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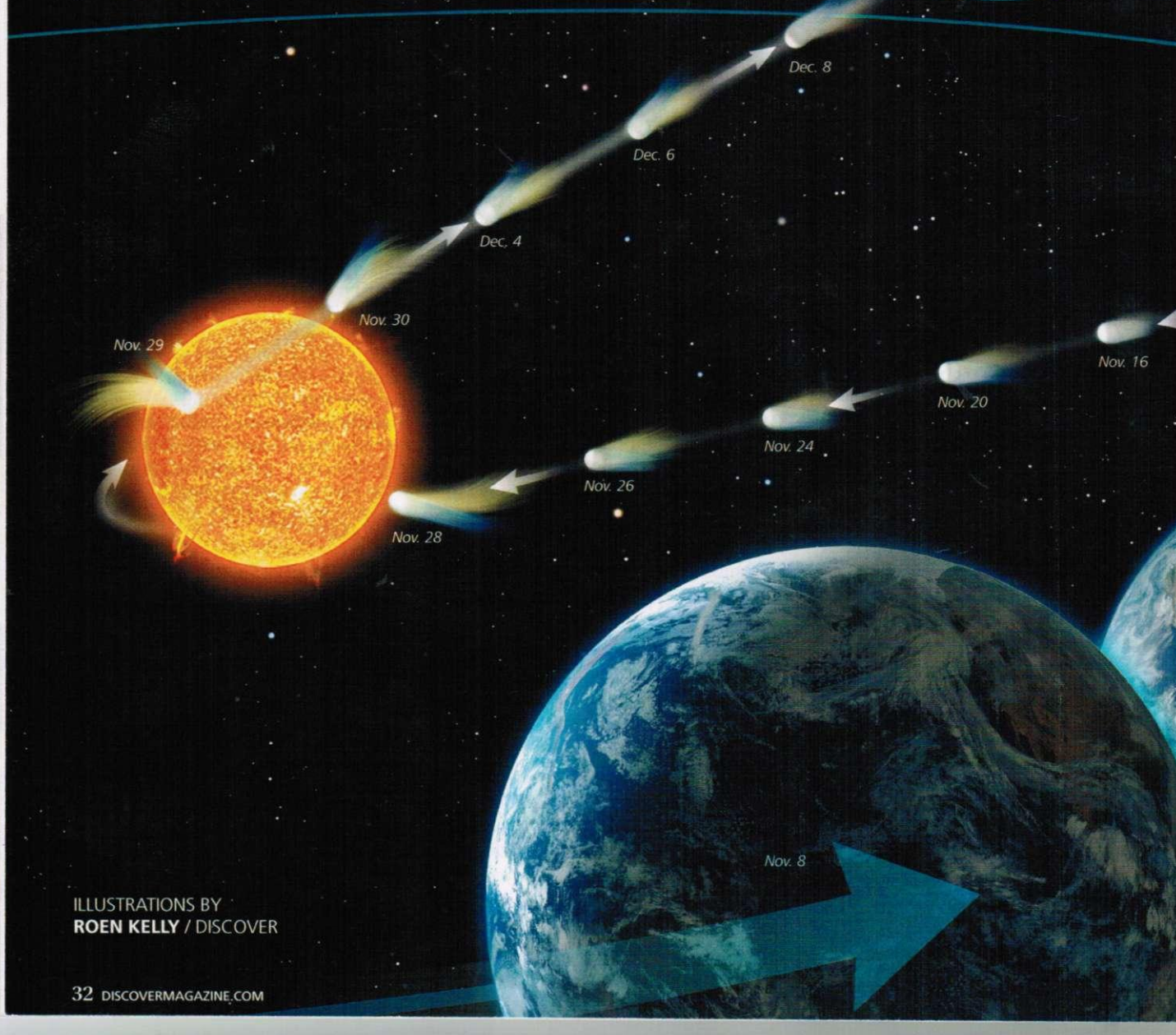
The Life and Death of COMET ISON

Minute by minute, a rare comet is unraveling, exposing 4.56 billion years of cosmic history in the process.

