Summary of Personnel and Work Efforts

Individual		Year 1	Year 2	Year 3
Michael Mendillo	Effort	0.5 M	0.5 M	0.5 M
Principal Investigator	Cost	XXX	XXX	XXX
Paul Withers	Effort	4.0 M	4.0 M	4.0 M
Co-I and Science-PI	Cost	XXX	XXX	XXX
Jim Murphy	Effort	1.0 M	1.0 M	1.0 M
Co-I	Cost	XXX	XXX	XXX
NMSU Graduate Student	Effort	3.5 M	3.5 M	3.5 M
	Cost	XXX	XXX	XXX

Analysis of Accelerometer Data from Aerobraking

Summary of proposal:

We propose a three-part effort using Mars Odyssey (ODY) accelerometer (ACC) data that involves (1) data processing, (2) delivery of data products and documentation to the Planetary Data System (PDS), and (3) scientific analysis. We will derive profiles of atmospheric density along each aerobraking pass, as well as tables of density and density scale height at 5 km vertical intervals, from raw and poorly documented ODY ACC data. We will develop documentation in PDS-compliant formats, store our data products and ancillary data in PDS-compliant formats, deliver data and documentation to the PDS for peer-review, and then revise them for final deposition in the PDS archive. We will perform scientific analyses of our data products, namely a basic survey, correlation with solar output, polar mapping, and numerical simulations, and publish them as an introduction to the scientific potential of the dataset for other workers. Early results will be delivered to the Mars Reconnaissance Orbiter Project to support their aerobraking in March-September, 2006. Our results will be important for the success of future NASA missions. They will be useful for planning and performing aerobraking, for targeting high-resolution cameras from 200 km altitude, and for deciding when an orbiter must be raised to a parking orbit.

A. OBJECTIVES AND SIGNIFICANCE OF PROPOSED WORK

We propose a three-part effort using Mars Odyssey (ODY) accelerometer (ACC) data that involves (1) data processing, (2) delivery of data products and documentation to the Planetary Data System (PDS), and (3) scientific analysis. We will derive profiles of atmospheric density along each aerobraking pass, as well as tables of density and density scale height at 5 km vertical intervals, from raw and poorly documented ODY ACC data. We will develop documentation in PDS-compliant formats, store our data products and ancillary data in PDS-compliant formats, deliver data and documentation to the PDS for peer-review, and then revise them for final deposition in the PDS archive. We will perform scientific analyses of our data products, namely a basic survey, correlation with solar output, polar mapping, and numerical simulations, and publish them as an introduction to the scientific potential of the dataset for other workers.

The Atmospheres Node of the PDS has received two deliveries of ODY ACC data. Measurements of density and temperature at 110 and 120 km were delivered in August 2002 (Raw Dataset #1). They were "mostly undocumented" and have not been peer-reviewed yet (PDS, 2005d). A larger dataset was delivered in January 2005 (Raw Dataset #2). It is also poorly documented; its format and structure are not consistent with PDS standards. It has not been peer-reviewed yet. Successful completion of this proposal will ensure that the ODY ACC dataset is documented and peer-reviewed, thus making it available to the scientific community via the PDS.

The ODY ACC instrument is not discussed in the NRA. We have verified with the Program Scientist that proposals concerning this instrument will not be rejected as non-responsive. The main operational phase of the ODY ACC instrument has ended, like that of MARIE, so we do not propose the collection of additional ACC data. However, our proposed work does have strong operational components, including support for MRO, planning the end of ODY's mission, and calibration of data. Our data reduction and archival tasks cannot be funded through a research and analysis program.

Density and other atmospheric properties can be derived from ODY ACC data for each aerobraking pass through the atmosphere (Keating et al., 1998). Thermospheric densities will be obtained between about 100 and 150 km altitude (Tolson et al., 2002, 2005). The martian thermosphere is not well-understood at present (Bougher et al., 2002; Bruinsma and Lemoine, 2002; Forbes, 2004a; Fox, 2004; Angelats i Coll et al., 2005). We do not have a clear picture of its dynamics, its composition, its coupling to the lower atmosphere, nor its energy balance and thermal structure. We do not know how these properties vary with altitude, latitude, longitude, local solar time (LST), season (Ls), interannual variability, or the solar cycle (Bougher et al., 1988, 1990, 1991, 1999, 2000; Fox et al., 1996; Fox, 2004; Krasnopolsky, 2002; Angelats i Coll et al., 2005).

The 100 to 150 km altitude region spans or is close to the exobase (~200 km), the homopause (~125 km), the ionosphere (100-200 km), and the region where upwardly propagating tides break (100-150 km, Forbes, 2004a) . Scientifically important atmospheric processes are associated with these four levels. It is not possible to understand the escape of water from Mars without an understanding of the thermosphere near the exobase (Krasnopolsky, 2002). Nor is it possible to understand the full impact of tides on the dynamics of the martian atmosphere without an understanding of how they break in the thermosphere and of how their energy and momentum are dissipated into the background atmosphere (Forbes et al., 2002).

This atmospheric region is also important for the success of future NASA missions. Atmospheric models can be improved by validation against the ODY ACC observations once the observations are properly archived on the PDS (Bougher et al., 2000; Justus et al., 2000; Bruinsma and Lemoine, 2002; Angelats i Coll et al., 2005). NASA uses these atmospheric models to plan and perform aerobraking, to target high-resolution orbital cameras from 200 km altitude, and to determine whether an orbiter can continue performing science or whether it must be raised to a parking orbit (Dwyer et al., 2002; Lyons, 2002; Hanna Prince and Striepe, 2005). Future human missions to Mars and robotic missions that support them will require significant improvements in our ability to predict the state of the martian upper atmosphere.

Mars Reconnaissance Orbiter is scheduled to aerobrake from March to October 2006. We will generate approximate density profiles as quickly as possible at the start of this project and offer them to the MRO project in support of their risky aerobraking activities. One of ODY's goals for its extended mission involves "operational support for critical phases of future missions," including "atmospheric monitoring for aerobraking" (p6, JPL, 2004).

This proposed work builds on extensive past experience, acquired at no cost to this proposal. Co-I Withers participated in the Atmospheric Advisory Group (AAG) for MGS and ODY, in which scientists advised mission managers about the state of the atmosphere, as a student of AAG member Steve Bougher. Co-I Murphy was also a member of the AAG for MGS and ODY, so we are familiar with the ODY mission operations during aerobraking, the ACC instrument performance and data quality, and the state of the atmosphere during aerobraking. We have software and tools already available to speed our data processing, data archiving, and scientific analysis tasks, as demonstrated in the subsequent figures. Co-I Withers has developed software to derive atmospheric densities from accelerometer measurements. He used it as a Huygens HASI/ACC team member and as a MER Atmospheric Advisory Team member (Fulchignoni et al., 2002, 2005; Withers and Smith, 2005). Co-I Murphy has chaired several PDS peer-review panels as the representative of the PDS Atmospheres Node, including the MGS and MER ACC datasets. He has developed PDS documentation and formatted PDS data products for several datasets. Co-I Withers participated in the peer-reviews of the MGS and MER ACC datasets. Co-I Withers scientifically analysed MGS ACC data for his PhD dissertation (Withers, 2003; Withers et al., 2003a). He will also analyse MGS and ODY ACC data under an MDAP grant to PI Mendillo concurrent with the first year of this proposed work.

This proposed work is relevant to the NASA strategic objectives that state: "enable and support sustained human and robotic exploration of Mars", "conduct robotic exploration of Mars", and "acquiring adequate knowledge about [Mars] using robotic missions" (Table 1, Summary of Solicitation of this NRA).

B. INVESTIGATION AND TECHNICAL PLAN

ODY underwent Mars Orbit Insertion into a highly elliptical (e~0.8) orbit with an 18.6 hour period on 24 October 2001 (Smith and Bell, 2005; Tolson et al., 2002, 2005). ODY's periapsis was carefully lowered into the atmosphere over the first few orbits, remaining below 140 km from orbit P007 until the final aerobraking pass, orbit P336, on 11 January 2002. ODY's orbital period was reduced to 2 hours as a result of the 77 days of aerobraking.

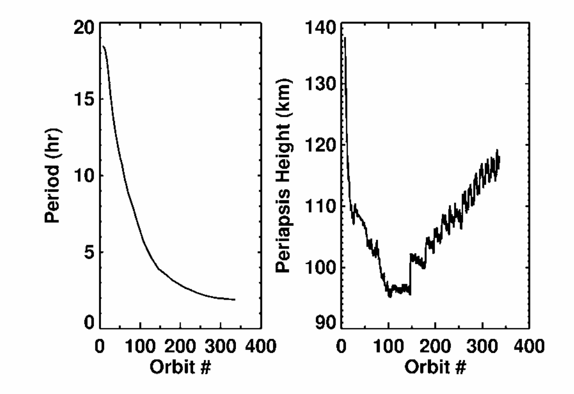

Figure 1 - Period and periapsis altitude vs. orbit number, extracted from the AAG Quick Look Reports.

The ODY ACC dataset is not merely a duplication of previous MGS measurements; it extends the coverage of that dataset in latitude, season, LST, and time within the solar cycle (Bougher et al., 2003, 2004a; Keating et al., 2003a, 2003b). ODY's aerobraking differed from that of MGS in several important respects. Since ODY's solar panels were not broken, ODY was able to fly deeper into the atmosphere than MGS was (Keating et al., 1998). MGS's density measurements were dominated by regular variations in density with longitude in the near-sun-synchronous orbit, now known to be non-migrating tides propagating upwards from the martian surface, whereas ODY's density measurements exhibit irregular variations with longitude (Joshi et al., 1999; Forbes and Hagan, 2000; Wilson, 2002; Withers et al., 2003a). In some cases, these variations appear to have a well-defined 17° per day eastward phase drift in ODY's near-sun-synchronous orbit (Tolson et al., 2005). The dominant tides in the MGS and ODY ACC datasets are different. ODY's periapsis passed through the north polar region, which was characterized by low densities, low variability, and high temperatures (Keating et al., 2003c). MGS did not observe similar phenomena when it passed through the south polar region (Bougher and Murphy, 2003).

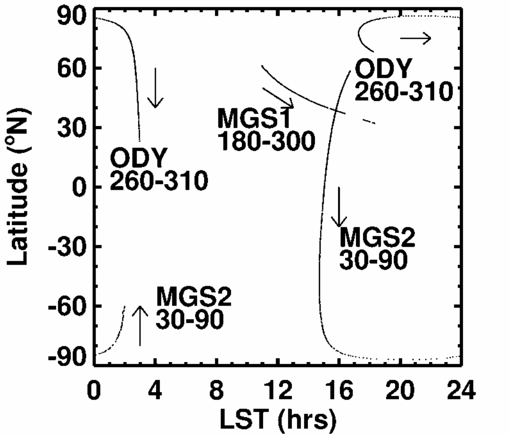

Figure 2 - Latitudes and LSTs of MGS and ODY periapses, with Ls indicated. ODY data extracted from Quick Look Reports.

