As a result, successful long-term field studies, like those of chimpanzees at Gombe and Mahale (*6*), gorillas at Karisoke (*7*), savannah baboons at Amboseli (*8*), and Japanese macaques at Arashiyama (*9*), provide many of the best opportunities for novel, innovative research on primate ecology and behavior. Many of these studies are now collaborative ventures involving multiple scientists from separate disciplines and universities, who can together draw on detailed records of the life histories of large samples of individuals. The protracted presence of scientists at particular sites also contributes to the conservation of study populations and their habitats (*10*).

Long-term, individual-based studies are not restricted to primates; however, most involve birds or mammals (see the figure), and only a few have focused on fish, reptiles, and amphibians (*11*). Despite extensive interest in the evolution of insect societies, few studies of social insects have yet been able to track the full careers of reproductive individuals; the first study to explore the extent and causes of individual differences in lifetime breeding success in social insects was published only last year (*12*). The longest-running field studies are of passerine birds and were started in the Netherlands in the 1930s (*13*). Several long-term studies of seabirds, wildfowl, ungulates, carnivores, and primates have been running since the late 1950s and early 1960s, producing vital insights into the causes of population declines and responses to climate change (*14*). Among mammals other than primates, long-term individual-based studies of African lions, elephant seals, wild sheep, African elephants, red deer, and marmots have been running for over three decades.

Compared to primates, many other mammals are relatively easy to catch and mark and (with the exception of elephants) have shorter life spans. As a result, some studies now provide records of the full life histories of several thousand individuals spanning multiple generations and offer opportunities to investigate biological questions that are not yet accessible in primates. Multigenerational pedigrees that can be used to assess the relative contributions of genotype and environment to individual differences now exist for an increasing number of birds and mammals (*15*), and modern genomic approaches have also started to yield new insights. However, their application requires the existence of extensive phenotypic and ecological data, and there are no short-cuts to obtaining these data (*16*).

Long-term field projects are often at risk to bandits or rebels because they are usually located in isolated areas. Several have lost staff and some have had to close. Poaching and human encroachment are common problems and are often exacerbated by political instability. But the greatest problem faced by long-term studies is their need for continuous funding. Most long-term individual-based studies are run by universities and rely on short-term research grants for support. These studies will eventually face a rejection and interruption in the collection of data. For studies of long-lived species, this may mean abandoning the study or starting from scratch. Protection for the continuity of long-term studies has been elusive, and even the most productive studies spend much of their lives teetering on the brink of closure.

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PHYSICS

Controlling Implosion Symmetry Around a Deuterium-Tritium Target

Fusion power is a step closer with the demonstration of control over the extreme thermal radiation pressure created by high-power laser beams within a cavity.

Peter A. Norreys

One of the goals of 21st-century physics—controlling the implosion of a target and initiating nuclear fusion—has its origins in one of the puzzles of 19th-century physics. The understanding of thermal radiation emitted from a cavity ("blackbody radiation"), which is an important component of the fusion problem, began by abandoning classical physics and adopting the revolutionary idea of energy quantization. Thermal radiation has reappeared in the fusion problem because the powerful megajoule-class lasers do not implode their targets directly—instead, they create intense radiation pressure within a cavity. On pages 1231 and 1228 of this issue, Li *et al*. (*1*) and Glenzer *et al*. (*2*) show that the distribution of radiation inside a cavity can be accurately controlled to create a symmetrical implosion, thereby removing major obstacles to the realization of fusion energy in the laboratory. These new insights promise another revolution in physics in the near future, one that provides access to new states of matter with unprecedented energy densities.

