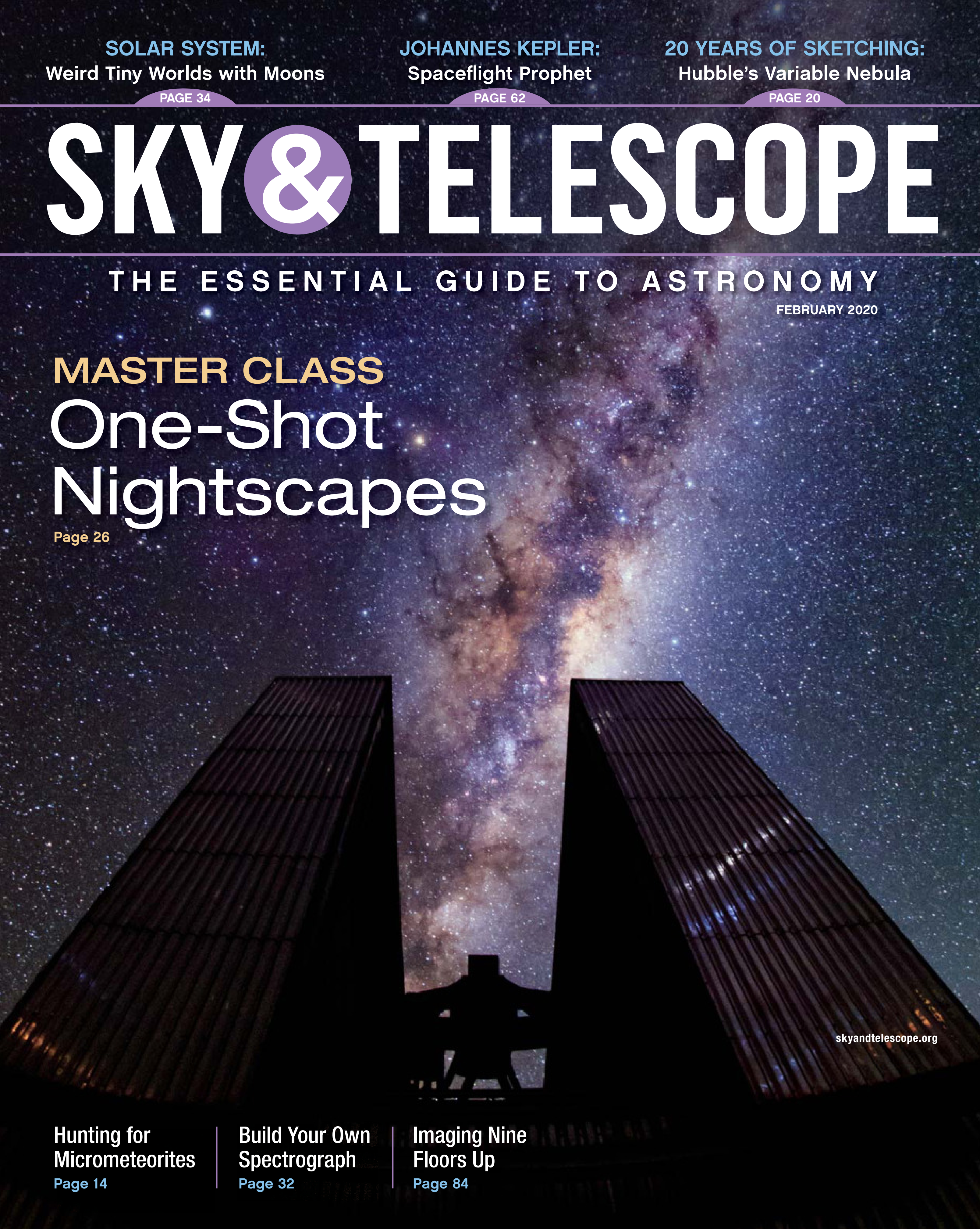

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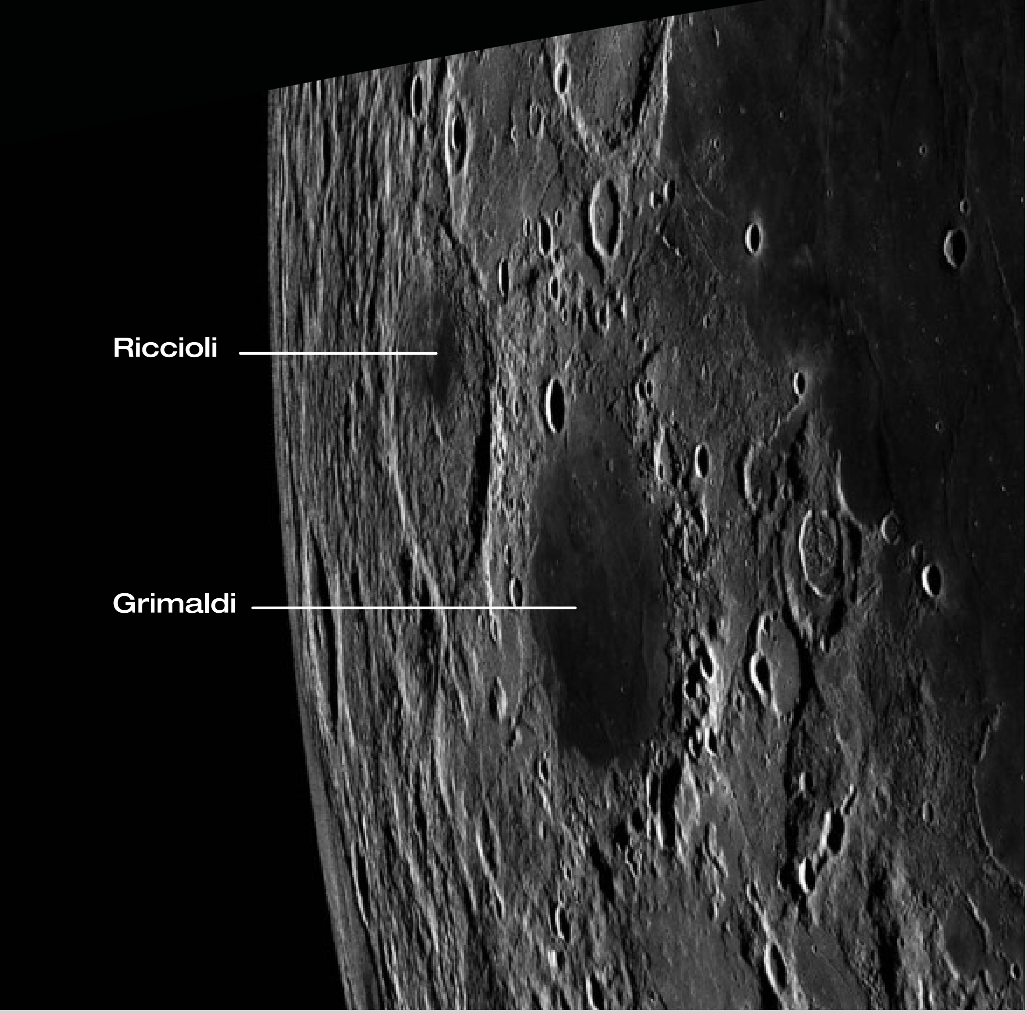


◀ Located on the western limb, Riccioli and Grimaldi are both mare-flooded craters visible after full Moon.

NASA / GSFC / ARIZONA STATE UNIVERSITY

Prospecting and Landing

The Moon may hold the fuel for future energy production.

For thousands of years we've relied on coal and more recently on oil for civilization's energy needs. Other power sources such as solar, wind, and nuclear fission have entered the energy market in recent decades. An additional potential energy source is nuclear fusion, which has the advantage that it produces no radioactive byproducts, though estimates have continually put fusion "about 20 years in the future" for the past half century.

The goal of fusion is to merge deuterium (^{2}H) with tritium (^{3}H) to create helium-4 (^{4}He) and one neutron, while releasing prodigious amounts of energy. This process powers the Sun and other stars. Two problems we've yet to surmount are the technical requirements to build a reactor able to contain the immense heat and pressure that fusion reactions produce and the extremely limited availability of helium-3 (^{3}He), the ideal fuel. After hydrogen, helium is the most abundant element in the universe, but nearly all helium found on Earth is ^{4}He, with ^{3}He being only about one-millionth as abundant.

