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

- Grier *et al.*, “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
- **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.*

Selected Conference Presentations

- **Withers** *et al*., “MGS Accelerometer-derived profiles of Upper Atmospheric Pressures and Temperatures: Similarities, Differences, and Winds” (2002) *Spring AGU Meeting*, Abstract #P41A-10. **1 of 11 on weather in the martian upper atmosphere**
- **Withers** and Neumann, “Shallow Ridges in the Martian Northern Plains” (2000) *Fall AGU Meeting*, Abstract #P62B-02. **1 of 4 on ridges in the martian northern plains**
- **Withers**, “Meteor storm evidence against the recent formation of lunar crater Giordano Bruno” (2001) *32nd LPSC Meeting*, Abstract #1007. **1 of 2 on the age of lunar crater Giordano Bruno**
- **Withers** *et al.*, “Errors in Viking Lander Atmospheric Profiles discovered using MOLA Topography” (2002) *33rd LPSC Meeting*, Abstract #1294. **1 of 2 on atmospheric structure profiles from entry accelerometers**
- Grier *et al.*, “Defining Long Term Goals and Setting Priorities for Education and Outreach, 2003 to 2013 - Panel Report” (2001) *33rd DPS Meeting*, Abstract #19.29. **1 of 5 on other subjects**

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.

Martian Atmospheric Dynamics

I propose to analyze recent Hubble Space Telescope (HST) and other spacecraft observations to improve our understanding of martian atmospheric dynamics. Instruments on the Mars Global Surveyor (MGS), Mars Odyssey (ODY), Mars Exploration Rovers (MER), and Mars Reconnaissance Orbiter (MRO) spacecraft either have made, or will make, observations relating to martian atmospheric dynamics. HST observations of martian atmospheric dynamics have primarily come from the long-term monitoring program of P. James, which uses WFPC1/WFPC2/ACS and FOS/STIS to study the interannual, seasonal, latitudinal, and longitudinal behavior of many atmospheric properties and boundary conditions, including surface albedo, polar cap albedo, polar cap retreat, polar hoods, equatorial cloud belts, discrete clouds, dust storms, and column abundances of ozone and water [e. g. Clancy *et al.*, 1996; Wolff *et al.*, 1997; Cantor *et al.*, 1998; Mischna *et al.*, 1998; Wolff *et al.*,]. Half of these items relate to the transfer of radiation, which affects vertical thermal structure, and half to the meridional transport of both the dominant species and radiatively important trace species, which affects horizontal thermal structure and winds. This proposal will complement and extend HST's discoveries about martian atmospheric dynamics by studying atmospheric tides, which are controlled by these HST-observed lower atmospheric properties, and by comparing the upper atmosphere to these lower atmosphere observations.

Broad Goals:
(1) 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].
(2) Studies of tides in the upper atmosphere [Keating *et al.*, 1998; Withers *et al.*, 2002c].
(3) Studies of the lower atmosphere, in conjunction with the upper atmospheric results of goals 1 and 2, to test theories of how it is dynamically coupled to the upper atmosphere [Banfield *et al.*, 2000; Hinson *et al.*, 2001].

Background:
Wind affects the martian climate by transporting energy, momentum, condensable species, and radiatively important aerosols. Direct wind measurements on Mars are limited to two vertical profiles of horizontal winds from the entry of the Viking Landers and surface winds measured at their landing sites [Zurek *et al.*, 1992]. Indirect wind measurements derived from temperature gradients via the thermal wind equation have greater spatial and temporal coverage, but are only constrained relative to an unknown reference wind speed [Smith *et al.*, 2001]. HST observations have tracked clouds at unknown altitudes to measure wind speeds [Mischna *et al.*, 1998]. The two possible MER vertical profiles of horizontal wind speed and direction will double the number of wind profiles with vertical resolution of less than half a scale height. There are no measurements, direct or indirect, of martian wind speeds in the upper atmosphere. These winds affect the upward propagation of atmospheric tides and other wave phenomena, which can break and deposit their energy and momentum locally [Forbes, 1995]. My innovative technique for measuring winds 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 constant and 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.

Solar heating is stronger in the atmosphere of Mars than Earth's, per unit mass, and this causes strong thermal tides [Zurek *et al.*, 1992]. 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, then 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 winds in the lower atmosphere 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 and middle atmosphere as they propagate upwards to the upper atmosphere, observations of upper atmospheric tides contains 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 information about the state of the lower atmosphere to be deduced from observations of the upper atmosphere alone.

