The TeV Cosmic-Ray Anisotropy from Local Dark Matter Annihilation

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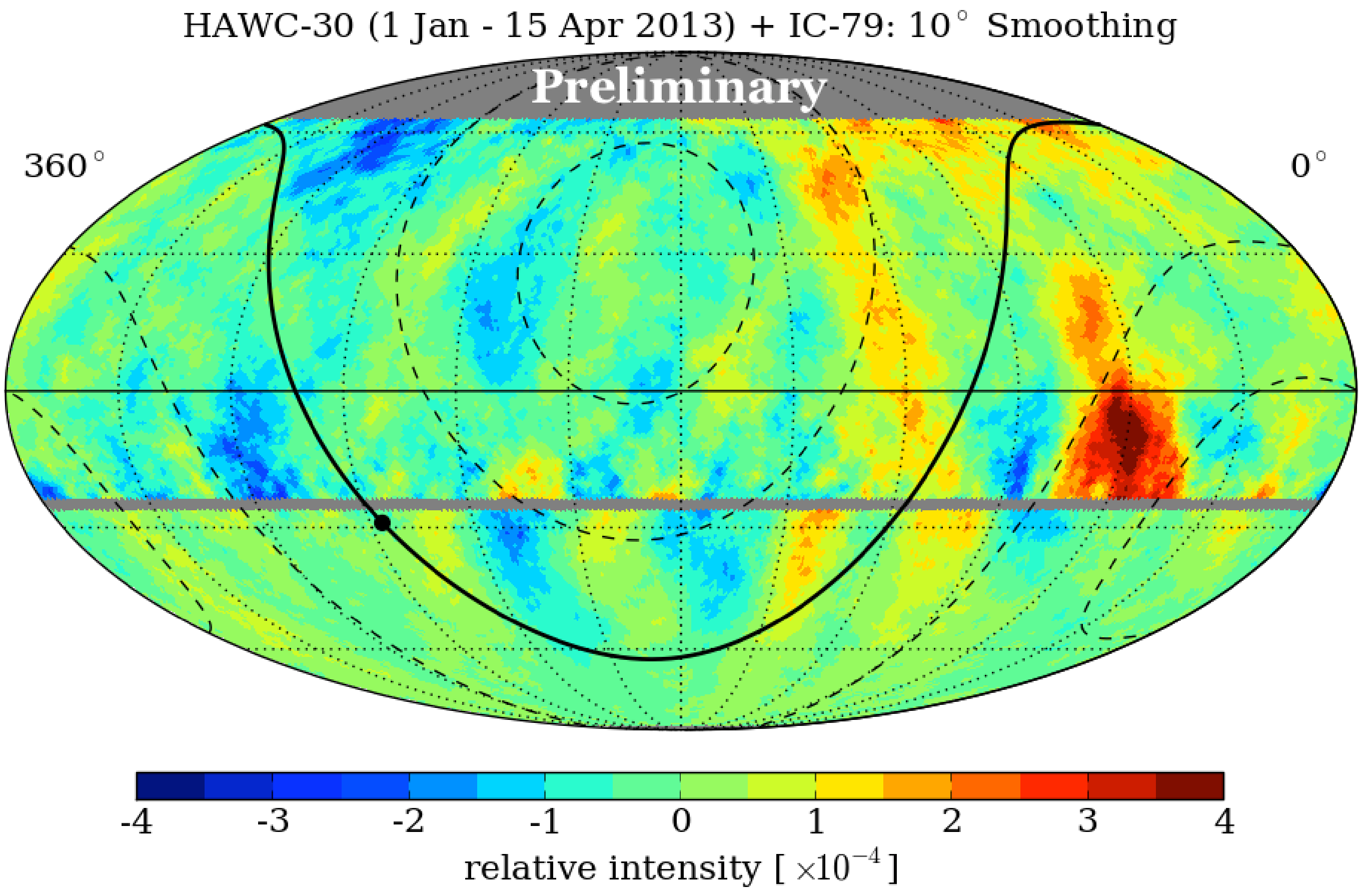
The TeV Cosmic-Ray Small-Scale Anisotropy



