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Abstract

It is shown that a very small axially symmetric eccentricity of the pulsar discovered in SN1987A could cause cyclic appearance and disappearance of the signals due to the slow rotation about the body symmetry axis which could carry the magnetic axis out of our line of sight. Taking account of gravitational radiation damping, eccentricities that are consistent with the measured small rate of change of the millisecond period, would yield a period for the disappearances ranging from about an hour to the age of the universe. We also examine precession as a possible explanation of the observed eight hour modulation of the millisecond pulses. While a sinusoidal frequency modulation of the correct period can be found, the amplitude of the modulation is much too small compared to observation.

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The half millisecond pulses discovered in the remnant of supernova 1987A and ascribed to a new pulsar born in that event, were observed over an eight hour interval, but not seen two weeks later on the next search, nor subsequently on scattered dates [1]. We discuss how a very small eccentricity whose symmetry axis is inclined at an angle to the angular momentum axis will slowly rotate the pulsar about the symmetry axis causing cyclic disappearance and reappearance of radiation beamed along a magnetic axis fixed in the star. Using the observed rate of change of the millisecond period as a constraint on the eccentricity, we find that the period of the cycle for dissapearances could range from an hour to the age of the age of the universe, if no subsequent adjustment of the shape occurred.

Precession in planets and stars has been discussed previously assuming that the body is neither perfectly rigid nor fluid [2]. In such a case the motion is described relative to a reference system in which the elastic energy vanishes. Otherwise the precession is like that of a rigid body. In the following what we refer to as the body symmetry axis should be understood more generally as the symmetry axis of the above reference system, which coincide for rigid bodies, and similarly other variables should be understood as effective variables in the reference system. From the mechanics of a rigid body possessing an axis of symmetry that makes an angle β with the angular momentum axis which is fixed in space, the body will rotate about its own symmetry axis with an angular velocity of [3],

$$n = \Omega \frac{e}{1+e} \cos\beta, \qquad e \equiv \frac{I_3}{I_1} - 1 \tag{1}$$

where $I_1 = I_2 \neq I_3$ are the principal moments of inertia and Ω is the precession frequency of the symmetry axis about the fixed direction of the angular momentum vector. For very small 'eccentricity', e, Ω is almost equal to the angular velocity, ω, of the body. The precise relation is given by,

$$\Omega \cos\beta = \omega \frac{(1+e)}{\sqrt{1+(1+e)^2 \tan^2\beta}} \tag{2}$$

From eq.(1) we have the inequality,

$$\left|\frac{n}{\Omega}\right| < \left|\frac{e}{1+e}\right| \tag{3}$$

If the pulsar in SN1987A is deformed the eccentricity must be very small because of the measured $\dot{T} < 3 \times 10^{-14}$ and the short period, $T \approx .5 \times 10^{-3}$ seconds. Gravitational radiation yields a rate of change of the period according to,

$$\dot{T} = (2\pi)^4 \frac{64}{25} \frac{1}{T^3} M R^2 e^2 \tag{4}$$

in gravitational units ($G = c = 1$). For a rapidly rotating neutron star near the limits of stability, we take $M = 1.7 M_\odot$, $R = 11$ km [4]. We obtain the constraint $e < 3 \times 10^{-7}$. According to eq.(3) this would yield a period for the rotation of the star around its own axis of $> 2 \times 10^3$ seconds. If instead we assumed a period of a week for the rotation about the symmetry axis, then we find $e \geq 8 \times 10^{-10}$, which would make gravitational radiation completely negligible at the bound.

