Multi-Messenger Connections among High-Energy Cosmic Particles

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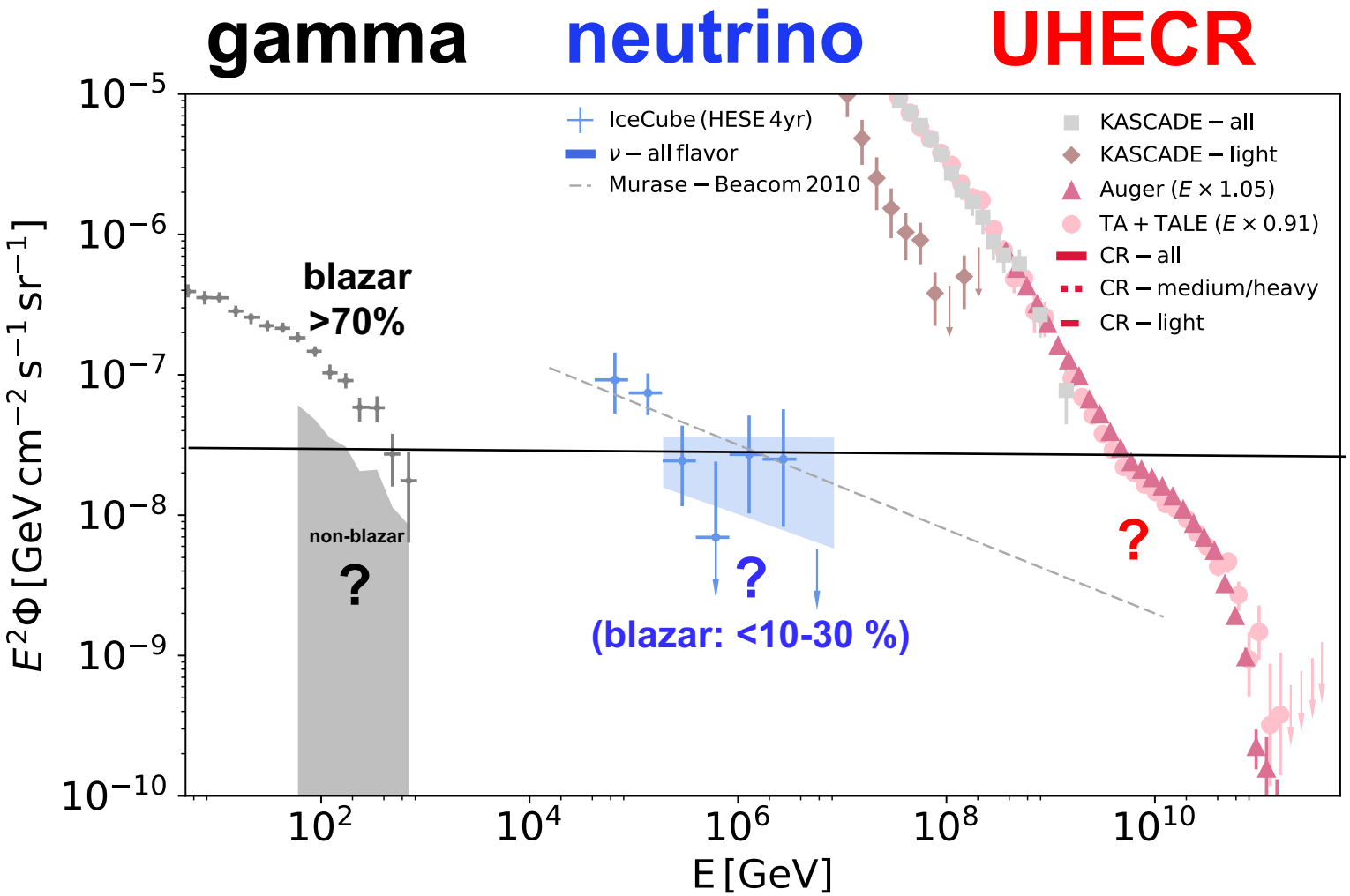
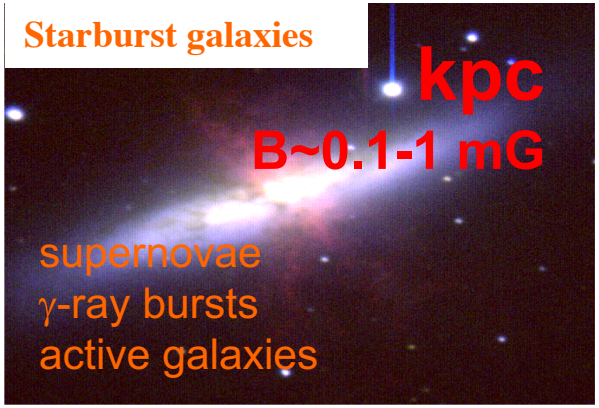
July 25 @ Madison

