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Observing Our Origins

Fred J. Ciesla

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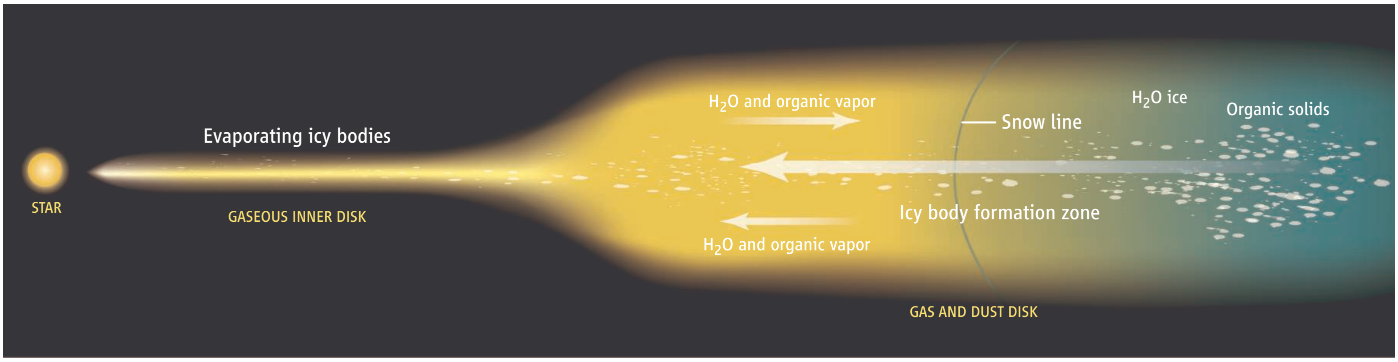
PLANETARY SCIENCE

Observing Our Origins

Infrared observations of water and organic materials will help astronomers determine how our solar system formed.

Fred J. Ciesla

Planetary systems are born around young stars and grow from vast clouds of dust and gas called protoplanetary disks. Models predict that as our own solar system's protoplanetary disk evolved, the dust and gas pushed each other around while constantly being stirred and jolted by magnetic fields and gravitational torques. The resulting mixing and motion set the chemical compositions of the planetesimals that formed and from which planets eventually grew. Although evidence for mixing is found in objects in our solar system, such as primitive meteorites, questions remain about the details of the processes responsible and whether this mixing was common in other protoplanetary disks. On page 1504 of this issue, Carr *et al.* (*1*) report observations of the disk around the star AA Tau that suggest that we will soon be able to address these questions.



Birthplace of the planets. The temperature of a protoplanetary disk decreases with distance from the star, so some compounds "freeze out" of the gas beyond a certain point in the disk. For example, water condenses to form water ice beyond the "snow line." Models predict that water ice boulders drifting into the warm inner region of the disk, where terrestrial planets are expected to form, supply this region with water vapor that would otherwise be lost. Organic compounds could be delivered in a similar manner. Carr *et al.* report signatures of these materials in the inner disk of the star AA Tau, providing observational support for such models. These processes may be responsible for the chemical and isotopic variations observed in the chondritic meteorites that formed within our own protoplanetary disk.

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The gas and solids in a protoplanetary disk drift inward with time, representing the final stages of growth for the star (*2*). On their journey inward, the solids collide with one another and stick together. From the time they grow from the submicrometer-sized grains originally inherited from the parent molecular cloud to the kilometer-sized bodies that eventually accrete to form planets, solids migrate inward slightly faster than the gas (*3*). As bodies drift into hotter regions of the disk, they vaporize, with the vapor then either continuing inward with the flow of disk material, albeit at a slower rate, or diffusing outward where it would freeze out at lower temperatures and be incorporated into other solids only to repeat the journey again (see the figure). The whole process acts as a chemical conveyer belt, delivering materials from one part of the disk to another, where they can accrete or undergo chemical reactions.

Models of this transport and cycling have largely focused on water, owing to its high abundance in the solar nebula (*4*). Initially, the influx of water ice to the warm inner nebula is predicted to have been large, leading to an increase in the relative abundance of water vapor in the gas phase. With time, the influx decreased as water was locked up in immobile planets and comets, allowing the vapor to be redistributed without being replenished, leading to a decrease in the abundance of water in the inner disk.

Because water is a major oxidizing agent, variations in its abundance would be recorded in the mineralogy of the rocks that formed in the solar nebula. Indeed, chondritic meteorites—relatively unaltered remnants from the solar nebula—contain minerals that formed in environments ranging from highly oxidizing (increased abundance of oxygen) to very reducing (depleted oxygen) (*5*). In addition, photochemical effects could enrich water with the heavy isotopes of oxygen, providing an explanation for the range of isotopic ratios seen in chondritic materials (*6*, *7*).

Although agreements of this type between the models and the chondrites hint that we are beginning to understand how our solar system formed, they are far from definitive. Alternate models have been proposed and have equal success in explaining the properties of chondritic materials. For example, Clayton (*8*) suggests that the differences in oxygen properties arise because chondritic materials formed at high temperatures near the Sun and were then tossed outward by strong jets. Identifying which of these models is correct is critical to furthering our understanding of how planetary systems form because it has implications on other issues, ranging from the origin of cometary grains to the manner by which giant planets form. Unfortunately, researchers have been unable to settle the debate by examining the chondrites alone.

