PRELIMINARY RESULTS FROM THE MARS RECONNAISSANCE ORBITER RADIO SCIENCE GRAVITY INVESTIGATION.

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Introduction: In September 2006 the Mars Reconnaissance Orbiter (MRO) mission [1] initiated global mapping of Mars. The Radio Science Gravity investigation [2] on MRO utilizes the spacecraft's telecom system to address scientific questions regarding solid and volatile parts of the planet. The objectives of the RS Gravity investigation are to improve knowledge of the static structure and characterize the temporal variability of the Martian gravitational field relevant to the planet's internal dynamics, the structure and dynamics of the atmosphere, and the orbital evolution of spacecraft at Mars. This presentation presents an overview of the investigation and preliminary results.

Telecom System: The MRO Primary Telecom Subsystem operates at X-Band, with an uplink frequency of 7.2 GHz and a downlink frequency of 8.4 GHz. The tracking system utilizes MRO's 3-m-diameter high-gain antenna (HGA) and a 100-Watt X-band radio traveling wave tube amplifier (TWTA) to transmit signals to Earth. In addition, MRO also has two broader-beam, low-gain antennas that are mounted on the HGA dish for lower-rate communication and for use in critical maneuvers (*i.e,* orbit insertion) or during spacecraft upsets.

Communication with Earth is accomplished using 34-m and 70-m antennas of NASA's Deep Space Network (DSN) stations in Goldstone, California, Madrid, Spain, and Canberra, Australia.

MRO also includes a technology demonstration experiment consisting of a Ka-band transponder on the spacecraft that produces an RF downlink at a frequency of 32.2 GHz [3]. The Ka-band subsystem has a 35-Watt TWTA to amplify its signal so that it can be downlinked to DSN antennas that have been modified to receive at that frequency. The Ka-band system experienced an anomaly during the mission aerobraking phase in June 2006. Detailed troubleshooting is underway and if function is not regained the system could switch to the backup.

Data Types: The tracking data is used to determine the velocity of the spacecraft and its position in inertial space. Range rate is measured from the downlink signal transmitted from the spacecraft's X-band transponder. The frequency of the signal is Doppler shifted, and the magnitude of the Doppler shift yields the velocity of the spacecraft in the line of sight to the observer. The velocity of the spacecraft in orbit around Mars changes due to forces acting on the spacecraft that include gravitational perturbations due to Mars' mass distribution, spacecraft maneuvers, and radiation pressure. The accuracy of the Doppler measurement is limited by the performance of the X-band system and is specified to be ±0.1 mm s^{-1} over a 60-s integration period [4]..

A second data type is the range from the ground tracking station to the spacecraft. Ranging measurements are made via standard sequential tone ranging. The DSN transmits a series of ranging tones; the on-board transponder receives these tones and re-transmits them back to Earth. The difference between the time of transmission of the ranging tones and the time of reception, along with knowledge of the transmission delay within the spacecraft, yields the spacecraft range. Range accuracies are of order a few m [4].

Gravity Field Determination: Analysis of radio tracking data requires first the determination of precision orbits for the MRO spacecraft. The precision orbit determination process requires the full integration of the spacecraft trajectory from an initial state, with application of various physical models to account for the non-conservative forces that act on the spacecraft. The GEODYN/SOLVE programs [5] at NASA/GSFC and DPODP program [6] at the Jet Propulsion Laboratory are used in the determination of precision orbits. Both software systems employ a Bayesian least-squares approach to determine the convergence of spacecraft orbit segments referred to as arcs. In practice arcs are usually about 5-days in length.

The physical models that are utilized in the precision orbit determination process include an *a priori* gravitational model for Mars; third-body perturbations from the sun, moon, all planets in the solar system, and the Martian moons, with positions from the JPL DE410 ephemeris; relativistic correction to the force model (due to the modification of the Mars central body term) and in the measurement model (for light time and range corrections, combined with the ephemerides); the effect of the Mars solid tide, k_2; corrections for solar and Mars-reflected albedo and infrared radiation;

DSN ground station position corrections due to solid tides, ocean loading, and tectonic plate motions; corrections to the radio signal for its propagation through the troposphere, dependent on local weather; and a correction for atmospheric drag. In addition, angular momentum desaturations of the spacecraft's momentum wheels that cause small perturbations on the spacecraft orbit are also estimated.

