INVERSE COMPTON EMISSION FROM THE GALAXY

G. Youssefi, A.W. Strong

Max-Planck Institut für Extraterrestrische Physik, Garching, F.R.G.

Abstract

New estimates have been made of the Galactic inverse-Compton emission using an interstellar radiation field based on the most recent available data. The contribution from optical radiation is probably smaller than previously calculated. The far infrared component dominates over the optical, especially at low energies.

INTRODUCTION. Inverse-Compton scattering (ICS) of relativistic electrons on the various components of the radiation field in the Galaxy is one of the principal processes which produce the diffuse galactic γ-ray emission. Especially at lower energies (below 100 MeV) it is expected that it will compete with bremsstrahlung as the dominant process; at higher energies it is less important but still significant especially at higher galactic latitudes. There is some indication in the COS-B data for a component distributed as would be expected for ICS (Strong et al. 1988). It is now thought that a rather extensive cosmic-ray 'halo' may exist; ICS of the electron component on the interstellar radiation field (ISRF), which has a very gradual falloff with z, would provide an excellent way to detect it. The arrival of data from the Gamma Ray Observatory GRO with its increased sensitivity and resolution prompts a careful look at how the ISRF can be most reliably estimated.

Previous calculations of ICS have been made by Kniffen and Fichtel (1981), Bloemen (1985) and most recently Chi and Wolfendale (1990). Until recently a large source of uncertainty was the ISRF in the far-infrared, but now the IRAS satellite survey of the Galaxy and the analysis of the galactic emission (Bloemen et al. 1990) make this the least uncertain component. The computation of the optical ISRF remains difficult because of the effects of absorption and because the distribution of stars in the Galaxy is not accurately known. However new astronomical data can be used to reduce this uncertainty significantly.

ISRF: OPTICAL REGION. As in previous work we define 'optical' to include wavelengths up to $8\mu m$. The distribution of stellar populations in the Galaxy is not known exactly due to the great absorption in the plane; models have been based on local populations together with radial variations based on galaxies similar to ours. The model of Mathis et al. (1983) was used by Bloemen (1985) and Chi and Wolfendale (1990). Mathis et al. represented the stellar distribution as the sum of four dilute blackbody components. The total luminosity was taken to be 4 $10^{10}L_\odot$; this is one of the main uncertainties, and it is here in particular that a re-evaluation is required.

A significant improvement in our knowledge of the ISRF comes from the Pioneer 10 all-sky survey of the galactic background radiation made from beyond a heliocentric distance of 3.2 AU where the zodiacal light is negligible (Toller et al. 1987, Toller 1990). This survey has a resolution of 2^o and was made in two bands B and R. A model of the distribution of luminosity in the disk of the Galaxy based on fitting to Pioneer 10 data has been given by van der Kruit (1986, 1990): $L(R,z) = L(0,0)e^{-R/h}sech^2(\frac{z}{z_o})$. Two stellar populations, 'old disk' (including 'old disk dwarfs' and 'disk giants') and 'young population I' with L=1.1 and 0.7 $10^{10}L_\odot$respectively, are included. For the parameters van der Kruit gives h=5.0±1.0 kpc for both components, z_o=0.35±0.05 kpc for the 'old disk' and z_o=0.08 kpc for the 'young Population I'. A model for the Galactic bulge is included; this contributes an additional 0.2 $10^{10}L_\odot$. The total input luminosity L_{Gal} is 2.0 $10^{10}L_\odot$. The distance R_o to the Galactic centre is taken as 8.5 kpc. We approximate the old disk component as a Planck spectrum with T=5000 ^{o}K and the young Population I with T=10000 ^{o}K. The total local surface brightness of the Galactic disk is $20L_\odot pc^{-2}$ corresponding to an intensity at each pole of $38S_{10}(V)_{G2V}$ Pioneer 10 units (unit : 1.16 10^{-9} erg cm^{-2} sr^{-1} s$^{-1}\AA^{-1}$).