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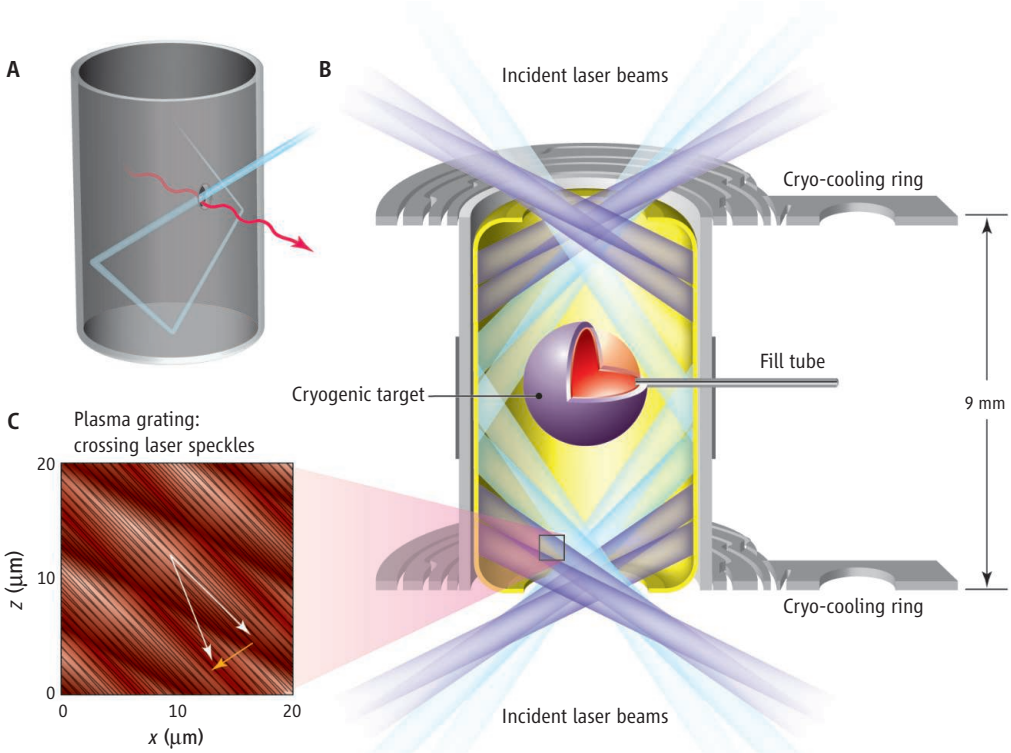
The ideal limit of a thermal emitter, a "black body," absorbs all incoming radiation. In practice, the best black body to study is a small hole in an enclosed cavity; almost all incoming light will be absorbed on its walls before finding a reflecting pathway back out (see the figure, panel A). Classical physics accounted for thermal emission from an object as a continuous process resulting from accelerating electrical charges and predicted that more radiation would be emitted as the wavelength of light decreased. The classical theory not only failed to account for the intensity of thermal emission peaking at some frequency, but also suffered from the "ultraviolet catastrophe"—a

black body, or any other object with a temperature, would emit an infinite amount of energy.

The solution would lie with the concept that light is emitted in packets, or quanta, as pioneered by Max Planck in 1900. His new theory accurately predicted the intensity and the frequency spectra of blackbody radiation as a function of temperature. In doing so, Planck reconciled electromagnetism with statistical mechanics, which describes the energy distribution of a gas in thermal equilibrium.

Unlike molecules in a gas, radiation in a cavity does not come to equilibrium by experiencing collisions in the middle of the box. Energy can shift from one frequency mode to another by charge oscillations induced in the wall material. Energy can then be transferred to other charges in the wall, and these will oscillate and radiate at different frequencies. Eventually, the radiation inside the box comes to thermal equilibrium, which can be measured when it eventually escapes the cavity through the hole.

This old problem received a new lease on life with the invention of lasers in the second half of the 20th century. It was quickly realized that these devices can deliver immense energy densities to a small target. If that energy could be captured and enclosed in a cavity similar to Planck's black box, called a hohlraum, then the resulting blackbody radiation would have its maximum at frequencies in the soft x-ray regime, which corresponds to cavity temperatures of millions of kelvin. This value is many orders of magnitude more powerful than anything that Planck considered. Indeed, this blackbody radiation is so powerful that it can then be used to implode a small shell of material containing fusion fuel (deuterium and tritium, the isotopes of hydrogen) to high velocity. The resulting density and temperature increase at peak compression would be sufficient to create conditions where large numbers of fusion reactions take place (*3*).



Thermal radiation, then and now. (**A**) The classical blackbody source is a hole in a blackened cavity. Light coming in (shown in blue) will absorb as it bounces around; the emission (red) is thermal radiation from the cavity walls. (**B**) A schematic illustration of the radiation cavity, or hohlraum, containing the shell that has a layer of deuterium-tritium fusion target frozen on its inner surface. The cavity is kept at cryogenic temperatures by two cooling rings at the top and bottom; laser radiation will increase the temperature above 3 million kelvin. The 192 laser beams of the National Ignition Facility enter the hohlraum from both the top and bottom of the chamber. They are arranged in four cones of beams. The radiation symmetry is controlled by adjusting the wavelength of the two inner cones with respect to the outer two cones. (**C**) An expanded view of the overlap point of the beams, which combine to form a plasma diffraction grating. The arrows depict how the wave vectors of the beams (long arrows) combine to generate the wave vector of the grating (short arrow).

