Lower limits on ultrahigh-energy cosmic ray and jet powers of TeV blazars

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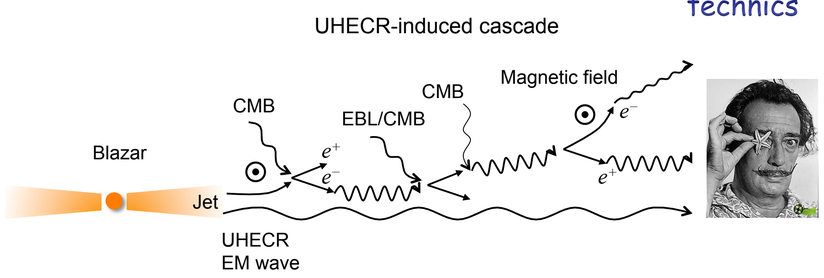
Abstract: Lower limits on the power emitted in ultrahigh-energy cosmic ray (UHECR) protons are derived for TeV blazars with the assumption that the observed TeV gamma rays are generated due to interactions of these protons with cosmic microwave photons. This mechanism may be at work in four blazars, namely 1ES 0229+200; 1ES 1101-232; 1ES 0347-121 and 1ES 1426+428, which are at sufficiently high redshift (>0.1) that allow efficient cascade development to make TeV emission and which are non-varying or very weakly varying at > TeV energies. The lower limits on the UHECR power are lower than the respective synchrotron luminosities in case of all blazars except for 1ES 1426+428. The proposed Auger North Observatory can detect 40 EeV cosmic rays from this extraordinary source and test the UHECR-generated TeV emission model, which requires the intergalactic magnetic field strength to be below 10^{-16} G. The lower limits on the jet power for all four TeV blazars exceed the Eddington luminosity of a 10^9 solar mass black hole in case the injected UHECR spectrum is softer than $E^{-2.2}$.

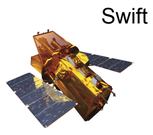
What are the sources of UHECRs?

Blazars are among the most favorite candidates
Many are TeV sources



Blazar detection technics

Swift Satellite



Fermi Gamma-Ray Space Telescope

MAGIC TeV Telescope

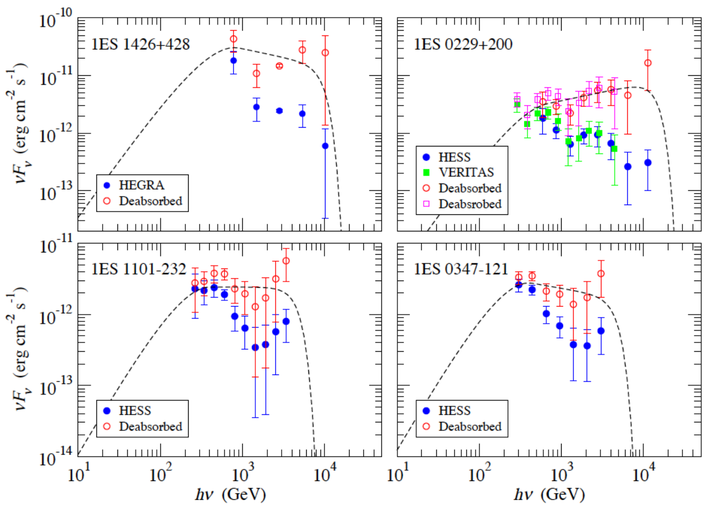
Goldstone Radio Telescope

- UHECR protons lose energy while propagating in the CMB
- If intervening magnetic field is small, primary UHECRs and EM emission from secondary particles can reach us

→ TeV emission from some blazars are from EM cascades induced by UHECR protons, while propagating along our line-of-sight

Apparent γ-ray Luminosity of Selected TeV Blazars

Empirical fits to TeV data deabsorbed to z = 0.1



Energy Losses by UHECR Protons

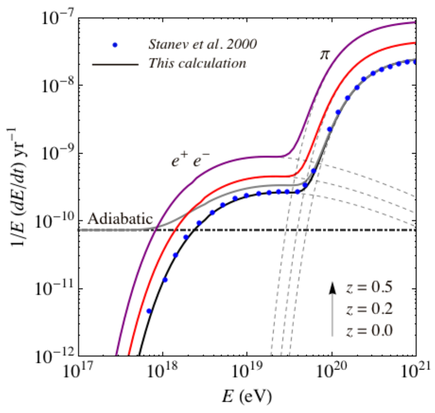
UHECR protons lose energy dominantly by interacting with CMB photons, producing pions and $e^+ e^-$ pairs

