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Light on stratocumulus: GCR–cloud physics will remain a hot topic.

multitude of cycles on almost all timescales, detection of a correlation among climate variables usually meets with initial and healthy scepticism. But variations in cloud properties observed on timescales that are unique to GCRs[8] will always prompt a hunt for a plausible mechanism.

The second reason that GCR–cloud physics will remain a hot topic is that we have yet to explore all the possible mechanisms. Attention may now shift to the 'ion–aerosol near-cloud' mechanism[2]. GCR ionization modulates the fair-weather conduction current (about 2 picoamps per square metre) flowing between the ionosphere and Earth, thereby altering the charge that has been observed to accumulate around cloud layers. Just like static electricity, this charge can influence how cloud drops stick to aerosol particles. If the particles are effective nuclei for ice formation, then GCRs may influence cloud glaciation and precipitation. And the charge on some aerosol particles in the near-cloud environment could possibly become large enough to influence the formation of cloud drops directly[9]. But our understanding of the relevant physics is incomplete, and it will be some time before global-impact investigations along the lines of Pierce and Adams's study can be made.

Some would argue that the link between cosmic rays and climate is just too tenuous to be worth pursuing. Others would point out that, by ignoring the fact that the atmosphere is actually a dilute plasma (that is, is weakly ionized), we are missing some potentially important cloud physics — and clouds are a very large lever by which to influence climate. Despite the controversy, it is clear that the study of cosmic rays in our climate system has come of age. Sophisticated models of ion–aerosol processes now exist. They are supported by observations and laboratory studies, which will include the upcoming CLOUD experiment at the CERN laboratory near Geneva, Switzerland, in which a proton beam will generate highly controllable ionization events in an aerosol–cloud chamber[10]. ■

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GALAXY FORMATION

Anatomy of elliptical galaxies

Luca Ciotti

The family of elliptical galaxies is remarkable for the structural regularity of its members. Inspecting irregularities in this regularity could help in understanding how these galaxies form.

One of the most-debated subjects in modern astrophysics is how elliptical galaxies, which are among the oldest known objects in the Universe, formed. Among the various likely formation mechanisms, merging is the most popular. According to this theory, different galaxies are the aftermath of merger events between progenitors of different morphologies and of varying encounter geometries. But observations indicate that there is room for other mechanisms. Despite great endeavour in trying to match the regularities observed in the structures of elliptical galaxies with theoretical models, there is still no consensus view of how they formed. Writing in *The Astrophysical Journal Supplement Series*, Kormendy and colleagues[1] report a meticulous study of all known elliptical galaxies in the Virgo cluster (one of the clusters of galaxies nearest to Earth) that investigates how departures from the observed regularities can be diagnostic of the processes that triggered the formation of these galaxies (Fig. 1, overleaf).

The most striking property of elliptical galaxies is that their brightness profiles — that is, the way in which the combined luminosity of their stars varies with distance from the centre — depend in a regular way on their total luminosity (Sérsic's law). Other properties of elliptical galaxies that correlate with their total brightness include size, mean star velocity and metal content. Another trait shared by these stellar systems is a supermassive black hole, with a mass of the order of one-thousandth of the galaxy's stellar mass, at their centre[2].

In their study of the Virgo cluster of galaxies, Kormendy *et al.*[1] report galaxy luminosity profiles over large radial ranges and argue that elliptical galaxies are not arranged as a continuous sequence of objects with properties that scale well with their total luminosity. Instead, elliptical galaxies seem to branch out into two families according to a threshold value for the total luminosity. This dichotomy manifests itself in two kinds of departure from the Sérsic law at small radii. Luminous ellipticals have 'cuspy' cores — that is, their luminosity profiles are characterized by 'missing light' at small radii, because their brightness at such radii drops below the Sérsic-fitted, larger-radii profile. By contrast, less-luminous ellipticals are all 'coreless' — their central luminosity profiles seem to have 'extra light' at small radii (but see Graham *et al.*[3] for a different interpretation of the central-light profiles).