We tentatively propose that the subsequent failed searches for the signals in Sn1987A have occurred during the portions of the above cycle when the magnetic axis has been rotated too far out of our line of sight by the slow rotation about the symmetry axis. If this explanation is correct, the pulsar should reappear and disappear at cyclic intervals. The duration of the appearance need not be the same as the duration of the disappearance. This depends on the angle between the symmetry axis and the angular momentum axis, on the angle between the magnetic axis and the symmetry axis, and on the beam width of the radiation about the magnetic axis. As shown above, a period of the reappearance cycle anywhere from an hour to infinity is compatible with the observed rate of change of the precession associated with the millisecond period. (An eccentricity associated with the mass of a fly (taken as 1/10 g) situated on the surface of the star would yield a period for the rotation about the symmetry axis of $\sim 10^{23}$ years, assuming a solar mass for the star and assuming no readjustment in the shape of the star. Because of the eccentricity of the earth ($e \approx -0.003$), it rotates about its polar axis with a period of a little more than 400 days.) With respect to very long dissappearance cycles we should mention the caveat that the shape is likely to make adjustments on a shorter time scale that brings the star to a different precessional motion. Starquakes (with periods of months to years) are an example of an adjustment. The new motion might never bring the beamed radiation back into view.

We show in Fig. 1 an example of how the frequency is modulated by a precession such as discussed above and how the signal seen by an observer fixed in space will vary in intensity. We use parameters suitable for graphical display which leads to a ratio of periods of 100 rather than 10^9. The intensity variation is more clearly illustrated in Fig. 2. The signals from the model pulsar were computed assuming a beam of radiation whose intensity is gaussian about the direction of the magnetic axis. This axis is taken to be inclined at an angle γ from the symmetry axis. The polar angles of the magnetic axis referred to the angular momentum direction as the z-axis, with origin at the center of the star are given by,

$$\Theta(t) = \arctan\left(\frac{\sqrt{(\sin\beta + \cos\beta\tan\gamma\cos nt)^2 + \tan^2\gamma\sin^2 nt}}{\cos\beta - \sin\beta\tan\gamma\cos nt}\right) \tag{5}$$

$$\Phi(t) = \Omega t + \arctan\left(\frac{\tan\gamma\sin nt}{\sin\beta + \cos\beta\tan\gamma\cos nt}\right) \tag{6}$$

The first term of eq.(6) shows that the *precession* frequency, and not ω, is the pulsar frequency and the second term exhibits a frequency modulation.

The frequency modulation exhibited in Fig. 1 raises the question of whether the observed eight hour modulation of the millisecond pulses could be related to precession. The frequency modulation in the second term of the equation for $\Phi(t)$ is sinusoidal to high accuracy under the condition $\tan\gamma << \tan\beta$,

$$\dot{\Phi} \approx \Omega + \left\{1 + \left(\frac{\tan\gamma\sin nt}{\sin\beta}\right)^2\right\}^{-1} n\frac{\tan\gamma}{\sin\beta}\cos nt \tag{7}$$

as for a pulsar whose signal is modulated by circular orbital motion. We check the constraints imposed on such an hypothesis for the pulsar discovered in the remnant of SN1987A. The eight hour modulation is closely sinusoidal and its amplitude is $\Delta\Omega/\Omega \approx 7.5 \times 10^{-7}$. The eight hour period requires $e > 10^{-7}/6$, which together with the constraint calculated above for the rate of change of the short period due to gravitational radiation, imposes the compatible conditions, $\frac{1}{6} < e/10^{-7} < 3$. However from eq.(7), the amplitude of the frequency modulation is given by,

$$\frac{\Delta\Omega}{\Omega} << \left|\frac{e}{1+e}\right| < 3 \times 10^{-7} \tag{8}$$

whereas the observed amplitude of the frequency modulation is 2 times larger than the right side. Although the general form of the modulation is difficult to analyze, it seems unlikely that the observed modulation is due to precession.

The proposition seems viable that the disappearance of the pulsar is due to the slow rotation of the magnetic axis, fixed in the star, about a symmetry axis established by a very small eccentricity. It can be tested if the slow period is not too long by making observations over a sequence of nights that would not be synchronous with a periodic phenomenon. Of course the disappearance could have been occasioned by debris moving into the line of sight. However this hypothesis becomes less tenable as time passes, because such supernova debris is expanding. Elsewhere we have discussed the possible extinction of the pulsar by collapse to a black hole [5].

