Multi-messenger signatures of Dark Matter in Blazar jets

Andrea Giovanni De Marchi

1/09/2026, Tendo

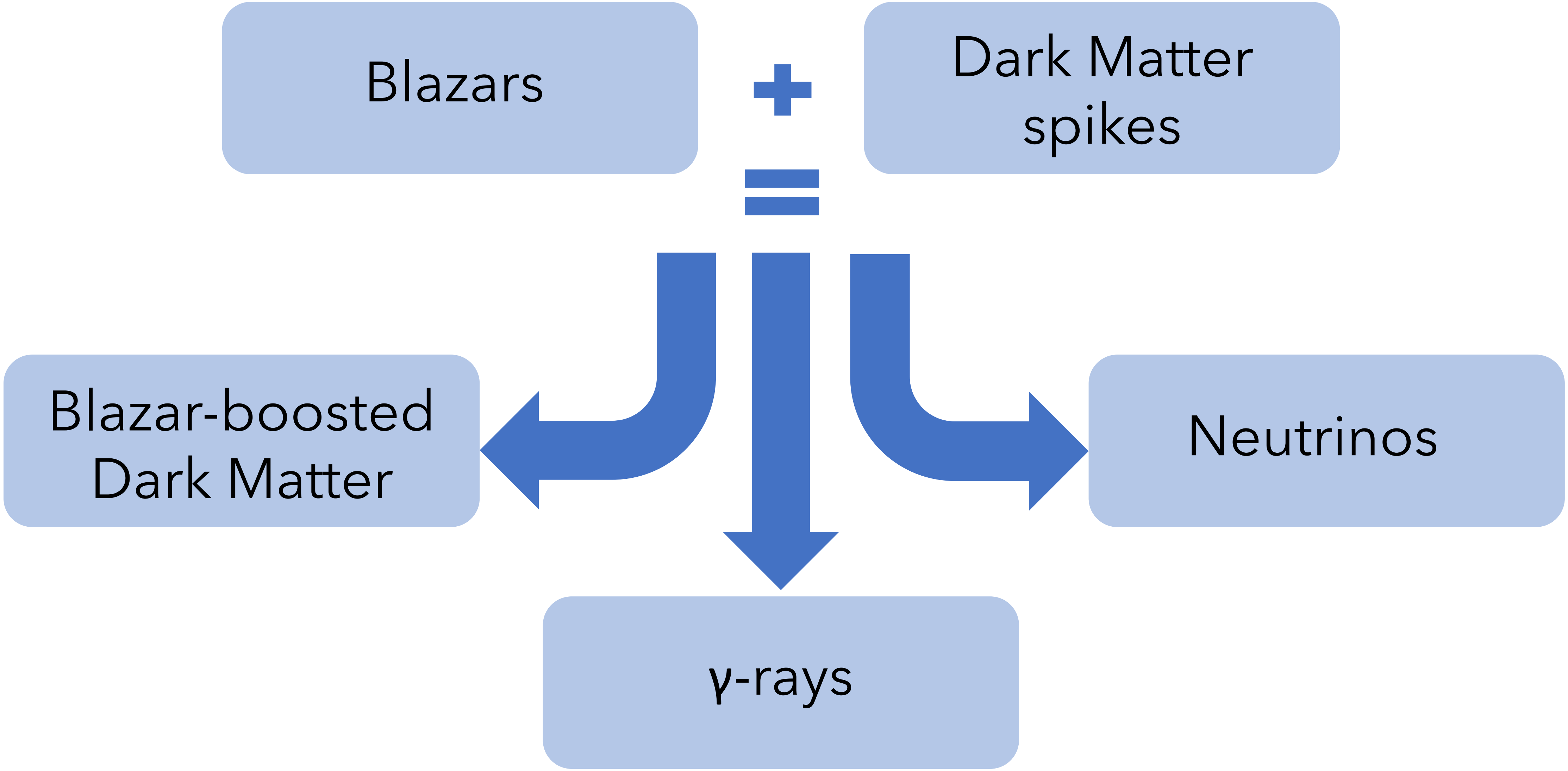
Based on 2412.07861 AGDM, Granelli, Nava, Sala
2507.12278 AGDM, Granelli, Nava, Sala
WIP Cerruti, AGDM, Granelli, Nava, Rodrigues, Sala

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

TeV Particle Astrophysics
TeVPA 2026
Tendo
Japan
August 30 - September 4, 2026

INFN
Istituto Nazionale di Fisica Nucleare

Outline

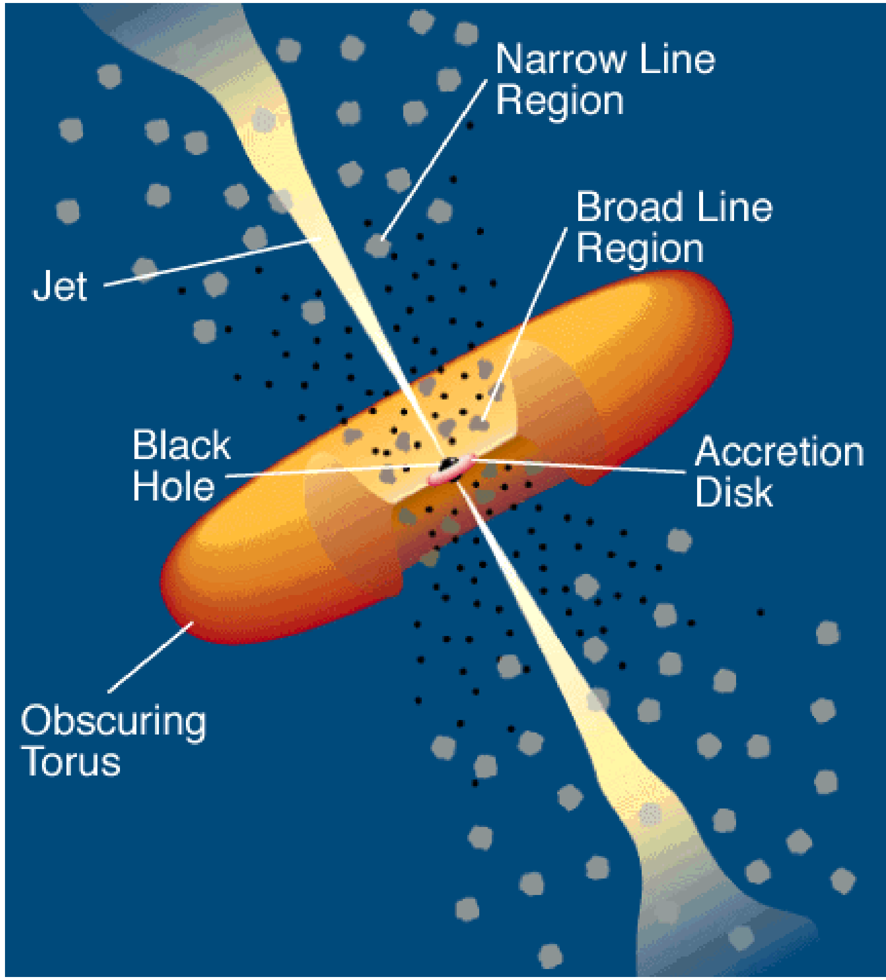

Blazars
+
Dark Matter spikes
=
Blazar-boosted Dark Matter
Neutrinos
γ-rays

I

Blazars

AGNs

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

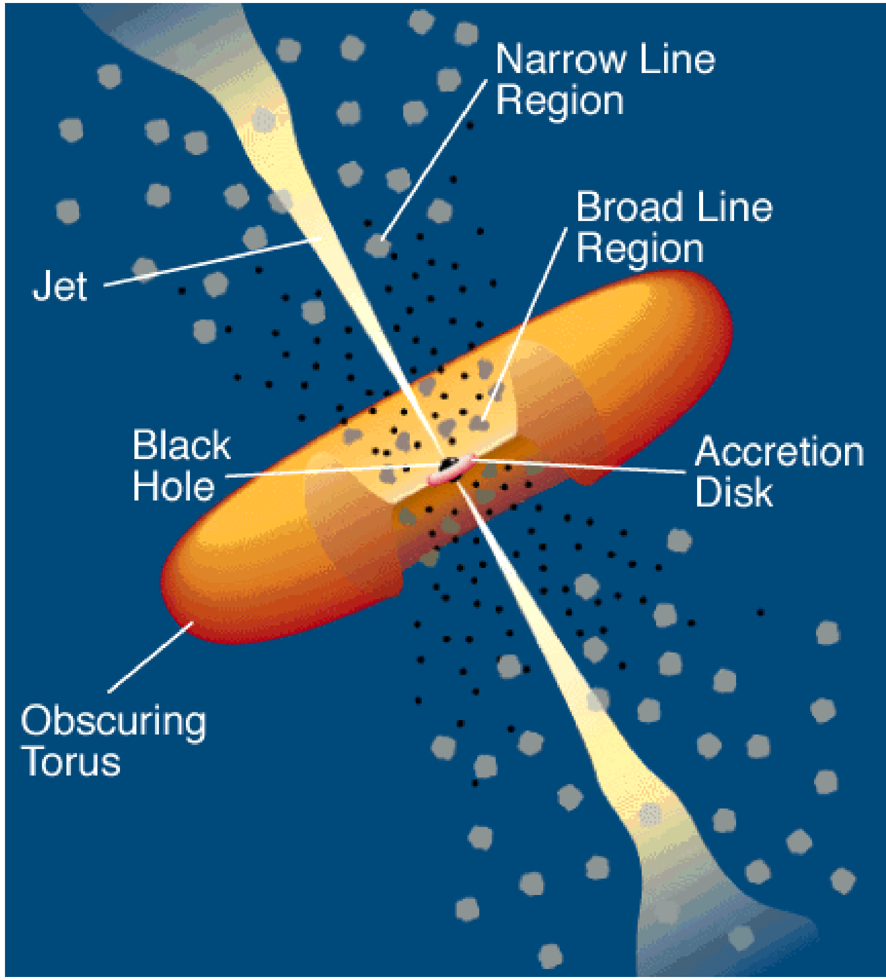


Urry, Padovani 1995

AGNs

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

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



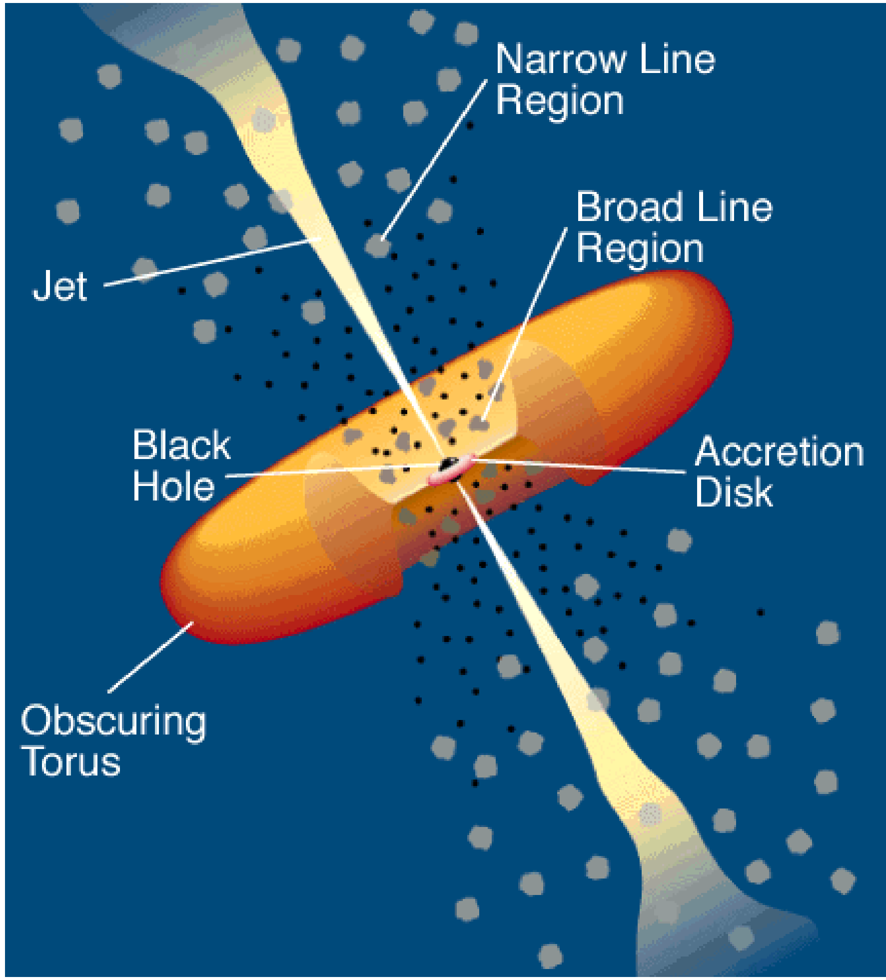
Urry, Padovani 1995

AGNs

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

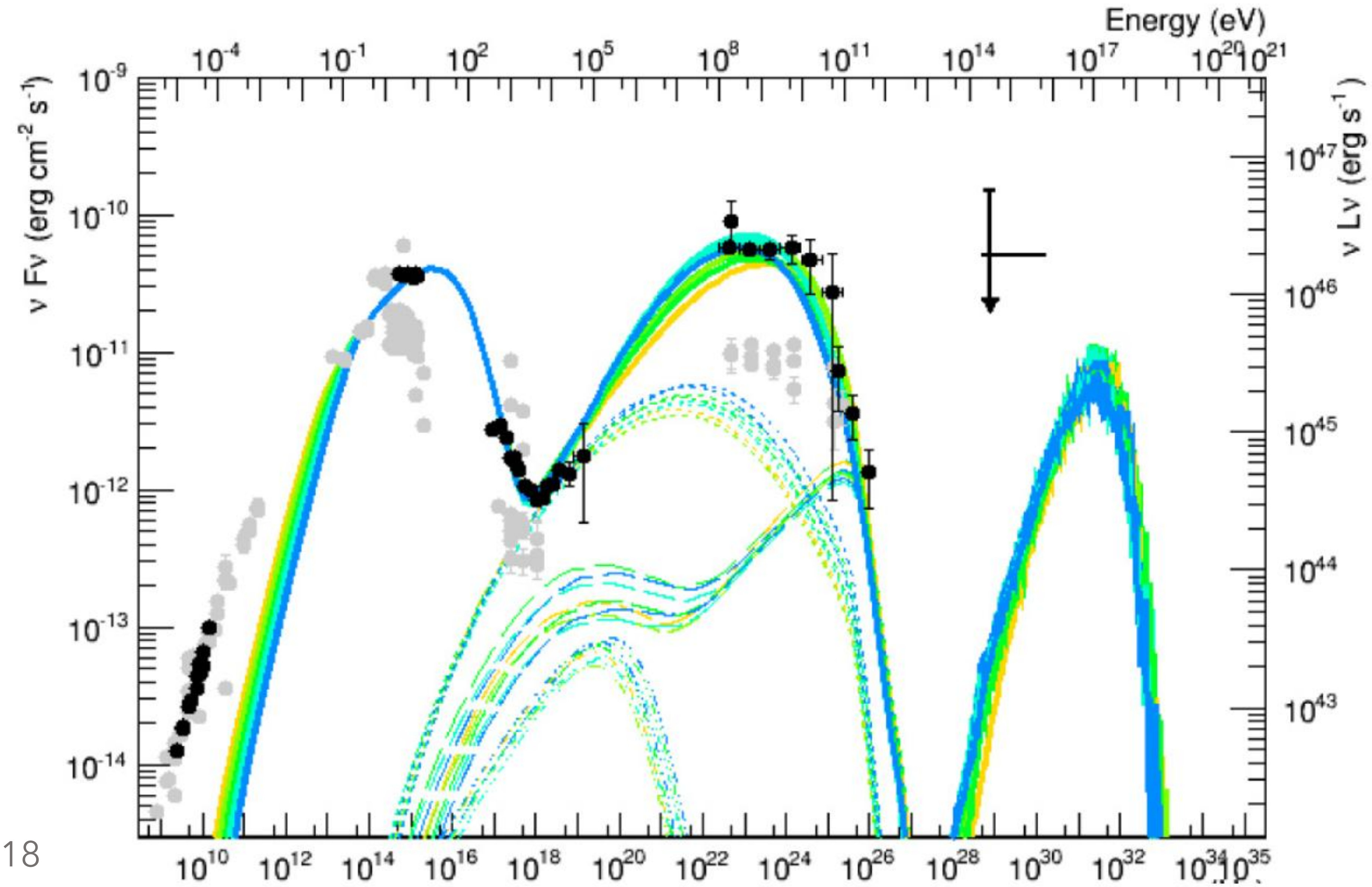
Depending on the angle of line-of-sight wrt to SMBH, you observe different features

