Antimatter in the Universe: constraints from gamma-ray astronomy

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Abstract We review gamma-ray observations that constrain antimatter – both baryonic and leptonic - in the Universe. Antimatter is probed through ordinary matter, with the resulting annihilation gamma-rays providing indirect evidence for its presence. Although it is generally accepted that equal amounts of matter and antimatter have been produced in the Big Bang, gamma-rays have so far failed to detect substantial amounts of baryonic antimatter in the Universe. Conversely, positrons are abundantly observed through their annihilation in the central regions of our Galaxy and, although a wealth of astrophysical sources are plausible, their very origin is still unknown. As both antimatter questions – the source of the Galactic positrons and the baryon asymmetry in the Universe - can be investigated through the low energy gamma-ray channel, the mission concept of a dedicated space telescope is sketched out.

Keywords Baryonic antimatter · Galactic positrons · Annihilation radiation · Gamma-ray telescopes

1 Introduction

The present short review focuses on gamma-ray observations of baryonic and leptonic antimatter in the Universe. Following a trail that starts in our solar system, passing through our Milky Way, and out to galaxy clusters, the observational evidence (of absence) for baryonic antimatter in the Universe is reassessed, using recent high-energy data from the Fermi Gamma-ray Space Telescope. We then revisit
older Compton-GRO observations that have been used to constrain possible matter-antimatter domain boundaries in the early Universe - i.e. characteristic annihilation signatures in the diffuse Cosmic Gamma-Ray background spectrum of the MeV domain. According to the presently accepted paradigm, a matter-antimatter symmetric Universe can be ruled out on the grounds of the existing MeV observations. Today however, there is not only a need for new theoretical studies, revisiting these models in the light of 21st century cosmology, but most of all the need for a new gamma-ray mission that would be able to draw up the first map of the Cosmic Gamma Background (CGB) at MeV energies.

Positrons, on the other hand, are the most common and easily produced form of antimatter. The characteristic line at 511 keV emitted by the annihilation of Galactic positrons has been measured for almost four decades with balloon and satellite experiments. The sky map of electron-positron radiation has been drawn and redrawn by INTEGRAL, and the physical conditions in the sites where annihilation occurs are reasonably well understood. Nevertheless, the very origin of the positrons and their propagation has remained as enigmatic as ever.

Remarkably, even though their rest masses differ by nearly a factor of 2000, both the leptonic and the baryonic antimatter question can be investigated through low energy gamma-ray astronomy, at 0.5 MeV and a few MeV, respectively. In the last section, the requirements for future space-based telescope emphasizing on these questions are drawn up, and a possible mission-concept is presented.

2 Constraining baryonic antimatter with gamma-rays

When nucleons annihilate with anti-nucleons, they disintegrate into pions ($\pi^0$, $\pi^\pm$) which decay in flight to stable leptons and high energy photons. Characteristic gamma-rays are produced through the decay of neutral pions ($\pi^0$), their energies being distributed in a broad spectral bump extending from several tens of MeV to several hundreds of GeV and peaking between 100–200 MeV. A typical rest frame spectrum is shown in Fig. 1 [6].

Yet, a “pion-decay bump” is not a unique signature of annihilation as it also can be created in energetic proton-proton collisions, for example. The Fermi Large Area Telescope (Fermi-LAT) has recently detected the pion-decay feature in the spectra of two supernova remnants (SNRs), IC 443 and W44 [3], providing direct evidence for diffusive shock acceleration of relativistic particles in these objects. Nonetheless, $\pi^0$ gamma-rays are