We presume that we shall coordinate our activities and analyses with the ODY Project Office at JPL, unlike GRS, MARIE, or THEMIS participating scientists who will work closely with the respective instrument PIs and science teams. This is because the ODY ACC is an "engineering instrument", not a "science instrument". It does not have a science team. Funding of the accelerometer operations team at NASA-Langley, led by Dr. Keating, and the AAG was focused on operational activities during aerobraking. By contrast, the science teams associated with GRS, MARIE, and THEMIS were expected and funded to archive their data with the PDS, publish scientific papers, and operate their instruments. These teams are still funded. This "engineering instrument" status is partially responsible for the lack of peer-reviewed publications and archived datasets from the ODY ACC instrument, which the proposal will address. This proposed work cannot be accomplished through a NASA research and analysis program, because they will not fund work on data that is not publicly available through the PDS.

B.I Data Processing

We propose to generate scientifically useful data products using Raw Dataset #2. We will also require some ancillary data from the ODY project.

B.I.1 Determine Trajectory. The trajectory of ODY through the atmosphere can be calculated accurately from its Keplerian orbital elements at periapsis because atmospheric drag has only a small effect on the trajectory close to periapsis. The aerodynamic acceleration on ODY is so small, ~0.05 m s^{-2} for v=5 km s^{-1} and density=10 kg km^{-3}, that v/a ~ 1 day, whereas each aerobraking pass lasts only a few minutes. We shall use these orbital elements to determine the position and velocity of ODY as a function of time along each aerobraking pass through the atmosphere. As ODY AAG members, we have access to tabulated orbital elements in file Nav_reconstr_thru_P338.xls on JPL's MMONT1 server. Each profile will be near-meridional, except when crossing the polar region, due to ODY's nearly sun-synchronous orbit. For instance, orbit P010 spanned nearly 20° in latitude below 150 km altitude and orbit P300 spanned nearly 60° below 150 km altitude.

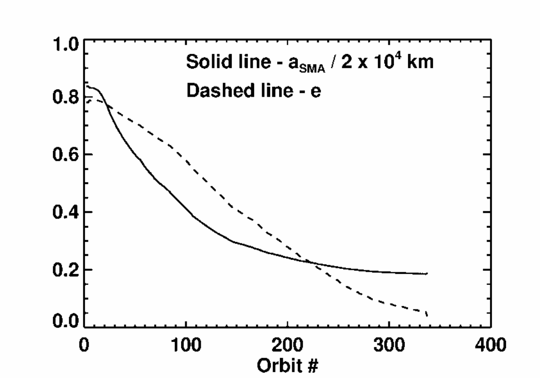

Figure 3 - Some of ODY's orbital elements for each orbit. Semi-major axis, a_{SMA}, and eccentricity, e, from JPL's file Nav_reconstr_thru_P338.xls

B. I. 2 Generate Rapid Data Products for MRO. MRO will aerobrake in ~480 orbits from March to September, 2006, which spans Ls=20-100. Its periapsis will mainly be in the southern hemisphere and its LST will decrease from 8 hrs to 3 hrs (Lyons, 2002; Hanna Prince and Striepe, 2005).

The basic equation relating density to acceleration in a given direction is:

$$m\,a = \rho\,v^2\,C\,A / 2 \qquad (1)$$

where m is ODY's mass, a is acceleration, ρ is density, v is the speed of ODY relative to the atmosphere, C is a numerical coefficient, and A is ODY's reference area. According to Smith and Bell (2005), m=460 kg at the start of aerobraking and A=11 m^2. We will need m as a function of time from the ODY Project. C for flow conditions experienced during aerobraking and directions close to the flow direction is within 10% of 2 (Takashima and Wilmoth, 2002, 2003; Tolson et al., 2005). We shall make a rapid estimate of atmospheric density as a function of position and time along each aerobraking pass. We shall use C=2, m, A, and position and inertial velocity from the trajectory determined in Section B.I.1. We shall use raw ACC data from file pXXXacc.txt in Raw Dataset #2, selecting measurements along the y-axis, which is almost parallel to the nominal flow direction. We shall provide profiles based on raw 1 Hz data, 7 point means, and 39 point means to give a series of vertical resolutions and vertical ranges, as discussed in Section B.I.5. The resultant density profiles, Data Product #1, will be made available to the MRO project via a website or FTP server. They can be supplied to MRO within one month of receipt of the necessary data.

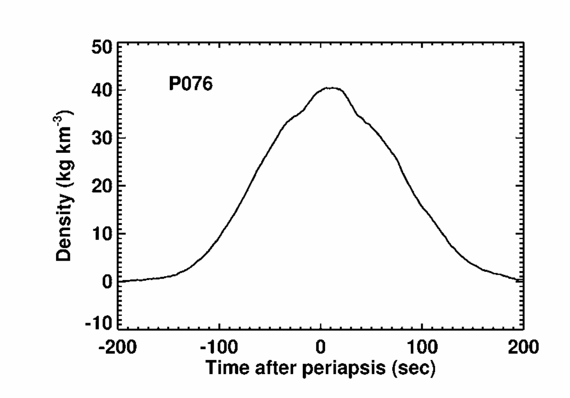

Figure 4 - Preliminary density profile for orbit P076 using m=460 kg, A=11 m^2, v=value at periapsis, $(GM/a_{SMA} \times (1+e)/(1-e))^{0.5}$, C=2, and 39 point mean accelerations from p076acc.txt in Raw Dataset #2. This is consistent with Figure 10 in Tolson et al. (2005).

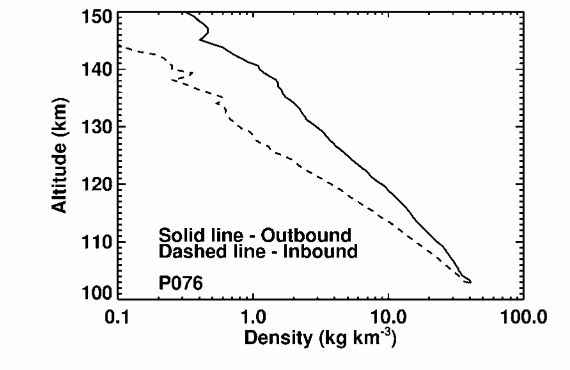

Figure 5 - As Figure 4, but vs. altitude. Altitude above 3379 km generated from a_{SMA} and e. Inbound densities are lower than outbound because the inbound leg is further poleward. The latitudes of the inbound and outbound legs at 150 km are 84N and 65N, respectively. This is consistent with Figure 11 in Tolson et al. (2005).

B.I.3 Reduce ODY ACC Data. Data Product #1 will be inaccurate. This will be due in part to non-aerodynamic contributions to the measured accelerations. We will reduce the 3-axis measured accelerations (file pXXXacc.txt in Raw Dataset #2) to aerodynamic accelerations by correcting for (a) attitude control system (ACS) thruster activity, (b) effects of rotational motion, and (c) instrument bias (Tolson et al., 1999, 2002, 2005). File pXXXthot.txt in Raw Dataset #2 records which of the four ACS thrusters is on at any time. As discussed by Tolson et al. (2005), these accelerations are not very repeatable and may be difficult to remove. If the ODY project can provide us with the vector acceleration caused by each thruster when it fires, then we shall remove this effect (Chavis and Wilmoth, 2005; Hanna Prince et al., 2005). If this information is not readily available, then we will request that JPL obtain it by firing the ODY thrusters whilst monitoring the ODY ACC and gyroscopes during orbits dedicated to this task. Since the accelerations caused by thrusters are two orders of magnitude smaller than those caused by drag at periapsis, our profiles will be limited to about 4 scale heights above periapsis if they cannot be removed (Tolson et al., 2005).

The effects of rotational motion will be removed using the measured angular rates from file pXXXrate.txt in Raw Dataset #2 (Tolson et al., 2005). Instrument bias will be removed by calculating the mean acceleration before and after each aerobraking pass. The uncertainty in the reduced acceleration will be calculated from the scatter in the acceleration data before and after each aerobraking pass. Likely uncertainties are 0.16 mm s^{-2}, 0.25 mm s^{-2}, and 0.50 mm s^{-2} for orbits P007-136, P137-268, and P269-336, respectively (Tolson et al., 2005). The changes are due to changes in onboard software. The reduced aerodynamic accelerations are Data Product #2.

B.I.4 Determine ODY attitude. The aerodynamic characteristics of ODY, specifically C in Eqn. 1, depend upon its attitude (Tolson et al., 2005). We will determine ODY's attitude with respect to the flow direction using its orientation and velocity. File pXXXquat.txt in Raw Dataset #2 gives the orientation of the ODY spacecraft-fixed reference frame in terms of quaternions with respect to a Mars-centred J2000 coordinate frame. The trajectory derived in Section B.I.1 gives the direction of the ODY velocity vector in an inertial frame, which can be transformed in the Mars-centred J2000 coordinate frame. Assuming that the atmosphere rotates with the rigid body of Mars, the wind can also be expressed in this coordinate system.

B.I.5 Derive density profiles. The above steps provide all the information necessary to determine density profiles, except C. The dependence of C on attitude and density is quantified in ODY's aerodynamic database, which was generated before aerobraking by NASA engineers (Takashima and Wilmoth, 2002, 2003; Tolson et al., 2005). We will need a copy of the aerodynamic database provided to us by the ODY project. We will then use Eqn. 1 to iteratively determine density profiles from reduced aerodynamic accelerations along the spacecraft y-axis (Withers et al., 2003b; Tolson et al., 2005). Accelerations along this axis, which parallels the nominal flow direction, have greater signal-to-noise than those along the other axes. The minimum detectable density, which will be about $m \sigma_a / (v^2 A)$, will increase with time as v and a_{SMA} decrease and σ_a increases. We shall calculate uncertainties in density using the uncertainty in acceleration.

Using the raw 1 Hz data gives vertical resolution of <1 km, but noise limits useful results to within about 2 scale heights of periapsis. Averaging the ACC data reduces the noise and increases the vertical range, but at the cost of worse vertical resolution. We will average the ACC data in two ways to (a) preserve small-scale features and (b) maximize the vertical range. We will use 7 point and 39 point means with vertical resolutions of ~2 and ~8 km, respectively, and vertical ranges of ~30 and ~ 50 km, respectively. This will also make our results consist with the MGS ACC PDS archive. We will average accelerations then derive density profiles. We will not average one density profile to obtain another density profile. We will archive the 1 Hz density profiles for completeness and because they will be most sensitive to any unusual spacecraft behaviour. We will express altitude in terms of the ODY project's preferred reference areoid and use areocentric latitudes and longitudes. The derived density profiles are Data Product #3.

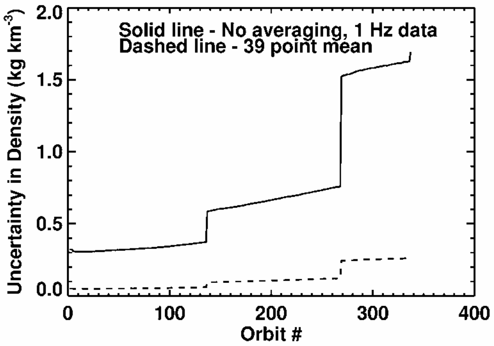

Figure 6 - Uncertainty in density for 1 Hz data and 39 point mean using σ_a from Tolson et al. (2005) and v=value at periapsis.

