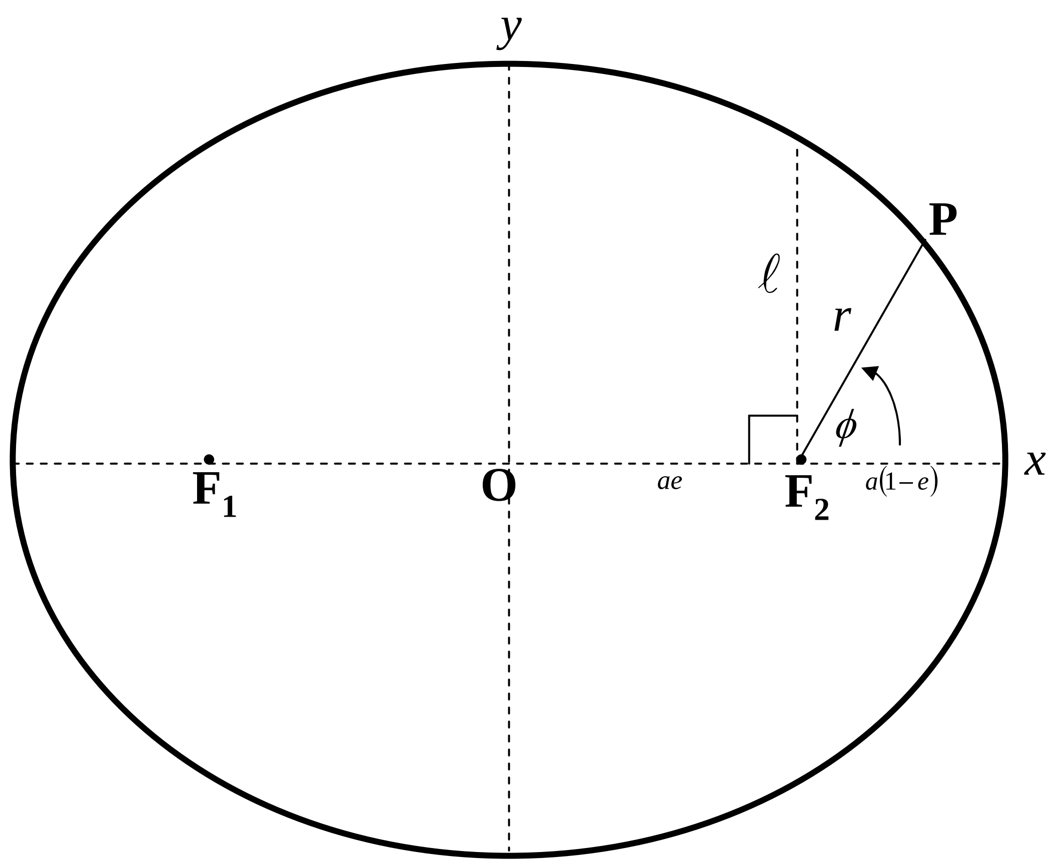


Foci at $\mathbf{F_1}$ and $\mathbf{F_2}$

$\mathbf{O}x \;=\; a \;=\;$ semi-major axis

$\mathbf{O}y \;=\; b \;=\;$ semi-minor axis

$$b^2 = a^2\left(1 - e^2\right)$$

$e \;=\;$ eccentricity

$\mathbf{P}$ defined by

$$\boxed{r = \frac{\ell}{1 + e\cos\phi}}$$

$\ell \;=\;$ semi-latus rectum

$\;\;\;=\; b^2 / a$

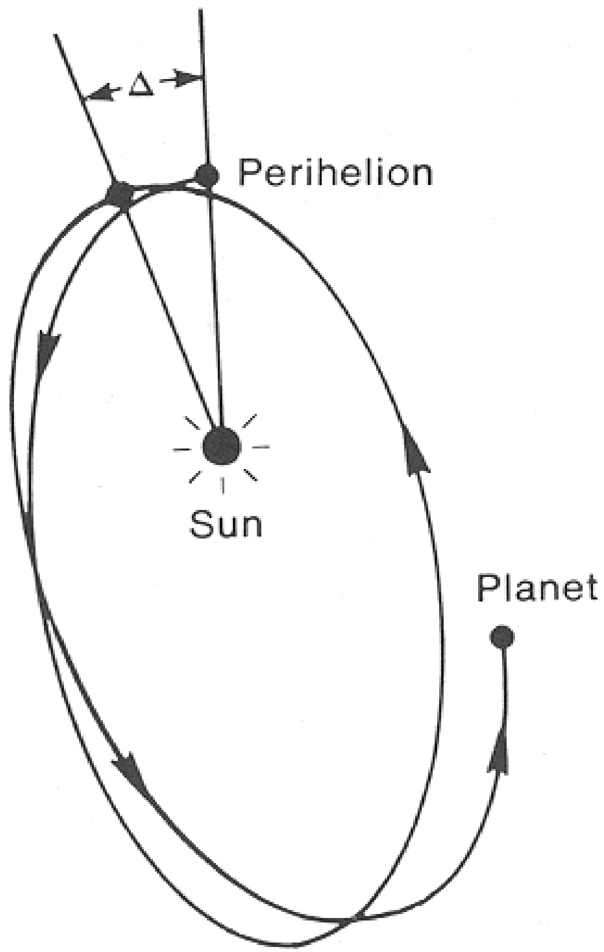


Figure 1

Advance of perihelion, as predicted by General Relativity, resulting in a planetary orbit which is not a closed ellipse, but which precesses slowly.

