COSMIC RAYS: A MULTIMESSENGER VIEW FROM EARTH TO SOURCES

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Technological advances of the past few decades have poised us to make substantial headway toward solving the longstanding mystery of cosmic ray (CR) origins, their underlying acceleration mechanisms, and propagation conditions, in addition to providing significant insight into the extreme environments in which they exist and the high energy physics mechanisms which power them. With the advent of multimessenger astrophysics, we now have the ability to use photons to precisely study astronomical sources and interaction sites, providing direct associations between sources and inferred emitting particle populations. As charged particles that are bent by magnetic fields, cosmic rays' composition and spectra yield detailed information about the pool of accelerated material and the acceleration and propagation end states. Only by combining this multimessenger information will we be able to make substantially stronger statements about CR origins, acceleration, and propagation. Such knowledge will also enable significant advances in fields ranging from the physics of high energy particle acceleration and interactions to galaxy formation and evolution as CRs act as tracers of energy flow and particle dynamics, e.g. from massive stars and supernova and via stellar winds, both within galaxies and between them and the intergalactic medium. Likewise this knowledge will illuminate the complex interplay between dust, gas, metals, and cosmic rays, further leveraging such upcoming missions as JWST.

Advances in γ-ray and X-ray instrumentation as well as radio and infrared observations have substantially contributed to our ability to identify the underlying particle populations emitting the observed photons, tracing both thermal and energetic processes. A recent example of this multiwavelength (MW) synergy is Fermi Gamma-ray Space Telescope's detection of energetic protons in the supernova remnants (SNRs) IC443 and W44 (Ackermann, et al 2013), where the spatial and spectral resolution played a key role in discriminating between hadronic and leptonic emission. By combining this MW view with environmental tracers such as CO and dust emission, we can not only better understand SNR's ability to accelerate particles, but also the particle populations they draw from in a variety of environments and evolutionary stages. We anticipate that our production of Fermi's first SNR catalog will provide a basis for systematically applying this type of study to the statistical population of galactic SNRs.

Likewise direct detection CR experiments have seen key recent advances allowing the measurement of individual element spectra at the highest energies as well as both elemental and isotopic composition, including at the highest charges ($\geq$Fe). Experiments such as Super-TIGER have extended the results from e.g. TIGER, which suggested that CRs are a mixture of massive star/OB association elements with preferential acceleration of nuclei generally found in dust (Rauch, et al 2009). By expanding our knowledge of CRs to higher energies and nuclear charge as well as isotopic abundances utilizing new advances in detector technologies and new ultra-long duration balloon opportunities, we will gain substantial clues to CR source particle populations and acceleration mechanisms, e.g. dust-bound refractory elements versus volatiles initially accelerated in moderate magnetic fields and then sputtered off to reach still higher energies via Fermi acceleration, as well as propagation densities via secondary elemental and isotopic CR production and possible time scales with rarer radioactive nuclides. By detecting CRs directly with e.g. mid-size space missions, we avoid issues such as production of secondaries in the atmosphere and gain at least an order of magnitude if not more in exposure, particularly at the highest energies and heaviest nuclei, where the fluxes are lowest.

Combining the view of CRs' origins and propagation from direct detection with our MW picture of probable sources will deepen our understanding of both CRs and their energetic astrophysical sources and environments, as well as the underlying physics processes. Such improved local understanding will be a critical component both when extending to larger and earlier systems such as galaxies and massive stars in their evolutionary stages, and when examining cosmological and other fundamental physics questions such as the nature of dark matter and dark energy. These measurements typically rely on accurate subtraction of foregrounds, most often galactic and energetic in nature, to which CRs, their sources, and interaction locations are directly related. Accurately representing them is thus a critical and complementary component enabling a deeper understanding of both our galaxy and our universe.