



**Figure 2 Matching theory to data. Lognormal (black) and neutral (green) expectations against the data on 21,457 trees in 225 species from the 50-hectare plot on Barro Colorado Island. Here the data are grouped in 12 logarithmic intervals; note the slight asymmetry in the neutral theory prediction, favouring the bulged left-hand tail of the empirical distribution. Reproduced from ref. 2.**

Fig. 2 here, might leave readers perplexed. Both the lognormal and the neutral theory predictions look very good and at the tails of the distribution they are essentially indistinguishable. Surely when 21,457 individual trees, distributed among 225 tree species, are counted there will be measurement uncertainty, particularly given that very tiny young trees are not included. Should we really care whether one function fits slightly better than the other? More generally, how should theory-testing in ecology proceed?

Proposed theories are valuable when they make many falsifiable predictions, preferably about a variety of phenomena not previously recognized as being interconnected. Arguments about whether this or that function fits an empirical relative species abundance slightly better are unlikely to advance the field. Consider the lognormal distribution first. It is not really a theory, but rather a proposed mathematical function; its connection to relative species abundance has been motivated by a conceptual model of how growth and death are regulated in ecology. Advocates of the lognormal distribution would best serve their cause if they actually examined and modelled the dominant mechanisms of growth and death, checked for the applicability of the central limit theorem, and then made a swarm of testable predictions — not just about relative species abundance but about growth and death rates under different circumstances, about the relationship between body size and abundance, about the spatial distributions of species, and about time series of population fluctuations under different environmental conditions.

The ability of the neutral theory to make testable predictions about a wide variety of behaviours could also be more fully

explored. One prediction of the theory pertains to what ecologists call beta diversity — the pattern of changing species composition in separated patches of habitat as a function of the distance between patches. In the neutral theory, species turnover with distance should result from dispersal but not from spatial variability in the different habitat niches. A test of this at the BCI plot found empirical patterns to be inconsistent with the prediction of the neutral theory<sup>4</sup>.

Indeed, theories such as Hubbell's are valuable because they can and will fail some tests. In failing, they will tell us about the importance of the mechanisms that they assume away at the outset. Perhaps ecologists will some day develop a theory whose simplifications resemble that of the ideal

gas assumption in thermodynamics and statistical physics: a seemingly preposterous assumption (point molecules, purely elastic collisions) that yields amazingly accurate predictions of a multitude of phenomena. No physicist would say that, because  $PV$  does not exactly equal  $nRT$ , the theory is wrong. Let's hope that ecologists heed that message. ■

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### Quantum gravity

## An astrophysical constraint

Sean Carroll

A quantum theory of gravity is proving elusive. Observations of radiation from the Crab nebula now place even stronger constraints on the likelihood of detecting the effects of quantum gravity.

For decades, physicists have been in search of quantum gravity, a theory that would encompass both general relativity and quantum mechanics. One of the difficulties in this quest is the paucity of detailed experimental data; direct effects of quantum gravity are generally thought to be out of reach of foreseeable experiments. But, if we are lucky, the effects of quantum gravity might cause small violations of spacetime symmetries, violations that could be directly observed through the behaviour of particles at high energies or over large distances. A new astrophysical test — reported by Jacobson *et al.*<sup>1</sup> on page 1019 of this issue — suggests, however, that we might not get lucky.

In the process of developing his theory of blackbody radiation in the late nineteenth century, Max Planck was forced to introduce a new fundamental constant into physics — what we now know as Planck's constant,  $h$ . Almost immediately, Planck realized that this number could be combined with the speed of light,  $c$ , and Newton's gravitational constant,  $G$ , to construct a set of natural units for quantities such as length, energy, mass and time (known as the Planck length, the Planck energy, and so on). He was happy to note that even extraterrestrials would understand these units, thus making quantitative communication between civilizations possible.

Planck's units combine the fundamental parameters of special relativity ( $c$ ), general relativity ( $G$ ) and quantum mechanics ( $h$ ). We therefore expect that they should indi-

cate the point at which quantum gravity begins to manifest itself. For example, if two particles collide with a total energy greater than the Planck energy, quantum gravity should have an important role in the outcome. Unfortunately, the Planck energy scale is approximately  $10^{19}$  gigaelectronvolts — 16 orders of magnitude larger than the regimes being explored by our highest-energy particle accelerators. So it seems difficult, even impossible, to get any direct experimental data relevant to the reconciliation of gravity and quantum mechanics.

