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Mini-SAR Imaging Radar and Lunar Polar Ice

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Abstract

Mini-SAR is a small, 8 kg synthetic aperture radar that flew on the Indian Space Research Organization Chandrayaan-1 mission to the Moon; a modified version of this instrument is now aboard NASA's Lunar Reconnaissance Orbiter spacecraft [1]. Mini-SAR is designed to map the permanently dark areas near the lunar poles and characterize the nature of the deposits there. We have found evidence for water ice at the north pole of the Moon.

1. Introduction

The possible existence of ice in the polar cold traps of the Moon has been debated [2]. The Clementine spacecraft conducted a bistatic RF experiment in 1994, which supported the idea of ice deposits within Shackleton crater, near the south pole of the Moon [3]. This interpretation has been debated [4, 5] and there is still disagreement whether observed polarization anomalies are caused by the presence of water ice [6]. Despite this uncertainty, there is little argument related to the discovery by Lunar Prospector of enhanced hydrogen levels in the polar regions [7]. The question is whether this hydrogen is in the form of water ice [2]. By mapping the dark areas near the poles and determining the backscatter properties of these surface materials, we can help to constrain the nature and occurrence of water ice deposits on the Moon.

Mini-SAR uses an unusual analytical approach to look for ice [8]. Traditionally, the key parameter used to determine if ice is present is the circular polarization ratio (CPR) of surface materials [6]. This quantity is defined to be the received magnitude of the same sense (i.e., the left or right sense of the transmitted circular polarization) divided by the opposite sense polarization. Volumetric water-ice reflections are known to have CPR greater than unity, while surface scattering from dry regolith has CPR less than unity [2]. Mini-SAR uses a hybrid dual polarization technique, transmitting a left-circular polarized signal and receiving coherently the linear horizontal (***H***) and vertical (***V***) polarization signals. This hybrid architecture preserves all of the information conveyed by the reflected signals [8]. From these data, all four Stokes parameters of the backscattered field are fully recoverable and offer a very powerful tool to investigate the nature of lunar radar backscatter. In addition to calculating the magnitude of both circular polarizations, it is also possible to ascertain other scattering properties such as the degree of linear polarization that will help distinguish between multiple surface reflections versus volume scattering. These characterizations are critical to determine if the returned signal is caused by an ice-regolith mixture, or simply dry rocks on the lunar surface.

While no remote measurement can fully characterize the presence, phase, and stratigraphy of potential ice deposits at the lunar poles, an orbiting SAR provides the most robust method of obtaining a positive indication of ice deposits. The 6° inclination of the Moon's orbital plane around the Earth means that large areas of permanent shadow that might contain water ice can never be seen from Earth, and also, all polar areas that can be seen from Earth are viewed at high incidence angles, reducing the coherent backscatter predicted for ice deposits. However all permanently shadowed regions can be imaged multiple times by an orbiting radar with incidence angles favorable for determining their scattering properties.

2. The Mission

The Mini-SAR was launched on the Chandrayaan-1 mission on October 22, 2008 [9] and operated for the following nine months. The principal goal of Mini-SAR on Chandrayaan-1 was to systematically map both polar regions higher than 80° latitude. Mini-SAR uses S-band (2380 MHz, 12.6 cm wavelength), has an illumination incidence angle of 35°, and image strips have spatial resolution of 75 meters per pixel. During mapping, it imaged both poles in SAR mode every 2-hr orbit, covering both polar regions in a single 28 day mapping window from mid-February to mid-April, 2009. Because the instrument looks off-nadir, there is a gap in SAR coverage within a couple of degrees of latitude around both poles. Portions of these gaps in coverage were partly filled by high-incidence angle SAR on Chandrayaan-1, but we hope to fill in some of those coverage gaps with the currently operating Mini-RF instrument on the LRO spacecraft.

Our data products include maps of both polar regions of the Moon at 75 m/pixel. These images consist of opposite sense image mosaics (to reveal the terrain of the dark areas near the poles), images of Stokes parameters, and derived maps of CPR and other derived products, including degree of linear polarization [8]. All raw data as well as processed data including higher order products such as mosaics are available to the scientific community through the international portal of the Indian Space Science Data Center and through the Geosciences node of the NASA Planetary Data System.

3. Results

The Mini-SAR instrument operated nearly continuously for the two month period planned and collected SAR data for over 95% of the area of both lunar poles as well as selected test and calibration strips of several non-polar targets of a variety of terrains around the Moon. Data quality is excellent and initial results for the north pole of the Moon recently have been published [10].

Both poles were well covered by Chandrayaan data. The north polar region displays backscatter properties typical for the Moon, with circular polarization ratio (CPR) values in the range of 0.1-0.3, increasing to >1.0 for young primary impact craters. These high CPR values likely reflect a high degree of surface roughness associated with these fresh features. We have identified a group of craters in the north polar region that show elevated CPR (between 0.6 and 1.7) in their interiors, but no enhanced CPR in deposits exterior to their rims (typical CPR values ~0.2 to 0.4). Almost all of these features are in permanent sun shadow and correlate with proposed locations of polar ice modeled on the basis of Lunar Prospector neutron data [11]. These relations are consistent with deposits of water ice in these craters [10]. The south polar region shows similar relations, except that it has more extensive low CPR terrain and fewer anomalous high-CPR interior craters. Massifs that make up the rim of the South Pole-Aitken basin show high CPR, similar to results seen in basin massifs in the near-equatorial Apennine mountain range. These results are somewhat unexpected; lunar massifs are some of the oldest terrain on the Moon and are expected to be covered with thick, fine-grained regolith. Downslope movement has apparently removed much of this material, exposing an abundance of decimeter-scale blocks. Small areas of high CPR are found in some south pole craters, notably Shoemaker, Haworth and Faustini; these areas might be deposits of water ice.

We obtained several SAR strips covering a wide variety of lunar geological units at low latitudes for both calibration and to create a catalog of the backscatter properties of geological units [12]. Initial results are congruent with measurements from Earth-based radar; from our SAR data, the smooth, fine-grained pyroclastic deposits near Sulpicius Gallus have CPR on the order of 0.179 ± 0.055, agreeing closely with the value measured from Arecibo radar (0.18 ± 0.05; [13]). Fresh craters such as Aratus and Aristarchus have high CPR values while the average combined CPR of mare and highland terrain is ~0.32 ± 0.11. Other geologically interesting targets were covered and we will study their backscatter properties in detail to compare with the polar data and to derive their surface properties.

Mini-SAR supported the selection of the LCROSS impact site by mapping the south pole with both Chandrayaan and LRO radar; the Mini-RF experiment has a high resolution mode, roughly a factor of 5 higher than Mini-SAR. The Cabaeus impact site has very low CPR, on the order of 0.24 ± 0.12 [14]. This result suggests that massive, pure water ice deposits do not exist in this region of the Moon, a supposition apparently confirmed by the LCROSS results, which indicate water concentrations of a few percent at most.

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