Paul Withers

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Citizenship: British

Education

- PhD, Planetary Science, University of Arizona 2003(planned)
  All requirements, except thesis, satisfied. Completion expected in late spring.
- MS, Physics, Cambridge University, Great Britain 1998
- BA, Physics, Cambridge University, Great Britain 1998

Professional Experience

- Graduate research assistant Dr. Stephen Bougher (Univ. of Arizona) 1998 – present
  Studied weather in the martian upper atmosphere. Played an advisory role in mission operations for Mars Global Surveyor and Mars Odyssey aerobraking
- Research consultant Dr. John Zarnecki (Open University) 2001(summer)
  Worked in Great Britain, developed techniques to analyze accelerometer data from entry probes, concentrating on the British Beagle 2 Mars Lander.
- Research assistant Dr. Greg Neumann (NASA/Goddard) 2000(summer)
  Worked with MOLA team to investigate the geology of the northern plains of Mars, supported by the competitive Goddard Summer Student Program.
- Research assistant Dr. Andrew Melatos (Caltech) 1997(summer)
  Modeled pulsar outflows, supported by a competitive Caltech Summer Undergraduate Research Fellowship.
- Website designer Dr. Nicholas Walton (ING) 1996(summer)
  Worked at the Isaac Newton Group (ING) of Telescopes, La Palma, Spain.

Fellowships, Honors, and Awards

- Kuiper Memorial Award from the University of Arizona for excellence in academic work and research in planetary science. 2002
- Nominated for the Meteoritical Society/Geological Society of America's Best Student Paper in Planetary Sciences Award. 2002
- Galileo Circle Graduate Scholarship from the University of Arizona. 2001
- Highly Commended in annual British Young Science Writer Contest. 2000
- Graduate Registration Fellowships from the University of Arizona. 1999 – 2002

Research Interests

- Current research interests include the dynamics of upper atmospheres, accelerometer data analysis, historical astronomy, and martian tectonism. Future research directions will include the outer solar system, building on the results of Galileo and preparing for Cassini.

Professional Activities

- NASA 2003 Mars Rovers – Atmosphere Science Advisor for Landing. 2002(selected)
- Author of publicly available programs to analyze entry accelerometer data (http://www.lpl.arizona.edu/~withers/beagle2/). 2002
- Attended two-week Summer School on Planetary Geology in Italy. 2002
- Reviewer for *Icarus*, *Meteoritics and Planetary Science*, and *Science*. 2001 – present
- PI and Co-I on 2 proposals to NASA, neither funded. 2001
- Community discussion forum moderator and member of community panel on Education/Public Outreach for Solar System Exploration Decadal Survey. 2001
- "Oceans on Mars" – invited colloquium at Imperial College, Great Britain. 2001
- Participated in PDS review of MGS accelerometer dataset (MGSA_0002). 2000

Teaching Experience

- Participated in the University of Arizona's Scientist-Teacher Alliance, developed teaching plans and visited classrooms with middle school teachers. 2002
- Attended three national workshops on graduate student teaching. 2000 – 2002
- Teaching Assistant for Profs. John Lewis and Jonathan Lunine in introductory science classes for non-science majors, including lecturing on human evolution. 1999 – 2000

Public Outreach

- Presentation on "Shallow Ridges on the Northern Plains of Mars" at a University of Arizona Open House Evening. 2001
- Media interviews about my research on the martian northern plains and lunar crater Giordano Bruno, featured on CNN, print, and online media. 2001
- Presentations on "The Martian Upper Atmosphere" and "The Age of Lunar Crater Giordano Bruno" at the University of Arizona's Student Showcase, best presentation by a graduate student in the physical sciences in 1999. 1999 – 2000
- Named NASA's Deep Space 2 Mars Microprobes *Scott* and *Amundsen.* 1999

Geological Field Experience

- Organized short sections of the University of Arizona's planetary geology fieldtrip each semester, planning field stops and leading discussions. Went on 9 geological fieldtrips around the southwestern US and nearby Mexico. 1998 – 2002
- Participated in week-long Cambridge University geological fieldtrip to study the tectonics of Greece. 1997

Language Skills: Proficient in written French. Conversational level in French and Spanish.