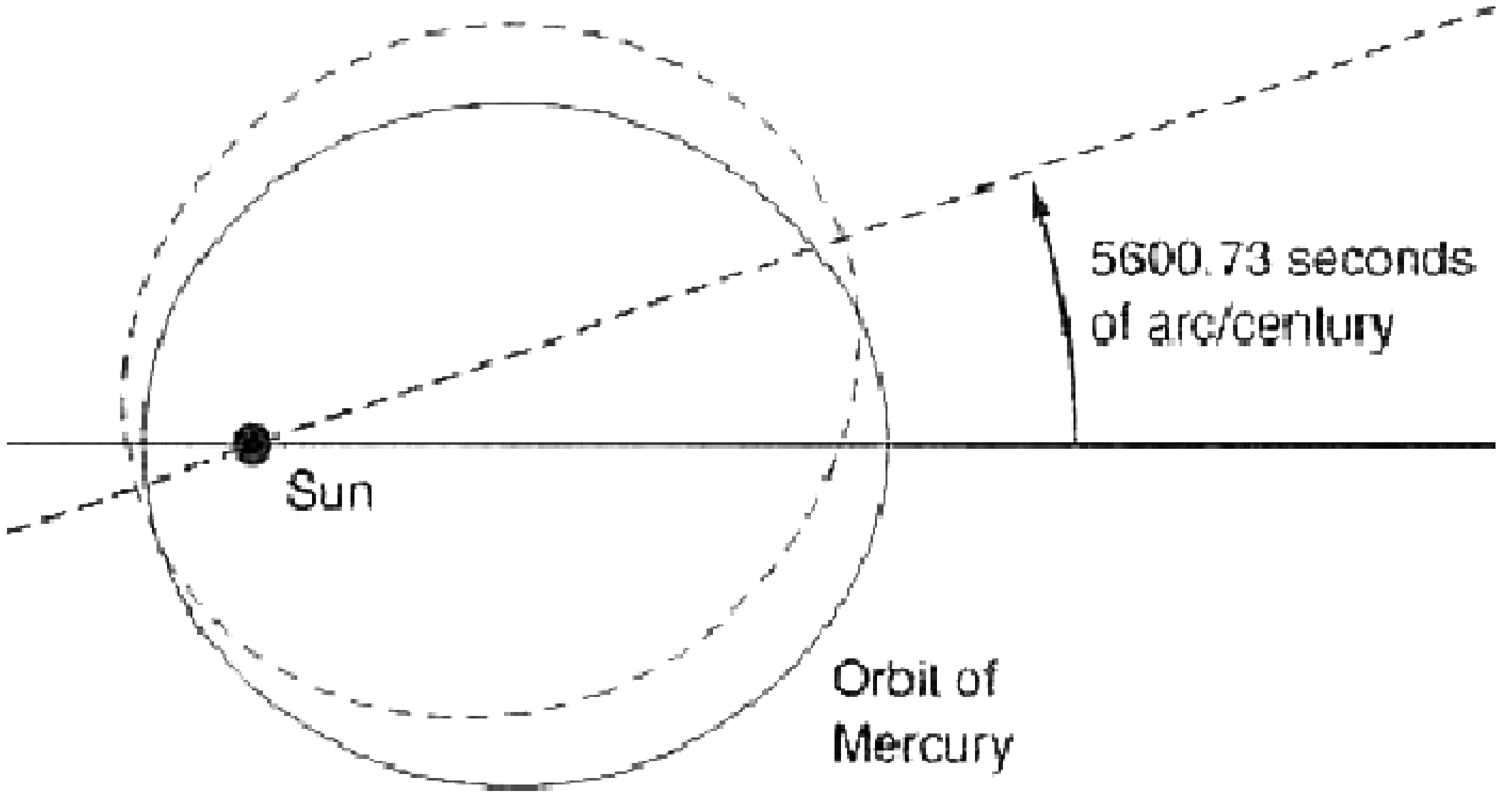