B.I.6 Validate density profiles. We shall validate our density profiles by comparison against (a) Quick-Look Reports, (b) Quick-Look $\rho(z)$ plots, and (c) published engineering papers. Quick-Look Reports were generated during aerobraking within a few hours of the ACC data reaching Earth and distributed to the AAG. We have copies from our service on the AAG as well as from access to the archive on JPL's MMONT1 server. They tabulate density at periapsis and 150 km (inbound and outbound) for each orbit. Results shown in our Figure 5 can be compared to the P067 Quick-Look Report values of periapsis density (39.701 kg km^{-3}), inbound density at 150 km (0.047 kg km^{-3}), and outbound density at 150 km (0.214 kg km^{-3}). The periapsis and outbound results are very consistent, but the inbound result, which is much smaller, is not. This is because our Figure 5 does not include the data reduction process described in Sections B.I.3-5.

Quick-Look ρ(z) plots accompanied the Quick-Look Reports for most orbits. Several papers concerning ODY ACC data have been published in engineering journals, some of which show plots of atmospheric properties (Takashima and Wilmoth, 2002; Tartabini et al., 2002; Smith and Bell, 2005; Tolson et al., 2005). We will extract density profiles from these plots and quantitatively compare them to our derived profiles.

B.I.7 Derive atmospheric properties at fixed altitude. Many scientific uses of the ODY ACC data will benefit from atmospheric properties at fixed altitude. We shall fit an exponential function to all density measurements from a given profile within 5 km of a reference altitude and record the fitted density and density scale height, with uncertainties, at the reference altitude. We shall use the 39 point mean profiles to maximize the vertical range of our data products. The uncertainties will be derived using least-squares error analysis (Bevington, 1969). Density scale heights will be converted into temperatures assuming an isothermal atmosphere and mean molecular masses from publicly available simulations that were generated in preparation for ODY aerobraking (Bougher 2001, Withers et al., 2003b). Reference altitudes will range from 100 to 150 km and be 5 km, or about half a scale height, apart to provide sub-scale height resolution. Uncertainty in density at a fixed altitude with be on the order of the uncertainty in the density profile at that altitude divided by the square root of the number of measurements used in the fit. The relative uncertainty in the density scale height at a fixed altitude will be on the order of the relative uncertainty in the density profile at that altitude. The derived densities, scale heights, and temperatures are Data Product #4.

B.I.8 Ancillary data. The above data processing requires ancillary data, including orbital elements for each orbit (source: Nav_reconstr_thru_P338.xls or equivalent), spacecraft reference area (Smith and Bell, 2005), spacecraft mass for each orbit (ODY Project), IMU position in spacecraft reference frame (Tolson et al., 2005), instrument bias for each orbit (determined by us in Section B.I.3), effects of ACS thrusters (ODY project), aerodynamic database (ODY project), and description of reference areoid (ODY project). We do not expect any of the items that we require from the ODY project to be ITAR-sensitive. We shall combine these items into Data Product #5.

B.II Data Archiving

B.II.1 Content of Data Products. Since many of these items will be repeated, we use the following abbreviations in this section: D/T = UTC date and time, t = time after periapsis, lat = latitude, lon = longitude, r = radial distance, v = speed, ρ = density, ay = y-axis acceleration, a3 = 3-axis acceleration, σ = uncertainty, 7pm = 7 point mean, 39pm = 39 point mean, ρfit = fitted density, Hfit = fitted density scale height, and Tfit = fitted temperature.

Each entry in Data Product #1 will include D/T (20 characters), t (10), lat (10), lon (10), r (10), v (10), 1 Hz ay (10), 1 Hz ρ (10), 7pm ay (10), 7pm ρ (10), 39pm ay (10), and 39pm ρ (10).

Each entry in Data Product #2 will include D/T (20 characters), t (10), lat (10), lon (10), r (10), 1 Hz raw a3 (30) 3-axis angular rate (30), a3 due to angular motion (30), a3 due to thrusters (30), bias in a3 (30), 1 Hz reduced aerodynamic a3 (30), and σ in 1 Hz reduced aerodynamic a3 (30).

Each entry in Data Product #3 will include D/T (20 characters), t (10), lat (10), lon (10), r (10 characters), altitude (10), LST (10 characters), SZA (10), 1 Hz reduced aerodynamic ay (10), σ in 1 Hz reduced aerodynamic ay (10), 7pm reduced aerodynamic ay (10), σ in 7pm reduced aerodynamic ay (10), 39pm reduced aerodynamic ay (10), σ in 39pm reduced aerodynamic ay (10), ODY attitude (10), C (10), 1 Hz ρ (10), σ in 1 Hz ρ (10), 7pm ρ (10), σ in 7pm ρ(10), 39pm ρ (10), and σ in 39pm ρ (10). LST and SZA will be calculated using JPL's Horizons server and other online resources.

Data Products #1-#3 will each include one ASCII file for each of the ~300 aerobraking orbits. Each of these file will contain results every 1 s. Data will cover the period during which the reduced 39 point mean aerodynamic acceleration consistently exceeds its uncertainty, approximately 500 seconds per orbit, giving 500 entries per file. The maximum altitude will vary, but should be ~150 km. The estimated size of Data Product #1 is 300 orbits x 500 entries per orbit x 130 characters per entry = 2 million characters or bytes. The estimated sizes of Data Products #2 and #3 are 4 million and 3.5 million bytes, respectively.

Data Product #4, the fixed altitude atmospheric properties, will consist of one ASCII file for each of ~10 reference altitudes. Each file will contain one entry for each of the ~300 aerobraking orbits. Each entry in the file will include D/T (20 characters), lat (10), lon (10), LST (10), SZA (10), Ls (10), ρfit (10), σ in ρfit (10), H (10), σ in Hfit (10), Tfit (10), σ in Tfit (10), and mean molecular mass (10). The approximate size of Data Product #4 is 10 reference altitudes x 300 entries per altitude x 140 characters per entry = 0.4 million characters or bytes. Ls will be calculated using JPL's Horizons server and other online resources.

Data Product #5, a collection of ancillary data, will be organized and structured in consultation with the PDS. It should be smaller in size than the other Data Products.

B.II.2 PDS Deliverables. We shall deliver Data Product #1 to the MRO Project. We shall archive Data Products #2-#6 at the PDS in two volumes. Volume A will contain Data Products #2-#3 and Volume B will contain Data Products #4-#5. We shall follow the PDS standards for formatting, documentation, directory structure, delivery media, and so on (PDS, 2005a, b, c). Our documentation will fall into two classes: (1) documentation of the processing we have performed on Raw Dataset #2, which will be detailed and complete, and (2) documentation of Raw Dataset #2, the ACC instrument, and mission operations during aerobraking, which will be based on published papers, any documentation accompanying Raw Datasets #1 and #2, and ODY project documents. The second class of documentation will not be as accurate nor as complete as the first class. Each file in the Data Products will be delivered as ASCII files with detached labels, with each Data Product having a separate subdirectory within the DATA directory. Documentation will include an upper-level README file (general introduction), INDEX files listing each file containing data, CATALOG files, and DOCUMENT files. CATALOG files will include a description of each Data Product, similar to altds.cat and profds.cat in the MGS ACC archive, lists of personnel and references, descriptions of the ODY spacecraft and mission (provided by the ODY project), and a description of the instrument. DOCUMENT files will include a software interface specification (SIS). The instrument description and parts of the SIS file will fall into our second class of documentation. We expect the structure of our delivery to be similar to that of the MGS ACC volume MGSA_0002.

The sequence of major events leading up the peer-review of each of our volumes will be as follows: generate data products; generate documentation; format data products, documentation, and associated labels; organize files into correct structure; create high-level index files; deliver preliminary volume to PDS Atmospheres Node on CD for review; assist PDS in preliminary verification of correct format and documentation. The PDS will then organize the peer-review. We presume that peer reviewers will submit reports to the PDS electronically, then participate in a telecon that will recommend a list of changes. After we make these changes, we shall submit our revised volume to the PDS on CD. After any final checks by the PDS, it will be deposited into the PDS archive and made publicly available.

ODY aerobraking finished in January 2002. Raw Datasets #1 and #2 were delivered to the PDS in August 2002 and January 2005, respectively. We will deliver our processed data products to the PDS within 6 months of generating them, consistent with the Mars Odyssey Data Policy.

B.III Science

Our scientific analyses are designed to explore the dataset, identify interesting features and phenomena, and provide a firm foundation for the future research and analysis of other workers. We have previous experience analysing MGS and ODY ACC data (Withers, 2003; Withers et al., 2003a; Withers et al., 2005c)

B.III.1 Previous Studies. There is a close dynamical coupling between the lower and upper atmosphere at Mars (Keating et al., 1998; Joshi et al., 1999; Forbes and Hagan, 2000; Bougher et al., 1999a, 2001, 2004b). Densities in the upper atmosphere have been observed to double within a few days in response to regional-scale dust storms on the other side of Mars (Keating et al., 1998). The strong response to the entire martian atmosphere to dust storms is unique in comparative planetology (Gierasch and Goody, 1972; Zurek and Leovy, 1981; Zurek et al., 1992; Leovy, 2001). It is an extreme example of the basic processes of radiative transfer and atmospheric dynamics that occur in all atmospheres.

Studies of the martian lower atmosphere have shown that thermal tides, a common atmospheric phenomenon, are very strong on Mars (Conrath, 1981; Haberle et al., 1993; Wilson and Hamilton, 1996; Smith et al., 2001). MGS discovered that tides are even stronger in the upper atmosphere and observed that densities varied by a factor of two, and occasionally a factor of four, with longitude due to thermal tides propagating upwards from the martian surface (Withers, 2003; Withers et al., 2003a). Some migrating tides are seen as fixed in longitude when observed from the near-sun-synchronous orbits of MGS and ODY (Forbes and Hagan, 2000; Forbes et al., 2002). These tides break in the thermosphere, which makes ACC measurements in the 100 - 150 km range ideal for quantifying their contributions to the energy and momentum budgets of the atmosphere (Wilson 2000, 2002; Forbes et al., 2002; Forbes, 2002, 2004b, 2005). Since the upward propagation of different tidal modes is controlled by the wind in the lower and middle atmosphere, the presence or absence of tidal modes indicates the wind regime below the thermosphere (Angelats i Coll et al., 2004).

Processes with smaller scales are also important. Along-track variations in density have been studied, both well-behaved oscillations and step-like changes (Tolson et al., 1999, 2005; Forbes, 2003; Fritts, pers. comm., 2005). The well-behaved along-track oscillations are gravity waves. The step-like changes, during which density can change by over 50% over 15 km horizontally and 1 km vertically, are more mysterious.

Solar EUV and X-ray photons are absorbed in the thermosphere. MGS ACC observed near-doubling of density at 160 km around orbit P090 that appeared to be associated with an increase in solar EUV flux (Keating et al., 1998). In our ionospheric work, we have observed dramatic increases in ionospheric electron density at 110 km due to increased X-ray fluxes during solar flares (Withers et al., 2005b). Are neutral atmospheric properties also affected by flares? Studies of the thermospheric response to changes in solar EUV and X-ray flux will improve our understanding of the thermosphere's energy balance. The effects of solar outbursts, which often include enhanced fluxes of X-rays and energetic particles, are operationally important to NASA. This was illustrated by the loss of MARIE during a solar particle event.

Preliminary studies of the ODY ACC dataset have concluded that the north polar warming that was observed in the thermosphere was due to "dynamical heating associated with a meridional circulation cell from the summer hemisphere into the winter polar region" (Keating et al., 2004). No such warming was observed at the southern winter pole during MGS aerobraking, illustrating that the martian seasons are not symmetric (Bougher et al., 2003). This is well-known for the lower atmosphere and is usually attributed to changing distance from the Sun and the large pole-to-pole topographic gradient (Richardson and Wilson, 2002). The polar warming was not predicted by either empirical or physics-based models used by NASA during ODY aerobraking (Justus et al., 2000; Bougher, 2001; Keating et al., 2003c).

