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White dwarfs as infrared sources in the galactic centre

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Abstract. It is suggested that infrared radiation from the galactic centre is due to magnetic bremsstrahlung in intense magnetic fields from the non-degenerate layers of some white dwarfs.

The most interesting galactic infrared emission is from the centre of the Galaxy. Narrow emission peaks from the centre region (the source size being typically 15 minute of arc × 15 minute of arc) at frequency $\nu \sim 3\times10^{12}$ Hz that contains up to 90% of the entire luminosity of the nuclei has been detected (Hoffman *et al* 1971). The origin of this 100 μm emission is still unknown. Most astrophysicists tend to believe that a significant portion of the 100 μm emission is probably thermal re-emission of the starlight by dust grains which surround the central star (Neugebauer *et al* 1971, Harwit *et al* 1972). A suggestion of coherent plasma radiation emitted during the accretion of gas by neutron stars and perhaps collapsed stars as a possible explanation has been considered recently by Bisnovatyi-Kogan and Syunyaev (1972), and several other authors have tried to attribute the 100 μm emission to synchrotron radiation (Low 1970, Pacholzyk 1970, De Sabbata *et al* 1972). We would like to point out that quantized magnetic bremsstrahlung radiation in intense magnetic fields from the surface layers of white dwarfs could serve as one of the possible explanations. In particular, we assume that the infrared radiation is from clusters of white dwarfs. Taking the cluster radius of 10^{19} cm (roughly corresponds to the typical source size) and the star population of 10^4, we find that the total energy emitted by quantized magnetic bremsstrahlung is in approximate agreement with experimental data.

In intense magnetic fields, when the gyrating radius of the electron is comparable to its de Broglie wavelength, the classical description of electrons is not valid, and a quantization process similar to that for atomic electrons takes place, resulting in discrete energy levels (known as Landau levels) in the motion perpendicular to the magnetic field, but the motion is still free along the field direction. The Landau levels of a non-relativistic electron, neglecting spin, are given by

$$E(n, P_z) = (n+\tfrac{1}{2})\frac{e\hbar}{mc}H+\frac{P_z^2}{2m} \tag{1}$$

where $n = 0, 1, 2, \ldots$ and H is the homogeneous magnetic field in the z direction (homogeneous over the gyrating orbit which is of the order of the de Broglie wavelength much less than 10^{-8} cm, and constant in time over the gyrating period which is much less than 10^{-8} s). The quantization replaces the kinetic energy of the electron in the plane perpendicular to the magnetic field by $(n+\frac{1}{2})(e\hbar/mc)H$, a quantum harmonic oscillator with angular frequency $\omega_c = eH/mc$. The criteria for application of the quantum description of electron motion can be stated as (Ziman 1960)

$$\frac{e\hbar}{mc}H > kT$$

or

$$10^{-3}H > T. \tag{2}$$

In a non-degenerate medium, the electrons satisfy a maxwellian-type distribution

$$N(n, E_z) = \frac{2Ve}{h^2c}\left(\frac{2m}{E_z}\right)^{1/2} H \exp\left(\frac{-E(n, E_z)+\epsilon}{kT}\right),$$

where $N(n, E_z)$ is the number of electrons in the volume V in state n with an average energy E_z $(= p_z^2/2m)$, ϵ is the chemical potential, and all other symbols have their usual meanings. The total number of electrons is (Chow 1969)

$$N = \int_0^\infty \sum_n N(n, E_z)\, \mathrm{d}E_z = \frac{2Ve}{h^2c}(2m)^{1/2} H \frac{(\pi kT)^{1/2}}{\mathrm{e}^\alpha - \mathrm{e}^{-\alpha}} \exp\left(\frac{\epsilon}{kT}\right),$$

where

$$\alpha = \frac{e\hbar}{mc}\frac{H}{kT}.$$

The electron population at different energy states is then given by

$$N(n, E_z) = \frac{\mathrm{e}^\alpha - \mathrm{e}^{-\alpha}}{(\pi kT E_z)^{1/2}} N \exp\left(\frac{-E(n, E_z)}{kT}\right), \tag{3}$$

and

$$\frac{N(n, E_z)}{N(n-1, E_z)} = \exp(-2\alpha). \tag{4}$$

Now for white dwarfs with effective temperatures around 10^4 K and magnetic fields of the order of 10^7 G (Kemp *et al* 1970) in their non-degenerate layers, we observe that, after the substitution of the numerical values of H and T into equations (2) and (4), at these temperatures and fields, the quantization of electron states should take place in the non-degenerate gaseous envelopes and most electrons are in the very lowest eigenstates. For white dwarfs with smaller fields ($< 10^6$ G), the classical description of the motion of electrons is adequate and the quantization process will not take place.

