Neutrino and Gamma-Ray Constraints on Heavy Dark Matter

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CCAPP

NDM 2012

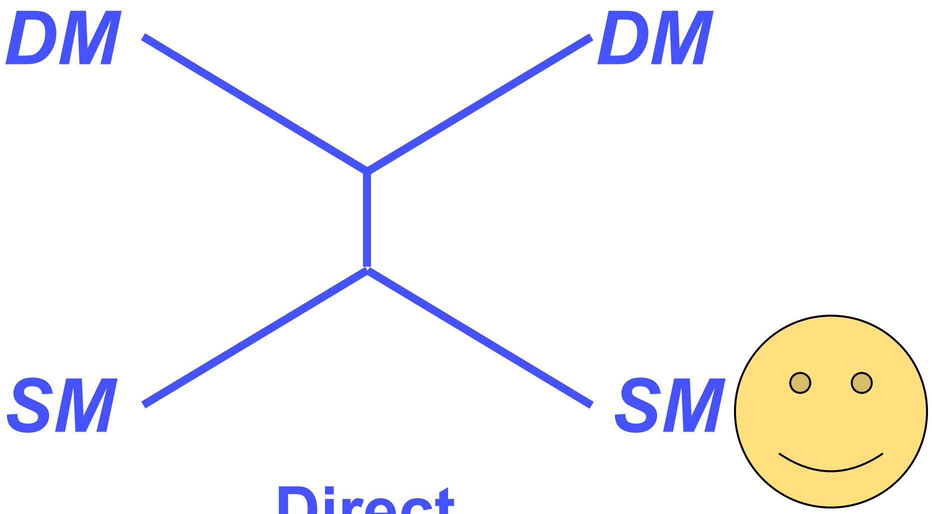
THE OHIO STATE UNIVERSITY

DM Indirect Search: Motivation

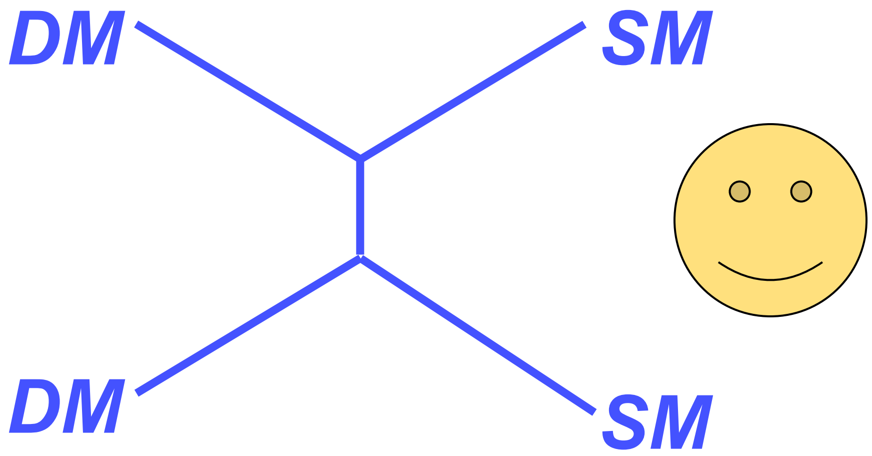
Dark matter (DM): discovered by gravitational effects

- Non-baryonic
- Slow-moving (cold or perhaps warm)
- Stable or long-lived
- ~23% of the Universe (from WMAP)

Particle properties are unknown → many models beyond SM!



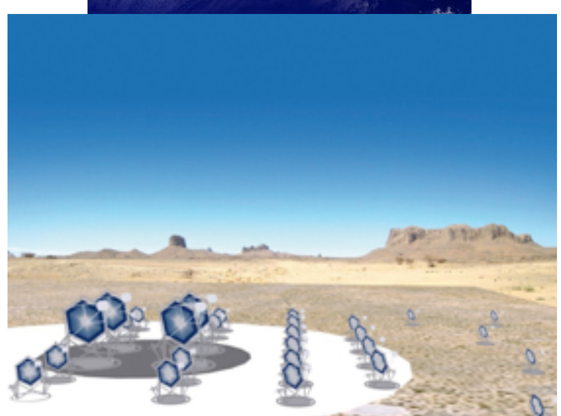
Direct



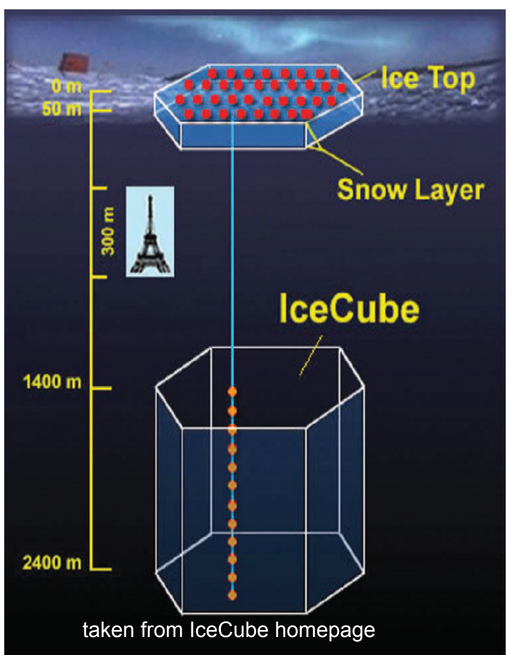
Indirect

Era of Multi-Messenger Astronomy

Gamma Rays
IACTs (HESS, MAGIC, CTA)
Fermi, HAWC etc.



Neutrinos
IceCube/KM3Net
Super-K etc.



taken from IceCube homepage

Cosmic Rays
PAMERA, AMS-02
Auger, TA etc.

Theory ⇔ Observations

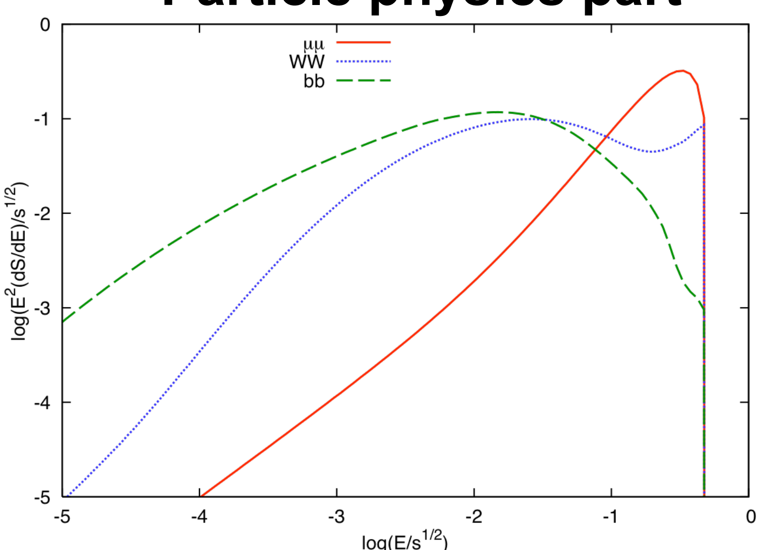
Annihilation

$$I_E^{\mathrm{ann}}(\psi) = \frac{1}{4\pi}\int dl\ \frac{<\sigma v>_{\mathrm{dm}}}{2}\left(\frac{\rho_{\mathrm{dm}}(r)}{m_{\mathrm{dm}}}\right)^2\frac{dS}{dE} = \frac{<\sigma v>_{\mathrm{dm}}}{8\pi m_{\mathrm{dm}}^2}\frac{dS}{dE}\int_0^{l_{\max}} dl\ \ \rho_{\mathrm{dm}}^2(r)$$