We mention that the above model of an axialy deformed pulsar gains some support from the fact that it can qualitatively simulate several features observed in the signals of many other pulsars, namely subpulse drifting, nulling, and mode switching, which is the subject of another manuscript [6].

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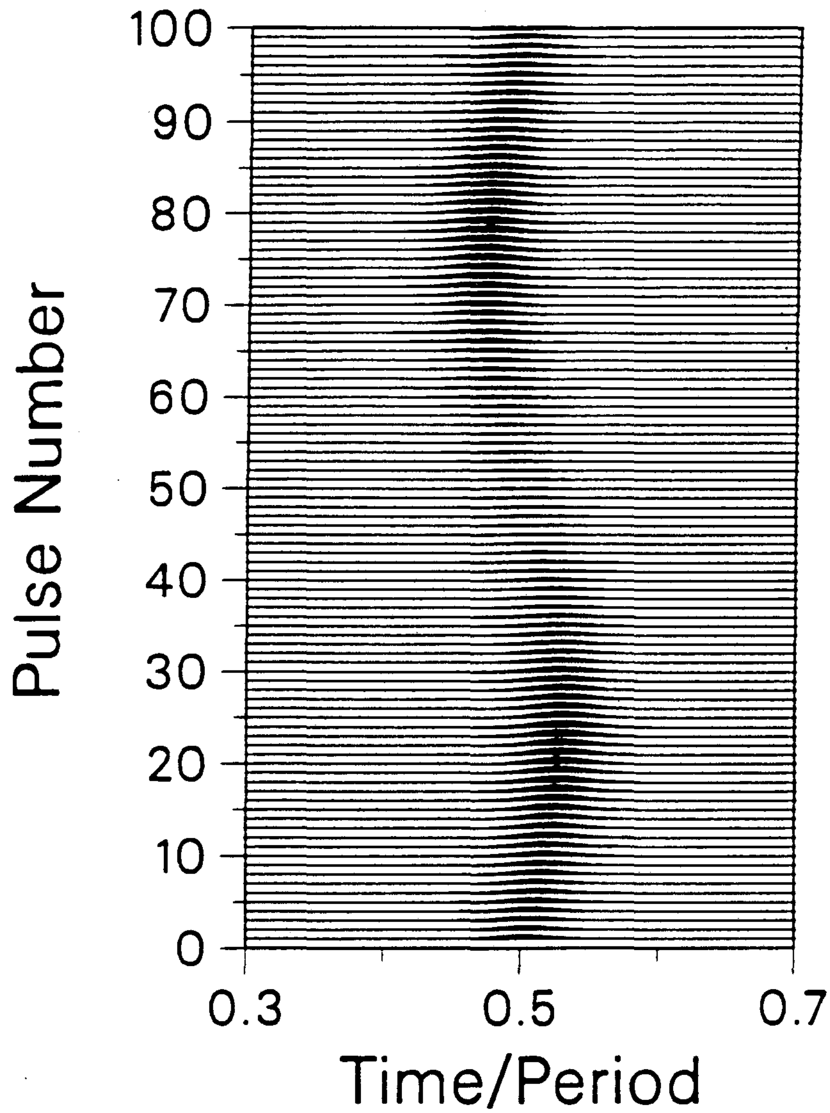

Figure 1. Pulses are plotted modulo the period for a central slice of the period and stacked by pulse number, for $e = -0.02$, $\Omega/n = 100$, $\gamma = 0.05\pi$. The observer's orientation is given by the polar angle $\theta = 0.35\pi$.

This representation shows both the frequency modulation and the intensity variation.