We shall perform four scientific tasks: a basic survey, a correlation with solar output, a polar mapping exercise, and running supporting numerical simulations.

B.III.2 Basic Survey. We shall investigate basic trends in density, density scale height, and temperature at fixed altitude in the ODY ACC dataset and compare our results to the MGS ACC dataset (Bougher et al., 1999a). Latitudinal trends can be studied using the later ODY orbits, when 60° latitude separated the inbound and outbound legs at 150 km. Diurnal variations can be studied using the early ODY orbits (60N, 18 hrs LST) and the later ODY orbits (60N, 03 hrs LST). Interannual variations can be studied using the MGS Phase 1 data from 1997 (periapsis at 30N, higher altitude data to the north, 18 hrs LST, Ls~300) and the early ODY data from 2001 (periapsis at 60N, higher altitude data to the south, 18 hrs LST, Ls~300).

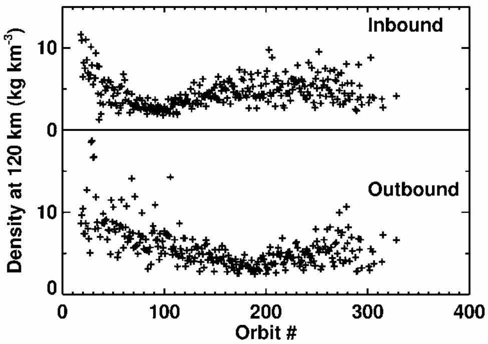

Figure 7 - Inbound and outbound density at 120 km from Raw Dataset #1. Note low polar densities and variabilities (P100 inbound, P200 outbound) and latitudinal differences between inbound (30N) and outbound (56N) around P280.

This work will contribute to "characteriz[ing] and document[ing] as fully as possible the state of the martian atmosphere as a function of season, latitude, longitude, and local time," which is part of the THEMIS extended mission science objectives (p29, JPL, 2004). Much of the subsequent justification of that objective in JPL (2004), such as the annual cycle and its variability, and the relationship between atmospheric dust and thermal structure, can be directly connected to the ODY ACC dataset. ODY GRS calibration requires correction for atmospheric attenuation that depends on the integrated thickness of the atmosphere. Improving this correction is an ODY GRS extended mission science objective (p35, JPL, 2004). The contribution of the lower atmosphere to this correction has been calculated from models and MGS Thermal Emission Spectrometer (TES) observations. Though densities at >100 km are not particularly important for this calibration, interpolation between ODY ACC data at high altitudes and atmospheric properties at low altitudes could be helpful for improving the correction due to the middle atmosphere, for which few observations are available.

B.III.3 Correlation with Solar Output. We shall inspect our density and density scale height results at fixed altitudes to identify occasions when these properties increase or decrease significantly on both the inbound and outbound legs of a given aerobraking pass. Changes driven by solar forcing should occur on both legs simultaneously. We shall correlate any such changes with time series of solar EUV and X-ray fluxes to identify atmospheric changes that can be attributed to the Sun's output. Time series of solar EUV fluxes and flux proxies are available from the Solar2000 model (Tobiska et al., 2000) and time series of X-ray fluxes in the 0.5-3 A and 1-8 A range are available from the GOES satellites (GOES, 2005). These fluxes are measured at Earth, so we shall scale them to the Sun-Mars distance and time-shift them to account for the ~5 days taken for the Mars-facing solar hemisphere to rotate 60° to face the Earth (Withers and Mendillo, 2005). Earth-Sun-Mars angles are available from JPL's Horizons server.

The response of the martian thermosphere to changes in solar forcing was noted by Keating et al. (1998) in MGS ACC data. Our Figure 8 shows a similar response in MGS ODY data. High inbound and outbound densities on December 19th correlate with high solar flux.

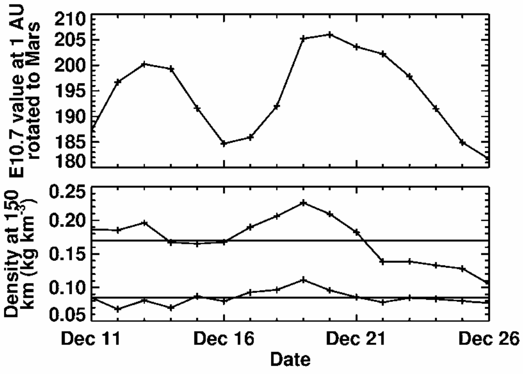

Figure 8 - Top: E10.7, a solar flux proxy at 1 AU, shifted in time by 5 days to represent flux incident on Mars, not Earth. Bottom: 3-day average of inbound (~0.1 kg km^{-3}) and outbound (~0.2 kg km^{-3}) densities at 150 km extracted from Quick Look Reports.

B.III.4 Polar Mapping. Large portions of many of ODY's aerobraking passes were spent in the north polar region. The central core of the polar region was distinctly different from the surrounding mid-latitude region and had higher temperatures, lower densities, and lower variabilities (Bougher et al., 2003; Keating et al., 2003a, b, c, 2004). The boundary of this region was around 80N (Tolson et al., 2005). Periapsis was poleward of 80N for orbits P080 to P166 and poleward of 70N for orbits P019 to P205. The along-track distance between 105 km and 115 km altitude for most of these orbits was 200-300 km inbound and the same for outbound. We shall use the fitted density and density scale height at 110 km to estimate densities at 110 km for latitudes and longitudes where the aerobraking pass was between 105 and 115 km. We shall build up a contour map of density as a function of latitude and longitude in the polar region from many orbits. Figure 9 illustrates the excellent coverage. We shall take care not to include too wide a range of SZA or LST in these maps. This will be repeated for several reference altitudes. The results will be useful for understanding the polar region and will guide the modelling work of other groups. This work will contribute to understanding the energy balance of the polar regions, part of the THEMIS extended mission science objectives (p28, JPL, 2004). If the north polar warming is due to meridional circulation, then it will involve the whole atmosphere, not just the thermosphere. This meridional circulation can also be related to the growth and retreat of the CO_2 polar cap, the study of which is part of the GRS extended mission science objectives (p31, JPL, 2004). The state of the polar atmosphere, specifically its argon mixing ratio and related transport processes, is also part of the GRS extended mission science objectives (p34, JPL, 2004).

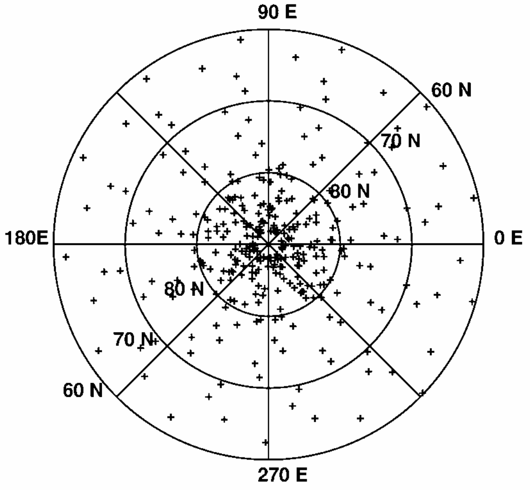

Figure 9 - Latitudes and longitudes of periapses.

B.III.5 MGCM Simulations: We shall use the NASA-Ames Mars General Circulation Model (MGCM) to simulate the martian atmosphere between 0 and 90 km for the ODY aerobraking period (Haberle et al., 1993). These simulations will incorporate spatial and temporal variations in dust opacities based on TES observations (Smith et al., 2001). The predictions of the dynamics and thermal structure of the lower atmosphere will be used to interpret the ODY ACC observations of the thermosphere. This will support our Basic Survey and Polar Mapping tasks.

C. IMPACT OF THIS WORK AND RELEVANCE TO NASA PROGRAMS

The ODY ACC dataset will serve as valuable context for the interpretation of a variety of other NASA-supported observations, including studies of MGS RS ionospheric profiles (Bougher et al., 2001, 2004b); drag on MGS during its Science Phasing Orbits (Tracadas et al., 2001); drag on MRO during its mapping orbit; Mars Express (MEX) SPICAM observations, including vertical profiles of CO_2 number density and airglow observations (Bertaux et al., 2005); and MEX ASPERA energetic neutral atom observations, since the thermosphere is the source region for many of these ENAs (Barabash et al., 2004; Lundin et al., 2004). One of the themes “common to the extended mission science plans” is interannual variability, to which MGS/ODY ACC comparisons are relevant (p8, JPL, 2004).

This work will ensure that the results of the ODY ACC instrument become available on the PDS in a form that is useful to the scientific community, which is highly relevant to the goals of the ODY mission. The scientific community can then use this dataset to study important questions in Mars science, including questions related to escape, atmospheric dynamics, and atmospheric energy balance. This will lead to improved atmospheric modelling capabilities (Bougher et al., 2002; Bruinsma and Lemoine, 2002; Forbes, 2004a; Fox, 2004; and Angelats i Coll et al., 2005). Both the ODY ACC atmospheric observations and the improved models will be useful to future NASA missions in areas such as planning aerobraking, performing aerobraking, targetting instruments, and parking retired orbiters (Dwyer et al., 2002; Lyons, 2002; and Hanna Prince and Striepe, 2005).

We believe that this proposal is cost-effective. We have become familiar with the ODY spacecraft, its aerobraking operations, and its Quick-Look data products, we have developed software that can be used for the data processing tasks, Co-I Murphy has acquired expertise in PDS policies and procedures, and Co-I Withers has developed tools for scientific analysis - all at no cost to this proposal.

We have proposed a multi-year effort. This is because we are not proposing to join an existing ODY science team, such as the THEMIS team, which already has an established data processing procedure, a PDS delivery pipeline with settled formats and documentation, and a program of ongoing scientific research. The ODY ACC dataset cannot be reduced and archived on the PDS in a single year. If we are funded for one year only, we will complete the Year 1 tasks laid out in our Work Plan and put Data Products #2 and #3 (reduced accelerations and density profiles) on a public website.

This proposed work is very relevant to NASA's goals and objectives. Relevance to NASA's Strategic Objectives was stated earlier (Section A). It is relevant to the Mars Exploration Program Analysis Group (MEPAG) goals of "Understanding the processes and history of climate on Mars" and "Prepare for human exploration." It is relevant to the MEPAG objectives of "Characterize Mars' atmosphere, present climate, and climate processes", "Characterize the state and processes of the martian atmosphere of critical importance for the safe operation of spacecraft", and "Acquire martian environmental data sets" (MEPAG, 2004). It is also relevant to some of the scientific goals of THEMIS and GRS for the extended mission as discussed in Section B.III.

The human capital available to future NASA missions will also be enhanced by this proposal. Few teams in the US have demonstrated the capability to operate facility accelerometer instruments during aerobraking. We believe that NASA would benefit from additional competition in this area and that we will be qualified to respond to future AOs in this area after successful completion of this proposed work. We believe we would have a comparatively strong record of publishing peer-reviewed science and delivering data to the PDS.

We will devote 1-2 weeks per year to providing materials to the ODY project for incorporation into their E/PO activities and participation in their E/PO programs.

