

In 1997, the maize gene *tb1* was reported as the first domestication QTL to be cloned (4). *tb1* controls the complex differences in plant architecture between maize and its progenitor, teosinte. In 2000, a major QTL (*fw2.2*) contributing to the massive increase in fruit size that was a central feature of tomato domestication was cloned (5). In 2005, the maize domestication QTL *tga1*, which provides naked grains to maize (as opposed to the covered grains of teosinte), was cloned (6). And thus far in 2006, in addition to the two rice shattering genes, cloning of the wheat *Q* gene was reported (7). *Q* controls the compaction and fragility of the ear of wheat and also the ease with which the grain can be separated from the chaff.

A notable feature of this list of six domestication genes is that five of the six encode transcription factors that regulate other (target) genes by directly binding to their DNA. Transcription factors represent only about 5% of genes in plant genomes (8, 9) but 83% of the domestication genes listed above. Interestingly, the five domestication transcription factors belong to five separate families: TCP (*tb1*), SBP (*tga1*), AP2 (*Q*), MYB3 (*sh4*), and HOX (*qSH1*). This suggests that the exaggerated proportion of transcription factors among domestication genes is the product of some general feature of transcription fac-

tors and not of one particular class of transcription factors. The predominant role of transcription factors in domestication mirrors their equally large role in controlling plant development (10), which supports the view that they have properties that predispose them to become the major genes contributing to morphological evolution in plants (11).

Another remarkable feature of this list is that the domesticated alleles of all six genes are functional. If domestication involved the crippling of precisely tuned wild species, one might have expected domestication genes to have null or loss-of-function alleles. Rather, domestication has involved a mix of changes in protein function and gene expression. As a consequence of domestication, *sh4* shows changes in protein function and expression level (2), *qSH1* shows a change in the spatial pattern of its expression (3), *tb1* shows increased expression (4), *tga1* shows a change in protein stability or protein function (6), *fw2.2* shows a heterochronic shift in its expression (5), and *Q* shows changes in protein function and gene expression (7). Given that the cultivated allele of not one of these six domestication genes is a null, a more appropriate model than “crippling” seems to be adaptation to a novel ecological niche—the cultivated field. Tinkering and not disassembling is the order of

the day in domestication as in natural evolution, and Darwin’s use of domestication as a proxy for evolution under natural selection was, not surprisingly, right on the mark.

A consequential question now is whether modern plant breeders might borrow from the playbook of their Neolithic predecessors. Might one tinker with the expression patterns or protein functions of known domestication genes to create superior alleles? Can every transcription factor in the genome be manipulated in a systematic manner to generate a pool of new trait variation? Knowledge of past successes should help to intelligently guide future crop improvement.

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PLANETARY SCIENCE

Exploring Other Worlds to Learn More About Our Own

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The exploration of our solar system was originally driven primarily by curiosity and the search for answers to the eternal question: Are we alone? As the first spacecraft began to visit our neighboring planets in the solar system, hopes of finding life quickly faded and instead the focus began to shift toward gaining a more scientific understanding of their nature and history. After a generation of exploratory robotic spacecraft missions from the 1960s through the 1980s, it became clear that most planets—except Mercury—and some moons had permanent and substantial atmospheres. These atmospheres can be subdivided into three large families: those composed primarily of nitrogen (Earth, Titan, Triton, Pluto), carbon dioxide (Venus, Mars), and hydrogen/helium (Jupiter, Saturn, Uranus, Neptune). On page 1366 of this issue, Forbes et

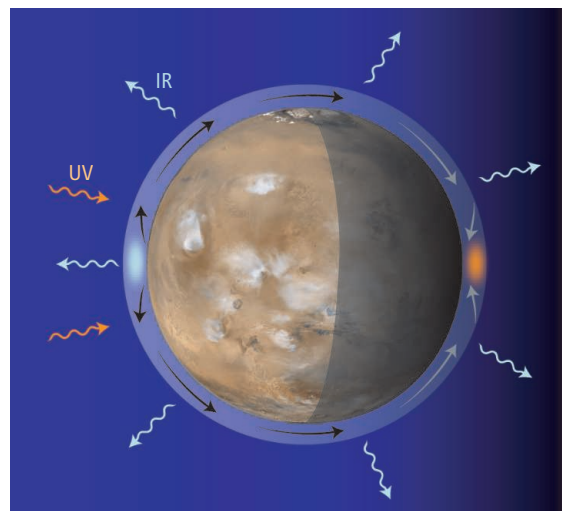
al. (1) provide fresh insights into the effects of variations in solar radiation intensity on the upper atmospheres of Mars and Earth, which have now been simultaneously observed.

Numerous space missions, along with Earth-based observations and theoretical models, have given us an unprecedented understanding of planetary atmospheres. Yet some of their fundamental prop-

Energy flow on Mars. Solar ultraviolet radiation heats the dayside to 300 K; winds transport some of this energy toward the nightside, where temperatures are typically lower by 100 K. On the dayside, vertical conduction and adiabatic cooling offset solar heating, whereas the nightside temperatures are raised by adiabatic heating. A portion of the solar energy is radiated back into space through infrared cooling by CO₂.

Simultaneous observations of the drag of satellites through the upper atmospheres of Mars and Earth reveal how carbon dioxide is differentially cooling their upper atmospheres.

erties are still poorly understood, including the atmospheric energy balance (see the figure). What are the sources of energy incident upon an atmosphere, how is this energy redistributed



internally, and how much of it is lost back into space? The key common source of energy in our solar system is the Sun, and this energy is distributed either through radiation or via the solar wind. Since the time of formation of our solar system, some energy has been stored internally in the planetary bodies as thermal, chemical, or rotational energy. Energy also reaches us from outside our solar system in the form of cosmic radiation, in particular gamma rays.