BY **COREY S. POWELL**



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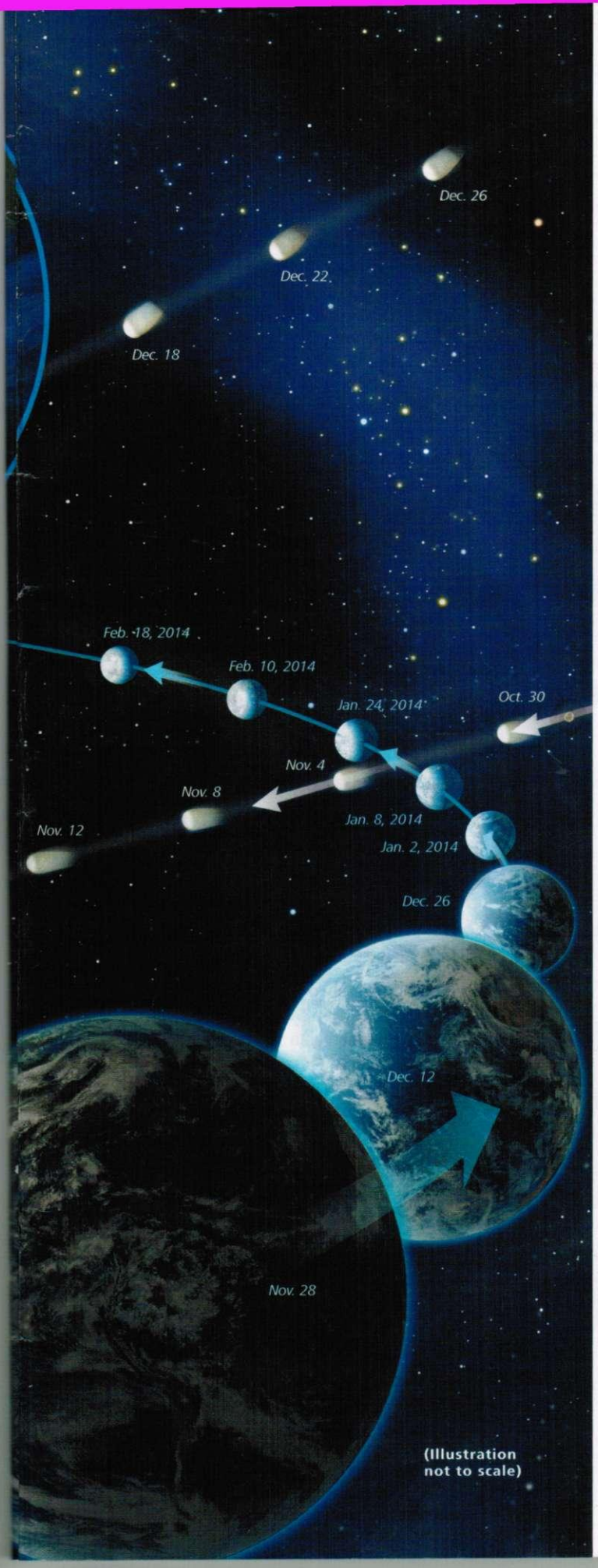


An End Foretold

Like every great comet, C/2012 S1 — better known to the world as Comet ISON — is dying. You could say the story of its demise began 14 months ago, when two observers near Kislovodsk, Russia, stumbled across a dim, fuzzy object while they scanned the sky near the constellations Cancer and Gemini. That fuzz was the outer layers of Comet ISON disintegrating and dispersing as it accelerated toward the warmth of the sun.

You could push further back and trace the comet's downfall to a fateful event a few million years earlier. At the time, it was an inert chunk of ice, dust and frozen gases, floating nearly motionless in the outermost region of the solar system, a thousand times more distant than Pluto. Then some unknown disturbance, perhaps the nudge of a passing star, dislodged the comet from its stasis and sent it on a self-destructive sunward plunge.

Or you could say that Comet ISON's end was foretold 4.56 billion years ago, when it and trillions of others like it formed during the birth of the solar system. Some of those comets collided with the infant planets; on Earth, they helped build the atmosphere and fill the oceans. But some of the comets were flung outward into distant cold storage. In that sense, the sunward journey of Comet ISON is a homecoming after a long exile.

