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High energy gamma rays from the Vela supernova remnant

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Abstract. Low energy gamma radiation was recently detected from the Vela supernova remnant and was attributed to synchrotron emission from high energy electrons. Microwave background photons can scatter from these electrons to give high energy gamma rays. This flux is calculated and found to agree with observation.

Key words: gamma rays: theory – ISM: supernova remnants – Vela SNR

1. Introduction

The Vela supernova remnant has been detected in radio, optical and x-ray wavelengths. Recently low energy gamma rays have been detected by De Jager, Harding and Strickman (1996) using the OSSE detector aboard the Compton Gamma Ray Observatory. The energy range of observations is between .044 and 0.765 Mev. These gamma rays have been attributed by the observers to emission from the central compact region around the Vela pulsar.The gamma ray flux together with the x-ray flux from the central compact region forms a power law spectrum. This emission is interpreted by De Jager, Harding annd Strickman (1996) as synchrotron emission from high energy electrons. The Universal microwave background photons can scatter from these high energy electrons by the inverse Compton process to give high energy gamma rays. Harding (1996) had calculated this flux using the x-ray flux measured by the ROSAT satellite and finds a value of 1.6×10^{-11} photons cm^{-2} s^{-1} at 1 TeV. The observations of OSSE imply the existence of electrons with energy higher than those implied by ROSAT satellite observations, and it seems worthwhile calculating the flux again. The high energy gamma ray flux estimated (Yoshikoshi, 1996)from observatios using the 3.8 m telescope of the CANGAROO collaboration , is $(2.5 \pm 0.5) \times 10^{-12}$ photons cm^{-2} s^{-1} above 2.5 TeV.

The x-ray spectrum is of the form $N(\nu) = K\nu^{-\gamma}$, where $N(\nu)$ is the energy in ergs cm^{-2} s^{-1} Hz^{-1} , ν is the frequency of the x-ray photon and K and γ are constants. If this spectrum is produced by the synchrotron process, then the electron spectrum is of the form $N(E) = K'E^{-p}$, where N(E) is the number of electrons of energy E and K' and p are constants. The indices γ and p are related as $p = 2\gamma + 1$. K' is given by (Lang,1980)

$$K' = \frac{4\pi d^2 K(6.26 \times 10^{18})^{(1-p)/2}}{1.17 \times 10^{-22}\alpha(p)B^{(p+1)/2}}$$

where α (p) is a slowly varying function given by Lang and B is the perpendicular component of the ambient magnetic field. The spectrum of the Universal microwave background is of black body form with temperature $T = 2.7^0$K. Then the scattering of these photons by the high energy electrons through the inverse Compton process yields high energy gamma ray photons. The power of the high energy photons per unit volume and unit energy is given by (Rybicki and Lightman,1987)

$$\frac{dP}{dV\,dt d\epsilon_s} = \frac{C8\pi}{m^3c^2} r_0^2 (kT)^{(p+5)/2} F(p)\epsilon_s^{-(p-1)/2}$$

Here r_0 is the electron radius,h is the Planck constant, c is the velocity of light and k is the Boltzmann constant. ϵ_s is the energy of the scattered photon in ergs. C is related to K' by the relation

$$C = \frac{K'}{(mc^2)^{p-1}V}$$

where m is the mass of the electron and V is the volume of the synchrotron emitting region. F(p) is given by (Rybicki and Lightman, 1987),

$$F(p) = A(p)\Gamma\{(p+5)/2\}\zeta\{(p+5)/2\}$$

where Γ is the Gamma function , ζ is the Riemannian Zeta function with the given arguments and

$$A(p) = 2^{(p+3)}(p^2 + 4p + 11)/(p+3)^2(p+5)(p+1).$$

To obtain the spectrum of the photon flux at the earth we have to multiply the power in the scattered high energy photons given above by the factor $(V/4\pi d^2\epsilon_s)$. (It is interesting to note here that the multiplication of the synchrotron power by this factor makes the calculation independent of the distance d to the source and also of the emitting volume V).

The observed low energy spectrum is given by De Jager, Harding and Strickman (1996) as

$$\frac{dN}{d\epsilon} = 3.7(\pm 0.6) \times 10^{-3}$$

$(\epsilon/0.1MeV)^{-1.8\pm0.4}cm^{-2}s^{-1}MeV^{-1}$

This can be converted to the form $N(\nu)$ given above using the appropriate constants. De Jager, Harding and Strickman (1996) give an average magnetic field of 6×10^{-5} gauss in the region. Using these and the temperature of the Universal microwave background as 2.7^oK, we have calculated the spectrum of the high energy photons which is given by,

$N_\gamma(\epsilon_s) = 4 \times 10^{-12}\epsilon_s^{-1.8}$photons $cm^{-2}s^{-1}$erg^{-1}

The integral spectrum is then

$N_\gamma(> \epsilon_s) = 5 \times 10^{-12}\epsilon_s^{-0.8}$ photons $cm^{-2}s^{-1}$

with ϵ_s in ergs. The flux of gamma rays with energy greater than 2.5 Tev is 1.5×10^{-12} photons $cm^{-2}s^{-1}$,which is in agreement with observation considering the uncertainties in the values of the parameters used (see below).

The calculated flux is dependent on the values used for the x-ray flux, the x-ray spectral index and the magnetic field. The predicted gamma ray flux is directly proportional to the x-ray flux. The high energy photon flux is dependent on the magnetic field through K'. An increase in the value of B by a factor of two will decrease the high energy photon flux by a factor of 3.5. The flux of gamma rays is not very sensitive to the spectral index.

High energy gamma ray flux from the Vela supernova remnant can also arise from scattering of background optical and infrared photons by the high energy electrons through the inverse Compton process.The galactic integrated starlight photon density (Toller, 1990) is lower by a factor of about 10^5 compared to the microwave background photon density,which is barely compensated by the increase in the number of the lower energy electrons (factor of about 3×10^4) which scatter the optical photons into the high energy gamma ray region; this contribution may just about equal that produced by the scattering of the microwave photons; the exact value depending on the value of the optical photon density near the Vela supernova remnant, which is difficult to estimate. The contribution of the galactic background infrared photon scattering from the high energy electrons can be calculated using the results of Fazio, Dame and Kent (1990). The infrared photon density is about 3×10^{-4} of the microwave photon density and the increase in the electron density again does not compensate for this reduction. The infrared photon density in the nebula may again be higher than implied by the average infrared brightness given by Fazio, Dame and Kent (1990), so that the process of inverse Compton scattering may contribute to the high energy gamma ray flux. However the near agreement of the flux obtained from the scattering of the microwave photons with the observation suggests that the scattering of optical and infrared photons may not contribute substantially to the high energy gamma ray flux.

The Janzos Air Shower Array has been used to search for high energy gamma rays with energy greater than 100 Tev; no flux was found (The Janzos Collaboration,1995) and an upper limit of 4.2×10^{-13} cm^{-2} s^{-1} was given. This flux limit is above the flux expected at this energy from this calculation.

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