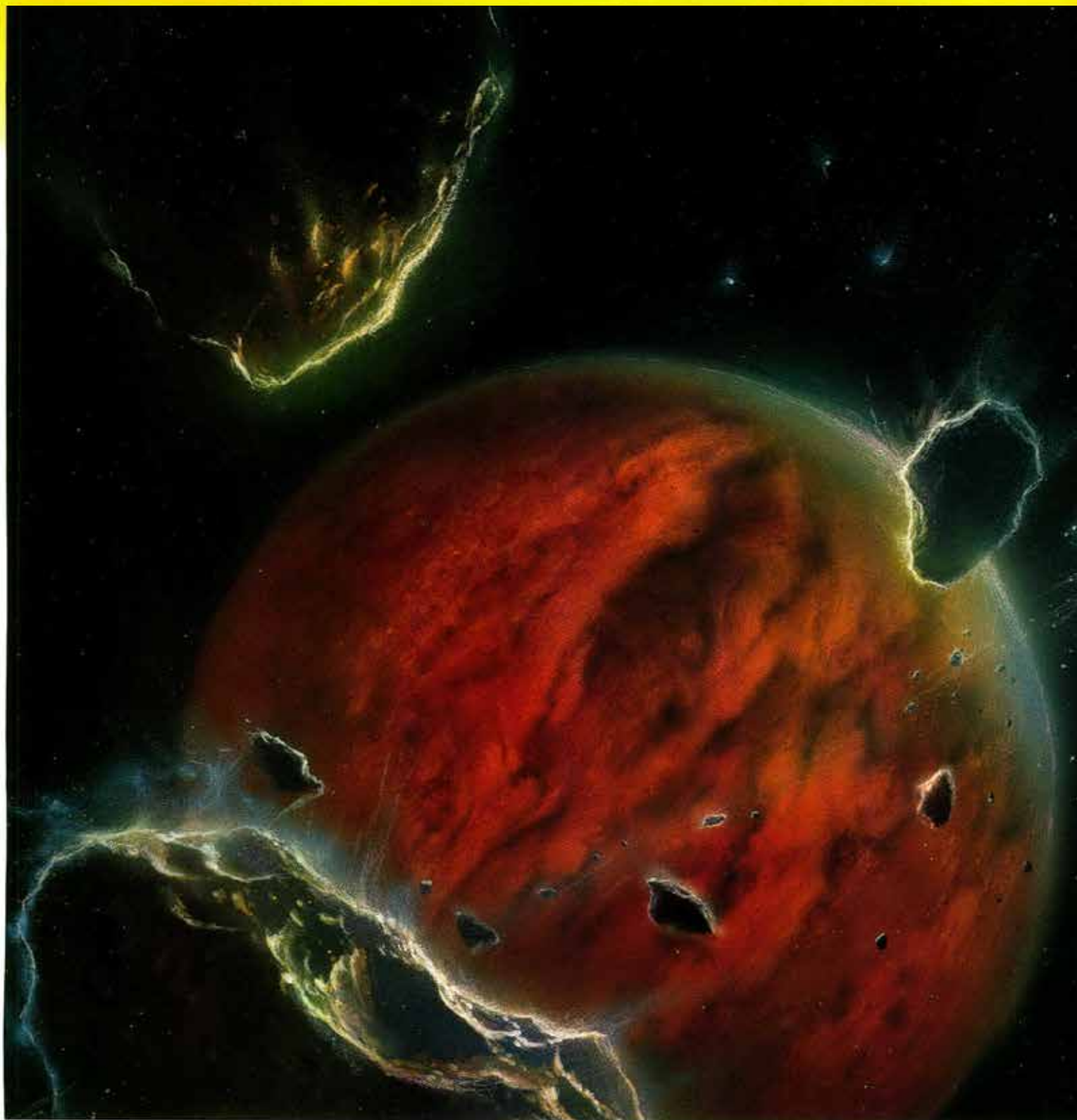


# Seeking Rog



# ue Comets

**We know  
interstellar  
comets exist,  
but astronomers  
have never seen  
one — yet.**

by S. Alan Stern

**R**emember those old, silent Keystone Cops movies of a busy 1920s downtown intersection, brimming with cars, kids, cops, and robbers, but without a single traffic light in sight? Confusion abounded. Collisions were common. Chaos reigned. That's the image that comes to mind when I picture our solar system's early days, 4.5 billion years ago.

Over the past 40 years, careful studies of meteorites, lunar samples, and planetary surfaces, along with increasingly sophisticated computer models, have led the planetary science community to converge on a fairly consistent picture of how planets are built. And the truth is it's an inefficient and messy business.

The process tosses tremendous amounts of debris out of the solar system into the galactic disk, including trillions of comets. If solar systems like ours are common, then with billions of stars ejecting trillions of comets into the Galaxy, there must be huge numbers of comets roaming interstellar space.

