by 70°. Additional polarized radiation must occur between the subpulses to prevent the polarization dropping below 50 per cent. The rate of change of direction of polarization for the radiation between the subpulses agrees with the simple model. The rate across the subpulses is considerably lower than expected, however; it could be due to the presence of discrete regions of radiation across which the polarization is relatively constant. The symmetry shown in the variation of polarization suggests that these regions are part of a symmetrical feature such as a conical annulus of emission centred on the magnetic pole. The subpulses would occur when the annulus passes through the line of sight, while the weaker radiation between the subpulses would come from near the pole.

To summarize, the results at 4,830 MHz are generally in agreement with an oblique rotator model for a pulsar, although a more complex radiation distribution is required than at lower frequencies. The large variations in pulse shape and intensity seem to arise in the mechanism producing the radiation, for the increase of variability with frequency rules out scintillation in the intervening medium. The mean energy spectrum points to a radiation cut-off frequency near 5 GHz.

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## Absorption of High Energy Gamma-rays in the Vicinity of Pulsar NP 0532

THE purpose of this article is to point out that photon–photon absorption may remove high energy γ-rays from the vicinity of pulsar NP 0532 in the Crab Nebula. The pulsar was discovered at radio frequencies by Staelin and Reifenstein[1], and recently Cocke, Disney and Taylor[2] discovered strong optical pulses. Fritz *et al.*[3] have found pulsed X-rays. The pulse durations at the three different frequencies are similar.

In recent years the effects of photon–photon absorption have been pointed out by many authors[4-6]. In addition, Jelley[7] has considered the same absorption process within the possible sources of γ-rays. The absorption of a γ-ray of energy $E_\gamma$ by a photon of energy ε has a threshold at $E_\gamma\varepsilon(1-\cos\theta)=2(mc^2)^2$, where $mc^2$ is the rest energy of the electron and θ the angle between their directions of motion. The cross-section σ for the process rises from zero at threshold to a maximum just above it. For an isotropic distribution of photons we take σ to be $10^{-25}$ cm$^2$. If $u$ is the energy density of the soft photons the number density of these photons will be $n=u/\varepsilon$ and the mean free path for photon–photon absorption is $\lambda=1/n\sigma$.

Here I assume that the volume occupied by the optical and X-ray photons is the same as or larger than that from which the pulsed γ-rays may originate. In addition, I consider that the emission of the optical and X-ray pulses is isotropic and that their distribution in the source is also isotropic.

First I consider absorption between optical photons and high energy γ-rays, $E_\gamma\sim10^{12}$ eV. If the Crab Nebula is located at a distance of 2 kpc the total optical luminosity[2] of the pulses is $10^{34}$ erg s$^{-1}$. The amplitude of the interpulse is about 30 per cent of the main pulse. The total energy in the main pulse is $3\times10^{31}$ erg, corresponding to $10^{43}$ photons during the pulse. The maximum size of the object ought to be comparable with the distance travelled by light in one pulse duration, $10^8$ cm, and the source volume should be $4\times10^{24}$ cm$^3$. The number density of optical photons is $2{\cdot}5\times10^{18}$ cm$^{-3}$ and the mean free path $\lambda\sim4\times10^6$ cm.

Second, I consider absorption between keV X-rays and γ-rays of energy greater than 50 MeV. Fritz *et al.*[3] have detected pulsed X-rays in the photon energy region 1 to 13 keV and found that 5 per cent of the total X-rays from the Crab Nebula were pulsed, with the pulsed component equally divided between the main pulse and the interpulse. The X-ray pulsar flux is about $2\times10^{-9}$ erg cm$^{-2}$ s$^{-1}$ or $6{\cdot}6\times10^{-12}$ erg cm$^{-2}$ during the pulse where the pulse durations have been taken as 3 ms and the repetition rate as 30 Hz. The total energy in the X-ray pulse is $3\times10^{33}$ erg corresponding to $\sim2\times10^{42}$ keV X-rays per pulse. The number density of these photons is $5\times10^{17}$ cm$^{-3}$ and the mean free path $\lambda\sim2\times10^7$ cm. Recently an upper limit of $8\times10^{-10}$ erg cm$^{-2}$ s$^{-1}$ has been measured[8] for the pulsed X-ray flux between 30 keV and 120 keV from the Crab Nebula. These results lead to a mean free path $\lambda>4\times10^7$ cm.

If the optical and X-ray pulsed fluxes are joined by a straight line and the conditions mentioned are correct, then pulsed γ-rays of energy greater than about 50 MeV will be strongly absorbed in the source.

If pulsar models[9,10] where the radiation is beamed are considered, then the photons will not be uniformly distributed throughout the source region and the absorption cannot be estimated. There are a number of effects that introduce large uncertainties. (i) The radiation will come out at small angles and the energy thresholds and photon–photon collision frequencies will be modified. (ii) The total optical and X-ray pulse luminosity may be either increased or decreased because we may be at the centre of the main radiation lobe or on the edge of or even in a side lobe. (iii) The radio, optical and X-ray pulses occur with the same period and pulse width but could be produced in the source at slightly different times. (iv) The volume of the source could be larger by many orders of magnitude. The upper limit on the radio and optical size of the source region is $<0{\cdot}1$ s of arc, that is, $3\times10^{15}$ cm, compared with the size as deduced from the pulse width, $10^8$ cm. The radiation could come from high energy particles travelling towards the observer and the pulse width as measured could be the difference between the particle velocity and that of the radiation.

In conclusion, high energy pulsed γ-rays of energy greater than about 50 MeV will suffer severe absorption if the optical and X-ray photons are isotropic in the source region; if beaming of the radiation occurs, as seems more probable, then the absorption, if any, cannot be estimated.

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