The magnetic bremsstrahlung radiation is emitted in the form of discrete lines when an electron jumps from an energy state n to another energy state n'. The energy of the emitted photon is dependent on the angle of emission with respect to the axis of the magnetic field (Canuto and Chiu 1971); in a first approximation, it is given by

$$\nu_{n,n-1} = \frac{E(n, E_z) - E(n-1, E_z)}{h} = 2{\cdot}8 \times 10^5 H \text{ Hz}, \tag{5}$$

and the energy emitted in unit time in connection with the transition $n \rightarrow n-1$ is

$$I_{n,n-1} = \hbar\omega_{n,n-1} A(n, n-1),$$

where $A(n, n-1)$ is the transition probability

$$A(n, n-1) = \frac{4}{3} \frac{e^2 \omega_{n,n-1}^3}{\hbar c^3} |r_{n,n-1}|^2,$$

and $r_{n,n-1}$ is the matrix element of the linear oscillator and is equal to $(n\hbar/2m\omega_{n,n-1})^{1/2}$. The total energy emitted in unit time is, after summation over all energy states n,

$$I = \sum_n N(n, E_z) I_{n,n-1} = \frac{2}{3} \frac{e^4 k}{m^3 c^5} N H^2 T \text{ erg s}^{-1}. \qquad (6)$$

Now, using equation (5), we obtain the frequency of the quantized electron magnetic bremsstrahlung radiation from a white dwarf with $H = 10^7$G as

$$\nu \simeq 3 \times 10^{12} \text{ Hz},$$

the corresponding wavelength is 100 μm. Self-absorption limits this radiation from a layer of one photon mean free path thick, which is a few metres inward from the non-degenerate gaseous envelope. After computing the energy emitted in unit time from a single white dwarf by using equation (6), we multiply this by the total number of white dwarfs in the cluster which, if taken to be 10^4, gives the total energy per second from the cluster

$$E \simeq 10^{41} \text{ erg s}^{-1},$$

which is in approximate agreement with experimental data. In equation (6), the total number of electrons N is given by $4\pi R^2(\Delta R)n_e$, where R is about $10^{-3}R_\odot$, ΔR is the photon mean free path and is of the order of 5 m, n_e is the electron density in the non-degenerate envelope and is around 10^{22} cm^{-3}.

In this short paper we presented our simple idea and made some rough estimates. There are many questions needed to be studied and answered. For example, is there any way one could possibly get the spectrum of radiation instead of just the one number at one frequency? This would help us to understand why the radiation is predominantly in the range near 100 μm. The magnetic bremsstrahlung radiation in intense magnetic fields also encounters a difficulty. That is the lifetime τ of the radiating electron is very short

$$\tau \simeq 3{\cdot}5 \times 10^{-19} \left(\frac{m^2 c^3}{e\hbar H}\right)^2 \text{ s},$$

which is approximately 10^{-6} s for a field of 10^7 G. Electrons may be supplied from the accretion of gas by white dwarfs. A neutral atom falling into the magnetic field of a white dwarf will experience an electric field, that is induced by the relative motion between the atom and the magnetic field. At a field of 10^7 G and above, the induced electric field can be so strong as to ionize the hydrogen atom. Some general properties of mass accretion on to a white dwarf without inclusion of magnetic field have been considered by Cameron and Mock (1967) in connection with x ray emission. According to them, the accretion causes the stellar atmosphere to split into a thin, hot layer ($T_e \sim 10^8$–10^9 K) where sizable flux of x ray emission is produced by bremsstrahlung, plus a comparatively cold inner region ($T_b \sim 500$–2000 K). Their conclusions can be misleading if applied generally to a white dwarf with strong magnetic field. If their findings are qualitatively valid for a magnetic white dwarf, one could then expect the x radiation from the thin, hot layer, and the magnetic bremsstrahlung radiation from the cold inner region. We would like to examine this, and other questions, in more detail. Therefore we shall not include any rough feasibility estimate here.

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