can be viewed at two levels. First, it will help to elucidate gene function on a global scale. For those proteins that are conserved during evolution, interactions between two worm proteins may clear the way to finding homologous interactions in mammals. For example, some of the new worm proteins that interact with the Rb complex are conserved, and their homologs might also be part of the Rb complex in mammals. Second, along with all of the other functional genomics projects in *C. elegans*, the protein interaction map will serve as a "model of models" to establish the experimental logic and techniques that will need to be developed to interpret the overwhelming amount of data generated by genome sequencing. If genomes are like books, then all of the words (19,293 genes) in the worm book are already known, and their definitions should soon be clarified by functional genomics. The grammar used to construct genetic pathways is simpler in worms than in mammals because there are fewer words, fewer synonyms and simpler sentence structures in the worm genome (that is, fewer genes, less genetic redundancy and fewer feedback loops). Thus, to learn how to read the book of an organism's genome, it makes sense to start with the worm.

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PERSPECTIVES: PLANETARY SCIENCE

Charon's First Detailed Spectra Hold Many Surprises

Eliot Young

Pluto and its satellite Charon are the two brightest members of the Kuiper Belt, that no-longer exclusive club of objects orbiting the sun beyond the orbit of Neptune (*1*). The Pluto-Charon system is expected to be a fairly pristine reservoir of the outer solar system's volatile materials, although some processing does occur: ultraviolet (UV) photolysis, charged particle bombardment, impacts by meteorites or comets, and (in the case of Pluto) wholesale resurfacing through periodic condensation and sublimation of frosts. But Pluto and Charon continue to surprise us at every turn, and the most recent spectra of Charon on page 107 of this issue by Brown and Calvin (*2*) are no exception.

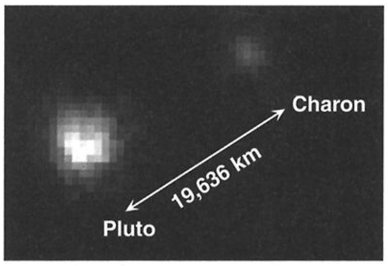
Pluto and Charon are not particularly large (with radii of about 2370 and 1252 km, respectively) and are separated by only 19,636 km (one and a half times Earth's circumference) (*3*). Up until last year, the only spectrum of Charon had been obtained over 10 years ago by exploiting a serendipitous orbital geometry. Throughout 1987 and 1988, Charon could be observed from Earth, passing in front or behind Pluto's disk every 6.38 days (Charon's orbital period). A spectrum of Pluto by itself, obtained when Charon was hidden behind Pluto's disk, was subtracted from the combined Pluto-Charon spectrum. The difference yielded a Charon spectrum at sufficient resolution to show a surface dominated by H_2O ice (*4*).

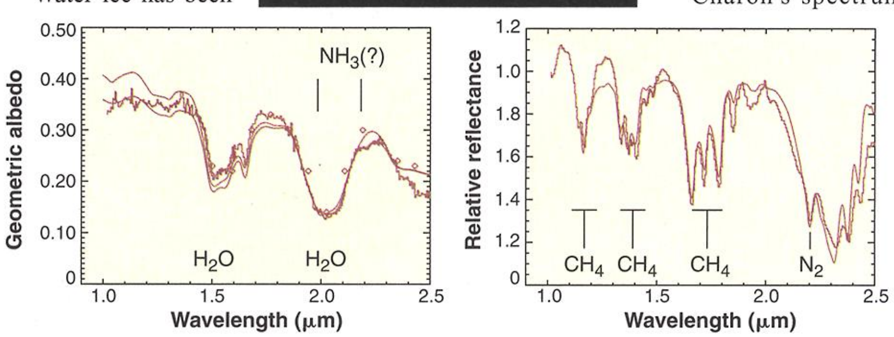
A surface spectrum dominated by water came as a surprise, because nearby Pluto's spectrum is dominated by methane, CO, and N_2 frosts (see the figure). The current consensus is that Charon has lost the relatively volatile N_2, CO, and CH_4 frosts because of its lower escape velocity, leaving water ice (which is about as volatile on Charon as a rock is in your backyard) behind.

Fast forward 10 years to September 1999, when three groups presented distinct Charon spectra at a workshop held at Lowell Observatory in Flagstaff, AZ (*5*). Two of these were obtained with the Near Infrared Camera and Multi Object Spectrometer (NICMOS), an infrared spectrometer on the Hubble Space Telescope, and the third was obtained with the Keck telescope on a particularly calm night (*2*). All three spectra confirm that Charon's spectrum looks like water ice; furthermore, they show that the ice is in a crystalline (as opposed to amorphous) state. This is the second surprise.

Water ice has been found on satellites of Jupiter, Saturn, and Uranus, and it is always crystalline. This is not surprising, because amorphous ice will rapidly crystallize if the temperature is ~120 K or higher (*6*); indeed, the phase transition from amorphous to crystalline is exothermic. But on Charon, where the surface temperature due to the heat from the sun will never exceed 80 K (and is probably tens of degrees colder), the phase transition should not take place. Instead, crystalline ice should gradually become amorphous under the constant bombardment of UV photons and fast protons. This radiation breaks hydrogen bonds in the ice that subsequently reform, but not in their original crystalline positions. The presence of crystalline ice on Charon may mean that Charon's surface is fresh (for example, resulting from recent deposition of H_2O via comets) or that it was recently hotter than the expected temperature range of 35 to 80 K. Alternatively, some process we have so far failed to consider is converting amorphous to crystalline ice. Its presence raises two questions for future observations: Is there any amorphous ice on Charon? And if not, is there any amorphous ice anywhere in the solar system (such as on the cold surfaces of other Kuiper Belt objects)?

