A COMPARISON OF THE RADAR RETURNS FROM THE ICY POLES AND OTHER REGIONS OF MARS AND MERCURY; B. Butler, D. Muhleman, California Institute of Technology, M. Slade, Jet Propulsion Laboratory

Introduction: The first full disk radar images of the planet Mercury were obtained during the inferior conjunction in August of 1991. These images were constructed using the Very Large Array (VLA) in Socorro, New Mexico to receive and map radar flux at 3.5 cm which was continuously transmitted from the Jet Propulsion Lab (JPL) 70 meter antenna at Goldstone, California and reflected from the surface of the planet. This radar mapping technique has been used in the past to image Mars (1) and Venus (2), and to obtain echoes from Saturn's largest moon, Titan (3). Approximately 77% of the surface was imaged, at resolutions as good as 140 km. About half of the hemisphere photographed by Mariner 10 was imaged, as well as most of the hemisphere which has not previously been photographed. At the time of the observations, the north pole was visible, and the most prominent feature in the images is at the nominal polar position.

Observations: We observed Mercury on two occasions, August 8 and 23 of 1991. The distances, and subearth latitudes and longitudes were: 0.67 AU, 11°, 253° for day 1, and 0.63 AU, 11°, 353° for day 2. Since the rotation rate of Mercury is slow enough that the planet only rotates about 2 degrees during 8 hours of observation from earth, an entire evening's data can be combined into one map of the visible surface at the time. The transmitted signal was Right Circularly Polarized (RCP), and we received both RCP and Left Circularly Polarized (LCP) echoes on both days. I will refer to the RCP echoes as Same Sense (SS), and the LCP echoes as Opposite Sense (OS). On each date, periodic observations of quasi-stellar objects were used to calibrate the phases of the observed visibilities, and an observation of a source of known flux was used to calibrate the amplitudes. The data was then self-calibrated using the phase closure method on the specular spike in the OS visibilities. The data for each polarization were then mapped and the known antenna response ("beam") deconvolved out using the CLEAN algorithm. The result is a calibrated radar reflection image for each received polarization of the entire visible hemisphere of Mercury for each day. Important information about the surface and near surface structure and composition can be obtained by consideration of several quantities, among which are: SS and OS reflectivities ($\sigma_{ss}$ and $\sigma_{os}$), and polarization ratio ($\mu = \sigma_{ss}/\sigma_{os}$). The reflectivities are defined as: $\sigma_p = J_{rec}/J_{ref}$, where $p$ indicates the polarization, $J_{rec}$ is the received flux in that polarization, and $J_{ref}$ is the reference flux, obtained from knowledge of the system parameters. The reflectivities and ratio are all functions of the incidence angle, or the angle between the radar line of sight and the surface normal.

