PULSAR NEBULAE:

Relativistic Hot Clouds of Electron-Positron Pairs

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1. Introduction

Recent observation with ASCA reveals that radio pulsars own X-ray diffuse nebulae around them. 11 such nebulae have been reported (Harrus, Hughes & Helfand 1996, Shibata et al. 1997, Kawai, Tamura & Shibata 1997). It is most likely that these nebulae are synchrotron nebuale powered by the pulsar wind, the outflow of relativistic particles. Kawai, Tamura and Shibata (1997) reduced an empirical law for the nebula luminosity $L_{\rm X}$ as a function of the rotation power $\dot{E}_{\rm rot}$ of the central pulsar: $L_{\rm X}/\dot{E}_{\rm rot} = -12.3 + 0.27 \log \dot{E}_{\rm rot}$.

2. Pulsar Wind

A pulsar radiates its rotational energy at the rate $\dot{E}_{\rm rot} = \Im\Omega\dot{\Omega}$, where Ω and $\dot{\Omega}$ are the angular velocity and its time derivative, and $\Im$ is the moment of inertia of the neutron star. Since we have an reasonable estimate of $\Im$, the rotation power $\dot{E}_{\rm rot}$ is practically observable. However, most of this power is unseen. The pulsed luminosity is only a tiny fraction of $\dot{E}_{\rm rot}$. Studies of the Crab Nebula suggest that the pulsar wind carries off most of the rotation power.

K. Koyama et al. (eds.), The Hot Universe, 267-268.

The pulsar wind interacts with surrounding matter to form a shock. The shocked wind radiates in synchrotron radiation and is observed as a synchrotron nebula, whose luminosity is still a small fraction of $\dot{E}_{\rm rot}$.

The energy flux of the pulsar wind is composed of the electromagnetic part $\dot{E}_{\rm EM}$ and the kinetic energy part in bulk motion $\dot{E}_{\rm KE}$ (thermal energy is negligible). Near the star, $\dot{E}_{\rm EM} \gg \dot{E}_{\rm KE}$, and the pulsar magnetosphere is such a machine that $\dot{E}_{\rm EM}$ is transferred into $\dot{E}_{\rm KE}$. Therefore, the ratio $\sigma \equiv \dot{E}_{\rm EM}/\dot{E}_{\rm KE}$ (the magnetization parameter) at the preshock region defines the acceleration efficiency and has great importance in the theory of the relativistic wind.

Another important point in the pulsar nebula is its morphology. Recent ROSAT and HST images (Hester et al. 1995) shows a ring and a pair of bipolar jets. The efficiency of the wind acceleration is closely related to the wind structure.

3. Pulsar Wind as a Calorimeter: Results

Nebulae luminosity and spectrum depend on properties of the wind and the pressure confining the pulsar. Following the Kennel-Coroniti model (1984a, b) for the Crab, we have developed a scheme in which nebulae are used as calorimeter to detect wind paramters (Shibata, Kawai and Tamura 1997).

We have three model parameters; the magnetization parameter σ, the wind Lorentz factor $\gamma_{\rm w}$, and the nebula magnetic field B (magnetic pressure would roughly equal to the confining pressure). The model is aplied to the empirical luminosity curve, and we find $\gamma_{\rm w} \approx 6 \times 10^7 (\sigma/0.003)(B/10\mu{\rm G})^{-2}$ for the middle-aged pulsars, the spindown power of which is of order of 10^{35}erg/sec. Combining this result with the ASCA spectrum, we suggest that the wind Lorentz factor increases with spindown in spite of decrease of the electromotive force. The magnetization parameter σ is found to stay much smaller than unity as was found for the Crab pulsar wind. It is also found that the nebula pressure relaxes toward the pressure of the general interstellar medium in time scale of 10^5yr.

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