sex determination, such that each cell establishes its sexual identity at the same time that X-chromosome dosage is regulated[14]. However, even in *Drosophila*, a cell's sexual identity can be overridden by secreted signals[15].

How should Zhao and colleagues' results[3] be reconciled with the substantial body of work involving hormone-induced sex reversal in chickens? Seventy-five years of research have definitively demonstrated that oestrogen is necessary and sufficient for female development: ZZ (male) embryos exposed to oestrogen develop as females, whereas ZW (female) embryos depleted of oestrogen develop as males[16]. ZZ 'females' revert to a male phenotype at puberty if the hormone treatment is discontinued[16], possibly because ZZ cells cannot produce enough oestrogen to maintain ovarian structures. By contrast, adult ZW 'males' have fairly normal-looking testes, indicating that, when oestrogen is absent, ZW cells can become Sertoli cells and organize into male patterns. Do these hormone treatments simply override cell-autonomous sexual identity? Investigation into the adult phenotypes of castrated chick embryos should show whether an underlying sexual identity does indeed exist in the absence of hormones. Although this procedure was previously attempted using irradiation, the animals did not survive to hatching[17].

A final question is whether cell-autonomous sexual identity will turn out to be a common element in the arsenal of sex-determining systems in vertebrates, with variable influence on the outcome of sexual differentiation. Perhaps it will. These funky chickens, oddities of nature that they are, may well provide new perspectives on questions of sexual identity long thought to have been resolved. ■

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COSMOLOGY

Gravity tested on cosmic scales

J. Anthony Tyson

Einstein's theory of general relativity has been tested — and confirmed — on scales far beyond those of our Solar System. But the results don't exclude all alternative theories of gravity.

Our understanding of the physics that underlies the dynamical evolution of the Universe and the development of cosmic structure is driven by astronomical observations. Historically, measurements on galaxy and larger cosmological scales conflicted with predictions based on a cosmological model that combined Albert Einstein's theory of gravity (general relativity) and the standard model of particle physics. Modifications to this model were later introduced, involving dark matter and dark energy (a dilute component that has been proposed to explain the observed recent acceleration of the Universe's expansion), that accounted for a wide range of observations[1]. But the physics of dark matter and dark energy is not understood. Although there are suggestions from particle physics about the nature of dark matter, that of dark energy remains a mystery.

Frustrated by the lack of theoretical candidates for dark energy, some researchers have instead considered models in which the Universe's dynamics, and so gravity itself, deviates from that predicted by general relativity on 'cosmological' scales — those larger than galaxies and clusters of galaxies. But how can one tell the difference between models that

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APPLIED ECOLOGY

Grass and the X factor

Symbiosis between plants and microorganisms is widespread, but research into its effects on the composition of a plant community is in its infancy. Such studies require patience. Jennifer Rudgers and colleagues have spent six years investigating the relative performance of cultivars of tall fescue grass with different forms of a symbiont, and now report the results and their recommendations for the use of this versatile yet vexatious grass (J. A. Rudgers *et al. J. Appl. Ecol.* doi:10.1111/j.1365-2664.2010.01788.x).

Tall fescue could well be the plant that makes a lawn near you. It is also grown for forage (pictured). It is highly invasive, however, and counts as a weed in situations in which plant diversity is desirable. Like many plants, it does not live alone, and has what might be called the X factor — symbionts that in the case of tall fescue often include the fungus *Neotyphodium coenophialum.* Like the grass, the fungus comes in different genotypic forms. For example, one common form (KY-31) produces alkaloids that are toxic to certain herbivores; another form (AR-542) does not.

By planting experimental plots, Rudgers *et al.* set out to test, among other things, how two cultivars of the tall fescue *Lolium arundinaceum* inoculated with KY-31, AR-542 or neither, affect the plant species composition of the plots. The two cultivars chosen were Georgia-5 and Jesup.

CAPMC

The authors' salient finding is that Georgia-5 plus AR-542 allows greatest growth of other grasses and herbaceous flowering plants, and produces fewest inflorescences (and so fewer seeds). Those characteristics would be appropriate for applications in which tall fescue has a job to do but where diversity of vegetation is the aim, for example in preventing soil erosion. There would also be reduced fescue spread from the planting site. Jesup with either symbiont is preferable for monoculture.

The significance of this line of research extends well beyond the specific performance and application of tall fescue. Plant breeders are becoming ever-more imaginative in exploring the intricate options offered by different genotypic mixes of plants and symbionts. Ecologists have a big task on their hands in checking the ecosystem consequences — and in taking into account the many other conditions that affect vegetation growth and invasiveness.

Tim Lincoln

include dark energy and modified models of gravity? In 2007, Zhang *et al.*[2] developed a method for distinguishing between these two cases that is minimally affected by our lack of knowledge of some key parameters. In this issue (page 256), Reyes *et al.*[3] apply Zhang and colleagues' method to data from the Sloan Digital Sky Survey (SDSS; Fig. 1) and find consistency with general relativity and one modified form of it.

Reyes and colleagues' measurements are significant not just because they are consistent within error with general relativity, but also because they point the way to future high-precision tests that will better distinguish between general relativity and some variant models. This is important because gravity is the least tested of the forces in nature. The predictions of gravity theory have undergone high-precision tests that have yielded remarkable agreement[4], but these were performed only on scales of our Solar System or smaller. The effects of modified general relativity on scales a hundred billion times larger may leak down to small-scale effects, and this could be tested by high-precision measurements of the Earth–Moon distance using laser ranging[5].