D. MANAGEMENT AND WORK PLAN

D.I Work Plan

Most of the BU-NMSU interactions required for us to accomplish these tasks will be carried out by email, telephone, and discussions at scientific meetings. Additional face-to-face meetings that are focused specifically on the work proposed here will resolve any major difficulties, enable detailed self-evaluation of our progress to date, and accelerate progress on future tasks. We will have one such team meeting per year and will alternate between Co-I Withers and PI Mendillo visiting NMSU and Co-I Murphy and an NMSU PhD student ("Student") visiting BU. Co-I Withers and Co-I Murphy will also make one trip per Year to JPL for ODY Project meetings.

D.I.1 Data Processing. In Year 1 we shall (a) determine trajectory, (b) generate rapid data products for MRO, (c) reduce ACC data, (d) determine attitude, (e) derive density profiles, and (f) validate density profiles. In Year 2 we shall (a) derive fixed altitude products.

Co-I Withers will lead the data processing and perform most of the tasks. Student, supervised by Co-I Murphy, will validate density profiles and derive fixed altitude products. Co-I Withers will make one trip to JPL in Year 1 to obtain ancillary data and documentation from the project, and to strengthen relationships with the ODY engineering teams that were involved in aerobraking.

D.I.2 Data Archiving. In Year 1 we shall (a) begin preparation of documentation. In Year 2 we shall (a) properly format Volume A files and labels, (b) organize structure of Volume A, (c) deliver initial Volume A to PDS, (d) participate in PDS peer review, (e) revise Volume A, (f) deliver final Volume A to PDS, and (g) complete preparation of documentation. In Year 3 we shall (a) properly format Volume B files and labels, (b) organize structure of Volume B, (c) deliver initial Volume B to PDS, (d) participate in PDS peer review, (e) revise Volume B, and (f) deliver final Volume B to PDS.

Co-I Murphy will lead the data archiving. He and Co-I Withers will generate the documentation, participate in the peer-review, and make revisions. Student will format data products and organize the structure of PDS Volumes under Co-I Murphy's supervision. Co-I Murphy's work on this task will be performed as part of his existing position within the PDS Atmospheres Node. He will also manage the peer review of these Volumes for the PDS.

D.I.3 Science. In Year 1 we shall (a) run MGCM simulations. In Year 2 we shall (a) perform basic survey and (b) submit results for publication. In Year 3 we shall (a) correlate results with solar output, (b) generate polar maps, and (c) submit results for publication.

Co-I Withers will lead the scientific analysis. Co-I Murphy will be responsible for the MGCM simulations. Co-I Withers will perform part of the basic survey and assign part of it to NMSU, where it will be carried out by Student under Co-I Murphy's supervision. Student will correlate results with solar output under Co-I Murphy's supervision. Co-I Withers will generate the polar maps. Interpretation of results and writing of papers will be carried out jointly. Co-I Withers will present results at a US scientific conference in Years 2 and 3, Student will do so in Year 3.

D.I.4 Key Tasks and Deliverables. Our pre-Year 1 deliverable is an implementation plan to the ODY Project

Our key tasks for Year 1 are (a) generate MRO rapid data products, (b) derive density profiles, and (c) run MGCM simulations. Our deliverables for Year 1 are (a) rapid data products to the MRO Project and (b) two semi-annual reports to the ODY Project.

Our key tasks for Year 2 are (a) derive fixed altitude products, (b) PDS review of Volume A, and (c) basic survey. Our deliverables for Year 2 are (a) initial Volume A to the PDS, (b) revised Volume A to the PDS, (c) scientific manuscript to a GRL-like journal, and (d) two semi-annual reports to the ODY Project.

Our key tasks for Year 3 are (a) PDS review of Volume B, (b) perform correlation with solar output, and (c) generate polar maps. Our deliverables for Year 3 are (a) initial volume B to the PDS, (b) revised Volume B to the PDS, (c) scientific manuscript to a JGR-like journal, and (d) two semi-annual reports to the ODY Project.

D.II Personnel

Principal Investigator (Michael Mendillo) Co-I Withers does not have PI status at Boston University, so Professor Mendillo will be PI for this proposal. He has extensive experience managing multi-institution research efforts, as well as scientific experience concerning the martian ionosphere, which is closely related to the thermospheric environment that will be studied by this proposed work. He will be responsible for the use of funds. He will also monitor progress made by other personnel in the various tasks, direct effort to ensure satisfactory completion, and write the semiannual reports. He will contribute to the interpretation of the scientific analysis and the writing of scientific papers. If close collaboration with the MRO project arises during this effort, he will manage that interaction. After selection, he will coordinate the development of the Implementation Plan for the work proposed here, as required by the AO. Full academic year salary support is provided by BU, and thus his participation will occur at no cost to this proposal.

Co-Investigator and Science-PI (Paul Withers) Postdoctoral research associate Dr. Withers will be in charge of the scientific direction of our work. His recent research has touched upon many aspects of the martian atmosphere, including the thermosphere, ionosphere, and results from thermosphere-to-surface entry profiles, and has involved the scientific analysis of processed MGS ACC data (Withers, 2003; Withers et al., 2003a, b; Withers and Mendillo, 2005; Withers and Smith 2005; Withers et al., 2005a, b, c). He has extensive experience working with unprocessed accelerometer data, including identifying errors in the Pathfinder volume at the PDS (see errata.txt in PDS volume MPAM_0001), deriving atmospheric properties and participating in EDL operations for MER, and deriving atmospheric properties for Huygens (Withers et al., 2003b; Withers and Smith, 2005; Fulchignoni et al., 2002, 2005). He participated in MGS and ODY aerobraking operations via the AAG.

Co-Investigator (Jim Murphy) Professor Murphy also participated in MGS and ODY aerobraking operations via their AAGs. He is a member of the MRO AAG. His research background in the lower atmosphere will be helpful for interpretation of our results in terms of whole-atmospheric processes and couplings between atmospheric regions (Murphy et al., 1990, 1993, 1995, 2002; Bridger and Murphy, 1998; Haberle et al., 1999). He has extensive experience with PDS policies and procedures, including the peer reviews of the MGS and MER ACC datasets. His office is in the same building as the PDS Atmospheres Node, which will greatly facilitate our interactions with the PDS. Full academic year salary support is provided by NMSU, and thus his participation will occur at no cost to this proposal.

Student The NMSU Astronomy department has ~25 graduate students, approximately 7 of whom are presently engaged in planetary science research. We expect to use this position to provide partial support for a beginning PhD student. Our work plan ensures that Student will be performing tasks under the supervision of Co-I Murphy, not Co-I Withers. Student has three main responsibilities. First, to validate the density profiles. Second, to carry out some of the more straight-forward tasks associated with PDS formats and volume structure. Third, to perform clearly-focused scientific research.

REFERENCES

Angelats i Coll, M, Forget, F, Lopez-Valverde, MA, Lewis, SR, and Read, PL (2004) The upper atmosphere of Mars up to 120 km: Mars Global Surveyor Accelerometer Data Analysis with the LMD General Circulation Model, J. Geophys. Res., 109(E1), E01011, doi:10.1029/2003JE002163.

Angelats i Coll, M, Forget, F, Lopez-Valverde, MA, and Gonzalez-Galindo, F (2005) The first Mars thermospheric general circulation model: The martian atmosphere from the ground to 240 km, Geophys. Res. Lett., 32, L04201, doi:10.1029/2004GL021368.

Barabash, S, Holmstrom, M, and the ASPERA Team (2004) The latest results on the energetic neutral atoms and plasma of Mars from the ASPERA instrument of Mars Express, 35th COSPAR Assembly, Abstract COSPAR-A-02768.

Bertaux, J-L, Leblanc, F, Witasse, O, Quemerais, E, Lilenstein, J, Stern, SA, Sandel, B, and Korablev, O (2005) Discovery of an aurora on Mars, Nature, 435, 790-794.

Bevington, PR (1969) Data reduction and error analysis for the physical sciences, McGraw Hill.

Bougher, SW, and Dickinson, RE (1988) Mars mesosphere and thermosphere: I - Global mean heat budget and thermal structure, J. Geophys. Res., 93, 7325-7337.

Bougher, SW, Roble, RG, Ridley, EC, and Dickinson, RE (1990) The Mars Thermosphere: II. General Circulation with coupled dynamics and composition, J. Geophys. Res., 95, 14811-14827.

Bougher, SW, and Roble, RG (1991) Comparative terrestrial planet thermospheres 1. Solar cycle variation of global mean temperatures, J. Geophys. Res., 96, 11045-11055.

Bougher, SW, Keating, GM, Zurek, RW, Murphy, JR, Haberle, RM, Hollingsworth, JL, and Clancy, RT (1999a) Mars Global Surveyor Aerobraking: Atmospheric Trends and Model Interpretation, Adv. Space Res., 23, 1887-1897.

Bougher, SW, Engel, S, Roble, RG, and Foster, B (1999b) Comparative terrestrial planet thermospheres 2. Solar cycle variation of global structure and winds at equinox, J. Geophys. Res., 104, 16591-16611.

Bougher, SW, Engel, S, Roble, RG, and Foster, B (2000) Comparative terrestrial planet thermospheres 3. Solar cycle variation of global structure and winds at solstices, J. Geophys. Res., 105, 17669-17692.

Bougher, SW, Engel, S, Hinson, DP, and Forbes, JM (2001) Mars Global Surveyor Radio Science electron density profiles: Neutral atmosphere implications, Geophys. Res. Lett., 28, 3091-3094.

Bougher, SW (2001) Odyssey predictions for aerobraking (F10.7 = 175), http://data.engin.umich.edu/tgcm_planets/predms01.html

Bougher, SW, Roble, RG, and Fuller-Rowell, T (2002) Simulations of the Upper Atmospheres of the Terrestrial Planets, in Atmospheres in the Solar System: Comparative Aeronomy, (M. Mendillo, A. Nagy, J.H. Waite, eds), AGU Monograph #130.

Bougher, SW, and Murphy, JR (2003) Polar warming in the Mars lower thermosphere: Odyssey Accelerometer data interpretation using coupled general circulation models, Fall AGU meeting, Abstract #P21C-05.

Bougher, SW, Keating, GM, Withers, PG (2004a) Mars aerobraking data and its interpretation with applications to future Mars missions, 35th COSPAR Assembly, Abstract COSPAR-A-00358.

Bougher, SW, Engel, S, Hinson, DP, and Murphy, JR (2004b) MGS Radio Science electron density profiles: Interannual variability and implications for the martian neutral atmosphere, J. Geophys. Res., 109, E03010, doi:10.1029/2003JE002154.

Bridger, AFC, and Murphy, JR (1998) Mars' surface pressure tides and their behavior during global dust storms, J. Geophys. Res., 103, 8587-8602.

Bruinsma, S, and Lemoine, FG (2002) A preliminary semi-empirical thermospheric model of Mars: DTM-Mars, J. Geophys. Res., 107, 5085, doi:10.1029/2001JE001508.

Chavis, Z, and Wilmoth, RG (2005) Plume modeling and application to Mars 2001 Odyssey aerobraking, J. Spacecraft and Rockets, 42, 450-456

Conrath, B (1981) Planetary-wave structure in the martian atmosphere, Icarus, 48, 246-255.

Dwyer, AM, Tolson, RH, Munk, MM, and Tartabini, PV (2002) Development of a Monte Carlo Mars-GRAM model for 2001 Mars Odyssey aerobraking simulations, J. of the Astronautical Sciences, 50(2), 191-211.