Professional Affiliations: Member of the American Geophysical Union's Planetary Sciences Section, the American Astronomical Society's Division for Planetary Science, and the British Planetary Forum.

Publications

Peer Reviewed Publications

- **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.

- Nockolds and **Withers**, "Comment and reply on "Meteor storm evidence against the recent formation of lunar crater Giordano Bruno" by Paul Withers" (2002) *Meteoritics and Planetary Science*, **37**, 465 – 466.

- **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.

- Lorenz, Lunine, **Withers**, and McKay, "Titan, Mars and Earth: Entropy Production by Latitudinal Heat Transport" (2001) *Geophys. Res. Lett*., **28**, 415 – 418.

Other Publications and Manuscripts under Review

- **Withers**, Bougher, and Keating, "The Effects of Topographically-controlled Thermal Tides in the Martian Upper Atmosphere as seen by the MGS Accelerometer" – under review by *Icarus*.

- **Withers**, Towner, Hathi, and Zarnecki, "Analysis of Entry Accelerometer Data: Preparations for Beagle 2" – under review by *Planetary and Space Science.*

- Grier, Atkinson, Barlow, Griffin, Hoffman, Kelly-Serrato, Keszthelyi, Klein, Klug, Kolvoord, Lanagan, Lebofsky, Lien, Lindstrom, Lopes, Lowes, Manifold, Mastrapa, Milazzo, Miner, Morris-Smith, Rivkin, Runyon, Sohus, Urquhart, Vasavada, Warasila, **Withers**, and Wood, "Setting Goals and Priorities for Education and Public Outreach" (2002) in *The Future of Solar System Exploration 2003-2013: Community Contributions to the NRC Solar System Exploration Decadal Survey* (*ed.* Mark Sykes) Volume 272 of the Astronomical Society of the Pacific's Conference Series.

- **Withers**, "Atmospheric Structure Reconstruction using the Beagle 2 Accelerometer" (2001) Technical Report to the Open University, Great Britain, available at http://www.lpl.arizona.edu/~withers/pppp/pdf/oureport.pdf

Conference Presentations: Weather in the Martian Upper Atmosphere

- **Withers**, Bougher, and Keating, "Measurements of Winds in the Martian Upper Atmosphere from the MGS Accelerometer" (2002) *34th DPS Meeting*, Abstract #05.05.

- **Withers**, Bougher, and Keating, "MGS Accelerometer-derived profiles of Upper Atmospheric Pressures and Temperatures: Similarities, Differences, and Winds" (2002) *Spring AGU Meeting*, Abstract #P41A-10.

- Bougher, Keating, Forbes, Murphy, Hollingsworth, Wilson, and **Withers**, "The Upper Atmospheric Wave Structure of Mars as Determined by Mars Global Surveyor" (2001) *Fall AGU Meeting*, Abstract #P32E-12.

- **Withers**, Bougher, and Keating, "Unpredictable day-to-day variability in the martian upper atmosphere" (2001) *33rd DPS Meeting*, Abstract #19.29.

- **Withers**, Bougher, and Keating, "Harmonic Analysis of Zonal Density Structures in Martian upper atmosphere" (2001) *Spring AGU Meeting*, Abstract #P41A-05.

- **Withers** and Bougher "Understanding the martian upper atmosphere with the MGS Accelerometer" (2001) *4th LPL Internal Conference*, Tucson.

- Keating, Tolson, Wilson, Dwyer, Bougher, **Withers**, and Forbes, "Persistent planetary-scale wave-2 and wave-3 density variations observed in Mars upper atmosphere from MGS accelerometer experiment" (2001) *26th EGS General Assembly*, Session #PS2.02.

