MINI-RF: IMAGING RADARS FOR EXPLORING THE LUNAR POLES. D. B. J. Bussey[1], P. D. Spudis[1], S. Nozette[2], C. L. Lichtenberg[2], R. K. Raney[1], W Marinelli[3], and H. L. Winters[1]. [1]Applied Physics Laboratory, Laurel MD 20723, ben.bussey@jhuapl.edu, [2]Naval Air Warfare Center, China Lake CA 93555. [3]NASA HQ, Washington DC USA

Introduction: Later this year two imaging radars will fly to the Moon to map the polar regions and search for ice. These ice deposits would represent a significant potential resource for the manned human base that is to be set up at one of the Moon's poles late in the next decade.

Lunar Ice: The existence of ice in the polar cold traps of the Moon has long been an intriguing possibility [1]. The Clementine spacecraft conducted a radar bistatic experiment in 1994, which supported the idea of an ice deposit within Shackleton crater, near the south pole [2]. However this result generated controversy [3,4] and there is still disagreement whether observed polarization anomalies are due to ice, particularly from the Earth based radar community [5]. However there is no argument related to the discovery by Lunar Prospector of enhanced hydrogen levels in the polar regions [6]. The question is whether this hydrogen is in the form of water ice. By mapping the dark areas near the poles and determining the backscattering properties of these surface materials, we will place firm constraints on the nature and occurrence of water ice deposits on the Moon.

The Instruments: An orbiting SAR provides the most robust method of obtaining a positive indication of ice deposits. One big advantage of orbital SARs compared to Earth based radar data is that ALL areas on the Moon can be seen. 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 areas that can be seen are viewed at high incidence angles, which reduces the coherent backscatter predicted for ice deposits. However all permanently shadowed regions will be imaged multiple times by an orbiting radar with incidence angles favorable for determining their scattering properties.

The Mini-RF instruments are lightweight SAR radars that will fly on the Indian Space Research Organisation's Chandrayaan-1 and NASA's Lunar Reconnaissance Orbiter missions. Mini-RF will use a different analytical approach to look for ice. Classically the key parameter used to determine if ice is present is the circular polarization ratio (CPR). This is equal to the same sense (i.e. the left or right sense of the transmitted circular polarization) divided by the opposite sense polarization signals that are received. Volumetric water-ice reflections are known to have larger CPR than usually observed from surface scattering.

Mini-RF will use an hybrid dual polarization technique, transmitting a circular polarized signal (either Right or Left Circular Polarization) and then receiving Horizontal and Vertical polarization signals, as well as the phase information between the two polarizations. This is an unusual architecture, but it preserves all of the information conveyed by the reflected signals. From these data we will determine all four Stokes parameters of the backscattered field. The Stokes parameters offer a very powerful tool to investigate the nature of lunar radar backscatter. In addition to calculating the response at both circular polarizations, and therefore also the circular polarization ratio, it will also be possible to ascertain properties which should help to distinguish between multiple surface reflections versus volume scattering. This is key in trying to determine if the nature of the returned signal is due to an ice-regolith mixture, or simply rocks on the lunar surface. Examples of these key properties include the Degree of Polarization and the Degree of Linear Polarization.

The Missions: Mini-RF instruments are flying on both the Chandrayaan-1 and LRO missions, both due for launch to the Moon in 2008.

Chandrayaan-1: ISRO's lunar orbiter is scheduled for a Spring 2008 launch. It will conduct a detailed analysis of the lunar surface using eleven instruments over the course of the two year nominal mission from an altitude of 100 km. The option of operating for some of the 2 years in a 50 km orbit is also being considered.

The main goal of Mini-RF on Chandrayaan-1 is to conduct systematic SAR mapping polewards of 80° for both poles. Mini-RF will use S-band and have a spatial resolution of 75 meters per pixel. The current ConOps consists of four observation opportunities per year, each one lasting approximately 32 days. This will permit all polar longitudes to be observed during a single opportunity.