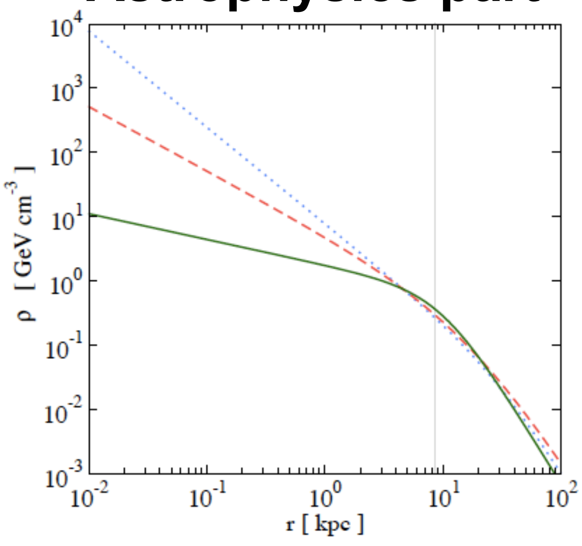
Decay

$$I_E^{\mathrm{dec}}(\psi) = \frac{1}{4\pi}\int dl\ \frac{\rho_{\mathrm{dm}}(r)}{m_{\mathrm{dm}}\tau_{\mathrm{dm}}}\frac{dS}{dE} = \frac{1}{4\pi m_{\mathrm{dm}}\tau_{\mathrm{dm}}}\frac{dS}{dE}\int_0^{l_{\max}} dl\ \ \rho_{\mathrm{dm}}(r)$$

Particle physics part



Astrophysics part



Very Heavy Dark Matter?

- Many models consider m<TeV (ex. neutralino) but m>TeV may be possible (ex. super heavy DM)
- VHDM may be produced as nonthermal relics
- Maybe difficult to access by direct/collider experiments

→ **We focus on very heavy dark matter in light of Fermi and IceCube observations**

Annihilation

$$Q_{\rm dm}^{\rm ann} = \left(\frac{\rho_{\rm dm}}{m_{\rm dm}}\right)^2 \frac{<\sigma v>_{\rm dm} g_0}{2} 2 m_{\rm dm} c^2$$

For given energy output, larger <σv> is required at higher m

Decay

$$Q_{\rm dm}^{\rm dec} = \frac{\rho_{\rm dm}}{m_{\rm dm}} \frac{m_{\rm dm} c^2}{\tau_{\rm dm}}$$

For given energy output, required τ is independent of m

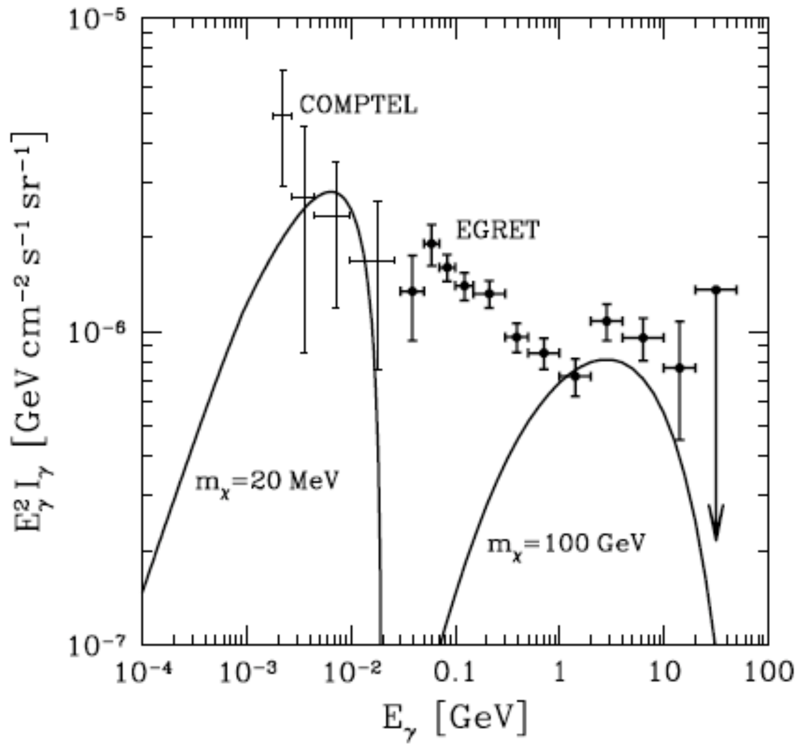
Where to Look?

Search Technique	advantages	challenges
Galactic center	Good Statistics	Source confusion / Diffuse background
Satellites, subhalos Point sources	Low background, Good source id	Low statistics
Milky Way halo	Large statistics	Galactic diffuse background
Extragalactic	Large Statistics	Astrophysics, galactic diffuse background
Spectral lines	No astrophysical uncertainties, good source id	Low statistics

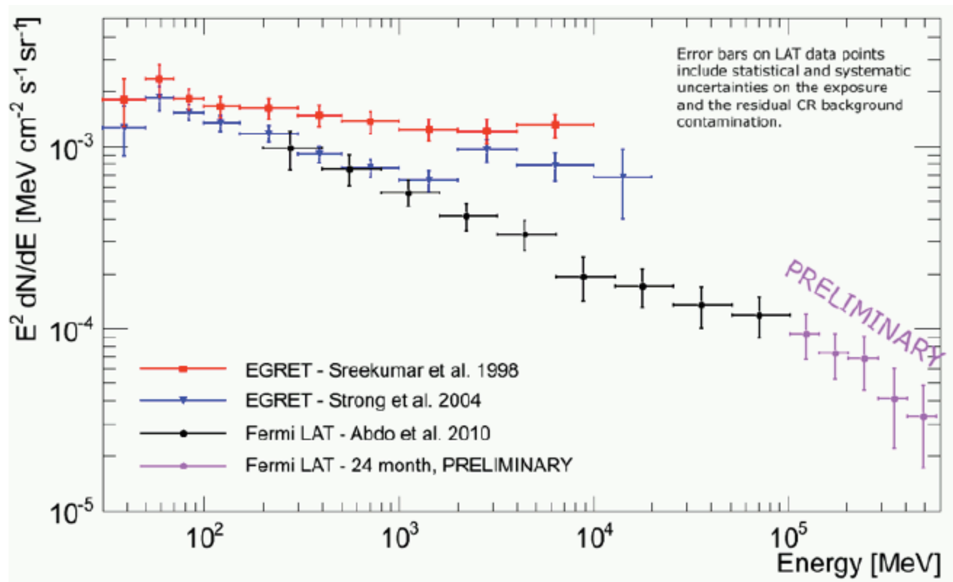
We mainly focus on diffuse background radiation

Diffuse Gamma-Ray Background (DGB)

Adapted from Ando & Komatsu 06 PRD
see Bergstrom+ 01 PRL, Ullio+ 02 PRD etc.