If jet pointed towards Earth: **blazar**



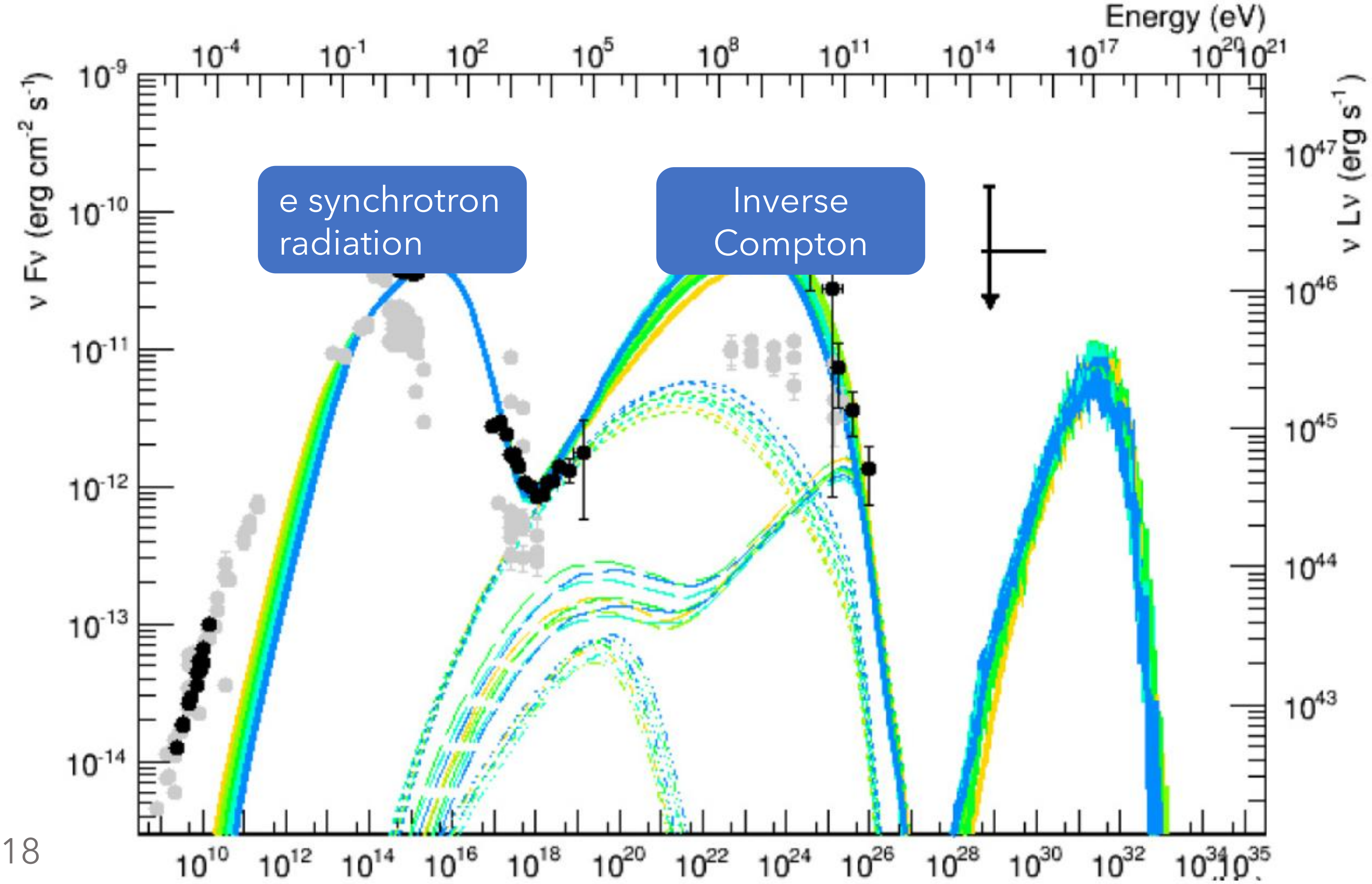
Urry, Padovani 1995

Leptohadronic single-zone models



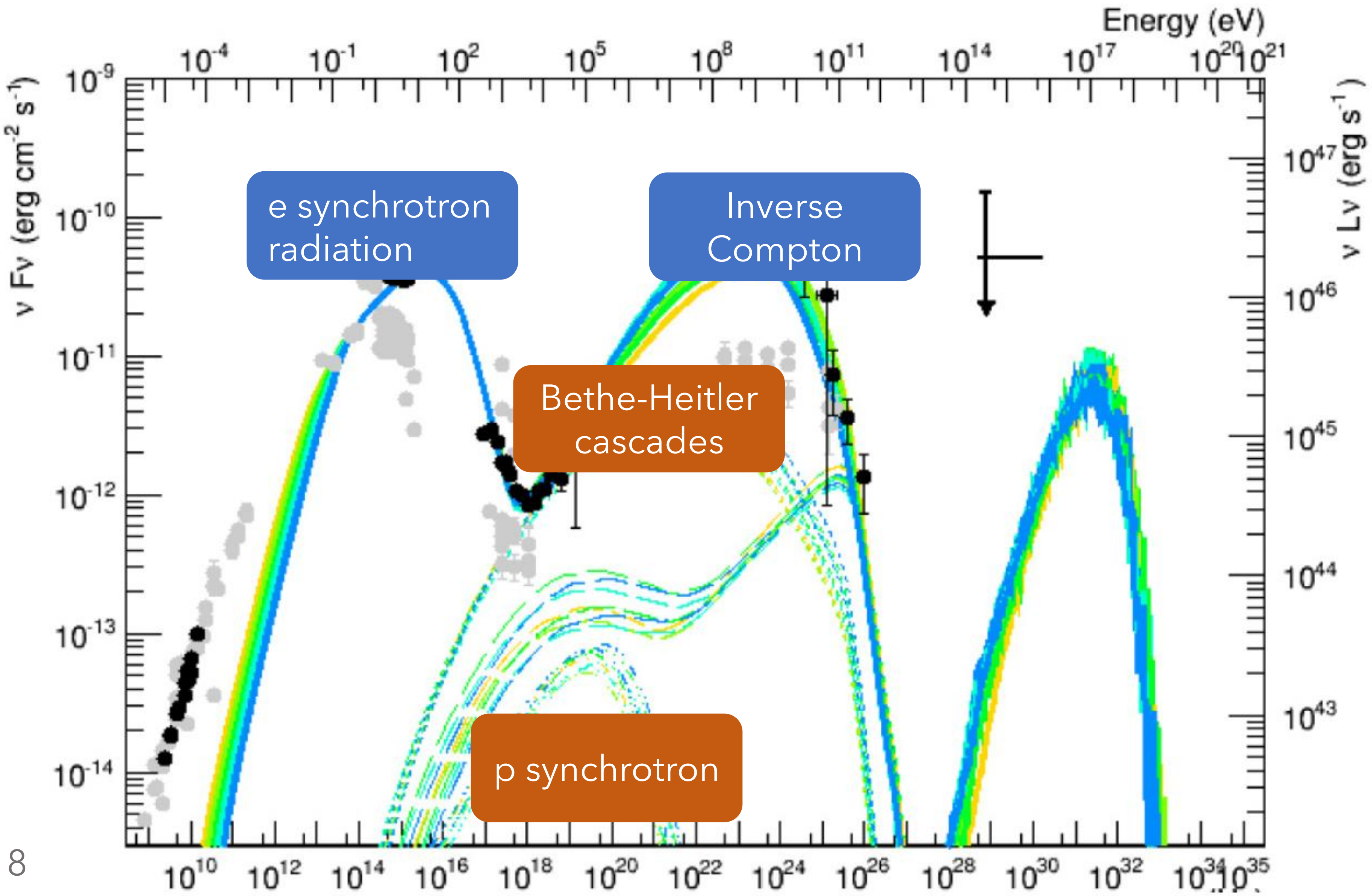
Cerruti et al 2018

Leptohadronic single-zone models



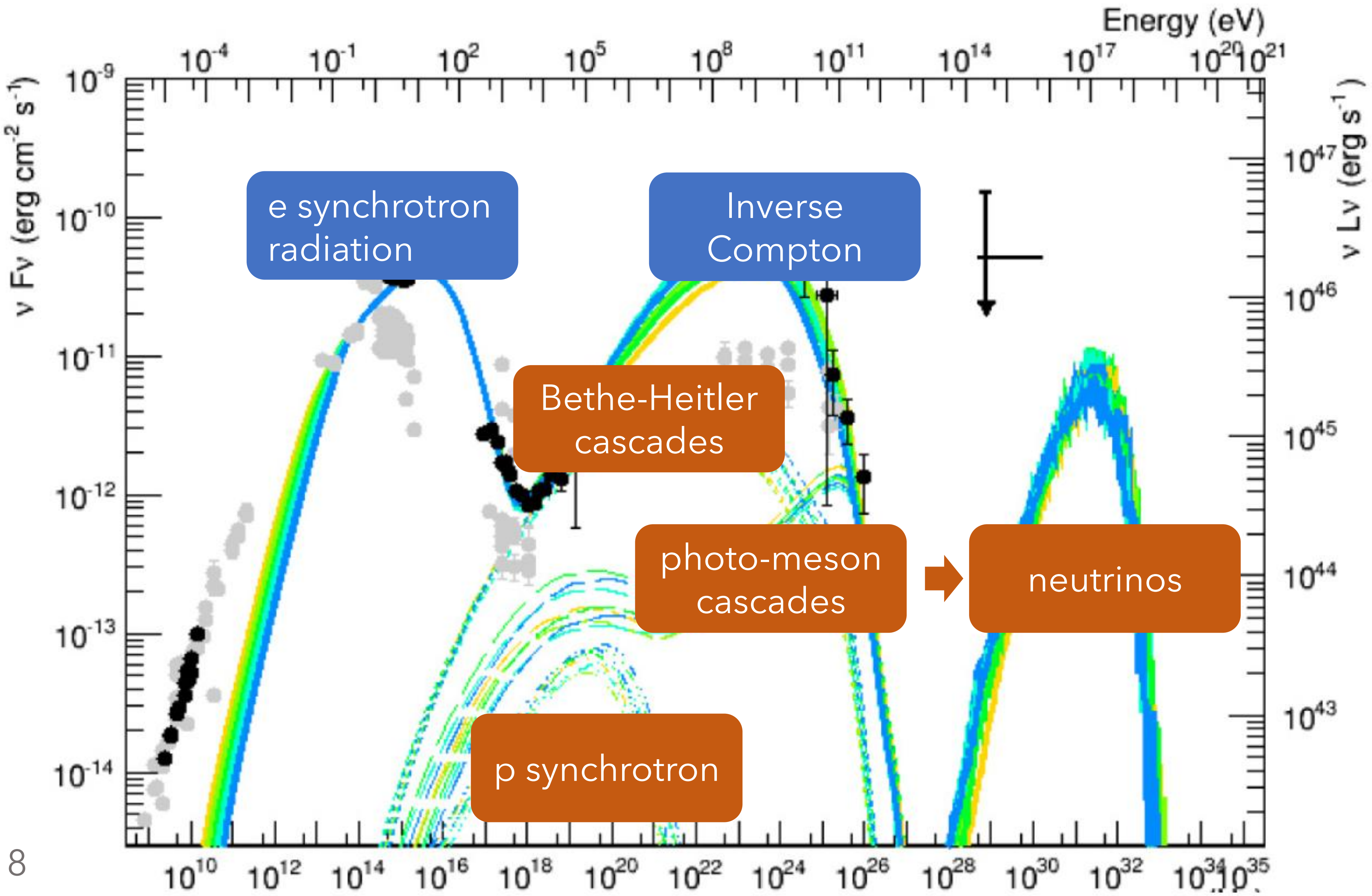
Cerruti et al 2018

Leptohadronic single-zone models



Cerruti et al 2018

Leptohadronic single-zone models



Cerruti et al 2018

II

Dark Matter spike

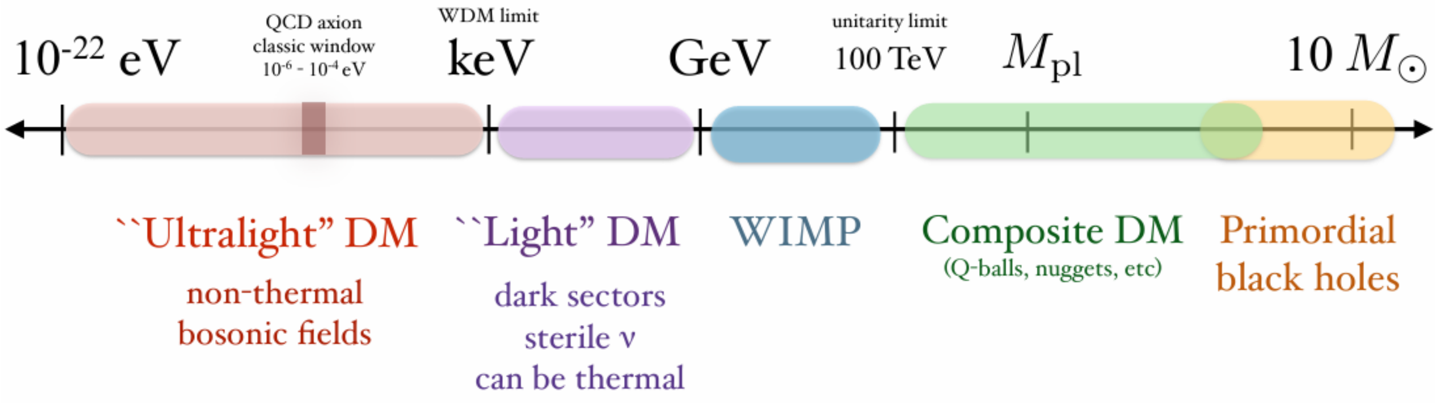
Evidence of Dark Matter

Since the 30s [Zwicky 1933] overwhelming evidence for Dark Matter on all scales: galactic rotation curves, galaxy clusters, CMB and large-scale structure

Evidence of Dark Matter

Since the 30s [Zwicky 1933] overwhelming evidence for Dark Matter on all scales: galactic rotation curves, galaxy clusters, CMB and large-scale structure

Somewhere in this mass range:

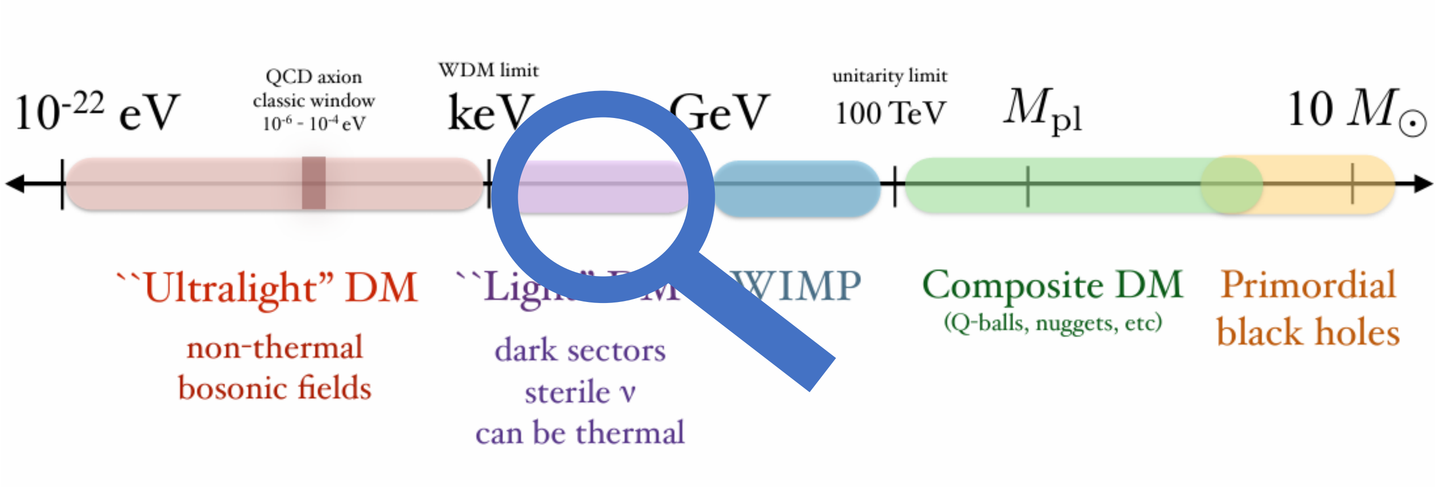


Lin, TASI lectures 2019

Evidence of Dark Matter

Since the 30s [Zwicky 1933] overwhelming evidence for Dark Matter on all scales: galactic rotation curves, galaxy clusters, CMB and large-scale structure

Somewhere in this mass range:

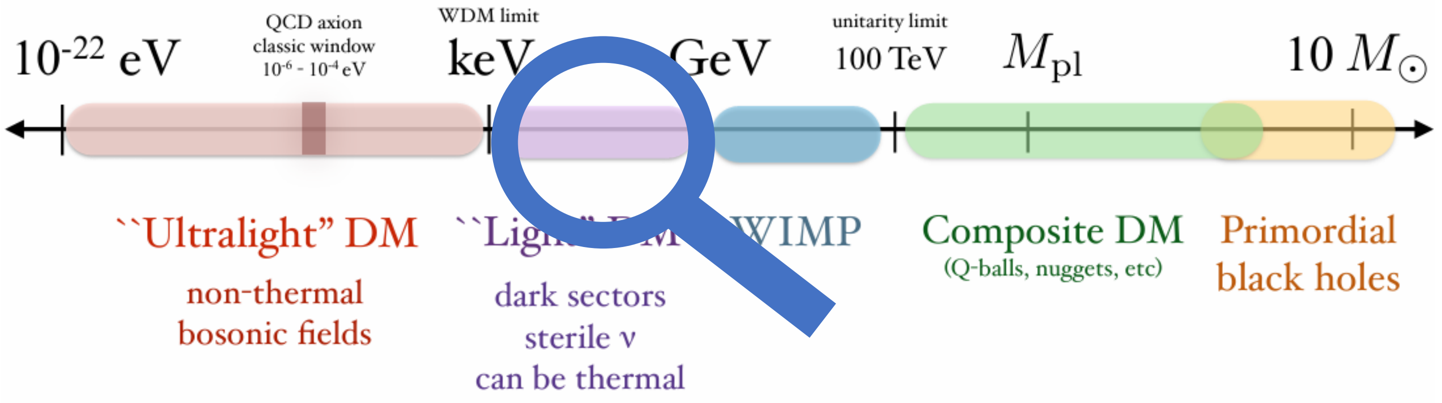


Lin, TASI lectures 2019

Evidence of Dark Matter

Since the 30s [Zwicky 1933] overwhelming evidence for Dark Matter on all scales: galactic rotation curves, galaxy clusters, CMB and large-scale structure

Somewhere in this mass range:



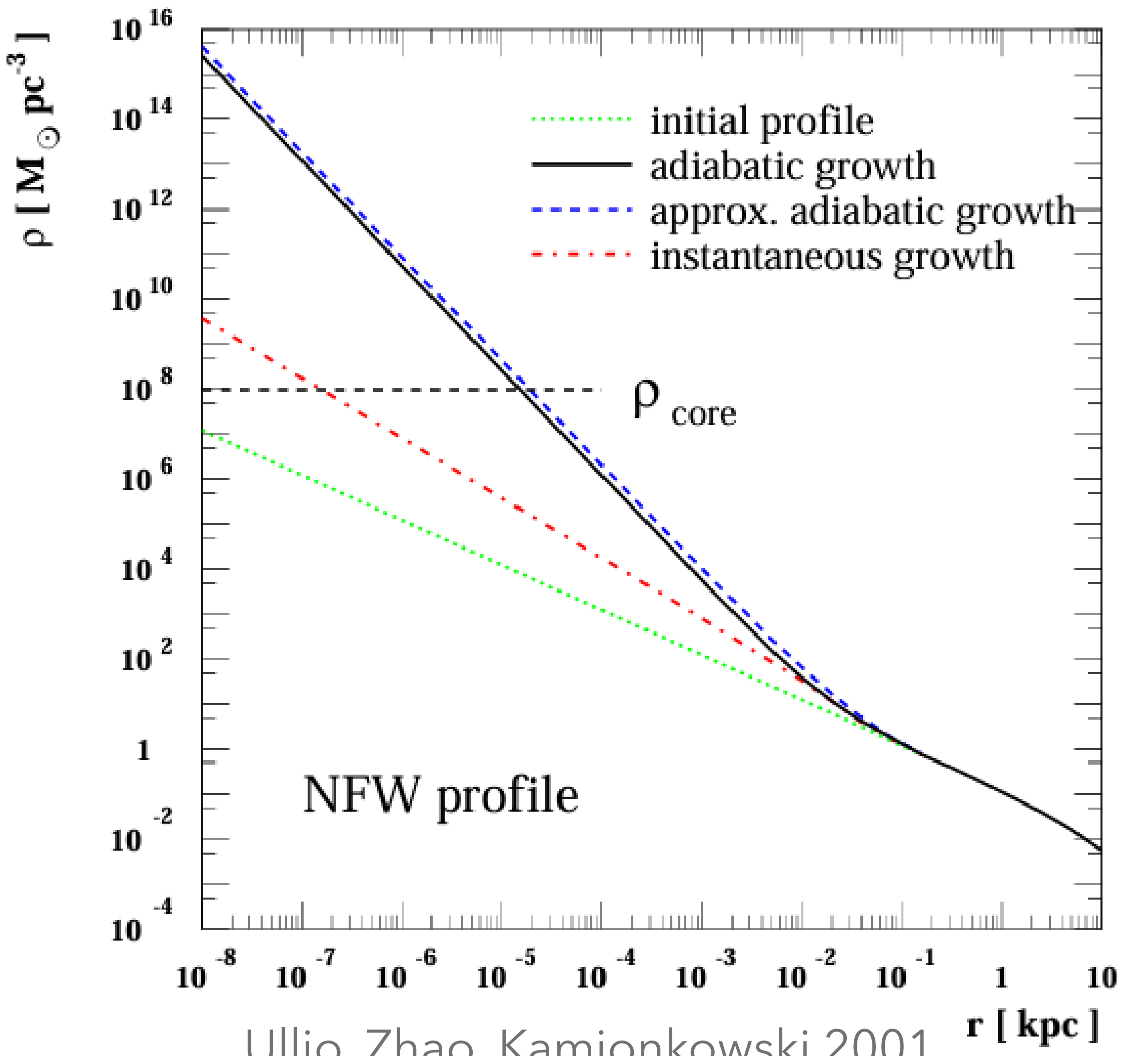
Lin, TASI lectures 2019

Toy model:

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

The Gondolo & Silk spike

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

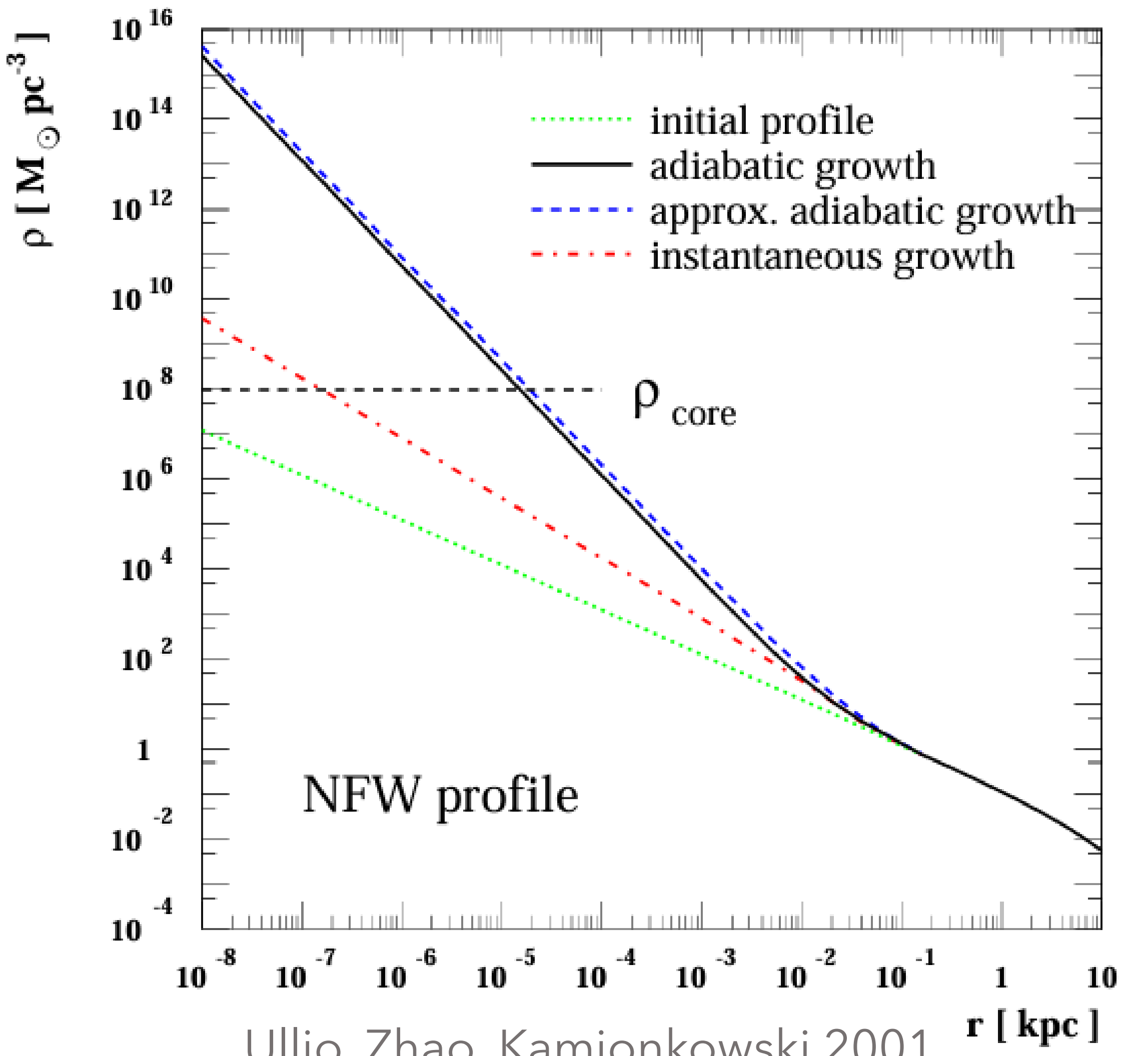


Ullio, Zhao, Kamionkowski 2001

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]