High-Energy Cosmic Particle Backgrounds

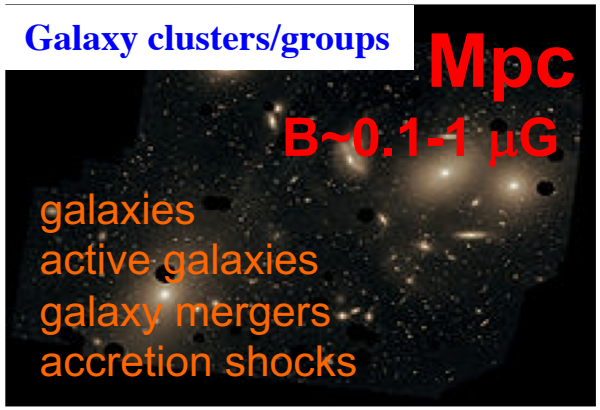


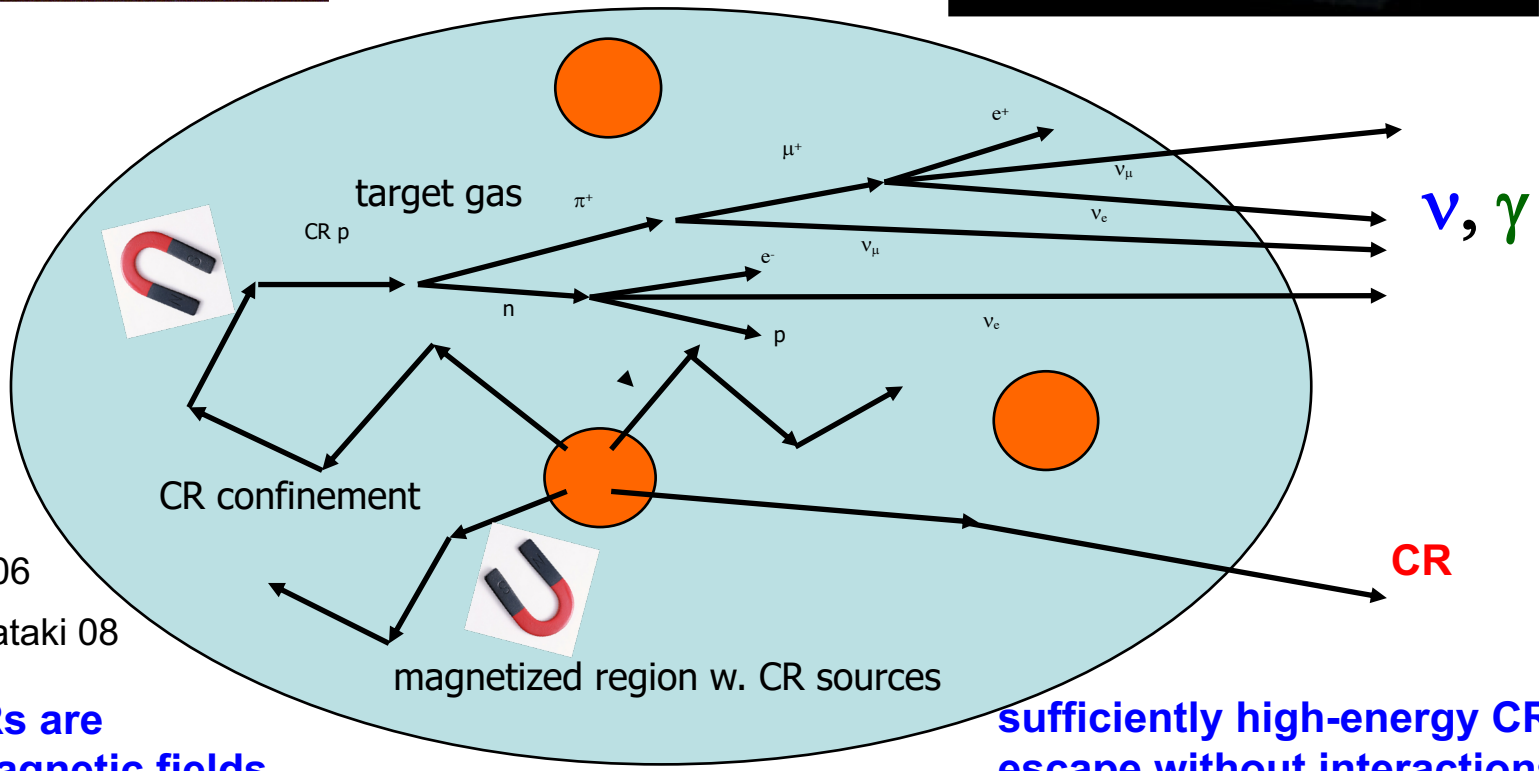
Particle energy budgets are roughly comparable (10^{43} -10^{44} erg Mpc^{-3} yr^{-1})

Cosmic-Ray Reservoirs



"cosmic-ray reservoirs"





Loeb & Waxman 06

KM, Inoue & Nagataki 08

low-energy CRs are confined by magnetic fields

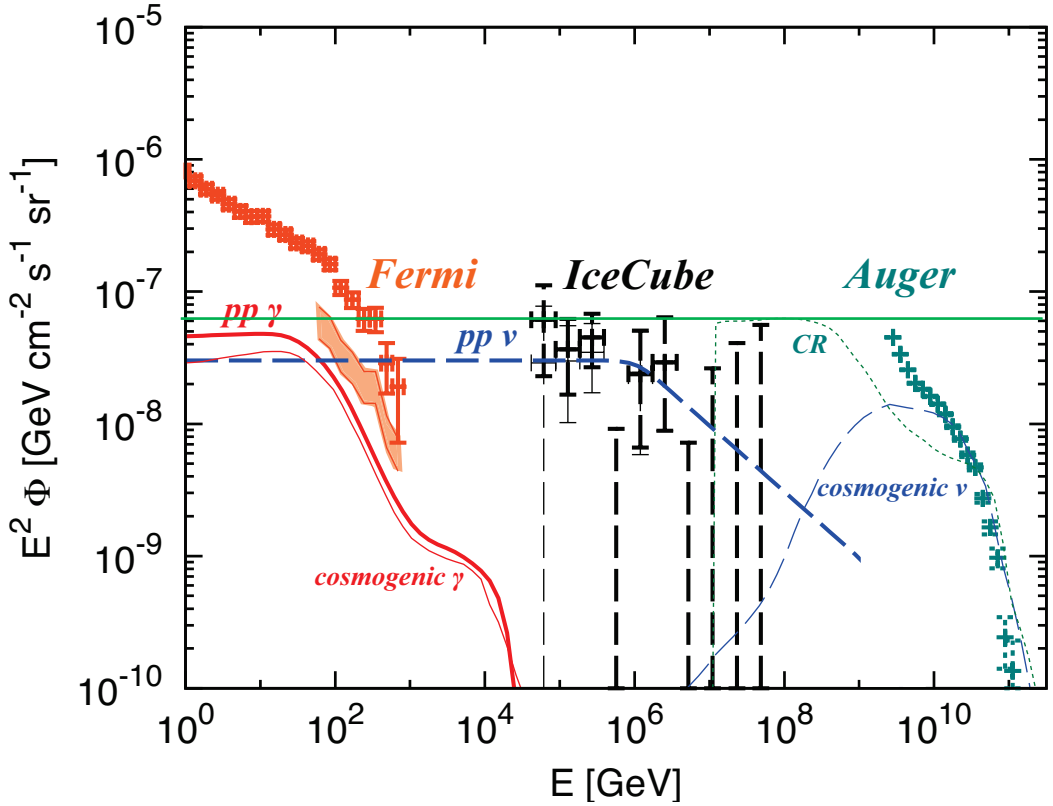
sufficiently high-energy CRs escape without interactions

Neutrino-Gamma-UHECR Connection?

(grand-)unification of neutrinos, gamma rays & UHECRs

simple flat energy spectrum w. s~2 can fit all diffuse fluxes

- Explain >0.1 PeV ν data with a few PeV break (theoretically expected)
- Escaping CRs may contribute to the observed UHECR flux



KM & Waxman 16 PRD

PeVν – confined CR
UHECR – escaping CR
sub-TeVγ – "sum"

Neutrino-Gamma-UHECR Connection?

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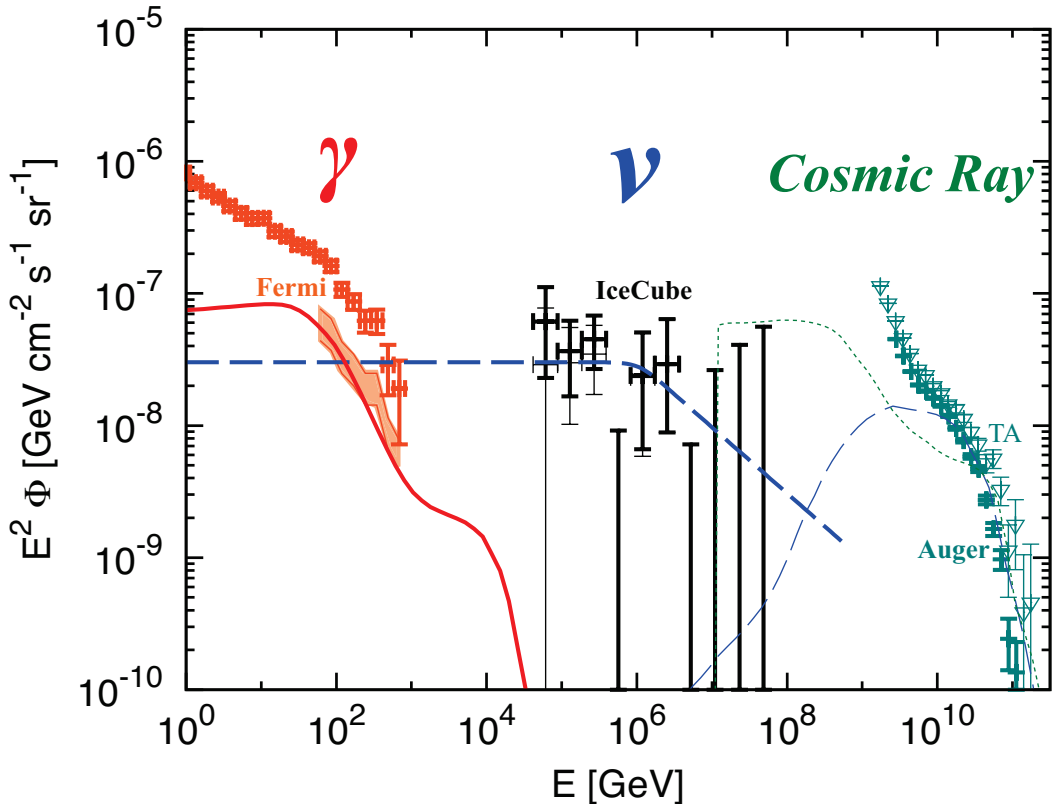