During each observation opportunity Mini-RF will image in SAR mode both poles every orbit, imaging the nighttime portion of each pole. Due to the side looking nature of SAR observations there will be a polar gap in SAR coverage immediately around both poles. The incidence angle for these observations is 35°. From the Chandrayaan-1 altitude of 100 km this corresponds to a polar image gap of approximately 2° latitude. These regions close to both poles contain some of the most promising sites for potential water deposits. We therefore have a couple of options for exploring these polar areas. The first option uses the natural wobble in the orbit inclination of the spacecraft to allow the ground track to wander. The orbit will naturally drift between 90° (pure polar orbit) and approximately 91° on a 14 day cycle. By operating Mini-RF during orbits of maximum inclination we will be able to obtain SAR strips of permanently shadowed regions within 2° latitude of both poles. The second option involves operating Mini-RF in a scatterometry or “vertical SAR” mode. In this mode the Chandrayaan-1 spacecraft is rolled so that the antenna is oriented to point to nadir. An advantage of this mode is that we can completely map the polar areas between 85° and 90° in 14 days, thus filling in the entire polar SAR gap. A disadvantage of operating in scatterometry mode is that you lose the ability to obtain high spatial resolution in the range direction. Essentially what is acquired is a profile, with 10 km width and 1 km along track resolution. However, due to the significant overlap between consecutive strips we are investigating processing techniques which improve the overall spatial resolutions of the scatterometry strips.

Lunar Reconnaissance orbiter: NASA’s LRO is currently scheduled for a late 2008 launch. It is carrying six instruments and the Mini-RF as a technology demonstration. It will orbit the Moon at an altitude of 50 km for a nominal mission duration of one year.

Mini-RF on LRO is an enhanced instrument relative to the one flying on Chandrayaan-1. It operates in both S band (like Chandrayaan-1) and X-band. Also as well as the baseline resolution (75 meters per pixel) it can also operate in zoom mode with a spatial resolution of 15 meters per pixel. The current allocation for Mini-RF is 20 strips of SAR data during the one-year mission. The goal will be to target areas already identified by Mini-RF on Chandrayaan-1 as potential ice deposits and use the enhanced capabilities of Mini-RF on LRO to further investigate these areas.

The current Con-Ops for Mini-RF on LRO consists of a single four-minute SAR data acquisition per month. This acquisition can consist of multiple modes of acquisition, e.g. one-minute each of the four SAR modes (S-baseline, S-zoom, X-zoom, and X-baseline). Additionally, twice a year, we get a set of four two-minute data takes, on four-consecutive orbits.

Mini-RF on LRO also has the capability to acquire data applicable for topographic processing. Topography products can be derived using interferometric or SAR stereo techniques. The current mission allocation permits the acquisition of 20 data takes applicable for topographic processing, similar to the SAR Con-Ops.

A third goal of Mini-RF is a communication experiment, which will measure how the Mini-RF technology can be used in a communications role. Mini-RF may act as the back-up communications for the LRO spacecraft.

In addition to the current plans for SAR, interferometry, and communications data collection, Mini-RF has a supplemental science plan which is a list of goals that we would like to achieve but that are not currently scheduled. These observations would become possible if Mini-RF were able to collect more data, possibly during an extended mission. One of the supplemental goals is to conduct a spacecraft to spacecraft bistatic imaging experiment (Figure 1). A signal would be transmitted from Mini-RF on Chandrayaan-1 and received by Mini-RF on LRO. Analysis of the returned backscatter signal as a function of phase angle of the same area on the Moon would provide potentially the most definitive remote technique for discriminating between ice and rock units.

Data Availability: All raw data as well as processed data including higher order products such as mosaics will be made available to the scientific community. This will be achieved by archiving of the data to the Geosciences node of the PDS.

References: [1] Watson K. et al., (1961) *JGR*, 66, 3033. [2] Nozette S. et al. (1996) *Science, 274*, 1495. [3] Simpson R. and Tyler L. (1999) *JGR*, 104, 3845. [4] Nozette S. et al. (2001) *JGR*, *106*, 23253. [5] Campbell D. et al., (2006) *Nature*, 443, 835. [6] Feldman W. et al., (2001) *JGR*, 106, 23231.

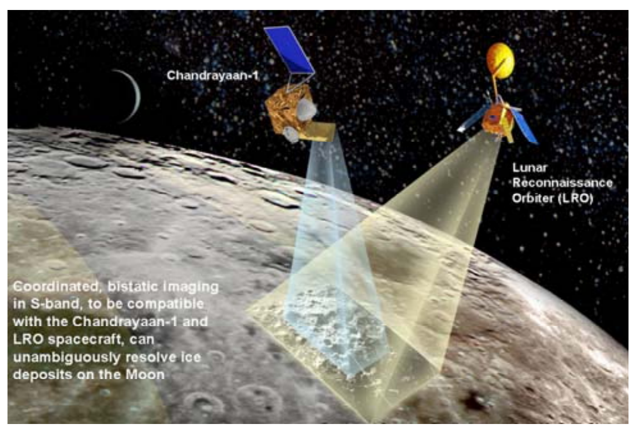

Figure 1. Coordinated bistatic imaging by two orbiting radars will help to discriminate between ice and rock units.