However, if the release of fusion energy is to exceed the energy of the input laser beams, a number of criteria must be met simultaneously. The energy coupling to the cavity generating the blackbody radiation must be high. The number of fast electrons generated from so-called parametric instabilities must be minimized to prevent preheating of the fuel as it implodes. The soft x-ray drive that surrounds the shell must be sufficiently symmetric. The high-pressure shock waves, which must converge at the center of the pellet at peak compression, must be timed accurately. Finally, hydrodynamic instabilities that are seeded by imperfections (residual mass perturbations in the original shell) must be controlled (*4*, *5*).

The radiation temperature needed for fusion is at least 3 million kelvin, which would require nearly a megajoule of laser energy delivered in several nanoseconds, corresponding to peak powers of 500 TW. Given that the entire world's electricity generation output is 17 TW, the energy density delivered to the cavity in that short time would be enormous. This megajoule energy requirement demands the use of many overlapping laser beams that create quite complex structures inside the hohlraum. This is beautifully demonstrated by Li *et al.* in their proton radiographs of the converging shell in a scaled-down experiment performed at the University of Rochester's OMEGA laser facility (*6*), which showed the formation and evolution of spoke-like electric field structures inside the cavity on a nanosecond time scale. The complex structure inside the cavity does not appear to have influenced the compression performance of the shell. Furthermore, striations previously observed with direct laser illumination of shell targets are absent with the soft x-ray drive (*7*).

The worry is that these structures could affect both the energy absorption (via laser beam scattering or self-focusing) and parametric instability growth in the larger targets needed for fusion energy gain that will be used at the National Ignition Facility (*8*). Fortunately, this is not the case. Indeed, Glenzer *et al.* demonstrate greater than 90% energy coupling to the hohlraum (see the figure, panel B). They also show that the fraction of laser energy converted to hot electrons is in the range of 1 to 2%, well within acceptable limits. They provide conclusive proof that they have achieved blackbody radiation temperatures of 3.3 million kelvin. Finally, in an extraordinary tour de force, they demonstrate the control the symmetry of the x-ray drive at the center of the cavity. Control is achieved by forming a novel plasma diffraction grating in the beam-crossing area near the laser entrance holes, which tunes the wavelength of the two outer cones of beams with respect to the two inner cones of beams (see the figure, panel C).

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These remarkable observations suggest that the remaining obstacles to fusion energy gain are now surmountable. These results also herald a new era in physics, that of high-energy-density science. It is truly fitting that this 21st-century frontier (*9*) can trace some of its origins back to the humble radiation cavity of the 19th century.

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CELL BIOLOGY

Burn Out or Fade Away?

A protein whose expression is turned on by stress delays the onset of age-related pathologies.

