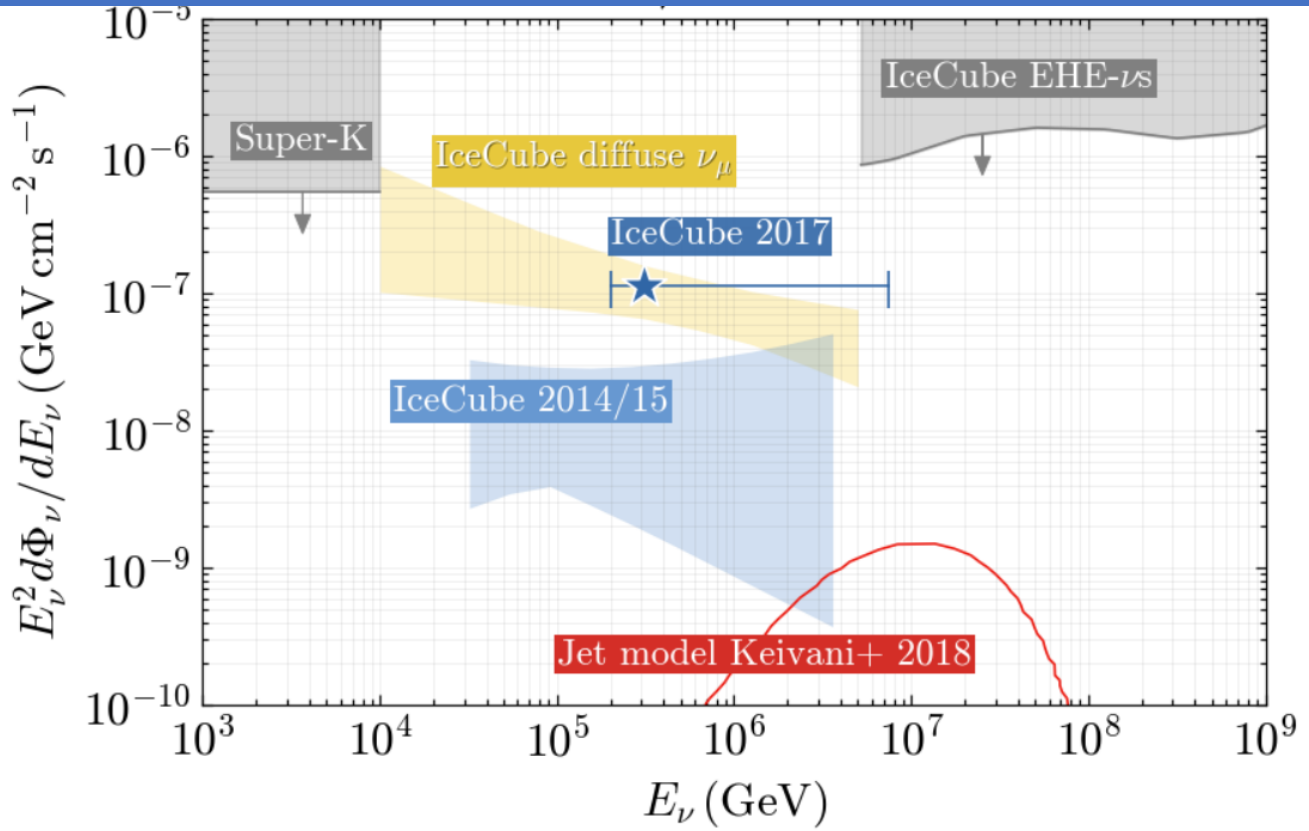

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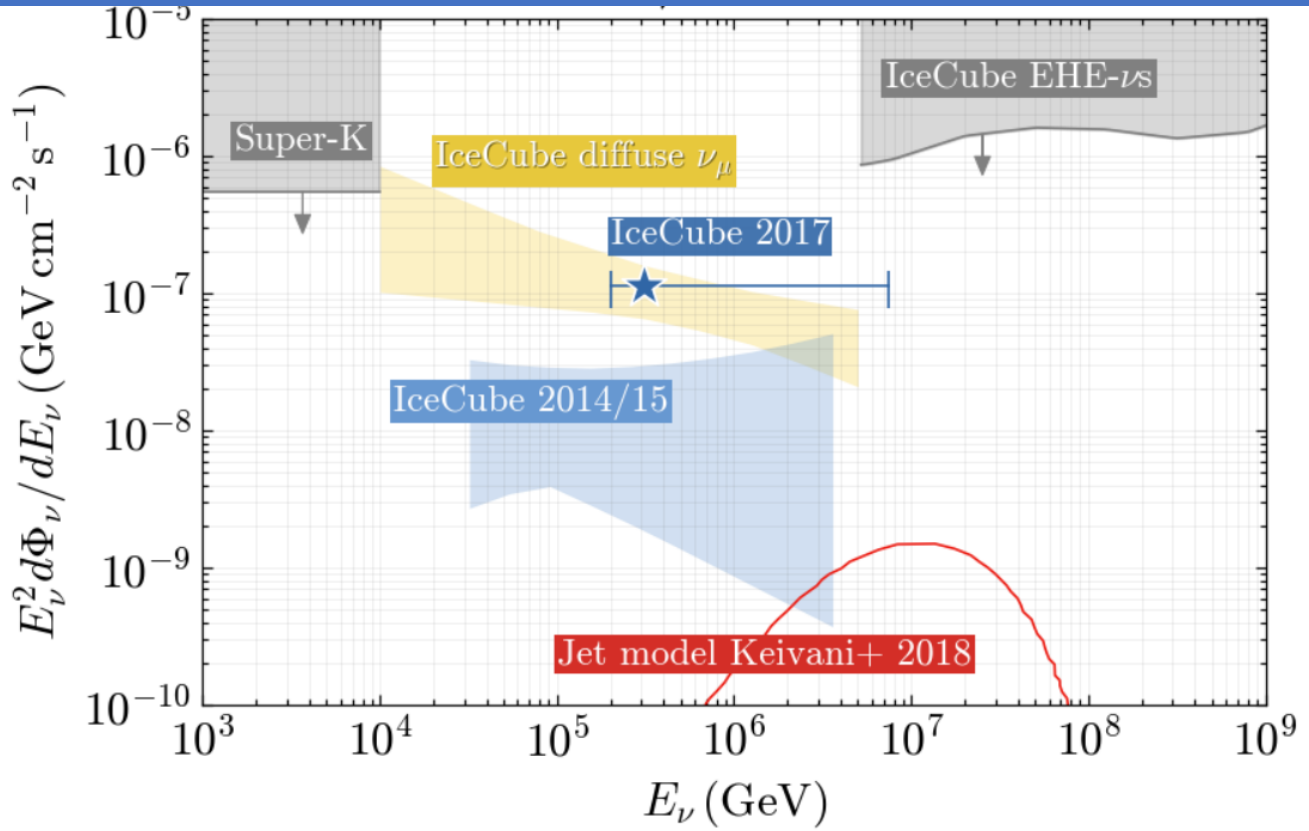
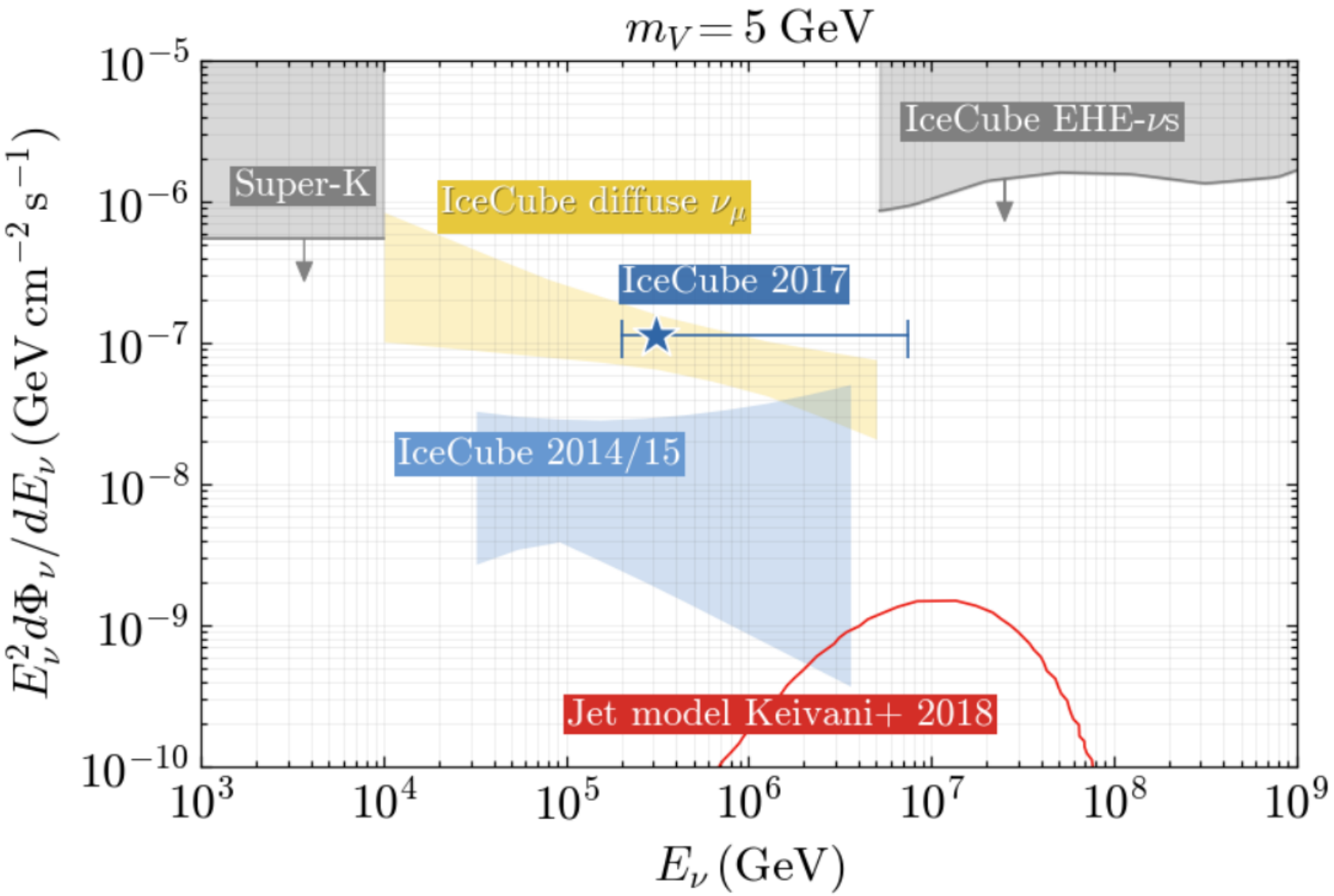