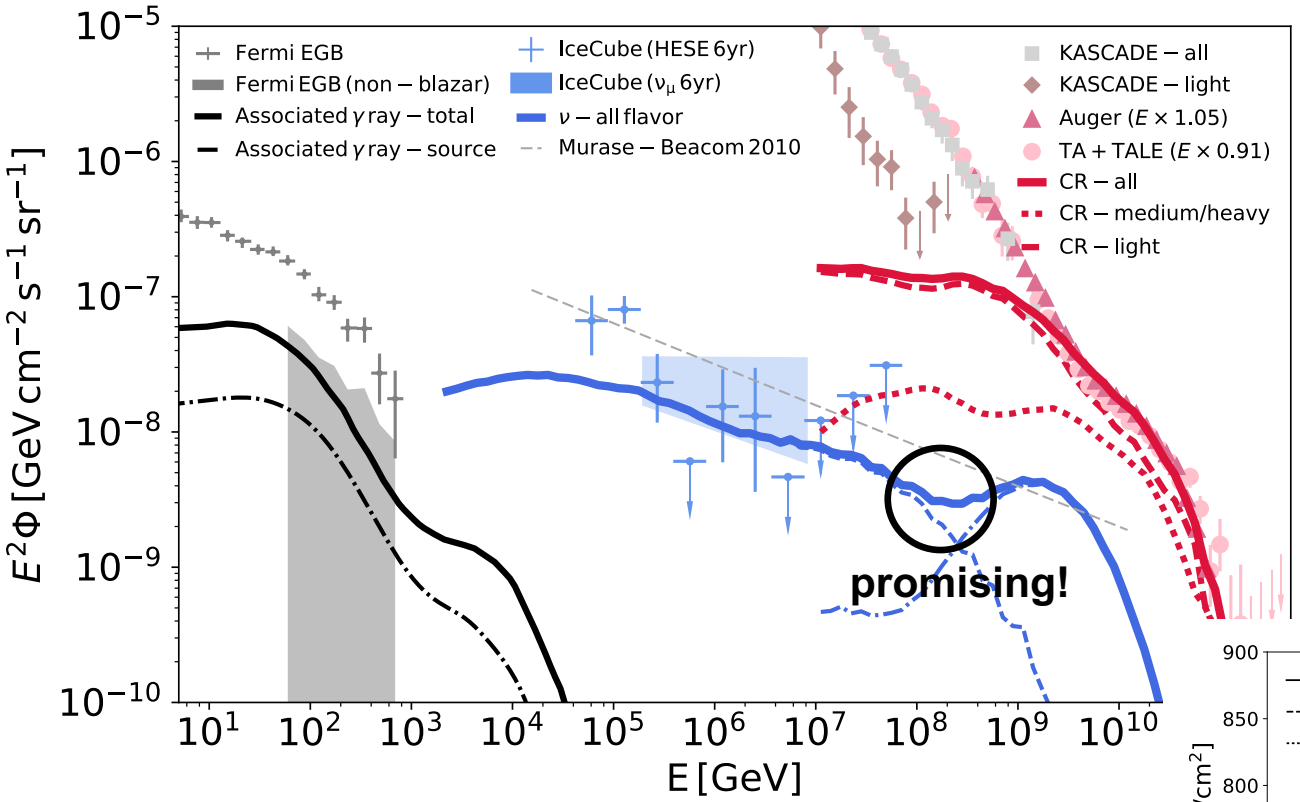
KM & Waxman 16 PRD

PeVν – confined CR
UHECR – escaping CR
sub-TeVγ – "sum"

cf. Yoshida & KM: ICRC for CR "accelerator" case

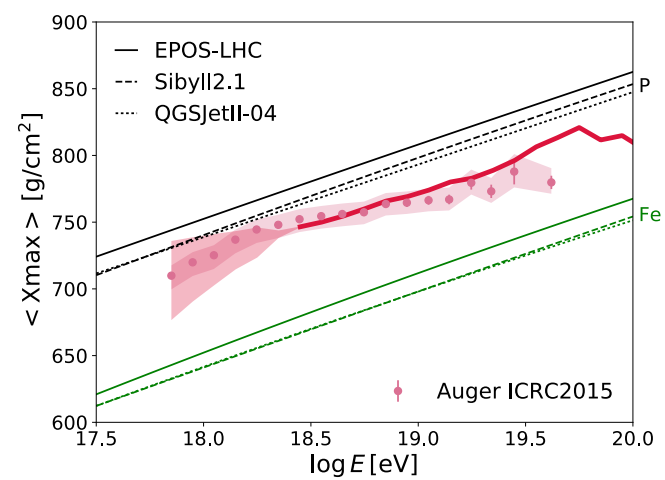
Ex. AGN Embedded in Galaxy Clusters/Groups

Unifying >0.1 PeV ν, sub-TeV γ, and UHECRs (including 2nd knee & composition)



see Ke Fang's review talk!

Fang & KM 18 Nature Phys.



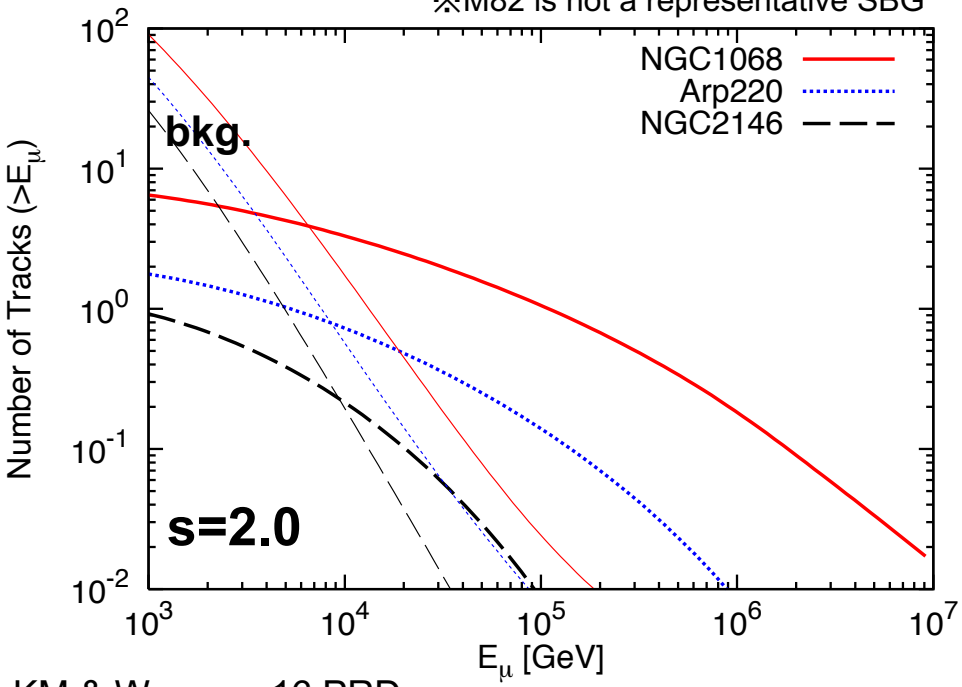
- AGN as "UHECR" accelerators
- confinement in cocoons & clusters → IceCube
- escaping nuclei: "hard" spectrum → Auger X_{max}
- smooth transition from source ν to cosmogenic ν