- Keating, Dwyer, Wilson, Tolson, Bougher, **Withers**, and Forbes,*et al.,* "Evidence of Large Global Diurnal Kelvin Wave in Mars Upper Atmosphere" (2000) *32nd DPS Meeting*, Abstract #50.02.

- Bougher, **Withers**, Murphy, Roble, and Keating, "Longitude Structure in the Mars Upper Atmosphere : Characterization and Model Simulations" (Solicited Key Note Paper) (2000) *33rd COSPAR Scientific Assembly*, Abstract #C3.2-0011.

- **Withers**, Bougher, and Keating, "New results from the Mars Global Surveyor Accelerometer" (2000) *31st LPSC Meeting*, Abstract #1268.

- **Withers**, Bougher, and Keating, "The martian upper atmosphere during phase 2 of Mars Global Surveyor aerobraking: comparison to predictions" (1999) *Fifth International Conference on Mars*, Abstract #6073.

- **Withers**, Bougher, and Keating, "The Martian Upper Atmosphere as Revealed by Mars Global Surveyor's Aerobraking (1999) *2nd LPL Internal Conference*, Tucson.

Conference Presentations: Ridges in the Martian Northern Plains

- **Withers** and Neumann, "Enigmatic northern plains of Mars" (2002) *Geoplanets Summer School*, Italy.

- **Withers** and Neumann, "A test of the martian northern ocean hypothesis" (2001) *4th LPL Internal Conference*, Tucson.

- **Withers** and Neumann, "Ridges in the Martian northern plains" (2001) *33rd Brown-Vernadsky Microsymposium*, Houston.

- **Withers** and Neumann, "Shallow Ridges in the Martian Northern Plains" (2000) *Fall AGU Meeting*, Abstract #P62B-02.

Conference Presentations: Age of lunar crater Giordano Bruno

- **Withers**, "Meteor storm evidence against the recent formation of lunar crater Giordano Bruno" (2001) *4th LPL Internal Conference*, Tucson.

- **Withers**, "Meteor storm evidence against the recent formation of lunar crater Giordano Bruno" (2001) *32nd LPSC Meeting*, Abstract #1007.

Conference Presentations: Atmospheric Structure Profiles from Entry Accelerometers

- **Withers**, Hathi, Towner, and Zarnecki, "Development of software for analysing entry accelerometer data in preparation for the Beagle 2 mission to Mars: Towards a Publicly Available Toolkit" (2002) *33rd LPSC Meeting*, Abstract #1203.

- **Withers**, Lorenz, and Neumann, "Errors in Viking Lander Atmospheric Profiles discovered using MOLA Topography" (2002) *33rd LPSC Meeting*, Abstract #1294.

Conference Presentations: Simple Extremal Climate Models

- **Withers** and Lorenz, "Simple Tests of Simple Climate Models" (2001) *Spring AGU Meeting*, Abstract #U32A-05.

- Lorenz, Lunine, **Withers**, and McKay, "Latitudinal Temperature Contrasts on Titan and the Principle of Maximum Entropy Production" (2000) *32nd DPS Meeting*, Abstract #17.07.

Conference Presentations: Simple Asteroid Shape Models

- **Withers**, "Angle of repose-limited shapes of asteroids" (2000) *3rd LPL Internal Conference*, Tucson.

- **Withers**, "Angle of repose-limited shapes of asteroids" (2000) *31st LPSC Meeting*, Abstract #1270.

Conference Presentations: Education and Public Outreach

- Grier, Atkinson, Barlow, Griffin, Hoffman, Kelly-Serrato, Keszthelyi, Klein, Klug, Kolvoord, Lanagan, Lebofsky, Lien, Lindstrom, Lopes, Lowes, Manifold, Mastrapa, Milazzo, Miner, Morris-Smith, Rivkin, Runyon, Sohus, Urquhart, Vasavada, Warasila, **Withers**, and Wood, "Defining Long Term Goals and Setting Priorities for Education and Outreach, 2003 to 2013 - Panel Report" (2001) *33rd DPS Meeting*, Abstract #19.29.