We can compute the flux (using MadGraph + Pythia) as:

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

What we get


$m_V = 5$ GeV
Super-K
IceCube diffuse ν_μ
IceCube EHE-νs
IceCube 2017
IceCube 2014/15
Jet model Keivani+ 2018
$E_\nu^2 d\Phi_\nu/dE_\nu$ (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

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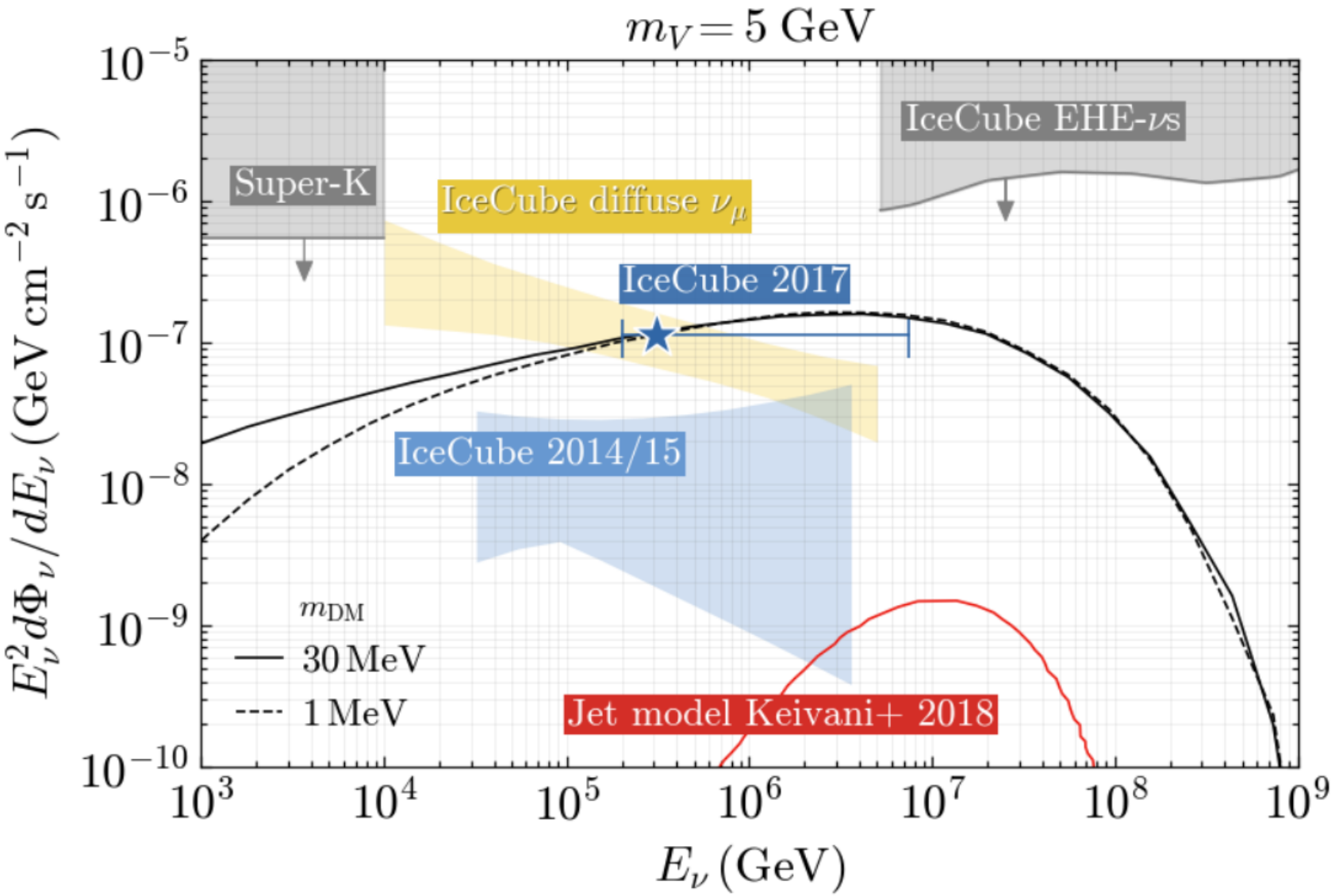
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30 MeV
1 MeV
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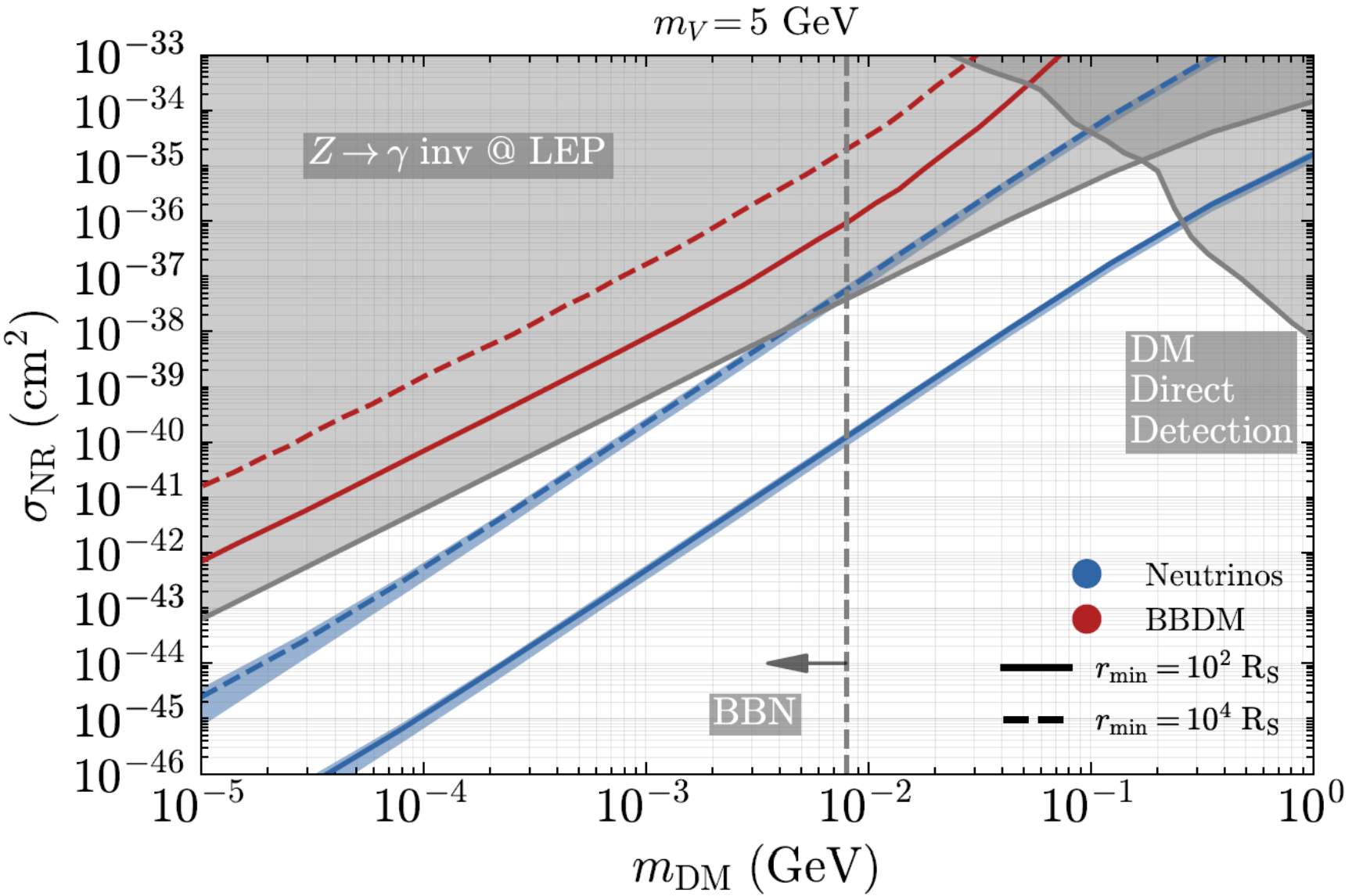
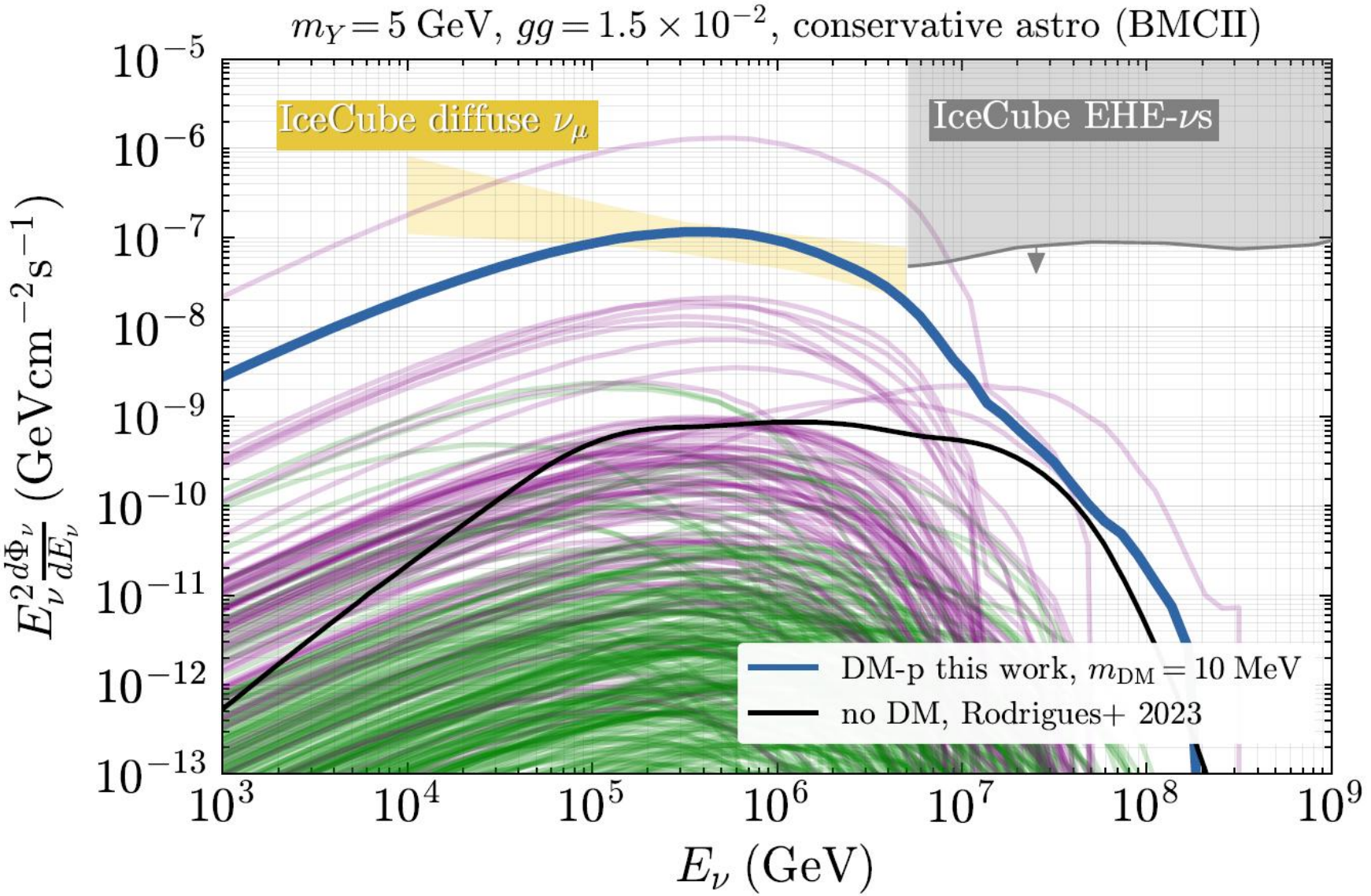
E_ν (GeV)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Probed parameter space