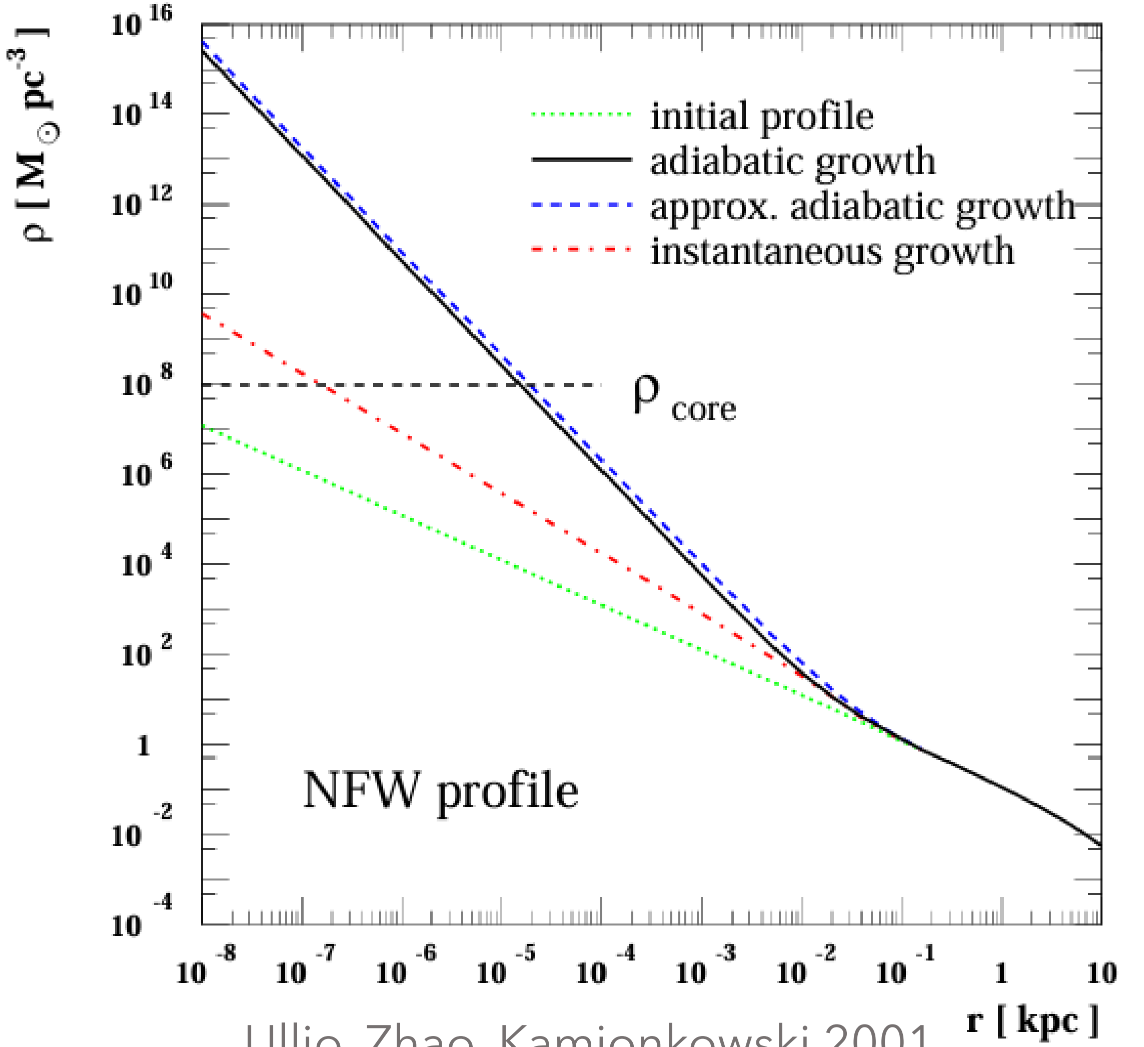
Ullio, Zhao, Kamionkowski 2001

The Gondolo & Silk spike

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

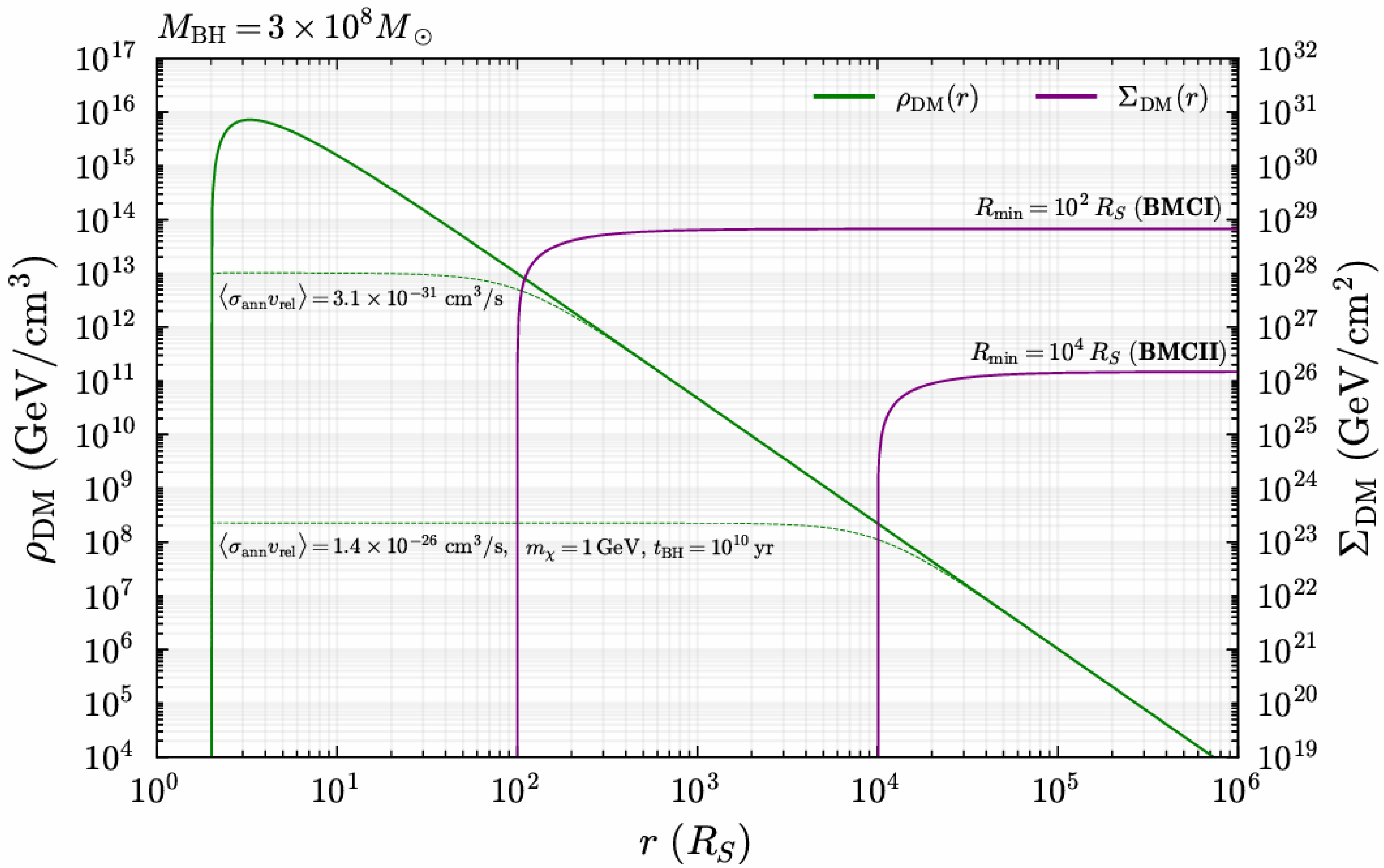
As SMBH grows, it contracts orbit around it, turns $r^{-\gamma}$ into $r^{-(9-2\gamma)/(4-\gamma)}$ [Gondolo, Silk 1999]

Many real world effects can change this, hard to model



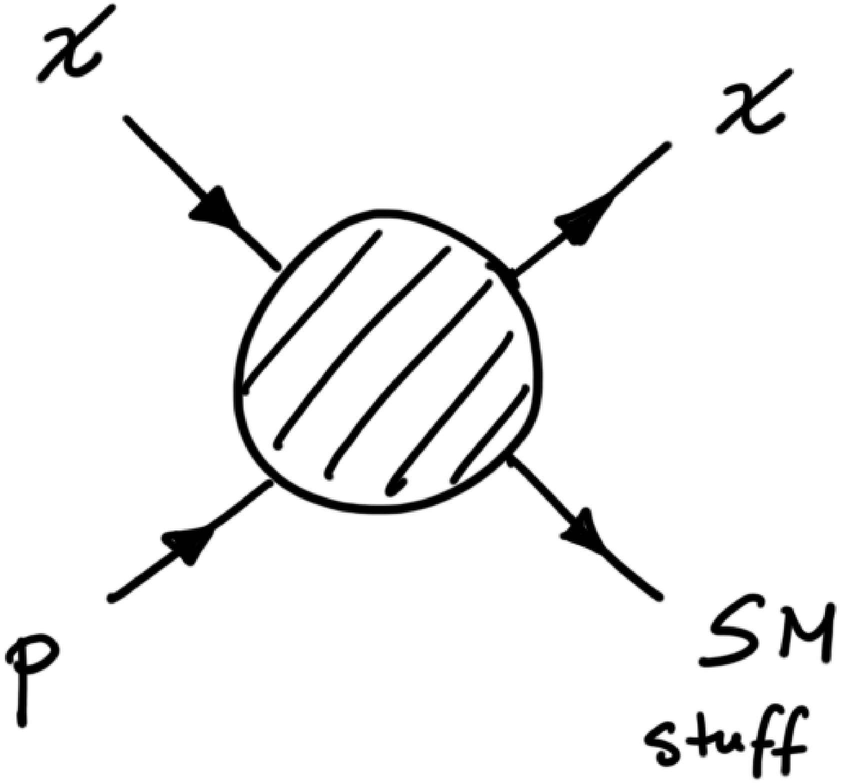
Ullio, Zhao, Kamionkowski 2001

Our benchmarks



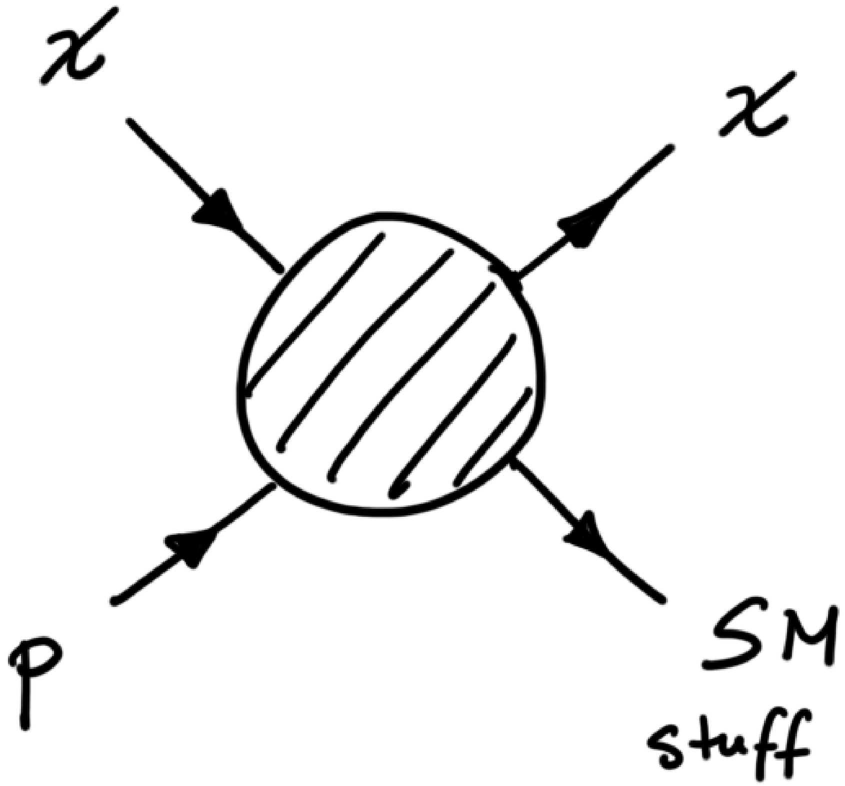
Multi-messenger signals

We now compute the $p - \mathrm{DM}$ scattering. We can look at complementary direct and indirect signals:



Multi-messenger signals

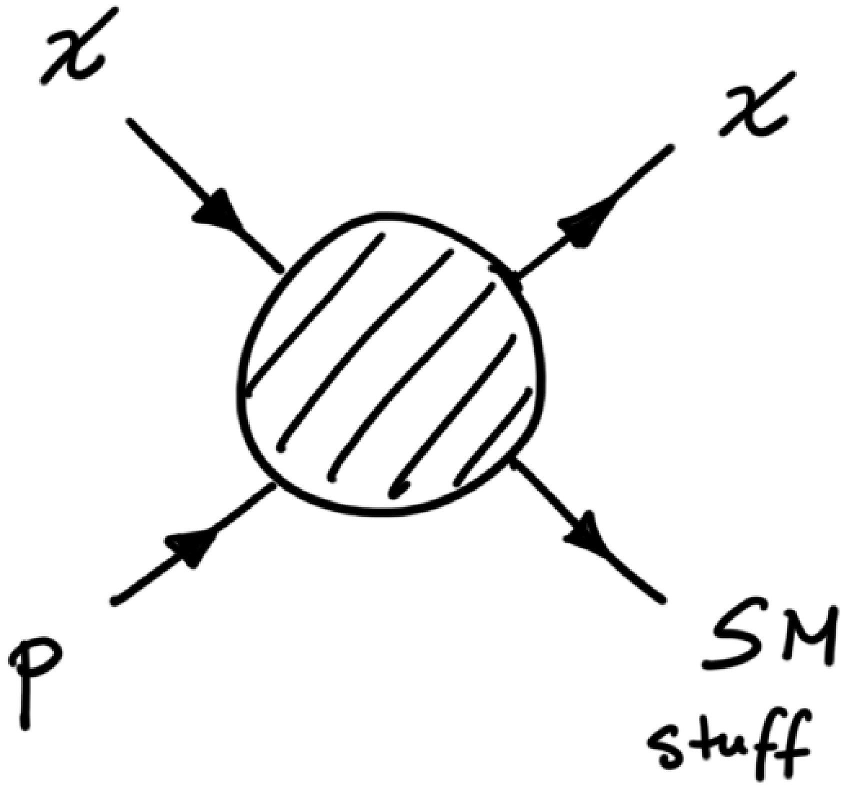
We now compute the $p - \mathrm{DM}$ scattering. We can look at complementary direct and indirect signals:



Blazar-boosted Dark Matter

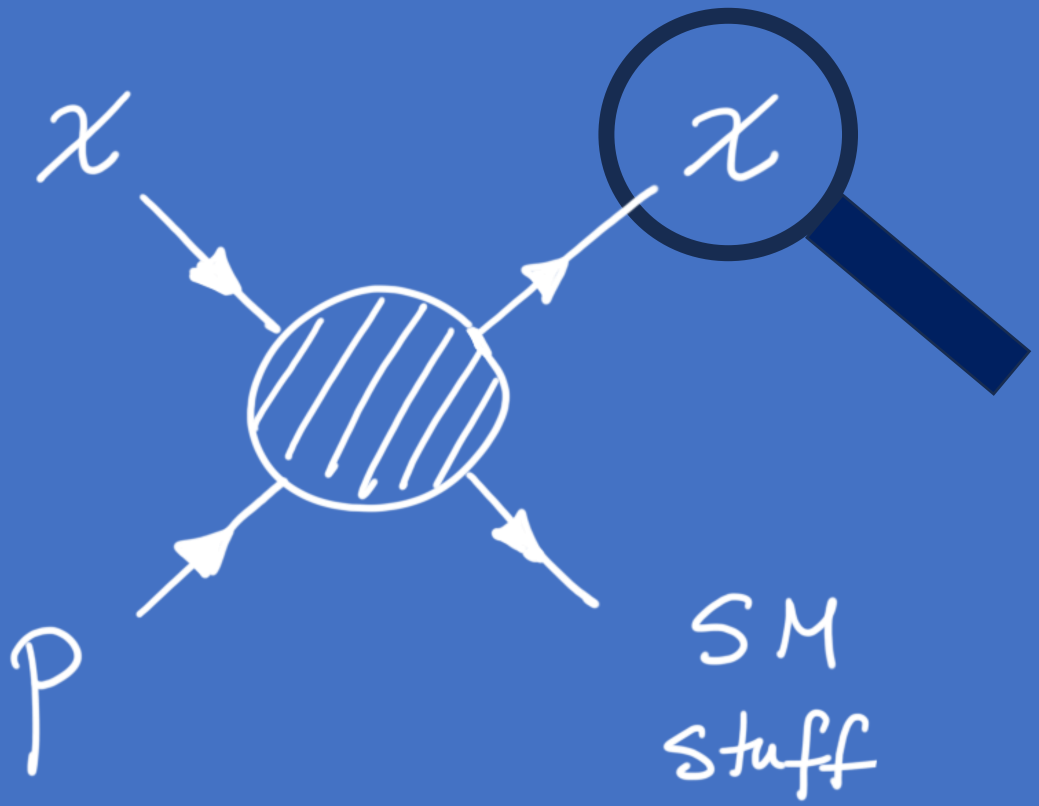
Multi-messenger signals

We now compute the $p - \mathrm{DM}$ scattering. We can look at complementary direct and indirect signals:



Blazar-boosted Dark Matter

ν, γ



III

Blazar-boosted Dark Matter

Overcoming detector threshold

Sub-GeV DM hard to see because recoil is below threshold

Overcoming detector threshold

Sub-GeV DM hard to see because recoil is below threshold

If boosted to high energies, that’s not a problem anymore!
Detectable at large volume neutrino detectors

Overcoming detector threshold

Sub-GeV DM hard to see because recoil is below threshold

If boosted to high energies, that's not a problem anymore!
Detectable at large volume neutrino detectors

We can compute the flux as

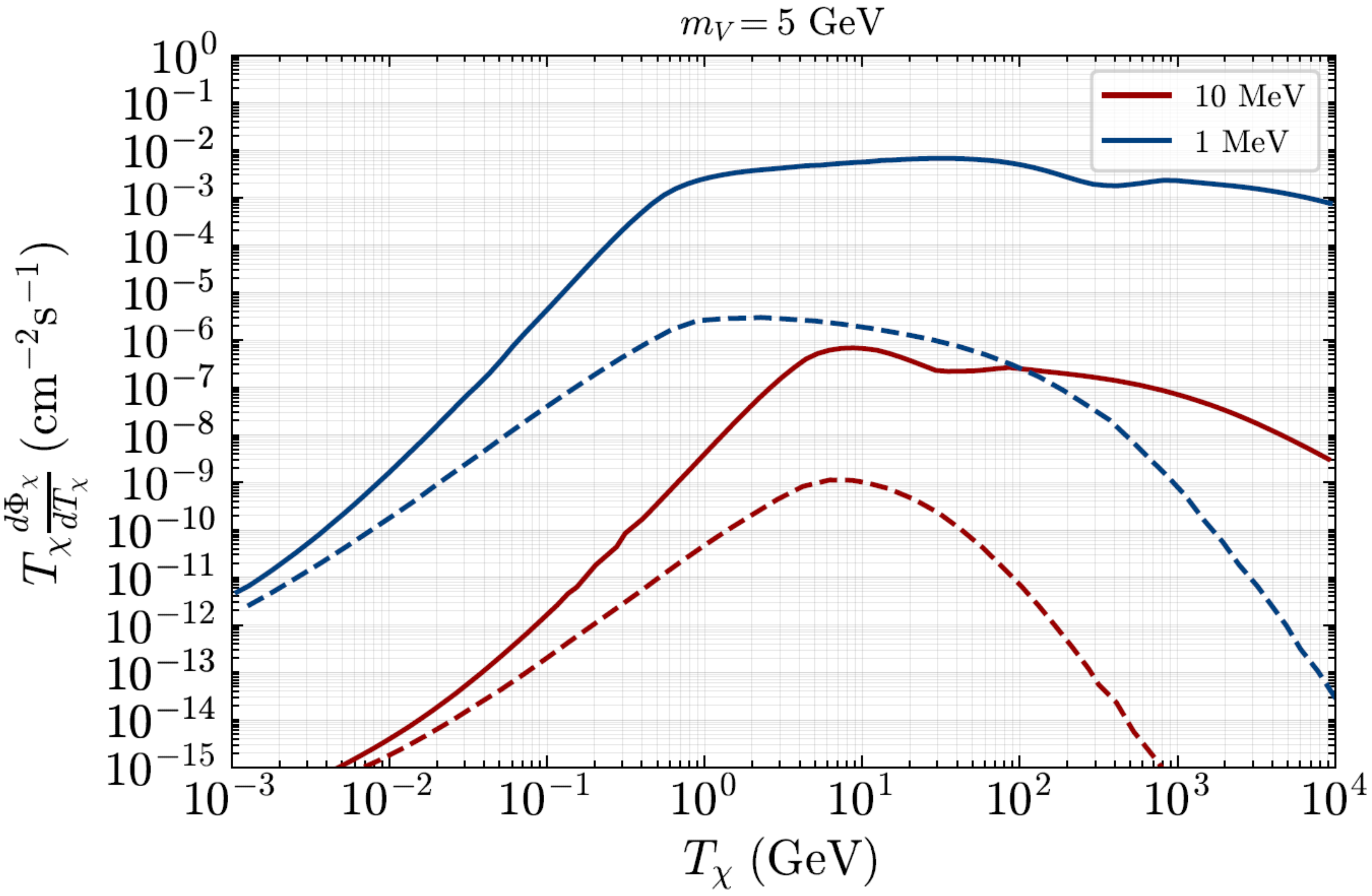
$$\frac{d\Phi_\chi}{dE_\chi} = \frac{\Sigma_{\mathrm{los}}}{m_\chi d_L^2} \int dE_p \frac{d\Gamma}{dE_p d\Omega} \frac{d\sigma}{dE_\chi}$$