Forbes, JM, and Hagan, ME (2000) Diurnal Kelvin wave in the atmosphere of Mars: Towards and understanding of "stationary" density structures observed by the MGS accelerometer, Geophys. Res. Lett., 27,3563-3566.

Forbes, JM, Hagan, ME, Bougher, SW, and Hollingsworth, JL (2001) Kelvin wave propagation in the upper atmospheres of Mars and Earth, Adv. Space Res., 27, 1791-1800.

Forbes, JM, Bridger, AFC, Bougher, SW, Hagan, ME, Hollingsworth, JL, Keating, GM, and Murphy, JR (2002) Nonmigrating tides in the thermosphere of Mars, J. Geophys. Res., 107, doi:10.1029/2001JE001582.

Forbes, JM (2002) Wave coupling in terrestrial planet atmospheres, in Atmospheres in the Solar System: Comparative Aeronomy, (M. Mendillo, A. Nagy, J.H. Waite, eds), AGU Monograph #130, 171-190.

Forbes, JM (2003) Gravity waves and their effects on the mean state and variability of Mars' upper atmosphere, proposal funded by NASA's Mars Data Analysis Program, http://research.hq.nasa.gov/code_s/nra/current/NRA-03-OSS-01-MDAP/winners.html

Forbes, JM (2004a) Tides in the middle and upper atmospheres of Mars and Venus, Adv. Space Res., 33, 125-131.

Forbes, JM (2004b) Nonmigrating tides in the thermosphere of Mars: A quasi-empirical description, Adv. Space Res., 34, 1690-1695.

Forbes, JM (2005) Solar semidiurnal tide in the dusty atmosphere of Mars, J. Atmos. Sci, under review.

Fox, JL, Zhou, P, and Bougher, SW (1996) The martian thermosphere/ionosphere at high and low solar activities, Advances in Space Res., 17(11), 203-218.

Fox, JL (2004) Response of the martian thermosphere/ionosphere to enhanced fluxes of solar soft X-rays, J. Geophys. Res., 109, A11310, doi:10.1029/2004JA010380.

Fulchignoni, M, et al. (2002) The characterisation of Titan's atmospheric physical properties by the Huygens atmospheric structure instrument (HASI) Space Sci. Rev. 104, 395-431.

Fulchignoni, M, et al. (2005) First HASI Results, Nature, submitted.

Gierasch, P, and Goody, R (1972) The effect of dust on the temperature of the Mars atmosphere, J. Atmos. Sci., 29, 400-402.

GOES (2005) http://www.ngdc.noaa.gov/stp/GOES/goes.html

Haberle, RM, Pollack, JB, Barnes, JR, Zurek, RW, Leovy, CB, Murphy, JR, Lee, H, and Schaeffer, J (1993) Mars atmospheric dynamics as simulated by the NASA Ames General Circulation Model. 1 - The zonal-mean circulation, J. Geophys. Res., 98, 3093-3123.

Haberle, RM, Joshi, MM, Murphy, JR, Barnes, JR, Schofield, JT, Wilson, G, Lopez-Valverde, M, Hollingsworth, JL, Bridger, AFC, and Schaeffer, J (1999) General circulation model simulations of the Mars Pathfinder atmospheric structure investigation/meteorology data, J. Geophys. Res., 104, 8957-8974.

Hanna Prince, JL, and Striepe, SA (2005) NASA-Langley trajectory simulations and analysis capabilities for Mars Reconnaissance Orbiter, American Astronautical Society conference paper AAS 05-217.

Hanna Prince, JL, Chavis, ZQ, and Wilmoth, RG (2005) Modeling reaction control system effects on Mars Odyssey, J. Spacecraft and Rockets, 42, 444-449.

Joshi, MM, Hollingsworth, JL, Haberle, RM, and Bridger, AFC (1999) An interpretation of martian thermospheric waves based on analysis of a general circulation model, Geophys. Res. Lett., 27, 613-616.

JPL (2004) 2001 Mars Odyssey Extended Mission Proposal, http://mars.jpl.nasa.gov/odyssey/em/

Justus, CG, James, BF, Bougher, SW, Bridger, AFW, Haberle, RM, Murphy, JR, and Engel, S (2000) Mars-GRAM 2000: A Mars atmospheric model for engineering applications, Adv. Space Res., 29, 193-202.

Keating, GM, and 27 colleagues (1998) The Structure of the Upper Atmosphere of Mars: In Situ Accelerometer Measurements from Mars Global Surveyor, Science, 279, 1672-1676.

Keating, GM, Theriot, M, Tolson, RH, Bougher, SW, Forget, F, and Forbes, JM (2003a) Global Measurements of the Mars Upper Atmosphere: In Situ Accelerometer Measurements from Mars Odyssey 2001 and Mars Global Surveyor, Abstract for the 34th Lunar and Planetary Science Conference, Houston, USA, March 2003, available online at http://www.lpi.usra.edu/meetings/lpsc2003/v31n4/dps99/390.htm

Keating, GM, Theriot, M, Tolson, RH, Bougher, SW, Forget, F, and Forbes, JM (2003b) The Mars Odyssey Accelerometer Thermospheric Experiment: Conditions Near the North Winter Pole and on the Nightside of Mars, Abstract for the European Geophysical Society Meeting, Nice, France, April 2003, available online at http://www.copernicus.org/EGS/egsga/nice03/programme/overview.htm

Keating, GM, Theriot, M, and Tolson, R (2003c) Winter polar conditions in the Mars upper atmosphere at both the north and south poles, Sixth International Conference on Mars abstract #3282.

Keating, G, Theriot, M, Blanchard, R, Tolson, R, Bougher, S, Forget, F, Krasnopolsky, V, Forbes, J, and Bertaux, J (2004) Recent measurements of the Mars neutral upper atmosphere above 100 km, 35th COSPAR Assembly, Abstract COSPAR-A-04091.

Krasnopolsky, VA (2002) Mars' upper atmosphere and ionosphere at low, medium, and high solar activities: Implications for evolution of water, J. Geophys. Res., 107, 5128, doi:10.1029/2001JE001809.

Leovy, C (2001) Weather and climate on Mars, Nature, 412, 245-249.

Lundin, R, et al. (2004) Solar wind-induced atmospheric erosion at Mars: First results from ASPERA-3 on Mars Express, Science, 305, 1933-1936.

Lyons, DT (2002) Mars Reconnaissance Orbiter: Aerobraking reference trajectory, American Institute of Aeronautics and Astronautics conference paper AIAA 2002-4821.

MEPAG (2004) Scientific goals, objectives, investigations, and priorities: 2004, http://mepag.jpl.nasa.gov/reports/index.html

Murphy, JR, Toon, OB, Haberle, RM, and Pollack, JB (1990) Numerical simulations of the decay of martian global dust storms, J. Geophys. Res., 95, 14629-14648.

Murphy, JR, Haberle, RM, Toon, OB, and Pollack, JB (1993) Martian global dust storms - zonally symmetric numerical simulations including size-dependent transport, J. Geophys. Res., 98, 3197-3220.

Murphy, JR, Pollack, JB, Haberle, RM, Leovy, CB, Toon, OB, and Schaeffer, J (1995) Three-dimensional numerical simulation of martian global dust storms, J. Geophys. Res., 100, 26357-26376.

Murphy, JR, and Nelli, S (2002) Mars Pathfinder convective vortices: Frequency of occurrence, Geophys. Res. Lett., 29, 2103, doi:10.1029/2002GL015214.

PDS (2005a) Proposer's Archive Guide, http://pds.jpl.nasa.gov/documents/pag/index.html

PDS (2005b) PDS Standards Reference, http://pds.jpl.nasa.gov/documents/sr/index.html

PDS (2005c) Data Preparer's Workbook, http://pds.jpl.nasa.gov/documents/dpw/index.html

PDS (2005d) http://pds-atmospheres.nmsu.edu/data_and_services/atmospheres_data/odyacc.html

Richardson, MI, and Wilson, RJ (2002) A topographically forced asymmetry in the martian circulation and climate, Nature, 416, 298-301.

Smith, MD, Pearl, JC, Conrath, BJ, and Christensen, PR (2001) Thermal Emission Spectrometer results: Mars atmospheric thermal structure and aerosol distribution, J. Geophys. Res., 106, 23929-23945.

Smith, JC, and Bell, JL (2005) 2001 Mars Odyssey aerobraking, J. Spacecraft and Rockets, 42, 406-415.

Takashima, N, and Wilmoth, RG (2002) Aerodynamics of Mars Odyssey, American Institute of Aeronautics and Astronautics conference paper AIAA 2002-4809.

Takashima, N, and Wilmoth, RG (2003) Rarefied aerothermodynamics of Mars Odyssey, America Institute of Physics Conference Proceedings, 663(1), 218-225.

Tartabini, PV, Munk, MM, and Powell, RW (2002) The development and evaluation of an operational aerobraking strategy for the Mars 2001 Odyssey orbiter, American Institute of Aeronautics and Astronautics conference paper AIAA 2002-4537.

Tobiska, WK, Woods, T, Eparvier, F, Vierreck, R, Floyd, L, Bouwer, D, Rottman, G, and White, OR (2000) The Solar2000 empirical solar irradiance model and forecast tool, J. Atmospheric and Solar-Terrestrial Phys., 62(14), 1233-1250.

Tolson, RH, Keating, GM, Cancro, GJ, Parker, JS, Noll, SN, and Wilkerson, BL (1999) Application of accelerometer data to Mars Global Surveyor aerobraking operations, J. Spacecraft and Rockets, 36, 323-329.

Tolson, RH, Keating, GM, George, BE, Escalera, PE, Werner, MR, Dwyer, AM, and Hanna, JL (2002) Application of Accelerometer data to Mars Odyssey aerobraking and atmospheric modeling, American Institute of Aeronautics and Astronautics conference paper AIAA 2002-4533.

Tolson, RH, Dwyer, AM, Hanna, JL, Keating, GM, George, BE, Escalera, PE, and Werner, MR (2005) Application of Accelerometer data to Mars Odyssey aerobraking and atmospheric modeling, J. Spacecraft and Rockets, 42, 435-443.

Tracadas, PW, Zuber, MT, Smith, DE, and Lemoine, FG (2001) Density structure of the upper thermosphere of Mars from measurements of air drag on the Mars Global Surveyor spacecraft, J. Geophys. Res, 106, 23349-23358.

Wilson, RJ, and Hamilton, K (1996) Comprehensive model simulation of thermal tides in the martian atmosphere, J. Atmos. Sci, 53, 1290-1326.

Wilson, RJ (2000) Evidence for diurnal period Kelvin waves in the martian atmosphere from Mars Global Surveyor TES data, Geophys. Res. Lett., 27, 3889-3892.

Wilson, RJ (2002) Evidence for nonmigrating thermal tides in the Mars upper atmosphere from the Mars Global Surveyor Accelerometer Experiment, Geophys. Res. Lett., 29, DOI 10.1029/2001GL013975.

Withers, P (2003) Tides in the Martian Upper Atmosphere - And Other Topics, PhD dissertation, University of Arizona, USA.

Withers, P, Bougher, SW, and Keating, GM (2003a) The effects of topographically-controlled thermal tides in the martian upper atmosphere as seen by the MGS accelerometer, Icarus, 164, 14-32.