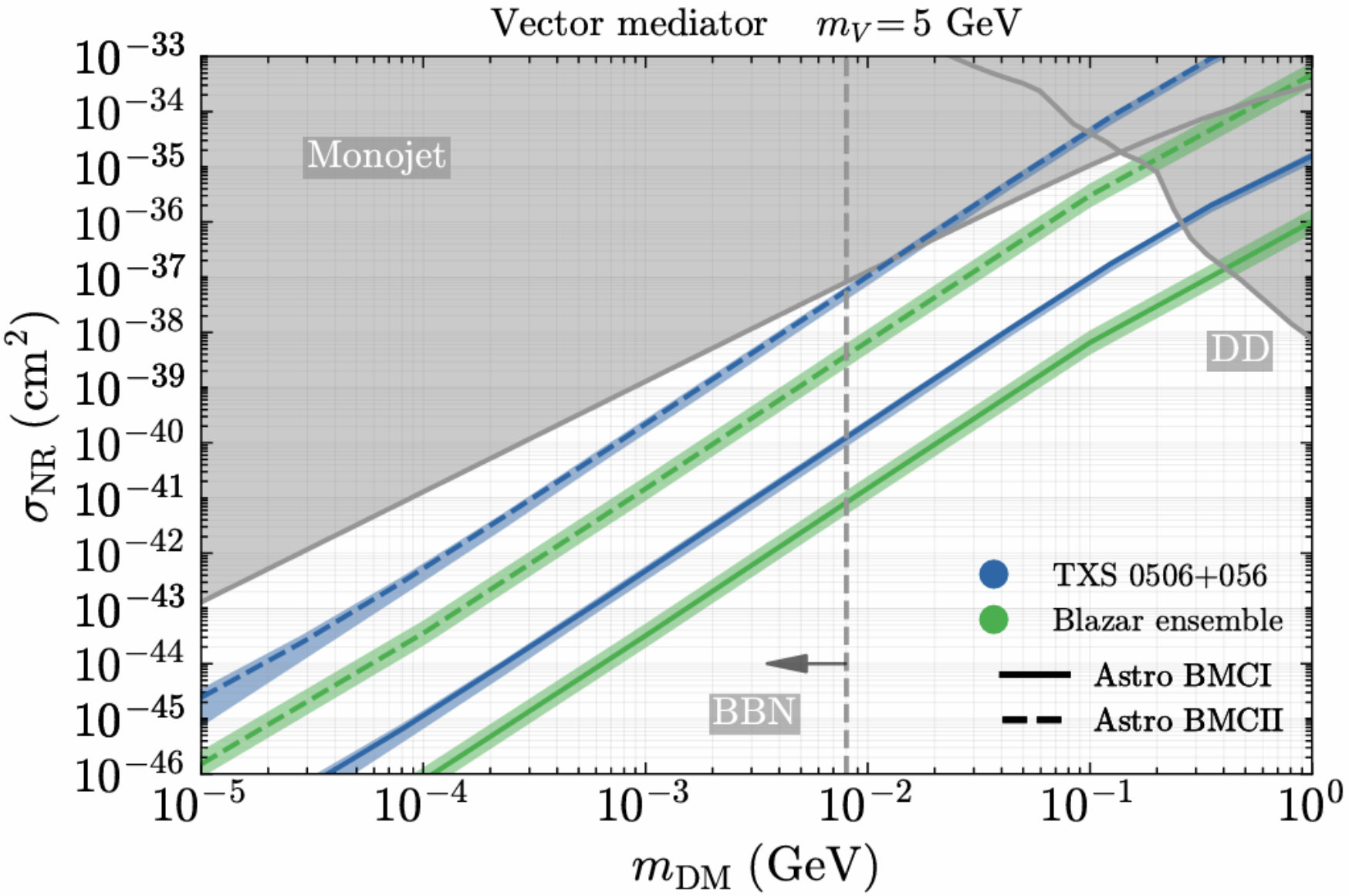
Blazar catalogue



Catalogue of blazars and leptohadronic fits [Rodrigues+ 2023, 2307.13024]

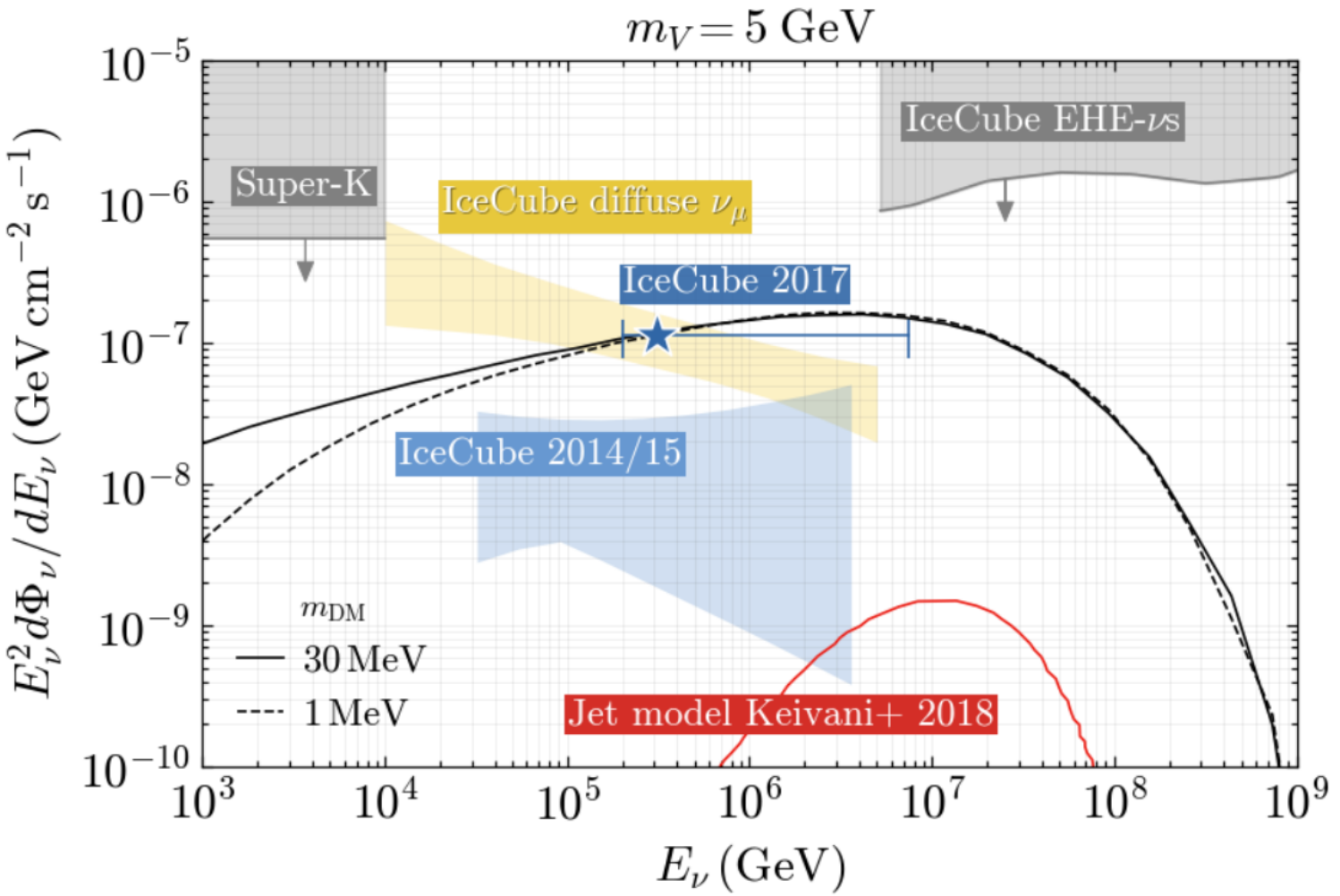
Diffuse neutrino flux correlates to blazar skymap above 100 TeV? [Buson+ 2022]