In the shell of space between here and Alpha Centauri — the nearest star system — there may be as many as 50 trillion rogue comets, ejected from as many as 100 billion galactic planetary systems, each silently coursing its way through eons of interstellar night. Stored at temperatures only a few degrees above absolute zero, these comets contain a treasure trove of information about the formation of planetary systems across the Milky Way. The effort to find these denizens of deep interstellar space could begin before the decade is out.

### **Throwing Their Weight Around**

One of the most interesting phases of planet building comes late in the game. Protoplanets larger than Earth have already formed. At this size, they begin to throw their weight (OK, actually their mass) around, their gravity begins to significantly stir the paths of objects in nearby orbits. This process is called gravitational scattering, and it has two profound effects. First, it increases the growth rate of the protoplanets,

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## When Oort Clouds Mingle: An Interstellar Comet Shower

Comets roam interstellar space unattached to other stars. However, comets don't have to be free of their parent stars to pass through our solar system. Oort Clouds, the shells of comets that surround stars, can intermingle.

Oort Clouds can be pictured as little bubbles in space, full of comets, with a diameter of roughly 20,000 AU, about 1/3 of a light-year. Whenever two stars with Oort Clouds pass within 20,000 AU of each other, their comet clouds temporarily intersect. Such encounters last about

3,000 years on average.

If half the stars in the Milky Way have Oort Clouds like our own, then about 500 encounters with foreign Oort Clouds have occurred over the age of the solar system. That's about one every 10 million years, on average. Of course, Oort Clouds may not exist around half of all stars, so these kinds of events could be much rarer. But if even one star in 1,000 has an Oort Cloud, then our solar system should have seen at least one comet shower from another sun.

During each encounter, up to 1,000 comets from the intruder Oort Cloud could be passing within 10 AU of the Sun at any given time, about 30 of which would be close enough to exhibit tails. Amateur astronomers would walk around like insomniacs from staying up late and looking at 30 comets every night. The odds of Earth being hit by any of these comets, however, are minuscule; only about one comet should hit Earth for every 300 intruder Oort Clouds that pass through our solar system.

because the rate at which they collide with smaller bodies increases. Second, it also begins to dramatically affect the orbits of bodies coming close to, but not colliding with these objects.

It's just this action that generates the Keystone Cops scenes. As you can imagine, small bodies, ranging in size from rocks to Manhattans, become corks adrift in a rather rough sea. With many protoplanets growing at once, these small bodies become billiard balls careening among the protoplanets.

### In the shell of space between here and Alpha Centauri there may be as many as 50 trillion interstellar rogue comets.

In the case of giant planets like Jupiter and Saturn, their gravitational effects are so strong that objects passing near them are frequently ejected into interstellar space. (This still occasionally happens today when a comet comes close to one of these behemoths). Of course, not all objects are ejected. Some, like Comet Shoemaker-Levy 9, actually do strike planets and help them grow. Others are scattered inward, closer to the Sun, where it's much harder for them to escape. Still others are not ejected because they don't quite get enough boost; these planetesimals end up in long, lonely orbits that can reach to distances as great as tens of thousands of astronomical units (AU) from the

Sun. This process is the one that populated the Sun's Oort Cloud with the icy planetesimals we call comets.

Scott Tremaine of the Canadian Institute for Theoretical Astronomy has recently shown that Jupiter and Saturn were so massive they tended to eject most of the planetesimals that came close to them. However, he also found that less massive Uranus and Neptune threw a much greater fraction of the planetesimals in their region of the solar system into the Oort Cloud, rather than onto one-way trips to galactic exile.

Other studies, by Wing Ip of the Max-Planck-Institute in Germany and Julio Fernández of the University of Montevideo in Uruguay, indicate that Jupiter and Saturn probably ejected about 10 objects from the solar system for every one they scattered to the Oort Cloud. But Uranus and Neptune only ejected one object for every two or three they injected into the cloud. Overall, the process of building the giant planets in our solar system is estimated to have injected several trillion (i.e., up to  $3 \times 10^{12}$ ) planetesimals into the Oort cloud, and between 10 and 100 trillion planetesimals into interstellar space. This planet-building stuff really is a messy business!

Put another way, our solar system alone ejected so many objects into the Galaxy that the number (but certainly not the mass) of comets in the Milky Way vastly exceeds the number of stars. If solar systems like our own are common, then this scenario has repeated itself billions of times, and the population of interstellar comets is impressive indeed.

#### Life in the Interstellar Outback

What is life like for interstellar comets? It isn't very exciting. They are subject to an eternal deep freeze that for all practical purposes puts them in permanent and very effective long-term cold storage.

