SCALING FROM JUPITER TO PULSARS AND THE ACCELERATION OF COSMIC RAY PARTICLES BY PULSARS, III

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1. Introduction. In our first paper on this subject (Fan and Wu, 1981), we derived an expression for the rate of energy generation by a pulsar and estimated the contribution from all the pulsars in our galaxy to the observed cosmic ray intensity. The theory was then developed to an expanded version, and observational facts supporting the theory were cited (Fan et al., 1982; Fan and Hang, 1983). In this paper we supplement additional evidences.

2. Brief Review. The theory is based on two propositions:

(1) The rate of the energy generation by a spinning pulsar is given by

$$\frac{dT}{dt} = K \frac{M^2\omega^2}{Rc^2} , \qquad (1)$$

where M, R, and ω are respectively the magnetic dipole moment, the radius, and the angular velocity of the pulsar; c is the velocity of light, and K is a characteristic constant of the surrounding medium. This expression should be viewed as Ohm's Law in cosmological scale in which the EMF is generated by the spinning magnetized celestial body and K is a measurement of conductivity of the medium.

(2) The magnetic dipole moment of the pulsar, M, is related to its angular momentum L by the following expression:

$$M = \alpha L , \qquad (2)$$

where α is a "form factor," a characteristic constant of the interior of the pulsar. It is an extrapolation of so-called "Bode's Law" of planetary magnetism. The relationship seems to hold approximately true for all celestial bodies whose magnetic diple moments and angular momenta have been estimated or measured. They are over 15 orders of magnitude with Mercury, Venus, and Mars at the lower end and 24 Babcock magnetic stars at the upper end of the ladder, including a neutron star in the middle. The physical reason behind this fundamental relation is not known.

By combining (1) and (2), we have for the rate of energy generation as

$$\frac{dT}{dt} = \frac{K\alpha^2}{c^2}\frac{L^2\omega^2}{R} = \frac{K\alpha^2}{c^2}\frac{I^2\omega^4}{R} , \qquad (3)$$

where I is the moment of inertia of the pulsar. Since $T = 1/2\, I\omega^2$, we have finally

$$-\frac{2}{\omega^3}\frac{d\omega}{dt} = \frac{2K\alpha^2}{c^2}\frac{I}{R} \qquad (4)$$

The values of K and α were determined from the observation on Jupiter; they are 2×10^{-2}/sec and 2×10^{-16} gauss cm.s.g^{-1}, respectively. The scaling constant $k\alpha^2$ is then 8×10^{-34} cm.s^{-1}.g^{-1}. Equation (4) allowed us to use measured values of ω and $d\omega/dt$ of a pulsar to calculate its I/R, and then, by invoking neutron star models, we determined the mass m, the moment of inertia I, and the radius R of the pulsar and calculated the value of dT/dt.

3. Additional Evidences. An integration of Eq. (4) yields

$$\frac{1}{\omega^2} - \frac{1}{\omega_0^2} = \gamma t \quad , \quad \gamma = \frac{2K\alpha^2}{c^2}\,\frac{I}{R} \quad , \tag{5}$$

where ω_0 is the initial angular velocity of the pulsar. Assume that $\omega_0 >> \omega$, then

$$\frac{1}{\omega^2} = \gamma t \quad . \tag{6}$$

Figure 1 is a plot of $\log(2/\omega^3)$ $(-d\omega/dt)$ against $\log\omega$ for 202 pulsars (Fan et al., 1982). The pulsars at the left lower corner of the figure appear to be on a straight line given by Eq. (6) with t as a parameter. We interpret the line as the age limit of all pulsars. Using 8×10^{-34} cm.$s^{-1}g^{-1}$ for the value of $K\alpha^2$, we find t ~ 6×10^{15} sec (0.5 billion years). Consider the fact that the scaling constant could be off by a factor of 10, the time limit seems to be reasonable.

