Since the times τ, t, τ' and δ and the steady gradient g_0 are already known, the pulsed gradient can straightaway be calculated.

There is an additional advantage in this method. Since the echo occurs sooner than before, the attenuation due to diffusion during $\tau - t - \delta - \tau'$ is no longer present. Then the echo intensity would be more than before, thus leading to an increase in the accuracy.

It is also possible to use a single pre-180° pulse gradient pulse instead of the post-180° gradient pulse as shown. In this case, of course, the echo would occur at a later time.

Another variation of the same technique, namely, by using two gradient pulses of different magnitudes on either side of the 180° pulse, would enable one to calibrate a very large range of pulse gradients.

This new scheme of applying the field gradients, namely the hybrid combination of the steady gradient and a pulsed gradient can also be used for the measurement of the self-diffusion coefficient in favourable cases. The details will be presented in a separate publication.

9 March 1984

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ON THE POST-NEWTONIAN EFFECTS IN THE MILLISECOND PULSAR 1937+214

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THE theory of rotating bodies[1] places constraints on the parameters characterizing a millisecond pulsar[2]. Upto a certain critical value of the angular momentum, the only possible equilibrium figure for a selfgravitating rotating body is a Maclaurin spheroid. At this critical value, called a point of bifurcation, nonaxisymmetric, Jacobi ellipsoids also become permissible equilibrium configurations. It is however more convenient to talk in terms of the angular velocity, which is not a monotonically increasing function of the eccentricity e (of the plane containing the rotation axis) as the angular momentum is. The rotational properties are determined by the parameter $\Omega^2/\pi G\rho$.

The Maclaurin sequence becomes secularly unsutable at $\Omega^2/\pi G\rho = 0.374$ (*i.e.* $e = 0.8127$), where the Jacobi sequence branches off. The sequence becomes dynamically unstable at $\Omega^2/\pi G\rho = 0.449$ ($e = 0.9529$) beyond which no equilibrium figure is possible. Note than an inviscid, classical Maclaurin spheroid continues to be stable even beyond the bifurcation point.

However, even if a small viscosity is present, the Maclaurin spheroid becomes unstable beyond the bifurcation point[1]. A Maclaurin spheroid being axisymmetric is not a source of gravitational radiation, but gravitational waves will be emitted during its oscillations. The gravitational radiation reaction also makes the Maclaurin spheroids unstable beyond the bifurcation point[3]. A toroidal magnetic field leaves the bifurcation point unaffected, whereas a field along the axis of rotation pushes it to higher values of eccentricity[4]. To significantly affect the bifurcation point, the ratio $\mathcal{M}_{33}/\pi G\rho I$, where $\mathcal{M}_{33}$ is the axial magnetic energy and I the moment of interia, should be of order unity[5].

For the 1.56 ms pulsar this ratio is only 10^{-18}, making the effect of the magnetic field negligible. In any case, a magnetic field cannot inhibit the instability due to either viscosity[5] or radiation reaction. The two instabilities however operate through different modes, each stabilizing the other. One can indeed construct situations where the two cancel[6]. But the viscosity required to offset the destructive effects of the gravitational radiation reaction is about 10^{13} times greater than that of the neutron star models[6]. Thus a Maclaurin spheroid is not likely to be stable beyond the point of bifurcation. Even if the neutron star is born spinning so rapidly that it is a truly triaxial figure, it will radiate away gravitationally its nonaxisymmery in a matter of a day and become axisymmetric[3].

In other words the shortest period pulsar can have is the one corresponding to the value of $\Omega^2/\pi G\rho$ at the bifurcation point with an appropriate choice of the average mass density.

One can write, for the point of bifurcation $\Omega^2/\pi G\rho = 1.884\, \rho_{14}\, P_{ms}$, where $\rho = \rho_{14} \times 10^{14}$ g cm^{-3} is the mean density and $P = P_{ms} \times 10^{-3}$ s the period. The 1.56 ms pulsar would be exactly at the point of bifurcation if its density were $\rho_{14} = 2.07$ which corresponds to a mass of 0.7 $M_\odot$. Obviously the millisecond pulsar cannot have $\rho_{14} < 2.07$ ($M < 0.7\, M_\odot$)[7]. If $M = 1.4\, M_\odot$ ($\rho_{14} = 4.64$) then the millisecond pulsar has an eccentricity $e = 0.56$ and $\Omega^2/\pi G\rho = 0.167$. The bifurcation point now corresponds to

$P_{ms} = 1.04$ ms. If their mass is 1.4 $M_{\odot}$, then faster pulsars, with periods as short as 1 ms, should also be seen.

The general relativistic effects are expected to be important for the millisecond pulsar. If one retains terms of order c^2, one can write the post-newtonian corrections[8]:

$$\frac{\Omega^2}{\pi G\rho} = \frac{\Omega_N^2}{\pi G\rho} + \frac{R_s}{a_1} f(e).$$

Here Ω_N is the newtonian angular velocity, $R_s = 2GM/c^2$ is the Schwarzschild radius of the neutron star and $a_1 = a_2$ the longer axis. $f(e)$ is an involved function of the eccentricity and is tabulated by Chandrasekhar[8].

Thus if the post-newtonian effects are included, then for a given $\Omega^2/\pi G\rho$ the eccentricity is lower than the classical value (figure 1). The point of bifurcation and the point of maximum Ω^2 still occur at the same value of e, but now correspond to a higher Ω.

For a 0.7 $M_{\odot}$ neutron star, the point of bifurcation occurs at $\Omega^2/\pi G\rho = 0.4$, whereas for a 1.4 $M_{\odot}$ neutron star the corresponding value is 0.43. Thus the post-newtonian effects are about 10% of the classical values.