Spike model

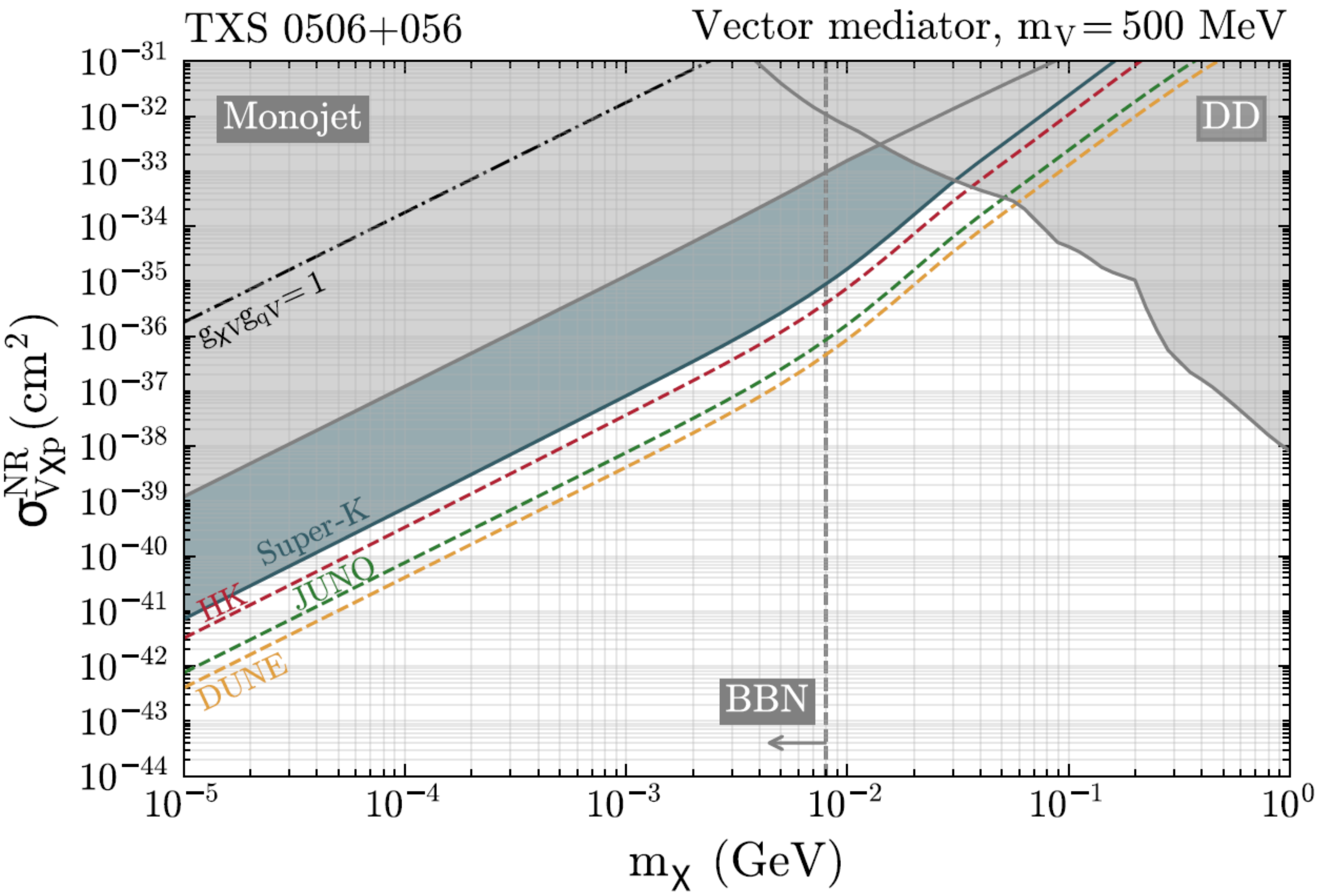
Jet model

Particle physics model

Boosted DM flux



Constraints



IV

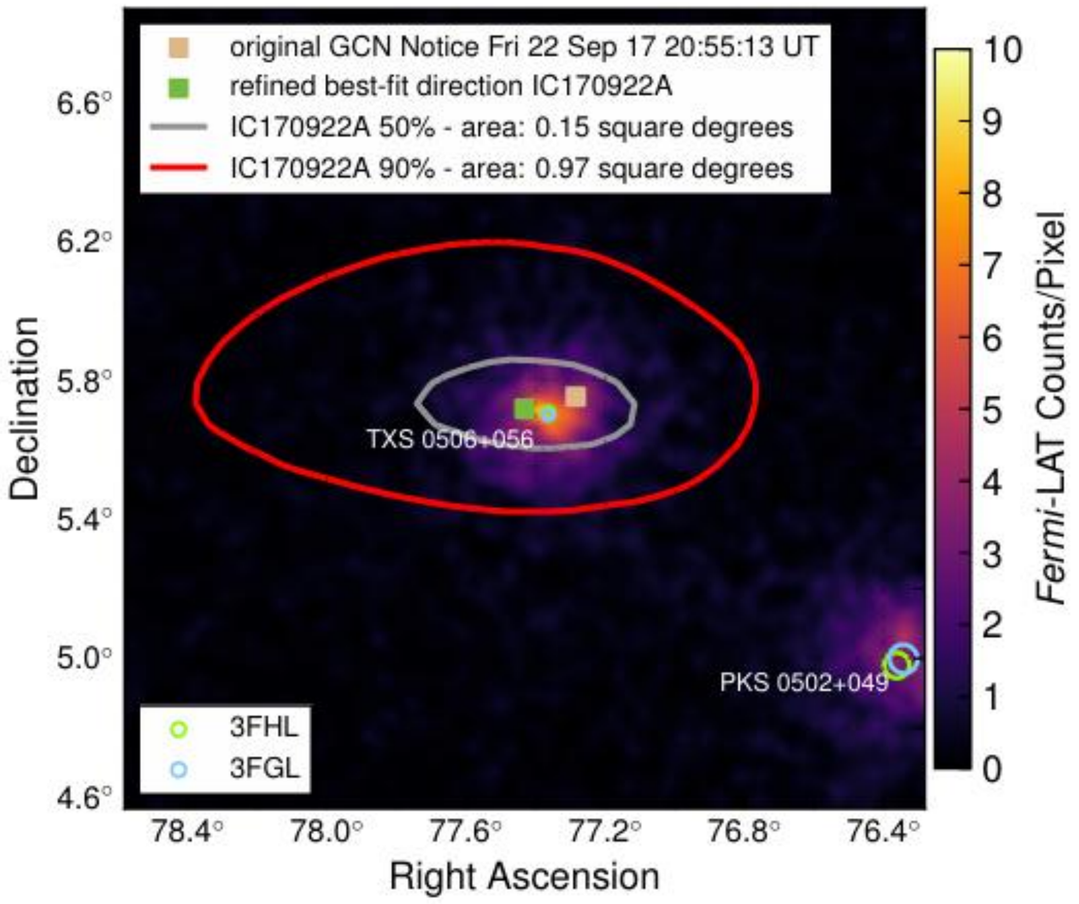
Neutrinos from blazars

Neutrinos from blazars

2017: IceCube detects ~ 300 TeV ν

First associated to astro source: blazar TXS 0506+056, while Fermi-LAT sees flare

(A)



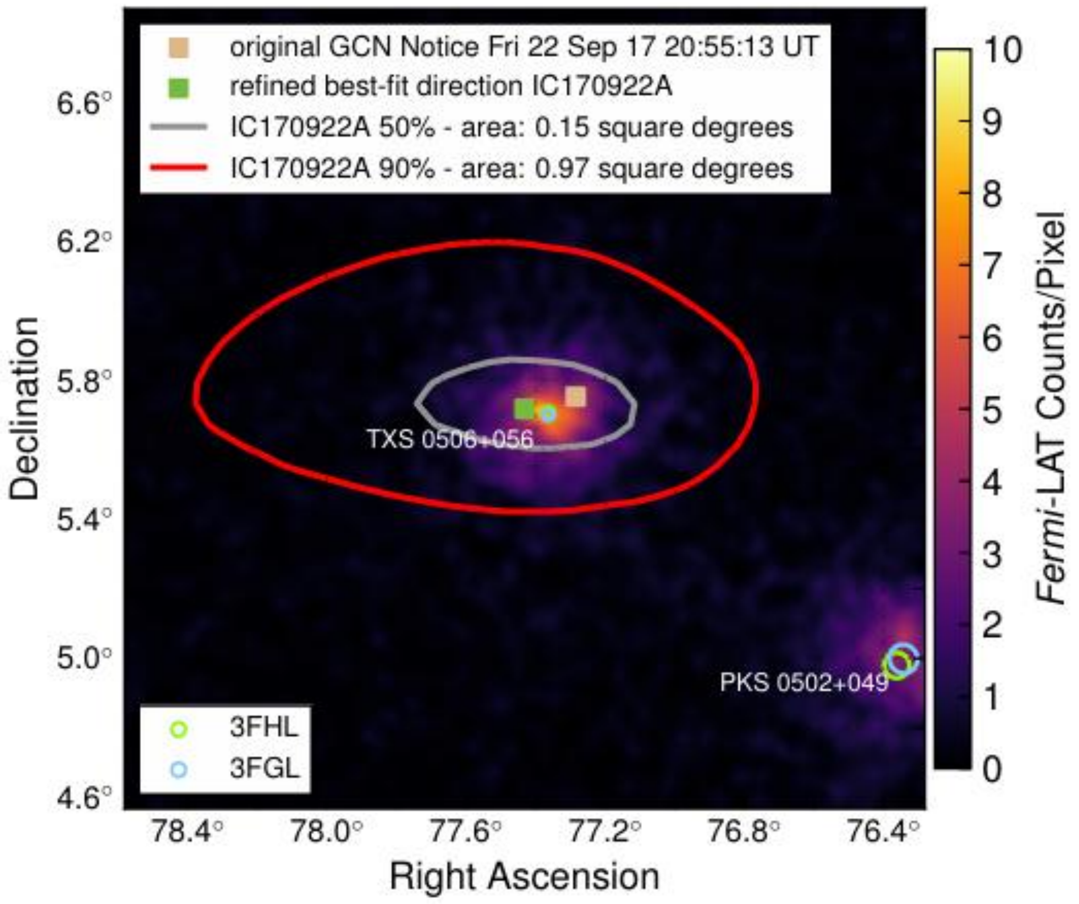
Neutrinos from blazars

2017: IceCube detects ~ 300 TeV ν

First associated to astro source: blazar TXS 0506+056, while Fermi-LAT sees flare

Archive data: 13±5 neutrinos in 2014/15 from same source, but no flare

(A)



Neutrinos from blazars

2017: IceCube detects ~ 300 TeV ν

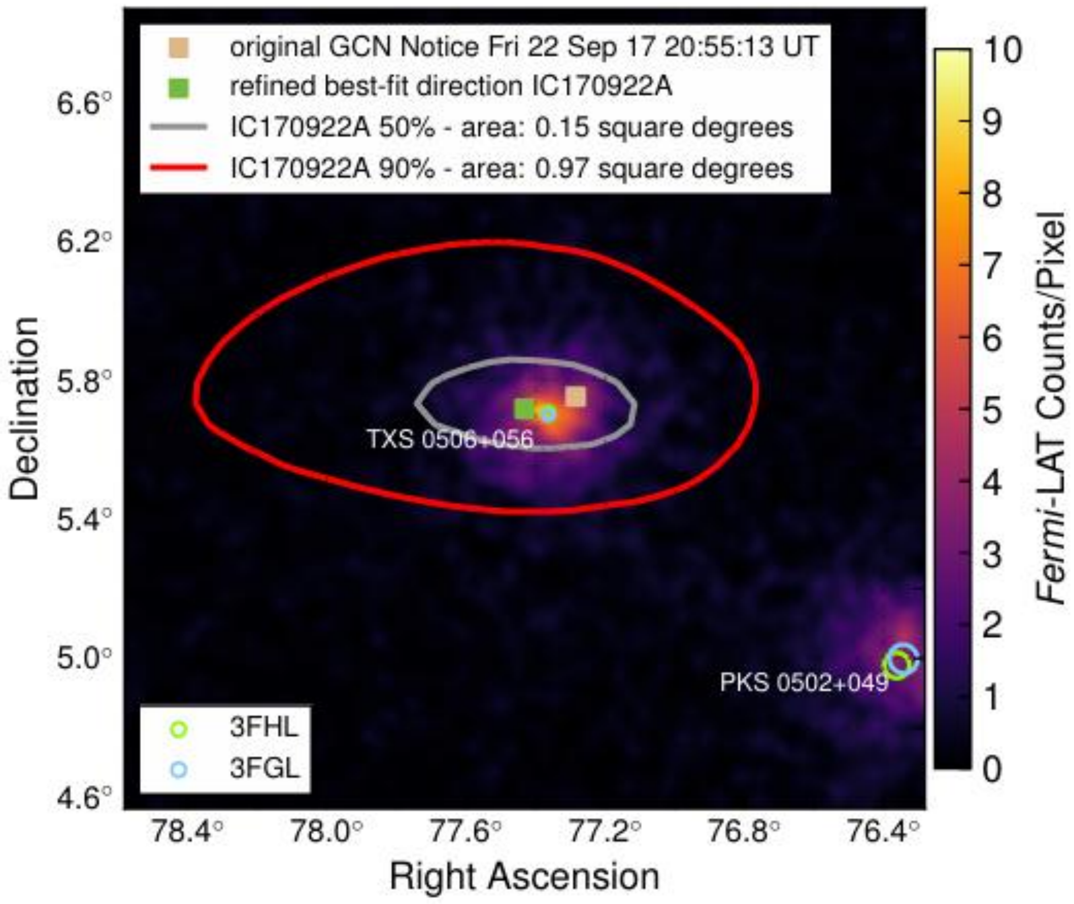
First associated to astro source: blazar TXS 0506+056, while Fermi-LAT sees flare

Archive data: 13±5 neutrinos in 2014/15 from same source, but no flare

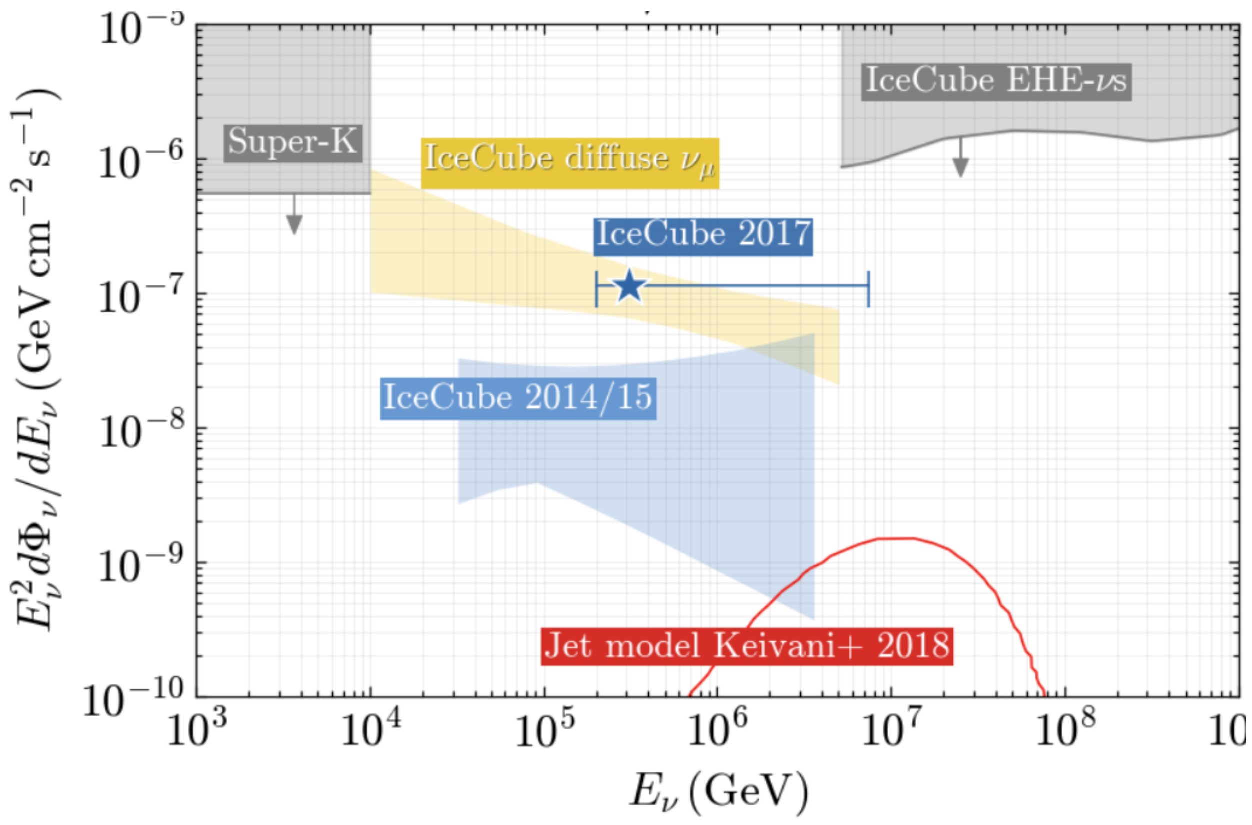
Many others blazar associations (not as significant)

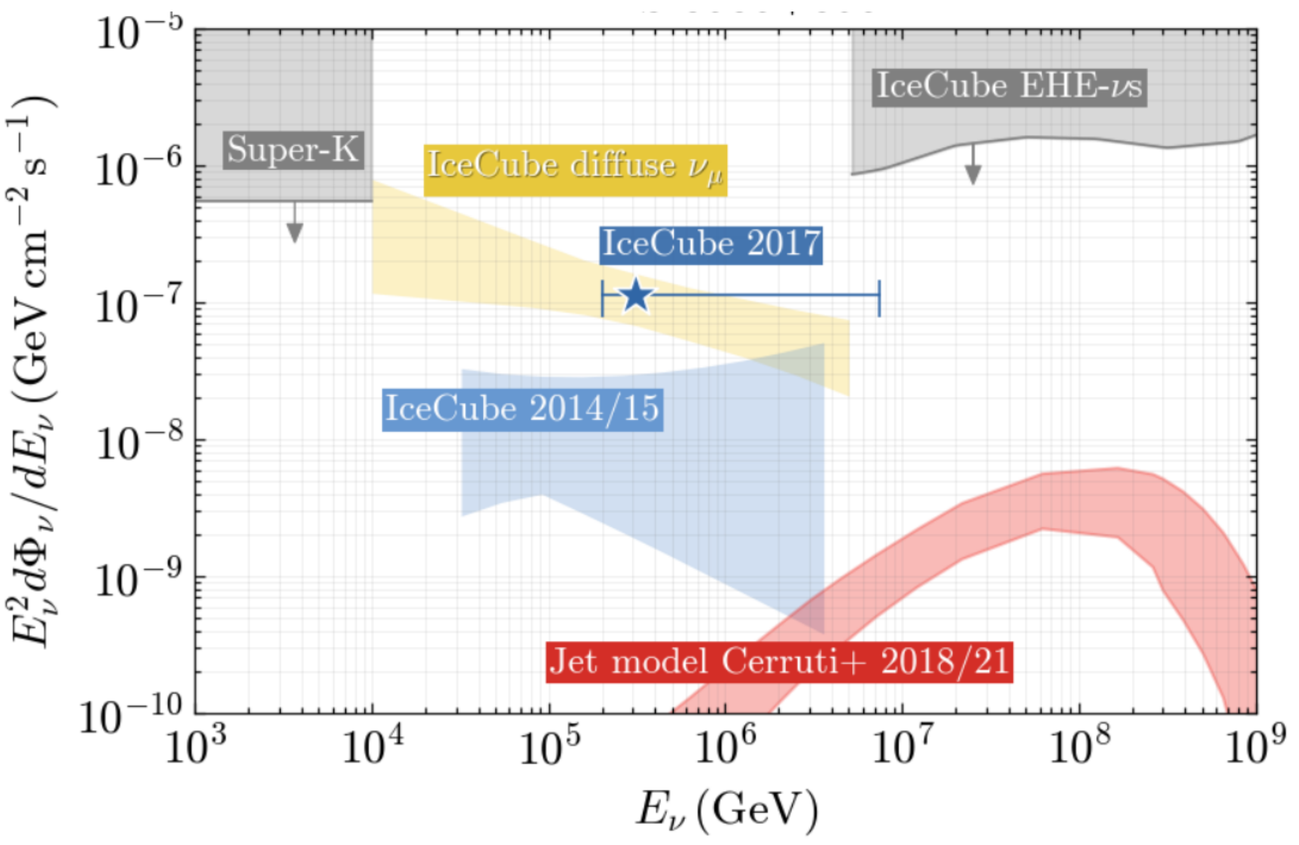
Blazars are HE neutrino sources!