However, the Moon is a veritable ^{3}He goldmine. Billions of years of solar wind has deposited ^{3}He in the lunar regolith. On the Moon, ^{3}He is available in the order of parts per billion, compared to the parts-per-trillion paucity here on Earth. Thus, the lunar-exploration programs of China, Korea, and other nations are partially focused on finding safe landing sites that have mineable concentrations of ^{3}He. Kyeong Kim (Korea Institute of Geoscience and Mineral Resources) and colleagues have created a global map of lunar ^{3}He abundances to determine potential landing-site locations that maximize mining opportunities and minimize landing danger. The most favorable of these sites are visible in backyard telescopes.

Soil samples brought back during NASA's Apollo missions show that the abundance of lunar ^{3}He is related to titanium dioxide (TiO^2) content, soil maturity, and solar wind flux. The element is found in the iron-rich mineral ilmenite, which efficiently traps ^{3}He carried by solar wind. Lunar lavas are classified as having high, medium, or low concentrations of TiO^2, with the high titanium lavas having greater-than-average ^{3}He concentrations. Since ^{3}He occurs in the regolith or lunar soil, those maria peppered with recent small impact craters have churned the soil more, reducing the concentration of ^{3}He. The third variable, solar wind flux, or the amount of solar wind that hits a particular area of the Moon, corrects for the fact that the Earth's magnetic field shields various areas of the Moon from solar wind and hence ^{3}He deposition.

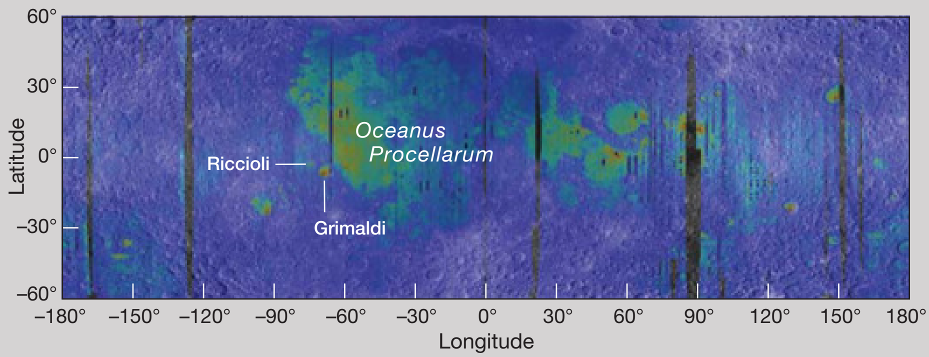
Kim and colleagues used data from the Clementine, Lunar Prospector, and Chandrayaan-1 lunar orbiters to construct high-resolution maps of TiO^2, and to correct for soil maturity as well as solar wind variations to create their ^{3}He map. They found that the highest abundances occur in the mare patches inside **Grimaldi** and **Riccioli** craters, as well as part of **Oceanus Procellarum**. Similar abundances were detected in Mare Moscoviense, but that lunar farside location would make control of mining operations difficult.

One additional parameter is needed to identify which area of high ^{3}He abundance is best for safe landings (as is necessary for commercial use), and that is a site's topographic slope. This was estimated by determining the average slope of the surface at each potential target location using the 2-meter-resolution images from NASA's Lunar Reconnaissance Orbiter narrow-angle cameras. Surfaces sloping less than 10° are considered level enough for safe landing. One final factor affects the site selection. The high ^{3}He abundance must occur over a wide enough area so that landing errors of up to 10-15 km still result in getting the miner into a rich ^{3}He zone. Considering all these requirements, and the fact that crater interior geology is more interesting than mare geology, Kim and coworkers state that Grimaldi and Riccioli are the most promising sites for a future mining operation.

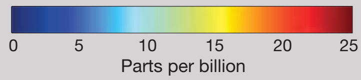
From the point of view of the backyard observer, these two depressions are relatively easy to find. When the Sun is high over this area, dark patches of mare lavas on the crater floors are quite visible against the bright background of surrounding highlands material. More details can be seen just after sunrise, when the grazing illumination reveals Grimaldi's dark floor to be relatively smooth, unbroken by detectable craters, with a flattish dome near the north end of the 145-km-wide mare patch. The highest ^{3}He region is near the southern edge of the dark mare.