Observed by:

Milagro: PRL 101:221101, 2008
IceCube: ApJ 765:55, 2013
ARGO-YBJ: PRD 88:082001, 2013
HAWC: arXiv:1310.0072, 2013

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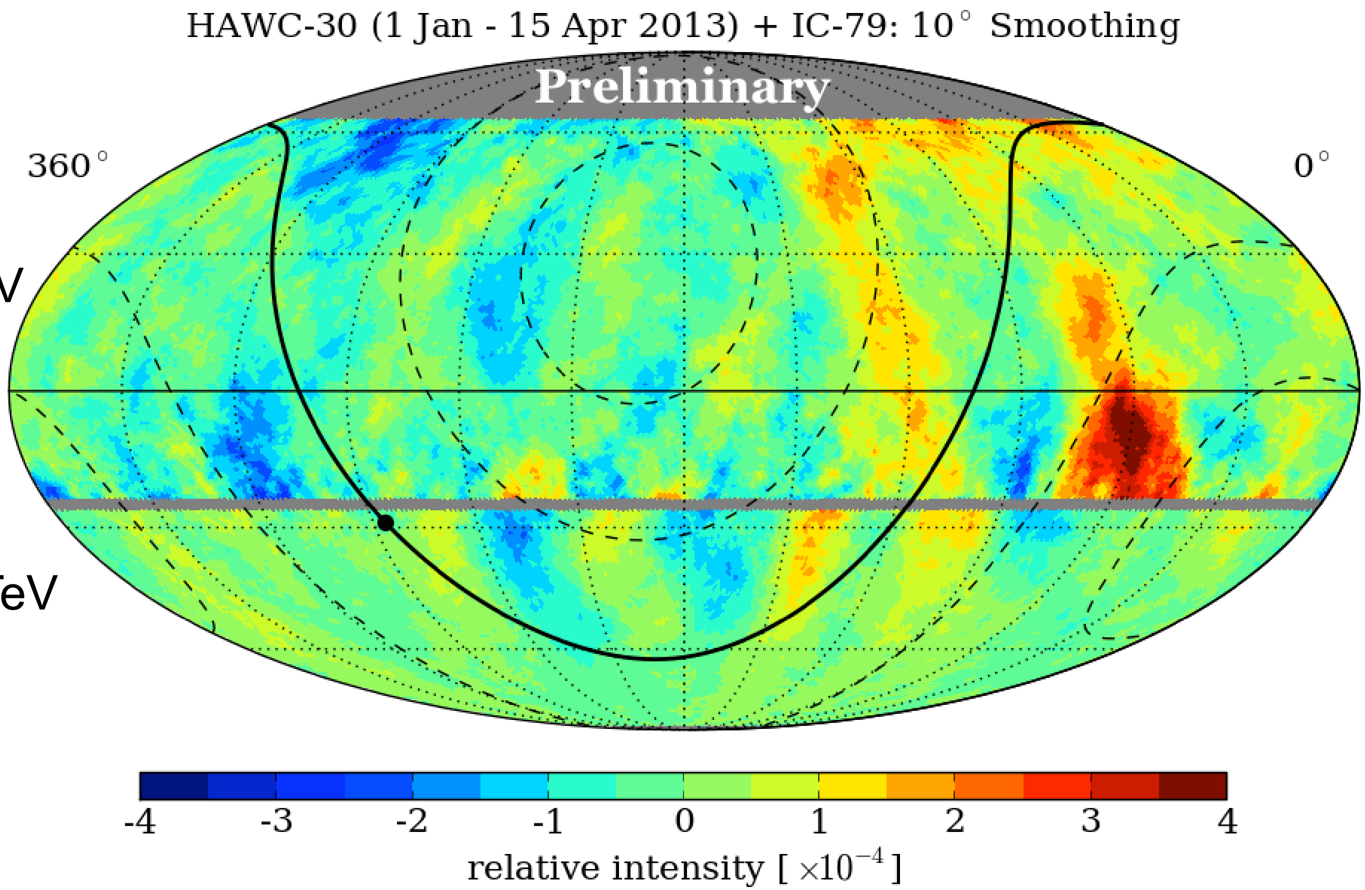
HAWC ~ few TeV