Previous and Current Research

When I started graduate school at the University of Arizona in August, 1998, I had no experience in identifying, researching, developing, and successfully achieving independent research goals. Learning how to do that has been the most satisfying achievement of my PhD studies. Supported by my advisor, I have pursued research goals in several different areas of planetary science and in two summer internships. Each of the areas listed below is represented by one or more publications or presentations in my publications list.

Weather in the Martian Upper Atmosphere:

- University of Arizona, Tucson, Arizona, USA
- 1998 – present
- Graduate Research Assistant and Associate, supervised by Steve Bougher

The main project that I have worked on in the last five years is analyzing accelerometer data from the aerobraking of Mars Global Surveyor to better understand weather in the martian upper atmosphere. I have participated in peer review of the accelerometer dataset for NASA's Planetary Data System public archive, and have been invited to participate in the peer review of the Mars Odyssey Accelerometer dataset. In addition to scientific research, I supported Steve Bougher in Atmospheric Advisory Group activities for Mars Global Surveyor, Mars Climate Orbiter, and Mars Odyssey. These typically included a daily teleconference during the aerobraking period of these spacecraft with scientists around the country, reviewing the available data, and making daily weather predictions to the mission operations staff to guide safe and timely aerobraking. The Mars Global Surveyor Accelerometer unexpectedly discovered large (factor of two) variations in upper atmospheric density with longitude at constant altitude, latitude, season, and time of day. My research has quantified this longitudinal structure and the effects on it of altitude, latitude, season, and time of day. By comparing these observations to predictions from classical tidal theory, I have identified what the dominant tidal modes, generated at the planet's surface, are in the upper atmosphere. I am developing a novel technique to measure winds in the upper atmosphere from this dataset, based on geostrophic balance and observed latitudinal gradients in density. Winds are challenging to measure, yet play a crucial role in a planet's climate. Once validated, this can be applied to many existing and anticipated datasets to measure atmospheric circulation at high altitudes on many planets.

Age of Lunar Crater Giordano Bruno:

- University of Arizona, Tucson, Arizona, USA
- 2000 – 2002
- Independent Research

The first independent research project that I devised and followed to completion was an investigation of the age of the young lunar crater Giordano Bruno. Based on a dramatic description in a medieval chronicle of the "Moon spewing fire, hot coals, and sparks," it has been suggested that the chronicle records an eyewitness account of its formation. This

would make it astoundingly young for a 22-km diameter lunar crater. I investigated the formation of this crater, its ejection of 10 million tonnes of debris from the Moon, and the subsequent meteor storm on Earth from the arrival of some of the ejected debris. Based on the expected, but not observed, spectacular meteor storm, I concluded that Giordano Bruno did not form in historical times and that there must be some other explanation for the striking medieval text.

Enigmatic Northern Plains of Mars:

- NASA Goddard Spaceflight Center, Greenbelt, Maryland, USA, later continued at the University of Arizona, Tucson, Arizona, USA
- 2000 – present (summer of 2000 spent at Goddard following successful application to the competitive Goddard Summer Student Program)
- Research Assistant to Greg Neumann while at Goddard, collaboration continued after my return to the University of Arizona and later collaborating also with Jay Melosh of the University of Arizona.

Topographic measurements from the Mars Orbiter Laser Altimeter (MOLA) have revolutionized our understanding of martian geology and geophysics. I spent the summer of 2000 as a summer intern with the leaders of the MOLA group, investigating a low-lying area of Mars that appears bland and featureless on existing images, and discovered a large network of ridges within it. We rejected an earlier, highly stimulating, interpretation that some of these ridges were once shorelines on a vast martian ocean and identified them as tectonic features, records of large impacts and the growth of volcanoes on Mars. These results were presented at several meetings of the MOLA Science Team. I later planned to study these features in more detail to learn about the history of martian volcanism, writing a funding proposal to NASA's Mars Data Analysis Program as a Co-Investigator (with Principal Investigator Jay Melosh). This was not funded, but the experience I gained then has improved my subsequent proposals.