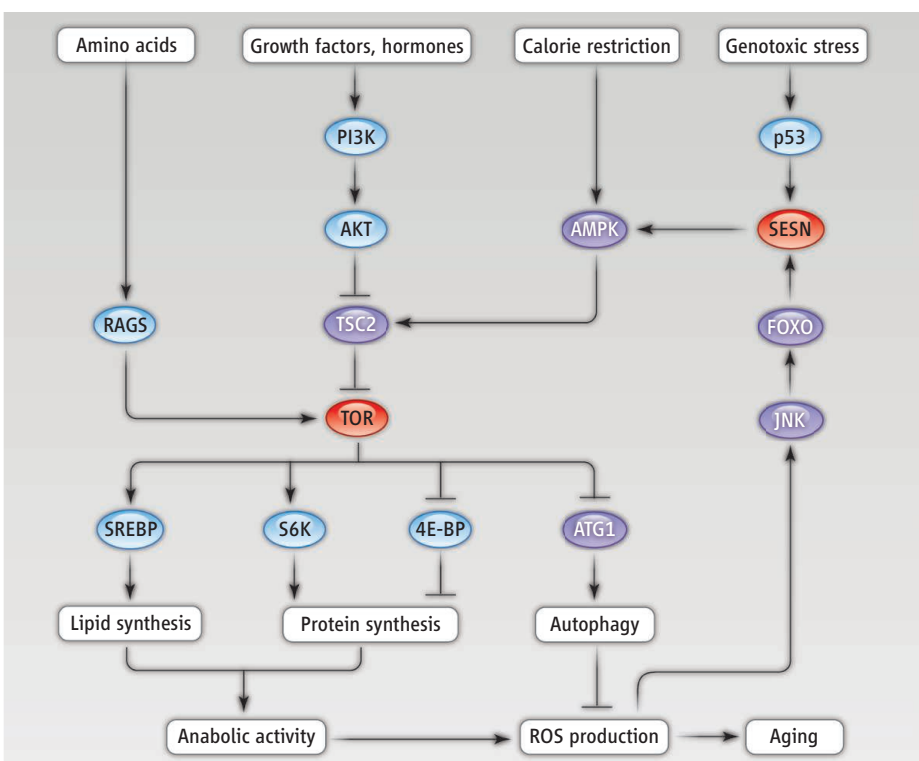
Ivan Topisirovic[1,2] and Nahum Sonenberg[1,2]

The target of rapamycin (TOR) kinase plays an evolutionarily conserved role, from yeast to human, in controlling metabolic activity in response to intracellular cues and extracellular stimuli (*1*). It stimulates anabolic processes that engender cell growth and proliferation by increasing protein synthesis and lipogenesis. TOR also inhibits autophagy, which is a major catabolic process. Persistent activation of TOR causes an imbalance between anabolic and catabolic processes, resulting in the accumulation of damaging reactive oxygen species (ROS), which favors the development of age-related disorders. Indeed, the inhibition of TOR by the drug rapamycin increases organism life span and reduces the incidence of age-related pathologies (*2*). On page 1223 of this issue, Lee *et al*. report that sestrin proteins prevent excessive TOR activation and delay the onset of age-related pathologies through a negative-feedback mechanism (*3*).

Sestrins are a family of highly conserved cytoplasmic proteins that contain a redox-active domain, and whose expression is induced by stress (*4*). There are three sestrins in mammals, but only one in the fly *Drosophila melanogaster*, making the latter an optimal model system for studying the physiological functions of sestrins. Activation of *Drosophila* TOR (dTOR) increases transcription of the gene encoding *Drosophila* sestrin (dSesn) through a signaling pathway that is not fully understood, but involves the enzyme c-Jun N-terminal kinase (JNK) and the forkhead box O (FOXO) transcription factor. In turn, increased abundance of dSesn inhibits dTOR signaling by activating adenosine monophosphate–activated protein kinase (AMPK) and tuberous sclerosis complex 2 (TSC2) proteins (see the figure).

Lee *et al*. report that the loss of dSesn results in chronic activation of dTOR, leading to the induction of anabolic processes and inhibition of autophagic degradation of dysfunctional mitochondria. This causes ROS accumulation and development of a variety of age-related pathologies in *Drosophila*, including muscle degeneration, cardiac arrhythmia, and lipid accumulation. Deletion of the gene encoding dSesn resulted in a 50% decrease in AMPK activity and a 50% increase in dTOR activity. Strikingly, feeding dSesn-deficient flies with pharmacological activators of AMPK (e.g., metformin), or the TOR inhibitor rapamycin, prevented the age-related phenotypes.

How does dSesn antagonize premature aging in flies? It has been proposed that aging is caused by the accumulation of stochastic molecular damage, which is mainly induced by mitochondrial ROS production (*5*). Treatment of flies lacking dSesn with the natural antioxidant vitamin E ameliorated most of the age-related pathologies, suggesting that they depend on ROS accumulation, and that the dSesn-induced negative feedback on TOR activity prevents ROS buildup. Although sestrins can eliminate ROS production in vitro (*4*), Lee *et al*. demonstrate that the intrinsic redox activity of dSesn is not critical for sup-



Metabolic network. Sestrins control the effects of TOR, in a complex network of pathways that regulate anabolism, catabolism, and the development of age-related pathologies. ATG1, authphagy-specific gene 1; P13K, phosphatidylinositol 3-kinase; RAGS, Ras-related GTP-binding protein; SREBP, sterol regulatory element-binding protein.

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