Neutrino Tests: Detectability of Neutrino Sources

γ-ray spectra of pp sources should be hard: **s<2.1-2.2** (KM, Ahlers & Lacki 13)
→ nearby "representative" sources w. **s~2.0-2.1 are promising**

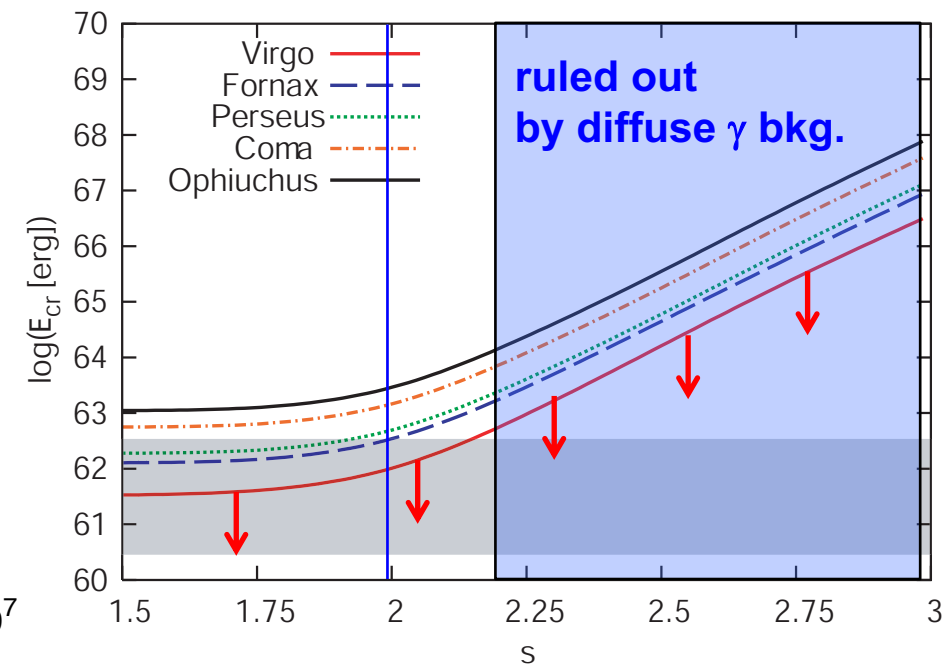
nearby starburst galaxies (north)
IceCube 10 year observations

※M82 is not a representative SBG



KM & Waxman 16 PRD

nearby galaxy clusters
IceCube 5 year observations



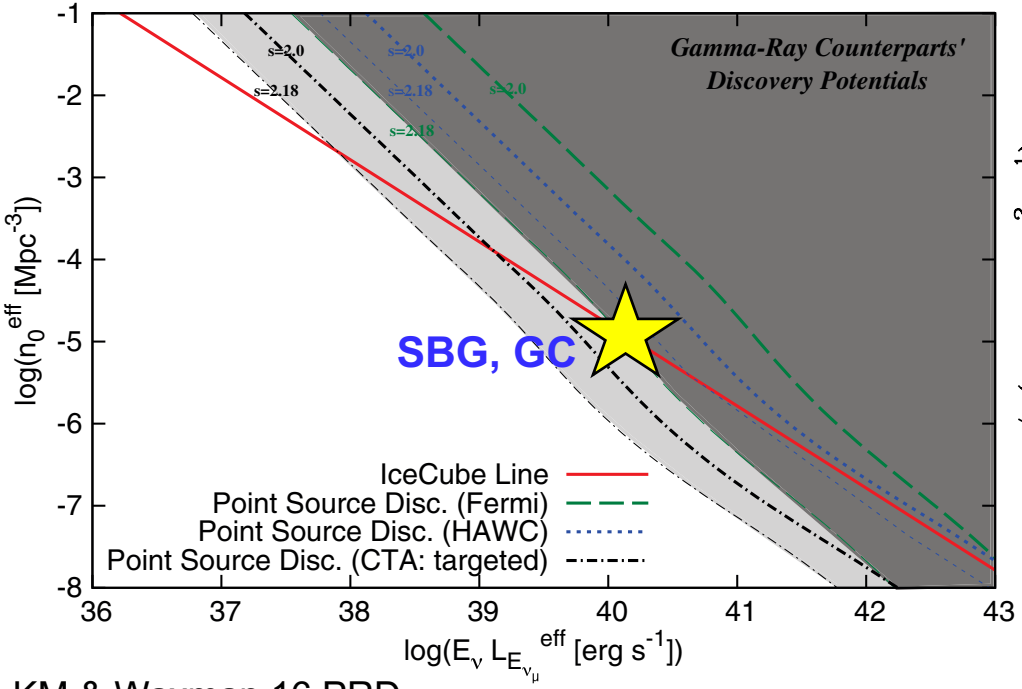
KM & Beacom 13 JCAP

- Current IceCube may see ~2-3σ fluctuations (ex. NGC 1068?)
- IceCube-Gen2 is necessary for discoveries anyway

Gamma-Ray Tests: Importance of TeV Observations

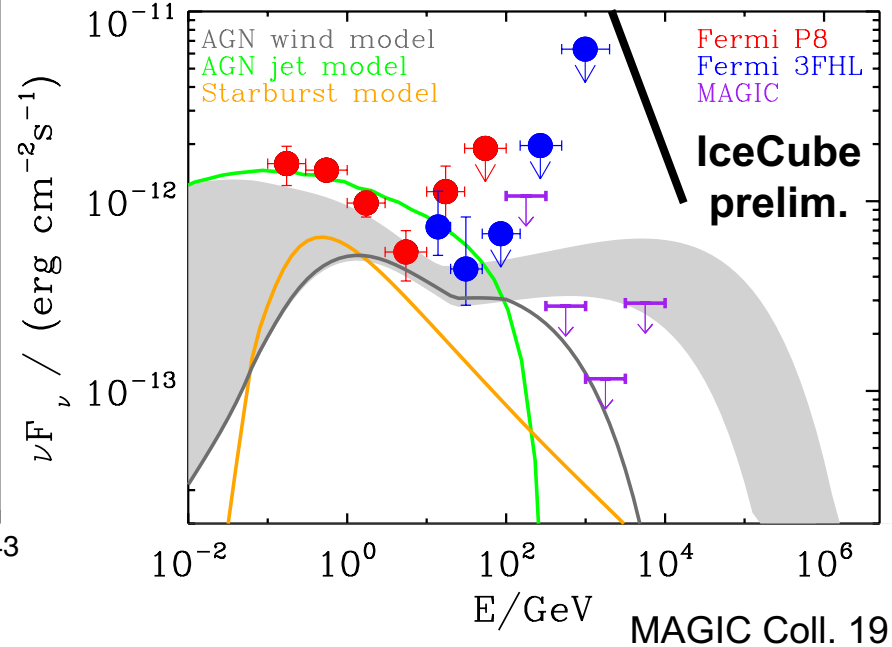
Starbursts & galaxy clusters/groups: γ-ray transparent up to ~1-100 TeV
s~2-2.1 → promising for γ-ray targeted (point-source & stacking) searches

