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2003.01.08

Daly Postdoctoral Search Committee
c/o Chenoweth Moffatt
Department of Earth and Planetary Sciences
Harvard University
20 Oxford Street
Cambridge MA 02138

Please find enclosed my application for a Daly Postdoctoral Fellowship. I include a curriculum vitae, contact information for three referees, a statement of my previous research, and a research proposal on Planetary Atmospheres.

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 communitypanel 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, “Winds in the martian upper atmosphere from MGS aerobraking density profiles” (2002) *Fall AGU Meeting*, Abstract #P61C-0353.

· **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.

Contact Information for Referees

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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.

Weather in the Martian Upper Atmosphere:

- University of Arizona, Tucson, Arizona, USA
- 1998 – present
- Graduate Research Assistant and Associate, supervised by Steve Bougher
- References 5, 15

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
- References 2, 3, 11

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.
- References 4, 13

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
- References 7, 10

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
- References 6, 12

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
- References 1, 14

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.

Others:

- References 8, 9

Refereed journal articles:

1. Lorenz, RD, JI Lunine, **P Withers**, and CP McKay (2001) Titan, Mars and Earth: Entropy Production by Latitudinal Heat Transport, *Geophysical Research Letters*, **28**, 415-418.
2. Nockolds, P, and **P Withers** (2002) Comment and reply on "Meteor storm evidence against the recent formation of lunar crater Giordano Bruno" by Paul Withers, *Meteoritics and Planetary Science*, **37**, 465-466.
3. **Withers, P**, (2001) Meteor storm evidence against the recent formation of lunar crater Giordano Bruno, *Meteoritics and Planetary Science*, **36**, 525 - 529.

4. **Withers, P**, and GA Neumann (2001) Enigmatic northern plains of Mars, *Nature*, **410,** 651.
5. **Withers, P**, SW Bougher, and GM Keating (2002, submitted) The Effects of Topographically-controlled Thermal Tides in the Martian Upper Atmosphere as seen by the MGS Accelerometer, under review by *Icarus*.
6. **Withers, P**, GA Neumann, and RD Lorenz (2002) Comparison of Viking Lander descent data and MOLA topography reveals kilometer-scale error in Mars atmosphere profiles, *Icarus*, **159,** 259-261.
7. **Withers, P**, MC Towner, B Hathi, JC Zarnecki (2002, submitted) Analysis of Entry Accelerometer Data: A Case Study of Mars Pathfinder, under review by *Planetary and Space Science*.

Selected Conference Presentations and Other Unrefereed Papers:

8. Grier, JA, and 28 coauthors, including **P Withers**, (2002) Setting Goals and Priorities for Education and Public Outreach, in *The Future of Solar System Exploration 2003-2013: Community Contributions to the NRC Solar System Exploration Decadal Survey* (ed. Sykes) Volume 272 of the Astronomical Society of the Pacific's Conference Series.
9. **Withers, P**, (2000) Angle of repose-limited shapes of asteroids, *31st Lunar and Planetary Science Conference*, Abstract #1270.
10. **Withers, P** (2001) Technical Report to the Open University (Great Britain) on *Atmospheric Structure Reconstruction using the Beagle 2 Accelerometer*.
11. **Withers, P** (2001) Meteor storm evidence against the recent formation of lunar crater Giordano Bruno, *32nd Lunar and Planetary Science Conference*, Abstract #1007.
12. **Withers, P** (2002) Errors in Viking Lander Atmospheric Profiles discovered using MOLA Topography, *32nd Lunar and Planetary Science Conference*, Abstract #1294.
13. **Withers, P**, and GA Neumann (2000) Shallow Ridges in the Martian Northern Plains, *Eos, Transactions of the American Geophysical Union, Fall Meeting Supplement*, **81,** Abstract #P62B-02.
14. **Withers, P**, and RD Lorenz (2001) Simple Tests of Simple Climate Models *Eos, Transactions of the American Geophysical Union, Fall Meeting Supplement*, **82,** Abstract #U32A-05.
15. **Withers, P**, SW Bougher, and GM Keating (2002) Measurements of Winds in the Martian Upper Atmosphere from the MGS Accelerometer, *Bulletin of the American Astronomical Society*, **34,** Abstract #5.05. (1 of 9 first-author conference presentations on weather in the martian upper atmosphere)

Planetary Atmospheres

My research aims are focused towards improving our understanding of the dynamics of upper atmospheres and their coupling to lower atmospheres. Dynamics controls the transport of energy and chemical species within an atmosphere, which affects 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. This proposed research would overlap with the work of the atmospheric science and planetary science research groups within the EPS department. It would also complement work at the CfA (e. g. Gurwell), at MIT (e. g. Lindzen, Zuber, and Tracadas), and at Boston University (e. g. Clarke and Mendillo).