Timeline for Progress in Specific Objectives:

My nominal publication plans are (Y1) a short paper on objectives 1A and a paper on objective 3A; (Y2) a comprehensive paper on objective 1B, a comprehensive paper on objectives 2A – 2B, and a short paper on objective 3B; and (Y3) a paper on objectives 2C – 2D and a comprehensive paper on objectives 3C – 3D.

(1A: Y1) 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].
(1B: Y2) Apply this technique to MGS and ODY 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

[Keating *et al.,* 1998; Plaut and Saunders, 2001]. If MRO neutral density data from its accelerometer is available in the third year covered by this proposal, either through a successful Participating Scientist proposal or public release, then it will also be analyzed.

(2A: Y2) Quantification of longitudinal structure, caused by thermal tides, in the martian upper atmosphere as seen in neutral and electron density data from MGS and ODY 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]. Comparison of neutral and electron density results will test how similarly ions and neutrals behave in the weak, inhomogeneous magnetic field of Mars. Investigate also the hot atom data of Clarke's HST proposal 8658 for similar structure.
(2B: Y2) Study the effects of solar variability (such as the 28 day solar rotation and short-term solar flares) on martian upper atmospheric neutral and electron densities, including Clarke's hot atom HST data (#8658), in comparison with published terrestrial research, to test how sensitive these upper atmospheres are to solar changes [Keating *et al.,* 1998].
(2C: Y3) 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].
(2D: Y3) Compare the observed upper atmospheric tides to published predictions from classical tidal theory and general circulation models [Wilson, 2002; Withers *et al.,* 2002c] to test whether any important processes are missing from either classical theory or existing general circulation models.

(3A: Y1) Study tidal signatures in MER entry accelerometer data [Seiff and Kirk, 1977; Magalhaes *et al.,* 1998]. I will have access to this data as a member of the Atmosphere Science Advisory Group for their Landing.
(3B: Y2) Compare upper atmospheric winds from goal 1 to published HST observations of martian winds, published thermal winds from MGS and ODY, and possible MER measurements [Mischna *et al.,* 1998, Smith *et al.,* 2001; Zurek *et al.,* 1992] to identify how winds in the lower atmosphere are related to winds in the upper atmosphere.
(3C: Y3) Use vertical profiles of temperature and pressure from MGS and ODY, and HST-derived cloud and dust measurements, to identify which tidal modes are dominant in the lower and middle atmospheres as a function of latitude and season, then compare these to upper atmospheric tidal observations [Banfield *et al.,* 2000; Hinson *et al.,* 2001].
(3D: Y3) Using observations of upper and lower atmospheric tides and winds, in conjunction with theory and models, identify relationships that will enable information about the state of the lower atmosphere to be deduced from observations of the upper atmosphere alone.

- Boston University has an established group studying upper atmospheres which has received several recent grants specifically focused on the martian atmosphere. M. Mendillo is a Co-I on HST proposal 6513, which studied the Moon's atmosphere. J. Clarke is the PI on HST proposal 8658 to study the martian upper atmosphere to measure the D/H ratio and "hot" species such as O and H. The D/H ratio is a crucial measurement for understanding the history of water on Mars. Hot atoms are probably important in the upper atmosphere, but have not yet been well constrained by observations. They impact future aerobraking and low science orbit operations, specifically MRO.