(A)

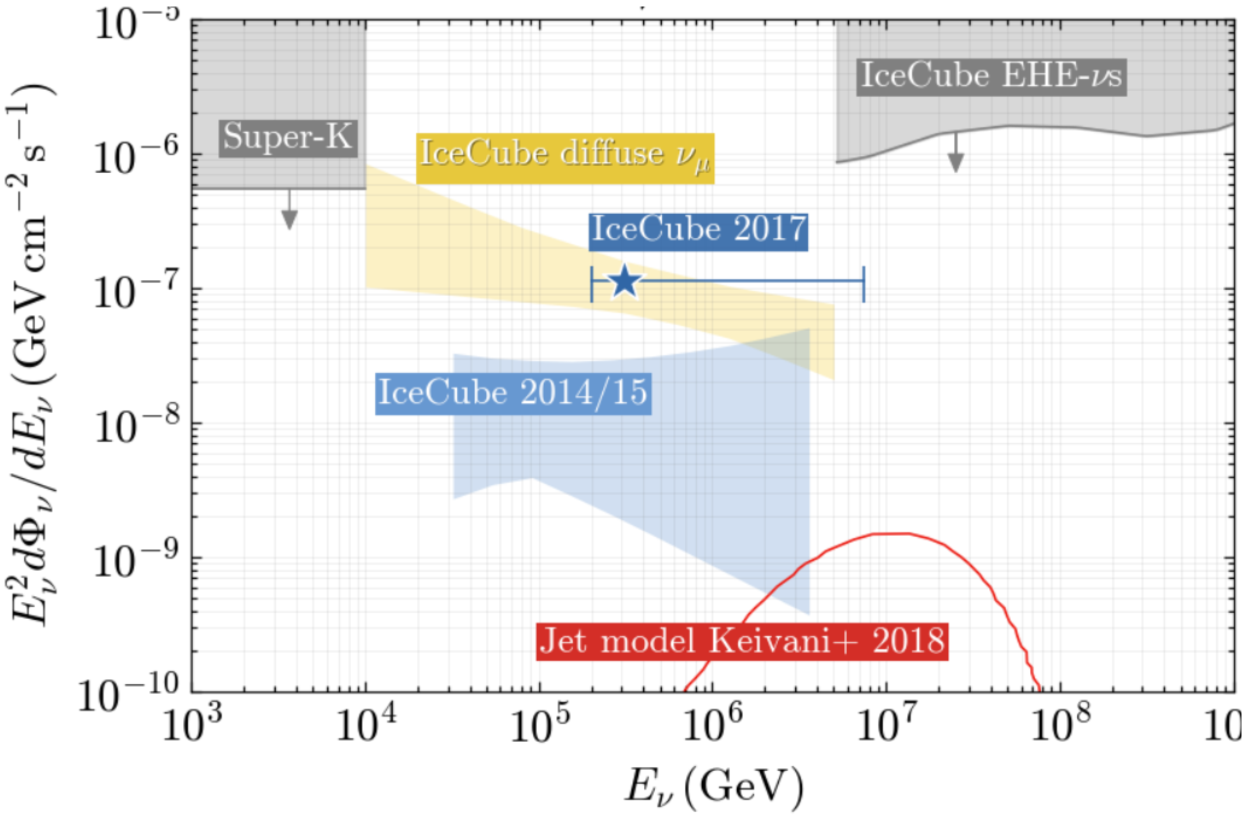


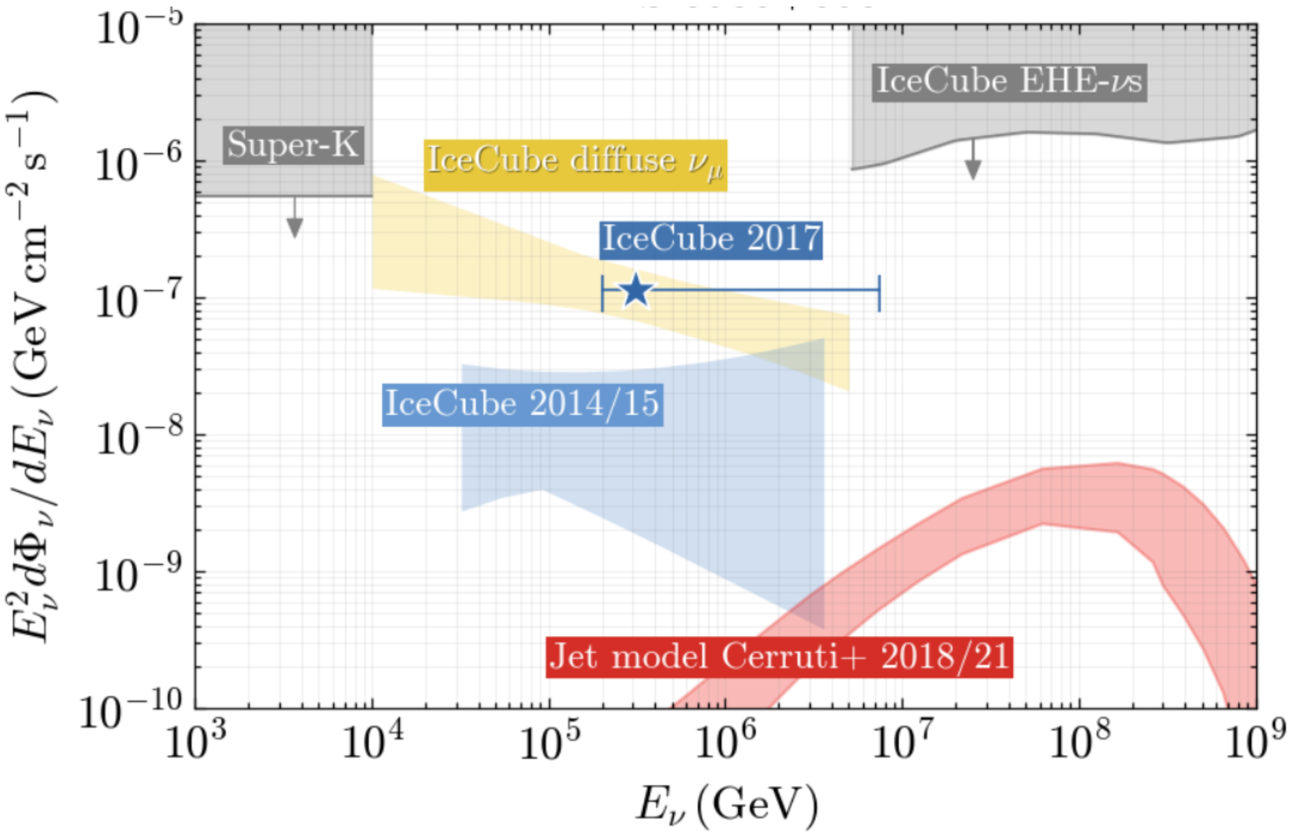
Standard picture undershoots it





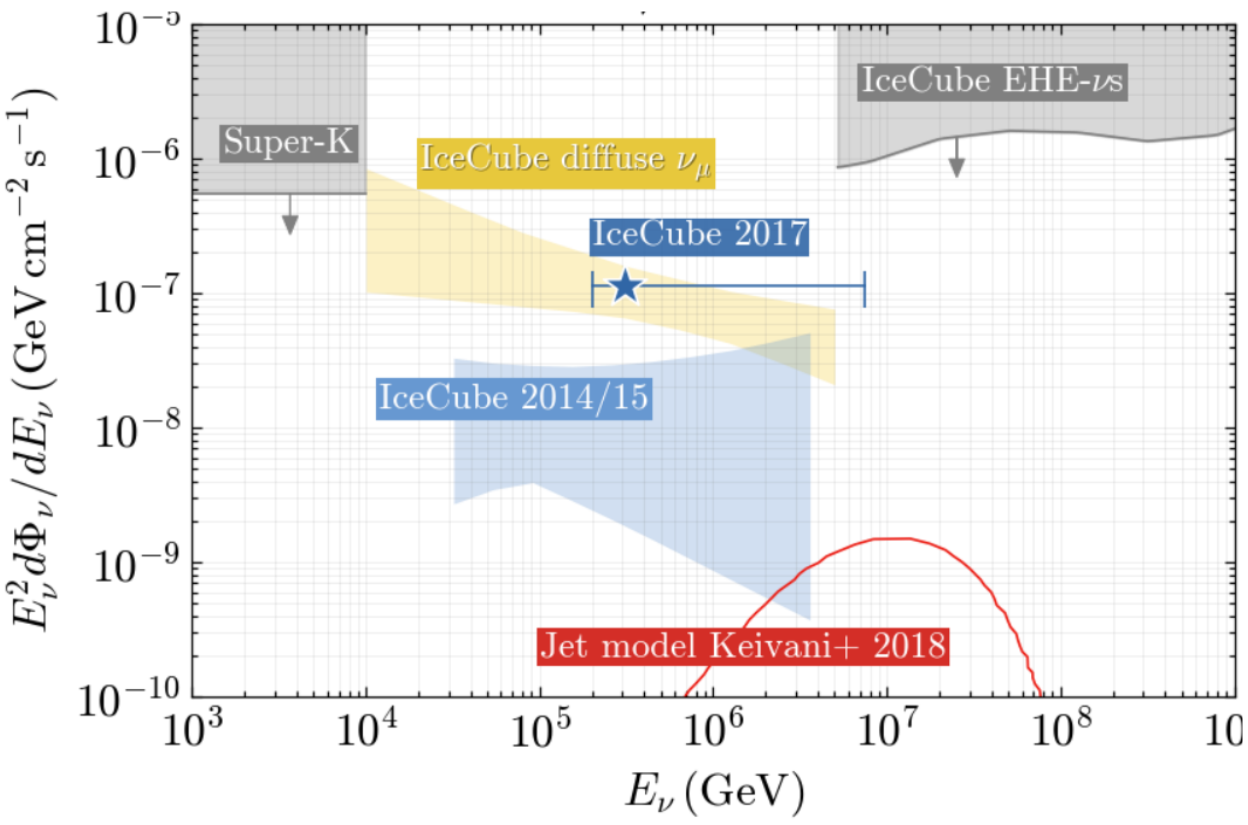
Standard picture undershoots it

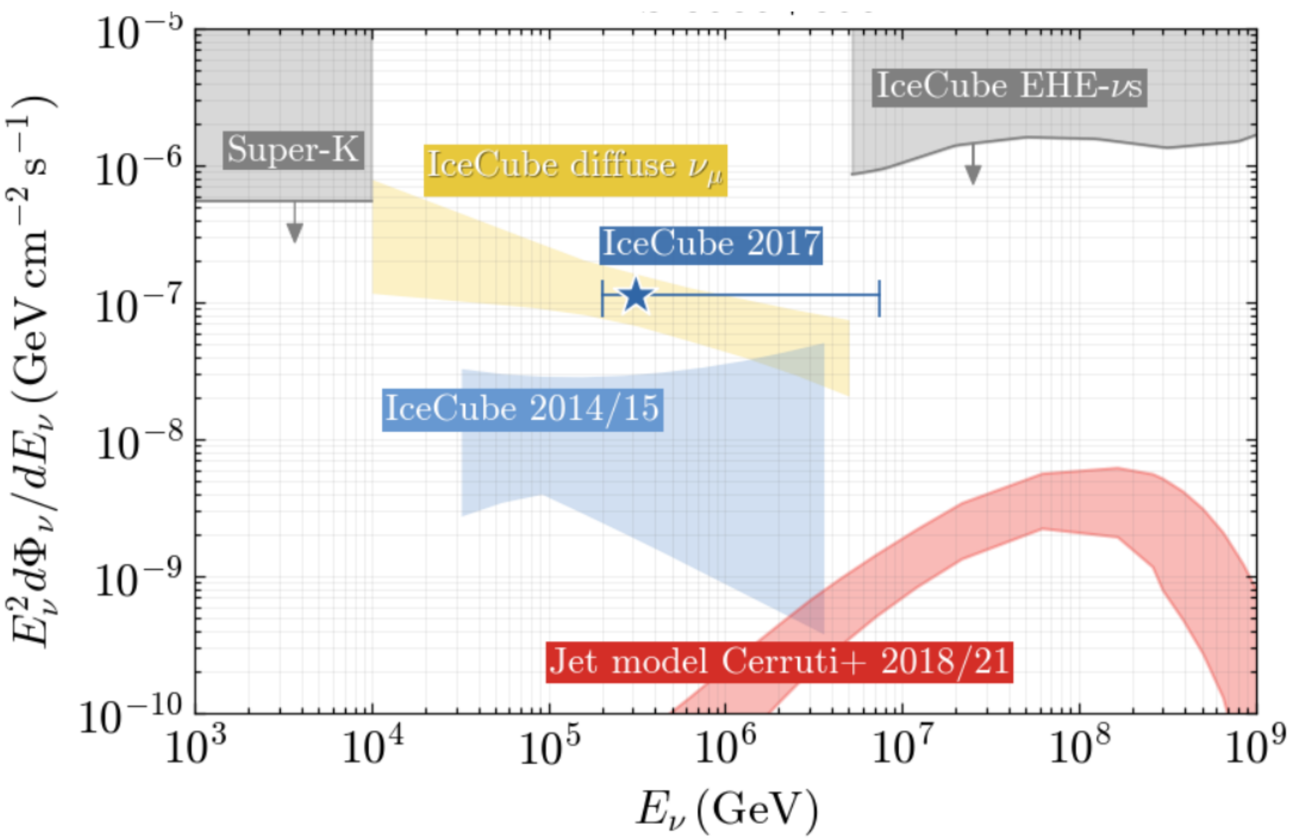




- Many ideas (BH corona, extended jet, jet-obstacle models…)

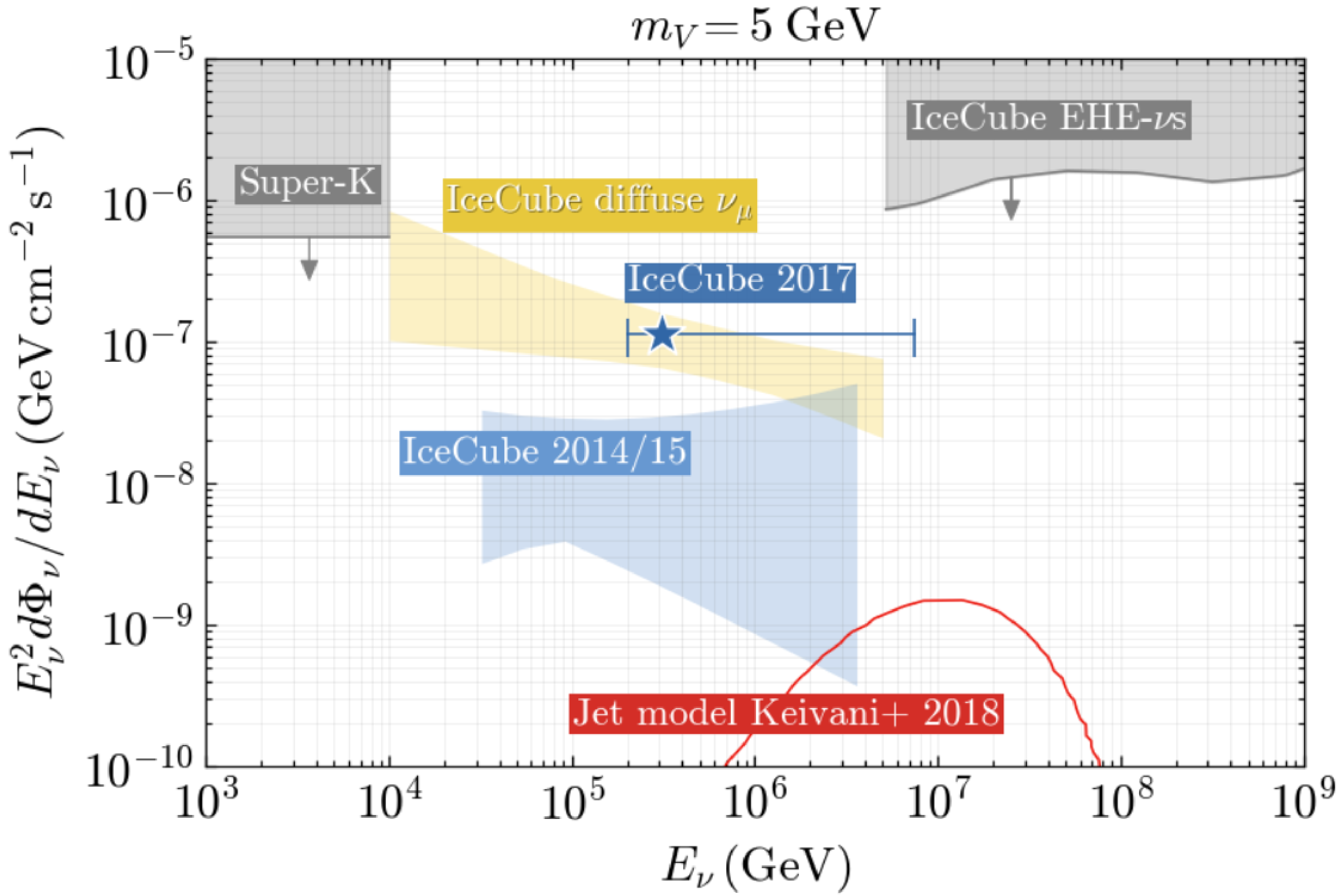
Standard picture undershoots it





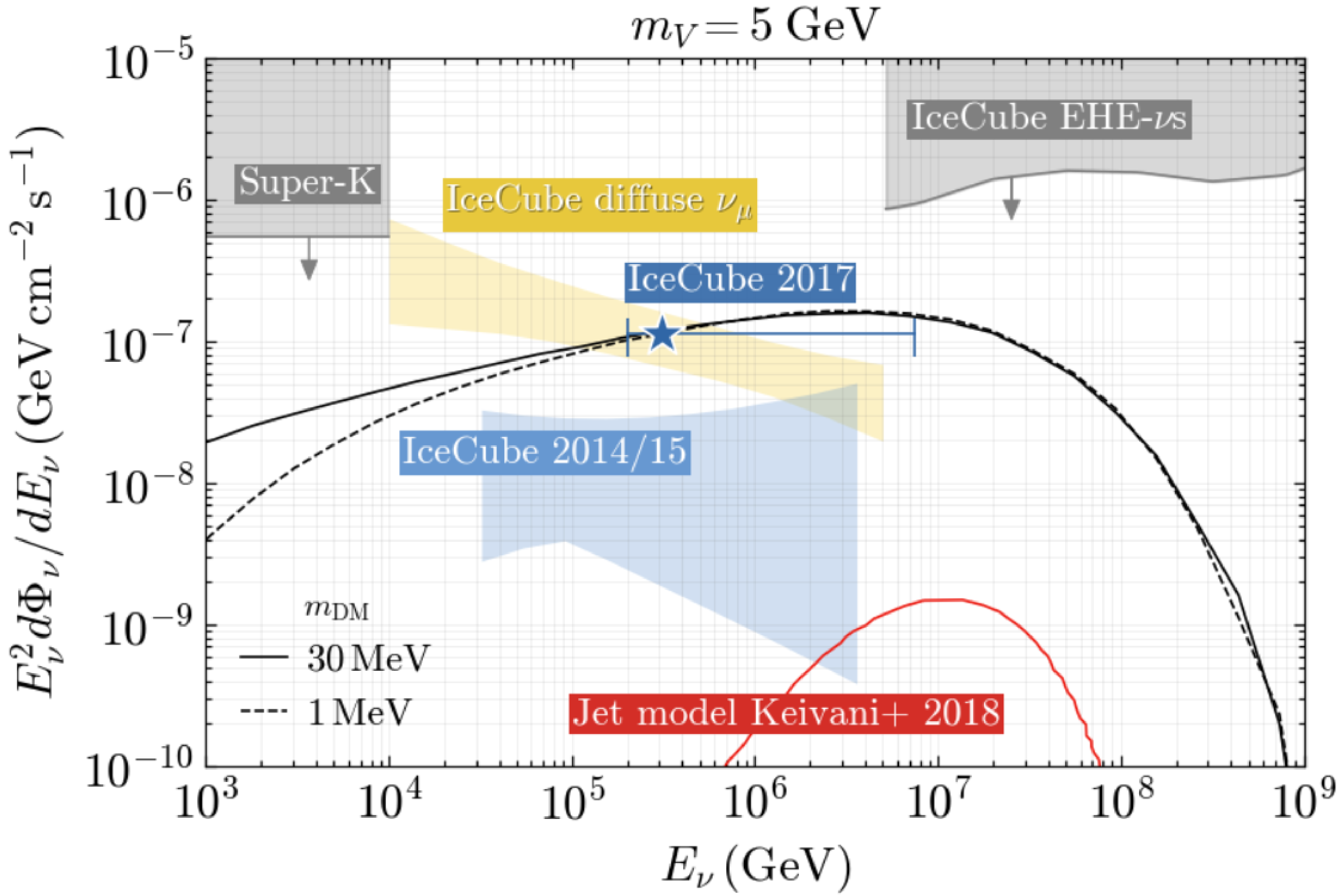
- Many ideas (BH corona, extended jet, jet-obstacle models…)
- What about $p - \mathrm{DM}$ scatterings?

