ASTRONOMY

Pinpointing Gravity

Accurate measurement of the distance to a double pulsar system will place stringent limits on theories of gravity.

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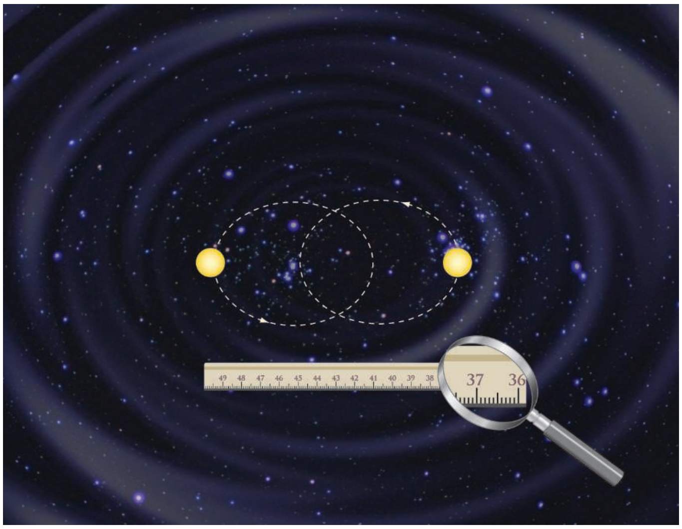

A dance of pulsars. As the two pulsars orbit around each other, gravitational waves are emitted. This emission results in energy loss and a secular shrinking of the binary system, whose decay law is precisely predicted by Einstein's theory of relativistic gravity. While the change in motion can be determined by timing techniques, other kinematic effects may mimic an orbital variation. VLBI, as shown by Deller *et al.*, quantifies these undesired effects, allowing accurate estimates of the true orbital decay, and thereby placing stringent limits on gravity theories.

One of the consequences of Einstein's theory of gravity is that a pair of orbiting stars generates ripples in space—gravitational waves. While gravitational waves have not yet been detected directly, experiments are being developed with which the indirect effects of such phenomena can be measured with unprecedented accuracy. On page 1327 of this issue, Deller *et al.* (*1*) use very long baseline interferometry (VLBI) to determine an accurate distance to the double pulsar system J0737-3039 A/B, thereby pushing further the limits on the precision with which tests of general relativity can be made.

Present large gravitational wave observatories, such as LIGO (*2*) and VIRGO (*3*), are sufficiently sensitive to be able to detect the burst of gravitational waves resulting from the merger of a pair of orbiting stars into a black hole at distances up to many tens of millions of light-years away. However, such events are rare, and these instruments might not detect the weak steady gravitational waves emitted by a binary system. At present, we can only observe the steady emission of gravitational waves from binary systems indirectly (see the figure). The intensity of the gravitational waves, and so the amplitude of the corresponding orbital-period decay, depend on the masses of the two bodies, the orbital period, and the eccentricity (*4*), thus implying that some binary systems are more relativistic than others.

Pulsars are rapidly rotating, highly magnetized neutron stars radiating collimated beams of radio waves, which we observe as pulses, like those produced by a lighthouse, once per rotation. Owing to the astonishing clock stability of the pulses, comparable to the best time standards available on Earth, a pulsar orbiting another star provides an accurate time reference for measuring the relativistic gravity effects such as the orbital decay due to the emission of gravitational waves. Indeed, the historical evidence of such orbital decay was provided by the binary pulsar PSR B1913+16 (*5*), the discovery of which earned Hulse and Taylor the Nobel Prize in 1993. Precision timing over decades has shown that the orbit of this system is systematically shrinking with a measured decay that agrees with the relativistic gravity prediction to an accuracy of 0.2%.

The demand to improve further on the accuracy of such measurements is rather high, because alternative gravity theories exist, whose measurable effects are marginally different from those predicted by relativistic gravity. Much more relativistic binary systems would therefore provide much more accurate tests. But if relativistic gravity is sufficient for most practical purposes, such as describing satellite tracking in the solar system (*6*), why should we care about alternative theories of gravity?

The point is that some alternative theories are related to fundamental models of the nature of matter, which in turn have major implications for cosmology and so for the origin, evolution, and fate of the universe. For instance, the alternative theories may better explain the large-scale structure of the universe, without necessarily invoking dark matter (*7*, *8*). Also, the attempt to unify all forces of nature might require modifications to the relativistic gravity equations, which seem ideal for testing by binary pulsars (*9*).

The discovery of the binary pulsar system PSR J0737-3039, the most relativistic found to date (*10*), provides a system in which the observed evolution of the orbital parameters can be measured with unprecedented accuracy. The system shrinks by 7 mm/day. The pulsar clock allows the orbital parameters to be measured with such accuracy that the galactic and kinematic contributions to the observed variation of the orbital period affect the estimate of the orbital decay. We need to exactly locate the system within the Galaxy, determining an accurate measure of its distance and proper motion. Using VLBI and pulsar timing observations, Deller *et al.* estimate that over a decade, the orbital decay of the system due to gravitational wave emission can be measured to an accuracy of ~0.01%.

