PSR B1913+16

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The first well-studied compact binary system was discovered in 1974, the binary pulsar PSR 1913+16, in the constellation Aquila.

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DISCOVERY OF A PULSAR IN A BINARY SYSTEM

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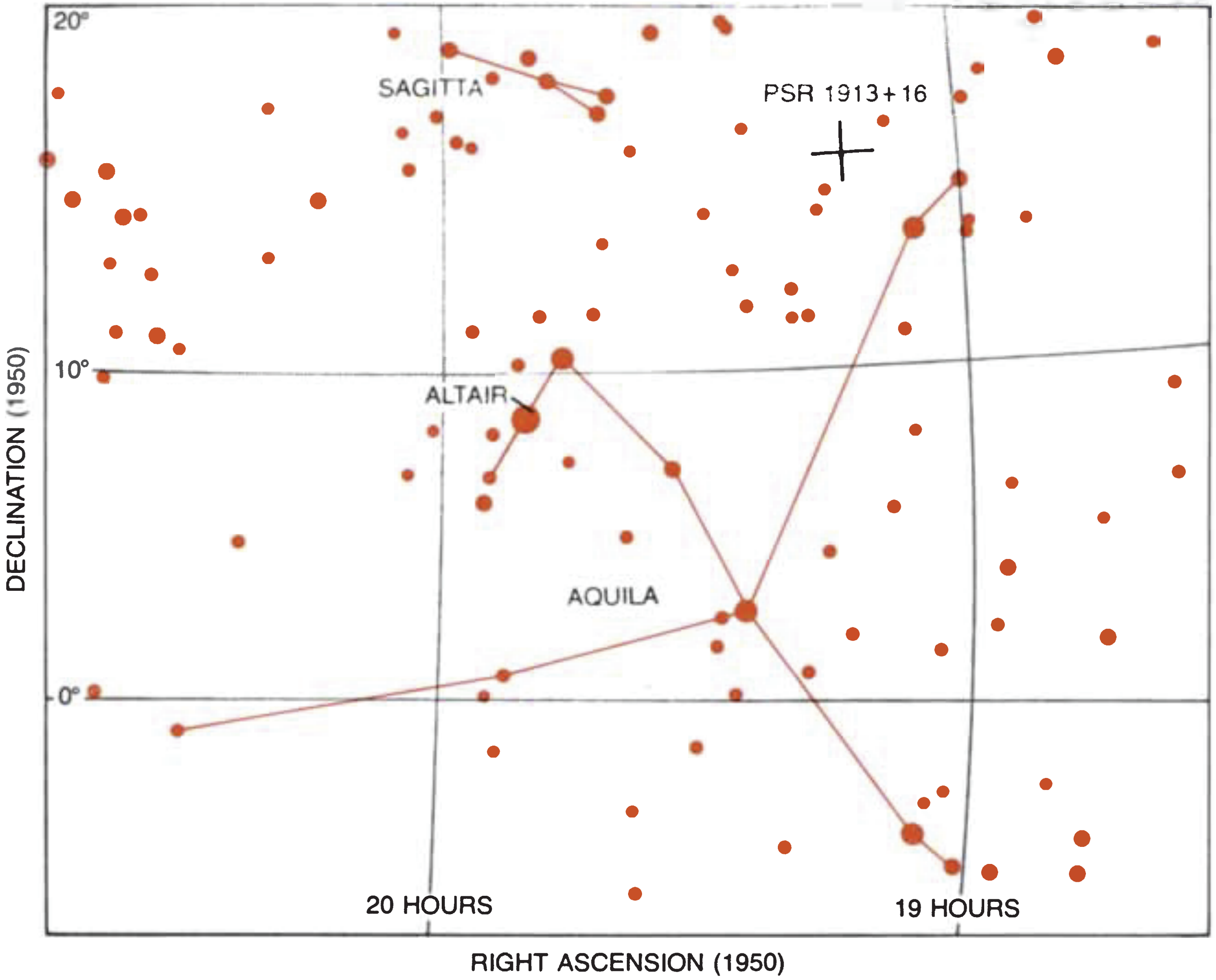
ABSTRACT

We have detected a pulsar with a pulsation period that varies systematically between $0^{s}.058967$ and $0^{s}.059045$ over a cycle of $0^{d}.3230$. Approximately 200 independent observations over 5-minute intervals have yielded a well-sampled velocity curve which implies a binary orbit with projected semimajor axis $a_1 \sin i = 1.0\ R_{\odot}$, eccentricity $e = 0.615$, and mass function $f(m) = 0.13\ M_{\odot}$. No eclipses are observed. We infer that the unseen companion is a compact object with mass comparable to that of the pulsar. In addition to the obvious potential for determining the masses of the pulsar and its companion, this discovery makes feasible a number of studies involving the physics of compact objects, the astrophysics of close binary systems, and special- and general-relativistic effects.