Regardless of when the story begins, we know exactly when it will reach its climax: at 1:41 p.m. EST on Nov. 28, 2013, when the ice-packed Comet ISON reaches perihelion — the point closest to the sun — passing less than 750,000 miles (1.2 million kilometers) above the solar surface. There, ISON will roast at more than 2,000 degrees Celsius (hotter than 3,600 degrees Fahrenheit), boiling off layer after layer of its frozen surface. In the process, it will offer a firsthand look at the raw material that Earth and the other planets were built from when the solar system was formed.

Maybe some diminished portion of the comet will remain intact; maybe it will break apart and disperse entirely. Either way, the public unraveling of Comet ISON will be cause for celebration, not mourning. "Comet ISON is an extraordinarily rare object," says Carey Lisse of Johns Hopkins University, who is coordinating an international observing campaign. "It isn't just hyperbole. We are going to go to town on it. And we are going to learn a lot."

Day of Discovery

Almost as soon as they sighted the comet on a cloud-streaked autumn night in Russia's North Caucasus, Vitali Nevski and Artyom Novichonok realized it was something special. They were performing a routine sky survey on Sept. 21, 2012, as part of the International Scientific Optical Network, or ISON, a project that normally tracks rocky asteroids and space debris. This one smudge in their images was neither. "My heart missed a beat. Is it really a comet?" Nevski jotted down in his broken English.

When the two observers calculated the object's orbit, their excitement mounted. The newly named Comet ISON

was headed almost directly toward the sun, falling into the group of daredevil objects that astronomers picturesquely call sungrazers. Cold comets are small and unspectacular, but when they heat up, the ice and dust that blow off catch sunlight, forming a round cloud (the head, or coma, of the comet) and long streamers (the tail). That is what makes comets so beautiful and spectacular.

Because of its Icarus-like trajectory, Nevski and Novichonok realized, Comet ISON would put on an extreme performance, boiling away madly under intense illumination. "The brightness of the comet in the maximum could reach the full moon," Nevski commented in his notes on Sept. 25, after the comet was formally announced. If so, Comet ISON would rank as the most brilliant comet since the Great January Comet of 1910 became easily visible in daytime skies. Even the newer, less upbeat forecasts suggest ISON will be lovely in binoculars.

For the casual sky gazer, a bright sungrazing comet means a delightful spectacle. For researchers like Lisse, it presents a rare opportunity to see exactly how a comet is constructed: By passing its light through a spectrograph that detects wavelengths, they can identify the visual fingerprints of the various chemical components that are present. From estimating how much of each component is present, they can learn a lot about where and how the comet formed.

"I look at comets as the dinosaur bones of solar system formation. If we can crack open a comet, we're going to be able to learn about the initial conditions that helped lead to the planets, and to us," Lisse says.

There's no need to figure out how to crack a comet; solar radiation is already doing the job. "Comet ISON is going to get close enough that the sun will not only boil off all the icy parts of the comet; it's going to boil the rock as well. It's going to give us a chance to literally count atoms in the gas and the dust."

The Plot Thickens

Soon after the discovery in Russia, other researchers traced Comet ISON's orbit backward to identify its point of origin. They found a path to the sun that looked nothing like the circle or oval traversed by most comets. Instead, Comet ISON's trajectory was more like a straight line. Its journey started in the Oort Cloud, a vast swarm of inert comets that stretches from the edge of our solar system nearly halfway to the next star.