IceCube ~ 20 TeV

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IceCube: ApJ 765:55, 2013
ARGO-YBJ: PRD 88:082001, 2013
HAWC: arXiv:1310.0072, 2013

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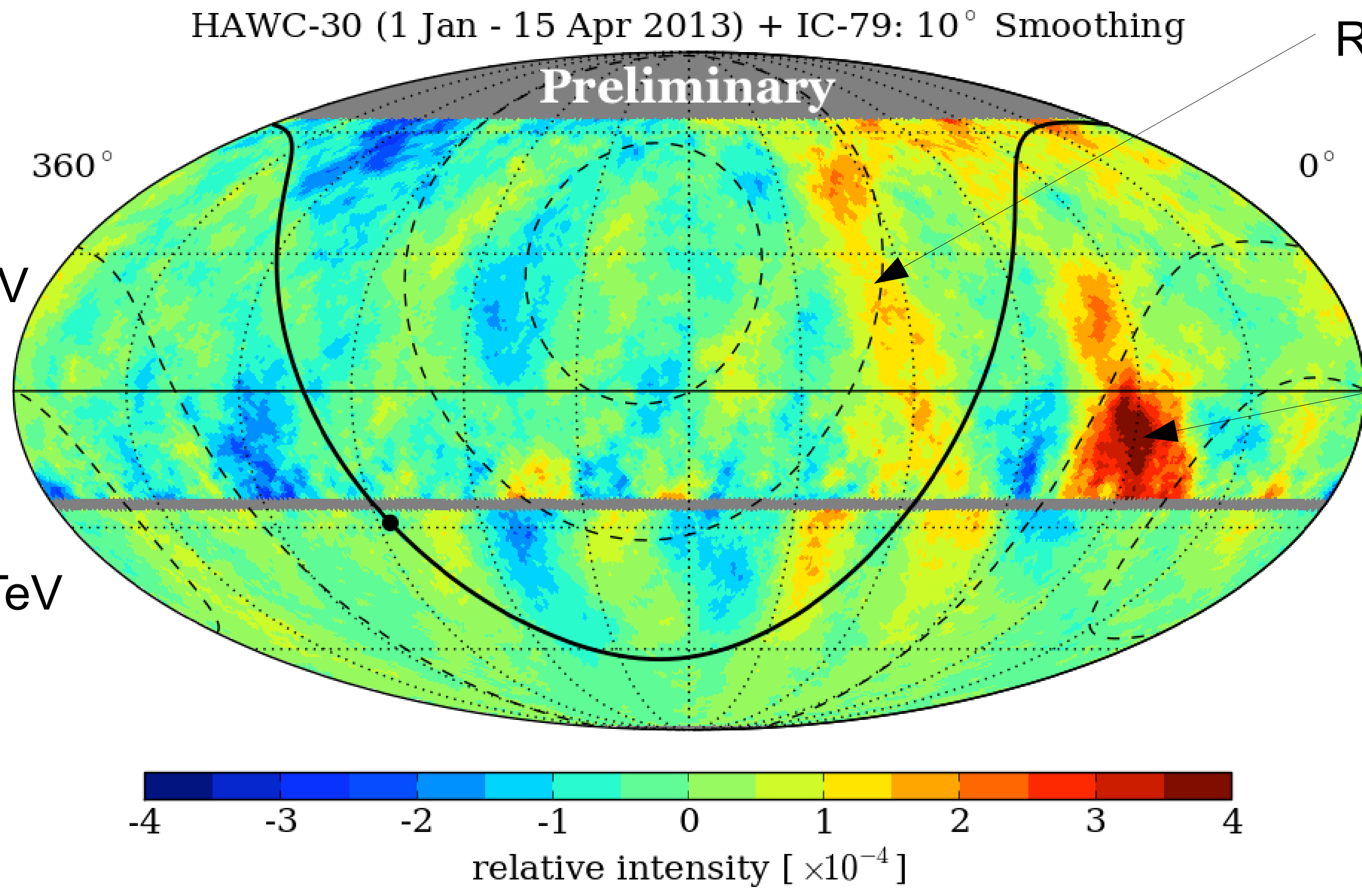