Entry Accelerometer Data Analysis:

- Open University, Milton Keynes, Great Britain, later continued at the University of Arizona, Tucson, Arizona, USA
- 2001 – present (summer of 2001 spent at the Open University)
- Consultant to John Zarnecki while at the Open University, collaboration continued after my return to the University of Arizona

The Mars Express and Beagle 2 missions to Mars, due to arrive in late 2003, represent major new commitments to planetary science by Europe and Great Britain, respectively. To discover how this is affecting planetary science in Great Britain and establish collaborations there, I spent the summer of 2001 with the Beagle 2 team in Great Britain. Building on my work on analyzing accelerometer measurements from aerobraking, I developed the programs that will process Beagle 2's entry accelerometer data into vertical profiles of atmospheric density, pressure, and temperature. These programs have been made publicly available to stimulate other groups interested in such projects. After returning to Arizona, I submitted a proposal as Principal Investigator to become a Participating Scientist on NASA's Mars Exploration Rover mission. This was highly

rated, but not funded. Subsequently, I was invited to join the mission's Entry, Descent, and Landing Atmosphere Science Advisory Team with responsibilities for advising the JPL engineers in assessing the performance of the spacecraft during its atmospheric entry. I have also been invited to participate in a Huygens Descent Trajectory Working Group meeting by the Group Chair, David Atkinson.

Comparison of Martian Topography Between Viking Lander and MOLA Data:

- University of Arizona, Tucson, Arizona, USA
- 2002
- Independent Research in loose collaboration with Greg Neumann and Ralph Lorenz

Having a broad range of research projects stimulates novel ideas. Whilst working on entry accelerometer data analysis, I found that one product of that analysis for the Viking landers was a topographic profile, derived from radar altimetry, beneath the non-vertical path of the descending spacecraft. I compared this measurement of martian topography to the MOLA data I had been studying the previous summer and discovered a one to two kilometer difference between the two. This is most easily explained by uncertainties in the altitude of the radar attached to the Viking lander, which affects the vertical profiles of atmospheric density, pressure, and temperature generated by the Viking entry accelerometer data analysis.

Simple Climate Models:

- University of Arizona, Tucson, Arizona, USA
- 2001
- Collaborator with Ralph Lorenz

Current models of planetary climate are based on general circulation models, which are highly computer-intensive and contain many uncertain parameterizations of physical processes. It has been suggested that complicated thermodynamic systems, like a planet's climate and atmosphere, can be understood by the application of some kind of extremal principle analogous to the principle of least action in physics. Ralph Lorenz has investigated the hypothesis that fluid motions within an atmosphere act to maximize the rate of change of entropy within the system. I collaborated with him by deriving analytical expressions for how this would affect a simple atmosphere.

Planetary Atmospheres

My research aims are focused towards improving our understanding of the dynamics of upper atmospheres and their coupling to lower atmospheres. Atmospheric dynamics control the transport of energy and chemical species, which affect the chemical and thermal state of the planet beneath. As a branch of fluid dynamics, it displays behavior not seen in other systems, which improves our understanding of this basic physical process. Accurate upper atmosphere weather predictions are needed to support aerobraking spacecraft and offer great ($100M+) savings over orbital insertion using rocket fuel. Upper atmospheric observations contain information on the dynamics of the lower atmosphere as well, which offers an alternative probe into the lower atmosphere. Research on planetary atmospheres is active at the CfA. The Radio and Geoastronomy Division's work includes atmospheric dynamics [e.g. Gurwell]. The Solar, Stellar, and Planetary Sciences Division's work includes the origin of planets and their atmospheres [e.g. Kenyon, Wood], as does the Theoretical Astrophysics Division's work [e.g. Lecar]. The CfA's extensive observational facilities support studies of planetary atmospheres.