Parameter space



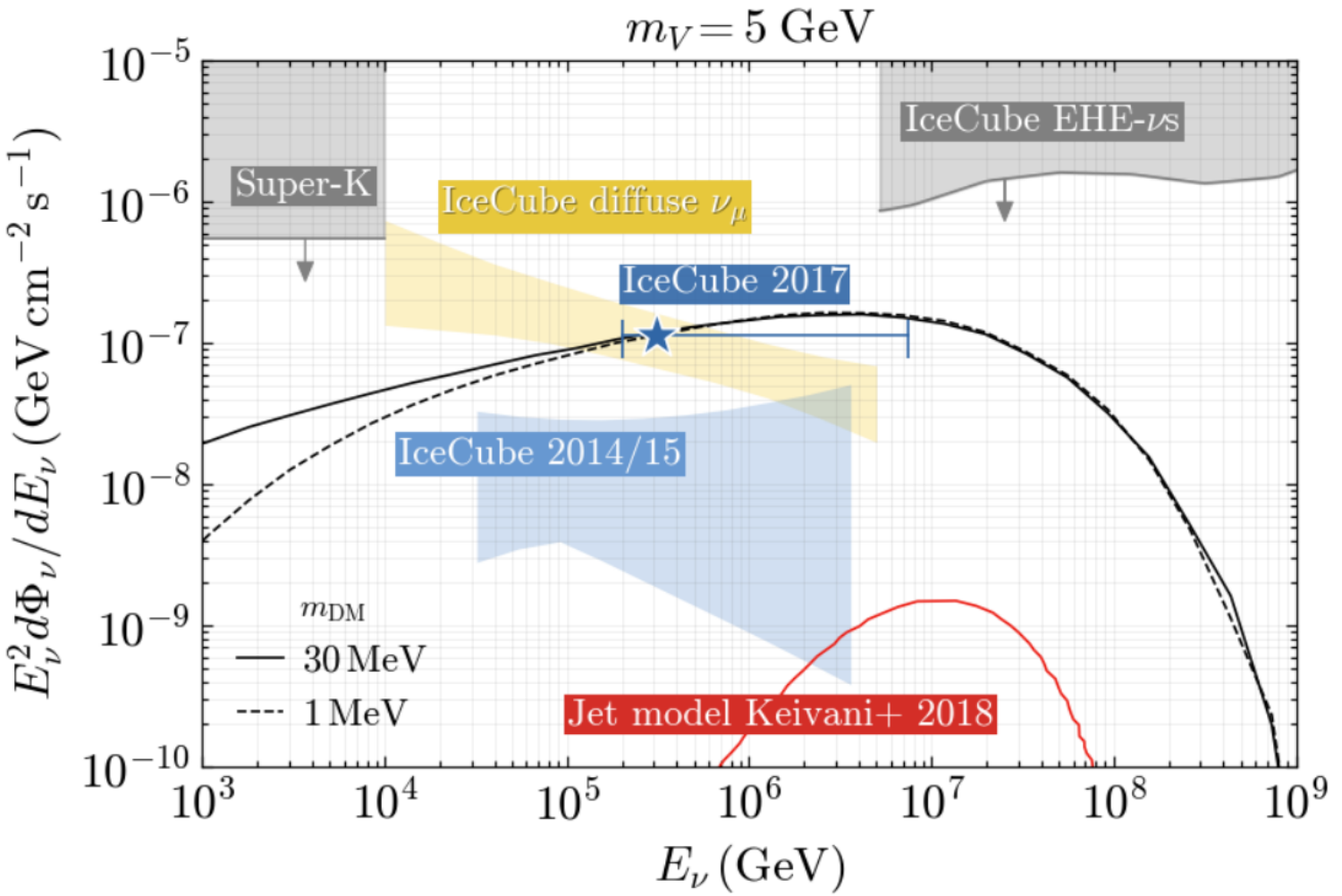
Key takeaways

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



Key takeaways

- We can probe very small $\sigma_{p\chi}$ via BBDM
- For even smaller $\sigma_{p\chi}$, more neutrinos from $p - \chi$ than SM.



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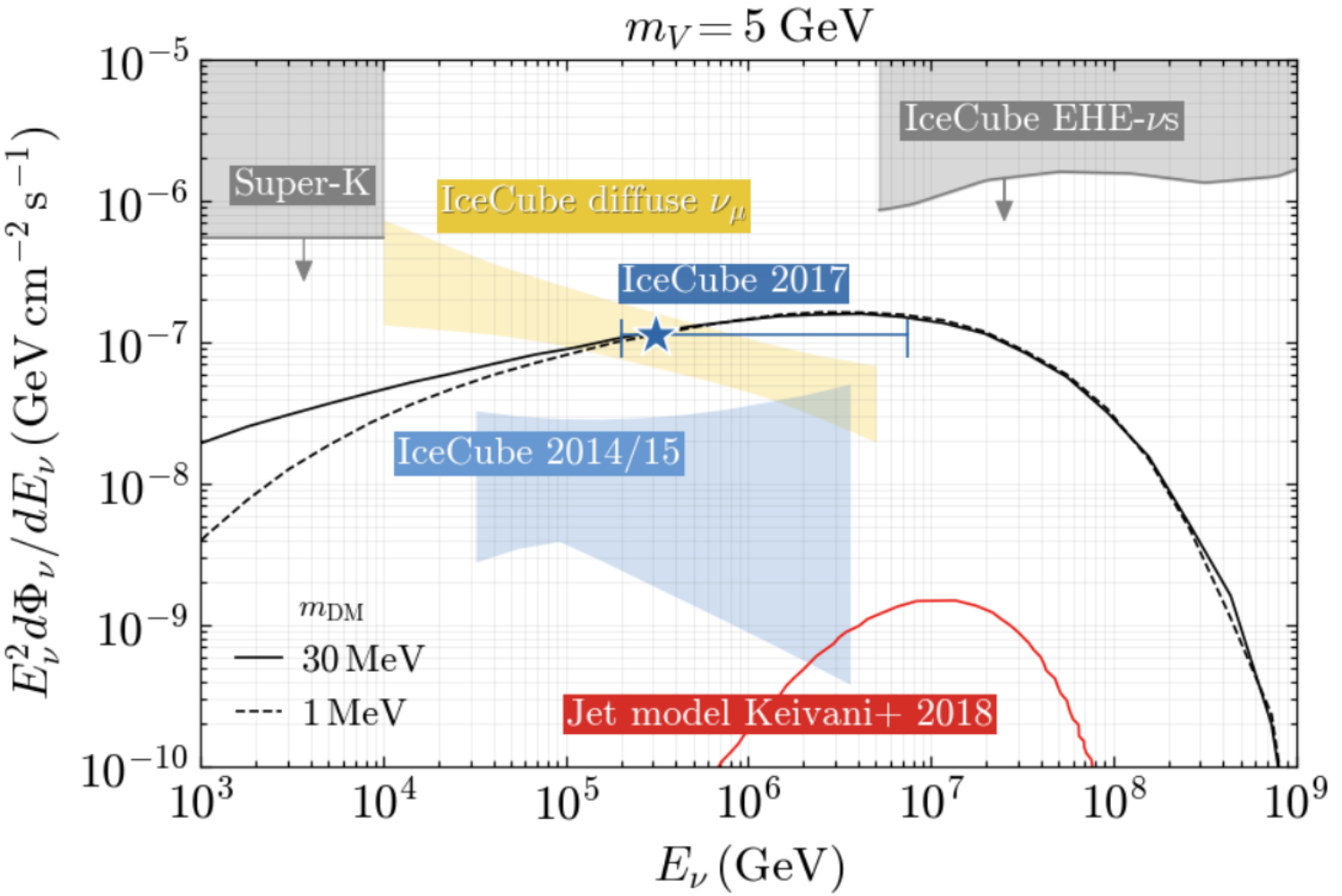

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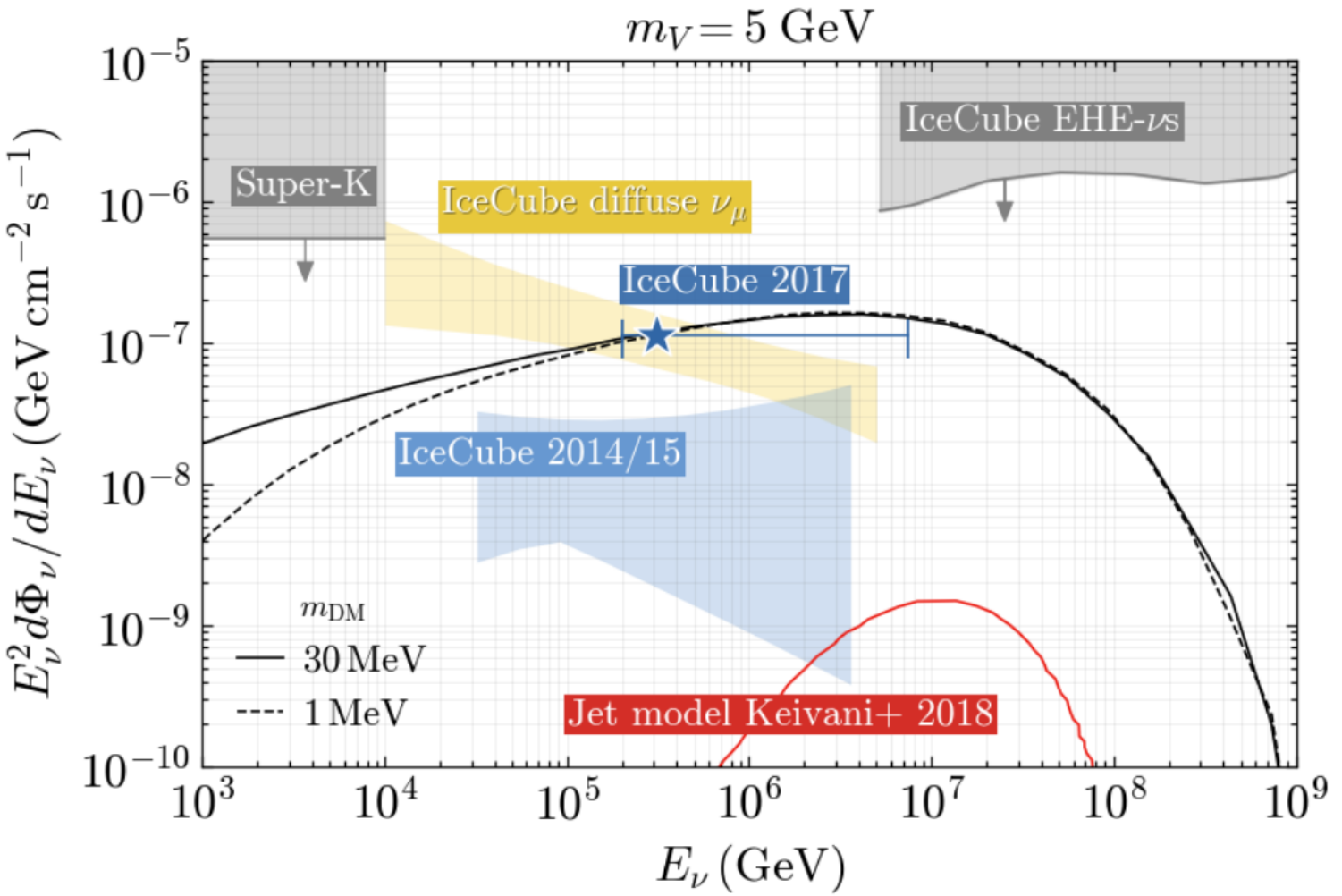