This is what makes the results of Carr *et al.* so exciting. With data from the Spitzer Space Telescope, they identified spectral emission features of water and basic organic molecules from the gas in the disk around AA Tau within 3 AU (one AU or astronomical unit is the distance from Earth to the Sun) of the central star, approximately where the chondrites formed in our solar nebula. Carr *et al.* infer abundances greater than predicted in stagnant disks, suggesting a dynamically active disk where inward drifting, volatile-rich boulders replenish water and organic molecules. Water emis-

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sion features have also been reported for the disks around the stars MWC480 (*9*) and SVS 13 (*10*), although these studies only probed distances <0.3 AU from the central star. Interestingly, water appears to be depleted in SVS 13 relative to what is predicted in stagnant disk models (*10*). The variation of observed water abundances in these disks mirrors that which has been inferred for our own solar nebula.

To date, these observations do not distinguish which of the models developed for our solar nebula is correct but rather lend support to recent models for the dynamic evolution of water and other volatiles in protoplanetary disks. However, as the techniques used by Carr *et al*. are applied to other disks, correlations between their chemical compositions and their physical properties can be identified. Models for water evolution predict that the enhancement of water in inner disks should be followed by periods of depletions, so systematic variations with age are expected. Also, larger disks would provide more water ice to drift inward and thus would produce greater enhancements in the inner disk. Searching for such correlations will thus allow us to test models developed for our own solar nebula and determine whether it evolved in a similar way as other disks in our galaxy or if, instead, our planetary system is the result of one or multiple unique circumstances. Right now, these new results, combined with the discovery of high temperature grains in comets (*11*) and in the outer regions of protoplanetary disks (*12*), suggest that the manner by which our solar system formed may have been the rule.

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SYSTEMS BIOLOGY

Customized Signaling Circuits

Altering cellular behaviors can be achieved through a synthetic approach by refashioning signaling circuitry.

Peter M. Pryciak

For nearly three decades, cell biologists have labored to identify and dissect the elaborate intracellular signaling pathways that control cellular responses to external stimuli. The emerging field of "synthetic biology" now seeks to move beyond mere understanding of these existing biological systems, and to begin exploiting the acquired knowledge for new purposes such as creating custom-configured signal transduction pathways (*1*–*3*). Much as an engineer assembles new electronic circuits from a toolbox of preexisting parts, the study by Bashor *et al.* on page 1539 in this issue (*4*) modifies and reconnects components of a well-characterized cellular signaling pathway to reshape fundamental input-output processing behaviors such as temporal dynamics and dose response.

The system chosen for modification is the signaling pathway that responds to mating pheromones in the budding yeast *Saccharomyces cerevisiae*. Because this pathway has long been a model for eukaryotic signal transduction (*5*), the depth of knowledge and the ease of experimental manipulations make it an ideal system for testing new theories of pathway engineering.

In principle, two general strategies can be used to alter signaling circuitry: a bottom-up approach involving de novo design of proteins with new properties (e.g., new interactions, substrate specificities, or kinetic parameters), or a modular approach in which existing proteins are co-opted as parts to be connected in new ways. Bashor *et al.* follow the latter scheme, which exploits the modular property of many natural signaling proteins (*6*). At the core of this effort lies a "scaffold" protein called Ste5, which serves as an assembly platform for a series of sequentially acting enzymes (protein kinases) that propagate signals through the pathway (*7*). The role of scaffold proteins as central signal processing hubs makes them a natural choice as the framework upon which to

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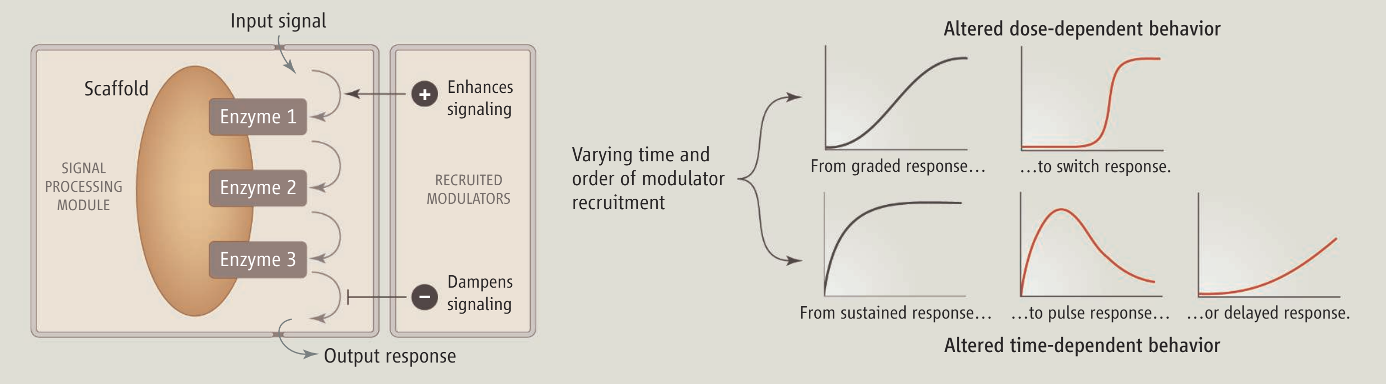

Changing behavior. The response of a cellular signaling pathway to a stimulus can be altered with positive and negative modulators. When such modulators are recruited to the scaffold protein in specific temporal sequences, through the use of feedback loops that control their expression and competitor recruitment sites that act as binding sinks, the time or dose dependence of the signaling response can be adjusted to adopt a variety of useful circuit behaviors.

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