ISAPP 2012 lecture:
Cosmic Rays, Gamma Rays and Multi Messenger Astronomy

Part 1 Discovery of the cosmic rays

At the end of the nineteenth century, pioneering scientists have unknowingly opened the Atomic Age. Soon after, their attention focused on the origin of the ambient radioactivity, as measured by devices (such as gold-leaf electroscopes) able to gauge the ionization of the air. At that time, it was generally admitted that such an ambient ionization was induced by the natural radioactivity of the rocks. To be convinced, some scientists decided to check that the ionization of the air decreased with altitude. In a series of balloon ascents, performed in 1911-1912, Viktor Hess demonstrated that the degree of ionization at 5 km height reached several times the observed value at Earth level. Hess then concluded that this ionization might be attributed to the penetration of the Earth's atmosphere from outer space by hitherto unknown radiation of exceptionally high penetrating capacity. In the 1920s, this radiation has been improperly called cosmic rays, a term coined by Robert Millikan who though that the radiation consisted of photons.

Part 2 Cosmic rays and the advent of particle physics

In the 1930s, Arthur Compton showed that the cosmic-ray intensity, as measured at the Earth's surface, was correlated with geomagnetic latitude. Being then proven to interact with the Earth's magnetic field, cosmic rays must be charged particles. In addition, thanks to the east-west effect detected in cosmic rays, it was inferred that the sign of the primary cosmic-ray particles must be positive (protons, for the most part). Up to the beginning of the 1950s, cosmic-ray studies have been mostly devoted to explore the subatomic world. Many of the key discoveries early in the history of particle physics (beginning with that of positrons) came from cosmic-ray studies and many short-lived subatomic particles (such as muons, pions and kaons) were discovered through cosmic-ray collisions. The field of particle physics was in fact established as a result of such discoveries. Even with the advent of powerful particle accelerators, some particle physicists have continued to study cosmic rays, albeit on a more limited scale, because they contain particles with energies far beyond those attainable under laboratory conditions.

Part 3 Back to the source of cosmic rays

Paradoxically, the cosmic-ray discovery did not quickly prompted astrophysical studies aiming to elucidate the mystery of their origins, except the pioneering work of Fritz Zwicky who hypothesized in 1934 with Walter Baade that most of the cosmic rays would come from supernova explosions. Because cosmic rays are electrically charged they are deflected by magnetic fields, and their directions have been randomized, making it impossible to tell where they originated (with the exception of those of ultra-high energy). At the beginning of the 1950s, when the high-energy particles produced in large accelerators were replacing cosmic rays for the study of the subatomic world, a new generation of astrophysicists began to search into the sky for sites where cosmic rays could be accelerated to very-high energies, based on the fact that cosmic rays can be traced by the electromagnetic radiation they produce. Such non-thermal radiations are detected at both ends of the electromagnetic spectrum, in the short wave radio band as synchrotron radiation emitted by cosmic ray electrons spiraling in the magnetic fields and in the gamma-ray domain as by product of cosmic ray collisions with interstellar gas.

Part 4 Cosmic-ray sources and gamma-ray astronomy

Up to the end of the 1960s, gamma-ray astronomy was solely based on theoretical considerations, whose predictions proved to be remarkably accurate as concerned the nature of the gamma-ray sources, but which often were overly optimistic as to their brightness. During the 1950s, such predictions obviously took advantage of the novel discoveries reported by radio astronomers. As an example, when radio astronomers detected the presence of huge amounts of atomic hydrogen within the whole Galactic disk, through the first observations performed at 21 cm, Satio Hayakawa was the first to point out that copious gamma-ray emission should inevitably result from interactions between cosmic rays and this newly discovered interstellar gas. As for most new branches of astronomy, gamma-ray astronomy must generally be carried out aboard space vehicles since, in spite of their penetrating power, gamma rays are totally absorbed by the terrestrial atmosphere. At the beginning of the space era early in the 1960s, many space experiments were vainly brought into play to detect the purported abundant flow of photons from potential gamma-ray sources. The failure of these first attempts can be explained in part by the small detector size, too small to collect sufficient photons emitted by gamma-ray sources whose energy output had been too largely overestimated. It is only in 1968 that the first cosmic-ray induced gamma radiation has been discovered thanks to the all sky surveys performed with a simple telescope aboard the OSO 3 satellite launched in March, 1967.

Part 5 Cosmic-ray acceleration studies and multi wavelength astronomy

A century after their 1912 discovery, the origin of the cosmic rays remains controversial. Where in the Universe is there an accelerator far more powerful than anything we can build on Earth? Supernova remnants, young stars, microquasars and even quasars have been suggested. Nowadays, astrophysicists are in the process of carrying out multi-wavelength observations of acceleration sites such as powerful associations of young and massive stars, supernova remnants and super bubbles. Thanks to observations performed in many wavebands (from radio to very high-energy gamma rays), observational evidence has recently emerged supporting the acceleration of particles to cosmic ray energies supernova remnants by first-order Fermi shock acceleration (also called diffusive shock acceleration), as particles gain energy by scattering back and forth across the shock.