Broad Goals:
(1) Development of my current work on an innovative technique for deriving upper atmospheric winds using geostrophic/cyclostrophic balance and measured latitudinal gradients in density [Holton, 1992; Withers *et al.*, 2002a; 2002b].
(2) Measurement of atmospheric properties, including winds, during the landing of NASA's two Mars Exploration Rovers (MERs) in early 2004 [Squyres, 2001]. I am a member of the Atmosphere Science Advisory Group for their Landing.
(3) Studies of tides in the martian atmosphere [Keating *et al.*, 1998; Withers *et al.*, 2002c].

1 – Upper Atmospheric Wind Speeds:
My innovative technique for measuring wind speeds from accelerometer or orbiting mass spectrometer density measurements is based on the observation that each such in-and-out pass through the atmosphere effectively measures two horizontally separated, vertical density profiles simultaneously [Keating *et al.*, 1998; Withers *et al.*, 2002a; 2002b]. The actual flight path typically extends over several tens of degrees in latitude as the spacecraft enters the atmosphere, descends several tens of kilometers to periapsis, and rises back up out of the atmosphere. By applying the assumption of hydrostatic equilibrium in a static atmosphere to the inbound (spacecraft descending to periapsis) leg of the pass, as has been done for many vertical density profiles from planetary landers or entry probes, the inbound density profile provides a pressure profile along the same flight path and a value for the pressure at periapsis. Similarly, the outbound (spacecraft ascending from periapsis) leg provides a second, independent measure of periapsis pressure. For Mars Global Surveyor (MGS) accelerometer data in the upper atmosphere, I have found that these two measurements of periapsis pressure are generally inconsistent. Scale analysis of the equations conserving momentum in the atmosphere, which originally led to the simple assumption of hydrostatic equilibrium in a static atmosphere, shows that the assumptions need to be relaxed to allow geostrophic balance, or latitudinal density and pressure gradients in response to the Coriolis force [Holton, 1992]. Lower atmospheric wind speeds have been measured using geostrophic balance on temperature/pressure data with complete latitudinal and vertical coverage, but geostrophic balance has never been applied to upper atmospheric density profiles with constrained latitudinal and vertical coverage before [Smith *et al.*, 2001]. Assuming a constant and uniform zonal wind, geostrophic balance, and requiring the two estimates of

periapsis pressure to agree, yields consistent estimates for the pressure profiles and the speed and direction of the zonal wind in this region. The sunsynchronous orbit of MGS renders this technique sensitive to only the zonal component of the horizontal winds.

On slowly rotating bodies such as Venus or Titan, cyclostrophic balance can be used instead with data from orbiting mass spectrometers (Pioneer Venus Orbiter and Cassini). Upper atmospheric densities on Earth have been studied with accelerometers in low-Earth orbit, and it is possible that terrestrial upper atmospheric wind speeds could be studied by applying this technique to their datasets [*e. g.*, Marcos and Forbes, 1985]. The ability to measure winds from accelerometer measurements during aerobraking, which will be made on many future NASA missions, extends the scientific breadth of these missions without requiring additional instrumentation.

2 – Atmospheric Properties Measured by MER:
I am a member of the Atmosphere Science Advisory Group for the Landing of these two spacecraft on Mars in Jan 2004 and will have access to their entry accelerometer data. I have already developed procedures to generate vertical profiles of atmospheric density, pressure, and temperature using such a dataset [Seiff and Kirk, 1977, Withers *et al.*, 2002c]. Similar datasets have been used to derive vertical profiles of horizontal winds in the lower atmosphere and I will work to repeat that difficult measurement on the MER data [Zurek *et al.*, 1992]. I am also involved with the European Beagle 2 Mars lander and will have access to their entry accelerometer data as well [Withers *et al.*, 2002c]. These three profiles of atmospheric density, pressure, and temperature will be collected in conjunction with extensive orbital remote sensing of the atmosphere from MGS, Mars Odyssey, and the European Mars Express. This is a unique opportunity to cross-calibrate the many instruments and obtain a snapshot of the martian atmosphere at both local and global scales, so I anticipate many opportunities to collaborate with a wide range of scientists from the different missions.