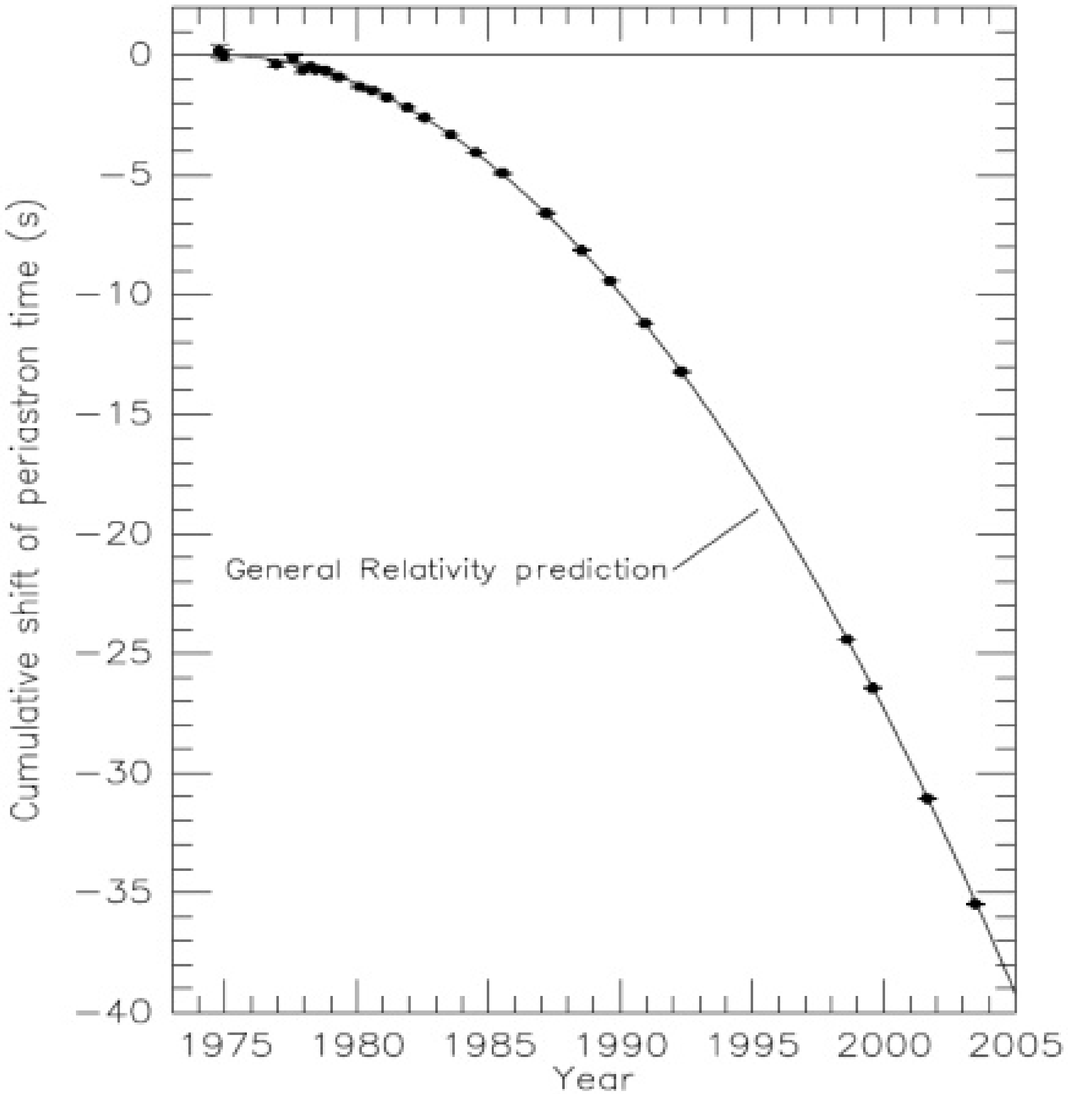