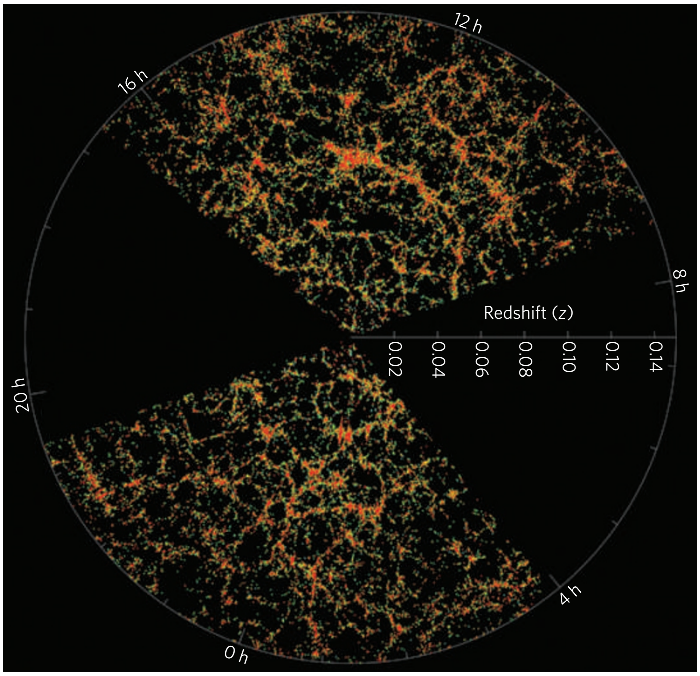

Figure 1 | Slices through the SDSS three-dimensional map of galaxies. Earth is at the centre, and each point represents a galaxy. The radial coordinate is the redshift, and the angular coordinate, in units of hours, is the right ascension (the celestial equivalent of longitude). The outer circle is at a distance of about 700 megaparsecs. Redder points denote galaxies composed of older stars. The regions between the slices are not mapped because dust in the Milky Way obscures the view in these directions. The clustering of galaxies (caused by the gravitational pull of huge unseen masses of dark matter) can be seen. Also evident is the redshift-space distortion, a radial smearing of galaxies due to their infall velocities near high-density regions. Reyes *et al.*[3] combine these measures of the effects of gravity in a sample of galaxies from the Sloan Digital Sky Survey (SDSS), which extends to somewhat higher redshift than those seen here, with another measure of the dark-matter mass in these cosmic structures: the 'gravitational lens distortion' of the shapes of yet more distant galaxy images.

M. BLANTON & SDSS

Departures from general relativity on cosmological scales will cause the growth of dark-matter structure and the cosmic geometry to differ from that predicted by Einstein's theory, in ways that are in principle distinguishable. However, a full investigation of any such effects, by tracing the dynamical history of the Universe over cosmic time, is currently fraught with systematic errors. Perhaps if general relativity breaks down on scales of clusters of galaxies, there is sufficient information encoded in the dynamics and the mass of a large sample of galaxies to detect this. Under the opposing influences of gravity due to dark matter and the cosmic expansion, there is a natural relationship between the clustering of galaxies, the mass of the underlying dark matter and the velocity distribution of the galaxies that could be used to test general relativity. But there are challenges in going from observations of these properties to a test of any departure from gravity theory on large scales.

One problem is that galaxies are a biased tracer of dark matter, and this bias varies with scale. Another is that we do not know to sufficient precision how the density of dark matter fluctuates across space in the Universe. Zhang *et al.*[2] recognized that, if a combination of several types of measurement is used, the bias and other poorly known quantities such as the dark-matter fluctuation will cancel out in the ratio of two different methods for measuring the dynamics of a large sample of galaxies. The two methods involve imaging and spectroscopy. For a population of galaxies, the masses of the huge dark-matter haloes in which they are embedded can be determined in two ways: from the distribution of galaxy velocities (via spectroscopy) and from the correlation of the galaxies with the weak distortion of the shapes of background galaxies by the effect of gravitational lensing (via imaging). Modified theories of gravity affect these two quantities differently from Einstein's gravity theory, producing an observable change in their ratio compared with the general-relativistic prediction.

In a first measurement of this diagnostic, Reyes *et al.*[3] used imaging and spectroscopy of more than 70,000 luminous red galaxies in the SDSS at a mean distance of about 1,700 megaparsecs. Clustering of these galaxies was measured by correlating their relative positions in space. To calculate one measure of dynamics, the authors determined the mass versus scale for the underlying dark-matter assembly by means of weak gravitational lensing, using the shapes of 30 million background galaxies, also in the SDSS. For the second measure of the dynamics, they used Tegmark and colleagues' measurement[6] of the distribution of galaxy velocities (the redshift distortion effect, which is visible in Figure 1 as radial (redshift) smearing of many of the (red) galaxies). They took care to address remaining systematic errors. And after applying correction factors derived from computer simulations, they measured this diagnostic of departure from general relativity on scales of about 14–70 Mpc to a precision of 16%. Although the results are consistent with general relativity and with one class of large-scale deviation from it, a particular example of a model of modified gravity, termed tensor–vector–scalar, which aims to explain both dark matter and the recent cosmic acceleration, seems less likely.

Zhang *et al.*[2] pointed out that the next generation of surveys will yield per-cent-level precision on this diagnostic. But these future surveys will do even more than that. With billions of galaxies charted across 80% of the age of the Universe (100 times the number of galaxies in Reyes and colleagues' study[3]), other probes of dark energy[7,8], which could more sensitively test the modified general-relativity alternative, will become possible. By combining observations of the cosmic microwave background (relic radiation from the Big Bang) with galaxy data, unprecedented studies will become possible, such as directly observing the homogeneity of the Universe on large scales. The recent acceleration of the Universe, whether caused by dark energy or a manifestation of a modification of gravity on scales a hundred billion times larger than the Solar System, presages new physics. Experiments in the next decade promise even greater insight into the fundamental physics of the Universe. ■

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