In addition, the neutron star companion to the pulsar in this system has been found also to be a pulsar (*11*). So, we actually have two clocks orbiting each other, providing further constraints on the system parameters (*12*). As a result, relativistic gravity in this system is expected to be probed with much more accuracy than in the solar system environment. Indeed, the accuracy allowed by this system, and its coherence with the relativistic gravity equations, should enable the presence of other perturbing stars in the vicinity of the binary system to be probed, including a potential companion, as in the speculative triple-system scenario mentioned by Deller *et al.*

Besides the uncertainty in locating a binary system in the Galaxy, other quantities affect the estimate of the galactic and kinematic contributions to the observed variation of the orbital period. Uncertainties in the galactic radius and speed of the solar system are ~15%, while the uncertainty in the vertical gravitational potential of the Galaxy is ~10%. Further searches for pulsars are in

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progress at the Parkes, Green Bank, and Arecibo observatories, and it is expected that even more relativistic binary pulsars will be found. With the advent of the Square Kilometer Array, a huge sample of relativistic binaries will be available (*13*). At the same time, VLBI techniques are rapidly evolving, which will provide an accurate location of these clocks within the Galaxy. A rich array of perfectly clocked shrinking binary systems, exactly located in different zones of the Galaxy, will be available, constituting a powerful gravity probe. As the present uncertainties in the gravitational potential of the Galaxy would be averaged by such an array, orbital decays and other non-Newtonian effects would be estimated with better accuracy, thus providing an unprecedented test of relativistic gravity. It would then pose challenging questions to those alternative theories of gravity.

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ECOLOGY

Warming Up Food Webs

How do predator-prey interactions influence ecosystem responses to climate change?

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Human changes to the global environment have long been known to affect organisms, for example by altering their physiology, range, or longevity (*1*, *2*). However, responses vary widely across species, making it difficult to predict how entire ecosystems will respond in the future (*3*). A key problem is that species do not respond to extrinsic drivers (such as climate) in isolation. Rather, species responses may be determined to a greater or lesser extent by other species with which they interact. On page 1347 of this issue, Harmon *et al.* elucidate one such interaction in a study of pea aphids and two of their ladybird predator species (*4*).

Early population models showed that interactions among species could weaken or strengthen within-species responses to environmental change (*5*). More recently, empirical evidence has demonstrated that species interactions can reverse the response of individual grassland species to climate change and subsequently alter their community trajectory (*6*). At the same time, numerous studies have identified rapid evolutionary responses to climate change (*2*). For example, evolutionary studies indicate that under strong climate-induced selection pressure, life history traits (such as phenology, longevity, and reproductive rates) may evolve within just a few generations (*7*).

The question thus arises whether ecological interactions among species can alter their respective evolutionary responses to external drivers such as climate change. Harmon *et al.* have now met the enormous challenge of addressing this question with an elegant study in which they tested the ecological and evolutionary responses of an insect herbivore to the combined effects of climate change and food web interactions.

Interactive effects. Harmon *et al.* show that predation rates of aphids by ladybirds depend on the response of the predator species to altered aphid density following heat shocks.

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Their study system involved the pea aphid, an important pest species, which has populations that differ in their susceptibility to short periods of high temperature (heat shocks), in part because of differences in internal microorganisms that are passed on from parents to offspring and confer heat tolerance. Harmon *et al.* introduced these symbiotic microorganisms to different aphid populations to simulate a mutation event conferring heat tolerance to the aphid line. Aphids are attacked by many natural enemies, including two species of ladybirds that differ in their foraging behavior (see the figure). Harmon *et al.* used field experiments to test the ecological and evolutionary responses of aphids to increased frequency of heat shocks, and to contrast the effects of the two predators on population growth rates after these shocks.

The authors found that behavioral differences between the predator species affected the prey population response: One predator reduced its attack rates at low prey densities after heat shocks, such that it did not compound the negative effect of heat on aphid population growth. In contrast, the other predator kept attacking aphids at the same rate, increasing aphid mortality beyond the rates caused by the heat shocks. Aphids did evolve tolerance to heat shocks (that is, tolerant strains increased in frequency), but in a model based on field data, predator-prey interactions, despite their effects on aphid population growth, did not affect the evolution of heat shock tolerance.

Future research is needed across species to determine whether rapid evolutionary responses to food web interactions and external drivers are generally additive in this way, such that the selection effects of predation operate independently of climate change and vice versa. If in other cases these forces have interactive effects—for example, if traits conferring resistance to one threat (such as climate change) are negatively correlated

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