- Banfield, D, BJ Conrath, JC Pearl, MD Smith, and P Christensen (2000) Thermal tides and stationary waves on Mars as revealed by Mars Global Surveyor thermal emission spectrometer, *J. Geophys. Res.,* **105,** 9521-9538.
- 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.
- Bougher SW, S Engel, DP Hinson, and JM Forbes (2001) Mars Global Surveyor Radio Science electron density profiles: Neutral atmosphere implications, *Geophys. Res. Lett.,* **28,** 3091-3094.
- Cantor, BA, MJ Wolff, PB James, and E Higgs (1998) Regression of Martian North Polar Cap: 1990-1997 Hubble Space Telescope Observations, *Icarus,* **136,** 175-191.
- Clancy, RT, MJ Wolff, PB James, E Smith, YN Billawala, SW Lee, and M Callan (1996) Mars ozone measurements near the 1995 aphelion: Hubble space telescope ultraviolet spectroscopy with the faint object spectrograph, *J. Geophys. Res.,* **101,** 12777-12784.
- Forbes, JM (1995) Tidal and Planetary Waves, in *The Upper Mesosphere and Lower Thermosphere* (eds. Johnson and Killen) American Geophysical Union.
- Garcia-Melendo, E, and A Sanchez-Lavega (2001) A Study of the Stability of Jovian Zonal Winds from HST Images: 1995-2000, *Icarus,* **152,** 316-330.
- Hinson, DP, GL Tyler, JL Hollingsworth, and RJ Wilson (2001) Radio occultation measurements of forced atmospheric waves on Mars, *J. Geophys. Res.,* **106,** 1463-1480.
- 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.
- Magalhaes, JA, JT Schofield, A Seiff (1999) Results of the Mars Pathfinder atmospheric structure investigation, *J. Geophys. Res.,* **104,** 8943-8956.
- Mischna, MA, JF Bell, PB James, D Crisp (1998) Synoptic measurements of Martian winds using the Hubble Space Telescope, *Geophys. Res. Lett.,* **25,** 611-614.
- Plaut, JJ, and RS Saunders (2002) 2001 Mars Odyssey: Science Mission Overview, *Bull. Am. Ast. Soc.,* **34,** Abstract #11.01.
- Sieff, A, and DB Kirk (1977) Structure of the Atmosphere of Mars in Summer at Mid-Latitudes, *J. Geophys. Res.,* **82,** 4364-4378.
- Smith, MD, JC Pearl, BJ Conrath, and PR Christensen (2001) Thermal Emission Spectrometer results: Mars atmospheric thermal structure and aerosol distribution, *J. Geophys. Res.,* **106,** 23929-23946.
- Sromovsky, LA, PM Fry, TE Dowling, KH Baines, and SS Limaye (2001) Neptune's Atmospheric Circulation and Cloud Morphology: Changes Revealed by 1998 HST Imaging, *Icarus,* **150,** 244-260.
- Wilson, RJ (2002) Evidence for nonmigrating thermal tides in the Mars upper atmosphere from the Mars Global Surveyor Accelerometer Experiment, *Geophys. Res. Lett.,* **29(7),** 10.1029/2001GL013975.

- 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*.
- Wolff, MJ, JF Bell, PB James, RT Clancy, and SW Lee (1999) Hubble Space Telescope observations of the Martian aphelion cloud belt prior to the Pathfinder mission: Seasonal and interannual variations, *J. Geophys. Res.,* **104,** 9027-9042.
- Wolff, MJ, SW Lee, RT Clancy, LJ Martin, JF Bell, PB James (1997) 1995 observations of Martian dust storms using the Hubble Space Telescope, *J. Geophys. Res.,* **102,** 1679-1691.
- Zurek, RW, JR Barnes, RM Haberle, JB Pollack, JE Tillman, and CE Leovy (1992) Dynamics of the atmosphere of Mars, in *Mars* (eds. Keiffer, Jakoksy, Snyder, and Matthews) University of Arizona Press.

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%          Fellowship Program Office at STScI:
%          a. Endorsement letter, signed by an authorizing official of the
%            first-choice Host Institution (this item ONLY may be sent by
%            e-mail instead, if desired, to hfellows@stsci.edu)
%          b. Recommendation letters from three referees
%        4. DEADLINE FOR RECEIPT OF MATERIALS FROM APPLICANTS IS
%          NOVEMBER 4, 2002. The deadline for receipt of letters of
%          reference is one week later, November 11, 2002.  It is crucial that you
EMPHASIZE
%          THIS DEADLINE TO YOUR REFEREES.
%        5. DO NOT LIST THE FOLLOWING INSTITUTIONS AS YOUR FIRST,
%          SECOND, OR THIRD CHOICE. As described in the Announcement of
%          Opportunity, these institutions are ineligible for new Hubble
%          Fellows in 2003:
%
%          o Center for Astrophysics
%          o Institute for Advanced Study

\documentstyle[hubble_fellow]{article}
\begin{application}

%   1.  Supply your name.