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Milagro: PRL 101:221101, 2008
IceCube: ApJ 765:55, 2013
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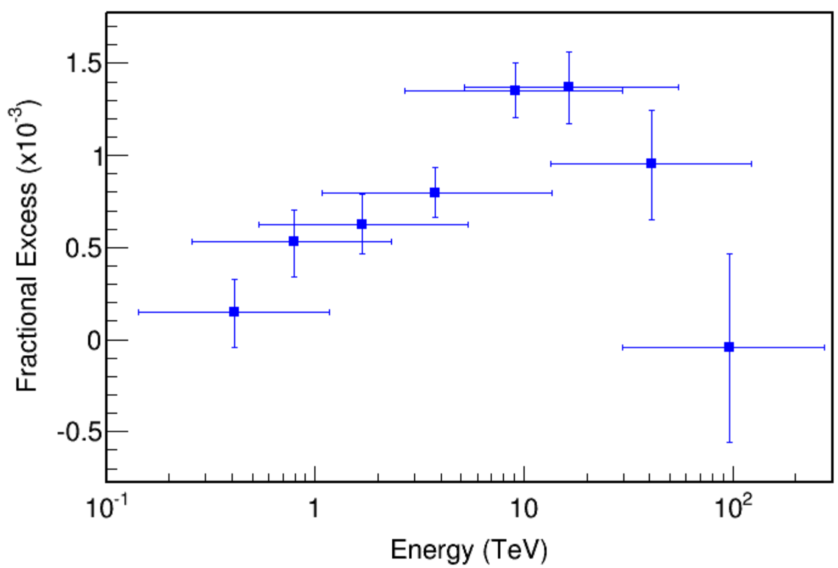
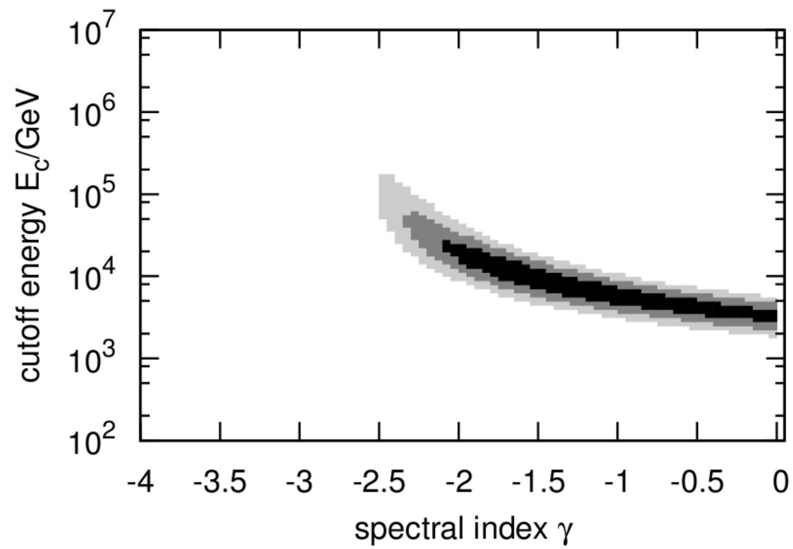
HAWC: arXiv:1310.0072, 2013

Details of the CR Anisotropy

- 10^{-4}-10^{-3} excess over the isotropic intensity
- Observed on angular scales down to 10º
- Inconsistent with gamma-ray emission
- The spectrum is peaked about ~10 TeV