Energy loss channels:

Photopion interaction Dominates above ~4×10^{19} eV

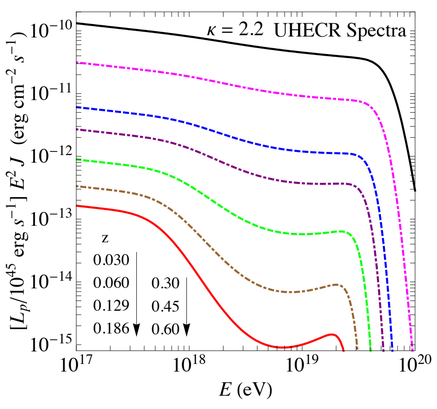
Photopair interactions Dominates below ~4×10^{19} eV

Energy loss-rate increases with redshift due to increasing CMB temperature



Flux of UHECRs is depleted due to collisional losses (Greisen-Zatsepin-Kuzmin effect)

UHECR protons from nearby sources (e.g. blazars) can be detected below the GZK energy if the intervening magnetic field is very small



Deriving The Lower Limits

- Assumption – Non-varying or weakly varying TeV gamma-ray emission from distant blazars is dominated by cascade emission, in the cosmic microwave background and optical-ultraviolet background, induced by UHECR protons that are originated in the blazar jets
- Reprocessing of the energy lost by UHECR protons to gamma rays happens efficiently below z = 0.1, when the Universe becomes optically thin to TeV gamma-rays
- Assuming the UHECR power, generated at the blazar redshift, lost till propagation to z = 0.1 fully reprocess to produce observed TeV gamma-ray data allows to produce lower limits on UHECR power of the selected blazars

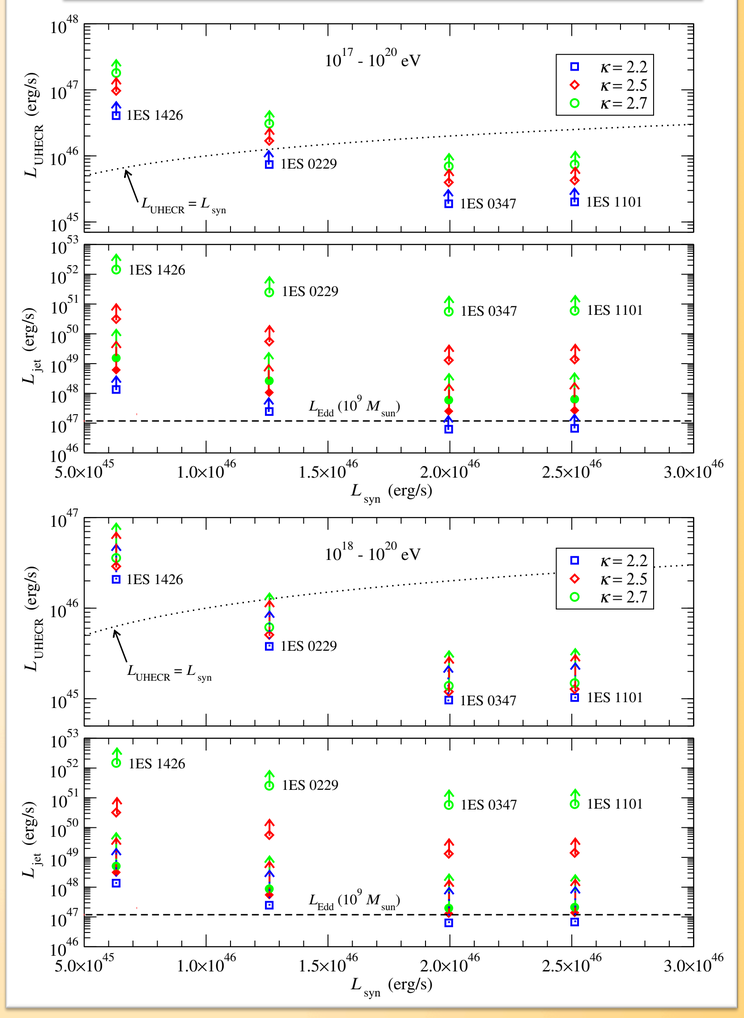
$$L_{\rm UHECR} > L(z_\gamma = 0.1)/f_{\rm CR}$$

