On Water's Origins

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Introduction –

From the mountaintop snows that feed our rivers and lakes to the springtime rains that anoint us all, water is a visceral part of our common experience as humans. Water touches our individual and collective lives so comprehensively, that we cannot help but think of it in a myriad of ways. In the accompanying white papers, scientists have offered a sampling of current thinking on water as it relates to our lives on Earth. Not surprisingly, their themes are as diverse as the scholarly interests and passions that these scientists have pursued. May their commentaries as part of Sigma Xi's *Year of Water* serve as wellsprings for further illuminating discussions.

Here, I consider the origin of water on Earth, as the mere existence of terrestrial water begs understanding. Astronomical observations at sub-millimeter wavelengths have identified the clear spectroscopic signature of water vapor in nearby comets of the Solar System and in more distant star-forming regions of our Milky Way galaxy. Planetary rovers have also found frozen water in the polar caps of Mars and underneath the red planet's dusty surface. NASA has invested billions of dollars to determine whether or not liquid water once flowed over the surface of Mars. More and more, it is looking like Mars was wet sometime during its first billion years. NASA-supported scientists are also developing robotic explorers that will seek evidence for the liquid water that they suspect lies beneath the frozen surfaces of Europa, Ganymede, and Callisto.

Water on Earth –

Despite compelling evidence for water throughout our Milky Way galaxy and within our local Solar System, the specific origin of water on Earth remains controversial. We know that the Earth formed some 4.6 billion years ago, as the primordial Solar System gravitationally congealed from the pre-planetary disk of debris that surrounded the proto-Sun. Once the Sun "turned on" its thermonuclear fires, things began to change in a big way.

Some scientists contend that the inner Solar System was too hot for any water to remain in the rocky bits that ultimately came together to form the Earth. They look to wayward comets and asteroids that formed farther from the scalding Sun as the key provisioners of Earth's oceans. However, others find important discrepancies in the relative amounts of regular water and "heavy" (deuterated) water in their comparisons of the Earth, comets, and meteorites. The comets have far more deuterated water than Earth's oceans –

indicating (to these scientists at least) that comets could not have delivered the bulk of Earth's water.

Meteorites are interplanetary rocks of various kinds that have fallen to Earth. They are thought to represent pieces of much larger asteroids that formed beyond Earth's orbit -- between the orbits of Mars and Jupiter. Some meteorites are found to be rich in water. Others are bone dry. Again, chemical and isotopic analyses rule out asteroidal meteorites delivering most of Earth's water, as they find that the early Earth was likely the beneficiary of mostly dry meteorites. The only way to wiggle around this situation is to have a single unusually wet and very large (Moon-size) body to hit Earth shortly after its birth. Something like the Jovian moon Europa could have done the trick.

Perhaps surprisingly, several scientists have gone back to square one – working out scenarios which retain the water in the inner Solar System despite the intense solar heating. Here, the water was in the form of a hot vapor that stuck to tiny grains of rock which then aggregated to build up pebbles – and ultimately – a wet Earth. Once the Earth's crust began to solidify, it would have belched out huge quantities of water during a period of rampant volcanic eruptions. As the saturated atmosphere cooled, it began to rain – and rain – and rain, filling the Earth's basins with the water that we inherit to this day.[1]

Larger Context –

Because of its molecular geometry and electronic affinities, water is the ultimate solvent for life-supporting chemistry. Each water molecule is made of one oxygen atom and two hydrogen atoms. What of their origins? Here, the scientific community is in remarkable agreement. The oxygen was likely forged in the thermonuclear core of a massive star during its final supergiant phase. Ending its life in a titanic supernova explosion, the star seeded the interstellar medium with oxygen (and many other elements of life), from which new solar systems could form. The hydrogen is thought to have "condensed" from the Hot Big Bang itself, as the primordial Universe <u>cooled</u> to a temperature of a trillion degrees Celsius for the central proton and to a billion degrees for the swarming electron. All told, this occurred within the first millisecond of our emergent cosmos.[2]

So many timescales to marvel at – our brief lives on Earth measured in decades, the last major glaciation that carved many of our mountain ranges and created many of our large lakes roughly 20 thousand years ago, the development of oceans on Earth a whopping 4.5 *billion* years ago, the nucleosynthesis of oxygen in some massive star and its explosive demise even longer ago, and the creation of hydrogen within an eyeblink of the Hot Big Bang some 14 billion years ago. And all of that cosmic history is in a single raindrop. Marvelous indeed!

Future Directions –

The field of research on water's terrestrial origins will likely benefit from future interplanetary probes – as they will ultimately determine the isotopic composition of water across the Solar System. That will help to pin down the status of oceanic water on Earth relative to the larger context of planetary, asteroidal, and cometary sources. Meanwhile, sub-millimeter spectroscopic observations of icy objects in the Kuiper Belt may help to determine the isotopic composition of these pristine Solar System objects beyond the orbit of Neptune.[3] Closer to home, deep-sea probes will help to determine the isotopic composition of water emerging from the upper mantle.

Whether Earth's oceans were delivered and/or outgassed has implications that go beyond our academic interests in what we are drinking. As supplies of fresh surface water get evermore scarce or compromised, we will be looking for new (well actually old) sources – including what's left of our polar caps, primordial water from ever deeper acquifers and vents, and maybe even fresh supplies from re-directed and dis-assembled comets. Knowing the mix of contributors to our oceans may help us to determine which sources are most available over the long haul. This knowledge of water sourcing will help to inform the larger discussion of water science, policy, and ethics, where considerations of water conservation, purification, desalination, and equitable distribution will challenge us all for decades to come.

References –

[1]Drake, M. J. 2005, "Origin of water in the terrestrial planets," *Meteoritics & Planetary Science*, vol. 40, no. 4, p. 1.

[2]Waller, W. H. and Hodge, P. W. 2003, *Galaxies and the Cosmic Frontier*, Cambridge, MA, Harvard University Press.

[3]Jewitt, D. 2003, "Water from Comets to the Sea?" *Na Hilo Koku*, Newsletter from the Institute for Astronomy, No. 9, Fall, http://www2.ifa.hawaii.edu/newsletters/article.cfm?a=121&n=8.

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