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Title: **Radio occultation studies at Mars**

Short title: **Radio occultation studies at Mars**

Summary of proposal:

The purpose of this proposal is to build the foundations of a research group that is capable of playing major scientific roles in radio occultation investigations by NASA planetary spacecraft. Few US groups currently have the expertise necessary to lead a radio occultation investigation from concept to completion, and this small and shrinking human capital poses risks to NASA's mission. Successful completion of this proposed effort will be a major step towards establishing Boston University's Center for Space Physics as such a group. We propose that a postdoctoral researcher develop three critical tools required for the reduction of radio occultation observations. First, predicting the vacuum Doppler shift between a spacecraft antenna and a terrestrial ground station. Second, converting a time series of frequency residuals into a vertical profile of ray path bending angle in a planetary atmosphere. Third, transforming the bending angle profile into vertical profiles of atmospheric and ionospheric properties. Several experienced collaborators provide valuable expertise.

Summary of personnel and effort:

Name	Role	Institution	Funded Effort per year	Unfunded Effort per year
Dr. Paul Withers	PI	Boston Univ.	0.45 months (0.04 FTE)	1 month (0.08 FTE)
Postdoctoral Researcher (TBD)		Boston Univ.	4 months (0.33 FTE)	0
Sami Asmar	Collaborator	JPL	0	As needed
Martin Pätzold	Collaborator	Uni. Cologne	0	As needed
Silvia Tellmann	Collaborator	Uni. Cologne	0	As needed

1 - Introduction

The purpose of this proposal is to build the foundations of a research group that is capable of playing major scientific roles in radio occultation investigations by NASA planetary spacecraft. Such investigations provide high-quality vertical profiles of ionospheric electron density and neutral density, pressure, and temperature (e.g., Tyler et al., 2001; Kliore et al., 2004). The importance of radio occultation investigations for planetary ionospheric studies can hardly be overstated - they have provided the vast majority of relevant measurements. Although less dominant for neutral atmospheric studies, they are still valuable. Radio occultation profiles of neutral atmospheric properties offer better vertical resolution (sub-km) than most other techniques, including an absolute altitude scale, and are unaffected by instrument calibration issues.

However, the expertise necessary to lead a radio occultation investigation from concept to completion is not widely distributed in the US. JPL (often Kliore) and Stanford (often Tyler) have provided PIs or Team Leaders for every NASA planetary radio occultation investigation (see list of experiments and personnel at http://nssdc.gsfc.nasa.gov/ planetary/ for each mission) and have also provided most of the team members with instrumentation, operations, or data processing expertise (as opposed to analysis of derived atmospheric and ionospheric properties). Moreover, the available expertise is aging. The Stanford group currently contains three senior individuals (Tyler, retired; Simpson, almost retired; Hinson, 55 years old, transitioning to SETI Institute) and no trained postdocs or students. JPL's planetary radio occultation work has been led by Kliore, who is now near retirement, since the beginning of the space age. The remaining radio occultation experts at JPL, such as Asmar, are mostly focused on the engineering and operational aspects of radio science investigations, not scientific analysis. In order to be able to implement successfully the next generation of planetary radio occultation investigations, NASA needs to nurture and develop a new generation of trained scientists.

PI Withers has long-standing research interests in the atmospheric and ionospheric environments that can be measured by radio occultation investigations, including scientific analysis of ionospheric measurements from MGS and MEX radio occultation instruments (Withers et al., 2005; Withers and Mendillo, 2005; Mendillo et al., 2006; Withers et al., 2008; Withers, 2009) and neutral atmospheric measurements from entry accelerometers and UV spectrometers (Fulchignoni et al., 2005; Withers and Smith, 2006; Withers and Catling, 2010; Withers et al., "Atmospheric tides in SPICAM data", in preparation). He also has a demonstrated track record working on radio occultation investigations. He has served as Co-I on the MEX and Venus Express (VEX) radio science teams, Co-I on the Radio Science Experiment for The Great Escape Mars Scout orbiter (Phase A study), and Co-I on the ASTRO radio occultation investigation proposed for the 2016 Mars Trace Gas Orbiter (not selected). His planned contributions to the two proposed, but not selected, radio occultation instruments extended beyond scientific analysis of derived data products to operational planning and data processing. He has also developed analytical relationships between the uncertainties in key atmospheric data products, namely neutral density and electron density, and the technical specifications of radio occultation investigations (Withers, 2010).

We propose a two year effort to support a postdoctoral researcher at 0.33 FTE per year. The other portion of the postdoctoral researcher's effort, which will be focused on scientific projects related to the atmospheric and ionospheric environments that can be studied by radio occultation investigations, will be supported by other sources of funds (e.g. existing R&A grants, start-up funds provided by Boston University).

