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Constraints on UHECR sources and their environments, from fitting UHECR spectrum and composition, and neutrinos and gammas

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We perform high-precision joint fitting of the ensemble of Auger extragalactic spectrum, composition, IceCube neutrino spectrum and upper limits, and Fermi-LAT diffuse gamma spectrum, to constrain the properties of UHECR sources, the source environments, source evolution and distance to nearest source. At present, the largest source of uncertainty comes from the LHC-tuned hadronic event generators, limiting the ability to derive decisive conclusions on all of the above topics. Nonetheless, interesting constraints on UHECR, neutrino and gamma ray sources can (and will) be presented.

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1. Introduction

The origin of ultrahigh energy cosmic rays (UHECRs), cosmic rays with energies in excess of 1 EeV (10^{18} eV), has long been an open question in astroparticle physics. Flux and composition measurements of UHECRs by the Pierre Auger Observatory (Auger) and the Telescope Array (TA) have provided a much clearer picture of the flux arriving at Earth. However, these observables are an amalgamation of UHECRs accelerated by a variety of astrophysical sources over cosmic time and processed by interactions, both in their source environments and in propagation to Earth. To overcome this, we study the properties of typical sources indirectly by employing phenomenological source models that are agnostic about the specific astrophysical system accelerating CRs to ultrahigh energies. For this purpose, we use the Unger-Farrar-Anchordoqui (UFA) source model [1]. UFA has been shown to give high-precision fits to both the Auger spectrum and composition data by taking into account photodisintegration interactions in the source environment. The model characterizes the source using a number of physical parameters which can be tuned to obtain a good fit to data. These best-fit parameters give insight into the physical characteristics typical sources can have compatible with observations. In this way, constraints can be placed on UHECR sources.

Other observables also carry information about the properties of UHECR sources, however. Neutrino and gamma-ray secondaries are produced by CR interactions inside their source environment and in propagation to Earth. These secondaries act as neutral messengers probing both the source environment and global properties of UHECR sources. Auger [2] and IceCube [3] provide the strongest upper-bounds on the neutrino flux between ~ 3 PeV and $\sim$ EeV. To complement these bounds, the *Fermi*-Large Area Telescope (LAT) gives an upper-bound on the diffuse gamma-ray flux in the 100 MeV to $\sim$ TeV energy range [4, 5]. By calculating the predicted neutrino and gamma-ray fluxes in UFA models we can further exclude models which violate these bounds.

These multimessenger studies (in particular the neutrino flux limits) lead to constraints on the characteristic energy of the photon field surrounding the source. The UHECR spectrum and composition proves to be the strongest constraint on the source evolution, with a preference for a star-formation-like source evolution, and we report on constraints on the distance to the nearest source. Finally, we consider the possibility of two distinct primary CR populations, as could arise, e.g., if there are different source types. In particular, we explore a secondary pure-proton component and find that, for both hadronic interaction models considered, this improves the fit to the UHECR data — by up to 5σ — without producing a conflict with gamma-ray and neutrino constraints.

2. Results

Results will be presented at the conference. For a detailed discussion of this work see [6].

References

[1] M. Unger, G. R. Farrar, and L. A. Anchordoqui, *Origin of the ankle in the ultrahigh energy cosmic ray spectrum, and of the extragalactic protons below it*, *Phys. Rev. D* **92**, 123001 (2015), arXiv:1505.02153.

[2] A. Aab et al. (Pierre Auger), *Probing the origin of ultra-high-energy cosmic rays with neutrinos in the EeV energy range using the Pierre Auger Observatory*, arXiv:1906.07422.

[3] M. G. Aartsen et al. (IceCube), *Differential limit on the extremely-high-energy cosmic neutrino flux in the presence of astrophysical background from nine years of IceCube data*, *Phys. Rev. D* **98**, 062003 (2018), arXiv:1807.01820.

[4] M. Ackermann et al. (Fermi-LAT), *The spectrum of isotropic diffuse gamma-ray emission between 100 MeV and 820 GeV*, *Astrophys. J.* **799**, 86 (2015), arXiv:1410.3696.

[5] M. Ackermann et al. (Fermi-LAT), *Resolving the Extragalactic γ-Ray Background above 50 GeV with the Fermi Large Area Telescope*, *Phys. Rev. Lett.* **116**, 151105 (2016), arXiv:1511.00693.

[6] M. S. Muzio, M. Unger, and G. R. Farrar, *Progress towards characterizing ultrahigh energy cosmic ray sources*, arXiv:1906.06233.

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