Charon's spectrum





Charon reveals its secrets. This image of the Pluto-Charon binary (**top**) was taken in 1994 with the Faint Object Camera on the Hubble Space Telescope. N_2, CH_4, CO, and H_2O have been identified on Pluto (**bottom right**) and crystalline H_2O (and now possibly NH_3) on Charon (**bottom left**).

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fits that of crystalline water ice, although at 2.2 μm, it is a bit darker than that of pure ice. Brown and Calvin suggest that NH_3 or ammonia hydrates on Charon's surface can account for this discrepancy (see the figure). NH_3 and ammonia hydrate compounds do have absorption features at 2.2 μm. They also have absorption bands just below 2.0 μm, where Charon's fit to a water-ice spectrum is much better than at 2.2 μm. But the 2.0-μm feature of ammonia and its hydrate lies near the bottom of an absorption band of water ice, and the NH_3 absorption may thus be masked by the H_2O absorption. (Dark impurities have their strongest effect on a spectrum in a bright substrate, as in the case of a little street dirt darkening a roadside snowbank.)

The presence of ammonia and ammonia hydrates, which form if the NH_3 molecules lie within an H_2O matrix, can lower the melting temperature of H_2O ice dramatically (by around 100 K), making water ice more ductile and therefore more interesting from a geological standpoint. And because NH_3 represents a form of fixed nitrogen, it is potentially significant in the context of astrobiology and the formation of amino acid precursors.

One might expect NH_3 to be ubiquitous throughout the solar system. After all, methane and water (the fully hydrogenated versions of carbon and oxygen) are found nearly everywhere, so why not NH_3? The answer is that the formation and survival of NH_3 within the solar nebula are problematic, because it is only stable at very low temperatures but requires high temperatures (and high pressures) for its initial creation within the solar nebula (*7*). In addition, NH_3 is destroyed by some of the volatiles (such as CO_2) found elsewhere in the solar system. UV radiation will also destroy NH_3, forming hydrazine (N_2H_4) and then N_2 from the NH_2 radical. Aside from the atmospheres of the gas giants, where there is sufficient mixing with a large store of H atoms to recycle much of the NH_2 back to ammonia, the exploration of the solar system has thus far turned up no ammonia, with the notable exception of interstellar NH_3 found in comets (*8*).

The presence of NH_3 on Charon, if confirmed by further observations, thus represents the third surprise. Its presence would imply that comets have delivered interstellar volatiles to Charon, that NH_3 somehow survived on Charon but not on Pluto, and, most importantly, that NH_3 can survive on the surfaces of solid objects in the solar system. Perhaps we just needed to find an object that was cold enough. After decades of searching the solar system in vain, can we expect to find ammonia throughout the Kuiper Belt?

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NOTA BENE: AGING

Sensing Old Age

We humans sense old age through feeling those creaky joints or observing those graying hairs but, according to Apfeld and Kenyon reporting in a recent issue of *Nature* (*1*), the nematode worm senses its age by smelling and tasting the environment. These investigators show that worms with defective olfactory organs (that would normally detect odor molecules in the environment) live longer than their comrades with a keener sense of smell. By comparing these worms with other mutant nematodes that live an unusually long time, the researchers found clues to how a reduced ability to "smell the roses" might lengthen life-span.

The worm's olfactory sense organs—amphids on the head and phasmids on the tail—are composed of a cluster of nerve cells, the ends of which are modified into cilia. The cilia are encircled by a sheath and a socket cell that form a pore in the worm's skin through which the tips of the cilia protrude (see photograph). Odor molecules and soluble compounds bind to G protein–coupled receptors (similar to the olfactory and taste receptors of mammals) located at the tip of each cilium. Worms with a poor sense of smell—because their olfactory organs have defective or absent cilia, blocked pores, or damaged sheaths—live much longer, yet are otherwise normal (for example, their feeding and reproductive behaviors are unchanged). Mutations in TAX-4—a channel regulated by cyclic GMP that sits under the G protein–coupled receptor and transduces the sensory signals into electrical impulses—also imbue the worm with a longer life.

But mutations in the worm's olfactory machinery are not the only defects that extend its life-span. In an earlier study, Kenyon's group found that defects in the reproductive system could prolong life by decreasing the activity of DAF-2 (a receptor for an insulin-like molecule) and increasing the activity of DAF-16 (a transcription factor). By looking at worms defective in both sensory perception and reproduction, Apfeld and Kenyon worked out a putative pathway through which smell might influence a worm's longevity.

An environmental signal, perhaps produced by bacteria (the worm's favorite food), binds to G protein–coupled olfactory receptors on sensory cilia activating TAX-4, which then incites electrical activity in the sensory neurons. This activity triggers secretory vesicles in the neurons to release insulin-like molecules, which bind to DAF-2 and activate the insulin-like signaling pathway. This then switches on genes that will ensure the worm dies at the usual age (2 weeks). A reduced ability to sense olfactory cues would result in a decrease in DAF-2 activation and an increase in life-span.

This chain of events is not proven, but insulin-like molecules that might bind to DAF-2 have been identified in the nematode. Such a pathway would also make physiological sense. After all, if food is scarce it may behoove the worm to live longer to ensure that it has the chance to produce its full quota of offspring. A scarcity of food also promotes longevity in rodents and primates (and perhaps people). But so far it seems that in these more complicated creatures a poor sense of smell is not a harbinger of a ripe old age.

—ORLA SMITH

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CREDIT: CORI BARGMANN