Extrasolar planets and their atmospheres are an active field of research at the CfA. In the near future, observations of extrasolar planets should progress beyond merely their orbital dynamics to providing preliminary physical characterizations, including their atmospheric dynamics [e.g. Showman and Guillot, 2002]. Comparison with our solar system and published predictions will be a fruitful research area that is well suited to the CfA. Since there is no guarantee that such observations will be made successfully during the first year of this proposal, I have chosen to focus this proposal on our solar system. If observational data on extrasolar planet atmospheric dynamics becomes available during the time covered by this proposal, then I would hope to study them.

Broad Research Goals (First Year):
Winds – Development of my current work on an innovative technique for deriving upper atmospheric winds using geostrophic balance and measured latitudinal gradients in density [Holton, 1992; Withers *et al.,* 2002a; 2002b].
Tides – Studies of tides in the martian atmosphere [Keating *et al.,* 1998; Withers *et al.,* 2002c].

The CfA's sub-mm array facilities will be used to support this project. These wavelengths can measure vertical temperature profiles of planetary atmospheres, which relate to atmospheric tides, and winds may also be directly measured. Their high spatial resolution enables studies of regional weather systems, beyond the mere disk-average, on Mars, Venus, and Titan. I will compare Gurwell's anticipated results on atmospheric winds and tides from these observations to my results using complementary spacecraft data.

Winds:
Temperature, pressure, and constituent transport in an atmosphere are strongly influenced by winds. Measurements of winds on other planets have primarily been made by indirect techniques and are currently limited to lower and middle atmospheres. I have developed a novel technique to measure wind speeds from latitudinal gradients in density and tested it

on Mars Global Surveyor's (MGS) accelerometer data. This notes that any drag pass through the atmosphere effectively acquires two horizontally separated vertical density profiles simultaneously [Withers *et al.*, 2002a; 2002b]. Using the assumptions of hydrostatic equilibrium in a static atmosphere to the inbound leg of the pass, as has been done for many vertical density profiles from planetary landers, the inbound density profile yields a value for the periapsis pressure. Similarly, the outbound leg yields a second measure of periapsis pressure. For MGS data, these two measurements of periapsis pressure are generally inconsistent. The assumptions of hydrostatic equilibrium in a static atmosphere need to be relaxed to permit geostrophic balance, or latitudinal density and pressure gradients in response to the Coriolis force [Holton, 1992]. Assuming a uniform zonal wind, geostrophic balance, and requiring the two estimates of periapsis pressure to agree, yields consistent estimates for periapsis pressure and the wind speed. On slowly rotating bodies such as Venus or Titan, cyclostrophic balance can be used instead. The ability to study winds from accelerometer measurements during aerobraking, which will be made on many future NASA missions, or orbiting mass spectrometers, extends the scientific breadth of these missions without requiring extra instrumentation.

Specific Objectives for Winds Goal:

- Further develop my technique to derive vertical profiles of zonal winds, then extract synthetic density profiles representative of past and anticipated datasets from general circulation model simulations of the martian upper atmosphere, and finally verify the technique by comparing the actual wind speeds in the simulation to those I derive from the synthetic density profiles [Withers *et al.,* 2002a; 2002b]. These simulations have been made available by my current PhD supervisor [Bougher *et al.*, 1999].
- Apply this technique to MGS and Mars Odyssey neutral density data to measure zonal wind speeds, quantify how the zonal wind speed varies with altitude, latitude, season, longitude, and time of day, and then compare these results to existing predictions
- Compare results to sub-mm/mm observations of winds.

