MINI-SAR: AN IMAGING RADAR FOR THE CHANDRAYAAN 1 & LUNAR RECONNAISSANCE ORBITER MISSIONS TO THE MOON. Ben Bussey[1], Paul D. Spudis[1], Chris Lichtenberg[2], Bill Marinelli[2], Stewart Nozette[3] 1. Applied Physics Laboratory, MP3-E169, Laurel MD 20723-6099 (paul.spudis@jhuapl.edu) 2. Naval Air Warfare Center, China Lake CA 93555 3. NASA Headquarters, Washington DC 20546

The debate on the presence of ice at the poles of the Moon continues. We will fly a small imaging radar on both the Indian Chandrayaan-1 and NASA's LRO missions to the Moon, both to be launched in 2008. Mini-SAR will map the scattering properties of the lunar poles, determining the presence and extent of polar ice.

Introduction Although returned lunar samples show the Moon to be exceedingly dry [1], recent discoveries suggest that water ice may exist in the polar regions. Because its axis of rotation is perpendicular to the ecliptic plane, the poles of the Moon contain areas that are permanently dark. This results in the creation of "cold traps", zones that, because they are never illuminated by the sun, may be as cold as 50–70 K [2,3]. Cometary debris and meteorites containing water-bearing minerals constantly bombard the Moon. Most of this water is lost to space, but if a water molecule finds its way into a cold trap, it is there forever – no physical process is known that can remove it. Over geological time, significant quantities of water could accumulate.

In 1994, the Clementine polar-orbiting spacecraft used its radio transmitter to "illuminate" these dark, cold trap areas; echoes were recorded by the radio antennas of the Earth-based Deep Space Network. Analysis of one series of data indicated that at least some of the dark regions near the south pole had reflections that mimicked the radio-scattering behavior of ice [4]. These data sparked a major controversy; Earth-based observations were interpreted to be both inconsistent with [5] and consistent with the presence of ice [6,7]. In addition, the authors of an alternate analysis of the Clementine bistatic data found no evidence for unusual reflection behavior at the south pole [8]. Subsequently, the orbiting Lunar Prospector spacecraft found large quantities of hydrogen in the polar regions [9,10], corresponding closely with large areas of permanent shadow [7], consistent with the presence of water ice. Nozette *et al*. [7] noted several procedural aspects of the data analysis in Simpson and Tyler [8] that could have resulted in the disparate results. The controversy over lunar polar ice continues to this day [11].

The existence of ice at the lunar poles is significant in two respects. First, these cold traps have existed for at least two billion years [12]; they contain a record of the impact of volatile components (mostly comets) in the inner solar system for that period of time. Such a record would tell us about the dynamic processes that perturb material from the outer into the inner solar system. Second, significant quantities of water ice could become useful for production of propellant and consumables to support future space activities there and in near-Earth space [13].

One way to obtain this information is to map ice deposits from orbit using an instrument designed to detect and elucidate the properties of the polar ice deposits. A radar system can operate as both a scatterometer and as a synthetic aperture radar imager. This multifunction capability has been demonstrated by previous space borne radar instruments (e.g. Pioneer-Venus, Magellan), but has not been applied to the Moon. In scatterometer mode, the system will be nadir pointing and measure the radar scattering properties along the ground track. Backscatter maps are of low resolution, but will yield a good regional view of the extent of the polar deposits and allow an estimate as to their total mass, currently estimated at ~ 10^{10} metric tonnes [10].

Chandrayaan-1 Mission to the Moon. India plans to launch the Chandrayaan-1 mission to the Moon in February, 2008. This 550 kg spacecraft will enter a 100 km polar orbit and map the Moon for 2 years. It's core payload includes monochrome imaging at ~ 5 m/pixel, a hyperspectral imager (color camera) that images the Moon at 80 m/pixel, a laser altimeter (1 Hz freq.) and an X-Ray fluoresence spectrometer to map the light elements (e.g., Si, Al) of the surface. In addition, an AO released by the ISRO last year invited proposals for additional international instruments. Of the over 20 proposals received, 5 were selected for flight in November, 2004; one of these was Mini-SAR.

Mini-SAR Instrument on Chandrayaan-1 The Mini-SAR will transmit Right Circular Polarization (RCP) and receive dual orthogonal polarizations. The majority of data collected by Mini-SAR on Chandrayaan-1 will be collected in SAR mode. The principal mapping goal of Mini-SAR on Chandrayaan-1 is to cover from 80° to 90° at both poles. Mini-SAR will primarily operate during two 60 day windows (corresponding to high phase angle conditions which are non-optimal for the optical instruments). During these observing opportunities Mini-SAR will collect data of both poles every orbit. Thus, over 60 days it should be possible to obtain full polar coverage of both poles, twice. Spacecraft orientation is such that at the next 60 day window, 5 month later, the look direction will be opposite, i.e. left and then right, or vice-versa.

The intended data products include maps of LCP. RCP, radar albedo, and CPR which can be used to try and identify possible ice deposits.

The Mini-SAR antenna is orientated at 33° off nadir. From a 100 km orbit this will naturally result in a SAR data gap around both poles. This gap will correspond to approximately 2° latitude. It may be possible to reduce the size of this gap by taking advantage of the natural variation of the inclination of the Chandrayaan-1 orbit. This inclination will wander between 90° and 91°. By collecting SAR data during the orbits of maximum inclination it should be possible to collect numerous strips within the nominal SAR data gap.

However, in order to ensure that data will be collected over the key areas close to the pole, Mini-SAR can operate in a scatterometer mode. In scatterometer mode, the spacecraft is rotated so that the Mini-SAR antenna is orientated in a nadir direction. Mini-SAR will then collect radar profiles from 85° to the pole to 85° in order to totally fill in the SAR gap.

The Chandrayaan-1 laser altimeter [14] will collect new topographic data over both poles, providing a topographic control network for the polar regions of the Moon. It has been pointed out [15] that such a control network, combined with long-lived baseline shadow mapping, will enable much more precise determination of the location and extent of the permanently shadowed terrain, allowing for seasonal and topographic corrections. Such information will allow a more precise estimate of the extent and location of the polar cold traps and hence, ice deposits. This information is important to evaluating the habitability of the lunar poles.

Mini-SAR on LRO

A radar instrument is also being flown as a technology demonstration on NASA's Lunar Reconnaissance Orbiter mission, set for launch in late 2008. LRO is a nominal one year mission in a 50 km polar orbit.

The radar on LRO will be able to provide more detailed analysis of areas identified by Mini-SAR on Chandrayaan-1 as possible ice deposits. The LRO radar has two wavelengths (S band and X band) and also can operate in a zoom mode with a spatial resolution of approximately 30 m, a factor of 5 higher than Mini-SAR on Chandrayaan-1.

Observing opportunities for the radar on LRO are extremely restricted. However we do hope to conduct supplemental science observations if possible, particularly if there is an extended mission. Supplemental goals include mapping all areas of permanent shadow in zoom mode, to look for ice deposits that would be too small to have been identified by Chandrayaan-1. Another goal would be to take advantage of LRO's lower orbit, combined with any variation in the orbital inclination to fill in the Chandrayaan-1 SAR gap.

One exciting possibility exists due to the fact that two radars will be in lunar orbit at the same time. The would be to conduct a bistatic experiment where one radar transmits and the other receives. This lets you study the radar backscatter characteristics as a function of phase angle. This would represent another independent method to look for ice (figure 1).

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Fig.1 Coordinated bistatic imaging of the lunar poles can unambigously map lunar ice deposits.