Preliminary Observations: The early mapping mission data is non-optimal for precision analysis because of the proximity of the spacecraft to solar conjunction, which results in a relatively high level of noise due to solar plasma. Nonetheless, gravity field improvements have already been achieved thanks in part to the low orbital periapsis (~255 km) of MRO, which provides data appropriate for high-resolution spatial mapping.

Static Gravity Field: Figure 1 shows a comparison of a representative field from Mars Global Surveyor (MGS), based on more than two Mars years (~4 Earth years) of tracking observations (updated from [7]), and one month of MRO data. The MRO field was solved to 90 spherical harmonic degrees and orders and is based on 43 arcs of tracking from 08/30/06 through 10/05/06. Both MGS and MRO fields are plotted to degree and order 75 (spatial block size ~140 km). It is interesting and significant that even using a single month of MRO tracking data near solar conjunction, we obtain a field with higher signal than the MGS field. Visually, the MGS and MRO fields are not easily distinguishable.

Atmospheric Drag: Doppler tracking can be used to measure the orbital decay due to drag, which is directly related to air density [8]. The MRO Doppler tracking has a sensitivity at altitudes above those sampled by the MRO accelerometer [9], which was designed to yield high-accuracy estimations at aerobraking altitudes. Figure 2 shows a plot of atmospheric density vs. time for the time period surrounding solar conjunction. The scatter in the signal includes contributions of actual atmospheric variability and signal noise. As Mars moves farther from the sun as viewed from Earth, plasma noise will decrease and will enable reliable estimates of the dynamic variability of the Martian atmosphere.

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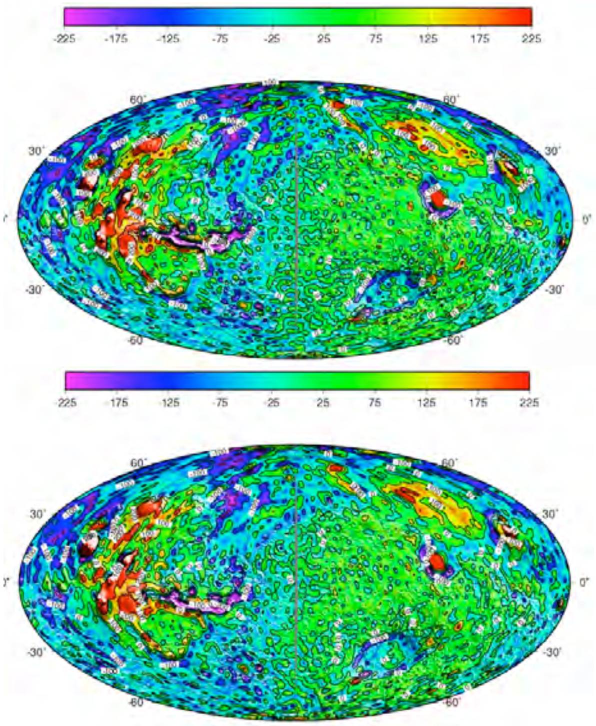

Figure 1. *(top)* An example of the best current gravitational field of Mars from MGS, based on two Mars years of tracking. Updated from [7]. *(bottom)* Mars gravity field from approximately one month of MRO tracking. Both fields are shown to degree and order 75.

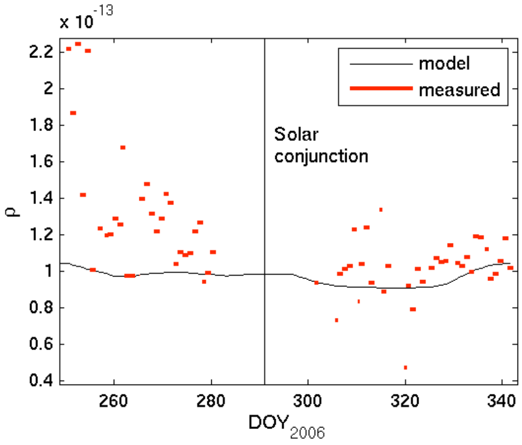

Figure 2. Plot of atmospheric density vs. time derived from MRO Doppler tracking in the time around solar conjunction. The density estimates are at an altitude of ~250 km above Mars' south pole. Shown for comparison is an atmospheric model by Stewart [9].