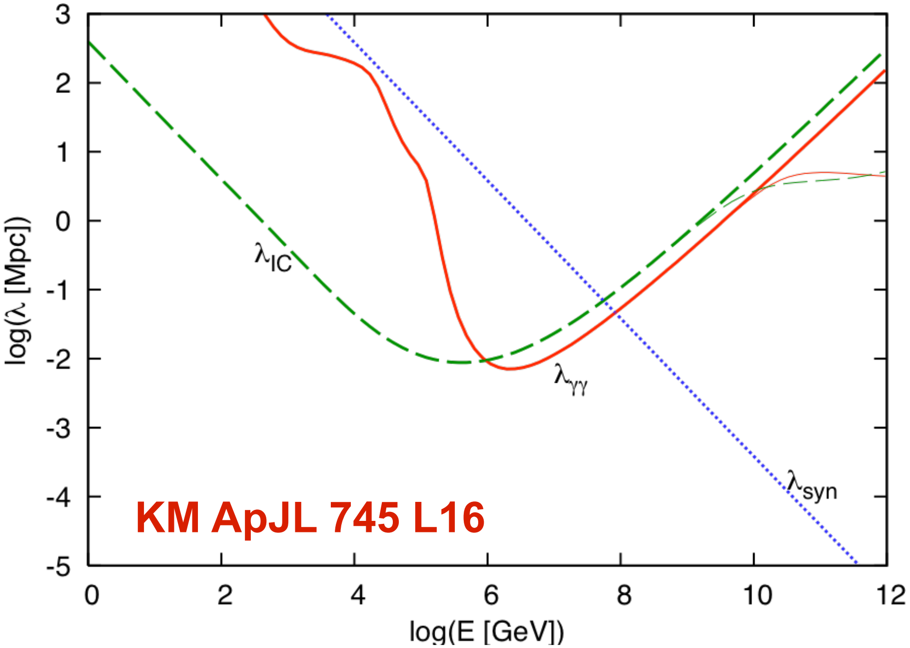
Fermi collaboration 11 @TEVPA



The origin is still unknown!

- EGRET excess: possible contribution at ~GeV
- After Fermi: power law & reduced by a factor of ~10

Remark on Extragalactic Gamma Rays



>TeV gamma rays are attenuated by the EBL/CMB

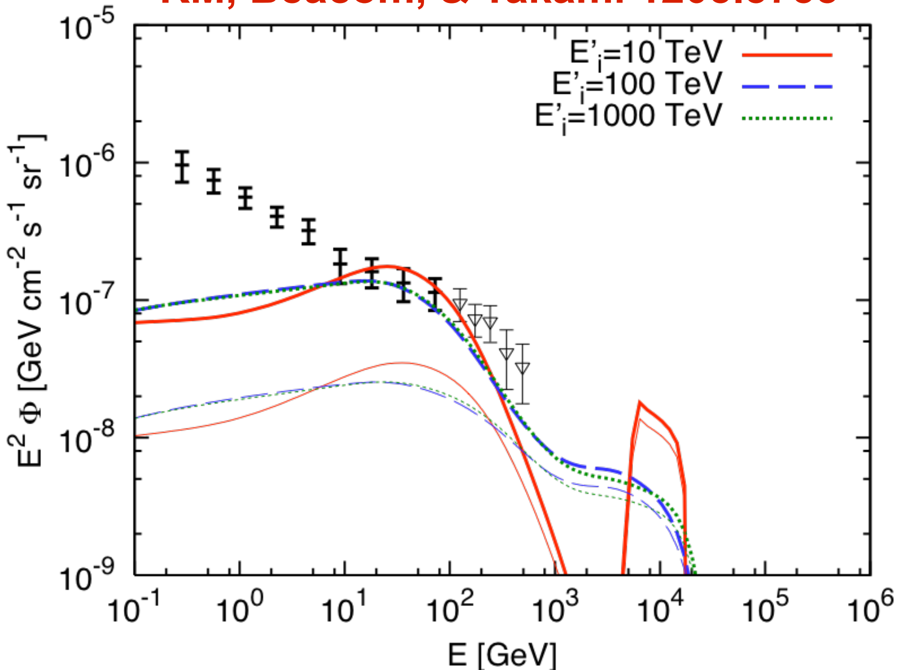
$$\gamma + \gamma_{\mathrm{CMB/CIB}} \rightarrow e^{+} + e^{-}$$