What we get



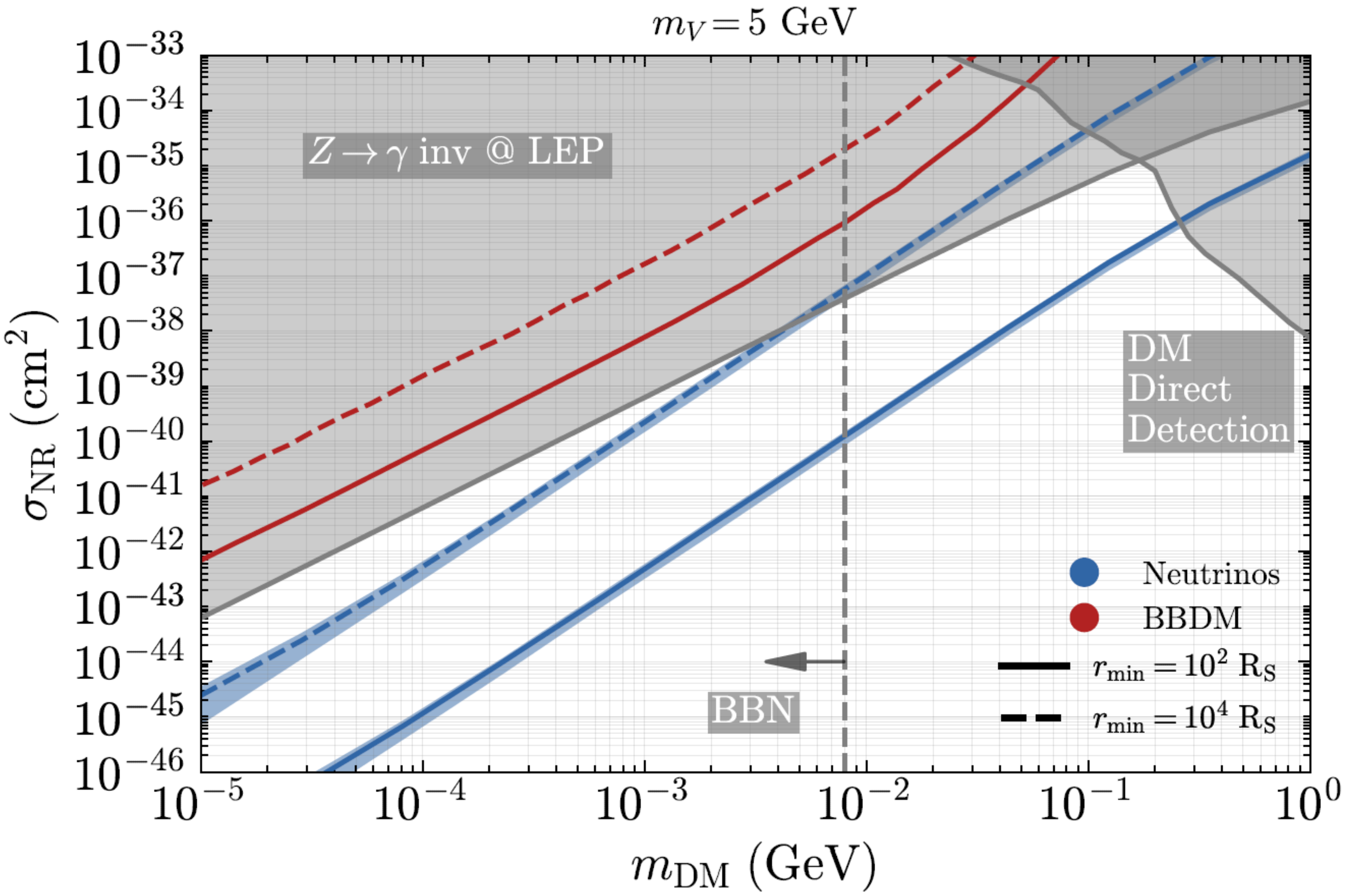
$m_V = 5$ GeV
IceCube EHE-νs
Super-K
IceCube diffuse ν_μ
IceCube 2017
IceCube 2014/15
Jet model Keivani+ 2018
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
$E_\nu^2 d\Phi_\nu/dE_\nu\,(\mathrm{GeV\,cm^{-2}\,s^{-1}})$
10^3 10^4 10^5 10^6 10^7 10^8 10^9
$E_\nu\,(\mathrm{GeV})$

What we get



$m_V = 5$ GeV
$E_\nu^2 d\Phi_\nu/dE_\nu\,(\mathrm{GeV\,cm^{-2}\,s^{-1}})$
$E_\nu\,(\mathrm{GeV})$
Super-K
IceCube EHE-νs
IceCube diffuse ν_μ
IceCube 2017
IceCube 2014/15
Jet model Keivani+ 2018
m_{DM}
30 MeV
1 MeV
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

Parameter space



Andrea Giovanni De Marchi - University of Bologna

V

What about photons?

What about them?

When you produce neutrinos, you also produce γ-rays

What about them?

When you produce neutrinos, you also produce γ-rays

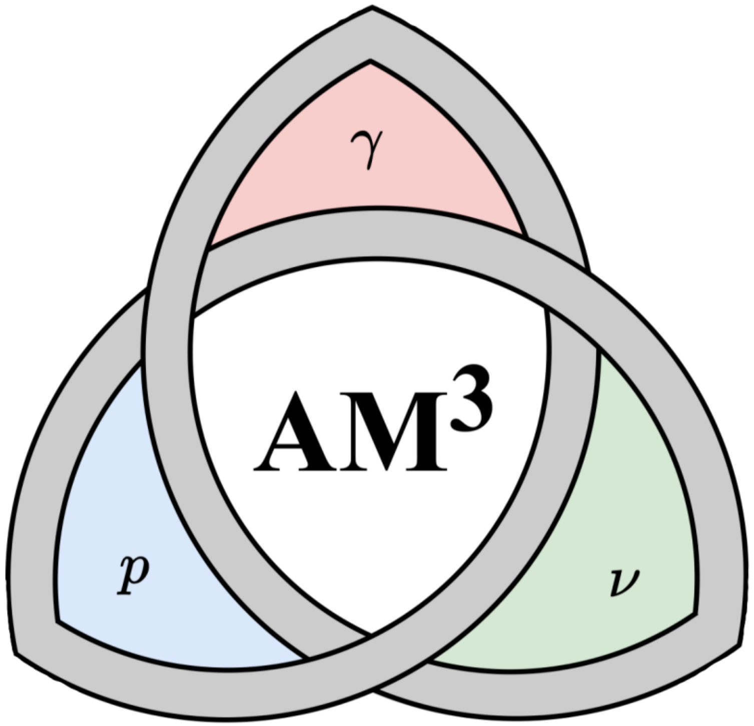
νs travel unperturbed, γs are much harder, they pair-produce and cascade down… needs numerical treatment

What about them?

When you produce neutrinos, you also produce γ-rays

νs travel unperturbed, γs are much harder, they pair-produce and cascade down… needs numerical treatment

We implemented $p-$DM processes into AM3 [Klinger+ 2024]



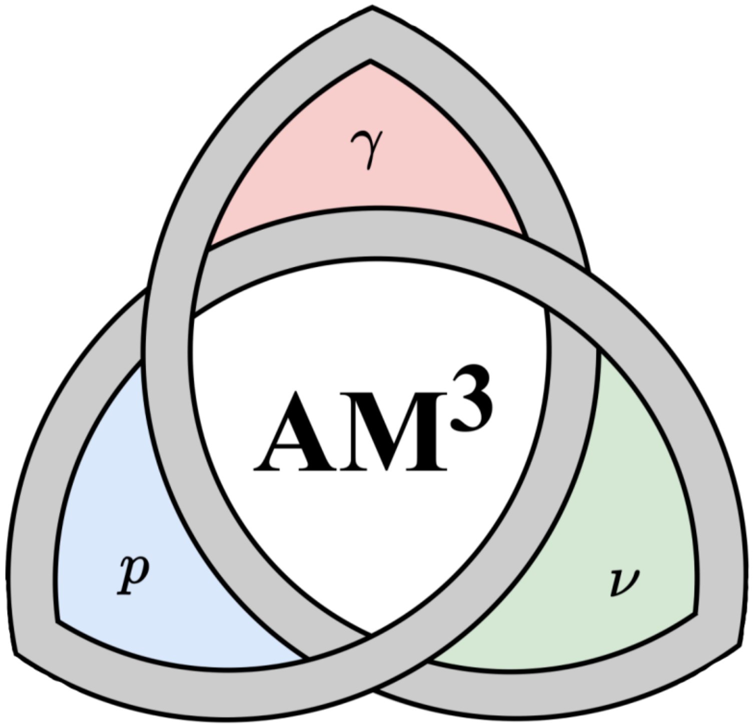
What about them?

When you produce neutrinos, you also produce γ-rays

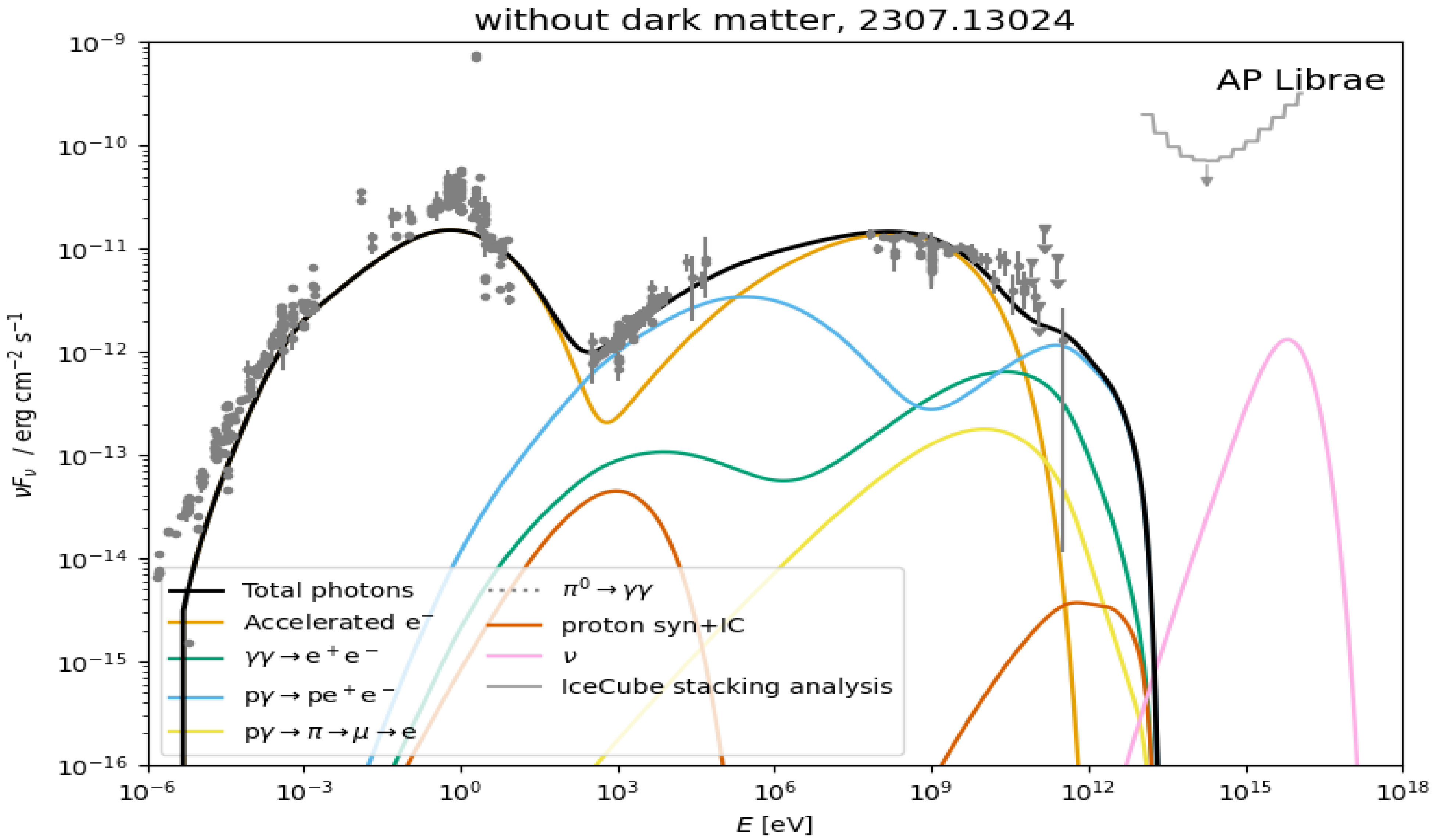
νs travel unperturbed, γs are much harder, they pair-produce and cascade down… needs numerical treatment

We implemented $p - \mathrm{DM}$ processes into AM3 [Klinger+ 2024]

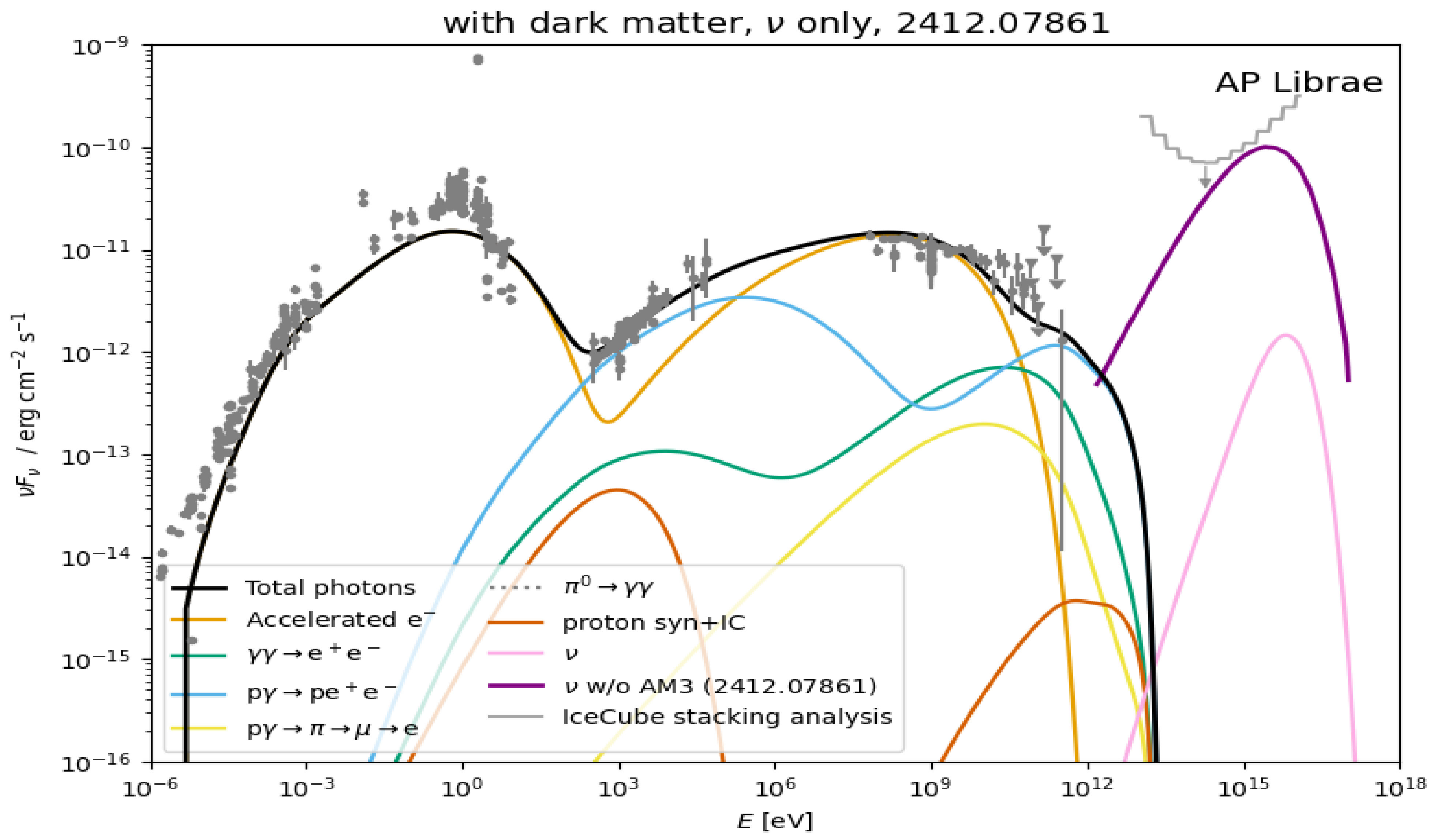
We chose the source AP Librae as a benchmark to test this (BL Lac, clean environment, bright and close)