The high-energy ultraviolet portion of radiation from the Sun is absorbed in Earth's upper atmosphere by the principal gases nitrogen (N₂) and oxygen, both molecular and atomic (O₂, O). Most of the absorbed energy is thermally conducted to lower altitudes. Near 90 km (the mesopause region), CO₂ and other radiating molecules are abundant enough to emit a large portion of the energy back to space through infrared radiation. At high latitudes, energetic particles precipitating from the magnetosphere interact with the atmosphere, leading to substantial heating as well as spectacular auroral emissions. Electrical currents between the magnetosphere and the atmosphere can also heat the atmospheric gases at high latitudes, particularly during geomagnetic disturbances.

In essence, most of the physical processes that control Earth's energy balance are also acting on other planets. On Venus and Mars, the large abundances of CO₂ lead to effective radiative cooling of their upper atmospheres. The heating processes at auroral latitudes on Jupiter and Saturn may exceed solar heating rates because of the larger distances from the Sun. Another likely heat source on the gas giants is the transfer of energy from inside the planets to their outer atmospheres via waves.

The exploration of other bodies in our solar system also helps us understand our own planet far better. Cooling by CO₂, which dominates Venus and Mars, is also acting on Earth and turns out to be one of the keys to understanding the evolution of our atmosphere as well as climate change. Major uncertainties, however, pertain to Earth's CO₂ cooling rate, which is controlled by the excitation of CO₂ through collisions with atomic oxygen. It turns out that observing Mars or Venus simultaneously with Earth can help us better determine this rate, but such observations are challenging and have not been made until recently.

Now, analyses by Forbes *et al.* of the atmospheric drag on satellites orbiting Earth and Mars have yielded measurements of how variations in solar radiation intensity affect atmospheric densities. At any given altitude, heating of the atmosphere will result in an enhancement of densities and stronger atmospheric drag on a satellite. Measuring these drag variations allows derivation of atmospheric temperature changes, and thereby of the effects of solar forcing. Mars is found to be half as responsive as Earth to changes in solar forcing, but is estimated to be

four to seven times as responsive as Venus. These numbers are corrected for distances from the Sun; thus, the differences are primarily due to the varying CO₂ cooling efficiencies, which have so far remained poorly understood. This study, in helping us to improve our knowledge of the CO₂ cooling efficiencies, is a prime example of how we can use other planets in our solar system as laboratories to better understand the complexity of our own atmosphere, and thereby improve our predictions of changes, including those due to anthropogenic effects.

Previous simultaneous observations of planets had focused on comparing solar forcing of the ionized portions of the atmospheres on Earth and Mars (2–4) and the propagation of interplanetary shocks through the solar system. Interplanetary shocks are triggered by violent solar eruptions and cause compression of magnetospheres around planets. Such compressions lead to increased levels of energetic particle precipitation into upper atmospheres, and thereby enhanced auroral brightness. Only recently, observations have followed an interplanetary shock as it propagated from the Sun to Earth, Jupiter, and Saturn and successively caused enhanced brightness of their aurorae (5), confirming the effects of solar forcing on planetary magnetic

and plasma environments and atmospheres. These comparative space weather observations have highlighted important differences between the ionospheres and magnetospheres of planets, again helping us to better understand Earth and its space environment.

The examples illustrate that comparative studies of planets are far more effective than examining each body individually. Knowledge of Earth's atmosphere and environment helps us understand aspects of other planets, but we can only understand the evolution of our own atmosphere by studying those of other planets. Ultimately, the lessons learned within our solar system can also be applicable to the exploration of planets orbiting stars far from our solar system.

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BEHAVIOR

Align in the Sand

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Many animal species form large organized groups, but how information is shared within swarms, flocks, and herds is not clear. Studies of locust swarms reveal distinct transitions from disordered to ordered phases.

Large, coordinated animal groups such as swarms, herds, schools, and flocks are widespread phenomena that strongly affect many biological systems (1). High population densities often bring negative consequences (increased competition for resources, disease transmission, and attention from predators), but species that take advantage of dense populations to form organized groups may benefit by more effective foraging, reproduction, migration, and escape from predators. The analysis by Buhl *et al.* of coordinated movement in juvenile desert locusts on page 1402 of this issue presents the most detailed description yet of the behavioral mechanisms enabling social animals to form and maintain coherent, large-scale groups (2).

Locust plagues can contain 10⁹ individuals and are among the most spectacular and consequential of animal aggregations (3). Seemingly

spontaneous appearances of multitudes of hungry locusts, which fill the air and carpet the ground as each eats its own weight per day of natural and agricultural vegetation, have caused ecological, economic, and (after these locusts die and putrefy) epidemiological catastrophes of historic proportions (4). All of this devastation originates with a profound transition by immature, nonflying locusts from a relatively innocuous solitary phase, in which they actively avoid each other, to a behaviorally and physiologically distinct gregarious phase, in which they seek each other out (5). When this happens, the locusts form massive, coherent, and highly mobile foraging groups (see the figure). Desert locusts almost completely destroy plant material as they go, and they go a long way; migrations routinely carry these insects thousands of kilometers across Africa and have reached as far as Europe and the New World (6).

"The locusts have no King, yet all of them march in rank," observed an insightful ancient naturalist (7), capturing the enduring mystery of

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