The low-energy charged particle (LECP) on Voyager 1 and 2 also detected a flux of hot plasma escaping from the Saturnian magnetosphere, just like in the case of Jupiter (Krimigis et al., 1981). Although the dynamics of the Saturnian magnetoshpere may be complicated by the existence of the rings, the energetic particles escaping from the system can be used to make an order-of-magnitude check of the prediction of Eq. (1). Estimating from their published figures, the escaping flux of 53-85 keV ions from the Saturn appears to be a factor of 100 lower than that from the Jupiter. The prediction of Eq. (1) is 1000.

Refererences

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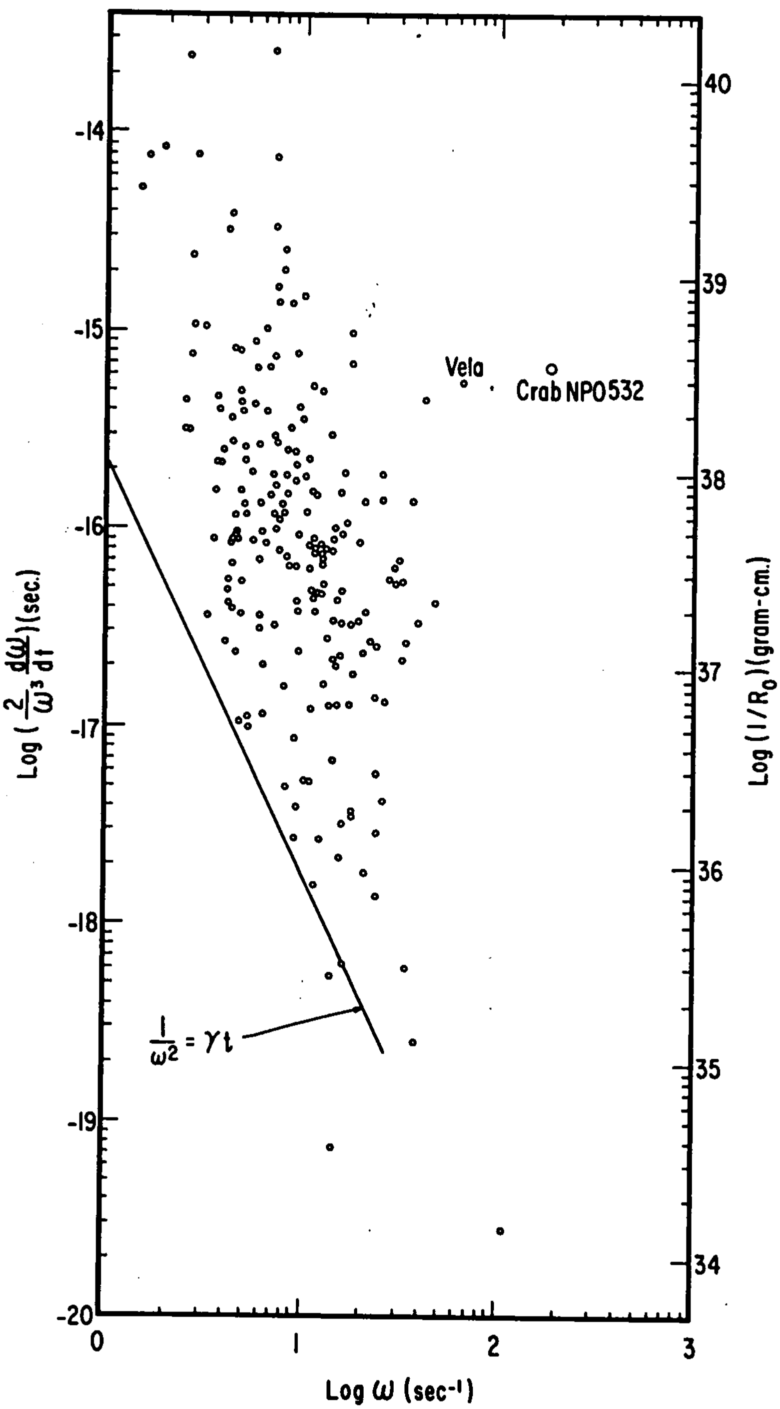

Fig. 1. A plot of $\log(2/\omega^3)$ $(-d\omega/dt)$ against $\log\omega$.