Did IceCube detect Dark Matter around blazars?

To do:

- What about gamma rays? Does this mess up the leptohadronic fit?
- What about other kinds of AGN?
- Understanding the diffuse neutrino background… could this mechanism explain it?
- Is the spike normalization reasonable?
- Large astro uncertainties… can we quantify them somehow?

Thank you!

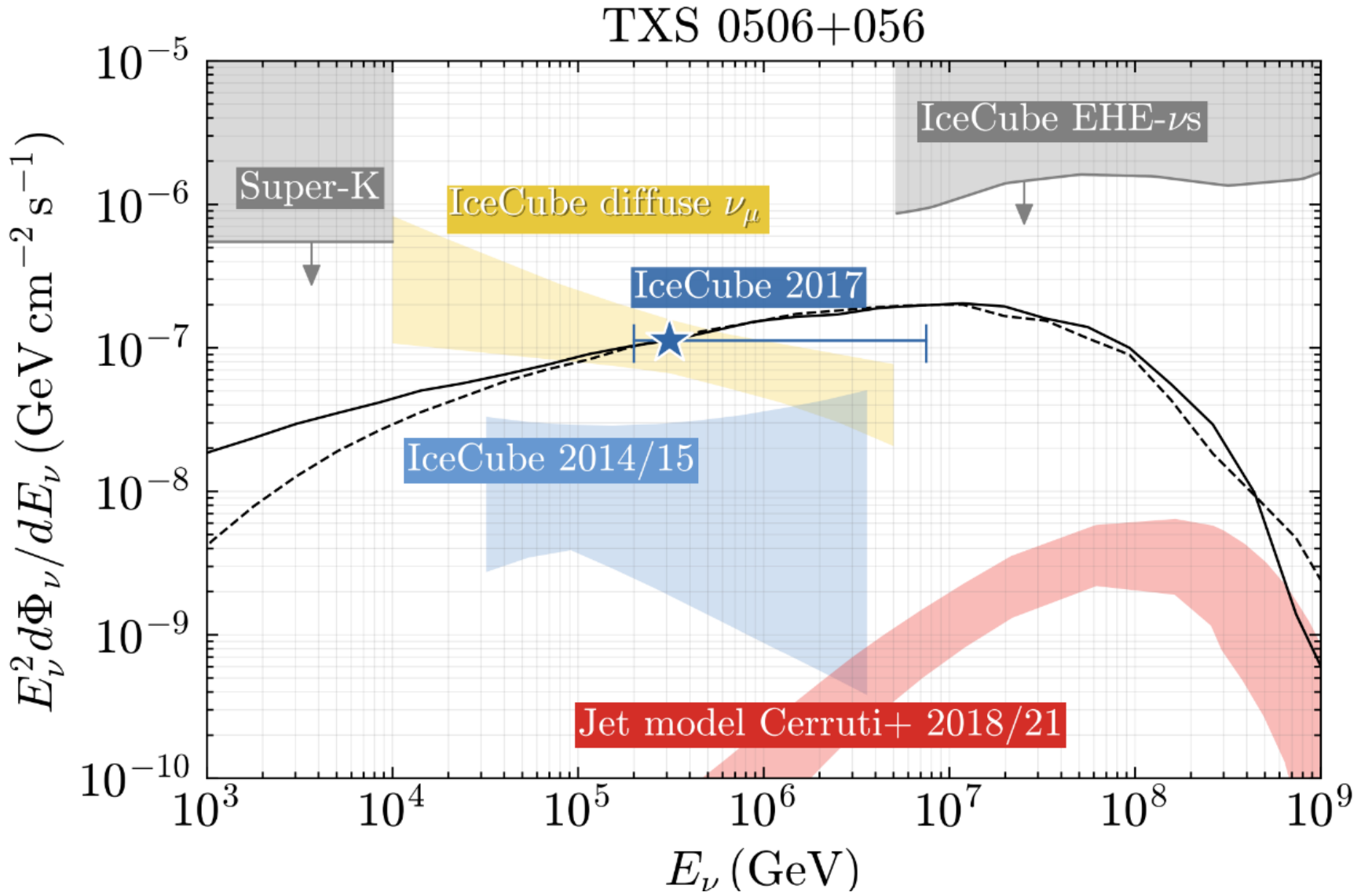
Backup

Depletion of the spike

- Many astro effects: mergers, thermalisation with stars, BH misaligned with halo…
- DM self-scattering: very problematic, softens the spike a lot [2506.12642]. Can be avoided with inelastic DM, doesn't change the neutrino signal
- Jet depletion of the spike:

$$\Sigma_{DM} = \int_{R_{min}}^{R_{spike}} dr\, \rho(r)\ \exp\{-A < \sigma > t/r^2\}$$