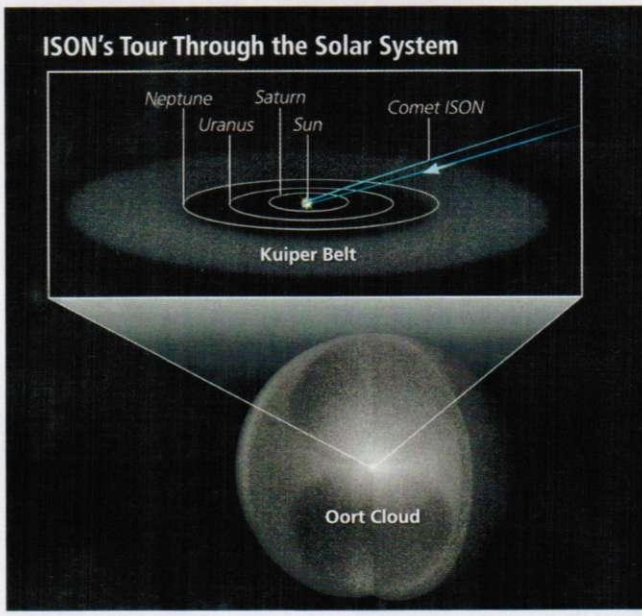
Suddenly the story got even more interesting.

Most of the comets that astronomers study have made previous journeys into the torrid inner reaches of the solar system, often multiple times, as they orbit the sun. As a result, they have been cooked, evaporated and eroded in ways that erase much of their original nature. Comet ISON, on the other hand, appears to be making its first trip in from the Oort Cloud. Extending Lisse's metaphor, Comet ISON is not just a bunch of dinosaur bones. It is more like the dinosaur itself.

Comet ISON's long trajectory has given astronomers yet another precious gift: a chance to prepare. Most sungrazing comets are scrappy objects spotted just hours before they race past the sun. That isn't nearly enough notice to set up observing campaigns at big observatories, which must be reserved months in advance. "But Comet ISON was found when it was far from the sun, six times Earth's distance, so we've had a lot of time to do observational planning," says Jian-Yang Li of the Planetary Science Institute in Tucson, Ariz.

The Witnesses Assemble

The first phase of that plan kicked off around the beginning of 2013, as observers around the world began monitoring Comet ISON and sending reports to the Minor Planet Center in Cambridge, Mass., the main clearinghouse for information about comets and asteroids. By spring, Karen Meech of



the University of Hawaii had scheduled a session on the giant Gemini North telescope atop Mauna Kea. From those observations, she documented a vigorous outpouring of gas and dust from the comet.

Around the same time, Li led a team working with the famed Hubble Space Telescope, which clarified the origin of the outpouring. The Hubble images captured an energetic geyser, almost 2,500 miles high (4,000 kilometers), shooting out from the sunward side of the comet. "I did not expect such an obvious jet, nothing as spectacular as that," Li says.

That geyser partly explains why Nevski and Novichonok spotted the comet so far ahead of perihelion, but it opened up a deeper mystery. The most common ingredient in a comet is ordinary ice, so comets typically remain fairly sedate until they receive enough sunlight to vaporize water. Comets do not generally get that hot until they approach Mars. But there was Comet ISON, puffing away in the frigid realm beyond Jupiter.

Meech thinks such flamboyant behavior reflects the unusual makeup of comets that have never experienced any warmth from the sun. She notes that as a new arrival from the Oort Cloud, Comet ISON might be covered with a layer of frozen

carbon monoxide and carbon dioxide, gases that vaporize rapidly when exposed to even a slight trickle of heat. "Carbon dioxide would be strongly outgassing as far out as the orbit of Saturn," twice the distance of Jupiter, Meech says.

Veteran comet researcher Michael A'Hearn of the University of Maryland points to another possible reason why Comet ISON was unraveling so rapidly as it plummeted toward the sun. Solar wind creates a huge magnetic bubble, known as the heliosphere, that protects Earth and the other planets from energetic subatomic particles that constantly zip around in deep space. But in the faraway Oort Cloud, Comet ISON received no such protection.

"After four and a half billion years outside the heliosphere, the outer 10 or 20 meters of the comet has been completely irradiated," A'Hearn says. "Essentially all the chemical bonds are broken down. You get lots of unstable molecular fragments. When they warm up, even a little, they recombine and tend to do so explosively." The outer layer of Comet ISON was like a thick blanket of TNT waiting for the slightest spark of heat to set it off.

Around April 2013, Meech and others noted that Comet ISON was no longer brightening so quickly. "I would interpret that as the end of the bomb," A'Hearn says. The super-reactive molecules had mostly been consumed, and ISON was now behaving more like an ordinary comet.