$$e + \gamma_{\mathrm{CMB/CIB}} \rightarrow e + \gamma \ \mathrm{(IC)}$$

electromagnetic cascades

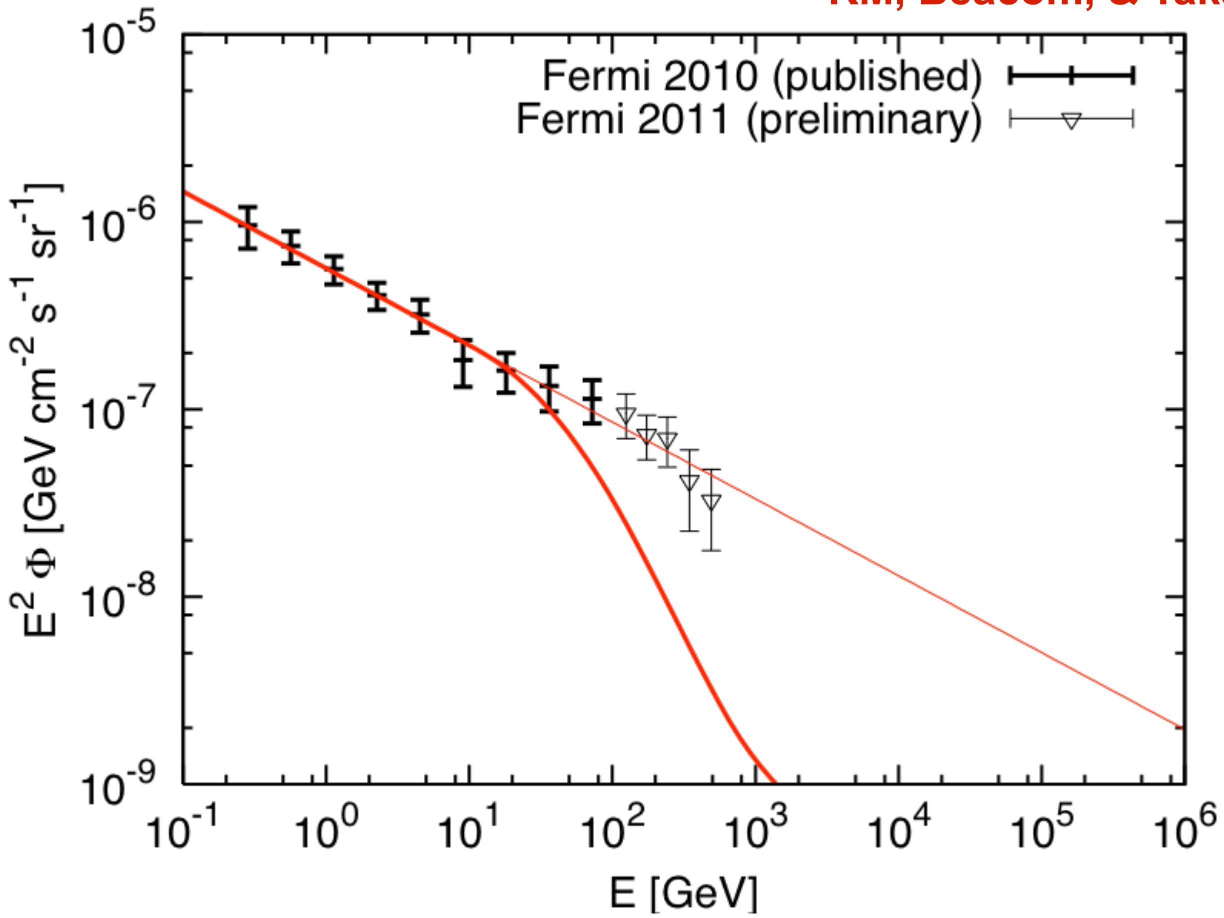
→ near-universal spectrum

KM, Beacom, & Takami 1205.5755



Possible VHE Excess in the DGB

KM, Beacom, & Takami 1205.5755



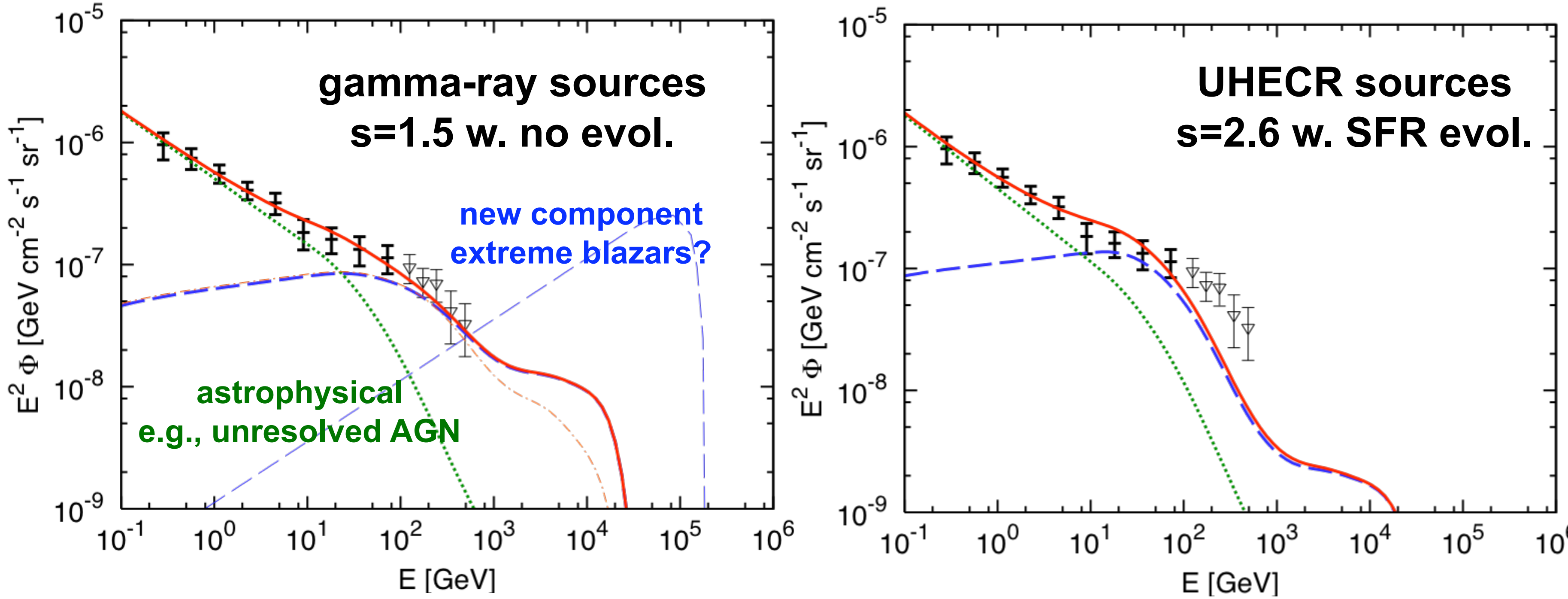
Caution!: we should wait for finalized data

A New VHE Component?