Different jet model



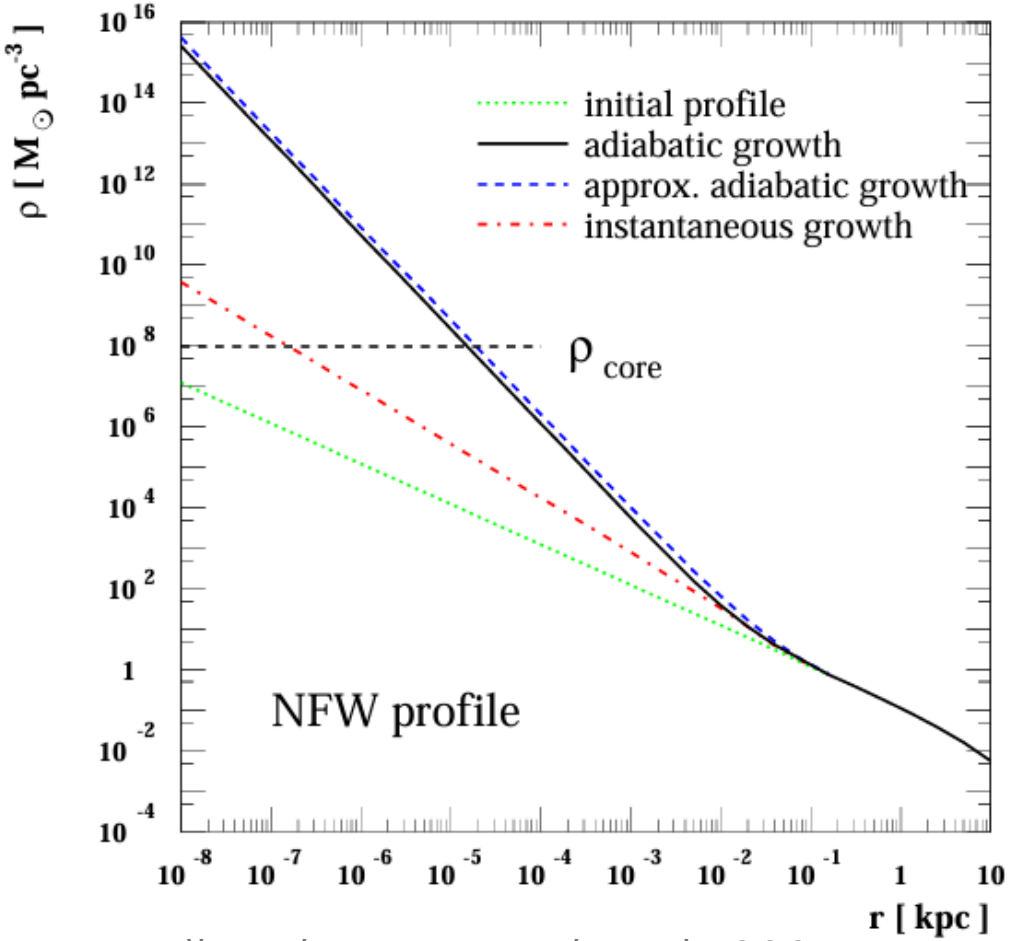
The Gondolo & Silk spike

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

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

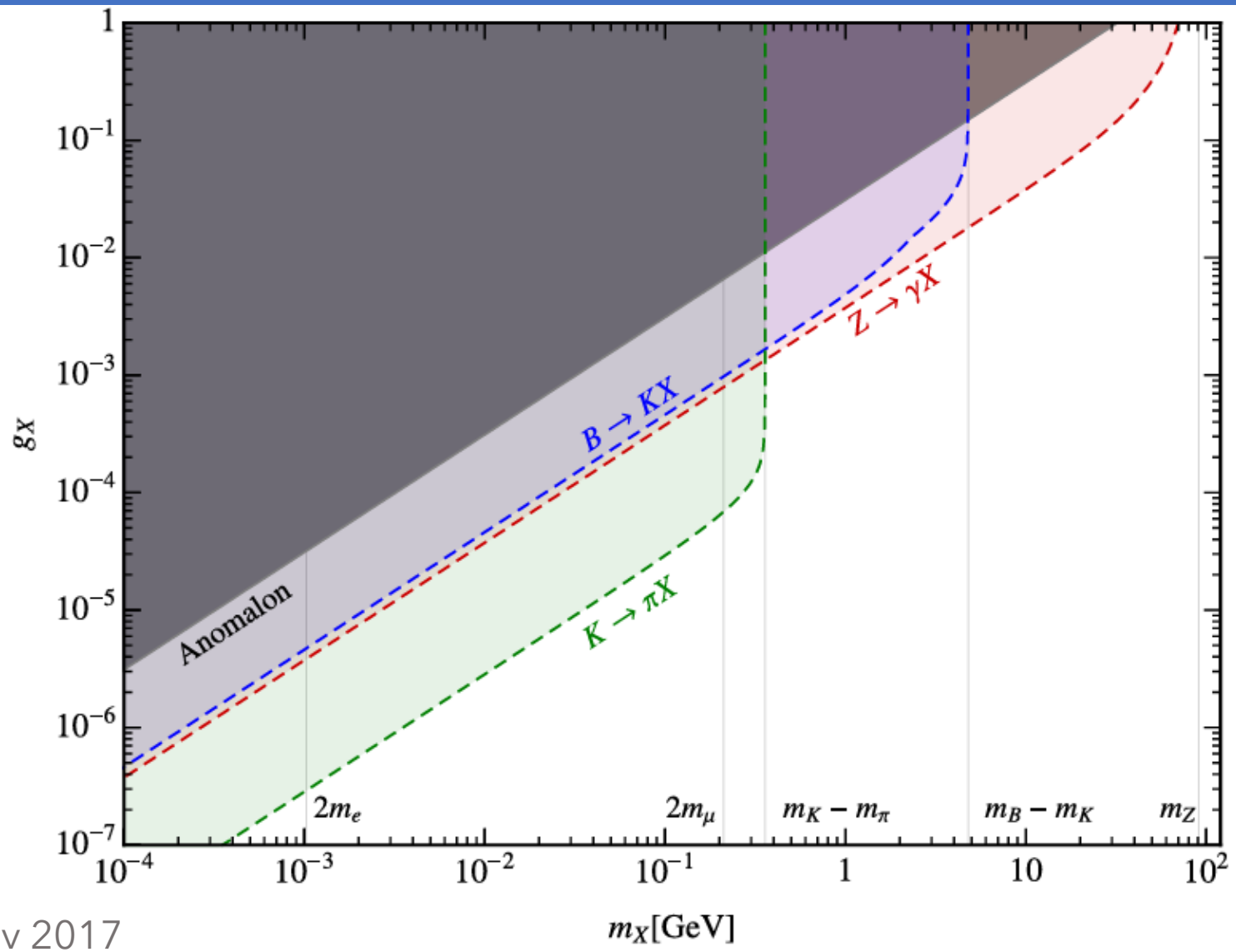
[Gondolo, Silk 1999]