At that point, astronomers realized they might have misjudged Comet ISON based on its front-loaded performance. Drawing on his data from the Hubble observations, Li estimates that the nucleus — the solid body of the comet itself — is no more than about 2.5 miles (4 kilometers) across, smaller than what many astronomers initially expected for such an energetic comet. Although the comet's tail may ultimately stretch millions of kilometers through the solar system, its nucleus is likely smaller than New York's Central Park.

Likewise, Comet ISON probably will not become as bright as the early extrapolations had suggested; contrary to Nevski's early hope, the comet is unlikely to rival the full moon. On the other hand, the dramatically changing nature of Comet ISON as it boils away is exactly what scientists were hoping for. With each new part of the comet exposed, a little more of its past — and our past — is revealed.

Celestial Hide and Seek

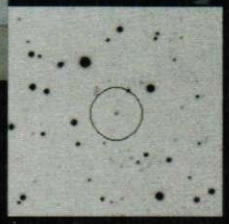
And then, just as Comet ISON began to lower its death mask a little more, it vanished. The comet passed behind the sun as seen from Earth, and for two months, comet researchers were effectively blinded. That gave them some much-needed time to plan their next round of studies and to anticipate what to look for when the comet rounds the sun on Nov. 28.

The kinds of questions that observers like Li investigate are informed by an origin story that is substantially different from the one that was written into textbooks just a few years ago. In the old view, the planets formed in an orderly manner, born from a swirling disk of gas and dust, known as the solar nebula, into stable orbits at their present locations from the sun. That interpretation left many details unclear, though, including how comets like ISON got tossed all the way out to the Oort Cloud while others were sent crashing into Earth. Then the doubts multiplied.

The discovery of strangely ordered planetary systems around other stars showed that the formation process cannot be so tidy after all. Some planets hug their stars, move in wildly stretched orbits or even circle backward. Such arrangements are possible only if newborn worlds interact and migrate in complicated ways. Another surprising clue came from comets that apparently derived some of their material from relatively warm parts of the young solar system. In this new, more chaotic picture of the solar system's early days, the planets seem to pass through a vagabond phase lasting a few tens of millions of years.

"It now seems clear to me — though I have not yet convinced everyone — that Jupiter must have migrated inward toward the sun during that time and then turned around and migrated back outward," says A'Hearn.

Artyom Novichonok (left) and Vitali Nevski discovered the comet during a sky survey (below) on Sept. 21, 2012.



Comet ISON's path (left) leads to the inner solar system after spending billions of years in the Oort Cloud.

Comet ISON was observed on April 20 by the Hubble Space Telescope, which produced this composite image of its coma and tail.

VITALI NEVSKI AND ARTYOM NOVICHONOK (2); NASA, ESA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

According to this theory, the other giant planets also shifted locations as they interacted with each other and with the thick disk of material swirling around the still-forming sun. Comet ISON got swept up in the drama.

A dynamic simulation of that process, carried out by A'Hearn's colleague Kevin Walsh of Southwest Research Institute, sheds light on many long-standing puzzles about the solar system: not only where the Oort Cloud comets come from, but also why Mars is so small and airless compared with Earth. As Jupiter migrated, its intense gravity stirred up everything around. It siphoned off raw material that would otherwise have reached Mars. It sent baby comets scattering far and wide.

During its travels, Jupiter flung swarms of those comets on paths that ran right into the still-forming Earth. When some of the comets collided, they deposited their water and organic compounds, helping to fill the oceans and turn our world into a blue planet. Then as Jupiter wandered away from the sun, A'Hearn explains, it stirred up a second, more distant group of comets and flung them out to the Oort Cloud. In this view, Comet ISON was one of Jupiter's victims on the planet's outward track.