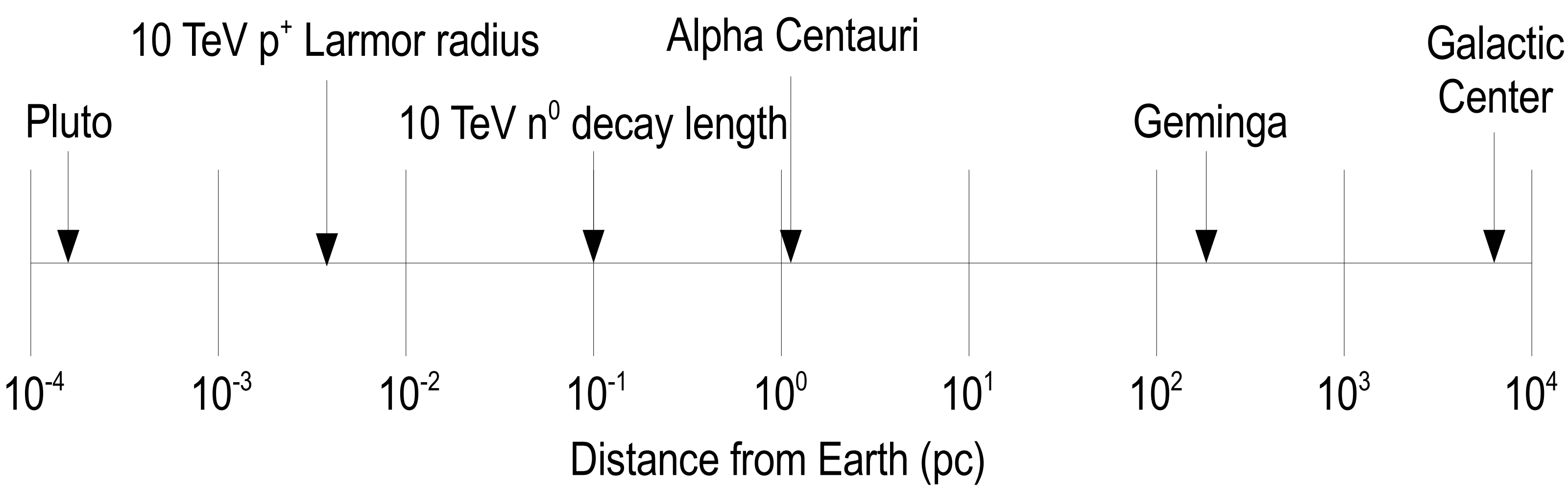




Abdo et al. 2008

The Impossible Signal

- From propagation over long distances, CRs should be isotropized due to diffusion in the turbulent magnetic field.
- For 10 TeV CRs, the Larmor radius in the local 2 μG magnetic field is only 0.005 pc
- For a source of neutrons, the decay length of a 10 TeV neutron is 0.1 pc
- No source of CRs is so close to Earth



Explanations Require Nonstandard Propagation

Magnetic mirror (Drury & Aharonian 2008)	Unlikely field configuration
Anisotropic turbulence (Malkov+ 2010)	Fields should have general isotropy
Local Source in the heliotail (Lazarian & Desiati 2010)	Extremely local unknown source
Strangelets in nearby molecular clouds (Kotera+ 2013)	New matter configuration
Power leakage from large-scale anisotropy (Ahlers 2014)	Should see power at smaller and larger scales as well – needs to be verified

Any explanation must determine why the features of the signal are not diffuse and/or why the source of the signal is so close to Earth