γ-ray constraints on number density



KM & Waxman 16 PRD

NGC 1068

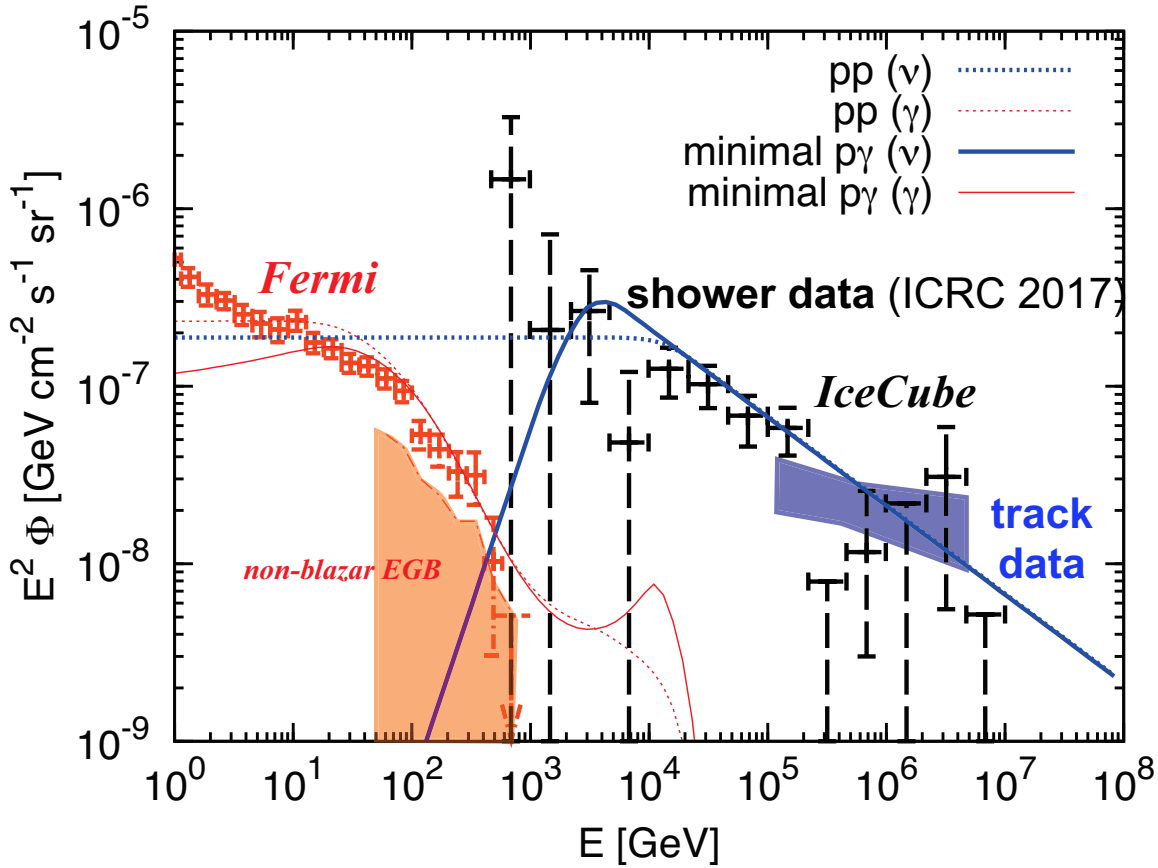


MAGIC Coll. 19

- About 10 representative sources should be seen by CTA
- Possible to have strong constraints even w. current IACTs

Medium-Energy Excess Problem

- 10-100 TeV shower data: large fluxes of ~10^{-7} GeV cm^{-2} s^{-1} sr^{-1}



KM, Guetta & Ahlers 16 PRL

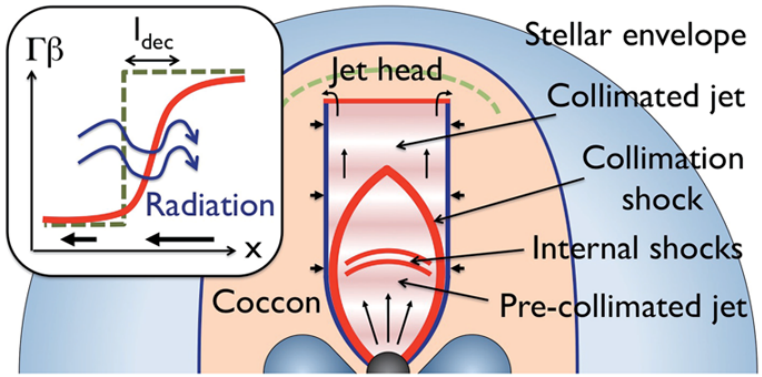
Fermi diffuse γ-ray bkg. is violated (>3σ) if ν sources are γ-ray transparent

→ **existence of "hidden (γ-ray dark) sources"**

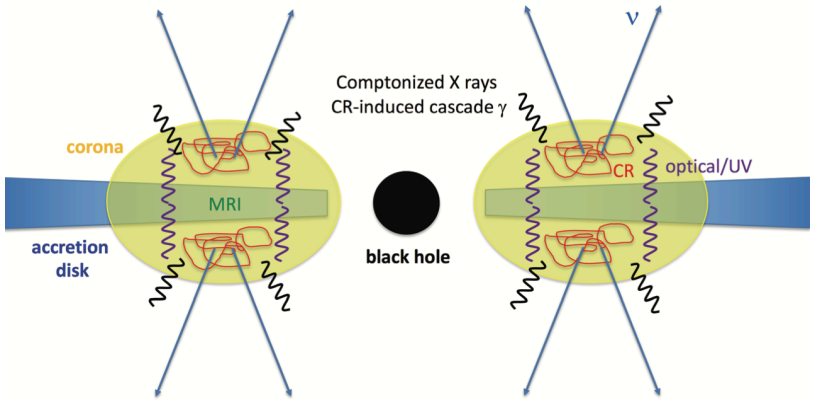
(ν data above 100 TeV can be explained by γ-ray transparent sources)

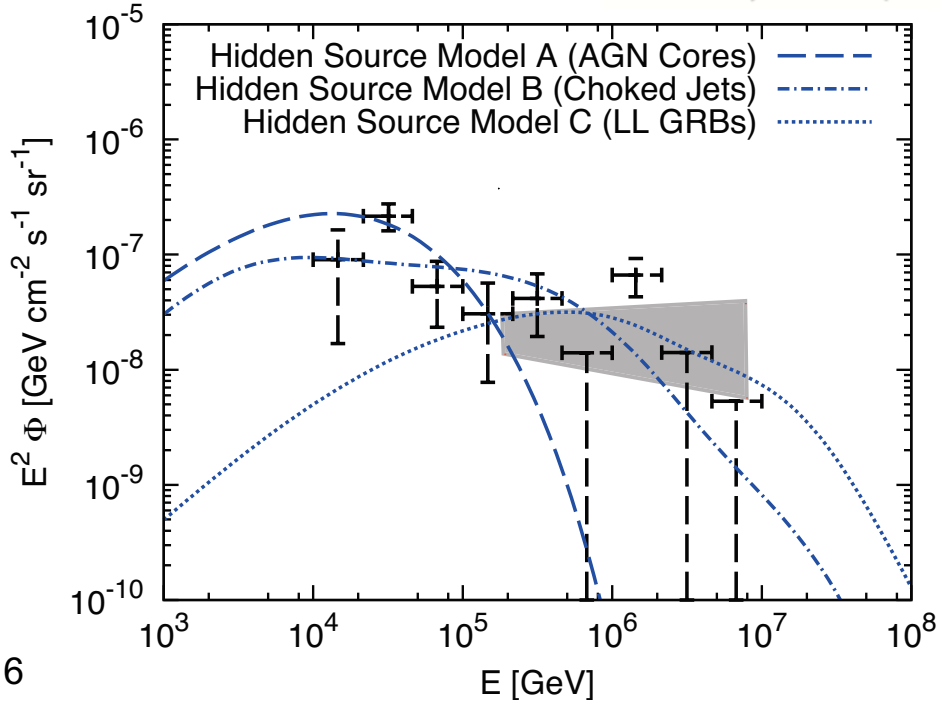
Hidden Cosmic-Ray Accelerators?

