blasting. It is intriguing to imagine a 217-km-long asteroid knee deep in powdered metal.

Ostro *et al.* also provide direct confirmation of an extraordinary dumbbell shape for Kleopatra, as already indicated by the brightness variations when it rotates. The images show an object shaped like a dog's bone, with lumps at each end. Other such asteroids of other taxonomic classes are also known. I suggested that a range of asteroid peculiarities, from occasional dumbbell shapes to asteroid satellites, could be a result of the catastrophic events that produced most asteroids as fragments of once larger parent bodies (*3*, *4*). The idea is that adjacent fragments moving nearly parallel in the chaotic expanding cloud of debris after a collision find themselves within each others' gravitational sphere and either fall together at low velocity (making a dumbbell-shaped object) or end up orbiting each other (producing an asteroid with a satellite) (see the figure). Some computer models (*5*) offer support for this idea. On the other hand, if Kleopatra's shape, as reconstructed from the radar data by Ostro *et al.,* is correct, it raises the question of how such a spectacularly long "neck" could form between the two lumpy objects, if they started out as a contact binary. Conceivably, impact erosion may have reduced the size of the two initial bodies and at the same time filled in the point of contact between them, thus producing Kleopatra's shape.

A final point of interest in the work of Ostro *et al.* is more visionary. Ostro *et al.* conclude that Kleopatra is a 217-km-long piece of nickel-iron, possibly in the form of chunks or broken masses, covered with a fine powder of pulverized metal grains or dust. In other words, the asteroid is an easily harvestable ore body floating in the sky. Half a century ago, the idea of mining asteroid resources was firmly in the realm of science fiction. However, in 1977, Gaffey and McCord noted (*6*), on the basis of early asteroid spectroscopic taxonomies, that some asteroids are probably metallic and pointed out that even kilometer-scale bodies of this sort could have enormous economic value. If the cost of interplanetary operations decreases as space capabilities are developed further, and the cost of raw materials increases as we use up Earth's resources, then the recovery of asteroid metal resources may become economically attractive (*7*). These resources include not just nearly pure nickel-iron alloys, such as seen in "iron" meteorites, but also other metals, such as platinum group metals, which are concentrated in other types of meteorites (and presumably asteroids). One of the difficulties has always been the question of how to harvest or process these high-strength metal materials. However, the work of Ostro *et al.* portrays a giant metal asteroid with enough gravity to retain a regolith of metal powder. The nickel-iron could be scooped up or gathered with a simple magnetic rake.

The idea of asteroid mining raises the question of who owns the resources. Is there a social mechanism by which the benefit of such resources can be spread to all humanity, instead of increasing sociopolitical instability by making only the discoverers (or discovering nations) rich and increasing the gap between the first and third worlds? Furthermore, should some asteroids be declared off limits to mining and set aside as scientific preserves, as suggested a few years ago by planetary scientist George Wetherill (*8*)?

The media tend to focus on the "asteroid threat"—the evidence that an asteroid may have wiped out the dinosaurs, the devastation that future modest-scale impacts could cause, and (relatively unproductive) schemes to blow threatening asteroids out of the sky with nuclear missiles. But time scales of global-scale threats are on the order of many millennia. The work of Ostro *et al.* moves us one step closer to capitalizing on the "asteroid opportunity," by investing in human capability to reach and explore asteroids over a time scale of a century in order to understand asteroid evolution, explore possible resource bases that would reduce the plundering of Earth, and develop the ability to deflect Earth approachers from dangerous paths.

