the amounts of a nutritionally responsive transcriptional activator Gcn4, and demonstrated that this is required for full lifespan extension from dietary restriction[9]. Similarly, autophagy must be induced for lifespan to be extended by dietary restriction in *C. elegans*[10].

On the basis of these studies, it is tempting to speculate that rapamycin may be functioning as a dietary-restriction mimetic — a small molecule that provides the benefits of dietary restriction without requiring a reduction in food intake. Like dietary restriction, TOR inhibition not only increases lifespan, but also confers protection in invertebrate and rodent models against age-associated disorders, including cardiovascular dysfunction, diet-induced obesity and cancer[7]. Cancer inhibition in particular is a hallmark of dietary restriction in rodents, and rapamycin analogues are already used clinically as a treatment for certain forms of cancer.

Despite these links, Harrison *et al.*[1] do not strongly favour the idea that rapamycin is mimicking dietary restriction in mice. This is based on their data that rapamycin extends lifespan without reducing body weight, and when treatment is initiated during middle age (late-life onset of dietary restriction has shown inconsistent effects on longevity in previous studies). It is worth pointing out, however, that a true dietary-restriction mimetic may not reduce body weight if it mimics the signalling events (and downstream responses) associated with dietary restriction without changing food consumption. Also, dietary restriction has not yet been extensively characterized in mice of the genetically diverse background used by Harrison *et al.*, so it is difficult to predict whether dietary restriction in these animals would have effects similar to rapamycin. Thus, although it is premature to say for certain that rapamycin is functioning as a dietary-restriction mimetic in mice, the known role of TOR in the nutrient response, and the genetic relationship between TOR signalling and dietary restriction in invertebrates, make this a reasonable possibility.

Is this the first step towards an anti-ageing drug for people? Certainly, healthy individuals should not consider taking rapamycin to slow ageing — the potential immunosuppressive effects of this compound alone are sufficient to caution against this. On the basis of animal models, however, it is interesting to consider that rapamycin — or more sophisticated strategies to inhibit TOR signalling — might prove useful in combating many age-associated disorders. Also, as relevant downstream targets of TOR are better characterized, it may be possible to develop pharmacological strategies that provide the health and longevity benefits without unwanted side effects. So, although extending human lifespan with a pill remains the purview of science-fiction writers for now, the results of Harrison *et al.*[1] provide a reason for optimism that, even during middle age, there's still time to change the road you're on. ■

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1. Harrison, D. E. *et al. Nature* **460,** 392–395 (2009).
2. Jia, K., Chen, D. & Riddle, D. L. *Development* **131,** 3897–3906 (2004).
3. Kaeberlein, M. *et al. Science* **310,** 1193–1196 (2005).
4. Kapahi, P. *et al. Curr. Biol.* **14,** 885–890 (2004).
5. Powers, R. W. 3rd, Kaeberlein, M., Caldwell, S. D., Kennedy, B. K. & Fields, S. *Genes Dev.* **20,** 174–184 (2006).
6. Vellai, T. *et al. Nature* **426,** 620 (2003).
7. Stanfel, M. N., Shamieh, L. S., Kaeberlein, M. & Kennedy, B. K. *Biochim. Biophys. Acta* advance online publication doi:10.1016/j.bbagen.2009.06.007 (2009).
8. Smith, E. D. *et al. Genome Res.* **18,** 564–570 (2008).
9. Steffen, K. K. *et al. Cell* **133,** 292–302 (2008).
10. Hansen, M. *et al. PLoS Genet.* **4,** e24 (2008).

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ATMOSPHERIC PHYSICS

Cosmic rays, clouds and climate

Ken Carslaw

Galactic cosmic rays could influence Earth's cloudiness by creating aerosol particles that prompt cloud formation. That possible effect looks to be smaller than thought, but the story won't end there.

Striking correlations have been observed between Earth's cloud cover and the flux of galactic cosmic rays entering our atmosphere. The decrease in galactic cosmic ray (GCR) flux by about 15% over much of the twentieth century has led to the hypothesis that GCRs could influence climate through their effect on cloudiness. This controversial possibility is revisited in a paper in *Geophysical Research Letters* by Pierce and Adams[1].