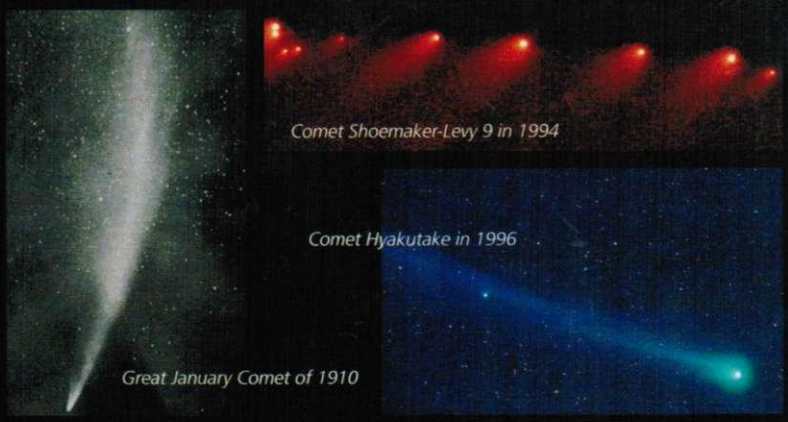
Each part of it makes for a cracking good story — and Comet ISON can help prove it is true. Every piece of the solar nebula had a distinctive composition, determined by its temperature and distance from the sun. Looking at Comet ISON's chemical fingerprints — its ratio of carbon dioxide to water, its mix of different kinds of hydrogen atoms, the kind of dust grains it contains — will indicate where it formed 4.56 billion years ago, and thus put the wandering-Jupiter theory to the test. The answers will not only help explain how Earth became an ideal place for incubating life; they will also tell a lot about the odds of finding similar habitable planets around other stars.

The Moment of Life and Death

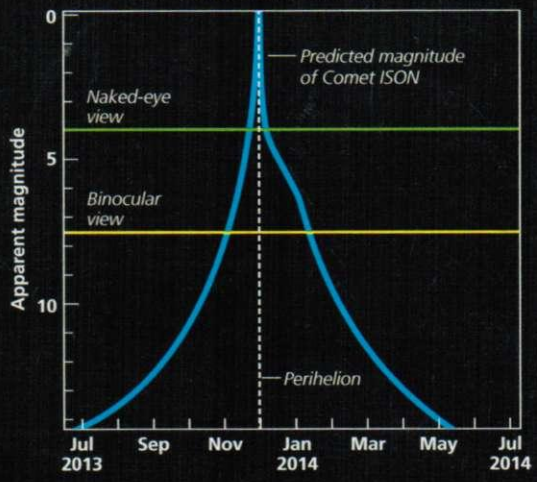
Now that Comet ISON has come back into view, almost every major telescope on Earth is watching it careen toward the sun. So are a lot of telescopes in space because of yet another happy accident. "The comet happens to be going through the inner solar system when the planets are just aligned right," says Lisse.

On Oct. 1, 2013, Comet ISON skirted just 10 million miles (16 million kilometers) from the Red Planet, where the Mars Reconnaissance Orbiter (MRO) was watching. And on Nov. 18, when Comet ISON slides 36 million kilometers past Mercury, another NASA spacecraft, MESSENGER, will be watching from there as well. Comet ISON grazed so close to Mars that MRO got the best view of any observatory in the solar system. It won't get nearly as close to Mercury, but that passage will be important all the same. "At that time, it's near impossible to observe the comet from the ground. That's why we're doing it, to look at the comet from different geometries and at different times," Li says.

Past Portraits
These past comets might provide some clues about ISON's coming appearance.



When Can You See Comet ISON?



Unfortunately, the most exciting moment of all, the perilous moment of perihelion on Nov. 28, will be impossible to observe using most ground-based telescopes because the comet will be so close to the sun; all instruments designed for nighttime viewing would be blinded by the light. Spacecraft orbiting other planets won't be any help this time around for the same reason, but another set of instruments will step up: solar observatories like SOHO, STEREO and the Solar Dynamics Observatory, all of which are designed to stare straight at the sun's surface. If anything spectacular happens as the comet rounds the sun, they will be watching.

Whether Comet ISON survives intact depends on heat and gravity. Heat turns out to be the lesser problem. Even at 2,000 degrees C, the outer layers of the comet vaporize more quickly than the heat can penetrate. Unless Comet ISON runs out of material — that is, it literally boils away — it should emerge still cool inside, like a giant baked Alaska.