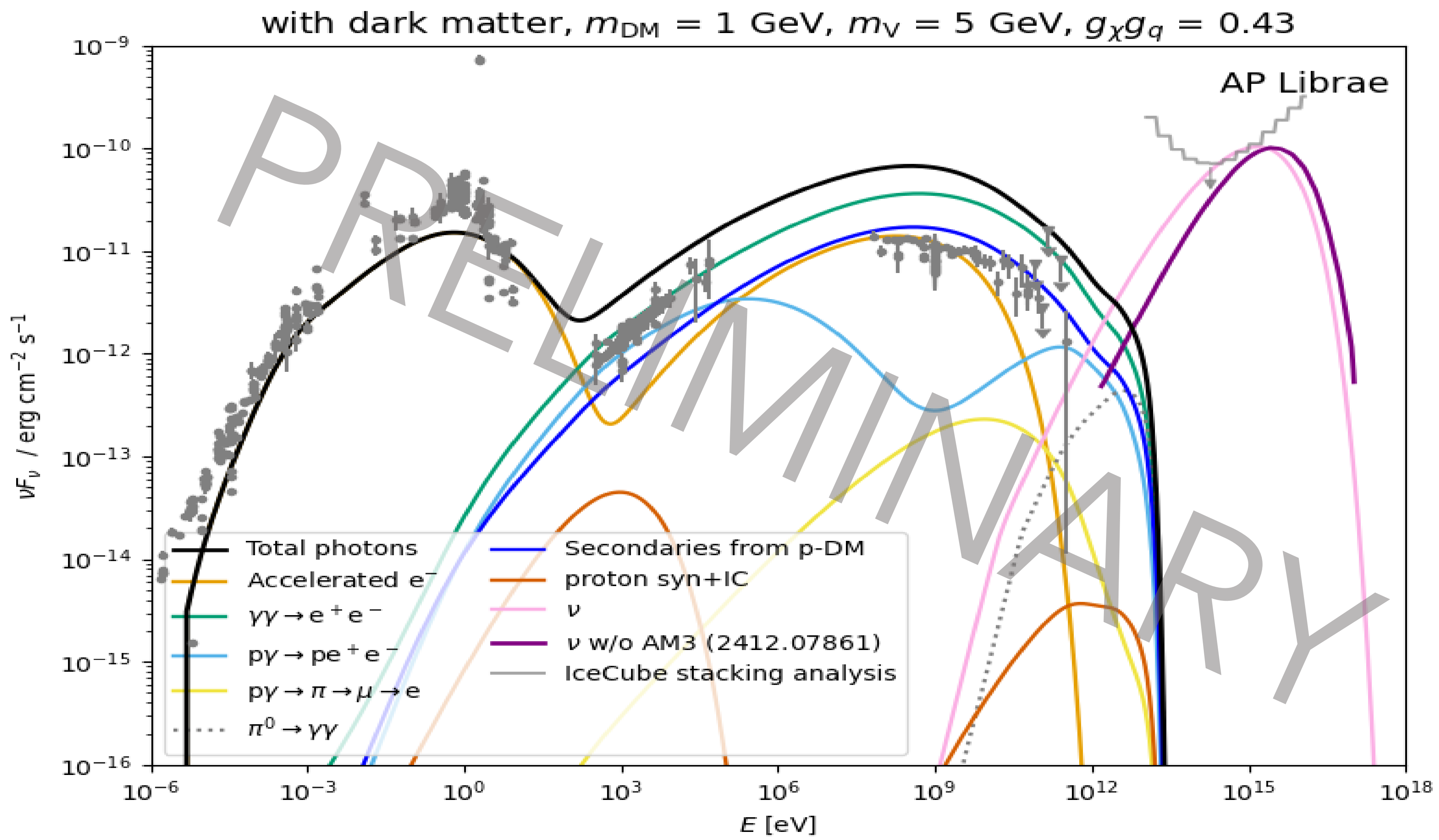
Standard leptohadronic fit



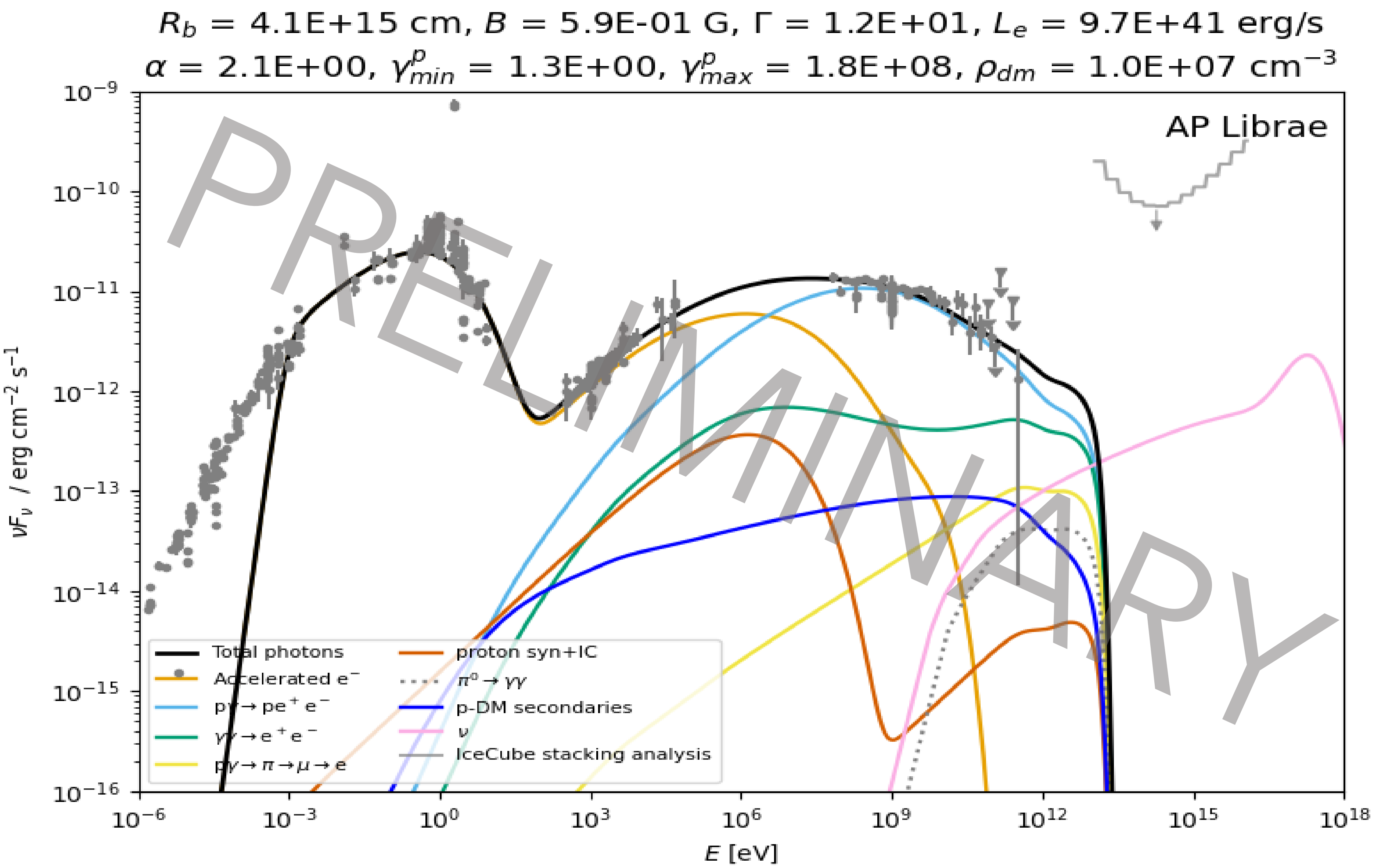
With dark matter, only neutrinos



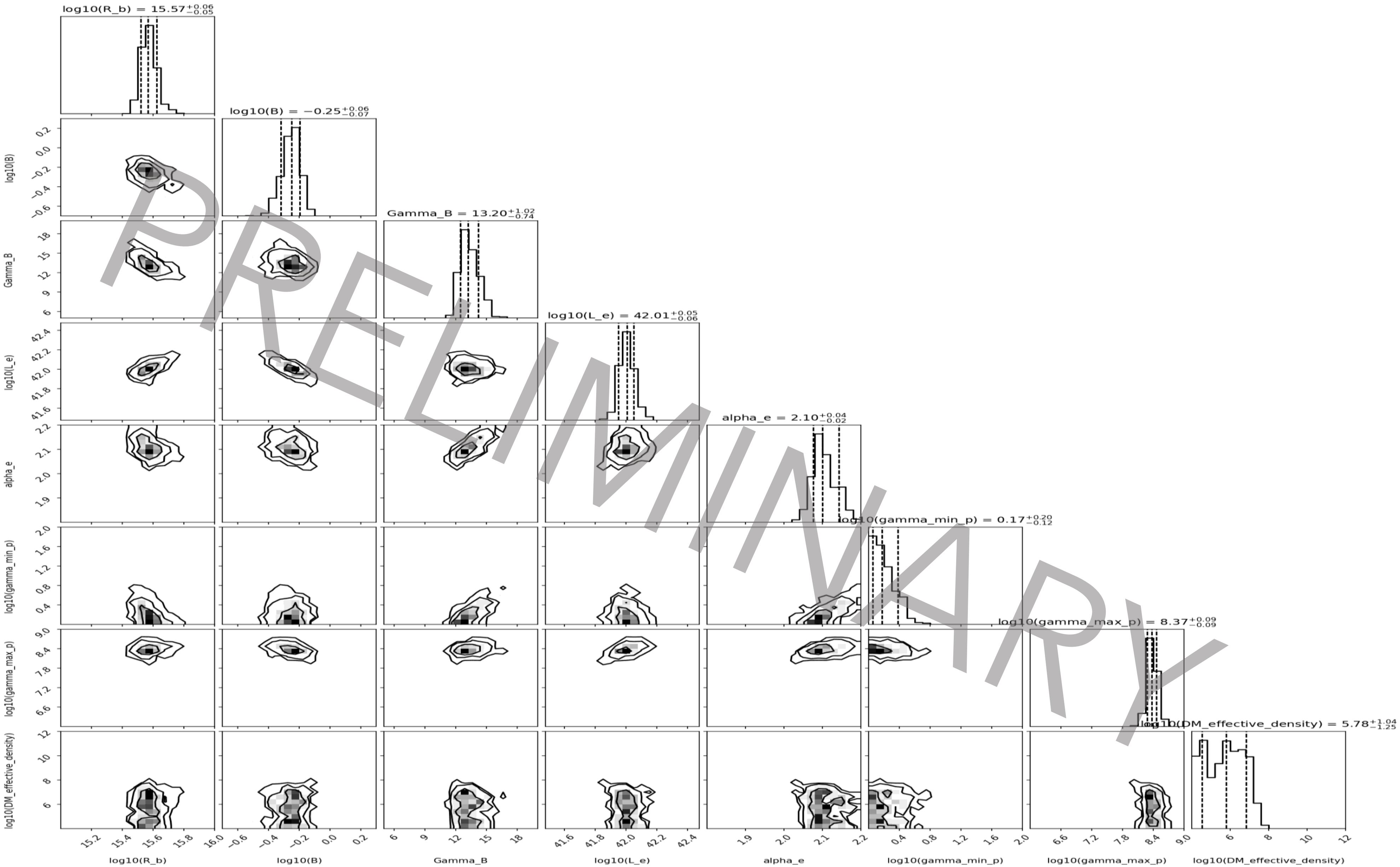
With dark matter, full



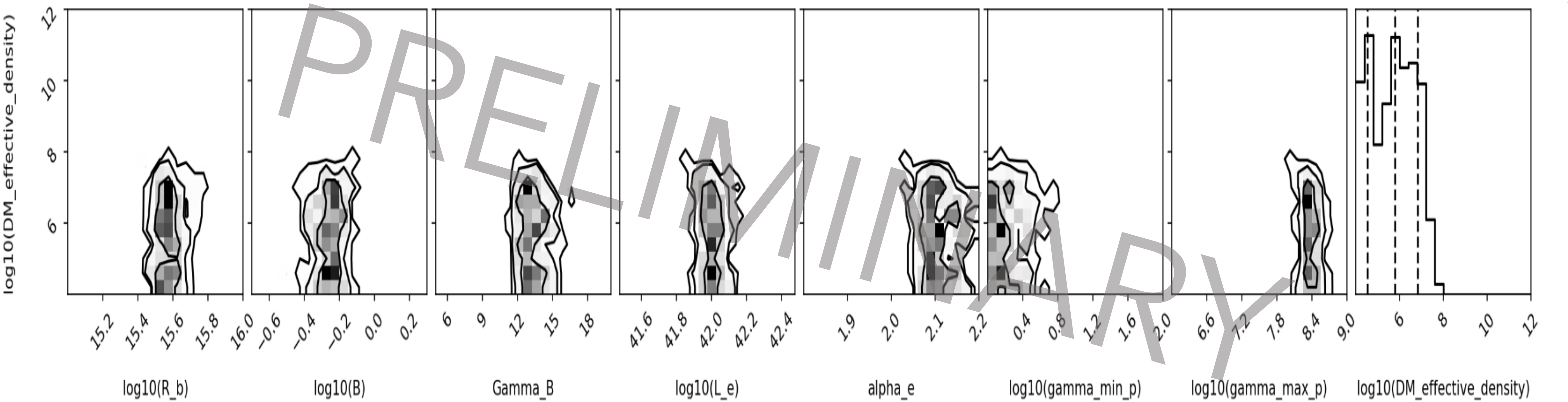
SSC + BH solution



SSC + BH solution



SSC + BH solution



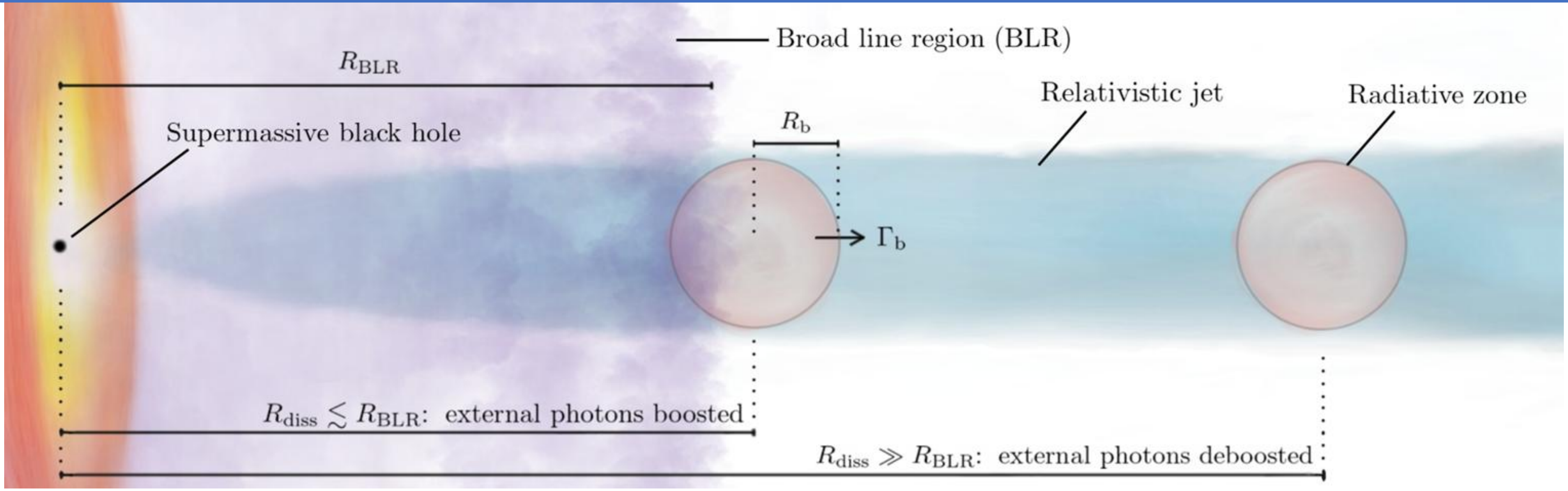
Summary and outlook

- We can probe very small $\sigma_{p\chi}$ with boosted dark matter
- We can probe smaller $\sigma_{p\chi}$ with neutrinos
- We can probe even smaller $\sigma_{p\chi}$ with the electromagnetic spectrum
- A full, multimessenger study can strongly constrain the role of dark matter in blazar jets

ありがとう

Backup

How to model a blazar jet



Blob moving towards Earth with Lorentz factor Γ_B

Rodrigues et al, 2023

In blob's frame of reference, electrons and protons follow an isotropic power law $\frac{d\Gamma}{dE'} \sim E'^{-\alpha}$, with $\alpha \sim 1-2$, up to $\gamma_{\max} \sim 10^9$

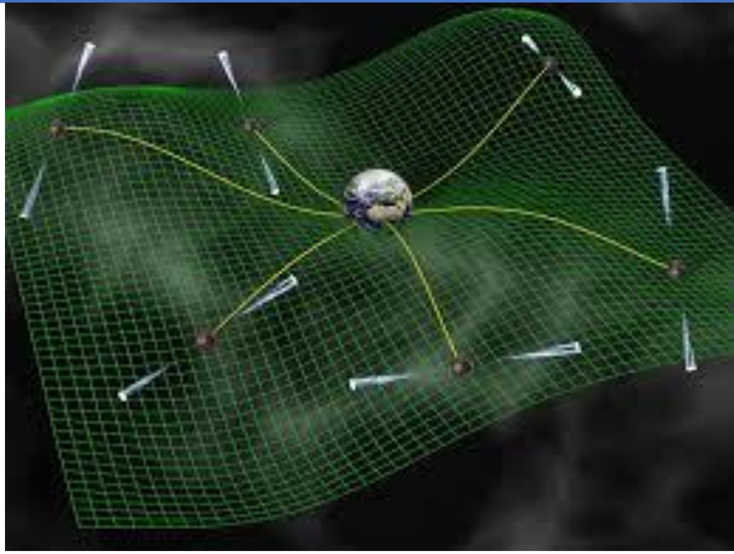
+ ambient photons from accretion disk and jet particle emissions

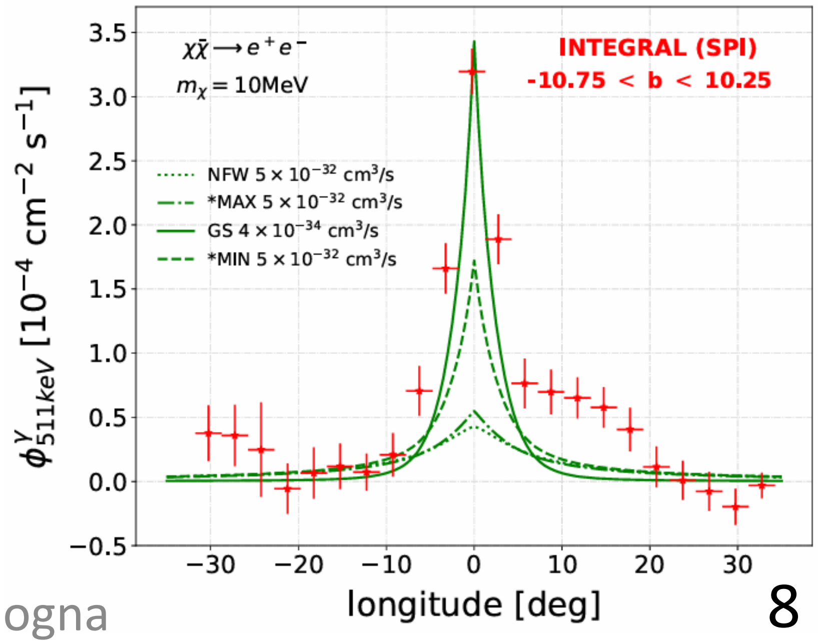
Why sub-GeV Dark Matter?

No luck in finding WIMPs

Dark sectors:

- Standard Model singlets, only portal interactions: allow small couplings and sub-GeV mass
- PTA signal as sub-GeV dark sector phase transition? [Bringmann+ 2023]
- 511 keV line from the galactic centre: annihilating DM? [Boehm+ 2004]. Ok for $m_{\rm DM} \gtrsim 10\ {\rm MeV}$ if there's a spike [De la Torre Luque+ 2024]





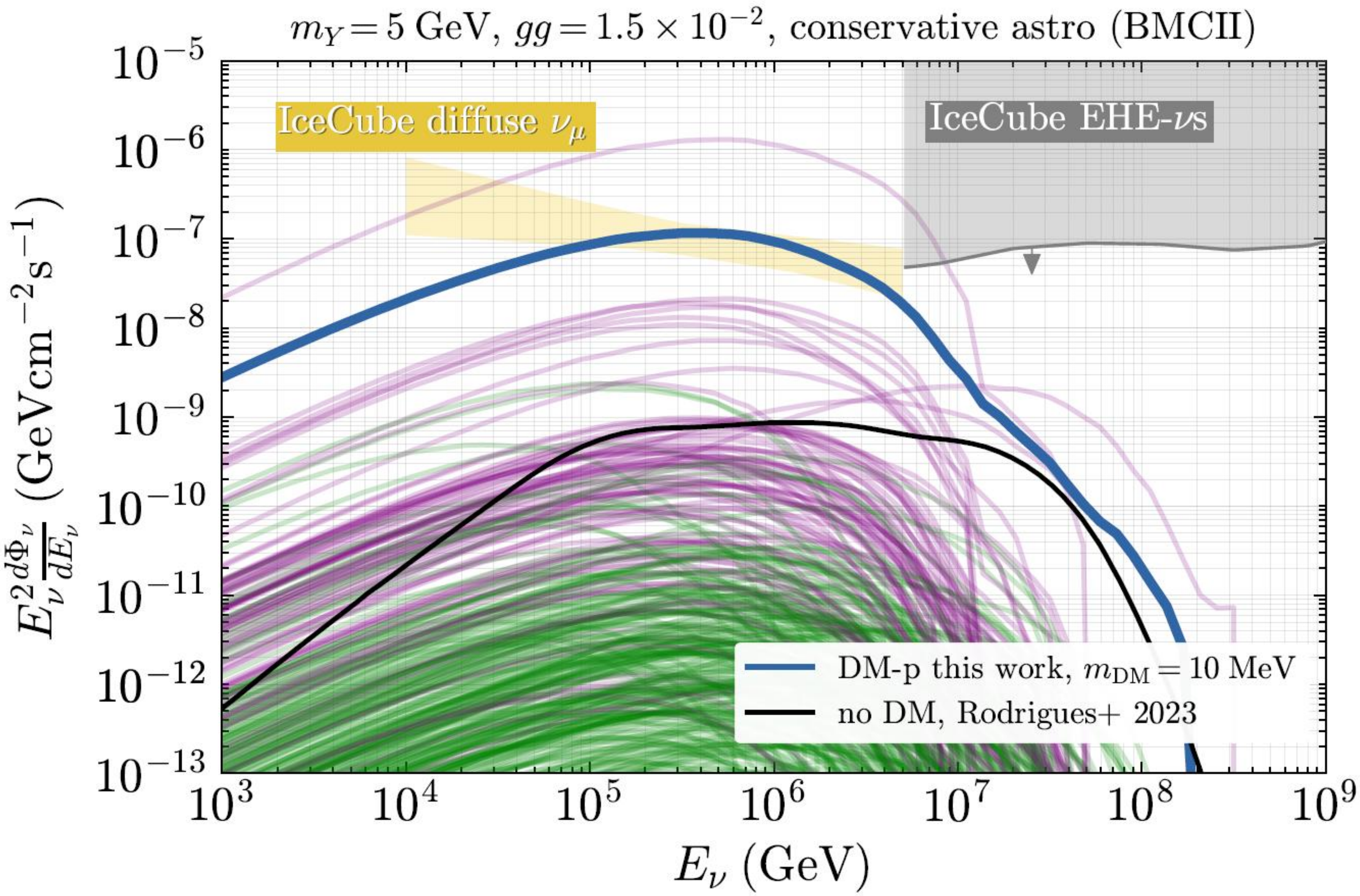
Many effects can change this

- Seed SMBH not in the center of the DM halo [Ullio+ astro-ph/0101481]
- Gravitational heating by stars [Herrera+ 2605.01023]
- Dark matter self-interactions [Kamenetskaia+ 2506.12642]
- Interaction with the jet [De Marchi+ 2507.12278]
- Collapse of supermassive progenitor -> «mound» [Caiozzo + 2512.09985]
- Galaxy mergers
- …

Still, there are hints:

- Extra mass from reverberation mapping [Sharma+ 2506.10122]
- Decay rate of SMBHB [Chan+ 2402.03751]

