O PULSAR PSR 1913+16

A Laboratory for Relativity (*)

N. Straumann, Inst. Theor. Physics, University of Zurich

Almost 20 years ago, Joseph Taylor And Russell, Hulse from Princeton University discovered, in a systematic search for new pulsars using a large radiotelescope, the binary radio pulsar PSR 1913+16 that appears to have been exquisitely designed as a laboratory for general relativity (1). In subsequent years, much effort has been put into measuring its pulse arrival times with increasing precision and comparing the results with general relativity.

Before entering into a brief description of the analysis and an appreciation of the importance of the results, we shall recall the gross features of the binary pulsar system. The nominal period of the pulsar is 59 msec. This short period was observed to be periodically shifted, which proved that the pulsar is a member of a binary system with an orbital period of 7.75 hours (precise numbers for various orbital parameters are given in the Table. Figures in parentheses represent uncertainties in the last quoted digit; those in square brackets represent expected values of unmeasured quantities, according to general relativity). With Kepler's third law and reasonable masses one concludes that orbit is not much larger than the Sun's diameter.

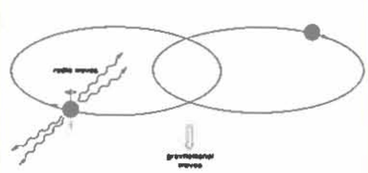
Correspondingly, the velocity of the pulsar is about 10^{-3} *c* and it moves through a relatively strong gravitational field (about 100 times stronger than the gravitational field of the Sun near Mercury). These numbers show that several special and general relativistic effects should be observable - a goal that has been explored since 1974 with increasing accuracy. It turned out that PSR 1913+16 is one partner of a "clean" binary system of two neutron stars each having approximately 1.4 solar masses M (see Figure).

In addition, PSR 1913+16 behaved very well all the time, for it has not made any discontinuous jumps (glitches) nor generated noise since being discovered.

From the shape of the radial velocity curve which is derived from the periodically changing pulse arrival rate due to the Doppler shift, Hulse and Taylor noticed very soon that the orbit is highly eccentric (an aspect ration $e \approx 0.62$). One of the main reasons why the Hulse-Taylor pulsar has become an ideal testing ground for general relativity is that there are regions of very strong field in the two-body system: at the surface of the neutron star the characteristic measure for the field strength G x mass/(c^2 x radius) becomes about 0.2 which is close to the maximum value of 0.5 at the horizon of a black note, where G is the gravitational constant.

Pulsars represent natural clocks which are remarkably stable. Owing mainly to magnetic dipole radiation, the period of the rotation magnetized neutron star increases slowly, and hence the intrinsic pulsar frequency ν decreases steadily with time. For PSR 1913+16 the first derivative with time is very small, but measurable: $\dot{\nu} = -2.47583\ (2) \times 10^{-15}\ \text{sec}^{-2}$. The pulsar is thus almost as stable as the best atomic clock. The sequence of arrival times on Earth of the electromagnetic pulses emitted by the orbiting pulsar is, however, slightly distorted by a number of effects. Besides the almost periodic Doppler modulation which is influenced by general relativistic effects of the orbital motion, the pulse originating from the vicinity of the pulsar (strongfield region) travels afterwards through the relatively weak-field region between the condensed objects, and finally through the weak field of the solar system.

Binary Pulsar



A pulsar emits radio waves in two bunches which sweep across space at the same rate as the pulsar rotates.
In a binary pulsar system such as PSR 1913+16, gravitational waves are also emitted.

Parameter	PSR B1534+12	PSR B1913+16
	Keplerian parameters	
Orbital period, P_b (s)	36351.70270(3)	27906.9807804(6)
Eccentricity, e	0.2736779(6)	0.6171308(4)
Projected semi-major axis, x (s)	3.729468(9)	2.3417592(19)
Time of periastron, T_0 (MJD)	48262.8434966(2)	46443.99588319(3)
Longitude of periastron, ω (°)	264.9721(16)	226.57528(6)
	Post-Keplerian parameters	
Advance of periastron, $\dot{\omega}$ (° yr^{-1})	1.7560(3)	4.226621(11)
Time dilation, γ (ms)	2.05(11)	4.295(2)
Orbital period derivative, $\dot{P}_b$ (10^{-12})	−0.1(6)	−2.422(6)
Range of Shapiro delay, r (μs)	6.2(1.3)	[6.836]
Shape of Shapiro delay $s \equiv \sin i$	0.986(7)	[0.734]

(*) De um artigo recente de N. Straumann, *A Laboratory for Relativity*, Europhysics News **24** 191 (1993). Neste trabalho encontra-se ainda uma apreciação extensa dos aspectos científicos que estiveram na base da atribuição do Prémio Nobel da Física de 1993.

(1) R. A. Hulse and J. H. Taylor, Astrophysis Journal **195 L51** (1975).