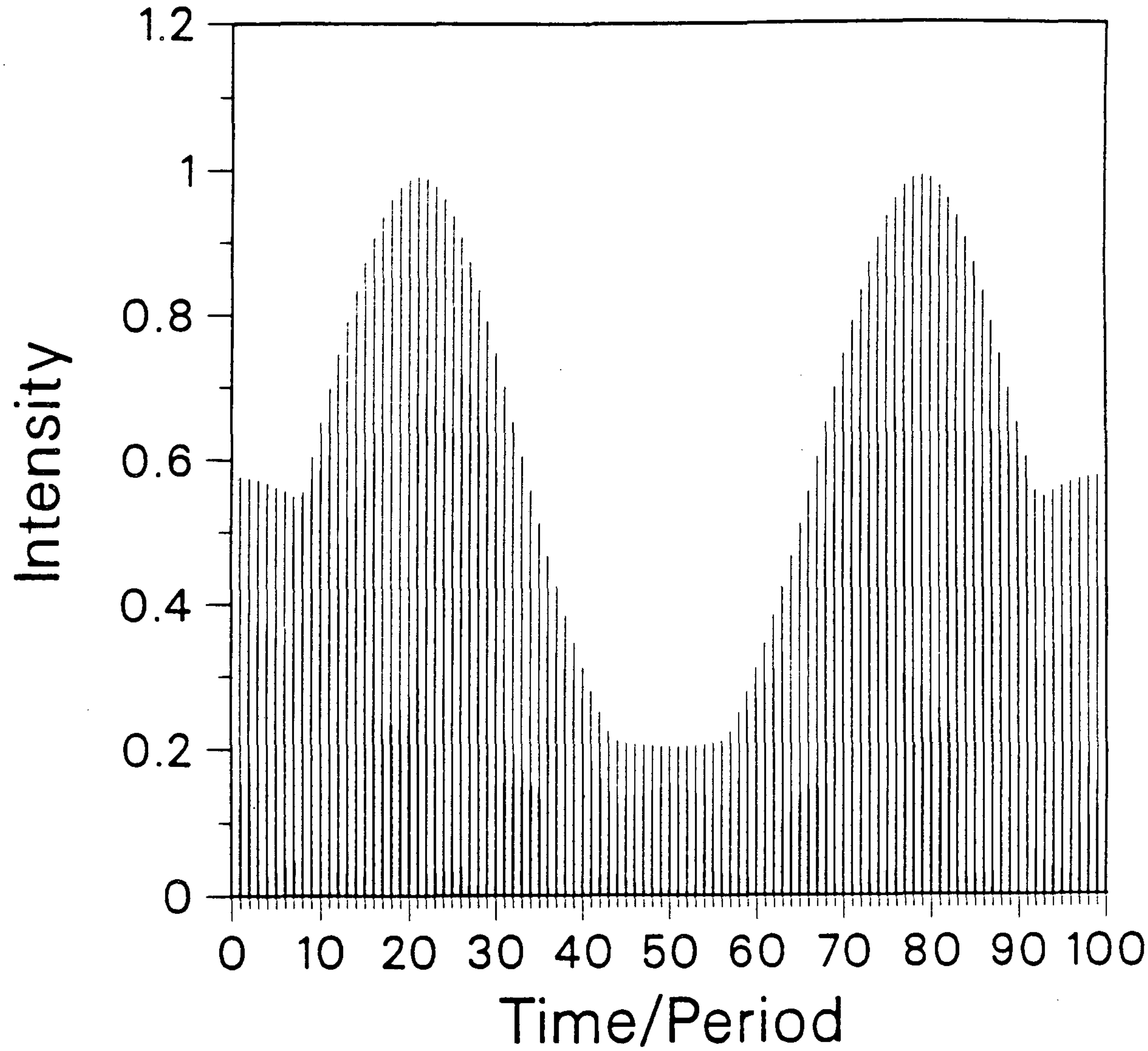

Figure 2. For the above case the intensity versus time is shown for a hundred of the fast pulses over one period of the rotation about the star's symmetry axis. (Generally the ratio will not be a rational number.)

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