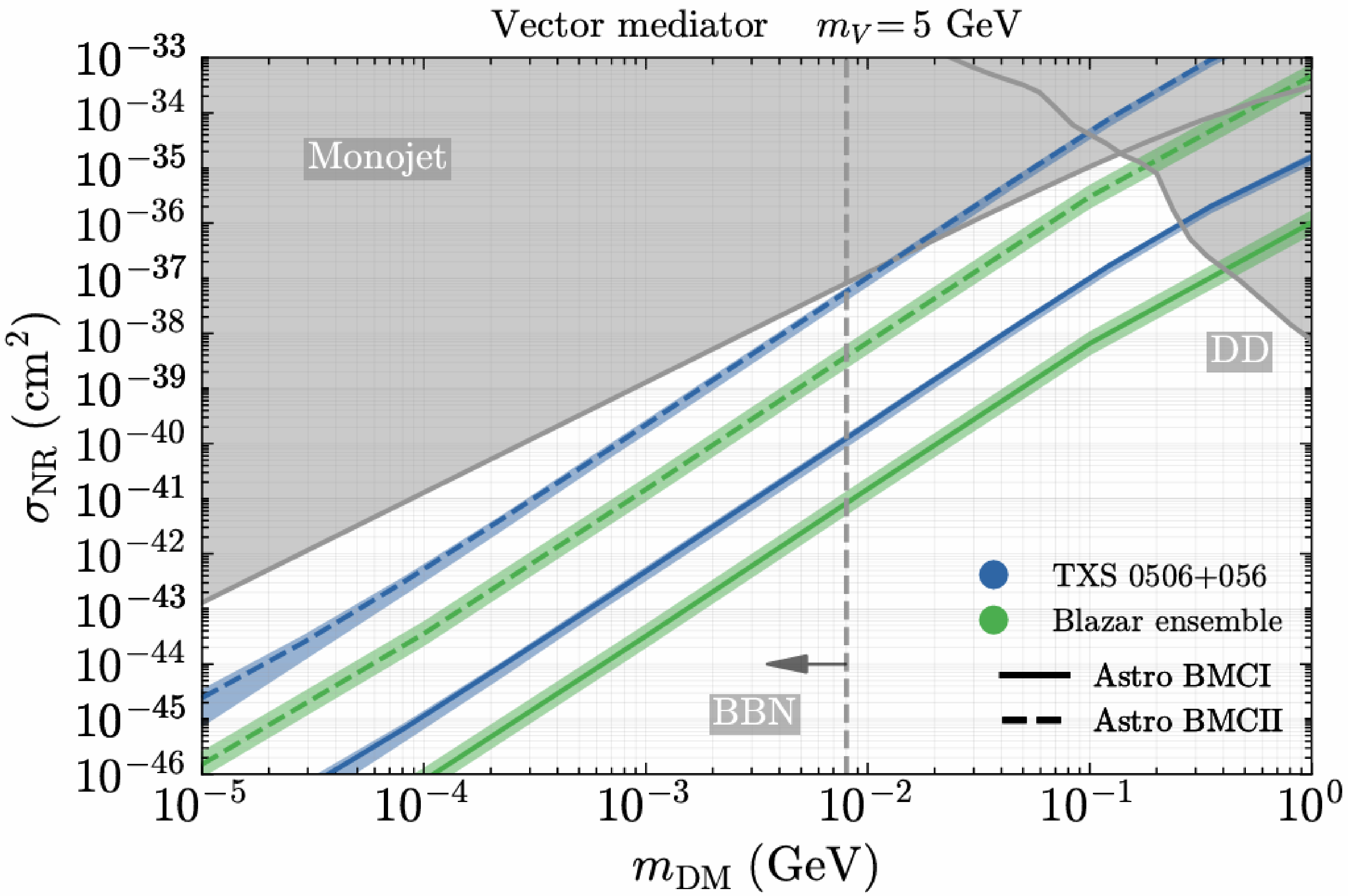
Blazar catalogue



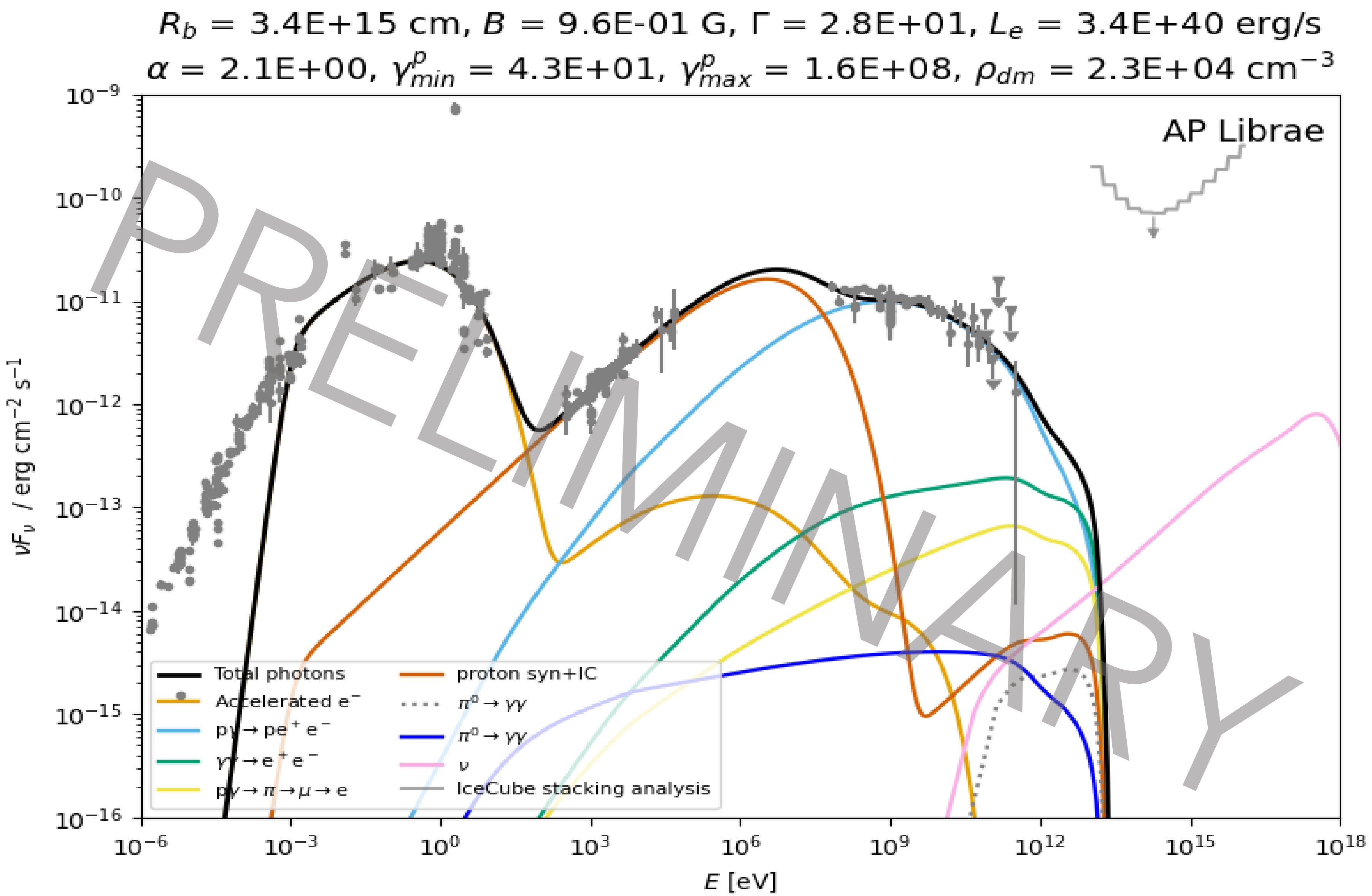
Catalogue of blazars and leptohadronic fits [Rodrigues+ 2307.13024]

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

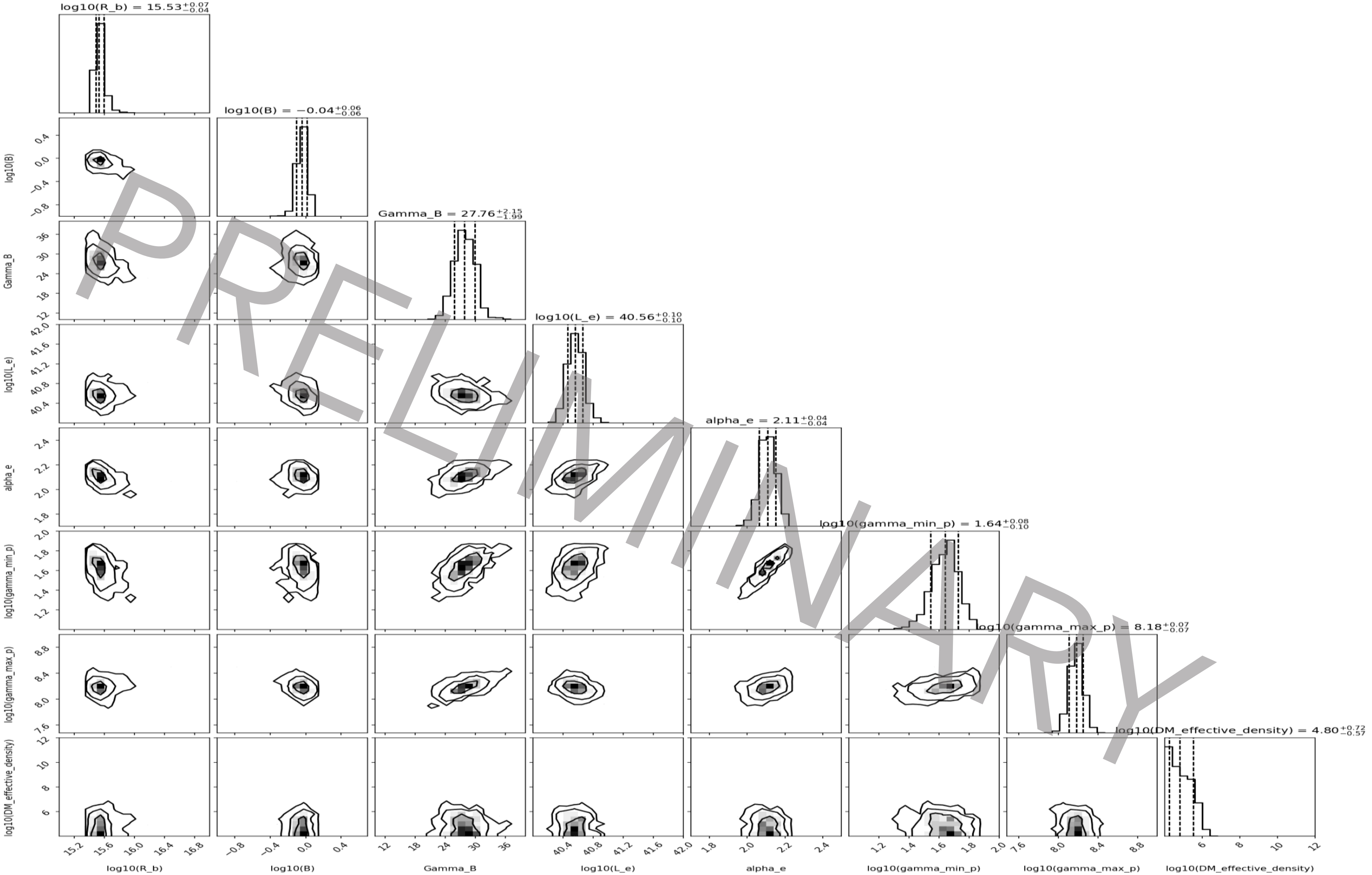
Parameter space



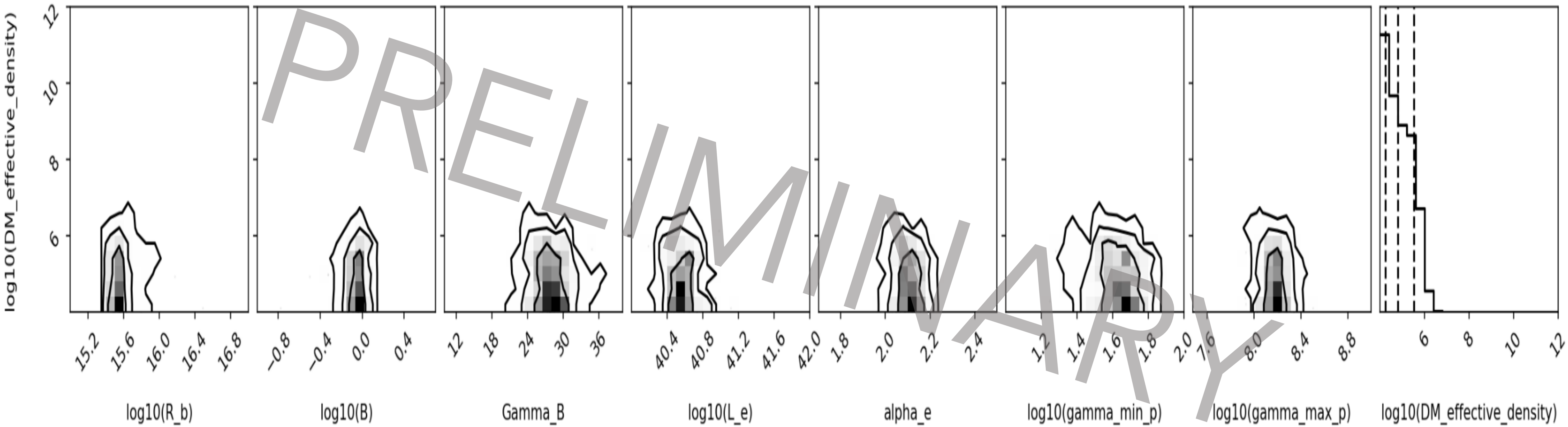
p-synchrotron solutions



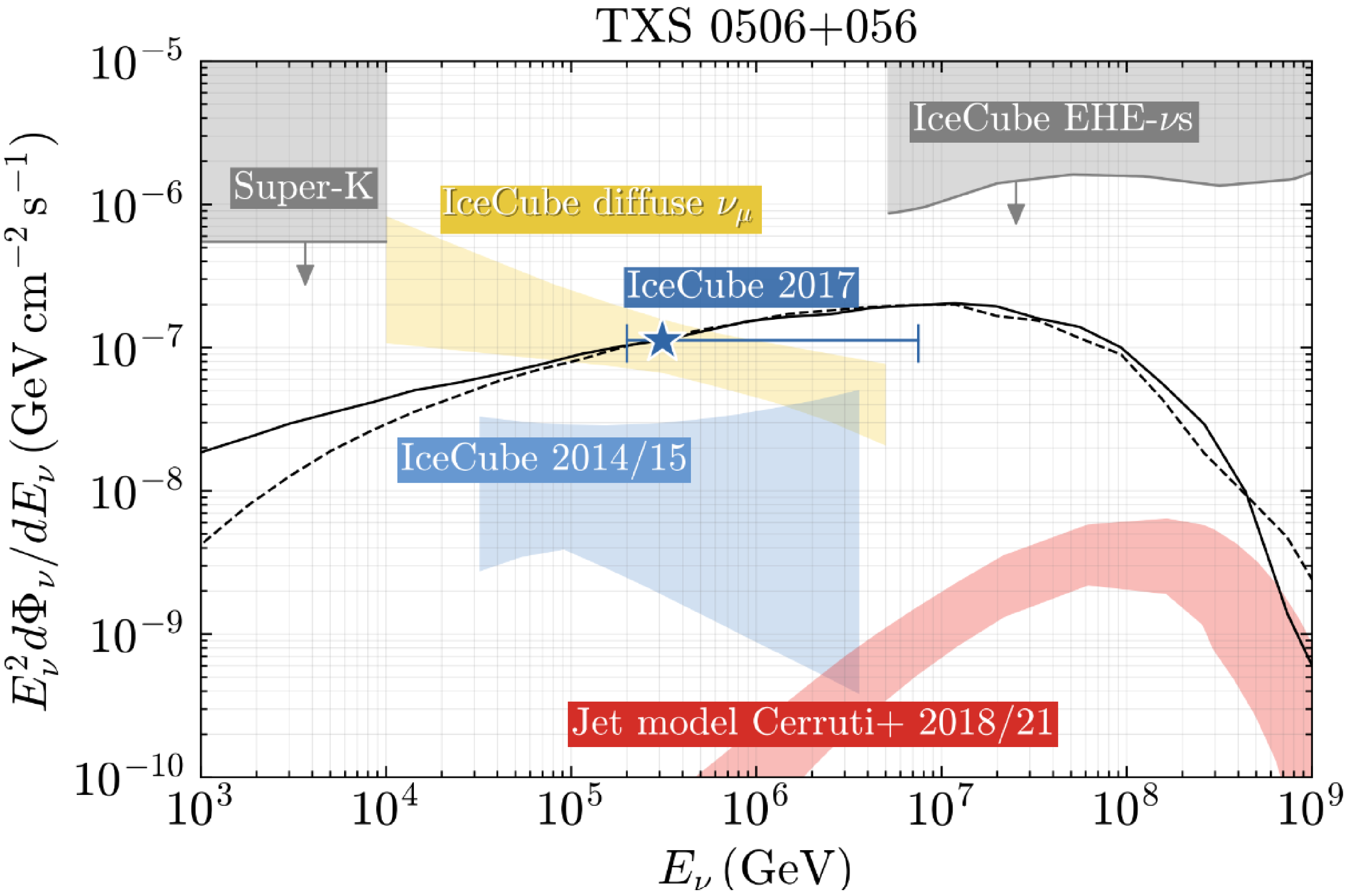
p-synchrotron solutions



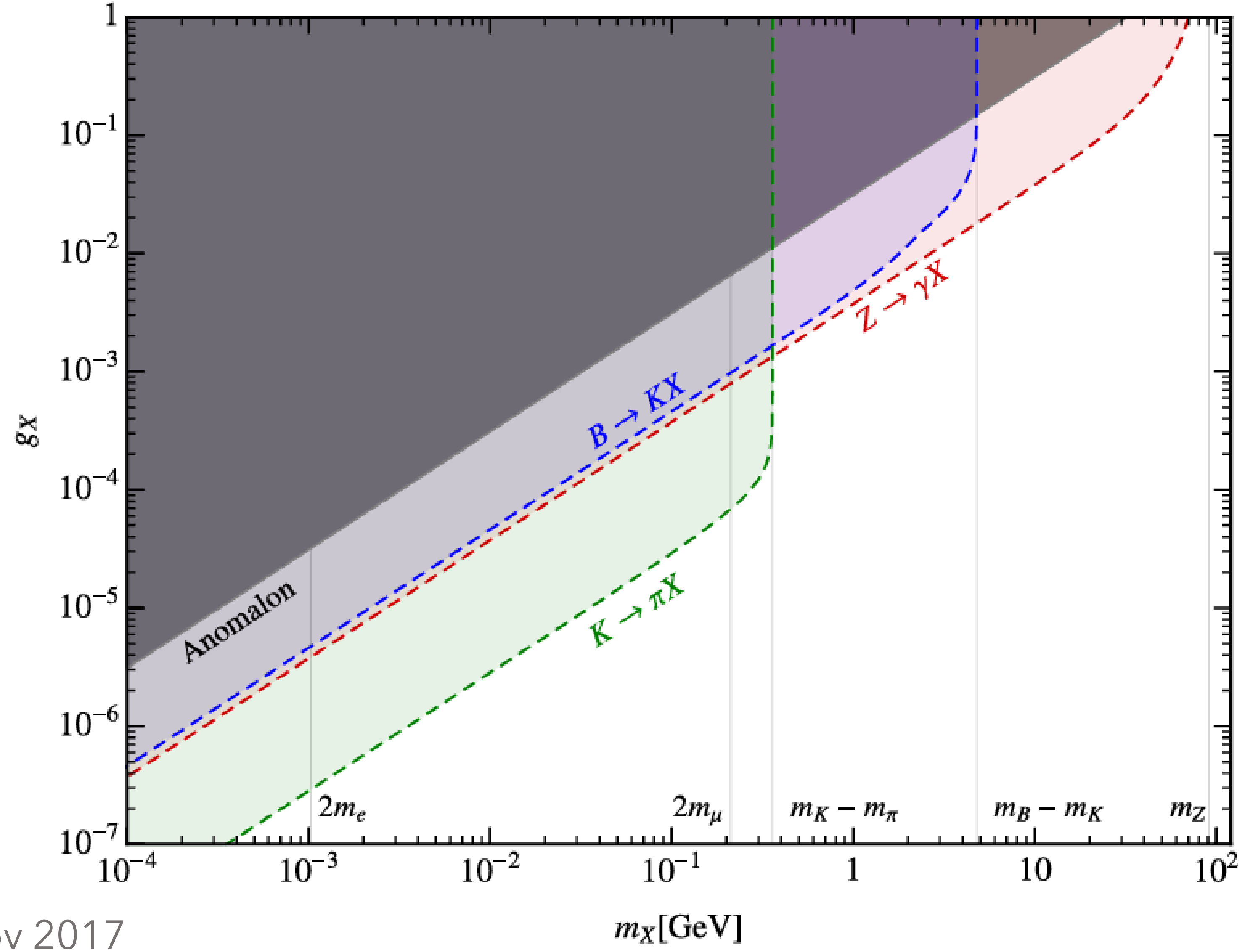
p-synchrotron solutions



Different jet model

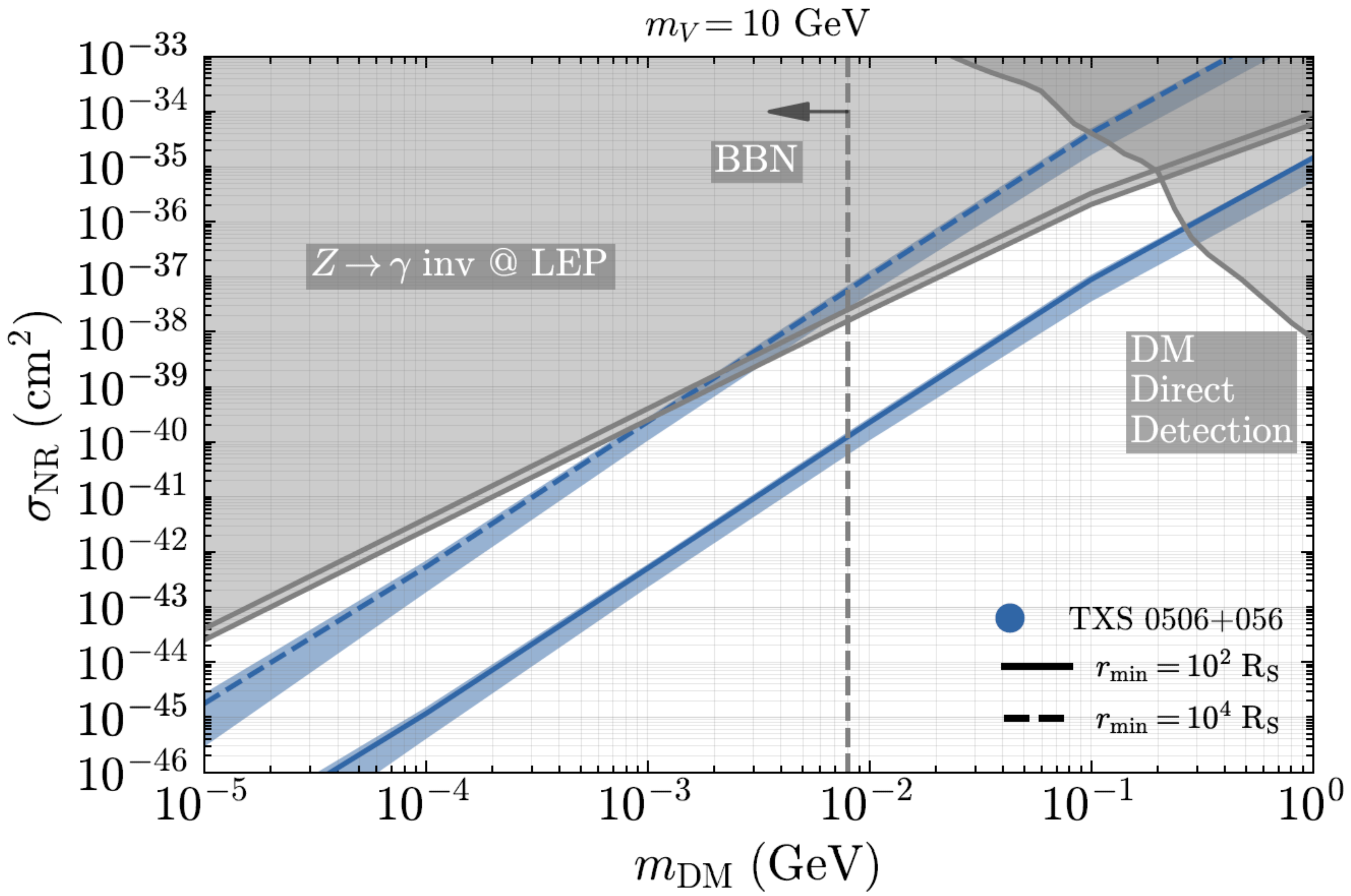


UV completion bounds



Dror, Lasenby, Pospelov 2017

Available parameter space (10 GeV)



Monochromatic