If true, some new component is necessary

- Astrophysical solutions

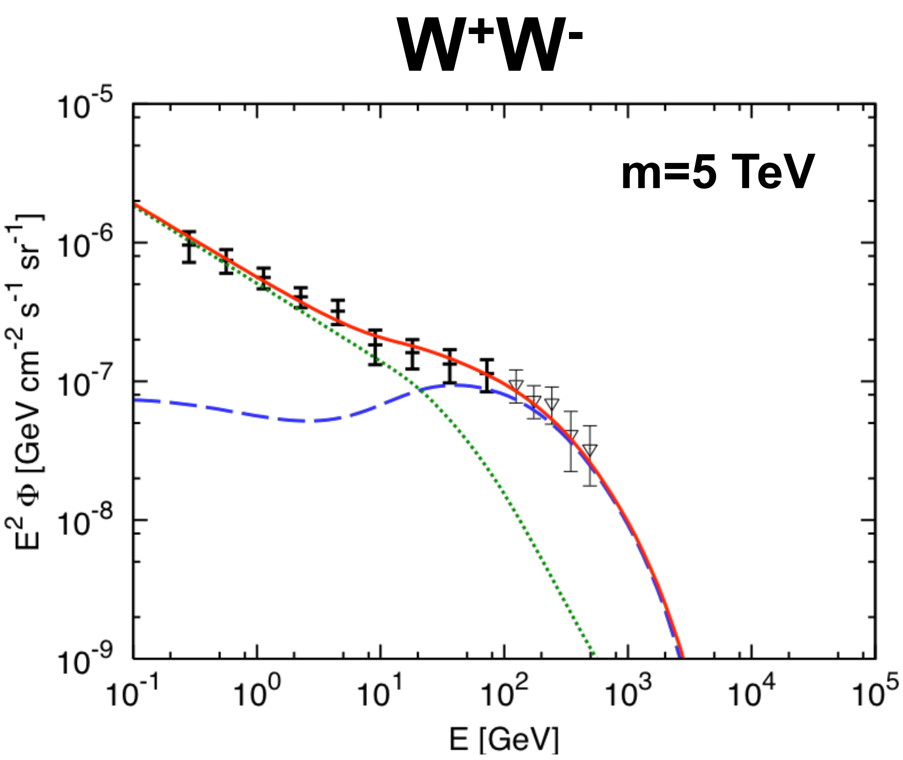
KM, Beacom, & Takami 1205.5755

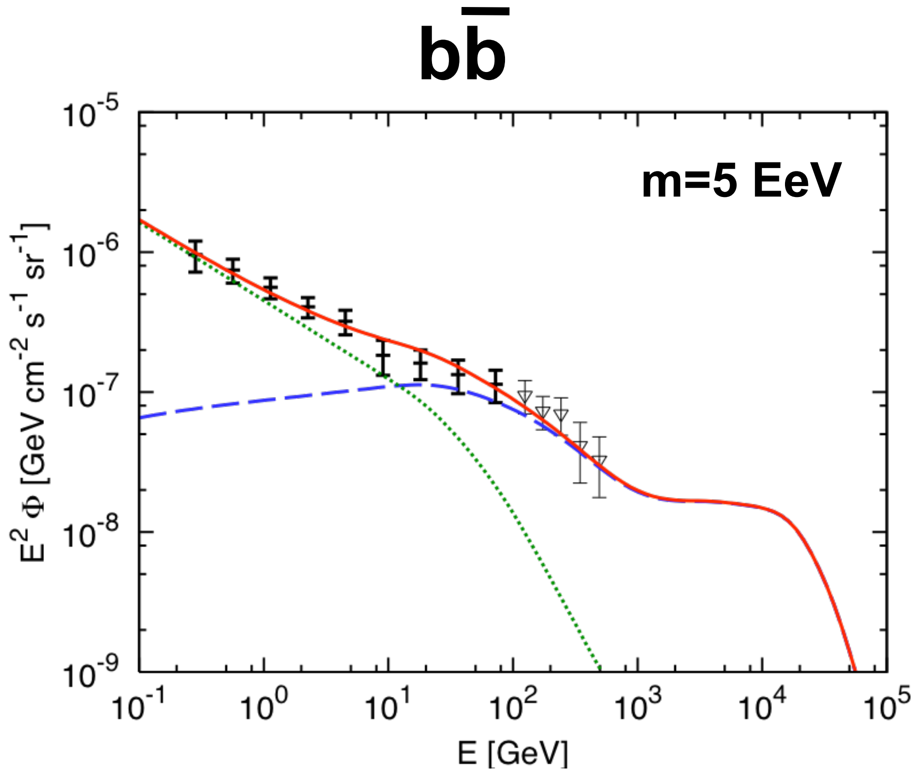


Other explanations seem possible

Can VHDM provide an alternative explanation?

Possible DM Explanation?: Annihilation





Seemingly possible:

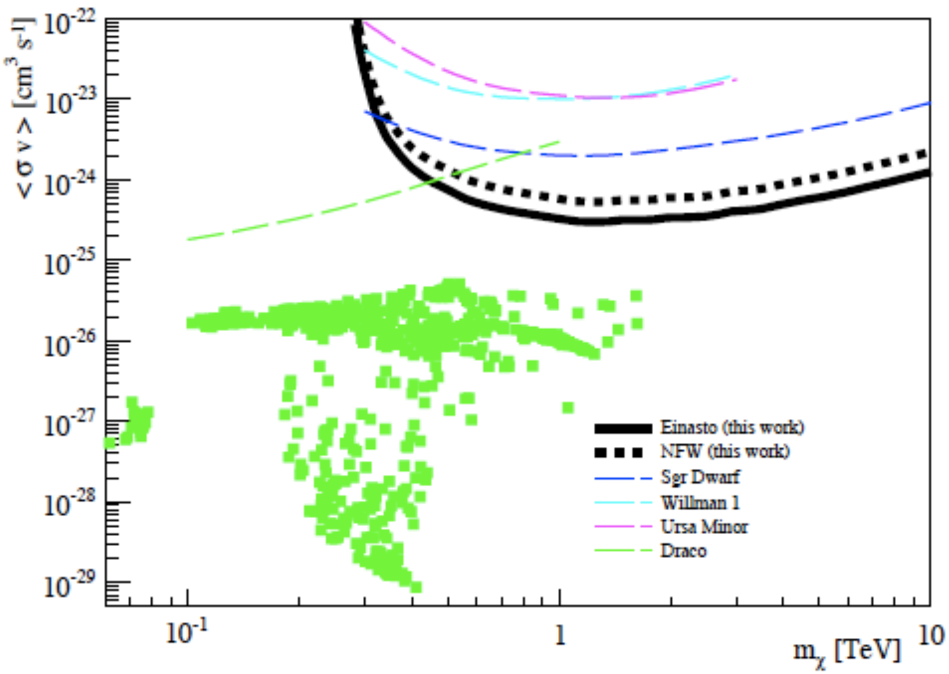
But large cross section and large boost factor