Low-power GRBs (choked jets)



Supermassive black hole cores





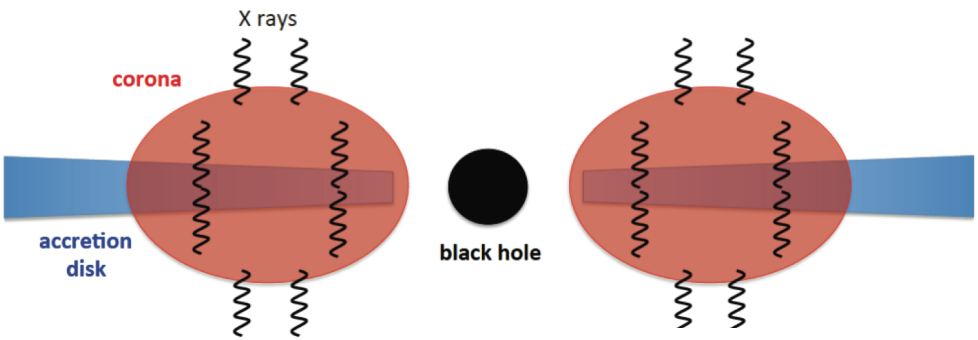
Kimura, KM & Toma 15 ApJ
KM & Ioka 13 PRL
KM+ 06 ApJL

see also:
Bhattacharya+ 15
Nakar 15
Senno, KM & Meszaros 16

see also:
Stecker 13
Kalashev+ 15
KM, Kimura & Meszaros 19

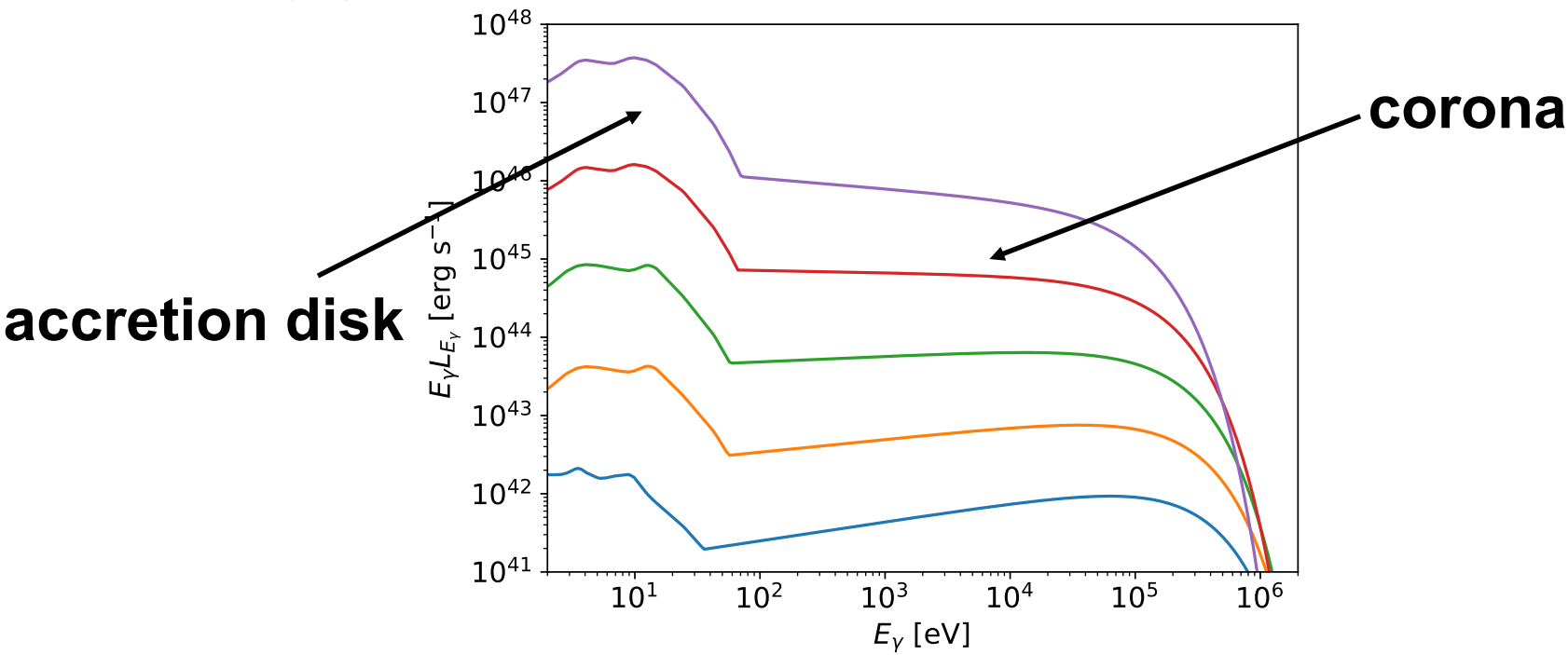
Vicinity of Supermassive Black Holes

Cores of active galactic nuclei (mainly radio-quiet AGNs)



disk-corona model

X-rays=Compton by thermal e
(not accretion shocks)
supported by observations & theory (simulations of MRI)

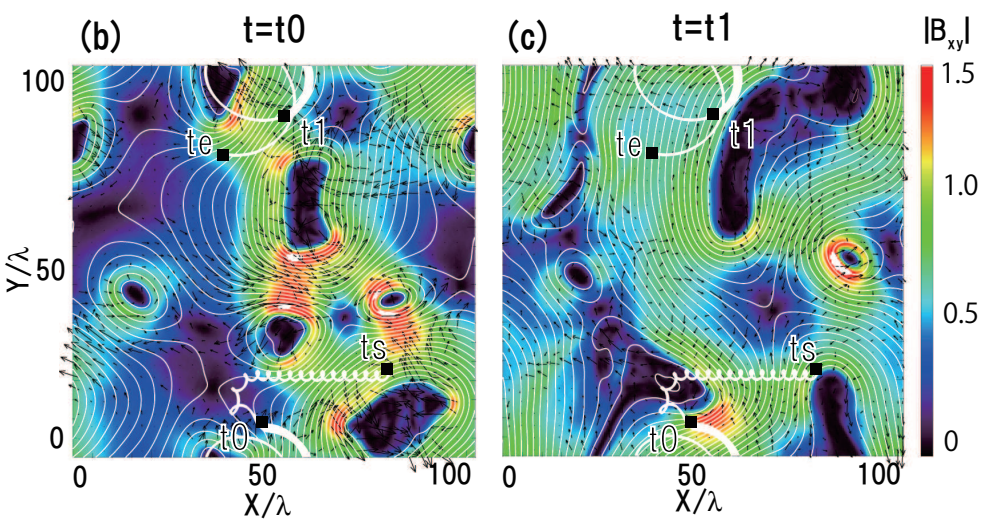


Particle Acceleration in RIAFs/Coronae

Magnetorotational Instability (MRI) -> turbulence & reconnection
collisionless for ions -> particle acceleration