An independent estimate of L_{Gal} comes from modelling of $2.4\mu m$ surveys of the Galactic plane using CO data to trace the absorption (Fazio et al. 1990). Their preliminary results give L_{Gal} =1.8 $10^{10}L_\odot$, in good agreement with the van der Kruit value. Thus there is evidence for a lower value than that normally used (e.g. Mathis et al. (1983), Cox and Mezger (1989) adopt 4 $10^{10}L_\odot$).

Although the calculation of the Galactic ISRF over the whole Galaxy cannot be very accurate since the distribution of stars and in particular absorption can only be derived indirectly, we would like to ensure that it is at least consistent with available data from Pioneer 10. Although we do not need to reproduce the detailed angular distribution, the large-scale variation should agree. We have computed the optical ISRF using an absorption model in which the opacity represented by: $k(R,z) = k(R_o,0)e^{-(R-R_0)/h_a - z/z_a}$ for R> 4 kpc, with h_a=3.4 kpc, z_a = 0.15 kpc. For R<4 kpc the absorption is assumed to fall linearly to zero at R=0. This model is based on Güsten and Mezger (1982). The absolute normalization of the absorption is left as a free parameter chosen to give agreement with (a) the local ISRF as measured by Pioneer 10, (b) the total far IR luminosity of the Galaxy as determined from IRAS data. We have used an absorption at 5500$\AA$ of k(R_o,0)= 1.0 kpc^{-1}, for which the agreement with the Pioneer 10 observations (Toller 1990) is satisfactory. The absorption to the galactic centre is about 18 mag, consistent with current measurements of the extinction (38 mag: Henry et al. 1984) assuming an extinction/absorption in the range 2-3. The wavelength dependence of k(R_o,0) is based on the dust model of Mathis et al. (1977). On our model the total optical luminosity of the Galaxy as seen from outside is 1.1 $10^{10}L_\odot$. The remaining 0.9 $10^{10}L_\odot$ must be re-emitted in the far-infrared and this is consistent with that deduced from IRAS (see below). Fig 1 shows the z-variation of the optical ISRF at R=5 kpc. Fig 2 shows the latitude distribution of the local ISRF at l=3^o compared with the Pioneer 10 observations.

Fig 1 z-dependence of ISRF at R= 5.0 kpc in optical and FIR.

Fig 2 Latitude dependence of optical ISRF at R= 8.5 kpc and l=3^o compared with Pioneer 10 observations (crosses).

ISRF: FAR INFRARED. Bloemen et al. (1990) analysed the IRAS Galactic plane emission by fitting to HI and CO survey data using a model with a radial variation in the FIR emissivity per atom. Our model of the FIR radiation field uses this emissivity combined with the HI and CO distributions to obtain volume emissivities which are then integrated over the Galaxy to obtain the ISRF at each point. Absorption is assumed to be negligible.

Bloemen et al. found for the total IRAS emission associated with HI and CO values 0.8-1.1 $10^{10}L_\odot$ and 0.25 $10^{10}L_\odot$ respectively. This can be compared with the optical input luminosity given above; it appears that at least 50% of the total radiation is absorbed and re-emitted in the FIR, and only 50% escapes into intergalactic space, and $L_{IR}/L_{opt} \geq 1$. Our model (above) also gives $L_{IR}/L_{opt} \approx 1$. This value is significantly larger than that quoted by Cox and Mezger (1989) where L_{IR} / L_{opt} = 0.3 - 0.5 based on the Mathis et al. (1983) model. As supporting evidence we note that Disney et al. (1989) have made an extensive study of the absorption in galaxy disks, concluding that they are probably optically thick in the inner regions; this result appears confirmed by Valentijn (1990) in a statistical analysis of the relation between surface brightness and inclination for a large sample of spirals. Disney et al. state that L_{IR}/L_{opt} has an average value of 1 for optically selected IRAS galaxies, and 10 for IRAS selected ones, so a value $\approx$1 is quite reasonable.

