In Quest of Comet Halley

Somewhere between the orbits of Uranus and Saturn, still more than a billion kilometers out, a mountain-sized fragment of ice and rock is falling toward the sun. It will not arrive here in the inner solar system until 1985, but already astronomers are searching the skies near the bright star Procyon in the constellation Canis Minor, watching for Comet Halley to reappear.

"Halley is not an easy object," says Michael J. S. Belton of Kitt Peak National Observatory. "It is very faint [about magnitude 25 or 26], it lies almost in the galactic plane [where background stars are very dense],

and it is moving very fast. On the other hand, we know where it is to within 10 seconds of arc."

Belton, a planetary astronomer, has recently been collaborating in a search for Halley's comet with Kitt Peak's Harvey Butcher, a quasar specialist experienced in the search for very faint objects.

"Of course we'd like to be the first to find it, but that doesn't get us telescope time," says Belton. "We want to see it as far away as possible so we can maximize our ability to study the nucleus. That's never been done before for any comet."

In a sense, the nucleus *is* the comet. It is the solid core, the source of all the dust and ionized gas that boil off during its passage near the sun to form the spectacular head and tail. Comet nuclei are thought to be kilometer-sized chunks of ice and rock—"dirty snowballs"—but no one really knows for sure because the surrounding vapors have always hidden the nuclei from view.

A number of people have guessed at what Halley's nucleus might be like, however, based on observations of the comet's brightness and activity during the 1910 appearance. One model predicts that Halley should already have reached magnitude 24, says Belton. This would make it just barely detectable with a large telescope. So last year he and Butcher decided to put in for time on the Kitt Peak 4-meter instrument. First there was the question of when to look. Some nights Halley passes too close to background stars, says Belton. Some nights the sky is swamped by moonlight and on some nights Canis Minor is below the horizon. "It turns out that for only three nights last year was there a strong case for big telescope time." One of the best, as it happened, was Christmas night 1981. "The telescope was closed that night!" says Belton. The astronomers were, however, able to get time on the night of 2 to 3 December 1981. Result: no Halley.

Though disappointing, this allowed them to put a lower limit of 24.3 on Halley's magnitude, Belton told *Science*, which means that its diameter is probably less than 4 kilometers. Four kilometers of ice would mass 34 billion metric tons.

Belton and Butcher have hardly given up their quest. "If Halley is as bright as I think it is, we'll certainly see it next year," says Belton. "If it's as faint as it could be, we won't see it until November 1985."

The advent of Halley has triggered tremendous surge of interest in comets in the planetary science community, Belton says. "People are planning their research way ahead of time instead of rushing to it when they see a new comet in the sky."

Much of the interest centers on the ultraviolet. "Lyman-α [the Lyman-α line of atomic hydrogen] tells you about water emission from the nucleus," he says. The rate of emission will allow scientists to estimate the surface area of the nucleus and thus its size.

Belton and others are negotiating with NASA about OSS-3, a package of ultraviolet telescopes now scheduled for a flight on the space shuttle in the spring of 1985. That flight will be devoted purely to extragalactic astronomy. The solar system scientists want to refly the instruments in November 1985 to watch Halley on its way in, then fly them a third time in March 1986 to observe the comet during the encounters of the European, Soviet, and Japanese spacecraft. Of lowest priority is a final flight of the package to look at Halley on its way back out. "The people at headquarters are very favorable to the idea," says Belton.

The Origin of the Moon

Efforts to understand the origin of the moon are constrained by this fundamental fact: unlike any of the other bodies in the inner solar system—Mercury, Venus, Mars, and Earth—the moon has little or no iron in its core. It consists almost entirely of rock.

Theorists are divided as to why. One possibility is that the moon formed out of material that was deficient in iron. The problem is that none of the other inner planets managed it. Besides, the typical planet-forming materials in the presolar nebula, the chunks and shards of solid stuff represented today by primitive meteorites, were quite rich in iron.

Another possibility, according to Michael J. Drake of the University of Arizona's Lunar and Planetary Laboratory, is that the moon's complement of iron is now in the core of the earth—in other words, that the moon was ripped out of the earth's rocky, iron-poor mantle after the iron fell to the center.

This is hardly a new idea, he says. Charles Darwin suggested more than a century ago that the outbound moon left a scar which is now filled by the Pacific Ocean. More recently, A. Edward Ringwood of the Australian National University and, independently, Alastair G. W. Cameron of Harvard University have suggested a modern version: very early on, while the earth was still molten, the stuff that was to become the moon was blasted out of the surface by collision with another large body.

This approach has its own problems, notably the question of how such a satellite could have settled into the near circular orbit enjoyed by the moon today. But at least the hypothesis is testable, says Drake. If it is true, a geochemist analyzing the mantle-rocks of the moon and the mantle-

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rocks of the earth should find that they are the same. He and his colleagues, along with many other planetary scientists around the world, are trying to do just that. But it is not as straightforward as it might seem.