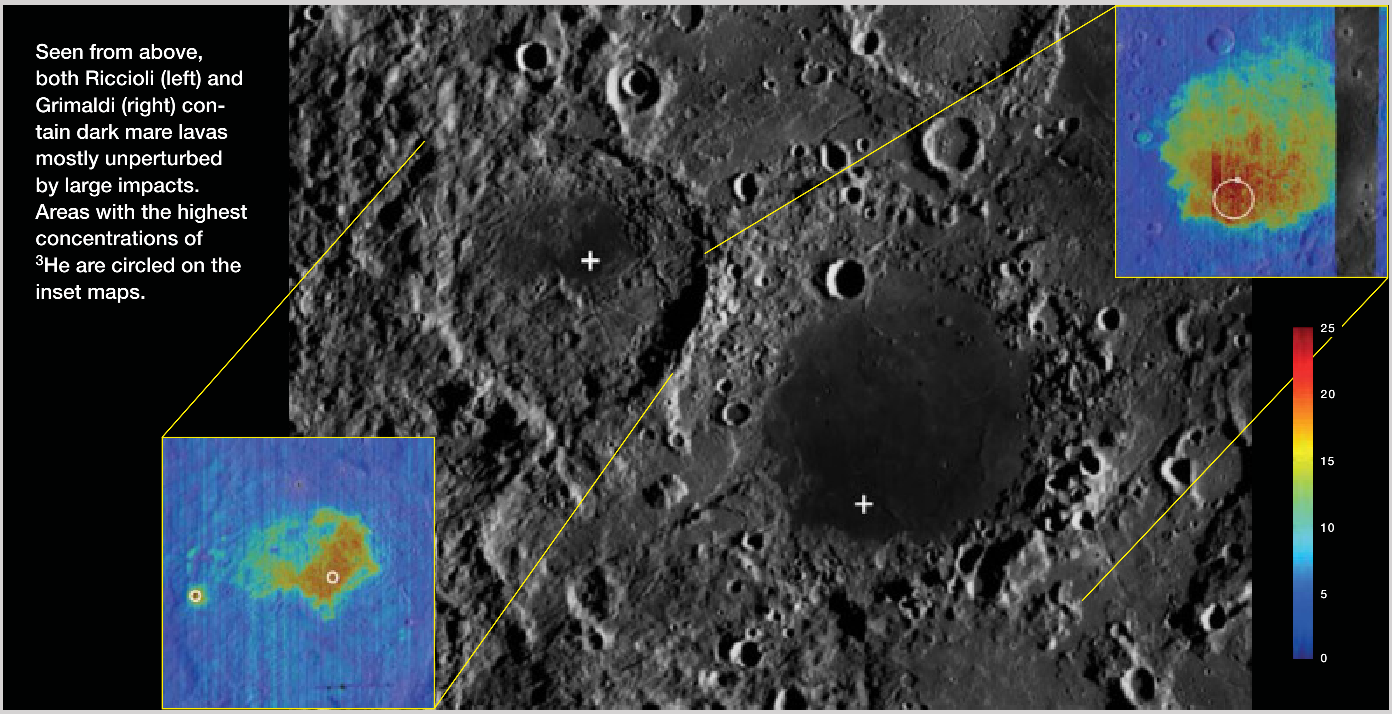
Riccioli crater's rim is about the same diameter as the mare material covering most of Grimaldi's floor. But unlike that smooth surface, the majority of Riccioli's floor is covered by ejecta emplaced during the impact formation of the Orientale Basin to the south-southwest. Only a 40-km-long "pond" of dark lava fills a low area in the northern half of Riccioli's floor — the greatest concentration of ^{3}He is at the southern end of this small mare patch. The fact that the dark lavas in these two craters are not defaced by ejecta demonstrates that they were volcanically emplaced after that basin's formation about 3.85 billion years ago. The dark floors of Riccioli and Grimaldi show no surface manifestation of the great isotopic wealth that we may someday harvest from those lavas.

■ Contributing Editor **CHUCK WOOD** has shared his lunar insights with *S&T* readers for more than 20 years.



▲The global map of ^{3}He shows the element to be concentrated in several locations mostly on the lunar nearside.





Seen from above, both Riccioli (left) and Grimaldi (right) contain dark mare lavas mostly unperturbed by large impacts. Areas with the highest concentrations of ^{3}He are circled on the inset maps.

GLOBAL MAP: NASA / GSFC / ARIZONA STATE UNIVERSITY; RICCIOLI & GRIMALDI MAP: LRO MOON: NASA / GSFC / ARIZONA STATE UNIVERSITY; 3HE DETAILS: K. J. KIM ET AL. / *PLANETARY AND SPACE SCIENCE* 2019