Landed missions: An essential link between remote sensing and in situ processes for icy world surface exploration

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Abstract

Remote sensing observations are our primary method of studying planetary surfaces, and in the inner solar system, in situ exploration quickly provided ground truth to these remote sensing observations. Our view of the surface appearance of worlds like the Moon, Mars, and even Venus has grown in tandem with our understanding of the large-scale structure from remote sensing. However, our knowledge of the icy worlds of the outer solar system is based solely on decades of remote sensing observations without any in situ surface data to help understand how geological processes are manifest on these worlds. The surfaces of icy worlds like Europa are likely to be truly alien in appearance, dominated by processes such as impact gardening, sputtering, sintering, and other types of physical and chemical weathering that act together in ways we have never yet observed in situ. Remote sensing has revealed that Europa's surface consists of an icy layer, exposed to the vacuum of space at cryogenic temperatures. The airless rocky Moon may be the best landed analog for Europa's surface, but the Moon is an old, battered world covered with impact craters, which have gardened the surface to a highly-mixed regolith depth of 5-15 meters overlying kilometers of broken-up megaregolith. Europa's young surface, approximately tens of millions of years old, likely has a gardening depth on the scale of centimeters up to a meter (Costello et al., AGU Fall Meeting, 2019). The rocky Moon is also compositionally different from icy Europa, and the thermal and radiolytic processes that shape the texture of the uppermost surface of an icy body have no rocky analog. As study of icy worlds has continued on the basis of remote sensing data only, multiple competing models exist for the formation of various surface features. Follow-up flyby and orbital missions may not be able to resolve these situations even with higher-resolution remote sensing data and digital elevation models. Images taken by an in situ surface lander on an icy world such as Europa, coupled with ground truth compositional and other measurements, will be essential to our understanding of how geologic processes work on these worlds. A mission such as a Europa Lander is the necessary next step, and will revolutionize our ability to interpret remote sensing data from myriad other bodies in the outer solar system.

Landed Missions: An Essential Link between Remote Sensing and In Situ Processes for Icy World Surface Exploration

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Overview

Remote sensing observations are our primary method of studying planetary surfaces, and in the inner solar system, in situ exploration quickly provided ground truth to these remote sensing observations. Our view of the surface appearance of worlds like the Moon, Mars, and even Venus has grown in tandem with our understanding of the large-scale structure from remote sensing. However, our knowledge of the icy worlds of the outer solar system is based solely on decades of remote sensing observations without any in situ surface data to help understand how geological processes are manifest on these worlds.

Timelines of Exploration

Planet / Moon	Date of first surface images from flyby or orbit	Date first observed from surface	Surface appearance
Moon	1959 (Luna 3)	1966 (Luna 9)	Rocks, regolith, space weathering processes
Venus	1983 (Venera 15)	1975 (Venera 9)	Volcanic, fluvial & aeolian processes
Mars	1964 (Mariner 4)	1976 (Viking)	Sedimentary, fluvial & aeolian processes
Titan	2004 (Cassini)	2005 (Huygens)	Fluvial & aeolian processes
Europa	1979 (Voyager)	NOT YET	Unknown

Table 1: *Timeline of remote and in situ solar system exploration*

Over the past 60 years, robotic spacecraft have observed the planets and satellites of our solar system at unprecedented resolution. In the case of the inner solar system, images taken from orbit or flyby of the Moon, Venus, and Mars were quickly followed up by images taken from the surface by a lander (or vice versa, in the case of Venus). Even Titan was imaged from the surface soon after the first images penetrated its thick haze (Table 1).

- **Moon**: 7 years from Luna 3 observation of "dark side" to Luna 9 images taken on the surface
- **Venus**: 8 years between when surface was imaged by the first lander, Venera 9, and when radar images from Venera 15 revealed the surface from orbit
- **Mars**: 12 years from the first flyby images of Mariner 4 to the surface images taken by Viking 1 & 2
- **Titan**: 1 year from first Cassini images of surface to Huygens probe landing image

From its earliest days, the field of planetary science has built models of how planets and satellites work, based on our knowledge from orbital and surface probes and our knowledge of how geology works on our own planet Earth. In the case of Venus, Mars, and Titan, while temperature and pressure conditions vary by several orders of magnitude, and the materials vary from sulfuric acid to rock to liquid hydrocarbons, the surfaces are modified by aeolian and fluvial processes, just as on Earth. In fact, surface images from each of these worlds (Figure 1) are shockingly similar both to each other, and to Earth, in what could be considered a triumph of our understanding of the physics of the solar system.