The main heat sources are the cosmic microwave



background (a 3° bath from the Big Bang) and plain old starlight from the dark interstellar sky. Together, these two feeble radiations aren't likely to warm comets much above 5° or 6° C above absolute zero. At these cryogenic temperatures, chemical reactions are so slow as to be effectively nonexistent, and none of the common cometary surface ices that turn into gas when heated in the planetary region, like water, carbon monoxide, nitrogen, and methane, show any activity. You might say deep interstellar space makes a very nice morgue, preserving our friendly comets for all eternity.

Well, not quite. Research in the last decade or so has revealed that a few types of very subtle changes can occur on the surfaces of interstellar comets. The first breakthrough came when Bob Johnson at the University of Virginia, Lou Lanzerotti of Bell Labs, and their co-workers showed that cosmic rays and ultraviolet radiation from distant stars will penetrate the upper surface layers to a depth of perhaps a meter or two, driving out lightweight volatile molecules and creating micro-flaws in ice crystals. These kinds of radiation damage may darken and perhaps redden the icy cometary surfaces over billions of years.

A few years later, work I did with Mike Shull of the University of Colorado showed that two other effects are also important. First, passing hot and massive O type and B type stars, and nearby supernovae explosions, will occasionally heat interstellar comets to comparatively balmy temperatures — perhaps 30° C above absolute zero (that's still about -440° F). At these very cold temperatures, which are ten times what interstellar comets normally experience, it's possible for noble gases and a few molecules like nitrogen and carbon monoxide to leak out of the surface layers.

More importantly, we also found that micro-impacts from smoke-sized interstellar grain particles will erode the surfaces of interstellar comets, perhaps removing their outer, radiation-damaged rind. But that's it. It's like the Middle Ages in Europe — only worse: *Time goes by, but nothing ever changes.*

### The Number of the Beasties

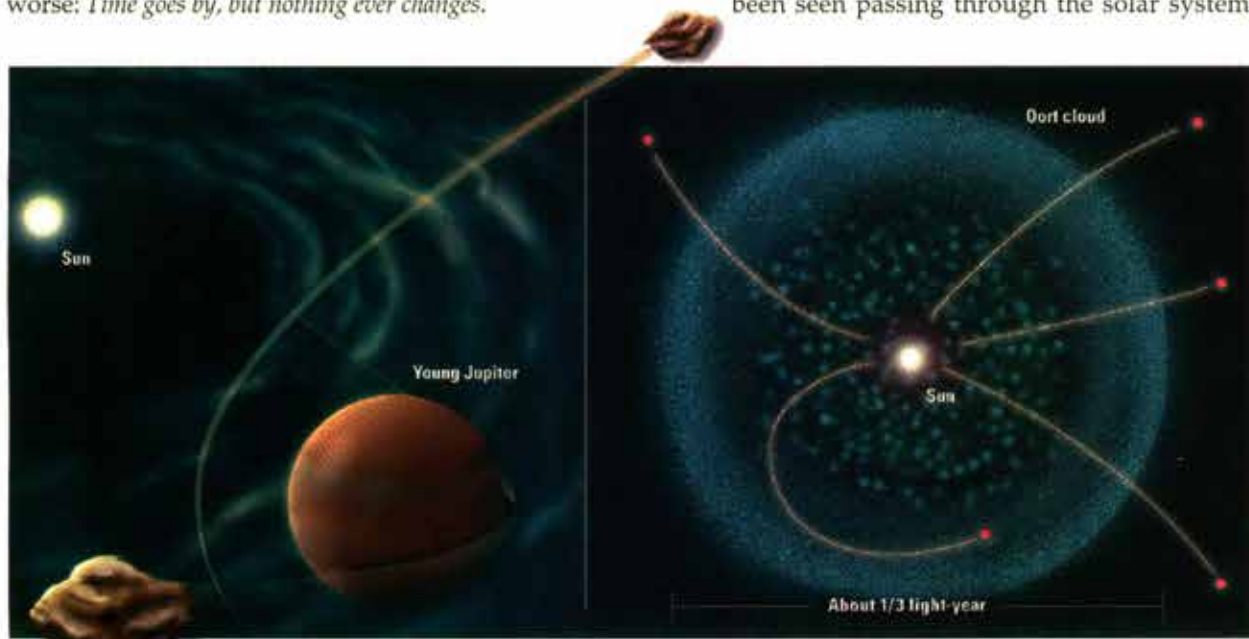
The wonderful thing about interstellar comets is that they are a direct product of giant planet formation. According to what we now know, if you form giant planets, you eject a lot of interstellar comets. The number of interstellar comets produced per solar sys-

**Deep interstellar space makes a very nice morgue, preserving our friendly comets for all eternity.**

tem depends strongly on the spacing and masses of the giant planets, the mass of the disks from which the planets formed, the race between the rate at which giant planets form and begin to eject comets, and the length of time the disk-like planetary nebula retains its gas. Still, it's an exciting prospect to think that by measuring the population of nearby interstellar comets we can get information on the total number of solar systems in the Milky Way's disk that have giant planets.

