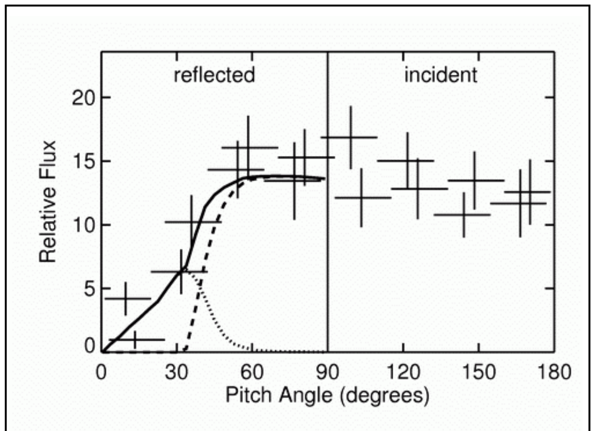
MAPPING WEAK CRUSTAL MAGNETIC FIELDS ON MARS WITH ELECTRON REFLECTOMETRY.

D. L. Mitchell[1], R. Lillis[1], R. P. Lin[1], J. E. P. Connerney[2], and M. H. Acuña[2], [1]Space Sciences Lab. (Univ. of Calif., Berkeley, CA 94720; mitchell@ssl.berkeley.edu), [2]NASA-GSFC (Greenbelt, MD 20771).

Introduction: One of the great surprises of the Mars Global Surveyor (MGS) mission was the discovery of intensely magnetized crust [1, 2]. These magnetic sources are at least ten times stronger than their terrestrial counterparts, probably requiring large volumes of coherently magnetized material, very strong remanence, or both [3]. Perhaps the most intriguing aspect of these fields is their large scale coherence and organization into east-west stripes thousands of kilometers long. The anomalies were almost certainly created by thermoremanent magnetization (TRM) in the presence of a strong Martian dynamo [4, 5, 6]. With few exceptions, the crustal fields are associated with the oldest terrain on Mars. Much of the northern lowlands appears to be non-magnetic, except for the relatively weak north polar anomalies and a few sources adja-cent to the dichotomy boundary [1], which appear to be associated with strongly magnetized crust south of the boundary. There is clear evidence for impact demag-netization of the Hellas, Argyre, and Isidis basins. Thus, Mars' crustal magnetic fields are among the oldest preserved geologic features on the planet.

Observations: The MGS Magnetometer has measured crustal magnetic fields on Mars at altitudes from 100 to >1000 km. Because of the long duration in the mapping orbit, the crustal field map at 400 km altitude is fully sampled on both the day and night hemispheres; however, the sampling is sparse at lower altitudes, and nearly all of those data were obtained on the sunlit hemisphere, where the solar wind distorts crustal fields, and obscures those weaker than ~10 nT. The presence and morphology of weak crustal fields exist in the northern lowlands could yield important clues about the thermal and magnetic history of the northern lowlands, how the northern and southern hemispheres are related, and further constrain the timing of the planetary dynamo.

The MGS Electron Reflectometer (ER) was designed to remotely probe crustal magnetic fields using the magnetic mirror effect, or the reflection of charged particles from regions of increased magnetic field strength [7]. In a uniform field, electrons move along helical paths of constant radius and pitch angle (α), which is the angle between the particle velocity and the magnetic field direction. However, if the field strength (B) increases towards the planet and the fractional change in the field is small over the distance traveled by the electron in one gyration, then the adiabatic approximation holds ($\sin^2\alpha/B$ = constant), and the electron will be reflected back along the lines of force when α reaches 90°. Electrons with pitch angles initially near 90° reflect at high altitudes, while those with smaller pitch angles reflect at lower altitudes. Since the neutral density increases exponentially towards the surface, the probability that an electron will impact a neutral atom increases rapidly as the reflection point gets lower. Nearly all electrons that suffer a collision are lost and do not reflect back up to the spacecraft. Thus, the flux of reflected electrons exhibits an attenuation that depends on pitch angle (Fig. 1).