Europa's Surface: Truly Alien

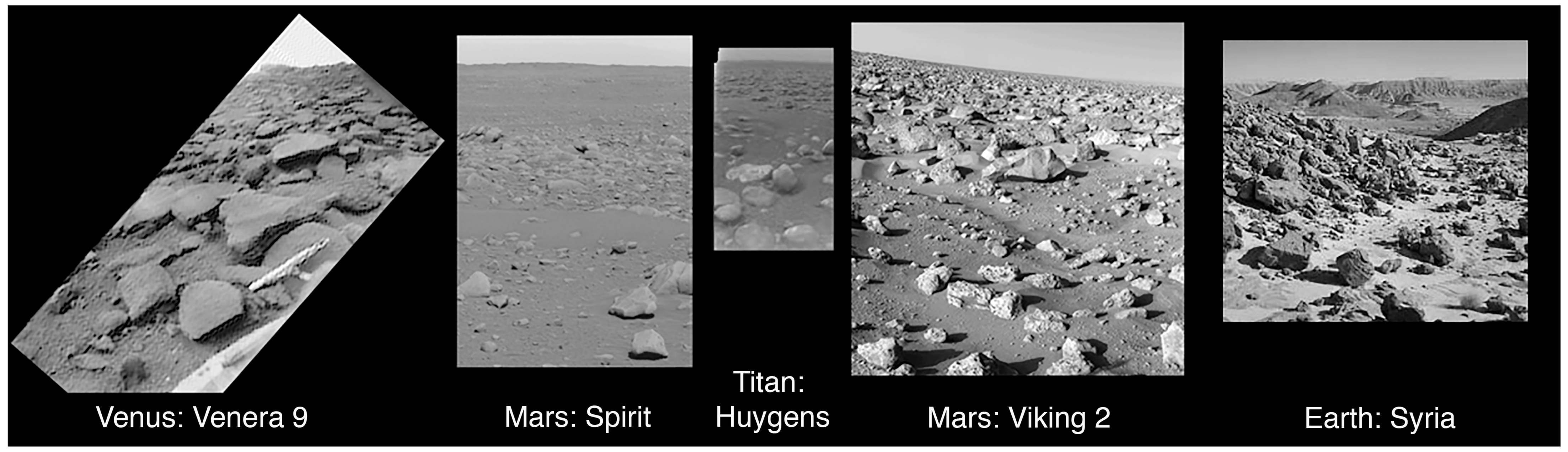
In contrast to worlds with atmospheres, the surfaces of airless icy worlds like Europa are likely to be truly alien in appearance, dominated by processes such as impact gardening, sputtering, sintering, and other types of physical and chemical weathering that act together in ways we have never yet observed in situ. Remote sensing has revealed that Europa's surface consists of an icy layer, exposed to the vacuum of space at cryogenic temperatures. The airless rocky Moon may be the best landed analog for Europa's surface, but the Moon is an old, battered world covered with impact craters, which have gardened the surface to a highly-mixed regolith depth of 5-15 meters overlying kilometers of broken-up megaregolith. Europa's young surface, approximately tens of millions of years old, likely has a gardening depth on the scale of centimeters up to a meter (E. Costello et al., P22A-03, AGU Fall Meeting, 2019). The rocky Moon is also compositionally different from icy Europa, and the thermal and radiolytic processes that shape the texture of the uppermost surface of an icy body have no rocky analog.

Icy World In Situ Observations

As the study of icy worlds has continued on the basis of remote sensing data only, multiple competing models exist for the formation of various surface features. Follow-up flyby and orbital missions may not be able to resolve these situations even with higher-resolution remote sensing data and digital elevation models. Images taken by an in situ surface lander on an icy world such as Europa, coupled with ground truth compositional and other measurements, will be essential to our understanding of how geologic processes work on these worlds. A mission such as the proposed Europa Lander mission concept would be the necessary next step, and would revolutionize our ability to interpret remote sensing data from myriad other bodies in the outer solar system.

A landed mission to an icy world like Europa will reveal fundamentally novel geologic surface processes, and may revolutionize our understanding of how such worlds work. Such a mission is a necessary next step in the exploration of our solar system.