Withers, P, Towner, MC, Hathi, B, and Zarnecki, JC (2003b) Analysis of entry accelerometer data: A case study of Mars Pathfinder, Planet. Space Sci., 51, 541-561.

Withers, P, and Mendillo, M (2005) Response of peak electron densities in the martian ionosphere to day-to-day changes in solar flux due to solar rotation, Planetary and Space Science, accepted.

Withers, P, and Smith, MD (2005) Atmospheric entry profiles from the Mars Exploration Rovers Spirit and Opportunity, in preparation for submission to Icarus.

Withers, P, Mendillo, M, Rishbeth, H, Hinson, DP, and Arkani-Hamed, J (2005a) Ionospheric characteristics above martian crustal magnetic anomalies, accepted by Geophys. Res. Lett.

Withers, P, et al. (2005b) Simultaneous observations of the effects of a solar flare on the ionospheres of Earth and Mars, in preparation.

Withers, P, et al., (2005c) Mars Global Surveyor and Mars Odyssey accelerometer observations of the martian upper atmosphere during aerobraking, in preparation.

Zurek, RW, and Loevy, C (1981) Thermal tides in the dusty martian atmosphere: a verification of theory, Science, 213, 437-439.

Zurek, RW, Barnes, JR, Haberle, RM, Pollack, JB, Tillman, JE, and Leovy, CB (1992) Dynamics of the Atmosphere of Mars, in Mars (Eds: Kieffer, HH, Jakosky, BM, Snyder, CW, and Matthews, MS), pp. 835-933.

Facilities and Equipment

Existing facilities and equipment at Boston University and New Mexico State University will be used to perform the proposed work.

CV for PI Michael Mendillo

Education: Boston University Graduate School, Boston, Massachusetts
Ph.D. in Physics and Astronomy, 1971;
M.A. in Physics and Astronomy, 1968
Providence College, Providence, Rhode Island
B.S. in Physics, cum laude, 1966

Membership: American Geophysical Union (AGU)
American Astronomical Society (AAS);
Division of Planetary Science; History Division
International Union of Radio Science (URSI)

Address: Boston University
Center for Space Physics
Boston, Massachusetts 02215
T: (617) 353-2629; F: 617-353-6463; e-mail, mendillo@bu.edu

Positions: Professor of Astronomy, 1985 to present
Professor of Electrical and Computer Engineering, 1993 to present
Associate Dean for the Graduate School, 1978 to 1987
Associate Professor of Astronomy, 1978-1985
Assistant Professor of Astronomy, 1971-1972, 1974-1978
National Research Council/National Academy of Sciences
Post-doctoral Research Associate, 1972-1974
Air Force Cambridge Research Laboratories

Research Fields of Specialization: Space Physics, Solar-Terrestrial Relations,
Active Experiments in Space Plasmas, Planetary Astronomy
History of Astronomy and Geophysics
Experimental: Low-light level optical imaging; incoherent scatter radar; satellite radio beacon techniques; groundbased atmospheric emission tomography (GAET)
Theoretical/Computer Modeling: Fluid Element Simulation (FES) techniques

Major Research Programs: NASA Spacelab-2 Mission (1977-86)
NASA SPINEX Rocket Program (1984-86)
NASA ERIC & RED AIR Rocket Programs (1987-89)
NASA CRRES Mission (1984-92); NASA RED AIR-2 (1990-1992)
Boston University's Mobile Ionospheric Observatory (1983-1991)
NSF CEDAR Class-I Imager and Optical Tomography Facility (1987-)
NASA Sodium Atmospheres of Solar System Bodies (1989 --)

Teaching Experience: General Astronomy for Non-Science Majors (undergraduate), Space Physics (graduate), Celestial Mechanics (graduate), History of Astronomy (undergraduate); Celestial Navigation (undergraduate)

Awards: Elected Fellow of the American Geophysical Union 2000
Elected President for Space Physics & Aeronomy (SPA) Section AGU 2004-2006

Service: Membership and/or Chairmanship of Science Advisors Committees at National Science Foundation, NASA, NAS Space Studies Board, Naval Research Laboratory, Air Force Geophysics Laboratory.
Membership and/or Chairmanship of many academic committees at Boston University.

RECENT PAPERS PUBLISHED IN SCIENTIFIC JOURNALS

Topics: Planetary Astronomy **Period**: 1990 - Present

1. The Extended Sodium Nebula of Jupiter, M. Mendillo, J. Baumgardner, B. Flynn and W.J. Hughes, *Nature, 348,* 312, 1990.
2. Imaging Observations of the Extended Sodium Atmosphere of the Moon, M. Mendillo, J. Baumgardner, and B. Flynn, *Geophys. Res. Lett., 18,* 2097, 1991.
3. Observations and Modeling of the Jovian Remote Neutral Sodium Emissions, B. Flynn, M. Mendillo and J. Baumgardner, *Icarus, 99,* 115, 1992.
4. Imaging Observations of Jupiter's Sodium Magneto-nebula During the Ulysses Encounter, M. Mendillo, J. Baumgardner, and B. Flynn, *Science, 257,* 1510, 1992.
5. A Picture of the Moon's Atmosphere, B. Flynn and M. Mendillo, *Science, 261,* 184, 1993.
6. The Jovian Sodium Nebula: Two Years of Ground-based Observations, B. Flynn, M. Mendillo, and J. Baumgardner, J. *Geophys. Res., (Planets), 99,* 8403, 1994
7. Constraints on the Origin of the Moon's Atmosphere From Observations During a Lunar Eclipse, M. Mendillo and J. Baumgardner, *Nature, 377,* 404, 1995
8. Simulations of the Lunar Sodium Atmosphere, B. Flynn and M. Mendillo, *J. Geophys. Res. (Planets), 100,* 23271, 1995
9. Modeling the Moon's Extended Sodium Cloud as a Tool for Investigating Sources of Transient Atmosphere, M. Mendillo, J. Emery, and B. Flynn, *Adv. Space Res., 19,* 157, 1997
10. Eclipse Observations of the Lunar Atmosphere from the TNG Site, M. Mendillo, J. Baumgardner, G. Cremonese and C. Barbieri, the Three Galileos: The Man, The Spacecraft, The Telescope, C. Barbieri, J. Rahe, T. Johnson, and A.M. Sohos (eds) p. 393, Kluwer Academic Publishing, Dordrecht, The Netherlands, 1997
11. Groundbased Remote Sensing of Energetic Neutral Atoms In Jupiter's Magnetosphere, M. Mendillo, J.K. Wilson, J. Baumgardner and N.M. Schneider, in the Three Galileos: The Man, The Spacecraft, The Telescope, C. Barbieri, J. Rahe, T. Johnson, and A.M. Sohos (eds) p. 411, Kluwer Academic Publishing, Dordrecht, The Netherlands, 1997
12. An HST Search for Magnesium in the Lunar Atmosphere, S.A. Stern, J.W. Parker, T.H. Morgan, B.C. Flynn, D.M. Hunten, A. Sprague, M. Mendillo, and M.C. Festou, *Icarus, 127,* 523, 1997
13. Three Tails of Comet Hale-Bopp, J.K. Wilson, J. Baumgardner, and M. Mendillo, *Geophys. Res. Lett., 25,* 225, 1998

14. Discovery of the Distant Lunar Sodium Tail and its Enhancement Following the Leonid Meteor Shower of 1998, S.M. Smith, J.K. Wilson, J. Baumgardner and M. Mendillo, *Geophys. Res. Letts., 26,* 1649, 1999
15. Modeling an Enhancement of the Lunar Sodium Tail During the Leonid Meteor Shower of 1998, J.K. Wilson, S.M. Smith, J. Baumgardner, and M. Mendillo, *Geophys. Res. Letts.,* 26, 1645, 1999
16. Observational test for the solar wind sputtering origin of the Moon's extended sodium atmosphere, M. Mendillo, J. Baumgardner, and J. Wilson, *Icarus, 137,* 13, 1999
17. Dynamics of Titan's thermosphere, H. Rishbeth, R. Yelle and M. Mendillo, *Planet. Space Sci., 48,* 51, 2000
18. A digital high-definition imaging system for spectral studies of extended planetary atmospheres: 1. Initial results in white light showing features on the hemisphere of Mercury unimaged by Mariner 10, J. Baumgardner, M. Mendillo and J. Wilson, *Astron. J., 119,* 2458, 2000
19. The thermosphere of Titan simulated by a global three-dimensional time-dependent model, I.C.F. Muller-Wodarg, R.V. Yelle, M. Mendillo, L.A. Young, and A.D. Aylard, *J. Geophys. Res., 105,* 20833, 2000
20. Imaging the surface of Mercury using ground-based telescopes, M. Mendillo, J. Warell, S. Limaye, J. Baumgardner, A. Sprague, and J. Wilson, Planet. Space Sci., 49, 1501-1505, 2001.
21. Monitoring the Moon's transient atmosphere with an all-sky imager, S. Smith, M. Mendillo, J. Wilson, and J. Baumgardner, Adv. Space Res., 27, (6&7), 1181-1187, 2001.
22. The atmosphere of the Moon, M. Mendillo, Earth, Moon and Planets, 85-86, 271-277, 2001.
23. The 1999 Quadrantids and the lunar Na atmosphere, S. Verani, C. Barbieri, C. Benn, G. Cremonese, and M. Mendillo, Mon. Not. R. Astron. Soc., 327, 244-248, 2001.
24. The dual sources of Io's sodium clouds, J. Wilson, M. Mendillo, J. Baumgardner, N. Schneider, J. Trauger, and B. Flynn, Icarus 157,476-489, 2002.
25. The Application of Terrestrial Aeronomy Groundbased Instruments to Planetary Astronomy, M. Mendillo., F. Roesler, C. Gardner and M. Sulzer, 329-338, Atmosheres in the Solar System: Comparative Aeronomy, (M. Mendillo, A. Nagy & J.H. Waite, eds), Geophys. Monograph #130, Amer. Geophys. Union, Washington, DC, 2002.
26. The outer limits of the lunar sodium exosphere J. Wilson, J. Baumgardner, M. Mendillo, Geophysical Reserch Letters, 30(12), 1649, 2003.
27. Modeling day-to-day ionospheric variability on Mars, C. Martinis, J. Wilson, M. Mendillo, *J. Geophys. Res., 108,* 1383, doi:10.1029/2003JA009973, 2003.
28. Simultaneous ionospheric variability on Earth and Mars, M. Mendillo, S. Smith, J. Wroten, H. Rishbeth, *J. Geophys. Res., 108,* 1432, doi:10.1029/2003JA009961, 2003.
29. Ionospheric effects upon a satellite navigation system at Mars, M. Mendillo, X.-P. Pi, S. M. Smith, C. Martinis, J. Wilson, D. Hinson, *Radio Science, 39,* RS2028, doi:10.1029/2003RS002933, 2004.
30. Effects of ring shadowing on the detection of electrostatic discharges at Saturn, M. Mendillo, L. Moore, J. Clarke, I. Mueller-Wodarg, W.S. Kurth, and M.L. Kaiser, *Geophys. Res. Lett., 32,* L05107, doi:10.1029/2004GL021934, 2005.
31. Ionospheric contribution to Saturn’s inner plasmasphere, L. Moore and M. Mendillo, *J. Geophys. Res., 110,* A05310, doi:10.10129/2004JA010889, 2005.