Subject headings: binaries — black holes — neutron stars — pulsars — relativity



BINARY PULSAR PSR 1913 + 16 is in the constellation Aquila at the coordinates that supply its designation: right ascension 19 hours 13 minutes and declination +16 degrees. Its position is marked by the reticle. It is estimated that the binary pulsar is some 15,000 light-years away, too far for it to be observed optically even with the most powerful existing telescopes.

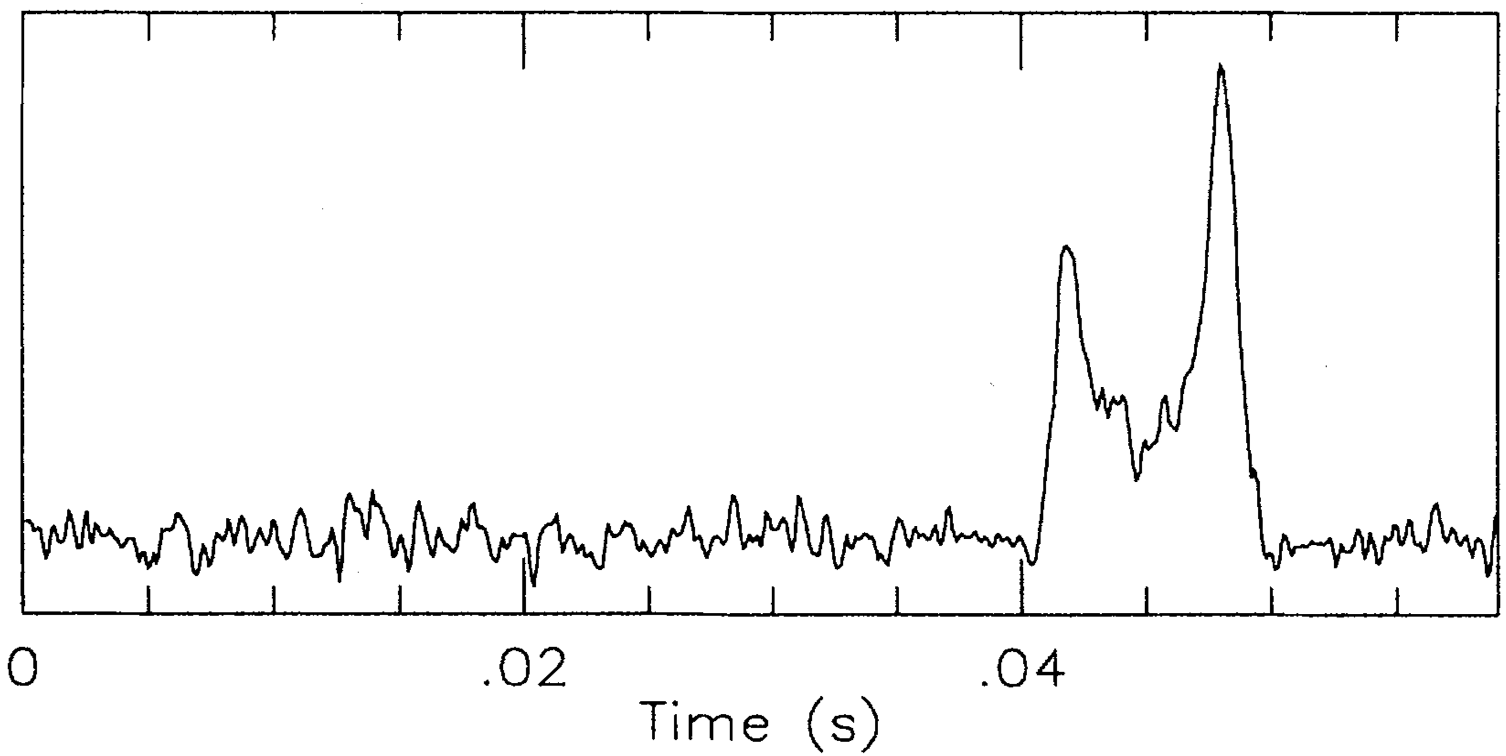
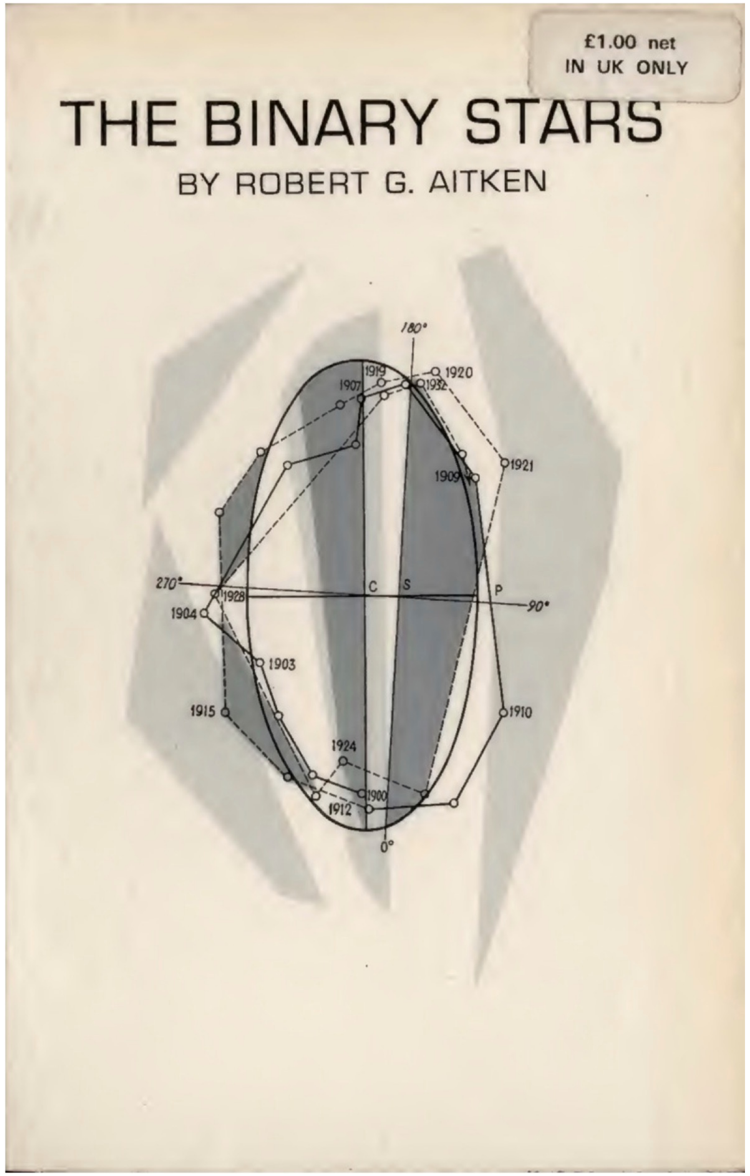