Figure 2

Advance of perihelion of the planet Mercury. All but 43 arcseconds per century of the observed advance of perihelion could be explained simply by Newtonian perturbations by the other known planets; GR provided an explanation for the remaining 43 arcseconds discrepancy. This additional advance is due to the effect of the curvature of spacetime in the vicinity of the Sun: loosely, one can think of this curvature as an additional source of mass-energy which adds to the perturbation on the planet.

PSR 1913+16

Russell Hulse and Joe Taylor



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LETTERS

A massive binary black-hole system in OJ 287 and a test of general relativity

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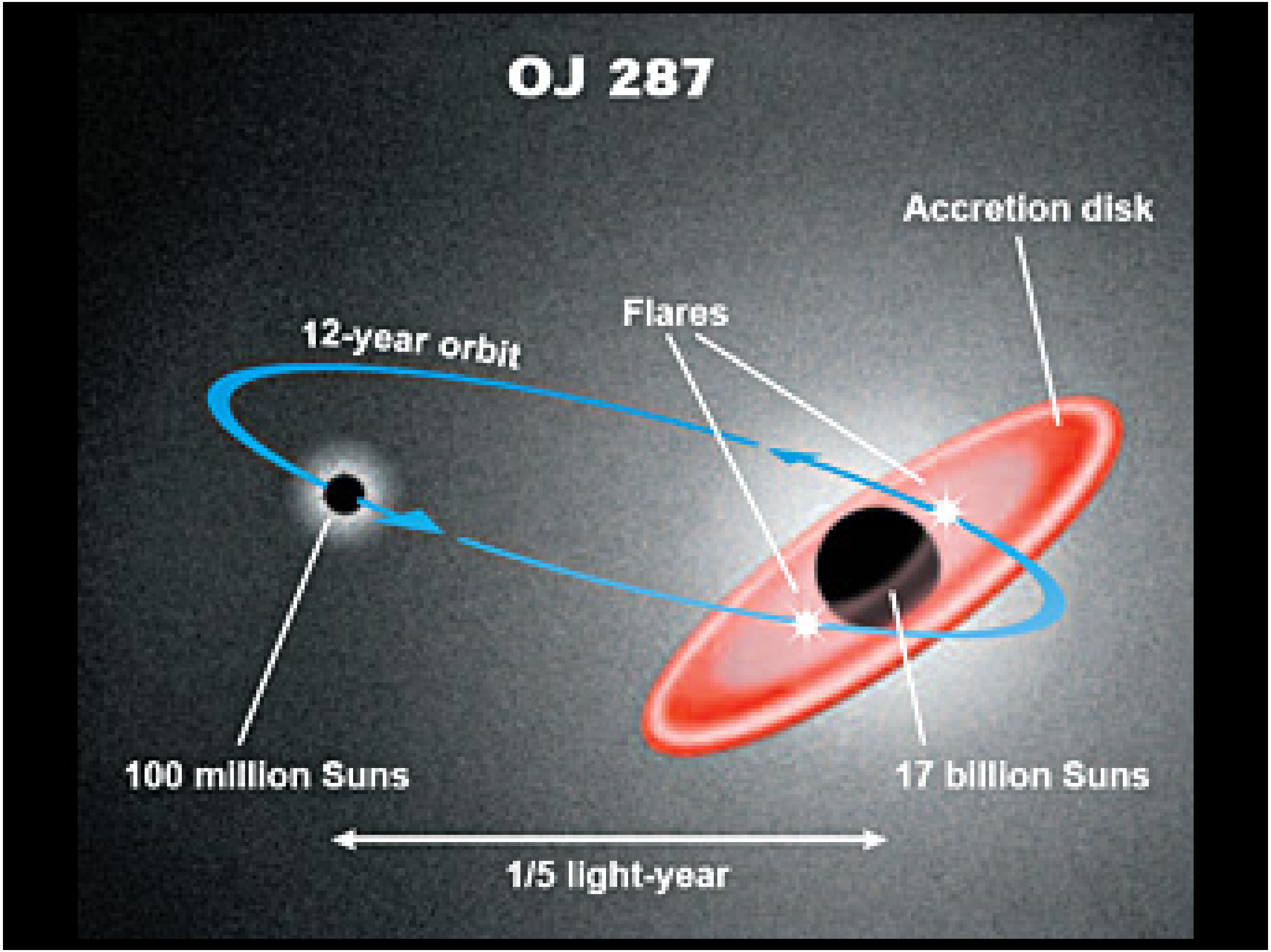
Tests of Einstein's general theory of relativity have mostly been carried out in weak gravitational fields where the space-time curvature effects are first-order deviations from Newton's theory[1–6]. Binary pulsars[4] provide a means of probing the strong gravitational field around a neutron star, but strong-field effects may be best tested in systems containing black holes[7,8]. Here we report such a test in a close binary system of two candidate black holes in the quasar OJ 287. This quasar shows quasi-periodic optical outbursts at 12-year intervals, with two outburst peaks per interval[9,10]. The latest outburst occurred in September 2007, within a day of the time predicted by the binary black-hole model and general relativity[11]. The observations confirm the binary nature of the system and also provide evidence for the loss of orbital energy in agreement (within 10 per cent) with the emission of gravitational waves from the system[12]. In the absence of gravitational wave emission the outburst would have happened 20 days later[13].

at the same phase angle plus 180°. This provides a well-defined mathematical series of outburst times. Although the series cannot be represented by a closed-form mathematical function (the same is true of the original Kepler problem), the times in the series are quickly calculable by computer. If the orbit is eccentric, there is a pair of outburst times that are close to each other relative to the orbital period.

Assuming that the constant phase angle is provided by the secondary passing through the accretion disk of the primary, the orbit can be reconstructed by using all the available information on past outbursts and straightforward astrophysics. For any general sequence of quasi-random times, there is unlikely to be a solution. There is an algorithm that converges to a solution of orbital elements if a solution exists[13]. Non-precessing orbits can be rejected immediately; no solution exists for such orbits. This is promising because, even at first order in general relativity, the major axis of the orbit must precess.


OJ 287
Accretion disk
Flares
12-year orbit
100 million Suns
17 billion Suns
1/5 light-year