A Study of the Mechanisms of Cosmic Gamma Ray Production in the Galaxy

Thesis

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بسم الله الرحمن الرحيم

﴿الحَمْدُ لِلَّهِ الَّذِي هَدَانَا لِهَذَا وَمَا كُنَّا لِنَهْتَدِيَ لَوْلَا أَنْ هَدَانَا اللَّهُ﴾

صدق الله العظيم

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Abstract

A theoretical study has been made of the diffuse gamma rays produced through electromagentic and nuclear interactions of cosmic rays with matter and radiation in the interstellar medium of the Galaxy.

A detailed mathematical formulation has been made for the different processes contributing to the production of the diffuse gamma ray flux. The results for the calculations of the emissivities using the different interaction processes over the energy range $10^{-3} \leq E_\gamma \leq 10^{9}$ GeV, and the contribution for each process are reported.

The emissivity results and the observed γ-ray emission near the Galactic plane have been used to search for possible spatial gradients of cosmic rays in the Galaxy. Cosmic ray gradients correlated with Supernovae Remnant distributions seem to be in good agreement with observations. The derived cosmic ray radial distribution strongly implies that cosmic ray protons with energies 1-10 GeV are of Galactic origin.

SUMMARY

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A theoretical study has been made of the different mechanisms for Cosmic Gamma rays production through electromagnetic and nuclear interactions of cosmic rays with matter and radiation in the interstellar medium of the Galaxy.

Different processes contributing to the production of gamma flux have been investigated in detailed mathematical formulation. The relevant processes were the decay of $\pi°$ mesons produced in high energy nuclear interactions of cosmic ray nuclei with interstellar matter, Bremmstrahlung of cosmic ray electrons as well as Inverse Compton Scattering of electrons on photon fields in the Galaxy. The results for the new set of calculations for the emissivities for each process cover the energy range $10^{-3} \leqslant E_\gamma \leqslant 10^9$ GeV and are given as follows :

(1) For $\pi°$ emissivity at energies $E \leqslant 100$ GeV, a new parameterization has been used to correct the invariant cross-section and results indicates good agreement with observations. This gives a differential emissivity peaking at 67.5 MeV corresponding to the energy of gamma rays when the pions decay at rest, and the spectrum is symmetric about this energy value.

(2) Taking the injection spectrum of electrons near their sources (local interstellar electron spectrum) and using a Leaky Box Model (LBM) as well as the ambient electron spectrum, the Bremsstrahlung and Inverse Compton Sctterming emissivities were derived. The results obtained indicate an agreement at low energy for the two different electron spectra. The results also indicate the dominance of these two processes (BR and ICS) in the energy regions $E_\gamma \leqslant 0.01$ and $E_\gamma \geqslant 10$ GeV respectively.

(3) The reltive contribution of protons to the total emissivity is found to be about 56% for $E_\gamma > 35$ MeV and about 74% for $E_\gamma > 100$ MeV.

To search for possible spatial gradients of cosmic rays in the Galaxy, we have used the emissivity results, and the experimental (observed) longitudinal flux. An unfolding technique has been developed and used to reconstruct the radial distribution of emissivities from

the longitude profile of γ-rays. Estimates of the Hydrogen gas densities are then used to determine the radial distribution of cosmic rays. The results obtained bin this respect are as follows :

a) There are marked gradients for cosmic rays in the inner Galaxy with the cosmic ray intensity in the region 3-7 Kpc being 3-4 times that locally.

b) There are indications for a higher gradient for lower energy cosmic rays.

c) There is a minimum in both emissivity and cosmic ray distributions at $R \simeq 9$ Kpc corresponding to a dip in the longitude distribution of γ-rays near $\ell \simeq 60°$. This minimum is indicative of long path lengths through the inter arm region between the Sagittarius and Orion arms.

d) The results point strongly to a Galactic origin for cosmic rays of energies 1-10 GeV which could be related to supernova remnant (SNR) or pulsar distributions.

e) There are indications for a difference between using two different electron spectrum models, the LBM electron spectrum giving higher values.

A supernova remnant model has been used to calculate the gamma ray profiles for comparison with observations taking into account the angular resolution and latitude window of detectors. The main results are as follows :

1) The gradients for cosmic rays indicate that a uniform cosmic ray radial distribution in the Galaxy can be excluded for proton energies 1-10 GeV, implying a "galactic" origin in this energy region.

2) Radial gradients from the SNR model are in agreement with those obtained by the unfolding methods.

3) The gradients are found to decrease with increasing energies and the cosmic ray distribution is possibly quite uniform for gamma ray energies above about 1 GeV.

INTRODUCTION

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The bulk of the information about the Galaxy and the Universe, in particular, comes from studying the electromagneting radiation emitted from their different sources.

The spectrum of such radiation covers the widest possible band, ranging from very low frequency radiowaves to extremely high energy gamma-rays.

There has been considerable interest of cosmic gamma rays in the last 10 years, and similar to optical astronomy, radioastronomy, etc., we now have a whole descipline called Gamma-ray Astronomy.

Astrophysical gamma rays form a part of the cosmic radiation falling on top of the earth's atmosphere (the other major parts consist of protons, nuclei, and electrons). Being undeflected in cosmic magnetic fields, detected gamma rays can be traced directly to their original sources and thus provide valuable information about these sources and the interstellar medium within our own Galaxy.

Cosmic Gamma-rays were discovered in 1911. The detection of primary γ-rays has been difficult when high altitude balloons were the only carriers of Gamma detection equipment. With the development of satellites as Gamma detector carriers, valuable information has become available on the intensity distribution of cosmic Gamma rays in the Galaxy as well as its spectral shape from about 30 MeV to a few GeV. From these experiments, there is now firm evidence for the existence of a Galactic component, mainly from the Galactic plane, beside a diffuse isotropic component probably of extra Galactic origin. Moreover, there are well defined discrete sources like the "Crab Nebula" and the "Vela Pulsar" (e.g. Hermsen et al, 1977) with a possible contribution of 10-40% to the continuum flux (e.g. Protheroe et al, 1979).

The mechanisms by which Gamma-rays are produced in the Galaxy were not studied completely until now. It was believed that most of the high energy (>50 MeV) radiation comes from the decay of neutral pions produced in the collision of cosmic ray nuclei with interstellar gas (mainly hydrogen). However, SAS-II and COS-B satellite measurements of the radiation from the Galactic centre are inconsistent with a pure pion spectrum and indicate contributions from electromagnetic interactions of cosmic ray electrons. These additional proceses are mainly non-thermal bremsstrahlung in the interstellar gas and Inverse Compton Scattering (ICS) of low energy photons in star light, 2.7°K microwave background, as well as in the far infrared emitted by interstellar dust.

A question of prime importance concerns the origin of the primary cosmic rays, whether it is Galactic or extragalactic in origin. The recent research in cosmic Gamma rays gives the possibility of drawing conclusions about the origin of low energy cosmic rays. The possibility arises because