Title:	Magnetars in the Metagalaxy: An Origin for Ultra-High-Energy Cosmic Rays in the Nearby Universe
Authors:	Arons, Jonathan
Affiliation:	AA(Department of Astronomy, University of California, 601 Campbell Hall, Berkeley, CA 94720)
Publication:	The Astrophysical Journal, Volume 589, Issue 2, pp. 871-892. (ApJ Homepage)
Publication Date:	06/2003
Origin:	UCP
Astronomy Keywords:	Acceleration of Particles, ISM: Cosmic Rays, Plasmas, Stars: Neutron, ISM: Supernova Remnants, Stars: Supernovae: General
DOI:	10.1086/374776
Bibliographic Code:	2003ApJ...589..871A

Abstract

I show that the relativistic winds of newly born magnetars (neutron stars with petagauss surface magnetic fields) with initial spin rates close to the centrifugal breakup limit, occurring in all normal galaxies with massive star formation, can provide a source of ultrarelativistic light ions with an E^{-1} injection spectrum, steepening to E^{-2} at higher energies, with an upper cutoff at 10^{21}-10^{22} eV. Interactions with the cosmic microwave background yield a spectrum at the Earth that compares favorably with the spectrum of ultra-high-energy cosmic rays (UHECRs) observed at energies up to a few times 10^{20} eV. The fit to the observations suggests that ~5%-10% of the magnetars are born with rotation rates and voltages sufficiently high to allow the acceleration of the UHECR. The form the spectrum incident on the Earth takes depends sensitively on the mechanism and the magnitude of gravitational wave losses during the early spin-down of these neutron stars: pure electromagnetic spin-down (the E^{-1} injection spectrum) yields a GZK feature [a flattening of the $E^3J(E)$ spectrum] below 10^{20} eV, rather than a cutoff, while a moderate GZK cutoff appears if gravitational wave losses are strong enough to steepen the injection spectrum above 10^{20} eV. The flux above 10^{20} eV comes from magnetars in relatively nearby galaxies (D<50 Mpc). I outline the probable physics of acceleration of such particles in a magnetar's wind: it is a form of ``surf-riding'' in the approximately force-free fields of the wind. I also show how the high-energy particles can escape with small energy losses from the magnetars' natal supernovae. In particular, I show that the electromagnetic energy emitted by the magnetar ``shreds'' the supernova envelope in times short enough to allow most of the relativistic energy to escape largely unimpeded into the surrounding interstellar medium, where it drives a relativistic blast wave that expands to parsec scale before slowing down to nonrelativistic speeds. I also show that since the ions are accelerated in a region where the magnetic field has the structure of a strong electromagnetic wave but propagate at larger radii through a region of weaker magnetic field near the rotational equator of the outflow, the ultra-high-energy particles escape with negligible adiabatic and radiation losses. The requirement that the magnetars' relativistic winds not overproduce interstellar supershells and unusually large supernova remnants suggests that most of the initial spin-down energy is radiated in kilohertz gravitational waves for several hours after each supernova. For

typical distances to events that contribute to E>100 EeV air showers, the model predicts gravitational wave strains ~3×10^{-21}. Such bursts of gravitational radiation should correlate with bursts of ultra-high-energy particles. The Auger experiment should see bursts of particles with energy above 100 EeV every few years.