Figure 1: *Surface images of Venus, Mars, Titan, and the Earth, scaled to a common horizon. Although temperature, pressure, and composition differ by orders of magnitude, these surfaces are modified by the same aeolian and fluvial processes that also dominate on Earth. In fact, despite their exotic locations, these images are all shockingly Earth-like.*



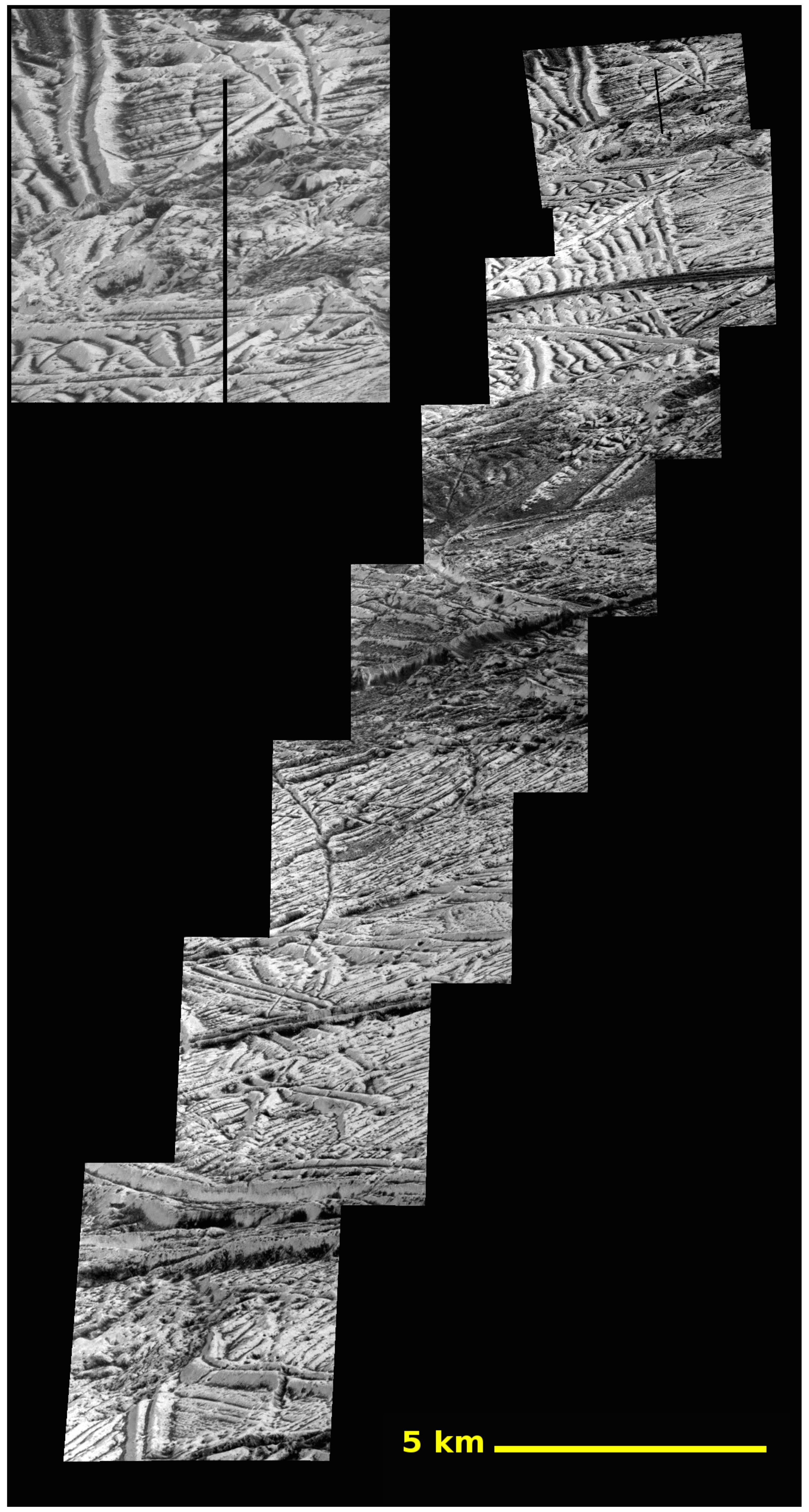


Figure 2. *High-resolution mosaic of Galileo SSI images, from orbit E12. These images, at 6 (top left inset) and 12 m/pixel, are some of the highest resolution images we currently have of Europa's surface, and reveal a surface that is fundamentally different from the solar system locations we have observed in situ.*

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