3 – Martian Atmospheric Tides:
MGS accelerometer data revealed longitudinal variations in density of a factor of two or more caused by thermal tides [Keating *et al.*, 1998]. I have studied this longitudinal structure as a function of latitude, altitude, and time of day and identified the likely dominant tidal modes [Withers *et al.*, 2002c]. I plan to extend this work using data from Mars Odyssey, and later from Mars Reconnaissance Orbiter, to examine changes with season and phase in the 11 year solar cycle. These accelerometer datasets reveal upper atmospheric phenomena on spatial and temporal scales not previously observed, have not yet been fully studied, and I plan to investigate them in detail.

Specific Objectives:
(1A) Extract synthetic density profiles, representative of the environmental conditions (season, time of day, longitude, phase in the 11-year solar cycle, latitude range, and altitude range) of past and anticipated datasets, from general circulation model simulations of the martian upper atmosphere, then compare the actual wind speeds in the simulation to those I derive from the synthetic density profiles. These simulations have been made available by my current PhD supervisor [Bougher *et al.*, 1999].

(1B) Extend the technique to generate vertical profiles of zonal winds by applying the principles of geostrophic balance at each individual altitude level [Holton, 1992]. The current implementation of the technique applies geostrophic balance to all altitudes together; this strongly weights the derived wind speed to the lowest altitudes.
(1C) Apply the improved technique to MGS and Mars Odyssey accelerometer data from the martian upper atmosphere to derive zonal wind speeds from each pass through the atmosphere, 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].
(1D) Instead of geostrophic balance, which is appropriate for rapidly-rotating bodies like Earth or Mars, use the principles of cyclostrophic balance to develop an analogous technique for measuring wind speeds from measured latitudinal density gradients on slowly-rotating bodies such as Venus or Titan [Holton, 1992].
(1E) Apply this version of the technique to Pioneer Venus Orbiter Neutral Mass Spectrometer data, quantify how the zonal wind speed varies with altitude, latitude, season, longitude, and time of day, and then compare these results to existing predictions [Schubert, 1983; Bougher, 1995].

(2A) Extend my current work on generating vertical profiles of density, pressure, and temperature from accelerometer measurements of linear acceleration made during the atmospheric entry of a lander or entry probe to include simultaneous gyroscopic measurements of angular accelerations and solution for profiles of atmospheric winds based on their effects on the spacecraft trajectory [Seiff and Kirk, 1977, Withers *et al.*, 2002c].
(2B) Apply these techniques to the atmospheric entry of NASA's MER spacecraft in early 2004 [Squyres, 2001].
(2C) Compare the derived atmospheric properties to existing predictions, and other measurements.

(3A) Quantify longitudinal structure, caused by thermal tides, in the martian upper atmosphere as seen in Mars Odyssey accelerometer data as a function of latitude, altitude, season and time of day and identification of the dominant tidal modes. Compare to MGS observations and published predictions [Keating *et al.*, 1998; Bougher *et al.,* 2001; Wilson, 2002; Withers *et al.,* 2002c].
(3B) Study the effects of solar variability (such as the 28 day solar rotation and short-term solar flares) on martian upper atmospheric densities. Study small-scale oscillations, possibly due to gravity waves, and any other interesting phenomena in individual density profiles.
(3C) Investigate whether observations of densities and winds, which are related by the dynamical equations of motion, can be explained solely by tidal processes, or whether additional processes are required to make them consistent [Holton, 1992].

Timeline for Research and Publication:

Assuming a start date in summer 2003, I plan to spend my first four months working on objectives 1A – 1C, the second four months working on objectives 2A – 2B, and the third four months working on objectives 3A – 3B. If renewed for a second year, I plan to concentrate on completing the remaining objectives for goal 1, then goal 2, and finally goal 3. My results will be published in the peer-reviewed literature. I plan to publish a comprehensive paper on objectives 1A – 1C, a short paper on objectives 2A – 2B in conjunction with the MER team, a paper on objectives 1D – 1E, a paper on objective 2C in conjunction with scientists analyzing simultaneous observations from other instruments and making theoretical predictions, and a comprehensive paper on objectives 3A – 3C.

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