Multi-messenger constraints on UHECR sources

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Pure-proton UHECR models strongly constrained by Fermi-LAT

Only narrow range of parameter space remains viable*

*and fit to UHECR spectrum and composition is poor

Pure-proton UHECR models strongly constrained by Fermi-LAT

Are mixed-composition models similarly constrained?

Only narrow range of parameter space remains viable*

*and fit to UHECR spectrum and composition is poor

The UFA Source Model


- Allows for injected nuclei to undergo photonuclear disintegration in the source environment
- Explains the origin of ankle and light composition at EeV energies
- Beautifully fits Auger spectrum and composition using escaping mixed-composition
Constraining UFA Source Evolution and Properties with Fermi-LAT and IceCube
Constraints on Source Evolution

LAT diffuse + unresolved point sources

LAT diffuse limits

IceCube limits

Photons

E^2 dN/dE (GeV/cm^2/sr/s)

m = -4
m = -2
m = 0
m = +2
m = +4
SFR

IGRB A
Diffuse Limit A
IGRB B
Diffuse Limit B
IceCube 2017
\gamma's
\nu's

Neutrinos

10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
Constraints on Source Evolution

**LAT diffuse + unresolved point sources**

**LAT diffuse limits**

**IceCube limits**

Sources are not mainly at high redshift

Large parameter space unconstrained
Constraints on Source Temperature

LAT diffuse + unresolved point sources

LAT diffuse limits

IceCube limits

Photons

Neutrinos

$E^2 dN/dE$ (GeV/cm$^2$/sr/s)

$T = 100$ K
$T = 150$ K
$T = 200$ K
$T = 250$ K
$T = 300$ K
$T = 350$ K
$T = 400$ K
Constraints on Source Temperature

LAT diffuse + unresolved point sources

LAT diffuse limits

IceCube limits

Neutrino flux very sensitive to source temperature

Increasing \( T \)

Photons

Neutrinos

\( E^2 dN/dE \) (GeV/cm\(^2\)/sr/s)

\( 10^{-10}, 10^{-9}, 10^{-8}, 10^{-7}, 10^{-6} \)

\( T = 100 \, K \)
\( T = 150 \, K \)
\( T = 200 \, K \)
\( T = 250 \, K \)
\( T = 300 \, K \)
\( T = 350 \, K \)
\( T = 400 \, K \)
Constraints on Source Temperature

**Neutrino flux very sensitive to source temperature**

- **LAT diffuse + unresolved point sources**
- **IceCube limits**
- **Increasing $T$**

**LAT diffuse limits**

**IceCube 2017**

**Photons**

**Neutrinos**

$I_{\nu} / I_{\gamma}$

**$T_{src} < 300 K$**
Several UFA variants give good fits to Auger spectrum + composition
Can $\gamma$ & $\nu$'s constrain UFAs?

LAT diffuse + unresolved point sources

LAT diffuse limits

IceCube limits

Photons

Neutrinos

$E^2dN/dE$ (GeV/cm$^2$/sr/s)

E/eV

Fiducial
Syst.
Gal. mix
Pure proton

IGRB A
Diffuse Limit A
IGRB B
Diffuse Limit B
IceCube 2017
$\gamma$'s
$\nu$'s
Constraints on Benchmark UFAs

LAT diffuse + unresolved point sources

LAT diffuse limits

IceCube limits

UFA models $\Rightarrow$ secondaries should be seen soon!
Summary

• Pure-proton models survive only in a narrow parameter space (and their UHECR fits are poor)

• Mixed-composition (UFA) models not yet constrained by secondary messenger limits

• Neutrino fluxes strongly constrain possible source temperatures

• UFA models:
  ✔ Auger spectrum
  ✔ Auger composition
  ✔ LAT compatible
  ✔ IceCube compatible