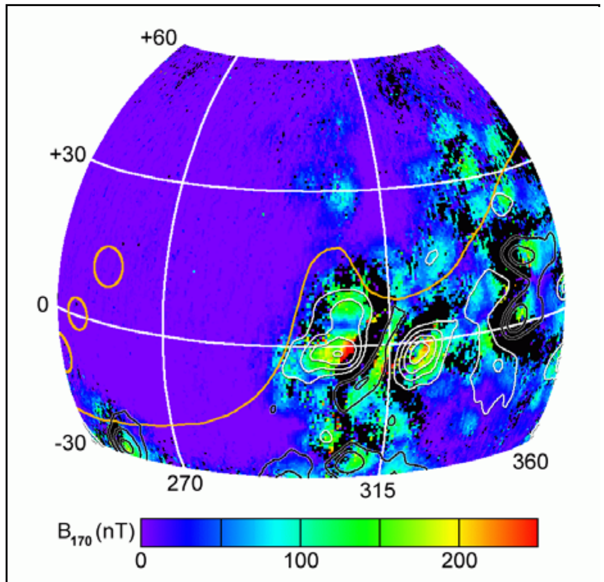
Model: In the simplest terms, ER measurements provide the ratio of the field strength at the electron absorption altitude to that at the spacecraft. The absorption altitude at Mars varies with electron energy, ranging from ~200 km at 200 eV to ~120 km at 20 keV. Electron reflectometry thus can increase the sensitivity to crustal fields over that of a magnetometer orbiting at 400 km, since the crustal field is probed at altitudes well below that of the spacecraft.

Electron reflectometry has been successfully used at the Moon to map surface magnetic fields with a spatial resolution of ~5 km and a sensitivity of ~0.1 nT [8, 9]. Since the Moon lacks a significant atmosphere, electrons that reflect before impacting the surface travel back towards the spacecraft without loss, while those that hit the surface are nearly all absorbed. The distribution of reflected electrons can thus be modeled as a step function that constrains the surface field strength, without detailed knowledge of the surface interaction.

Electron reflectometry at Mars is more complicated, because electrons are absorbed by the atmosphere over a range of altitudes. Solar wind electrons either follow the draped interplanetary magnetic field (IMF), or crustal magnetic field lines that have reconnected with the IMF, down into the upper atmosphere. These precipitating electrons collide with neutral atoms and molecules both elastically and inelastically, trans-ferring their kinetic energy into excitation and ionization of O, O_2, CO, N_2, and CO_2. Electron transport codes have been developed for Mars to simulate these processes [10, and references therein]. Although these models incorporate much of the relevant physics, they are impractical for global mapping of the crustal magnetic field, which requires the analysis of over one million ER measurements. We have recently developed a simplified technique for modeling electrons reflected from crustal magnetic fields at Mars. Through a series of approximations, we reduce the problem to one of calculating the survival probability for electrons traveling from the spacecraft to the reflection point and back (see Fig. 1). This technique is used to map the strength and topology of crustal magnetic fields over the Martian surface.

Discussion: We have systematically searched for crustal magnetic fields in the northern lowlands using electron reflection magnetometry and have detected several new magnetic features in the northern lowlands. Some of these appear to be northward extensions of previously identified magnetic sources along the dichotomy boundary (Fig. 2). A group of magnetic sources forms a partial ring around the Utopia basin perimeter, but no sources were detected within the basin itself. These observations suggest that the Utopia impact resulted in crustal demagnetization and that the magnetic sources surrounding Utopia are as old as those in the southern highlands.

There is now strong evidence that the northern lowlands preserve numerous impact structures as old as those in the southern highlands, and that the smooth, young surface is only a thin (few km) veneer covering much older crust [11]. The presence of crustal magnetization in the northern lowlands might indicate that the formation of the dichotomy boundary did not completely erase preexisting magnetization. However, the 1240-km-diameter Isidis basin bisects the dichotomy boundary and shows clear evidence of impact demagnetization. This suggests that the formation of the dichotomy boundary predates the oldest preserved crust and may have occurred close to the time when the core dynamo was still active. MGS topography and gravity data suggest that the northern hemisphere experienced high heat flow early in Mars history [12], which might be a consequence of low



order mantle convection [13]. Thus, the weaker magnetic anomalies in the northern lowlands may be a consequence of delayed cooling relative to the southern highlands, a thinner layer of magnetized crust, or both.

References: [1] Acuña M. H. et al. (1999) *Science, 284,* 790. [2] Acuña M. H. et al. (2001) *JGR, 106,* 23403. [3] Connerney J. E. P. et al. (1999) Science, 284, 794. [4] Arkani-Hamed, J. (2003) *JGR, 108,* 3-1. [5] Breuer D. and Spohn T. (2003) *JGR, 108,* 8-1. [6] Nimmo F. and Stevenson D. (2000) *JGR, 105,* 11969. [7] Acuna M. H. et al. (1992) *JGR, 97,* 7799. [8] Lin R. P. et al. (1998) *Science, 281,* 1480 . [9] Halekas J. S. et al. (2001) *JGR, 106,* 27841. [10] Liemohn M. W. et al. (2003) *JGR, 108,* 5134. [11] Frey H. V. et al. (2002) *GRL, 29,* 10.1029. [12] Zuber M. T. et al. (2000) *Science, 287,* 1788. [13] Zhong S. and Zuber M. T. (2001) *Earth Planet. Sci. Lett., 189,* 75.