A STUDY OF PRIMARY COSMIC GAMMA RAYS

A THESIS

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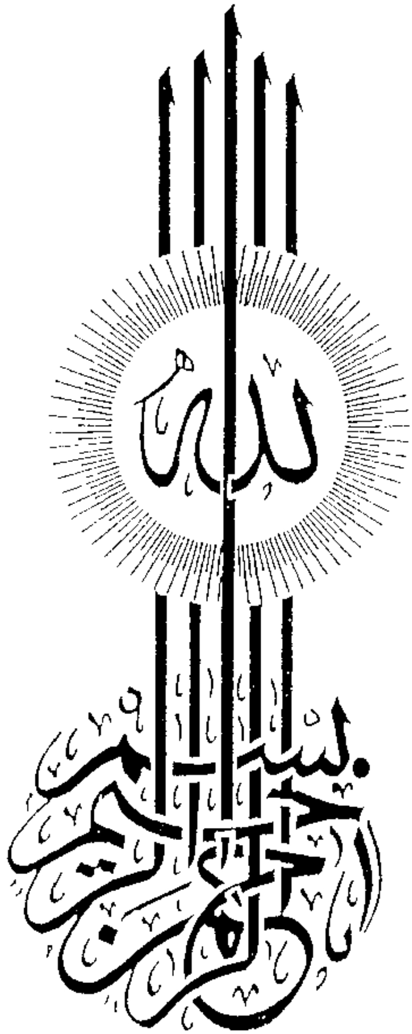
بسم الله الرحمن الرحيم

وقل اعملوا فسيرى الله عملكم ورسوله والمؤمنون

«صدق الله العظيم»


بسم الله الرحمن الرحيم

ALLAH ENJOINED MAN TO THINK AND HAVE
AN INSIGHT IN THE INFINITE NATURAL
PHENOMENA AT HIS DISPOSAL

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1. Gamma Ray Emissivity Calculations for Different π° Production Models.

   A. Goned and A. Wahdan

   9th Int. Computer Conf. (Cairo), 4, 65,(1984).

2. Computation of Galactic Gamma-Ray Fluxes for Different Cosmic Ray Spatial Distributions.

   A. Goned and A. Wahdan

   9th Int. Computer Conf. (Cairo), 4, 253 (1984).

3. Radial Distribution of Cosmic Ray Intensity in the Galaxy from Gamma Ray Data.

   A. Goned and A. Wahdan

   19th ICRC (USA), 1, 325, (1985).

4. Longitude Distribution of Cosmic Gamma Rays for Different Source Models.

   A. Goned and A. Wahdan

   Proc. 11th Int. Computer Conf. (Cairo), 2, 1, (1986).

5. Large Scale Emission of Cosmic γ-Rays and the Mass of Gas in the Galaxy.

   I.A. Ismail, A. Wahdan and A. Goned

   Int. Conf. Modelling and Simulation (Sorrento: Italy) 2, 184, (1986).

6. Leakage Life Time of Cosmic Ray Electrons in the Galaxy.

   I.A. Ismail, M. Khairy, A. Wahdan and A. Goned.

   Int. Conf. Modelling and Simulation (Sorrento:Italy), 2, 183, (1986).

CONTENTS

SUMMARY

SUMMARY

A theoretical study has been made of the diffuse gamma rays produced through electromagnetic 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 flux. The relevant processes were π° production in high energy nuclear interactions of cosmic ray nuclei with interstellar matter, bremsstrahlung 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 using different interaction models cover the energy range $10^{-3} < E_\gamma < 10^{9}$ GeV and are given as follows :

1) For π° emissivity at energies $E_\gamma \leqslant 100$ GeV, a strict scaling model gives a differential emissivity peaking at 67.5 MeV corresponding to the energy of gamma rays when the pions decay at rest. The spectrum is symmetric about this energy and takes the asymptotic form $q_{\pi^\circ}(E_\gamma) \sim E_\gamma^{-2.74}$.

2) For energies $E_\gamma \geqslant 100$ GeV, three models have been used to describe π° production in hadronic interactions corresponding to strict scaling, complete scale breaking, and an intermediate model. The asymptotic behaviour of the emissivity takes the form $q_{\pi^\circ}(E_\gamma) \simeq E_\gamma^{-u}$ with u being 2.75, 3.0 and 2.86 for the three models; respectively, The first model gives the highest emissivities, while the second gives the

other extreme with the intermediate model in between. These results allow a determination of the degree of scaling violations in pp interactions at energies higher than those obtained by present accelerators. Also the location of a possible break in the primary spectrum can be determined in this way.

3) Bremsstrahlung and Inverse Compton Scattering emissivities indicate the dominance of these two processes in the energy regions $E_\gamma \leq 0.01$ and $E_\gamma \geq 10$ GeV respectively. The relative contribution of protons to the total emissivity is found to be about 50% for $E_\gamma > 35$ MeV and about 74% for $E_\gamma >$ 100 MeV.

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. 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 distributions of cosmic rays. The results obtained in this respect are as follows :

1) 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.

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

3) 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 interarm region between the Sagittarius and Orion arms.

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

A quantitative theoretical treatment of cosmic ray gradients in relevance to γ-ray emission has been made to identify the possible sources of cosmic rays in the Galaxy. For this purpose, a model has been developed for the large scale γ-ray emission in the Galaxy assuming a Galactic origin for cosmic rays of energies 1-10 GeV. The model takes into account the various features previously obtained for γ-ray production in the interstellar medium. The main results are :

1) A hydrostatic equilibrium treatment for the Galactic disk constituents has been developed and used to obtain theoretical distributions above the Galactic plane.

2) From a balance between the outward pressure gradient due to magnetic fields, cosmic rays and gas motion on one side and the gravitational force excerted on the gas by the Galaxy on the other side, we obtain a half thickness for the cosmic ray disk of $Z_{\frac{1}{2}} \simeq 856$ pc.

3) The longitude and latitude profiles of gamma rays have been derived on the basis of the above model taking into account various target distributions, possible absorption processes as well as the angular resolution and latitude

window of detectors. The mathematical formulation allows the computation of gamma ray profiles for different cosmic ray gradients.

The above model has been used in conjunction with various cosmic ray distribution models to calculate gamma ray profiles comparable with observations. The main results are as follows :

(1) 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) Molecular hydrogen densities in the Galaxy are about 10 times the conventional estimates below 2 Kpc, resulting in a mass of H_2 of about $6.5 \times 10^8\ M_\odot$.

(3) The predictions of present model agree with observations on the basis of cosmic ray gradients correlated with SNR or with gas densities. Other models based on total matter density, Galactic magnetic field, arm structure or large scale acceleration are found to be inadequate for describing cosmic ray radial gradients.

(4) Radial gradients from the SNR and gas density models are in agreement with those obtained by the unfolding method. In both cases, the gradients are found to decrease with increasing energies and the cosmic ray distribution is possibly quite uniform for gamma energies above about 1 GeV.

(5) The SNR model seems to be in better agreement with observations near the 3 Kpc ring. SNR Shock waves are thus possible mechanisms for the production and acceleration of cosmic rays in the Galaxy.