North Polar Feature: The most reflective area on both days in the SS images is a large elliptic area coincident with Mercury's north pole. The area is centered at latitude ($\phi$) = 88° and longitude ($\lambda$) = 316° on day 1, and $\phi = 87^\circ$, $\lambda = 276^\circ$ on day 2. The size of the area was 340 X 970 km on day 1, and 300 X 640 km on day 2. We attribute the day to day differences to resolution problems, as a resolution element at the pole is 170 X 890 km on day 1, and 140 X 730 km on day 2, i.e. we are resolving the feature fully in one dimension, and barely in the other. The peak SS reflectivity in the area was 0.056 ± 0.004 for day 1, and 0.110 ± 0.007 for day 2. These are remarkably high reflectivities, considering the global average SS reflectivity was 0.016 ± 0.003 for day 1, and 0.020 ± 0.004 for day 2, and the fact that the incidence angle at the pole was $\sim 80^\circ$. The peak polarization ratio was $\sim 1.5$ for both days. The reflectivity values and ratios are similar to those obtained for the Galilean satellites (4), Titan (3) and the residual south polar ice cap on Mars (1), all of which are icy bodies or areas. There are many explanations for this phenomenon (5) (high reflectivity and high polarization ratio), most of which involve penetration into relatively lossless volumes (ices), and multiple scattering therein. We propose that since the north polar feature on Mercury is exhibiting this...
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effect, there should be deposits of ices there. Additional evidence pointing to this interpretation is the fact that a similar feature has been detected at the south pole (6), seemingly ruling out the remote possibility that the feature that we see just happens to be coincident with the north pole. Since the obliquity of Mercury is near 0, the poles receive very little sunlight, and thermal models (7) indicate that average temperatures there may be as cold as 125 K. In addition, any areas which are permanently in shadow would be much colder. Therefore, it is certainly cold enough to condense water vapor there, and may be cold enough to condense other volatiles. It is logical to assume that there would be a large influx of volatile material at both poles of Mercury, since the equatorial regions are heated to temperatures as high as 700 K, driving volatile substances from the surface which would eventually collect at the cold poles. Comets and asteroids would also deliver volatiles to Mercury. So, you have a large source of volatile material, and conditions at the pole sufficient to condense most of these volatiles. There is a problem with retention of the volatiles, considering the intense radiation environment at Mercury. In comparing the absolute reflectivities of the Mercurian north pole with that of the south polar residual ice cap on Mars, the reflectivity for Mercury is something like a factor of 10 to 20 lower. We see three possible explanations for this, although there may be more. First, the ice could be isolated in patches which only cover 5% of the surface area. Second, the ice could be contaminated, i.e. have foreign material mixed in, increasing the loss factor during propagation of the radiation through it. And last, the ice could be buried under a layer of powder and rock up to some meters in thickness, which also provides a mechanism whereby the ices can be protected from the radiation sources which would apparently destroy it. The real answer is probably a combination of all three of these. While we prefer the covered ice interpretation, there are many other possibilities. Similar reflectivities and polarization ratios have been measured on Maxwell Montes on Venus, and parts of the Tharsis and Elysium constructs on Mars. However, these structures are relatively young in age, and seem implausible on the ancient surface of Mercury.

"Basin" features: The 3 other most notable features in the SS images are near circular, and very large in extent (on the order of 1000 km in diameter). Because of the circular appearance of these enhanced reflectivity areas, we have termed them "basins". The centers of the three basins are located at: basin 1 - \( \phi \sim 17^\circ, \lambda \sim 240^\circ \), basin 2 - \( \phi \sim 55^\circ, \lambda \sim 348^\circ \), and basin 3 - \( \phi \sim -27^\circ, \lambda \sim 349^\circ \). The SS reflectivities of all 3 basins are \( \sim 0.04 \), and the polarization ratio of basins 2 and 3 is \( \sim 0.6 \). Basins 2 and 3 correspond closely to positions of two of the "emission patches" reported in (8), where enhanced atmospheric sodium was measured. In (8), the authors attribute the enhanced atmospheric sodium abundance to magnetospheric effects, since the emission patches usually occurred in north-south pairs. An alternative explanation to atmospheric enhancements of sodium and potassium has been proposed in (9), after measurement of a potassium enhancement over the Caloris basin. The alternative explanation is that the atmospheric enhancements are due to increased diffusion and degassing in the surface and subsurface of the Caloris basin due to its cracked and fractured nature. While our measurements do not rule out the first interpretation of the atmospheric enhancements, they certainly favor the second, since ground which is highly cracked and fractured will have enhanced SS reflectivity due to large amounts of multiple scattering at the surface and near surface. It is unfortunate that the Caloris basin was so near to the limb on day 1, and not visible at all on day 2, as it would have been good to compare it with our basins.

Other features: There are many other relatively low and high reflectivity areas on both days. Most of those identified on the photographed hemisphere seem to be associated with large craters and crater complexes (most notably the Kuiper crater area at \( \phi \sim -10^\circ, \lambda \sim 30^\circ \)), and in most of these areas, the ejecta blankets of the craters seem to have relatively high reflectivity, while the crater floors seem to have relatively low reflectivity. This is not surprising, as it is expected that the ejecta material will be relatively rough and contain many scatterers (rocks), while the crater interiors will be relatively smooth (most of the large basins on Mercury are filled with what has been termed "smooth plains" material(10)). Much work remains to be done on the small scale variations in reflectivity across the surface.