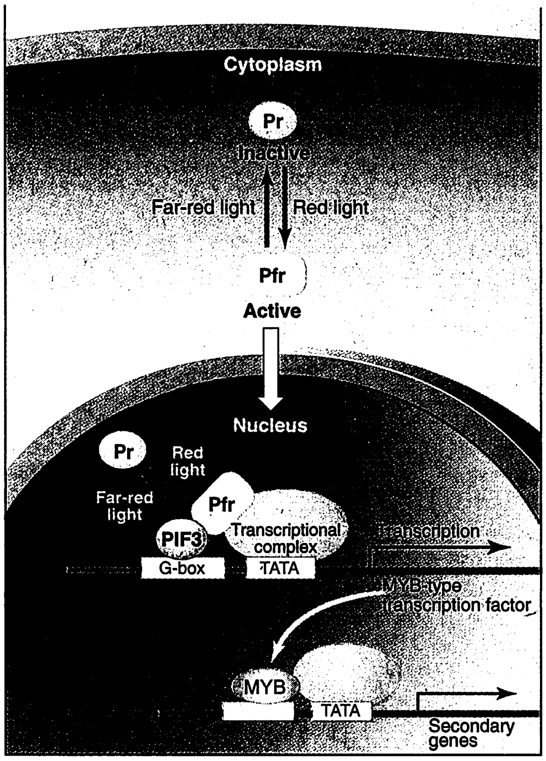

Molecular light switches. Light-activated gene expression in plants. The basic helix-loop-helix transcription factor PIF3 binds to a G-box motif in the promoter region of light-responsive genes. Upon absorbing red light, a phytochrome photoreceptor is converted from the inactive Pr form to the active 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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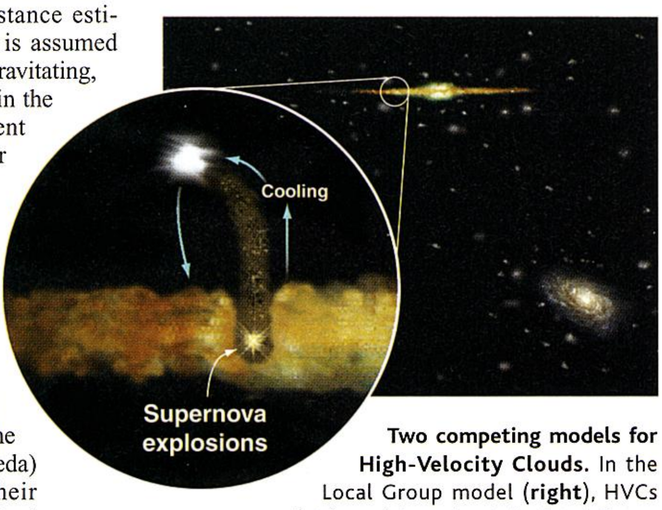
absorption lines caused by heavy elements such as carbon, iron, and magnesium are observed. If no such absorption is seen, the cloud is probably farther away than the stellar probe. Optical imaging through filters that select certain hydrogen emission lines has also proven useful (*4*). Ultraviolet radiation emitted from star-forming regions in the disk of the Milky Way may ionize hydrogen atoms in HVCs. The ionized region radiates so-called Balmer recombination lines. The closer the cloud to us, the stronger the effect of ionization and the stronger the resulting Balmer line flux. An alternative distance estimate can be made if it is assumed that the clouds are self-gravitating, stable entities that exist in the extragalactic environment (*5*). Comparison of their apparent size, flux, and velocity dispersion then yields a typical distance of about 30 million light-years (*6*), which places the clouds outside the Local Group (a galaxy group of at least 35 galaxies dominated by the Milky Way and Andromeda) (*7*) and implies that their neutral hydrogen content would be comparable to that of a normal spiral galaxy. But objects at these distances should be moving away from us because of the expansion of the universe, not toward us as actually measured. This has shed doubt on the extragalactic theory.



