Fast pulsars with disks

F. C. Michel

Space Physics and Astronomy Department, Rice University,
Houston, Texas 77251, USA

A. J. Dessler

Space Science Laboratory, NASA Marshall Space Flight Center,
Huntsville, Alabama 35812, USA

It is quite likely that fast pulsars are not rare; there are several point-like radio sources with pulsar-like radio spectra that might prove to pulse in the millisecond range (J. H. Taylor, personal communication). The possibility that the recently discovered pulsar¹ PSR1937+214 is a new class of object has been considered by adherents of the vacuum model^{2,3}. We point out here that the measured parameters of PSR1937+214 are consistent with the proposed disk model of radio pulsars^{4,5}. Using the measured values of P and $\dot{P}$ and the scalings provided in this theory⁵, we expect a surface magnetic field strength of $\sim 10^8$ G, a radio-emission output of 10^{31} erg s⁻¹, and a weak (below detection with present instruments) output of energy in the X-ray and γ -ray ranges. The surface magnetic field cannot be checked, but the observed radio luminosity¹ is 3×10^{30} erg s⁻¹, in gratifying agreement with the theoretical expectation of the disk model.

In our model^{4,5}, an isolated magnetized rotating neutron star is encircled by a massive ($\sim 10^{-5} M_{\odot}$) fluid disk. Relative rotation between the disk and neutron star induces potential differences across the disk, and between the disk and neutron star as in a Faraday disk dynamo, permitting a return of the polar cap current from the disk to the star by auroral arcing. Pulsed emission arises from the return current flow to preferential regions of the star controlled by its surface magnetic field structure⁴.

In the disk model, the predicted average radio luminosity⁵ is related to P and $\dot{P}$ by

$$L_{\text{rad}} = 10^{30} \text{ erg s}^{-1} (\dot{P}/10^{-18}) (10/P)^{8/3} \quad (1)$$

where P is in milliseconds. The expected luminosity is 10^{31} erg s⁻¹ for 1937+214, compared with the observed value $\sim 3 \times 10^{30}$ erg s⁻¹. The position of 1937+214 relative to other pulsars is shown in Fig. 1, along with lines of constant radio luminosity from equation (1).

On average, pulsars have the luminosity indicated by equation (1), although there is considerable scatter (a factor of ~ 30 about the mean) as can be seen in Fig. 5 of ref. 5. Consequently, the close agreement in this case is probably fortuitous. It is difficult to compare this prediction directly against the vacuum rotator models owing to recent changes forced by the failure of the aligned rotator model⁶, and also the tendency to concentrate on explaining only the Crab pulsar⁷ rather than pulsars as a class. In any event, PSR1937+214 would be considered anomalously dim in the vacuum model, because only about 10^{-6} of the energy output appears as radio-emission, in contrast with the ratio of energy output to input of 10^{-3} typical of other pulsars⁸. As can be seen from Fig. 1, however, this pulsar has the luminosity expected by the disk model and is not anomalously dim.

According to the disk model, PSR1937+214 should not be a strong emitter of X rays and γ rays. The auroral zone potential drop, which gives the maximum potential available for accelerating particles, is 10^{10} V (see Fig. 4 of ref. 5). This is about average for pulsars in contrast to 10^{11} – 10^{12} V across the auroral zone for the Crab and Vela pulsars⁵. The energetic photon flux emitted by curvature radiation scales as particle

Fig. 1 Predicted radio luminosity of pulsars in the disk model (adapted from Fig. 3 of ref. 5).

energy to the fourth power, which may explain why only the Crab and Vela pulsars are bright sources of energetic photons.

In the disk model⁵, the surface polar magnetic field strength is given by

$$B_{\text{surf}} = 10^{10} \text{ G} (\dot{P}/10)^{1/2} (P/10)^{1/6} \quad (2)$$

For 1937+214, equation (2) indicates a surface field of $\sim 10^8$ G. We should emphasize that this is the value of B required to give the correct total power output from the neutron star, whereas equation (1) corresponds only to the radio power emitted.

Our magnetic field value of 10^8 G is slightly less than the 3×10^8 G inferred by Alpar *et al.*² and Arons³. In the disk model, the disk forces the field lines to open and form a stellar wind at the co-rotation distance (roughly 3 neutron-star radii) rather than at the light-cylinder distance (8 radii). Therefore, a given torque is produced in the disk model with a weaker surface field than in the vacuum models; the typical pulsar magnetic field is only 10^{10} G in the disk model compared with 10^{12} G in the vacuum models⁹. Consequently, a field of the order of 10^8 G is less surprising on the basis of the disk model, although it is an unusually weakly magnetized object. (We do not discuss here the issue of neutron star magnetization.)

We conclude that PSR1937+214 is not necessarily a new class of pulsar but that its properties are consistent with the disk model and do not require special explanation, although it may have had a peculiar evolutionary history¹⁻³.

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