Low-luminosity AGN

accretion disk is "radiatively inefficient"
low density: collisionless

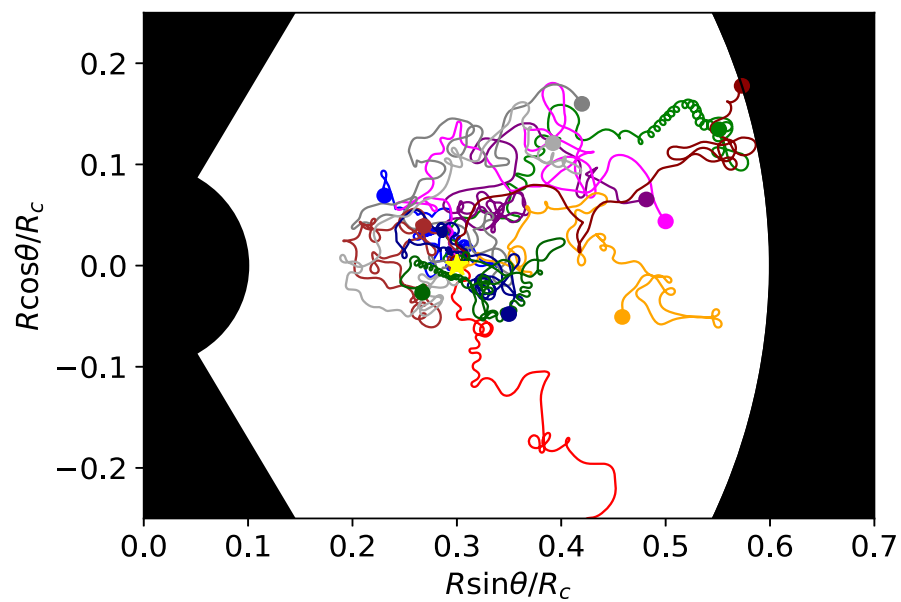


stochastic acc. w. PIC simulations

Hoshino 12 PRL

Seyfert/Quasar (radio-quiet AGN)