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PERSPECTIVES: PLANT BIOLOGY

Lighting Up the Nucleus

Akira Nagatani

A wide range of physiological and developmental processes in plants, such as seed germination, greening of seedlings, and flowering, are regulated by light. Thus, to increase their productivity and fitness plants must be able to detect and adapt to changes in light stimuli. They have skilfully achieved this by evolving light detecting photoreceptors, of which the best characterized are the five members of the phytochrome family. Phytochromes are water-soluble chromoproteins of ~120 kilodaltons that consist of a tetrapyrrole pigment molecule (which traps light photons) covalently attached to a polypeptide backbone (*1*). Since their discovery, enormous efforts have been devoted to elucidating how phytochromes transduce light stimuli into molecular signals that culminate in the expression of light-activated genes. Now, on page 859 of this issue, Quail and colleagues (*2*) present compelling evidence that phytochromes are recruited to the nucleus and bind to the promoters of light-activated target genes, regulating their expression. These findings demonstrate that plants have invented an extremely simple and efficient way of modifying gene expression in response to changes in light.

The inactive form of phytochrome absorbs red light and is activated; when the activated photoreceptor absorbs far-red light it is converted back to the inactive form. Present in all plants, phytochrome homologs have been found recently in photosynthetic cyanobacteria, but not in yeast or animals (although photoreceptors called cryptochromes have been found in flies and mammals). Phytochromes were thought to reside in the cytoplasm of plant cells, but this has turned out to be only half true because, when activated by light, they accumulate inside the nucleus (*3*, *4*).

Molecular genetic analyses have hinted that the nucleus might be the site of light-activated signal transduction (*5*). Putative components of the light signaling pathway have been identified by analysis of plant mutants that show changes in morphology usually associated with light, in the absence of a light stimulus. Some of these components are nuclear proteins of unknown function. More recently, mutants specifically deficient in phytochrome signaling have been isolated and mutations identified in *spa1* and *far1*, two genes that encode nuclear proteins.

Phytochromes contain a core signal transduction domain within their carboxyl-terminal region (*6*), and yeast two-hybrid screens have identified three proteins—PIF3 (*7*), PKS1 (*8*), and NDPK2 (*9*)—that interact with this region. Interestingly, their predicted functions and subcellular localization are different. Originally identified by Quail's laboratory,

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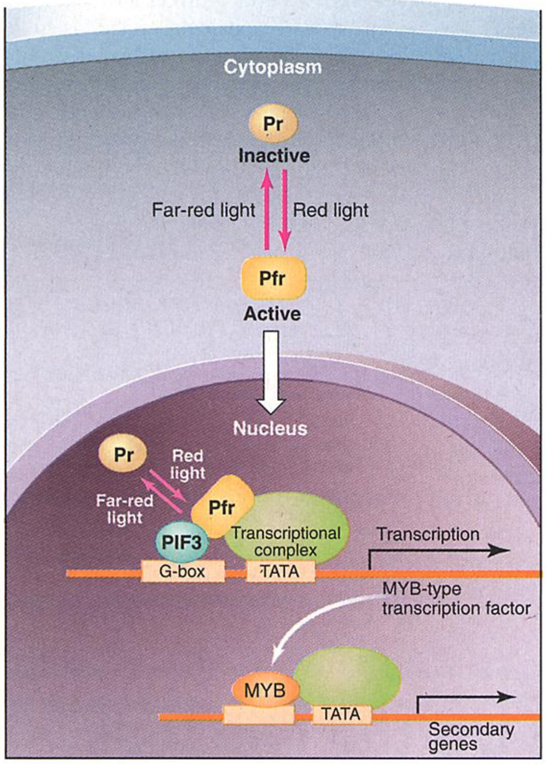

Molecular light switches. Light-activated gene expression in plants. The basic helix-loop-helix transcription factor PIF3 binds to a G-box motif in the promoter region of light-responsive genes. Upon absorbing red light, a phytochrome photoreceptor is converted from the inactive Pr form to the active Pfr form, which moves to the nucleus. Here, Pfr is recruited to the promoter region of target genes by binding to PIF3 and then activates the expression of genes encoding MYB class transcription factors (*CCA1*, *LHY*). The transcription factors in turn activate the expression of secondary genes. Far-red light shuts down this signaling pathway by converting Pfr back to Pr, promoting its release from the PIF3 complex.