CV for Co-I and Science PI Paul Withers

Education

PhD, Planetary Science, University of Arizona, 2003
Supervisor Dr. Stephen Bougher, "Tides in the martian upper atmosphere - and other topics"
MS, Physics, Cambridge University, Great Britain, 1998
BA, Physics, Cambridge University, Great Britain, 1998

Employment

Postdoctoral research associate with Dr. Michael Mendillo (Boston Univ.) 2003 - present.

Graduate research assistant with Dr. Stephen Bougher (Univ. of Arizona) 1998 - 2003. Research interests included analysis of MGS accelerometer data to studf atmospheric tides, winds, and other properties. Played an advisory role in mission operations for MGS and Mars Odyssey aerobraking.

Research consultant with Dr. John Zarnecki (Open University, Great Britain) 2001 (summer). Developed techniques to analyze accelerometer data from entry probes, concentrating on the British Beagle 2 Mars Lander and Huygens.

Fellowships, Honors, and Awards

NSF CEDAR Postdoctoral Fellowship
Kuiper Memorial Award from the University of Arizona for excellence in academic work and research in planetary science, 2002
Galileo Circle Graduate Scholarship from the University of Arizona, 2001.

Professional Activities

Author of publicly available programs to analyze entry accelerometer data (http://www.lpl.arizona.edu/~withers/beagle2/), 2002.

Participated in PDS review of MER accelerometer dataset MERIMU_1001, 2004
Participated in PDS review of MGS accelerometer dataset MGSA_0002, 2000.

Huygens HASI ACC sub-system Team Member, 2004-present.
Huygens SSP Team Member, 2004-present.
Mars Human Precursor Science Steering Group, Atmosphere Focus Team Member, 2004-2005.
Advisory Team Member for MER landings, 2002 - 2004.

External Reviewer and Panel Reviewer for NASA funding programs, 2004-present.
Reviewer for Icarus, Journal of Geophysical Research, Journal of Spacecraft and Rockets, Meteoritics and Planetary Science, and Science.

Selected Publications

Withers et al. “Mars Global Surveyor and Mars Odyssey accelerometer observations of the martian upper atmopshere during aerobraking” (2005) in preparation for submission to Geophys. Res. Lett.

Withers and Mendillo “Response of peak electron densities in the martian ionosphere to day-to-day changes in solar flux due to solar rotation” (2005) Planetary and Space Science, accepted.

Withers and Smith “Atmospheric entry profiles from the Mars Exploration Rovers Spirit and Opportunity” (2005) in preparation for submission to Icarus.

Withers, Mendillo, Rishbeth, Hinson, and Arkani-Hamed “Ionospheric characteristics above martian crustal magnetic anomalies” (2005) Geophys. Res. Lett., accepted.

Beaty et al. “An analysis of the precursor measurements of Mars needed to reduce the risk of the first human mission to Mars” (2005) MEPAG White Paper with contribution from Atmosphere Focus Team Member Withers.

Withers, Towner, Hathi, and Zarnecki, “Review of the trajectory and atmospheric structure reconstruction for Mars Pathfinder” (2004) in Proceedings of the International Planetary Entry Probe Workshop, ESA SP-544, pp. 163-174.

Withers, “Should we believe atmospheric temperatures measured by entry accelerometers travelling at ‘slow’ near-sonic speeds?” (2004) in Proceedings of the 2nd International Planetary Entry Probe Workshop, NASA/CP-2004-213456.

Withers, Bougher, and Keating, "The Effects of Topographically-controlled Thermal Tides in the Martian Upper Atmosphere as seen by the MGS Accelerometer" (2003) Icarus, 164, 14 - 32.

Withers, Towner, Hathi, and Zarnecki, "Analysis of Entry Accelerometer Data: Preparations for Beagle 2" (2003) Planetary and Space Science, 51, 541 - 561.

Withers, Neumann, and Lorenz, "Comparison of Viking Lander descent data and MOLA topography reveals kilometer-scale error in Mars atmosphere profiles", (2002) Icarus, 159, 259 - 261.

Withers and Neumann, “Enigmatic northern plains of Mars” (2001) Nature, 410, 651.

Withers, “Meteor storm evidence against the recent formation of lunar crater Giordano Bruno” (2001) Meteoritics and Planetary Science, 36, 525 – 529.

Curriculum Vitae - Dr. James R. Murphy (Co-I)

Department of Astronomy
New Mexico State University

PROFESSIONAL PREPARATION:

Texas A&M University	Meteorology	B.S., May 1984
University of Washington	Atmospheric Sciences	M.S., December 1986
University of Washington	Atmospheric Sciences	Ph.D., June 1991

POSITIONS HELD:

Academic Department Head, Dept. of Astronomy, New Mexico State Univ.	2005 - present
Associate Professor, Dept. of Astronomy, New Mexico State University	2004 - present
Assistant Professor, Dept. of Astronomy, New Mexico State University	1998 – 2004
Research Scientist: San Jose State University / NASA Ames Res. Cen.	1993 - 1998
NRC Resident Research Associate: NASA Ames Res. Cen.	1991 – 1993
NASA GSRP: University of Washington / NASA Ames	1987 – 1990

CURRENT RESEARCH ACTIVITIES:

- Global scale numerical modeling of Mars' atmospheric processes: dust and water cycles
- Mars atmospheric dynamical investigation employing observed non-condensable gas enhancement
- Investigation of atmospheric transport relationship to observed low-latitude regolith water content
- Atmospheric thermal tide analysis employing MGS' Mars Horizon Sensor Assembly observations
- Derivation of wind speed and direction data set from Mars Pathfinder wind sensor signals

MARS EXPLORATION MISSION INVOLVEMENT:

Mars Pathfinder: ASI/MET Development and Operation Teams
MGS, Mars Climate Orbiter, Mars Odyssey, MRO: Atmospheric Advisory Group for Aerobraking
Mars Polar Lander: Participating Scientist
Mars Microprobe (Deep Space 2): Science Team (Meteorology)
Mars Exploration Rovers: Near-surface environmental characterization

RECENT REFEREED PUBLICATIONS:

"Mars Pathfinder convective vortices: Frequency of occurrence", **Murphy, J.R.** and S. Nelli, *Geophys. Res. Letters*, **29** (23), 2103, doi:10.1029/2002GL015214,2002.

"Orbital change experiments with a Mars General Circulation Model", Haberle, R.M., **J. Murphy**, J. Schaeffer, *Icarus*, **161**, 66-89, 2003.

"MGS Radio Science electron density profiles: Interannual vatiability and implications for the martian neutral atmosphere, Bougher, S.W., S. Engel, D. Hinson, **J. Murphy**, submitted to *J. Geophys. Res.*, **109(E3)**, 2004.

"Composition and structure of the martian surface in the high southern latitudes from neutron spectroscopy, Prettyman T.H., W. Feldman, M. Mellon, G. McKinney, W. Boynton, S. Karunatillake, D. Lawrence, **J.R. Murphy**, S. Squyres, R.D. Starr, R.L. Tokar, and the 2001 Mars Odyssey Gamma Ray Spectrometer Science Team, *J. Geophys. Res.*, **109(E5)**, 2004.

"Observing the martian surface albedo pattern: Comparing the AEOS and TES data sets", Kahre, M.A., **J.R. Murphy**, N.J. Chanover, J.L. Africano, L.C. Roberts, and P.W. Kervin, ICARUS, in press, 2005.

"Simulation of the martian dust cycle with a finite surface dust reservoir", Kahre, M.A., **J.R. Murphy**, R.M. Haberle, F. Momtmessin, and J. Schaeffer, submitted to GRL, in revision.

Letter of Commitment from Paul Withers

From withers@bu.edu Wed Jul 27 17:15:08 2005 -0400
Date: Wed, 27 Jul 2005 17:15:08 -0400 (EDT)
From: Paul Withers <withers@bu.edu>
Reply-To: Paul Withers <withers@bu.edu>
To: Paul Withers <withers@bu.edu>
Subject: Letter of commitment

Dear Michael Mendillo,

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled ANALYSIS OF ACCELEROMETER DATA FROM AEROBRAKING that is submitted by Michael Mendillo to the NASA Research Announcement NNH05ZDA001N, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Signed
Paul Withers

****
Paul Withers
Office +1 617 353 1531
Fax +1 617 353 6463
Email withers@bu.edu

Center for Space Physics
Boston University
725 Commonwealth Avenue
Boston MA 02215, USA
****

Letter of Commitment from Jim Murphy

Date: Wed, 3 Aug 2005 13:58:47 -0600 (MDT)
From: Jim Murphy <murphy@NMSU.Edu>
To: Michael Mendillo <mendillo@bu.edu>, Paul Withers <withers@bu.edu>
Cc: murphy@NMSU.Edu
Subject: Commitment to Mars Odyssey Co-Investigator proposal

Dear Michael Mendillo,

I acknowledge that I, James Murphy, am identified by name as a Co-Investigator to the investigation, entitled, "ANALYSIS OF ACCELEROMETER DATA FROM AEROBRAKING" that is submitted by you, Michael Mendillo to the NASA Research Announcement NNH05ZDA001N, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Signed
Jim Murphy

****
Jim Murphy, Associate Professor
Academic Department Head

Department of Astronomy
New Mexico State University
murphy@nmsu.edu
(505) 646-5333 FAX (505) 646-1602
****

Statement of Work for Appendix

Scope of Work

Data Processing. In Year 1 we shall (a) Determine trajectory, (b) Generate Rapid Data Products for MRO, (c) Reduce ACC data, (d) Determine attitude, (e) Derive density profiles, and (f) Validate density profiles. In Year 2 we shall (a) Derive fixed altitude products.

Data Archiving. In Year 1 we shall (a) Begin preparation of documentation. In Year 2 we shall (a) Properly format Volume A files and labels, (b) Organize structure of Volume A, (c) Deliver initial Volume A to PDS, (d) Participate in PDS peer review, (e) Revise Volume A, (f) Deliver final Volume A to PDS, and (g) Complete preparation of documentation. In Year 3 we shall (a) Properly format Volume B files and labels, (b) Organize structure of Volume B, (c) Deliver initial Volume B to PDS, (d) Participate in PDS peer review, (e) Revise Volume B, and (f) Deliver final Volume B to PDS.

Science. In Year 2 we shall (a) Perform basic survey and (b) Submit results for publication. In Year 3 we shall (a) Correlate results with solar output, (b) Generate polar maps, and (c) Submit results for publication.

Deliverables

Our pre-Year 1 Deliverable is an Implementation Plan to the ODY Project

Our Deliverables for Year 1 are (a) Rapid Data Products to the MRO project and (b) Two semi-annual reports to the ODY Project.

Our Deliverables for Year 2 are (a) Initial Volume A to the PDS, (b) Revised Volume A to the PDS, (c) Scientific manuscript to a GRL-like journal, and (d) Two semi-annual reports to the ODY Project.

Our Deliverables for Year 3 are (a) Initial Volume B to the PDS, (b) Revised Volume B to the PDS, (c) Scientific manuscript to a JGR-like journal, and (d) Two semi-annual reports to the ODY Project.

Government Responsibilities

The JPL Odyssey Project shall supply us with the following:
Orbital elements for each orbit
Spacecraft reference area
Spacecraft mass for each orbit
IMU position in spacecraft reference frame
Acceleration and angular acceleration caused by firing of each ACS thruster
Aerodynamic database
Description of reference areoid