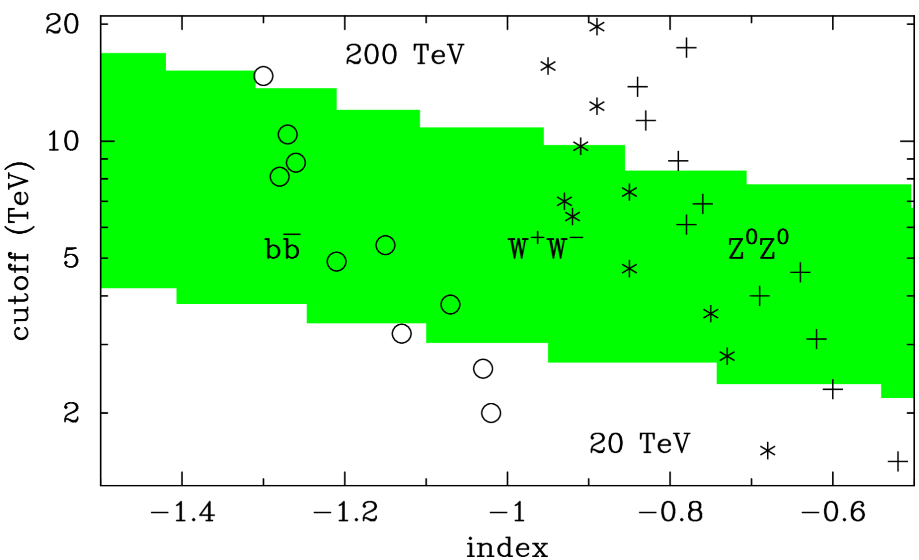
Anisotropy from Local Dark Matter Subhalos

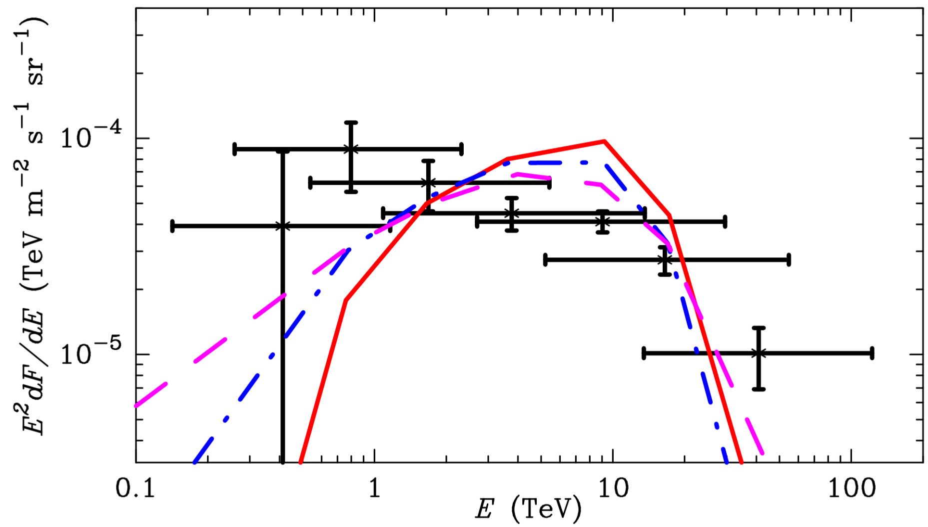
- Many subhalos expected in DM substructure
- A 10^6 $M_\odot$ subhalo corresponds to a density of ~10^{-4} probability at $R_\odot$ from GC
  - ~10 such subhalos ±100pc of $R_\odot$ in the Galaxy
  - Smaller, closer subhalos are even more probable and numerous, though below simulation resolution

Anisotropy from Local Dark Matter Subhalos

- Such a nearby subhalo could be the cause of the TeV CR anisotropy (JPH, arXiv:1307.6537)
  - Can be close enough that coherent magnetic fields are likely
  - Would cause nondiffusive CR transport
- Astro physics is largely insensitive to the details of the DM subhalo mass
- Particle physics is largely insensitive to the details of the DM particle model