PIF3 is a basic helix-loop-helix transcription factor found exclusively in the nucleus. PKS1 and NDPK2 are, respectively, a cytoplasmic phytochrome kinase substrate and a nucleotide diphosphate kinase found in both the nucleus and cytoplasm. Altered expression of these proteins results in reduced or enhanced responses of the plant to light (*7–10*). Thus, these three proteins are potential signal transduction partners for the phytochromes.

Last year, Quail and co-workers reported that there was a physical interaction between PIF3 and the phytochromes (*11*). They ligated the chromophore to the protein portion of a phytochrome synthesized in vitro and mixed the reconstructed photoactive molecule with immobilized PIF3. Then they demonstrated that brief irradiation of the mixture with red light induced rapid binding of the activated phytochrome to PIF3, whereas a pulse of far-red light released activated phytochrome from the complex. This in vitro work shows that phytochromes can behave as light-activated molecular switches.

As PIF3 is a transcription factor, it is expected to recognize specific DNA sequences. In their new work (*2*), Quail's group show that the principal DNA sequence to which PIF3 binds is a palindromic hexanucleotide, CACGTG, known as the G-box motif (see the figure). This motif is found in a variety of genes, some that are regulated by light and some that are not. The authors investigated whether PIF3 is necessary for the phytochrome-regulated expression of light-activated genes using an antisense strategy. Of the genes examined, the induction of *CCA1* and *LHY* was reduced in transgenic plants expressing *PIF3* antisense mRNA. Thus, these two genes are probably direct targets of the phytochrome-PIF3 pathway. Because *CCA1* and *LHY* encode MYB transcription factors, they can in turn switch on the expression of secondary genes. Indeed, CCA1 binds to the promoter region of some light-induced genes and activates their transcription. The emerging picture is unexpectedly simple: Phytochromes perceive a light stimulus, move into the nucleus, interact with PIF3, which is bound to the G-box motif of a light-activated gene, and that gene is switched on.

Of course, this is not the end of the story. Evidence suggests that there are PIF3-independent pathways through which phytochromes regulate gene expression (*2*). Also, it is not yet clear how phytochromes, once activated by light, switch on the expression of target genes. These photoreceptors have kinase activity (*12*) and so they might modify the transcription complex by phosphorylation (see the figure), although this still needs to be proven experimentally. Attention should also be directed to other nuclear factors that have been implicated in light-activated gene expression but have yet to be integrated into the current phytochrome-PIF3 pathway. We still do not know how other plant photoreceptors such as cryptochromes and phototropins act, although cryptochromes are known to reside in the nucleus (*13*). This reminds us that many factors, and more than one photoreceptor, may interact in the nucleus to fine-tune the responses of plants to light.

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PERSPECTIVES: ASTRONOMY

Primordial Rain or Galactic Pollution?

Martin Zwaan

In the early 1960s, astronomers discovered neutral hydrogen clouds with velocities departing from the ordered gas disk that co-rotates with the stars in our galaxy (*1*). Several hundred of these High-Velocity Clouds (HVCs) have now been discovered across the sky, but their origin and their exact location remain enigmas. A satisfactory and commonly accepted explanation exists only for the Magellanic Stream, the largest HVC. The stream, which follows an arcing orbit almost one-third of the way across the sky, is believed to have formed as a result of a gravitational interaction between the Milky Way and its two companion galaxies, the Large and Small Magellanic Clouds. This interaction has stripped gas from the large cloud and spread it along an orbit around the Milky Way (*2*).

From measurements of HVC Doppler velocities, we know that the vast majority of HVCs are approaching us. However, further understanding is hampered by the fact that it is notoriously difficult to determine how far away they are. The absence of starlight in HVCs prevents the use of techniques commonly used to determine distances to groups of stars or galaxies. Spectra of stars with known distances in the direction of the clouds can provide some distance constraints (*3*). If the cloud is between the observer and the star, spectral

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