The Goldstone Solar System Radar: 1988-2003 Earth-Based Mars Radar Observations. A. F. C. Haldemann[1], K. W. Larsen[2], R. F. Jurgens[1] and M. A. Slade[1], [1]Jet Propulsion Laboratory, California Institute of Technology (JPL M/S 238-420, 4800 Oak Grove Dr., Pasadena, CA 91109-8099, albert.f.haldemann@jpl.nasa.gov), [2]Laboratory of Atmospheric and Space Physics, University of Colorado – Boulder.

Introduction: The Goldstone Solar System Radar (GSSR) has successfully collected radar echo data from Mars over the past 30 years. The older data provided local elevation information for Mars, along with radar scattering information with global resolution (e.g. [1,2]). Since the upgrade to the 70-m DSN antenna at Goldstone completed in 1986, Mars data has been collected during all but the 1997 Mars opposition. Radar data, and non-imaging delay-Doppler data in particular, requires significant data processing to extract elevation, reflectivity and roughness of the reflecting surface [3]. The spatial resolution of these experiments is typically some 10 km in longitude by some 150 km in latitude. The interpretation of these parameters while limited by the complexities of electromagnetic scattering, do provide information directly relevant to geophysical and geomorphic analyses of Mars.

Landing Site Assessment with Radar Data: The usefulness of equatorial near-nadir backscatter radar data for Mars exploration has been demonstrated in the past. Radar data were critical in assessing the Viking Lander 1 site [4, 5] as well as, more recently, the Pathfinder landing site [6, 7] and Mars Exploration Rover (MER) landing sites [8, 9, 10]. In general, radar data have not been available to the Mars exploration community at large. We have recently completed submission to the PDS of Hagfors model fits to all delay-Doppler radar tracks obtained since 1988 in aid of landing site characterization for the Mars Exploration Program. The available Level-2 Derived data records consist of Hagfors radar scattering model fits to the delay-Doppler data every 0.1 degrees of longitude. The fit parameters are range (elevation), reflectivity (Fresnel), and surface roughness (RMS slope) for each 10km x 150km resolution cell. We are working on delivering all the individual calibrated delay-Doppler images to the PDS.

Interferometric Delay-Doppler Radar: In both the 2001 and 2003 observations, the reflected radar signal was received simultaneously at four of the Goldstone Deep Space Communications Center telescopes. Delay-Doppler observations map the radar signal reflected from a target into a coordinate system based on time delay and frequency shift imparted by the planets shape and rotation, respectively. Since multiple points on the surface have the same delay and frequency coordinates, the signal from those regions are merged, and must be deconvolved by other techniques in order to create an unambiguous radar map. Pairs of receiving telescopes are used to create interferometric baselines. The signal from each baseline pair, both complex power-spectra, are multiplied to form a power spectra that contains the radar reflection's magnitude and phase, due to the varied path lengths. An iterated maximum likelihood function algorithm can then unwrap the north-south ambiguity and map the radar backscatter coefficient of the surface, at a resolution of five kilometers per pixel.

Research Perspectives: Three areas of active research apply to the GSSR Mars data.

Solving the conundrum of east-west slope. The fitting routines used for the Hagfors analyses of the sub-Earth delay-Doppler data do not properly account for east-west (or north-south) regional slopes. We have demonstrated in the past [11] that this has minimal effect on landing site analyses where flat areas are desired, but hampers the use of the data for analyses of rougher lava flows on volcanic flanks, where the radar geomorphology could fruitfully compare to terrestrial data. This issue for the time being also applies to the 5 km high-resolution interferometric data. Solving this problem is a high priority of the GSSR team. It will probably require iterative calculation of scattering models using regional MOLA topography, whereas our current algorithm is based on templates fit to a sphere.

Stealth. We are working to develop an improved geomorphic, geologic, and radar understanding of the Stealth region on Mars, known for it very low (lack of) radar backscatter echo. To accomplish this we will use the best spatial resolution GSSR data available to map the boundary of Stealth at ~10x better spatial resolution than previously. In turn, the better definition of the boundary of Stealth will allow us to examine newer high resolution imagery and thermal data to study the nature of Stealth. We expect our new higher resolution approach will allow us to either (i) chose among existing interpretations of Stealth, or, alternatively, (ii) to propose a new, combined, geomorphic, geologic and radar model for this continent-sized Martian region that barely reflects incident centimeter radar energy. At issue is whether Stealth represents a huge volatile-driven volcanic eruption in recent Martian history [12, 13].

Ground-truthing Earth-based Mars radar. The results from the 2001 and 2003 GSSR interferometric observations and the MER landing sites allow an assessment of the radar slope evaluation. The RMS slope or roughness derived using the Hagfors model on the pre-2001 data indicated a smoother surface at Meridiani than at MPF (3.5 cm wavelength RMS slope of 1.4° vs. 4.5°) and a smoother surface at Gusev than at VL1 (12.6 cm RMS 1.7° vs 6°). Interpretation of all pre-existing radar data predicted that Meridiani Planum would be much less rocky and smoother than the VL 2 site, and that Gusev would have a combination of roughness at decimeter scales similar to or greater than VL 1 and MPF sites, but will be smoother at meter-scales. These predictions appear generally consistent with the generally smooth flat surfaces with moderate and few rocks observed by Opportunity and Spirit, where RMS slopes from MER Front Hazcam (FHAZ) stereo pairs average 3° at 3 m scale for both rovers, but average about 30° at 10 cm scale for Spirit and 20° for Opportunity at the same scale [14]. A small radar mystery arises from the fact that the Hagfors model analysis of the 3.5 cm 5 km x 5 km pixels that contain the MER landing sites have

θ_{rms}(Gusev) = 1.6° ● 0.5°

and

θ_{rms}(Meridiani) = 2.0° +1.0°/-0.5°

The Hagfors model suggests that these values represent surface roughness at scales 10λ to 100λ. Examination of the FHAZ plots shows that the "best" radar numbers undererestimate meter-scale RMS slope for Gusev, and overestimate it for Meridiani. We find this somewhat surprising, since the morphology of Meridiani in particular would intuively suggest that the "gently undulating" facet terrain conditions required by Hagfors are met. With the plethora of MER data, Mars radar scattering modeling can proceed apace

References: [1] Goldspiel J. M. et al. (1993) *Icarus, 106*, 346-364. [2] Moore H. J. and Thompson T. W. (1991) *LPS XXI*, 812-815. [3] Hagfors T., *JGR, 102,* 3779-3784. [4] Masursky H. and Crabill N. L. (1976) *Science, 193*, 809-812. [5] Tyler G. L. et al. (1976), *Science, 193*, 812-815. [6] Haldemann A. F. C. et al. (1997) *JGR, 102,* 4097-4106. [7] Haldemann A. F. C. et al. (1997) *Eos Trans. AGU, 78,* F404. [8] Golombek M. P. et al. (2003) *JGR, 108*, doi:10.1029/2003JE002074. [9] Larsen, K. W. et al. (2004) *LPS XXXV*, Abstract #1050. [10] Golombek M. P. et al. (2004) *Nature*, in press. [11] Haldemann A. F. C. et al. (2002) *IGARSS,* Abstract#INT1 A30 04. [12] Edgett K. S. et al. (1997) *JGR, 102*, 21545-21567. [13] Edgett K. S. and M. C. Malin (2000) *LPS XXXI*, Abstract #1065. [14] Haldemann A. F. C. et al. (2004) *Bull. AAS, 36*, 1161.

Acknowledgements: This research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.