But our understanding of fundamental physics will not be coherent, much less correct, until quantum gravity is understood. It is therefore worth trying to think of clever ways to access phenomena at the Planck scale that we might at first think are beyond our reach. One possibility, common to several (but certainly not all) models of quantum gravity, is a breakdown of Lorentz invariance. This symmetry, a cornerstone of special relativity, says that there is no universal standard of rest; reference frames that are moving with respect to each other at constant velocities should be physically equivalent, and the speed of light looks the same to any observer. But perhaps this is only an approximation; if spacetime is discrete (rather than smooth) at small scales, for example, Lorentz invariance may break down at very short distances or very high energies.

Astrophysical phenomena provide a way of testing this idea. A phenomenological model<sup>2</sup> has been proposed in which Lorentz-



**Figure 1** The Crab nebula. Located in the constellation of Taurus, this cloud of gas is all that remains of a star whose explosion in AD 1054 was recorded by Chinese astronomers. In this composite image (from the Chandra observatory and the Hubble Space Telescope), the blue regions are synchrotron radiation, generated by high-energy electrons whirling in the system's magnetic field. Jacobson *et al.*<sup>1</sup> have analysed the frequency spectrum of this radiation for a signature of quantum gravity — the theory uniting quantum mechanics and relativity. They find none.

violating effects are introduced into the so-called dispersion relations that relate the energy and momentum of particles. As a result, photons of different frequencies should travel at slightly different velocities; such an effect could potentially deform pulses of radiation from distant  $\gamma$ -ray bursts in an observable way. This approach introduces free parameters that can be expressed as dimensionless numbers divided by the Planck energy. Thus, if these numbers can be constrained to magnitudes less than unity, this sort of hypothetical quantum-gravity effect can be ruled out even at the Planck scale.

If we limit ourselves to considering photons and electrons, we seek to constrain two dimensionless numbers parameterizing Lorentz violation. Perhaps surprisingly, results from a variety of astrophysical and laboratory tests have already excluded a wide range of possible values for these parameters, to levels beyond the Planck scale; nevertheless, substantial regions have remained

open. But now Jacobson *et al.*<sup>1</sup> are able to essentially rule out any Lorentz violation of this type at Planck energies or below, at least under certain dynamical assumptions. (Almost simultaneously, laboratory experiments<sup>3</sup> have placed constraints that are not

quite as strong but are also beyond the Planck scale.)

Jacobson *et al.* consider synchrotron radiation, emitted by electrons circling in a magnetic field, from the Crab nebula (Fig. 1). To produce high-energy photons through synchrotron emission, the electrons must be moving close to the speed of light. If Lorentz invariance is violated, the maximum velocity for photons and for electrons can have a slightly different value, which imposes a cut-off on the frequency of synchrotron radiation that can be produced. Using observations of radiation at frequencies beyond this cut-off, Jacobson *et al.* are able to set the new stringent limit on Lorentz invariance. The crucial assumption made in their analysis is that the behaviour of photons and electrons can be described by an 'effective local field theory' at low energies. Such theories are well used in this area of physics, and this seems a reasonable assumption to make, but exceptions are known. So a window, albeit small, remains open for Planck-scale effects.

Searching for effects of quantum gravity through violations of Lorentz invariance is an optimist's game; it is certainly plausible that such violations are strictly absent from the correct theory. But optimism is necessary if we are to make progress in this field. Jacobson and colleagues' results<sup>1</sup> apply to perhaps the most optimistic proposal for observable Lorentz violation, in which new effects are suppressed by only a single power of the Planck scale; another realistic possibility is that Lorentz symmetry is indeed violated, but only at quadratic order. We should therefore remain hopeful, and search even harder for direct ways to detect increasingly subtle effects of spacetime structure on very small scales. ■

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## Mars

# The devil is in the dust

Conway B. Leovy

Mars is a highly dynamic planet — at least as far as dust is concerned. A better knowledge of how dust is lofted into the atmosphere will help to untangle the complex evolutionary history of the planet's surface.

New laboratory work by Greeley *et al.*<sup>1</sup> and numerical flow simulations by Toigo *et al.*<sup>2</sup>, both appearing in the *Journal of Geophysical Research*, provide insights into the role of 'dust devils' in injecting dust into the martian atmosphere.

Dust transport is a key to the long-term evolution of the martian surface, much of which has undergone episodes of erosion, deposition, burial and exhumation over the past four billion years<sup>3</sup>. Although flowing water is believed to be responsible for some