"How do you get at these rocks?" Drake asks. For the moon, paradoxically, this is not such a problem. Geologically, the moon is almost inert. Basaltic samples collected by the Apollo astronauts presumably erupted from the interior billions of years ago, and have remained chemically undisturbed ever since. Trace elements such as iridium or potassium are diagnostic of how a given sample was melted and fractionated during its upward trip, Drake says, "so if we're smart, we should be able to work back from these samples to the composition of the mantle."

In principle, the same thing could be done with earthly basalts. But the earth is an active planet, Drake points out. Its surface is in constant motion, and the underlying mantle does not necessarily have the composition it had 4.6 billion years ago when the planet formed. "So now we have another detective story," he says—reconstructing the primordial mantle of the earth.

"We're especially looking at the siderophile [iron-loving] elements," says Drake. These are elements such as platinum, gold, and iridium that followed iron to the earth's core when it was molten. "We need to know how the siderophiles partitioned between the solid and liquid iron phases and the solid and liquid silicate [rock] phases," he says. "There's no theory, so we melt rocks in the laboratory and do simulations."

The work is slow. Individually and in combinations, the trace elements must be combined with a wide range of minerals and tested over a wide range of temperatures. Already, however, Drake believes he and his coworkers have enough data to shed some light on how the earth formed.

Some people have argued that the core and the mantle formed first, says Drake. As accretion continued, a veneer of undifferentiated material was then plastered on the outside, mixing only with the upper mantle. The basis of this argument is that the siderophiles seem too abundant in the upper mantle and crust. If the earth had started out as one molten blob, more of these elements should have gone to the core.

"But people forget that the partitioning between solid and liquid phases has a profound effect on the way siderophiles distribute in the earth," he says. "Once you take this into account, the abundances are consistent with a simpler model. Our idea is that the accretion of the earth [from smaller bodies in the solar nebula] took place over about 100 million years, with the iron melting and falling to the core continuously throughout that time. Chemical kinetics suggests, however, that the differentiation would be far from perfect. So some of the iron, and some of the siderophiles, stayed near the surface.

"We're not yet in a position to say if the moon came from the earth," he adds. "But we recently presented a strategy document to NASA saying that with lots of work and lots of people, we [the planetary science community] could have the answer in 10 years."

Dreams of Preplanetary Fire

In the beginning, 4.6 billion years ago, there was the nebula: a disk of gas and dust from which condensed the sun and all the planets. Before that, parent to the nebula, there were interstellar clouds thick with silicate and iron-rich dust grains that had been strewed across the galaxy by exploding stars called supernovas. As the solar nebula collapsed these solid grains were mostly swept up into the primordial earth and the other newformed planets. But a few remain today in meteorites, clues to the thermal history of the solar system.

"From my work it's clear that there were very high temperatures in at least some parts of the nebula," says William V. Boynton of the University of Arizona's Lunar and Planetary Laboratory. "The problem is that there is no reasonable way to get such high temperatures. The nebula took so long to collapse that the heat should have just radiated away."

This is not a small problem; the temperature profile of the nebula 4.6 billion years ago is a key to understanding the planets today. The inner solar system is populated by dense, solid planets because the only miner- als that could survive so near th were iron and silicate rock. In th outer reaches more volatile r als were available, however, s moons of Jupiter and Saturn are ly mantled in ice.

"I tackle the problem by lc at carbonaceous chondrites," Boynton. These are rare, very tive meteorites that have en without change since the solar s formed. "A lot of the advances field stem from the favorable c of the Allende fall [a carbona chondrite that fell near the vill Allende, Mexico, in 1969], just time lots of scientists were gear for analyzing the Apollo sa There were hundreds of pounds material around, and it was pick quickly, before it was contam and weathered."

Of particular interest in Allen the centimeter-sized inclusio very refractory, calcium- and num-rich minerals. These we first grains to condense, B says, and it is here that isotopi have been found that a nearby nova injected material into the just before it started to collaps

Boynton, however, is studyi isotopes but trace elements, p larly the lanthanide rare ear group that has already been u study both terrestrial and luna ples. Chemically, these eleme very similar. Except for eur which is something of a ma they are distinguished only by size, which decreases smooth increasing atomic number.

"But vapor pressure is not a s function of size," Boynton says you find an anomaly in any e except europium, you kno something went on to partially ize (or partially condense) th ment."

And that is exactly what he Many of the individual inclusi Allende have deviant patterns earth abundances. There is r they could have acquired su terns before the solar system f Boynton says. An interstellar c a very cold environment. All t earths would have condensed "So something happened af solar nebula collapsed to vapo stuff and condense it all over Boynton says. The job now is t out exactly what that somethin

—M. Mitchell Wa