FIG. 4. Pulse profiles obtained on April 24, 1992 during a five-minute observation of PSR 1913+16. The characteristic double-peaked shape, clearly seen in the de-dispersed profile at the bottom, is also discernible in the 32 individual spectral channels.

First steps: accurate determination of orbital parameters according to classical Keplerian theory



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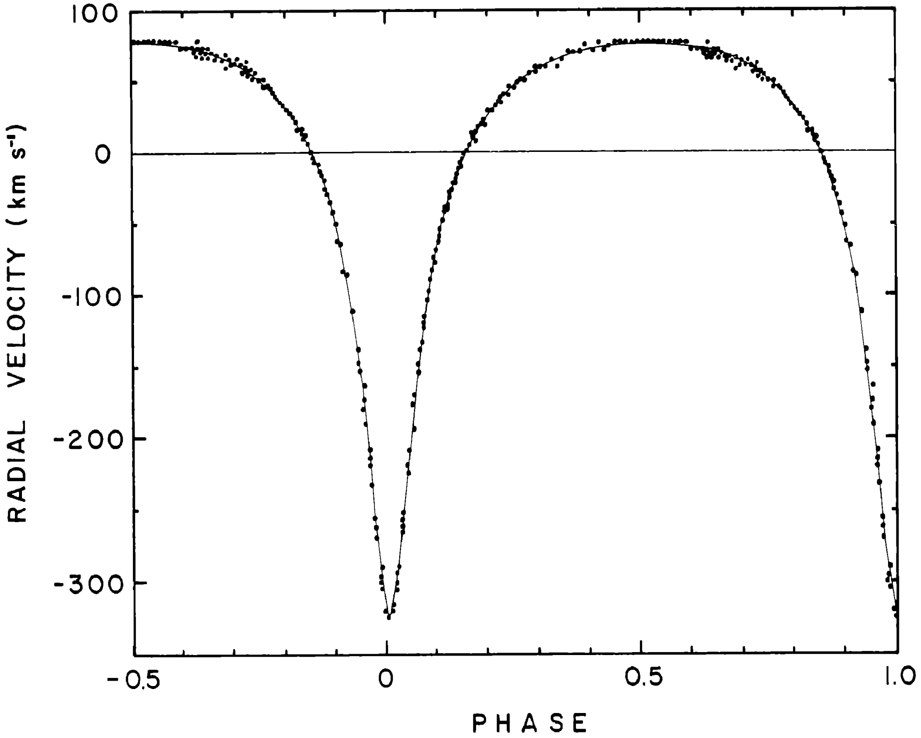


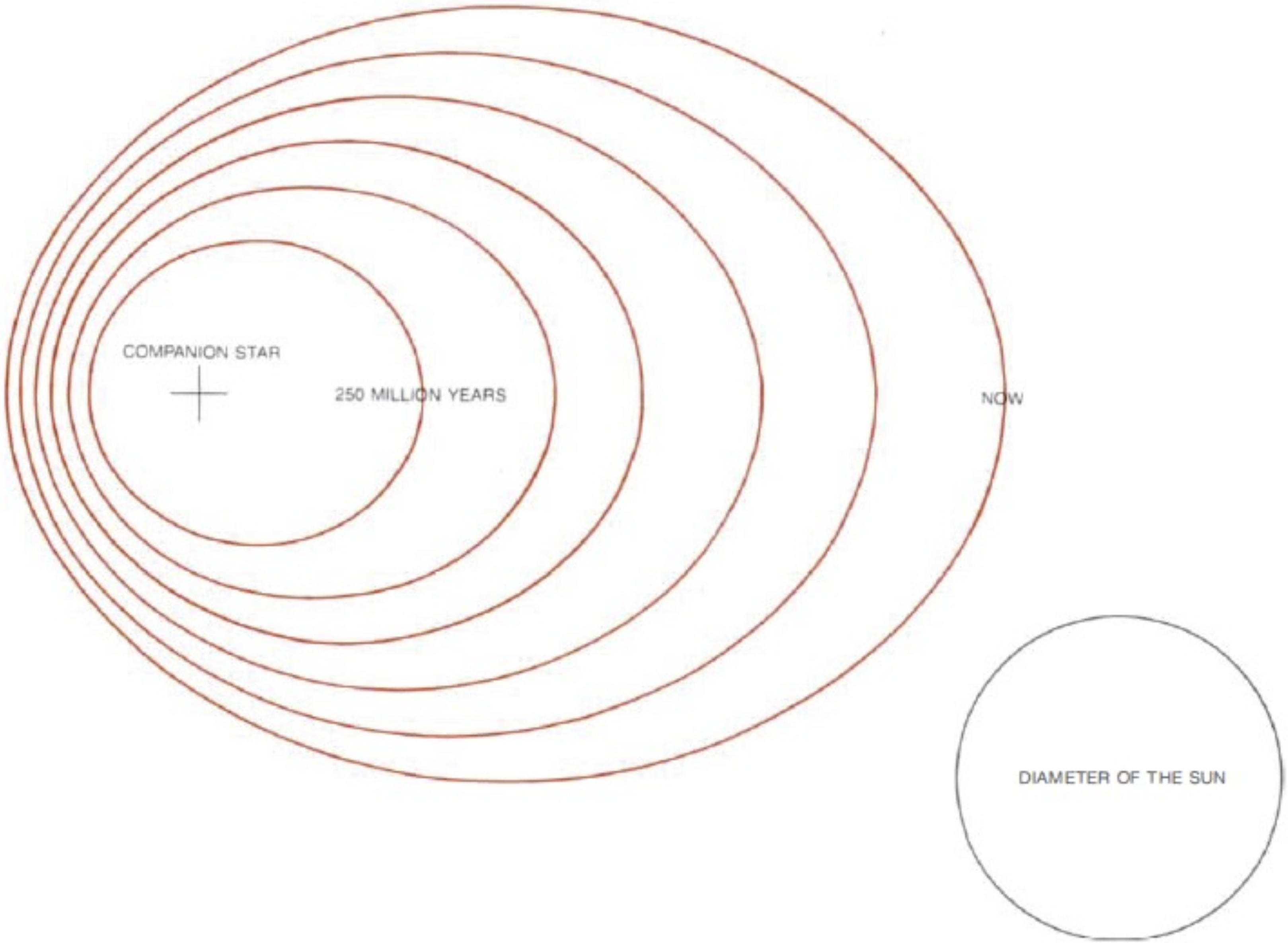
Velocity curve for the binary pulsar. Points represent measurements of the pulsar period distributed over parts of 10 different orbital periods. The curve corresponds to equations from Aitken, with the following orbital parameters:

Parameters of the Binary Pulsar

$\alpha(1950.0)$	$= 19^h13^m13^s \pm 4^s$
$\delta(1950.0)$	$= +16°00'24'' \pm 60''$
l	$= 49.°9$
b	$= 2.°1$
P_{cm}	$= 0.^s059030 \pm 0.^s000001$
dP_{cm}/dt	$< 1 \times 10^{-12}$
DM	$= 167 \pm 5$ cm^{-3} pc
S_{430}	$= 0.006 \pm 0.003$ Jy
W_e	< 10 ms

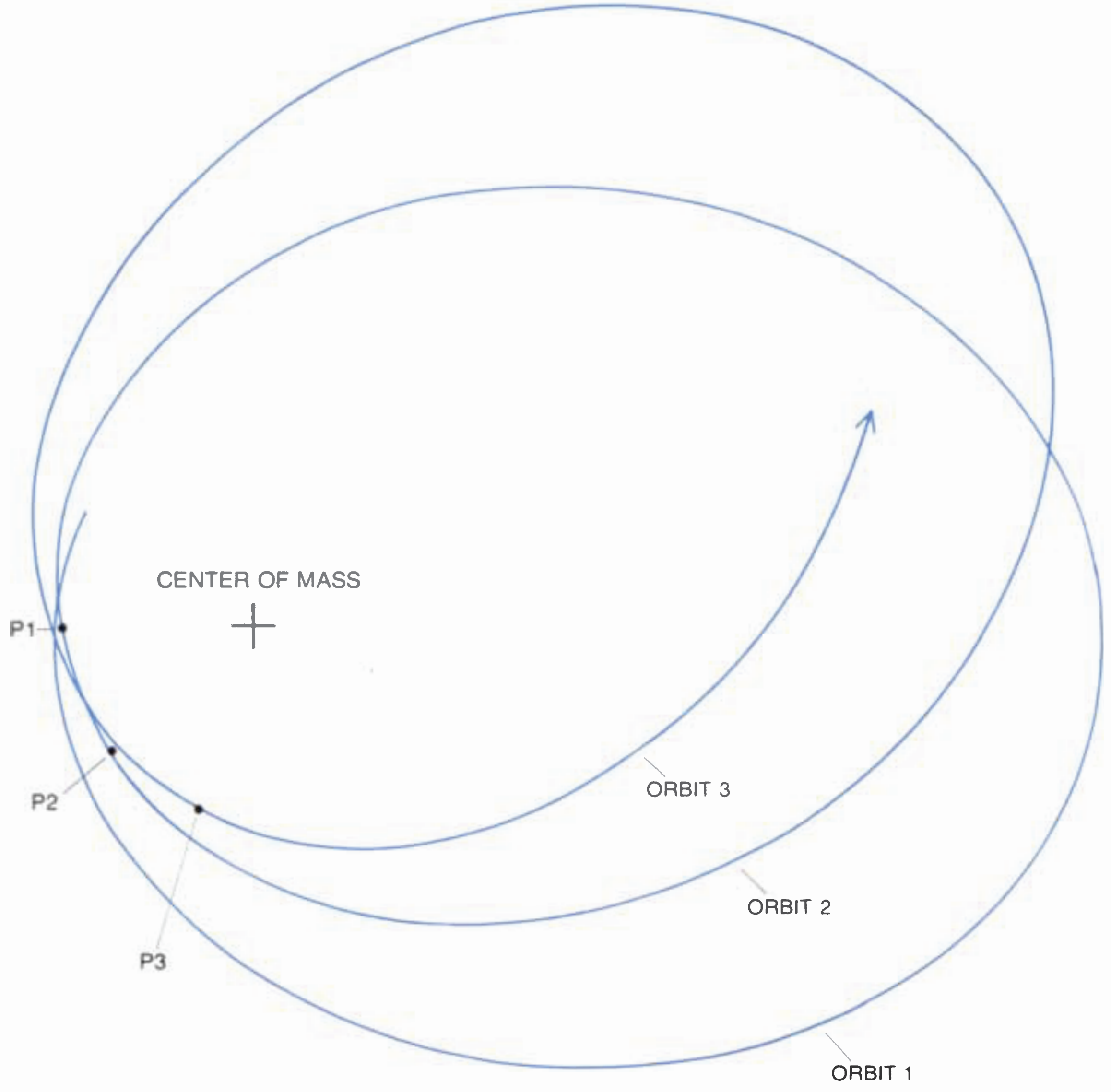
Elements of the Orbit

K_1	$= 199 \pm 5$ km s^{-1}
P_b	$= 27908 \pm 7$ s
e	$= 0.615 \pm 0.010$
ω	$= 179° \pm 1°$
T	$=$ JD 2,442,321.433 $\pm$ 0.002
$a_1 \sin i$	$= 1.00 \pm 0.02\ R_\odot$
$f(m)$	$= 0.13 \pm 0.01\ M_\odot$