There are several plausible mechanisms that could link GCR flux and cloud properties[2]. A leading candidate is the 'ion–aerosol clear-air mechanism', in which atmospheric ions created by GCRs act as nuclei for the formation of atmospheric particles. The nucleation of new nanometre-sized aerosol particles is observed frequently, and in many parts of the atmosphere, and is thought to be a major source of cloud-condensation nuclei (CCN) — particles large enough for cloud droplets to form around them. The link between GCRs and climate is therefore plausible because any change in GCR-ionization rate might be expected to drive changes in cloud-droplet concentrations, and hence the amount of solar radiation that clouds reflect back to space.

Atmospheric ions can indeed seed new particles[3], but two outstanding questions have hampered progress. What fraction of nuclei is created this way? And what fraction of these particles grows large enough to influence CCN? To be relevant to recent climate change, it would be necessary to show that the decrease in GCR flux during the twentieth century could lead to significant changes in CCN and clouds.

In their paper[1], Pierce and Adams estimate the magnitude of the ion–aerosol clear-air mechanism. They used a global atmospheric model with a detailed treatment of aerosol physics to estimate some limiting values of CCN formation from changes in GCR flux. Their conclusion is clear: CCN concentrations just aren't very sensitive to the changes in GCRs that have occurred during the twentieth century. The authors predict that CCN concentrations will change by less than 0.1% between solar maxima and minima as GCRs change by 15% — about the same as the change seen during the last century. They estimate that this change in CCN translates into a change of 0.005 watts per square metre in solar radiation reflected from clouds, insignificant compared with the greenhouse-gas warming of 2 watts per square metre or more over roughly the same period.

Pierce and Adams's model is quite sophisticated in the way it treats the global lifecycle of aerosols, from formation at nanometre sizes to their eventual growth over days to weeks to CCN sizes. But rather than trying to model the complex ion–aerosol processes in detail (physics that is still incompletely understood), they make an upper-limit assumption that all nucleation is due to ions, thereby circumventing one obstacle to making such a global assessment.

Is this negative result the last word on the ion–aerosol clear-air mechanism? Climate modellers are always quick to point out that predictions can be model-dependent. Certainly CCN may be more sensitive to the ion-induced nucleation rate in a different model or under conditions not explored by Pierce and Adams. But other global-model studies[4,5] of nucleation suggest that CCN are fairly insensitive to the nucleation rate for a simple reason: during the time taken for nuclei to grow to CCN sizes, coagulation depletes particle concentrations — just as raindrops are always fewer in number than cloud drops. Unless there is some as-yet-undiscovered process that accelerates the growth of a few charged nuclei all the way up to CCN sizes, this low sensitivity is likely to be a robust conclusion.

Despite this result[1], it is likely that a cosmic-ray–cloud–climate connection will continue to be explored, for two reasons. First, scientists continue to be intrigued by correlations between cosmic rays, Earth's electrical state and climate variables (clouds, precipitation, drought and so on) on timescales from hours to millennia[6,7]. Because the climate displays a

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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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1. Pierce, J. R. & Adams, P. J. *Geophys. Res. Lett.* doi:10.1029/2009GL037946 (2009).
2. Carslaw, K. S., Harrison, R. G. & Kirkby, J. *Science* **298**, 1732–1737 (2002).
3. Curtius, J., Lovejoy, E. R. & Froyd, K. D. *Space Sci. Rev.* **125**, 159–167 (2006).
4. Spracklen, D. V. *et al. Geophys. Res. Lett.* doi:10.1029/2007GL033038 (2008).
5. Pierce, J. R. & Adams, P. J. *Atmos. Chem. Phys.* **7**, 1367–1379 (2007).
6. Harrison, R. G. & Ambaum, M. H. P. *Env. Res. Lett.* **4**, 014003 (2009).
7. Kirkby, J. *Surv. Geophys.* **28**, 333–375 (2007).
8. Harrison, R. G. *Proc. R. Soc. A* **464**, 2575–2590 (2008).
9. Harrison, R. G. & Ambaum, M. H. P. *Proc. R. Soc. A* **464**, 2561–2573 (2008).
10. http://www.cloud-itn.uni-frankfurt.de/

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