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



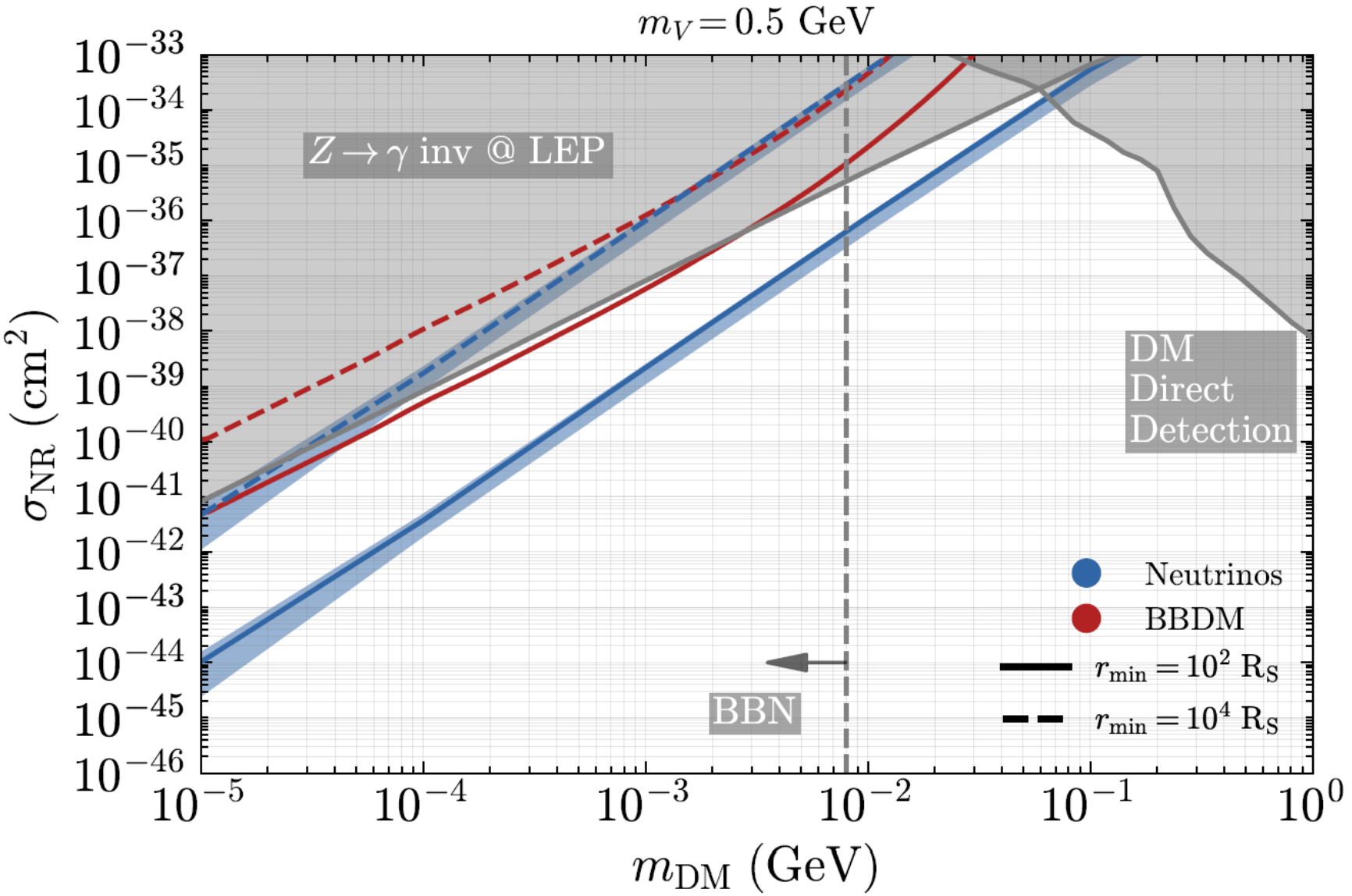
Ullio, Zhao, Kamionkowski 2001

UV completion bounds

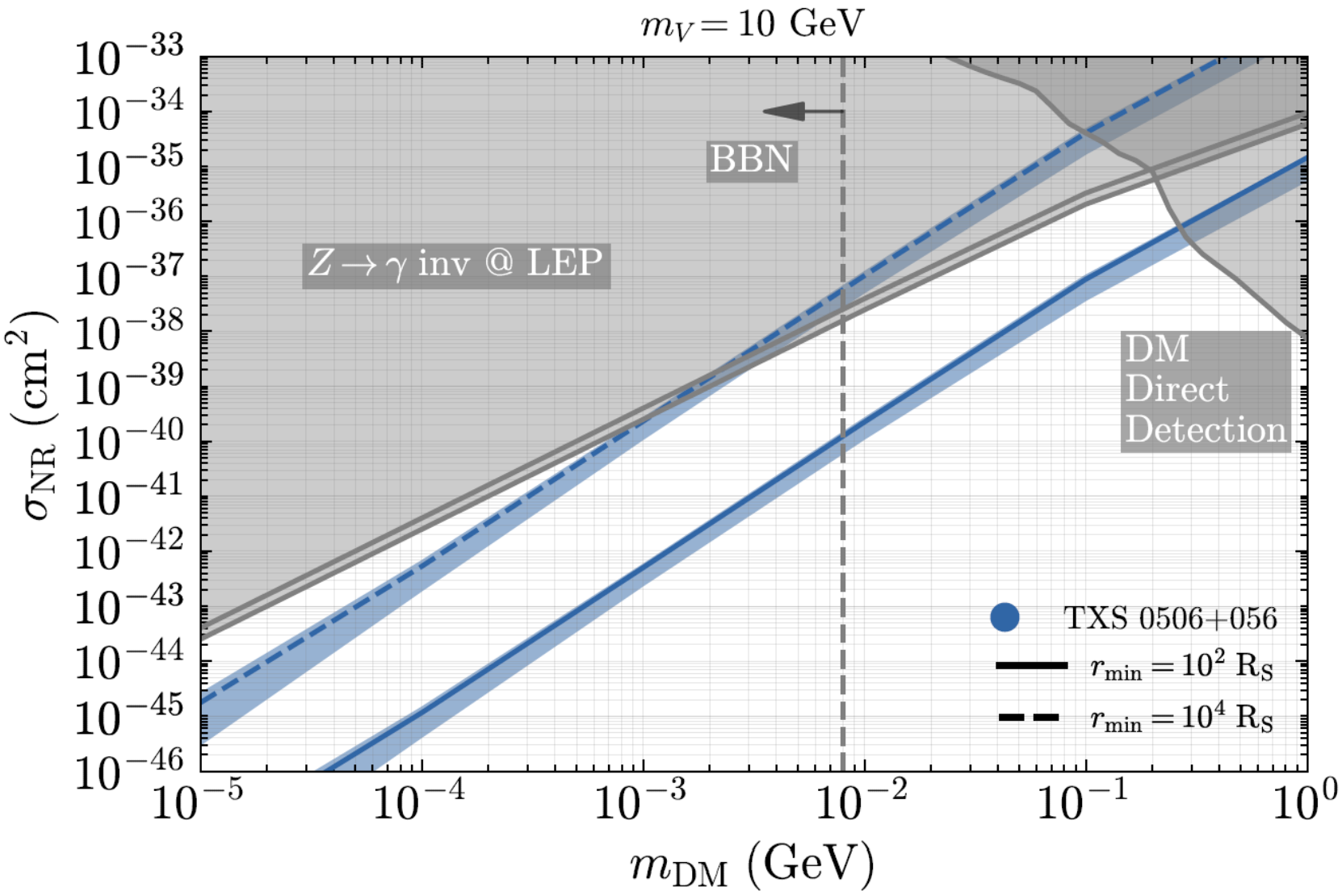


Dror, Lasenby, Pospelov 2017

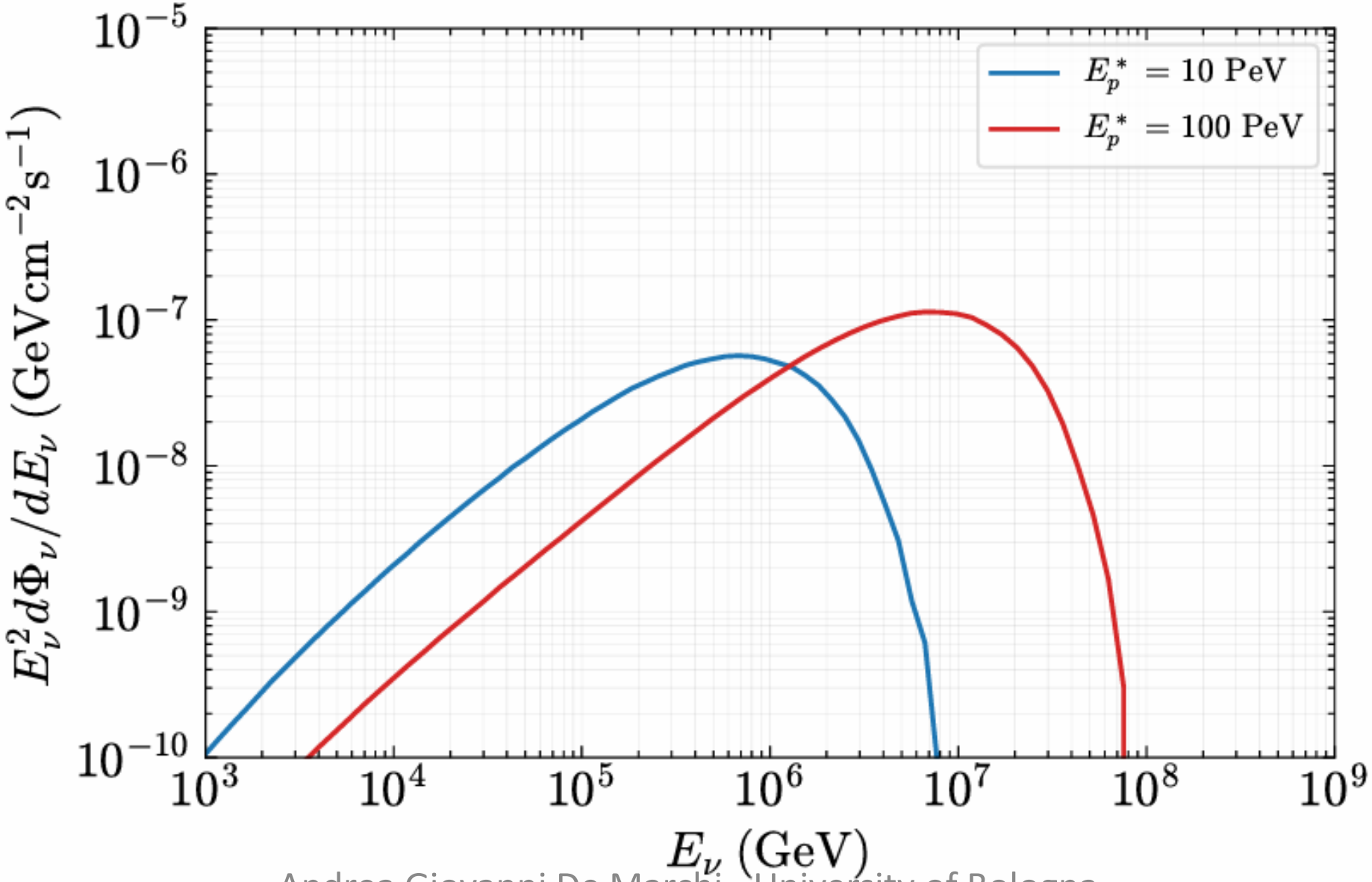
Available parameter space (0.5GeV)



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