INVERSE COMPTON EMISSION. The distribution of cosmic ray electrons is assumed to be exponential in z with scale height a free parameter. The local spectrum is taken from Ip and Axford (1982) below 30 GeV, scaled up by a factor 2 to be consistent with the local interstellar electron spectrum from γ-ray studies (Strong 1985): $I(E = 1GeV, R_o) = 0.2 m^{-2} sr^{-1} s^{-1} MeV^{-1}$. Above 30 GeV we use the Nishimura et al. (1980) spectrum.

The z-distribution of ICS from the various components at 1 MeV and 1 GeV for an infinite electron scale-height (Fig 3) shows a dominance of the 2.7K and FIR component which is particularly apparent at low energies. The slow falloff to large z, as noted by Chi and Wolfendale (1990), illustrates the possibility of detecting cosmic-ray interactions in the Galactic halo, and is also important for estimates of the extragalactic γ-ray background.

Fig 3 z-distribution of ICS emissivity for R=5 kpc, E_γ = 1 MeV and 1 GeV. The contributions from optical, FIR and 2.7K background are shown separately. The cosmic ray electron intensity is taken everywhere equal to the solar value in this plot.

Fig 4 shows the longitude distribution for $10^0 <| b |< 20^o$ compared to COS-B data in the range 70-5000 MeV. The electron scale height is taken to be 5 kpc. An estimate of the other components (π^o decay and bremsstrahlung) related to the interstellar gas (see e.g. Strong et al. 1988) is also shown. The ICS contributes only 10% of the emission in this energy range at these latitudes.

Fig 5 shows the longitude distribution for 5 MeV for the same latitude range, with bremsstrahlung estimates based on the same electron spectrum. The contribution from ICS is significantly larger, amounting to about 25% of our estimated total. This should be measurable by the COMPTEL instrument, although the emission is dominated by the bremsstrahlung component.

Our full spatial ISRF model, as well the ICS sky maps based on it, are available in FITS format from the authors.

.

Fig 4 Longitude distribution of γ-ray intensity at intermediate latitudes for energy range 70-5000 MeV compared to COS-B data. Lower curve: ICS; middle curve: HI component+ICS; top curve: total including H_2 component. All predictions include the instrumental background level indicated by the horizontal line.

.

Fig 5 Longitude distribution of inverse Compton emission and bremsstrahlung at 5 MeV. Curves as for Fig 4.

REFERENCES

Bloemen J B G M (1985) Astron. Astrophys. , **145**, 391
Cox P, Mezger P G (1989) Astron. Astrophys. Review **1**, 49
Bloemen J B G M, Deul E R, Thaddeus P, (1990) Astron. Astrophys. , **233**, 437
Chi X, Wolfendale A W, (1990) preprint
Disney M, Davies J, Phillips S , (1989) Mon. Not. R. astr. Soc. , **239**, 939
Fazio G G, Dame T M, Kent S (1990), IAU Symp. 139 ' The Galactic and Extragalactic Background Radiation' , 35
Güsten R, Mezger P G , (1982) Vistas in Astronomy , **26** , 159
Kniffen D A, Fichtel C E , (1981) Astrophys. J. , **250**, 389
Henry J P, DePoy D L, Becklin E E , (1984) Astrophys. J. Lett. , **285**, L27
Mathis J S, Mezger , Panagia N (1983) Astron. Astrophys. , **128**, 212
Mathis J S, Rumpl W , Nordsieck K H (1977) Astrophys. J. , **217**, 425
Nishimura J et al. (1980) Astrophys. J. , **238**, 394
Strong A W (1985) Proc. XIX ICRC , **1** , 333
Strong A W et al. (1988) Astron. Astrophys. , **207**, 1
Toller G N, (1990), IAU Symp. 139 ' The Galactic and Extragalactic Background Radiation' , 21
Toller G N, Tanabe H, Weinberg J L (1987) Astron. Astrophys. , **188**, 24
Valentijn E A, (1990), Nature , **346**, 153

van der Kruit P C, (1986), Astron. Astrophys. , **157**, 230
van der Kruit P C, (1990), IAU Symp. 139 ' The Galactic and Extragalactic Background Radiation' , 85