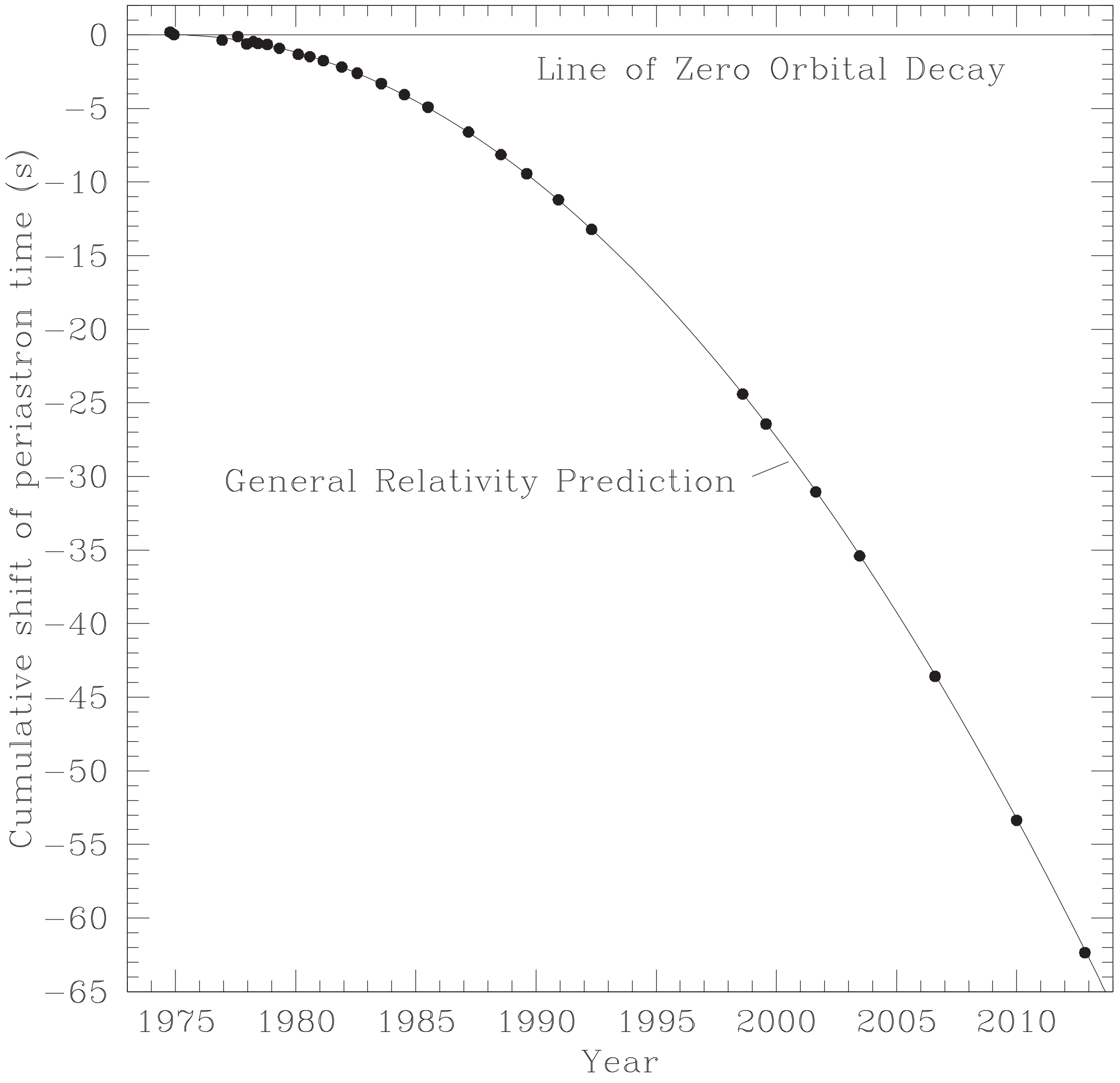


SHRINKING OF PULSAR'S ORBIT is projected on the basis of evidence that orbital energy is being converted into gravitational radiation, as is predicted by the general theory of relativity. According to the theory, the orbit of PSR 1913 + 16 should shrink by 3.1 millimeters per orbital revolution, or 3.5 meters per year. The orbital period should decrease accordingly by 6.7×10^{-8} second per orbit, or 7.6×10^{-5} second per year. This tiny change is measurable because it leads to a constantly accumulating deviation in the time of periastron passage. Here the orbit is drawn to scale as it will appear every 50 million years in the future until the two stars coalesce 300 million years from now. For comparison the sun is shown at the same scale. PSR 1913 + 16 is thought to be a 50,000th the diameter of the sun.

ORBIT OF PULSAR PSR 1913 + 16 lies in a plane tilted about 45 degrees from the line of sight. Like the more than 300 other pulsars discovered since 1967, PSR 1913 + 16 is thought to be a neutron star, 20 to 30 kilometers in diameter, that emits a radio beam that sweeps past the earth at precisely spaced intervals synchronized with the star's rate of spin. For PSR 1913 + 16 the spin rate is 16.94 revolutions per second. Unlike the large majority of other pulsars, PSR 1913 + 16 travels in an orbit around a companion star whose presence was inferred from a Doppler shift in the arrival time of the pulsar's "beeps." The beeps arrive slightly more frequently when the pulsar is traveling toward the earth and less frequently when the pulsar is receding. A complete picture of the pulsar's orbit around the center of mass of the binary system was derived through careful measurements of the Doppler shift