$L(z_\gamma = 0.1)$ is the apparent luminosity of TeV emission coming from redshift 0.1. $f_{\rm CR}$ is the fraction of UHECR power loss that depends on the generation spectrum $\sim E^{-\kappa}$ and on the energy range over which they are generated at the source

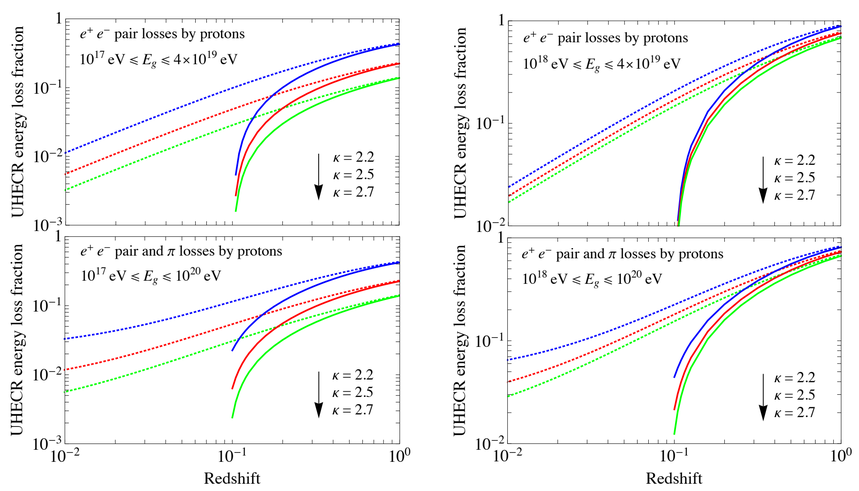
- The lower limits on the jet power is calculated by extrapolating (by a single- or a broken- power law) the UHECR proton spectrum down to ~10 GeV.
- The intergalactic magnetic field needs to be very small so that cascade electrons (also the primary protons) that upscatter CMB photons to TeV gamma rays do not deviate out of the blazar jet-opening angle

$$B < 10^{-16}\,(\theta_{\rm jet}/0.1)\,(E/{\rm TeV})^2\ {\rm G}$$

Lower Limits on UHECR and Jet Powers



Fractional Power Loss by UHECR Protons



Predictions and model tests: (1) Detection of 40 EeV protons (below the GZK cutoff) from 1ES 1426+428 along the line-of-sight should be possible by future Auger North in this model; (2) Sources of TeV gamma-ray emission from misaligned jets are expected if intervening magnetic field is moderately high

Results presented from:
Razzaque, S., Dermer, C. D., & Finke, J. D. 2011, "*Lower limits on ultrahigh-energy cosmic ray and jet powers of TeV blazars,*" Astrophys. J. (in press) [arXiv:1110.0853]

Further reading:
Berezinsky, V., Gazizov, A., & Grigorieva, S. 2006, Phys. Rev. D, 74, 043005
Dermer, C. D., Cavadini, M., Razzaque, S., Finke, J. D., Chiang, J., & Lott, B. 2011, ApJ, 733, L21
Essey, W., Kalashev, O., Kusenko, A., & Beacom, J. F. 2010, Phys. Rev. Lett., 104, 141102
Essey, W., Kalashev, O., Kusenko, A., & Beacom, J. F. 2011, ApJ, 731, 51
Finke, J. D., Razzaque, S., & Dermer, C. D. 2010, ApJ, 712, 238
Murase, K., Dermer, C. D., Takami, H., & Migliori, G. 2011, ApJ (submitted) arXiv:1107.5576
Razzaque, S., Meszaros, P., & Zhang, B. 2004, ApJ, 613, 1072
Stanev, T., Engel, R., Muecke, A., Protheroe, R. J., & Rachen, J. P. 2000, Phys. Rev. D, 62, 093005

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