Gravitational tides from the sun are another matter. Comets are loosely constructed. "If you were to scoop up a bunch of snow with your hand and do no more than that, that's the way a comet is put together," Lisse says. "It's not an ice ball. More like a dirty snowbank." In one particularly explicit

example of such instability, another bright sungrazer, Comet Lovejoy, largely disintegrated after its swing around the sun two years ago. Li also recalls Comet Shoemaker-Levy 9, which was torn into at least 21 pieces by Jupiter's gravity before colliding with the planet in 1994. Comet ISON could similarly fragment into a "string of pearls."

So will the comet make it? Sooner or later, every researcher studying Comet ISON offers odds. "I'm not a gambling man, but if I had to put money on that, I would tend to gamble on it surviving," says astrophysicist John Brown of the University of Glasgow. "I do play poker, and I'm a betting man, but I'm not going to bet the farm on it," counters Lisse. A'Hearn takes a more exact position: "I'm prepared to bet a beer that it will survive. I'm not sure I'm prepared to bet a bottle of good Scotch."

If Comet ISON comes out the other side, Meech, Li, A'Hearn and countless others around the world will resume their vigil, looking for changes in the shape and composition of the nucleus. But disintegration would in some ways be even more revealing because it would provide data on the comet's internal construction — and, by extension, on the way it formed in the first place. "If it fragments, that will expose more fresh interior, and we'll be able to measure the strength of the comet and study why it fragmented," Li says. And even if it breaks up, the fragments should still make for a stunning show in Earth's skies.

Comet ISON was between Mars and Jupiter and still quite dim in this amateur photo from Sept. 4. This and other early shots revealed it to be dimmer than earlier predictions for the time.

Comet ISON before dawn 2013

The Afterlife of Comet ISON

Whether it dies quickly or slowly, Comet ISON will be greatly diminished after Nov. 28. But nothing in the solar system is really lost. Material from the comet will spread, and some of that comet dust will hit our atmosphere on Jan. 12, when our planet passes through the edges of Comet ISON's trail. Large chunks of the comet will miss us, but solar radiation will push tiny particles — about the size of those in wood smoke — to Earth. Less than a pound of these minuscule particles will eventually drift to the ground, predicts meteor researcher Paul Wiegert at the University of Western Ontario. "Cometary seeding is still going on much the way it did when the Earth was young," he says.

As Comet ISON, or whatever is left of it, heads back out to the Oort Cloud, astronomers are keenly interested to see what happens next. "We're going to try and observe the comet after it has left the inner solar system, and we'll watch it turn off," Lisse says. One by one, each of its chemical components will return to a dormant, frozen state.

Long after Comet ISON has disappeared from view, its legacy will continue in other ways as well. Lisse's coordinated viewing effort, called the Comet ISON Observing Campaign, will make its datasets available to the public, so everyone can practice being a cosmic history detective.

Observations of Comet ISON from Mars will serve as a test run for another extraordinary cometary event: On Oct. 19, 2014, Comet Siding Spring will squeak by Mars, coming within 68,000 miles (or 110,000 kilometers) of the Red Planet — 100 times closer than Comet ISON's closest approach. For comet scientists, this is an unprecedented opportunity. Comet Siding Spring will pass so close to Mars that the planet will slide right through the comet's coma. Every probe orbiting Mars or roving around its surface will be recording the event.

"It happens to be a particularly good time for interesting comets," A'Hearn says. It could get even better. Theoretical models of the Oort Cloud say that gravitational disturbances should occasionally shake loose not just individual comets like Comet ISON, but large batches. As A'Hearn drily puts it: "Comet showers are to be expected." The odds that any of them would strike Earth are minuscule, but the effect would still be stunning.

The only question is whether you or I will live long enough to see not one but an entire storm of great comets, all racing sunward in a spectacular swoop of glory. D

Corey S. Powell *is editor at large of* Discover. *Follow him on Twitter* ***@coreyspowell****, and read his blog at* ***DiscoverMagazine.com/outthere.*** *For his advice on observing ISON, turn to the Urban Skygazer on page 70.*

DAMIAN PEACH; ROEN KELLY/DISCOVER