in combination with an analysis of subtle gravitational effects predicted by the general theory of relativity. The theory made it possible to calculate that the pulsar and its companion are both 1.4 times as massive as the sun and that the separation of the two stars varies from 1.1 to 4.8 times the radius of the sun.



ADVANCE OF PERIASTRON in the orbit of PSR 1913 + 16 has provided one of the first clear observations of a general-relativistic effect involving bodies outside the solar system. The periastron advances, or rotates, as the elliptical orbit of PSR 1913 + 16 itself rotates in a plane because of the curvature of space-time in the vicinity of the pulsar's massive companion. In this diagram the effect is greatly exaggerated. The general theory of relativity predicts a periastron advance of about four degrees per year in the orbit of PSR 1913 + 16, the exact value depending on the total mass of the pulsar and its companion. The authors' measurements show the periastron is advancing 4.2 degrees per year, in good agreement with the prediction.



Weisberg & Huang, ApJ 829 (2016) 55

Orbital decay of PSR B1913+16 as a function of time. The curve represents the orbital phase shift expected from gravitational wave emission according to General Relativity. The points, with error bars too small to show, represent our measurements.

The Nobel Prize in Physics 1993

Photo from the Nobel Foundation archive.

Russell A. Hulse

Prize share: 1/2

Photo from the Nobel Foundation archive.

Joseph H. Taylor Jr.

Prize share: 1/2

The Nobel Prize in Physics 1993 was awarded jointly to Russell A. Hulse and Joseph H. Taylor Jr. "for the discovery of a new type of pulsar, a discovery that has opened up new possibilities for the study of gravitation"