\firstname  {Paul}                % Include middle initial here as
                                  % well, as in \firstname{Robert E.}
\lastname   {Withers}

%   2.  Supply your country of citizenship

\citizenship{Great Britain}

%   3.  Supply your place of birth, and
```

% 4. date of birth (month, day, year)

\birthplace {Tittensor, Great Britain}
\birthdate {October, 03, 1975}

% 5. Supply your current postal address. Use \\ to indicate a line
% break, but your address may contain no more than three lines,
% as in:
% \address{My Institution\\Street Address\\City, State, Country,
% Postal Code or Zip}

\address {3002 East Hawthorne Street\\Tucson, AZ 85716}

% 6. Supply your telephone number.

\telephone {520 621 1507}

% 7. Supply your electronic mail address.

\email {withers@lpl.arizona.edu}

% 8. Supply the date on which you received your Ph.D. degree (month/year)

\PhDdate {May/2003}

% 9. Supply the name of the degree-granting institution for your Ph.D. degree

\university {University of Arizona}

% 10. Please supply information concerning your thesis: a Title,
% and Short summary.
%
% The combined title and summary must not exceed the space provided
% on the form. Switching to tiny fonts is not allowed!
% Paragraph breaks within your summary are allowed, but they use
% extra space. If your text is too long, you will get an "Overfull
% \vbox" error message.

\thesistitle {Weather in the Martian Atmosphere --- And Other Topics}
\thesissummary {My dissertation includes work on the martian upper atmosphere (the dominant theme), lunar crater Giordano Bruno, the northern plains of Mars, entry accelerometer data analysis, comparison of martian topography between Viking Lander and MOLA data, and simple climate models. Some has been published; the remainder is in preparation for publication. Density in the martian upper atmosphere varies regularly with longitude, unlike the Earth or early predictions for Mars. I have quantified this variability, compared it

to classical tidal theory, and identified the dominant tidal modes in the
upper atmosphere. I am also developing a novel technique to measure winds.}

%   11. Supply the name of your Ph.D. thesis advisor.

\thesisadvisor {Stephen Bougher}

%   12. Please list your choices for host institutions. Supply the
%   name of a faculty contact at your first choice institution.

\firstchoice   {Boston University}
\facultycontact {Michael Mendillo}

\secondchoice   {MIT}
\thirdchoice   {Earth and Planetary Sciences Department of Harvard University}

%   13. Please supply information concerning your proposed research:
%   a title and a brief summary. The instructions for this item
%   are the same as those for your thesis information (10).
%   If your text is too long, you will get an "Overfull
%   \vbox" error message.

\researchtitle {Martian Atmospheric Dynamics}
\researchsummary{I propose to analyze recent Hubble Space Telescope and other
spacecraft observations to improve our understanding of martian atmospheric
dynamics. Instruments on the Mars Global Surveyor, Mars Odyssey, Mars
Exploration Rovers, and Mars Reconnaissance Orbiter either have made, or will
make, observation relating to martian atmospheric dynamics. HST's mission
includes solar system science; by its long-term monitoring of planetary
atmospheres, HST has supported the study of atmospheric dynamics. My three
goals are (1) Development of my current work on an innovative technique for
deriving upper atmospheric winds using geostrophic balance and measured
latitudinal density gradients, (2) Studies of tides in the upper atmosphere,
and (3) complementary studies of the lower atmosphere to test theories of
how dynamically coupled it is to the upper atmosphere.}

%   14. Please list the names and addresses of three referees who have
%   been requested to send letters of reference directly to STScI.
%
%   Please use commas rather than "\\" to separate lines in the
%   addresses, so that they may print more compactly. Abbreviate as
%   necessary to keep each referee to one line of printed text.
%
%   DO NOT HACK THE FORM TO ADD ANY MORE THAN THREE
REFEREES! THREE IS
%   THE NUMBER THOU SHALT ENTER, NO MORE, NO LESS.

```
\refereeone     {Stephen Bougher, AOSS Dept, Univ of Mich, Ann Arbor,
MI 48109-2143}
%\refereetwo     {John Zarnecki,PSSRI,Open University,Walton Hall, Milton Keynes,
%MK7 6AA, GREAT BRITAIN}
\refereetwo     {Bill Hubbard, Lunar and Planetary Lab, Univ of Arizona,
Tucson, AZ 85721}
\refereethree   {Greg Neumann, Code 920, NASA Goddard, Greenbelt, MD 20771}

%       Leave the \date field empty to put in today's date.  For
%       a fixed date, enter "Month day, year", as in
%
%           \date{July 31, 2002}

\date{}

\end{application}
```