Anisotropy Spectrum is Consistent with TeV DM



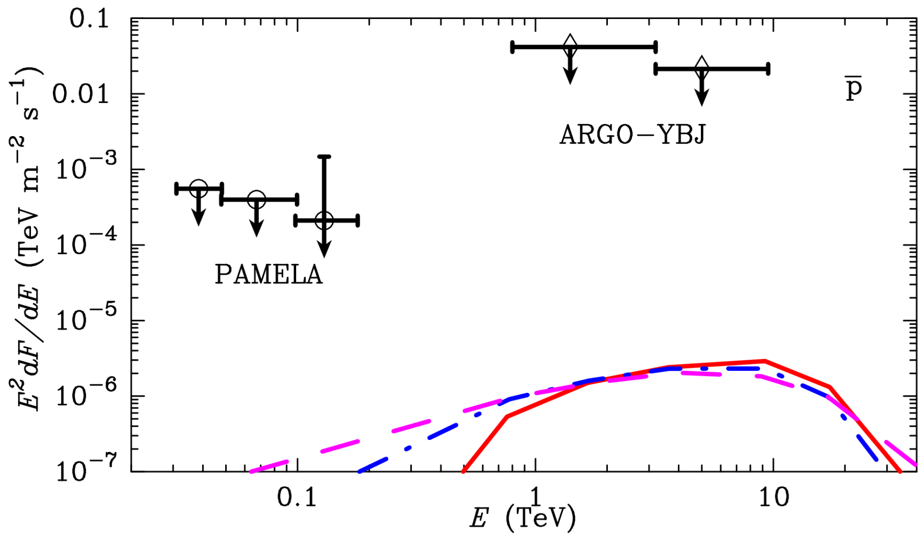


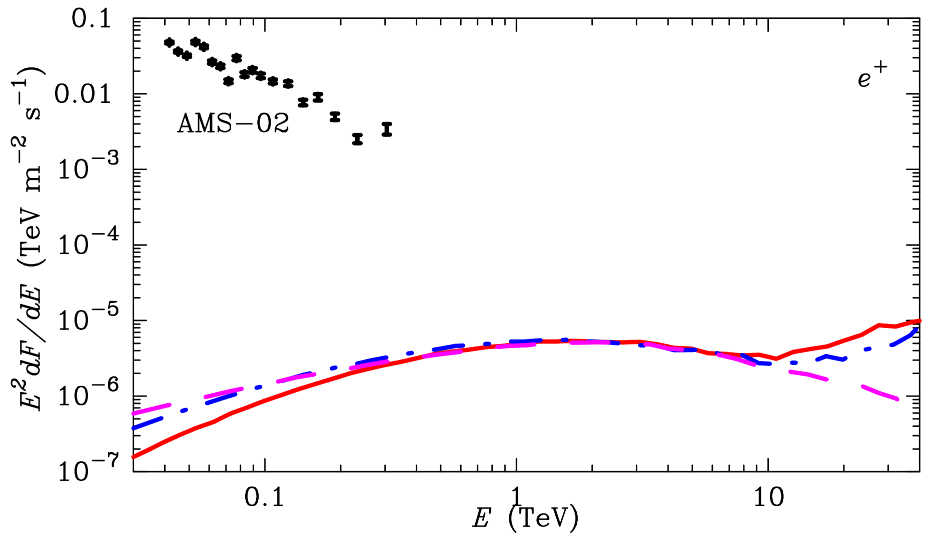
- Left: Milagro-consistent spectra (green region) vs DM spectral parameters
  - W^+W^- (stars), Z^0Z^0 (crosses), $b\bar{b}$ (circles) from 20-200 TeV
- Right: 60 TeV W^+W^- (red), 50 TeV Z^0Z^0 (blue), 100 TeV $b\bar{b}$ (magenta) vs Milagro spectrum
  - Need better error bars to distinguish spectra, verify consistency with DM
  - Energy losses during propagation may shift peaks to left and soften cutoffs