ex. $\langle\sigma v\rangle \sim 10^{-24}$ cm^3/s, b ~ 200-1000

Other Constraints

- Galactic center

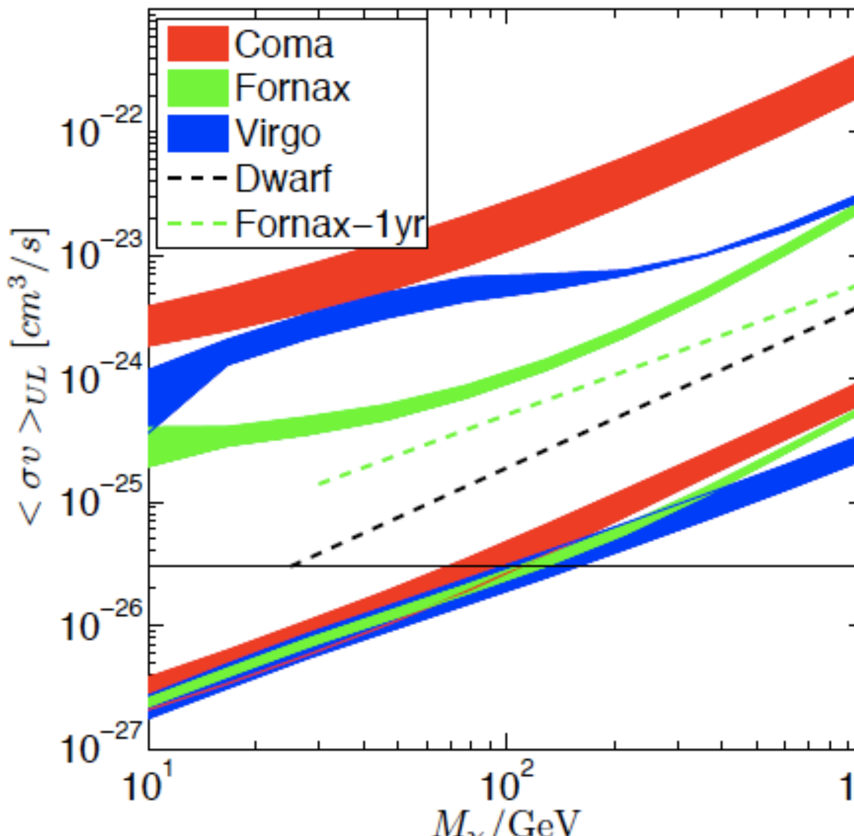
  large <σv> is constrained



HESS collaboration 11 PRL

- Galaxy cluster

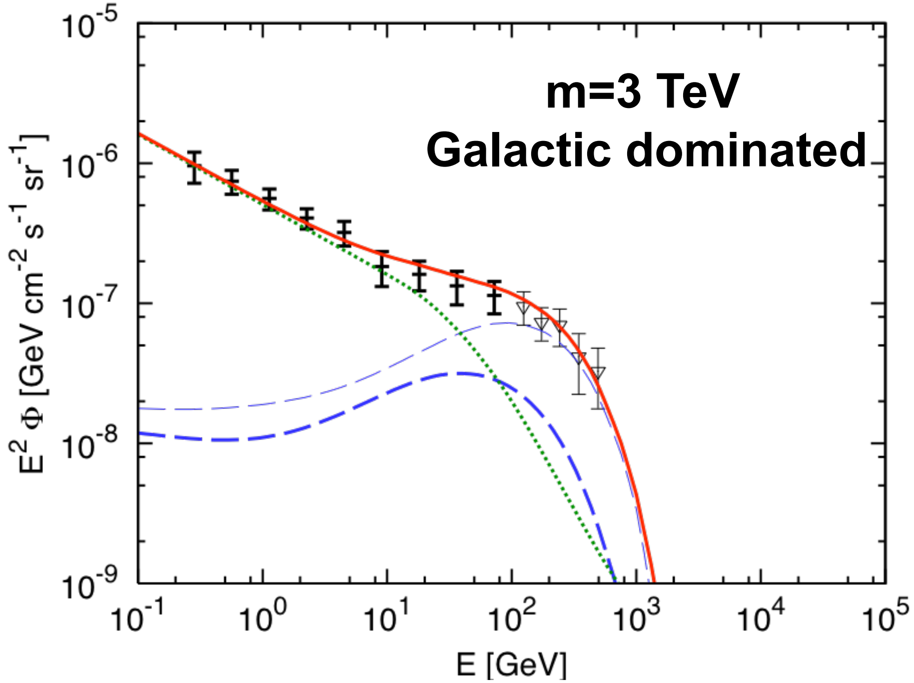
  large boost is limited



Han et al. arXiv:1201.1003

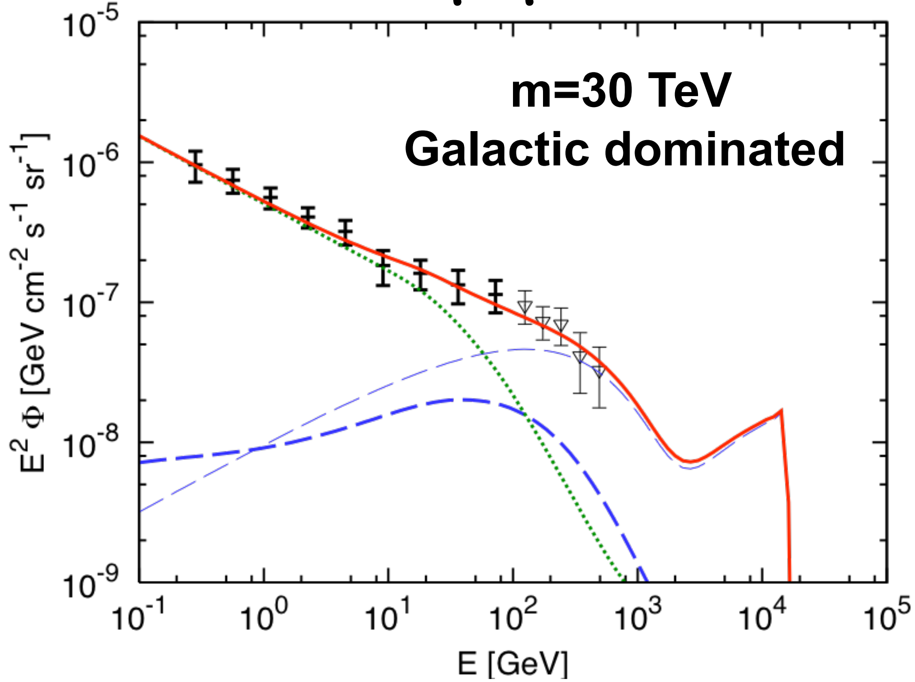
Possible DM Explanation?: Decay

W^+W^-



$\tau = 1.2 \times 10^{27}$ s

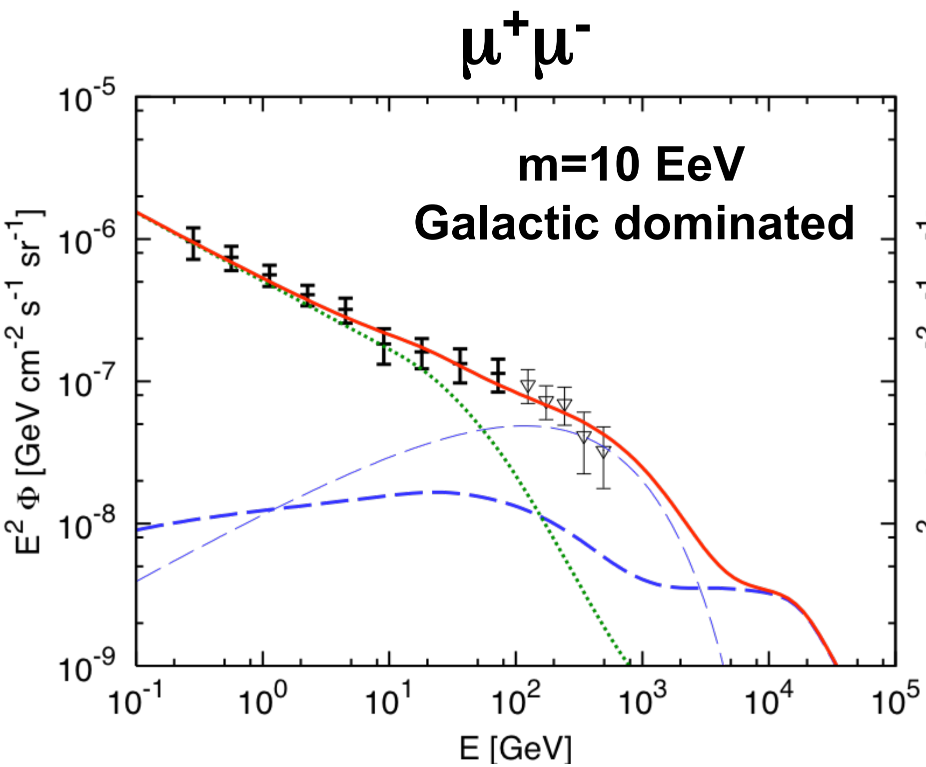
$\mu^+\mu^-$



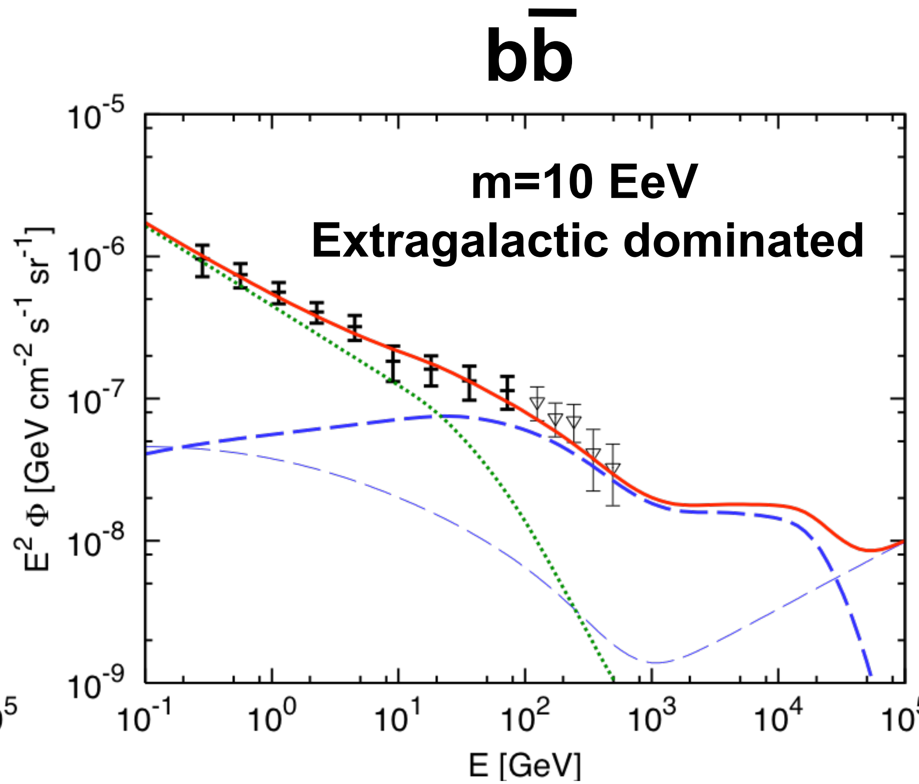
$\tau = 2.0 \times 10^{27}$ s

- Decaying VHDM could be an alternative explanation
- Required parameters do not violate current γ-ray limits

Contd.