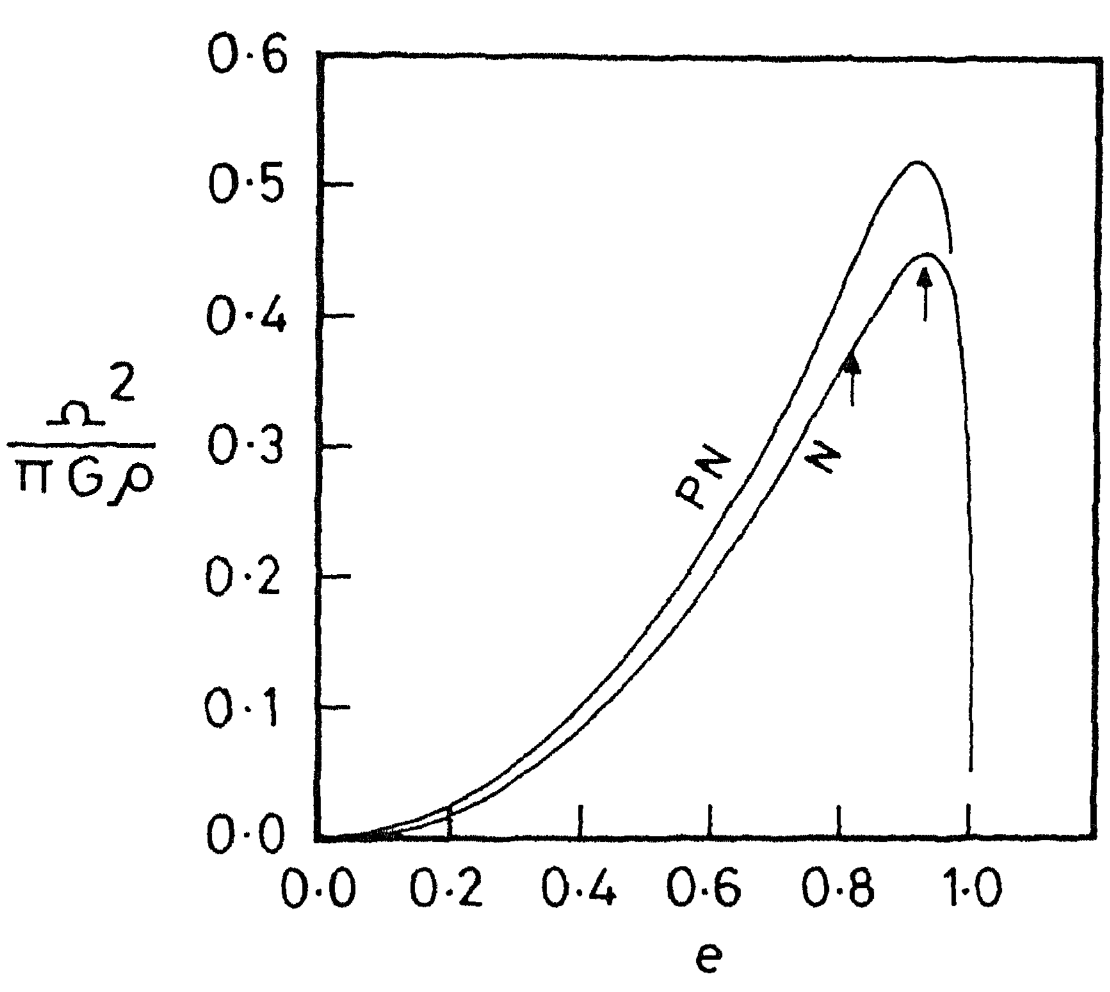

Figure 1. The square of the angular velocity (in the unit $\pi G\rho$) along the Maclaurin sequence as a function of the eccentricity. The classical (N) curve and the post-newtonian curve for mass = 1.4 $M_{\odot}$ (PN) are shown; for the latter only values upto $e = 0.98$ are plotted. Curve for $M = 0.7\,M_{\odot}$ is very close to the 1.4 $M_{\odot}$ curve and is omitted. The point of bifurcation ($e = 0.81267$) and the point of maximum Ω ($e = 0.93$) are the same for the newtonian as well as the post-newtonian case and are marked.

In the post-newtonian approximation, the 1.56 ms pulsar has an eccentricity $e = 0.73$ ($M = 0.7\,M_{\odot}$) or $e = 0.5$ ($M = 1.4\,M_{\odot}$). The point of bifurcation now corresponds to $P_{ms} = 1.5$ for a 0.7 $M_{\odot}$ neutron star. With post-newtonian effects included, a 1.4 $M_{\odot}$ neutron star will have a period of 0.98 ms at the point of bifurcation, which is the shortest it can have.

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PRODUCTION OF H^- ION BEAM USING DUOPLASMATRON SOURCE

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THE efficiency of direct extraction of H^- ion from a duoplasmatron ion source by on-axis and off-axis extraction technique has been found to be very small[1,2]. Recently a concept of ion source, in which negative surface ionization (NSI) of hydrogen can be used as a tool to produce H^- ion beam, has been proposed by several authors[3]. Measurement[4] of large conversion efficiency (up to 40%) of H^+ into H^- by NSI technique has given the prospect of utilising the duoplasmatron as an efficient negative ion source. We have started an experiment, the aim of which is to use a duoplasmatron to produce H^- ion beam efficiently, by the NSI technique. Since the NSI technique would need to impinging H^+ ion to be of lower energy, the duoplasmatron should be operated at its low-extraction voltage mode. But it is known that the usual