Tides:

Atmospheric tides are departures from a mean, static behaviour with a harmonic relation to diurnal solar forcing. Different tidal modes have specific zonal wavenumbers and periods which define their vertical and meridional structure. They originate at the planet's surface, and propagate upwards, affecting the transport of energy and momentum in the atmosphere. Tides should increase in amplitude as they propagate upwards, but are dissipated to varying degrees dependent on the lower atmospheric winds and their vertical wavelength [Forbes, 1995]. MGS accelerometer data have shown that tides are important in the upper atmosphere, causing longitudinal variations in density of a factor of two or more [Keating *et al.* 1998; Withers *et al.,* 2002c]. Since the tides are affected by the lower atmosphere as they propagate upwards to the upper atmosphere, observations of upper atmospheric tides contain information about the state of the lower atmosphere. For example, eastward winds in the lower atmosphere prevent the existence of stationary Rossby waves, a specific tidal mode, in the upper atmosphere [Joshi *et al.,* 2000]. By comparing lower and upper atmospheric observations of tidal signatures and winds, simple theoretical models of tidal propagation, and detailed general circulation models if simple models are inadequate, I hope to identify relationships that will enable knowledge

of the state of the lower atmosphere to be deduced from observations of the upper atmosphere alone.

Specific Objectives for Tides Goal:

- Quantification of longitudinal structure, caused by thermal tides, in the martian upper atmosphere as seen in neutral and electron density data from MGS and Mars Odyssey as a function of latitude, altitude, season, time of day, and phase in the 11 year solar cycle, and identification of the dominant tidal modes [Keating *et al.,* 1998; Bougher *et al.,* 2001; Withers *et al.,* 2002c].
- Investigate whether observations of densities and winds, which are related by the dynamical equations of motion, can be explained solely by tidal processes, or if additional processes are required to make them consistent [Holton, 1992].
- Compare results to sub-mm/mm observations of tides.

Future Years:

In the second year of this proposal, I will study winds in Titan's atmosphere, comparing the published lower atmospheric results of the Huygens Doppler Wind Experiment to wind measurements in Titan's upper atmosphere from application of my innovative technique to density profiles from Cassini's Ion and Neutral Mass Spectrometer (INMS). I am currently investigating possible upper atmospheric results with Roger Yelle, an INMS Co-Investigator. These two sets of observations can be compared to published predictions and other Cassini/Huygens results.

- Bougher, SW, GM Keating, RW Zurek, JR Murphy, RM Haberle, JL Hollingsworth, and RT Clancy (1999) Mars global surveyor aerobraking: atmospheric trends and model interpretation, *Adv. Space Res.,* **23(11),** 1887-1897.
- Forbes, JM (1995) Tidal and Planetary Waves, in *The Upper Mesosphere and Lower Thermosphere* (eds. Johnson and Killen) American Geophysical Union.
- Holton, JR (1992) *An Introduction to Dynamic Meteorology*, Academic Press.
- Joshi, MJ, JL Hollingsworth, RM Haberle, and AFC Bridger (2000) An interpretation of Martian thermospheric waves based on analysis of a general circulation model, *Geophys. Res. Lett.,* **27,** 613-616.
- Keating, GM, and 28 coauthors (1998) The Structure of the Upper Atmosphere of Mars: In Situ Accelerometer Measurements from Mars Global Surveyor, *Science,* **279,** 1672-1675.
- Showman, AP, and T Guillot (2002) Atmospheric Circulation and tides of "51 Pegasus b-like" Planets, *Astronomy and Astrophysics,* **385,** 166-180.
- Withers, P, SW Bougher, and GM Keating (2002a) Measurements of Winds in the Martian Upper Atmosphere from the MGS Accelerometer, *Bull. Am. Ast. Soc.,* **34,** Abstract #5.05.
- Withers, P, SW Bougher, and GM Keating (2002b) Winds in the martian upper atmosphere from MGS aerobraking density profiles, *Eos Trans. AGU,* **83,** Fall Meeting Supp., Abstract #P61C-0353.
- Withers, P, SW Bougher, and GM Keating (2002c, submitted) The Effects of Topographically-controlled Thermal Tides in the Martian Upper Atmosphere as seen by the MGS Accelerometer, under review by *Icarus*.