Cosmic ray astrophysics

Cosmic rays (CRs) below 10^{15} eV are thought to be Fermi accelerated in supernova remnant shocks, but the origin of CRs above that and up to the 'GZK' limit $Esiml10^{20}$ eV is debated. A steepening of the diffuse spectrum attributed to the GZK process (interaction with CMB photons) has been observed by the Auger observatory [2], so the sources appear to be inside $R_{GZK} \lesssim 50 - 100$Mpc, and a spatial correlation analysis of arrival directions [1] indicated a weak correlation with certain AGNs and a much firmer correlation with galaxy large scale structures inside that radius. These observations strongly favor an astrophysical, as opposed to a 'new physics', origin and the question is what are these sources.

AGNs, in particular luminous radio-loud (jetted) AGNs have long been considered candidates [3], but there are only a few of these inside R_{GZK}. A more promising possibility is that acceleration occurs in **radio-quiet AGNs**, [4], which may provide acceleration sites with the right properties in large enough numbers.

GRB are the other main candidates [5, 6, 7]. These are transient, and taking into account diffusion time delays, they occur at a sufficient rate inside R_{GZK} [8]. The maximum energy of protons achievable, both in AGNs and GRBs, is the GZK value

$$E_p \lesssim \beta_s ZeBR \sim 10^{20.5} \text{ eV}. \quad (1)$$

In GRB the number spectrum expected has slope -2, which is suitable for explaining the diffuse CR flux in the $10^{19} - 10^{21}$ eV range. Proof, however, is difficult. Neutrinos from $p\gamma$ at these energies would have $E_\nu \sim 10^{18}$ eV, which requires larger instruments than, e.g., ANITA. Secondary photon emission from $p\gamma$ cascades, however, may appear at GeV energies, providing potential CR signatures [15], and Fermi observations of GRB 090510 at GeV energies are indeed compatible with such hadronic GRB models [10]. If GRB indeed accelerate the observed GZK CRs, the supernova remnants of their progenitors could be sites of the late decay of neutrons (produced originally by $p\gamma$ interactions) back into protons and positrons, the latter leading to synchrotron-IC photon cascades which could be detectable with GeV and/or TeV telescopes [11].

At lower energies the -2 spectrum is flatter than the observed -2.7, and either nearby GRB [9] or other sources must be invoked. The latter may be **hypernovae**, supernovae with semi-relativistic ejecta, which can accelerate protons up to 10^{19} eV or heavy nuclei up to $10^{20.5}$ eV [12, 14, 13]. The numbers and the inferred distribution of ejecta velocities yield the appropriate spectrum and diffuse flux.

References

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