Two competing models for High-Velocity Clouds. In the Local Group model (**right**), HVCs are distributed throughout the Local Group. The two galaxies are the Milky Way and Andromeda, and the dots are the HVCs. In the Galactic fountain model (**left**, enlarged section), supernova explosions drive hot gas out of the disk, where it cools and then falls back as HVCs.

SOURCE: NASA

Two teams of researchers (*8*, *9*) have recently revitalized the idea of extragalactic HVCs. They show that the clouds' distribution on the sky and their kinematics as an ensemble are consistent with a model in which HVCs are distributed throughout the Local Group (see the figure), at typical distances of a few million light-years. The authors suggest that, like galaxies, HVCs are dominated by dark matter, which provides the binding potential that keeps the clouds from falling apart; the only directly observable constituent, neutral hydrogen, forms an insignificant fraction of the total mass. In this scenario, the HVCs are either remnants from the formation of the Local Group or representatives of an intergalactic population of dark matter–dominated minihalos in which hydrogen has accumulated and remained stable on cosmological time scales (*10*).

A theoretical basis for this Local Group explanation is provided by hierarchical clustering scenarios that explain the formation of galaxies by many generations of mergers of smaller masses. Large numbers of protogalactic gas clouds might survive to the present day if the mergers are not fully efficient. However, only 10% of these predicted numbers of Local Group satellites have been identified as dwarf galaxies which contain both gas and stars (*10*). Are HVCs the missing Local Group satellites?

An alternative explanation for HVCs is provided by the Galactic fountain model. In this scenario, hot gas is blown out of the Milky Way's disk into the halo, where it condenses and eventually precipitates on the Galaxy as HVCs (see the figure). The Galactic fountain is driven by a sequence of supernova explosions in the Galaxy. In this scenario, the HVCs must be associated with the Milky Way and must be located at considerably smaller distances than in the Local Group model.

Current HVC research aims to discriminate between these two competing scenarios. The clouds' chemical composition can provide a clue to their origin. In the Galactic fountain model, the HVCs are produced in violent supernova explosions, in which many heavy elements are formed. Therefore, if this model is correct, the spectra of these clouds should show a high abundance of metals. In contrast, if the clouds are primordial remnants of the formation of the Local Group, they would not have been contaminated with heavy elements and would retain a composition closer to the pristine environment of the early universe.

Results to date have been confusing, with different teams reporting different measured compositions, even for the same cloud. Hubble Space Telescope spectra of one cloud, Complex C, yield a sulfur abundance 10 times lower than that of the gas layer of the Milky Way, suggesting a primordial origin. But very recent data from the Far Ultraviolet Spectroscopic Explorer (FUSE), which probed a different position in the same cloud, show an abundance of iron that is nearly that of the solar neighborhood (*11*). Furthermore, the FUSE observations show the first detection in an HVC of highly ionized oxygen (O^{5+}), probably produced in interactions between the HVC and the halo gas of the Galaxy.

To discriminate between the two HVC models, one can also look for HVC counterparts in other galaxy groups. If the Local Group model is correct, then similar extragalactic clouds should be observable in other galaxy groups. Existing astronomical surveys should show evidence for such a population. In fact, external galaxy groups are more suitable for studying HVC distributions, because their distance from the group center can be derived from the projected separation on the sky. Several extragalactic neutral hydrogen surveys have attempted to identify primordial gas clouds, but to date no gas cloud without associated stars has been found. For example, a blind survey carried out by the Arecibo Telescope had sufficient sensitivity and sky coverage to identify several dozens of clouds around galaxies and groups, but found none (*12*).

The current evidence points to HVCs being metal-enriched debris from intergalactic interactions and supernova explosions, rather than pristine, primordial relics. This leaves galaxy formation theorists to wonder where the satellites predicted by their cold dark matter simulations are (*10*). Do we know even less about the nature of this unseen matter than we thought we already knew?

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