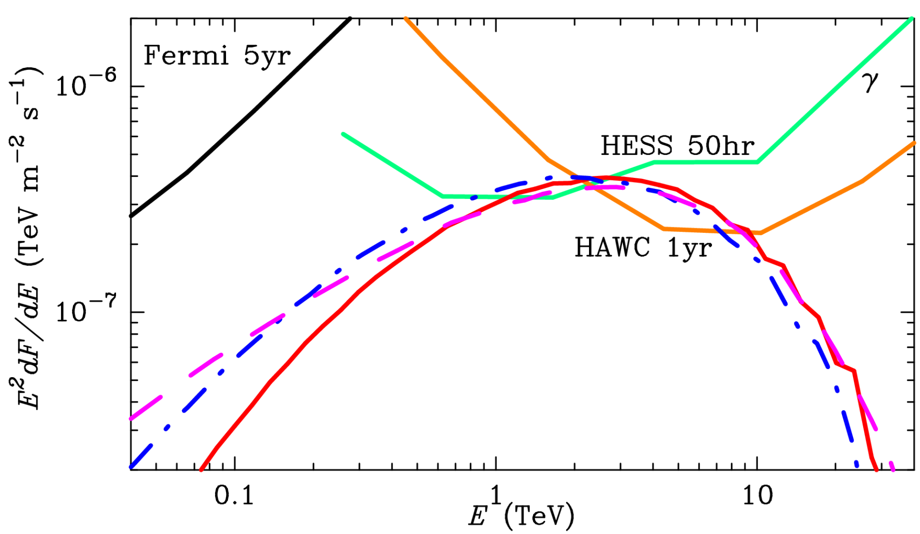
Example: DM Model Motivated by H.E.S.S. GC

- Interpretations of the H.E.S.S. GC include a DM particle of ~50TeV mass dominated by the Z^0Z^0 annihilation channel, with cross-section ~2000 times thermal
  - Cross-section could be explained by natural Sommerfeld enhancement from DM Z-exchange
- A $10^6 M_{sun}$ subhalo within 100pc of the Earth near a coherent magnetic stream, annihilating this DM, would give a CR signal large enough to produce the CR anisotropy.

DM Model is Consistent with Current Observations







DM fluxes for: 60 TeV W^+W^- (red), 50 TeV Z^0Z^0 (blue), 100 TeV bb (magenta) with a 10^6 M_{sun} subhalo

Top: Total flux from DM subhalo compared to isotropic flux from 0.03sr region for antiprotons (left) and positrons (right)

Left: Experimental sensitivities to 5°-extended (half-width) gamma-ray sources, compared to DM subhalo gamma-ray flux

Model is Consistent with Observations

- Diffuse anti-protons (PAMELA, ARGO)
- Diffuse positrons (AMS)
  - But pointed could detect it
- All-sky gamma-rays (Fermi, Milagro)
  - For expected extended source
- Pointed gamma-rays (HESS, VERITAS, MAGIC)
  - Would see it if they look at it for ~50 hours
- HAWC
  - Will detect it, if dec > -30

Summary

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- Small-scale anisotropies have been observed in the TeV cosmic rays
- Non-standard propagation and a local CR source are needed
- Local dark matter subhalos can be the source of the anisotropy
- Gamma-ray emission from the subhalo causing the Region A excess should be observable in gamma rays (HAWC)

Local Dark Matter Subhalo

- Expect many subhalos from DM substructure
- Minimum distance D_{min} to a subhalo consistent with the local DM density

M_{vir}	D_{min}	$J_{\Delta\Omega}(D_{min})$	$J_{\Delta\Omega}(D_{min}$-100 pc)
$10^9\,M_\odot$	933 pc	119	137
$10^8\,M_\odot$	465 pc	114	158
$10^7\,M_\odot$	225 pc	112	247
$10^6\,M_\odot$	108 pc	112	2840
$10^5\,M_\odot$	51.3 pc	111	-
$10^4\,M_\odot$	24.1 pc	110	-
$10^3\,M_\odot$	11.2 pc	109	-

- Scaling with subhalo mass from Bolshoi simulation
- DM flux to source is ~ independent of subhalo mass
- DM flux to magnetic stream is highly scenario-dependent