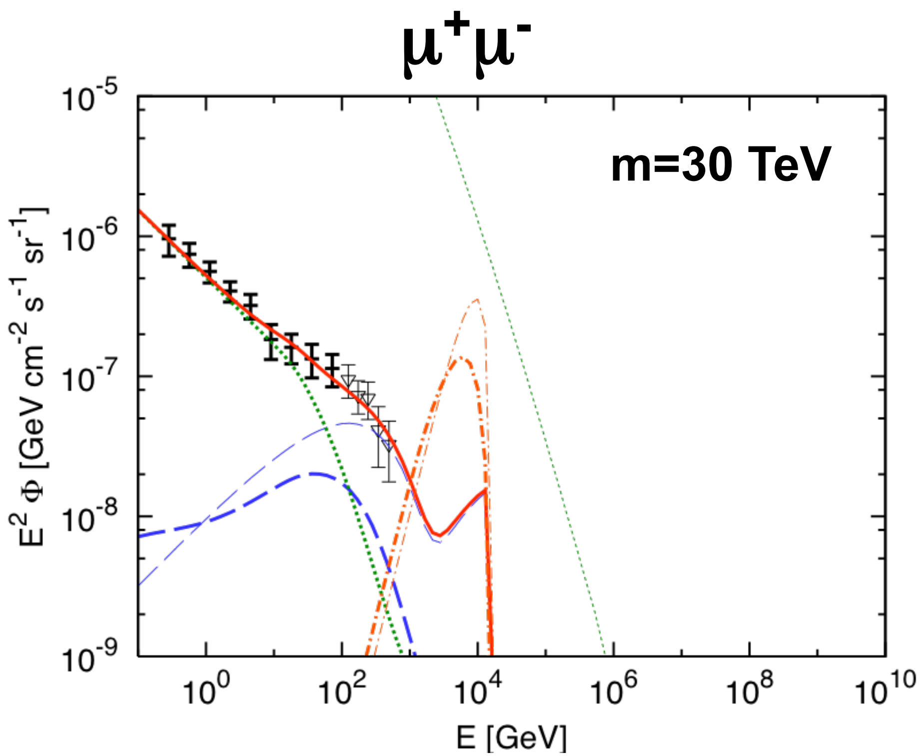
$\tau = 1.8 \times 10^{27}$ s

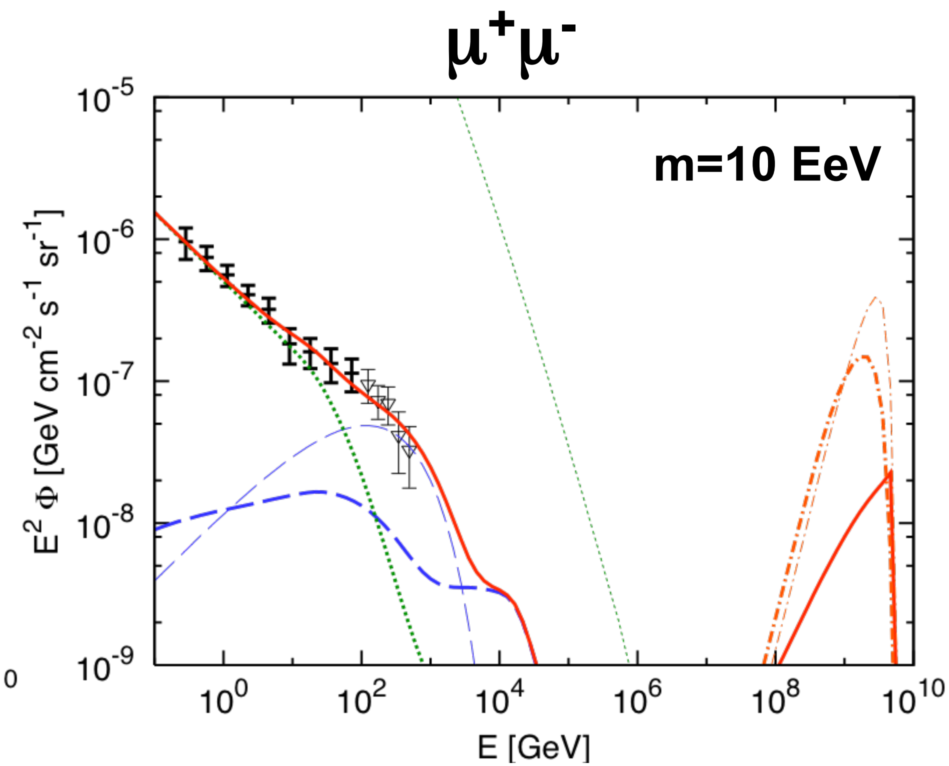


$\tau = 4.7 \times 10^{26}$ s

- More extreme cases…

Power of Neutrinos





Neutrinos will be seen by IceCube within three years

Super heavy DM cases are inconsistent

→ These demonstrate power of neutrino observations

Cautions

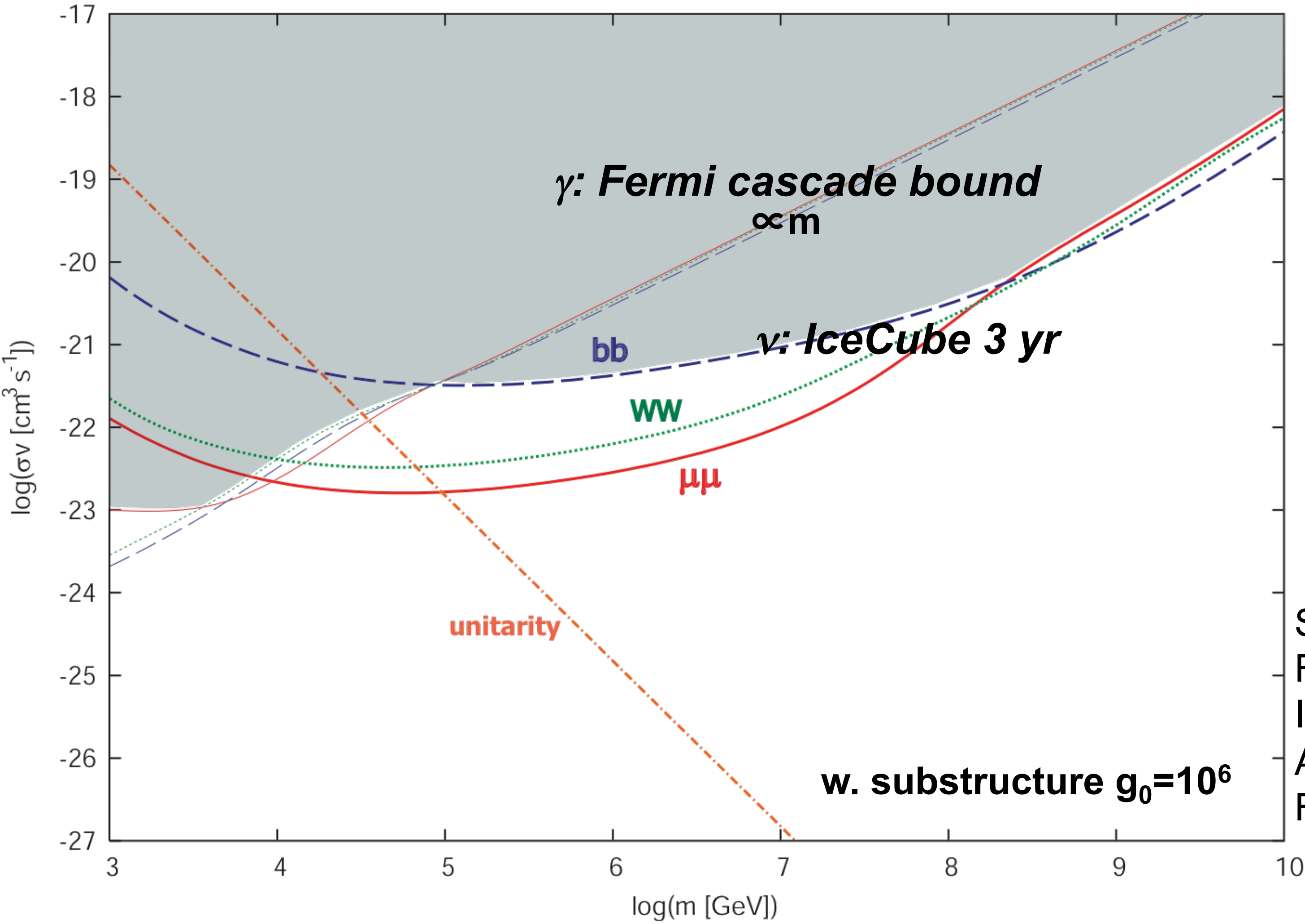
- There are allowed parameter ranges at present but super heavy DM does not seem allowed
  3-30 TeV DM can be probed by future observations (ex. neutrino observation, resolving the DGB)

- Astrophysical explanations (maybe more natural) discrimination? → ex. resolving the DGB, anisotropy

- More conservatively, we derive cascade gamma-ray bound and forecasted neutrino constraints

- We run PYTHIA and solve Boltzmann equations