But exactly how many interstellar comets should one expect in the Milky Way? There are two ways to get a rough handle on the size of this population. First, one could suppose all 200 billion stars in the Milky Way have formed Oort Clouds just like our own, each star ejecting some 30 trillion or so planetesimals. That would imply a population of roughly  $6 \times 10^{24}$  interstellar comets (that's 6 trillion trillion of the beasties, with a total mass of about 170 million Suns).

To get a second estimate on the number of comets, one can use the fact that no interstellar comet has ever been seen passing through the solar system.



Astronomer: Phil Kirchmeier



This gives astronomers an upper limit on their concentration in space. From this, Zdenek Sekanina of the Jet Propulsion Lab calculated that on average, there is no more than one interstellar comet for every 1,500 cubic astronomical units of space near the Sun. We can use this number to crudely estimate the upper limit by multiplying the concentration of comets ( $1/1500$ , or 0.00068 per cubic AU) and the volume of the galaxy (about 200 billion cubic parsecs, or  $1.5 \times 10^{27}$  cubic AU), which gives one trillion trillion ( $10^{24}$ ) comets.

It's surprising that these two estimates are in rough agreement. It means that the observational data don't tell us very much about the population of interstellar comets. As much as 20 percent of the stars in the Galaxy could have produced Jupiter- and Saturn-mass planets and we still wouldn't have run across an interstellar comet in our normal comet hunting.

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## It could take 1,500 years at the present rate of comet discovery to find an interstellar comet.

But don't take that 20 percent number to the bank. Our solar system might have ejected an unusually large number of planetesimals, in which case the existing constraints on the interstellar comet population could be consistent with jovian planets around every star in the whole Galaxy. Simply put, we just don't know enough to know — we must go and look.

### Visitors from Another Pond

Interstellar comets would be easily distinguishable from solar system comets because they will pass through the solar system with, on average, the same speed that the Sun is making against the local stars. That's about 20 to 30 kilometers per second, compared to 10 km per second for comets from our own Oort Cloud. Because of their high velocity, interstellar comets follow a hyperbolic trajectory, unlike the parabolic trajectory coursed by solar system comets such as Hale-Bopp. The hyperbolic velocity of 20 to 30 kilometers per second would make an unmistakable John Hancock for interstellar comet confirmation.

Comet hunters regularly detect comets from our Oort Cloud, but after 250 years of comet hunting, no comet with a clearly interstellar orbit has been found. Tom McGlynn and Bob Chapman of NASA's Goddard Space Flight Center have estimated that it could take 1,500 years at the present rate of comet discovery to find an interstellar comet, or to prove they are rare. We can do far better if we try an active search.

How would one conduct a search for interstellar comets? With a little ingenuity. As noted earlier, the best upper limit on the space density of interstellar



comets is about one per 1,500 cubic AU. That means that the mean distance between interstellar comets in the Milky Way could be as little as 11 AU. It might even be a little higher near the Sun, because the Sun's gravity will attract them toward our direction. That's about the distance from the Sun to Saturn, which means that at any time (such as now) there should be one interstellar comet somewhere in the shell of space around the Sun as defined by Saturn's orbit.

At a distance of 11 AU from the Sun a comet like Hale-Bopp would be inactive, and therefore would be a dark nucleus reflecting the diluted light of the distant Sun. As seen from Earth, it would have a visual magnitude between 22 and 25. This is faint, but not too faint to discourage us; most of the recently-discovered Kuiper Disk objects have magnitudes this faint.



Bob Eggleston

But where to search? Scouring the entire sky to 24th or 25th magnitude is a little much to ask. Fortunately we know something about where the needles are in this haystack. Interstellar comets will come from the apex of motion in the direction the Sun is moving in space, toward Hercules. It's a little like a meteor shower radiant, except for the fact that the so-called "meteors" are comets, and they will appear at the rate of perhaps one every few years. By searching a 1 degree-wide-strip about 45 degrees in radius centered on the apex of solar motion about once a week, one can ensure that no interstellar comet will slip by. Candidate objects can be followed up with subsequent observations after they pass through the detection strip in order to confirm whether or not they are in fact on hyperbolic trajectories from interstellar space.

With a search strategy like this, astronomers could double the present-day interstellar comet detection limit after about 18 months. After 10 years, a ten-fold improvement could be achieved. By that time, it's possible, maybe even probable, that a real, bona fide interstellar would have been bagged, giving us not only a chance to study a comet from another solar system, but also some solid evidence about the galaxy-wide frequency of solar systems with giant planets like our own. □

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