Auger results and the sources of UHECRs

Michael Kachelriess

NTNU, Trondheim
Outline of the talk

1. Motivation & expectations for UHECR astronomy
2. Auger data and their interpretation
3. Auto-correlation analysis
4. Cen A as UHECR source
What is the bonus of UHECR astronomy?

- astronomy with VHE photons restricted to few Mpc:

![Graph showing the photon horizon and its interaction with various astronomical phenomena like CMB, IR, and radio.]

log10(E/eV) on the y-axis and distance in Mpc on the x-axis.
What is the bonus of UHECR astronomy?

- astronomy with VHE photons restricted to few Mpc:
- astronomy with HE neutrinos:
  - large $\lambda_\nu$, but also large uncertainty $\langle \delta \theta \rangle \gtrsim 1^\circ$
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- astronomy with VHE photons restricted to few Mpc:
- astronomy with HE neutrinos:
  - large $\lambda_{\nu}$, but also large uncertainty $\langle \delta \theta \rangle \gtrsim 1^\circ$
  - small event numbers: $\lesssim$ few/yr for PAO or ICECUBE
  - identification of steady sources challenging
What is the bonus of UHECR astronomy?
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- use larger statistics of UHECRs
- well-suited horizon scale
- small enough deflections in magnetic fields?
Possible anisotropies of extragalactic CRs:

1. Dipole anisotropy – cosmol. Compton-Getting effect
   - induced by motion of Sun relative to cosmological rest frame
   - requires $\lambda_{CR}(E) \gtrsim \lambda_{LSS}$
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2. Anisotropies on medium scales
   - $z \leq 0.2$: spots with $\ell \sim 20-40$ degrees
   - reflects LSS of matter, modified by $B$
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   - Small-scale $\sim \text{exp. angular resolution/deflections in } B$
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4. Correlations with specific sources
   - requires small $qB/E$ and small $N_s$
   - good source catalogue
Correlations with AGNs: Auger analysis

AGN from VCC catalogue:

- mainly Seyfert galaxies
- expectation: $E_{\text{max}} \ll 10^{20}\text{eV}$ for most AGN in VCC
first data set with data < May 2006 to fix cuts:
\( E_{\text{th}} = 56\text{EeV}, \, \ell_0 = 3.1^\circ \) and \( d \leq 75 \text{Mpc} \).

second data set May 2006–August 2007:
13 events, 8 correlated, 2.7 expected \( \Rightarrow p_{\text{ch}} \approx 2 \times 10^{-3} \)
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- second data set May 2006–August 2007:
  13 events, 8 correlated, 2.7 expected \( \Rightarrow p_{\text{ch}} \approx 2 \times 10^{-3} \)
- just a “3 \( \sigma \) effect”, test against isotropy, no propagation
- not confirmed by HiRes
- AGN or something with similar distribution?
Correlations with AGNs: PAO analysis

- 27 CRs (☉) and 472 AGN (★):
Correlations with AGNs: PAO analysis

- 27 CRs (○) and 472 AGN (★):

  \[\text{correlated AGN are not promising UHECR sources}\]

  [Moskalenko et al. '08, Hardcaste et al. '08, Rachen '08, ...]
Deflections for $eE/Q = 4 \times 10^{19}$ eV in regular GMF:
Energy threshold consistent with GZK horizon?

- 8 out of 13 CRs ($E \geq 57\text{EeV}$) correlated within 75 Mpc:
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 _under-estimation of energy scale? or only LSS? safer method?_
Comparing with sources:

Use the auto-correlation function,

\[ w(\vartheta) = \frac{DD(\vartheta)}{RR(\vartheta)} - 1, \]

where

- **DD**: number of pairs in catalogue
- **RR**: number of pairs in random sets

for most popular sources of UHECRs:
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for most popular sources of UHECRs: AGN and GRB.
Auto-correlation function of different sources:

\[ A. \text{ Cuoco et al. '07} \]

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Auger results and the sources of UHECRs
Auto-correlation function of different sources:

- Full PSCz
- Absolute magnitude < -24
Auto-correlation function of different sources:

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Auger results and the sources of UHECRs
Auto-correlation function of different sources:

- reduced statistical error
- differences on all angular scales
- reduced dependence on $B$:
  - global comparison on all angular scales
  - only relative deflections enter
- possible to constrain $B$
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Clustering signal for the PAO–Science data

A. Cuoco et al. ’08

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Cen A as UHECR source?

[Romero et al. ’96, Farrar, Piran ’00, Rachen ’08, ...]
Cen A as UHECR source?

**Table:**

<table>
<thead>
<tr>
<th>Source</th>
<th>Initial Protons</th>
<th>Final Protons</th>
<th>Total Neutrinos</th>
<th>( \gamma )</th>
<th>( \gamma ) Spectrum from Cascading</th>
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</thead>
<tbody>
<tr>
<td>CGRO</td>
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<td>HESS</td>
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<tr>
<td>PAO</td>
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<td></td>
<td>acceleration close to AGN core</td>
<td>secondaries by ( p\gamma ) interactions</td>
<td>( \gamma ) spectrum from cascading</td>
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</tbody>
</table>
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• Cen A may be first source observed in TeV $\gamma$-rays and UHECRs