standard accretion disk: collisional
but coronal region: collisionless

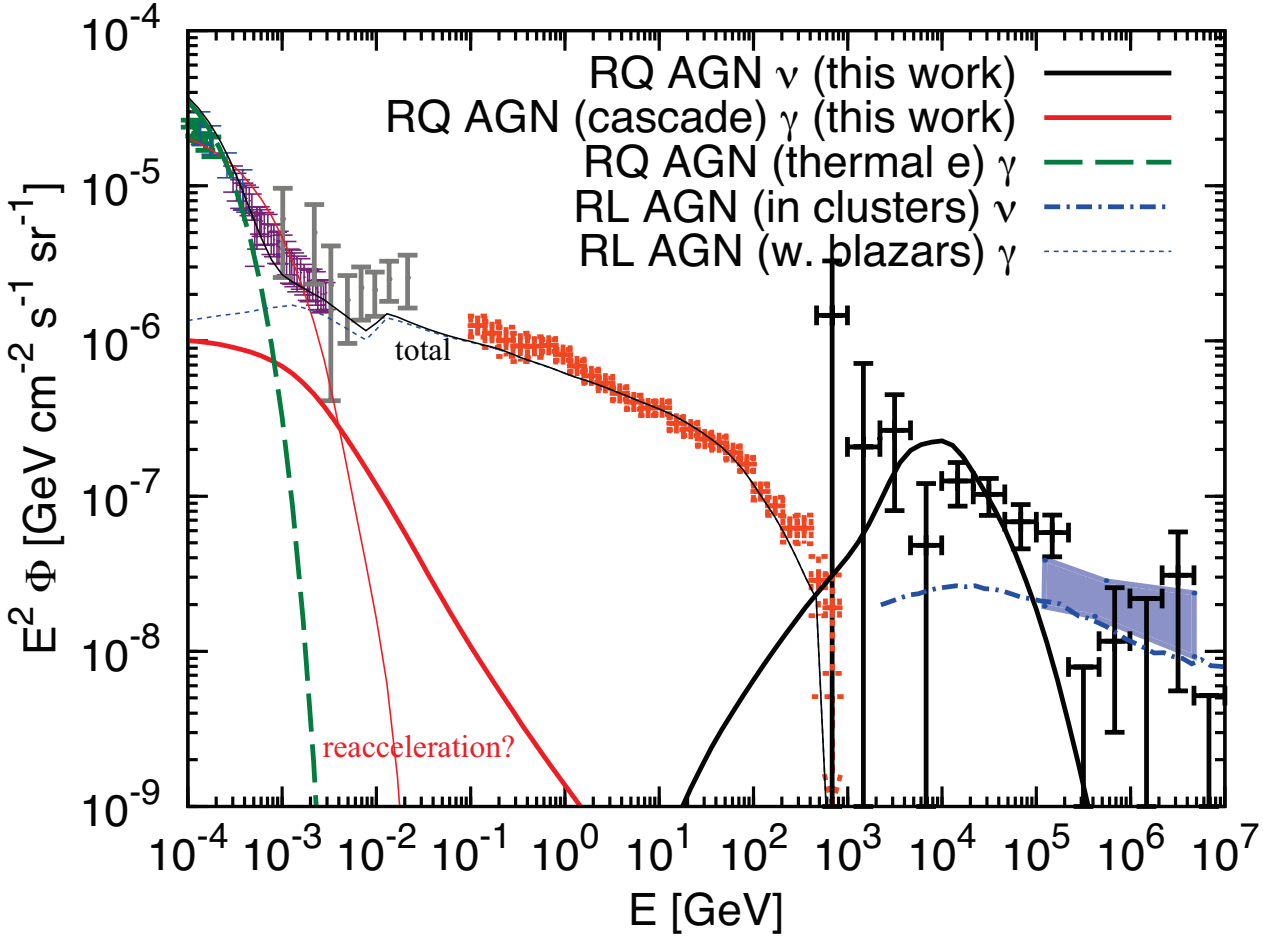


stochastic acc. w. global MRI simulations

Kimura, KM & Tomida 19 MNRAS

TeV Neutrino – "MeV" Gamma-Ray Connection

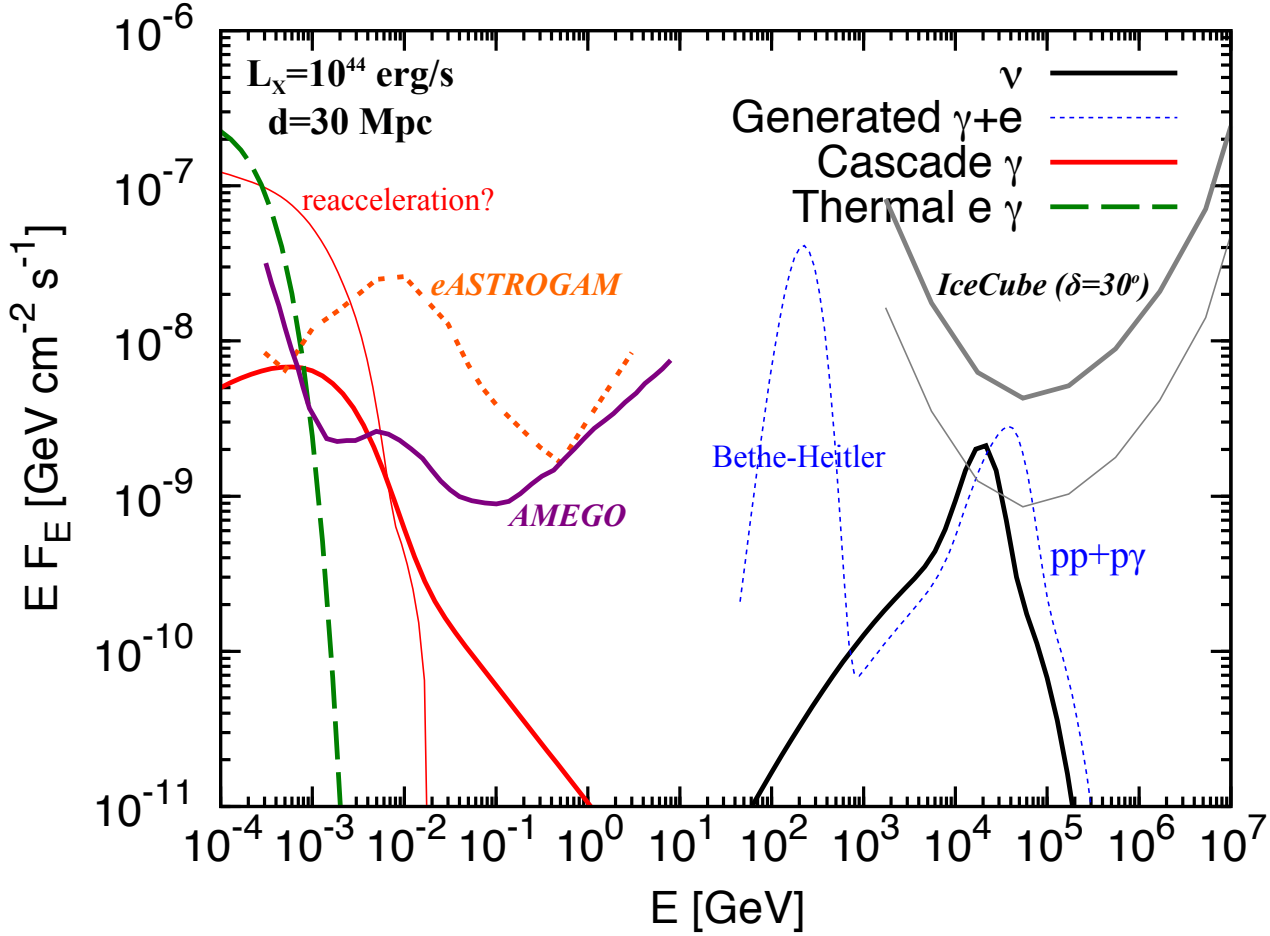
KM, Kimura & Meszaros 19



- 10-100 TeV ν by X rays from coronae & MeV γ by UV from accretion disks ("unique" consequence of disk-corona SEDs)
- X/MeV γ and 10-100 TeV ν backgrounds can be simultaneously explained

Detectability of Nearby Radio-Quiet AGN

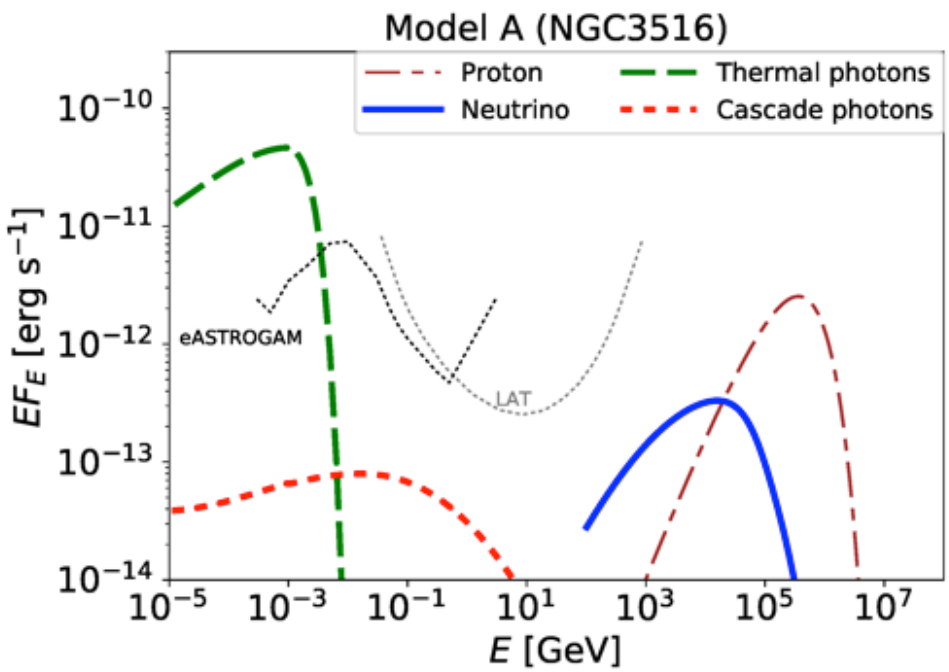
KM, Kimura & Meszaros 19

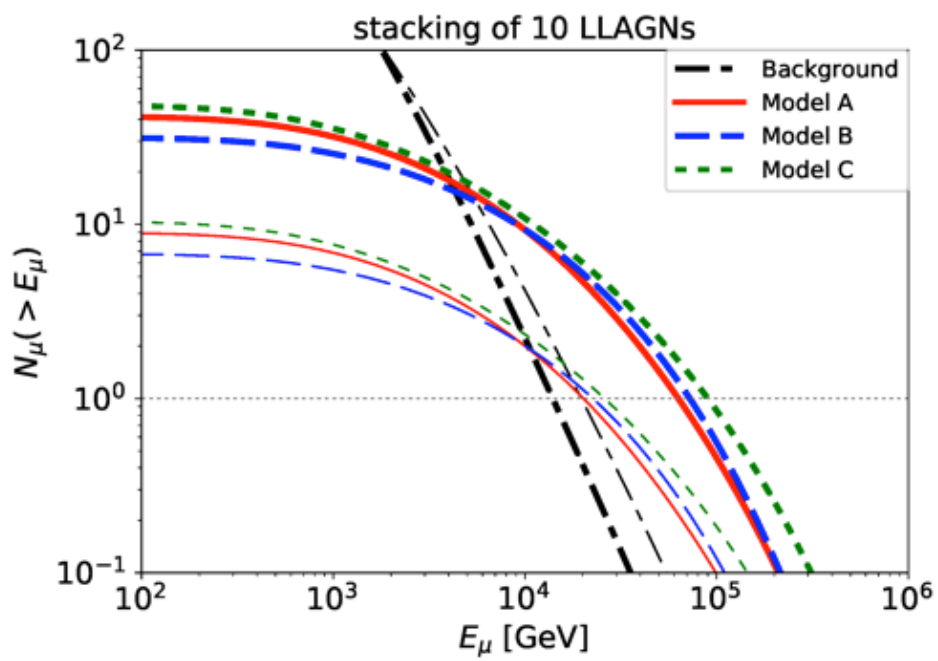


- Bethe-Heitler dominance (consequence of disk-corona SEDs)
  → "Robust" MeV γ-ray connection: detectable by AMEGO etc.
- Neutrinos: stacking on X-ray AGNs & point-source searches w. Gen2

Applications to Low-Luminosity AGNs

Kimura, KM & Meszaros 19





- CR-induced cascade γ rays are difficult to observe
- Detection of MeV γ due to thermal electrons is promising
- Neutrinos can be seen by IceCube-Gen2

Summary

Multi-messenger tests for the origin of IceCube neutrinos

>100 TeV neutrinos

- Consistent w. “predictions” of CR reservoirs (starbursts, clusters)
- Unification: connection to sub-GeV γ-ray background and UHECRs
- Neutrinos: Gen2 is essential but maybe hints in IceCube data
- γ rays: CTA is essential but current IACTs probe special sources

<100 TeV neutrinos

- Hidden neutrino sources (choked GRB jets, AGN cores)
- AGN core models: unique connection to X/MeV γ-ray backgrounds
- Nearby Seyferts should be detected by IceCube-Gen2 & AMEGO
- With the same physics low-luminosity AGNs are also detectable

Request for Gen2: ~0.1 deg resolution & keep threshold ~10 TeV