Kormendy and colleagues' results add weight to other observations that have hinted at a dichotomy in the properties of elliptical galaxies. Luminous-core galaxies are known to be slowly rotating; to be relatively anisotropic (properties such as stellar velocities depend on direction); to have triaxial shapes (they have different diameters in all three directions); to have quite 'steep' Sérsic profiles; and to have stars that are mostly very old and that formed on comparatively short timescales. Conversely, low-luminosity coreless ellipticals rotate rapidly; are more isotropic; have mostly oblate-spheroidal shapes; have quite

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Figure 1 | The deceptive looks of elliptical galaxies. Elliptically shaped galaxies, such as the larger system ESO 325-G004 (top left) seen in this Hubble Space Telescope image of the Abell cluster of galaxies S0740, appear to be quite simple objects. Kormendy and colleagues[1] show that these apparently uncomplicated galaxies disclose unexpected intricacies that could shed light on the mechanisms of their formation.

'shallow' Sérsic profiles; and have stellar populations that are younger and that formed on longer timescales. It is also well known that core ellipticals contain hot X-ray-emitting gas and tend to be radio-loud (they have strong radio emission), whereas the coreless galaxies do not[4].

The global regularities of the family of elliptical galaxies have already been used to set important constraints on their formation mechanisms[5,6]. Kormendy and colleagues' analysis now demonstrates that studies examining departures from those regularities could provide even more compelling clues. One previously recognized possibility is that the cores of luminous, large ellipticals could be naturally scoured by binary black holes[7], one likely product of the merging of two smaller elliptical galaxies, each of which harbours a central black hole. But binary black holes should also be found in coreless elliptical galaxies if merging is the main formation mechanism of the whole family of elliptical galaxies. So what thwarted core scouring by binary black holes in coreless ellipticals?

Kormendy *et al.*[1] suggest that if enough cold gas (provided by the merging companion) is carried to the centre of the forming coreless galaxy and turned into stars that provide the extra light, it could swamp core scouring by binary black holes. The picture that emerges from the new study[1], therefore, is one in which luminous-core ellipticals are the products of mergers between progenitors that had large numbers of old stars but little or no cold gas ('dry' mergers), whereas less-luminous coreless galaxies are the aftermath of mergers between (cold-)gas-rich galaxies ('wet' mergers). The wet mergers would trigger starburst activity; any energy released by the final black hole (the product of merging between the two progenitor black holes) because of gas accretion would not be sufficient to heat the gas and quench star formation.

Although the hypothesis discussed by Kormendy *et al.* is appealing, it is not the final word on elliptical-galaxy formation. Major evolutionary mechanisms are thought to be at work within elliptical galaxies. For example, in the several billion years of their evolution, the dying stars of an elliptical galaxy release an amount of gas equal to about 20–30% of the initial stellar mass of the galaxy. However, the observed present-day black-hole-to-galaxy mass ratio empirically dictates that, at most, 1% of this gas can be accreted by the central black hole. Therefore, essentially all of this gas is available to be recycled by the galaxy in some way other than black-hole accretion. If only a minor fraction of this gas flowed to the centre of the galaxy and was transformed into stars, it could suffice to produce the central extra light in low-luminosity ellipticals[8], whereas galaxy merging could be solely responsible for the creation of cores in high-luminosity ellipticals.

Increasingly refined computational simulations[9,10] are being devised to untangle the relative contributions of the different physical processes involved in galaxy formation. For now, Kormendy and colleagues' results demonstrate that research on elliptical galaxies, which were once considered rather dull objects, is revealing surprising secrets about galaxy formation. ■

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ECOLOGY

Towards a theory of biodiversity

Jayanth R. Banavar and Amos Maritan

Models of ecological communities that incorporate mutation and spatial dispersal can yield results that go some way to explaining observations. A further step is to add sexual reproduction to the mix.

Humans are wreaking havoc on the planet[1,2], and the result is a continuing mass extinction of species. Yet there is little understanding of the various ecological effects of this loss of biodiversity. An initial requirement is to work out how an ecological community is assembled in the first place, and on page 384 of this issue de Aguiar *et al.*[3] offer an advance in tackling this formidable task by extending an explanatory approach to biodiversity known as neutral theory.

First, some context. Life is a non-equilibrium phenomenon involving a 'dual-diffusion' process. Organisms diffuse and distribute themselves in space, and compete for resources, such as light, water and nutrients. At the same time, on different timescales, there is diffusion in 'genome space' that leads to new species and serves to maintain diversity. The evolution of an ecological community corresponds to the dynamics of the distribution of occupied regions in real space and genome space, and the development of interactions between the two. Owing to the constraints of the available resources, growth in the population of one species must necessarily lead to a decrease in the population of another and, in some cases, to extinction. Niche effects[4,5], which arise from the competition for resources in a spatially heterogeneous environment, provide a simple