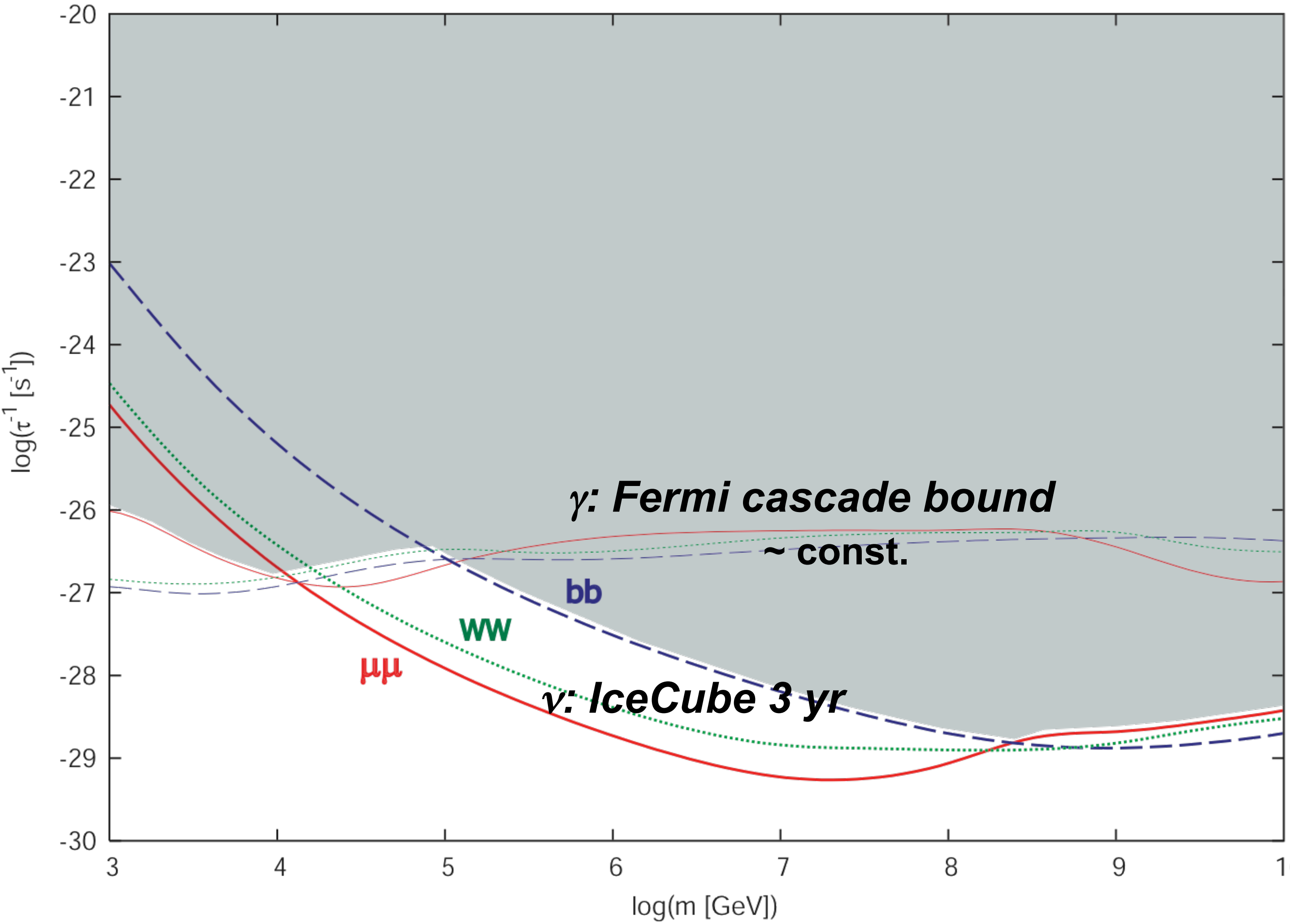
Constraints: Annihilation



See also
Fermi 10 JCAP
IceCube 11 PRD
Abazajian 12 PRD
Fermi 12 etc.

Neutrino constraint: more conservative at low m

Constraints: Decay



For EGRET bound
Gondolo 92 PLB

See also
Palomares-Ruiz 08 PLB
Covi+ 10 JCAP
IceCube 11 PRD
Esmaili+ 12 etc.

Cascade bound: more conservative and robust at high m

Summary

- We consider constraints on VHDM in light of Fermi and IceCube observations of background radiation

- Decaying VHDM could explain the VHE Excess
  → Neutrino observations can test some cases

- Fermi-era cascade gamma-ray bounds:
  improved by a factor of ~10 than in the EGRET era
  less channel-dependent & applied to super heavy DM
- IceCube forecasted neutrino constraints:
  stronger at sufficiently high masses

Cascade Bounds