2 - How radio occultations work

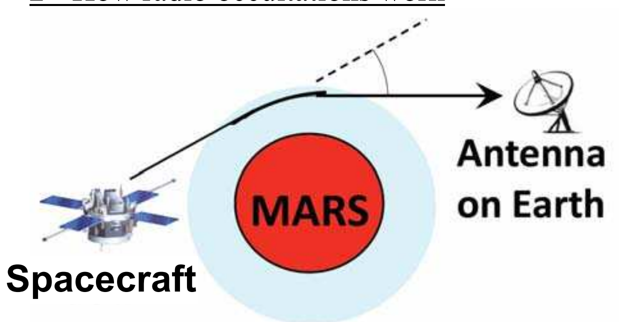

Figure 1.

The basic principles of radio occultation investigations are described in Hinson et al. (1999) and Withers (2010). In summary, a radio wave propagates between a spacecraft and a ground station (or vice versa). If its path passes close to a planet, then the path is affected by refraction in the planet's atmosphere and ionosphere. This refraction bends the ray by some angle (~1 μrad for Mars ionosphere, ~100 μrad for Mars neutral atmosphere - Hinson et al., 1999). This ray bending leads to a slight modification of the frequency recorded at the receiver (tens of mHz for Mars ionosphere, several Hz for Mars neutral atmosphere - Hinson et al., 1999). The received frequency differs from the transmitted frequency due to the classical Doppler shift between the moving transmitter and receiver (the vacuum Doppler shift, ~10^5 Hz), the effect of ray bending in the planetary atmosphere/ionosphere (the frequency residual, mHz to Hz), and various sources of noise (thermal and phase noise in the transmitter and receiver, effects of propagation through the interplanetary medium and Earth's atmosphere/ionosphere) (Withers, 2010).

This proposal is focused on developing the tools necessary to perform three critical steps in the data pipeline of a radio occultation observation. It is not necessary for us to develop an end-to-end pipeline because other important steps in this pipeline are performed routinely by a spacecraft project or the JPL Radio Science Systems Group (JPL's primary interface to the Deep Space Network, or DSN, for radio science activities). These three critical steps are as follows:

Step 1: Predict the vacuum Doppler shift due to the relative motion of the DSN and spacecraft antenna. This requires SPICE kernels for the DSN and spacecraft antenna.
Step 2: Use a time series of frequency residuals to determine a vertical profile of ray bending angle in the planetary atmosphere/ionosphere. This step applies principles of ray optics and requires SPICE kernels for the DSN and spacecraft antenna.
Step 3: Use the vertical profile of ray bending angle to determine a vertical profile of refractive index in the planetary atmosphere/ionosphere. This step is primarily a mathematical transformation.

We will use datasets from two spacecraft, MGS and MEX, to develop and test these tools. We define high-level data products as ones that are suitable for immediate scientific analysis, such as neutral density, pressure and temperature profiles or ionospheric electron density profiles. We define low-level data products as ones that need additional processing before being suitable for immediate scientific analysis. High-level data products can be obtained straight-forwardly from the refractive index (Step 3). The (refractive index – 1) is proportional to the electron density, which dominates at high altitudes, and the neutral density, which dominates at low altitudes (Withers, 2010).

Archived MGS (Hinson et al., 1999; Tyler et al., 2001) closed loop orbit data files (ODFs) and related ancillary files report the time series of observed frequency at the DSN during an occultation and the transmitted frequency at the spacecraft (such as the entry "MGS low-level" in our references). Corresponding high-level atmospheric and ionospheric profiles are also archived (such as the entry "MGS high-level" in our references). Experts may note that open loop data was used to derive the archived high-level MGS profiles - the ODF files are adequate, after baselining, for the conceptual and preliminary development that is proposed here.

MEX has archived low-level data products from hundreds of radio occultations (Pätzold et al., 2004). The "Level 02" low-level data products (such as the entry "MEX low-level" in our references) include time series of altitude sampled at Mars, transmitted frequency, predicted vacuum Doppler shift, and frequency residual. Corresponding high-level data products have been archived for 10-20 of these occultations (such as the entry "MEX high-level" in our references).

3 - Primary tasks

3.1 - Task A (Step 1 - Predict the vacuum Doppler shift due to the relative motion of the DSN and spacecraft antenna)

The simplest possible expression for the vacuum Doppler shift Δf is $\Delta f/f = v/c$, where f is frequency, v is the speed of the spacecraft with respect to the DSN, and c is the speed of light. This is too simple an approximation for practical use. More general expressions that include relativistic terms and gravitational terms exist in many papers and textbooks (e.g., Soffel, 1989). The first challenge here is to identify the appropriate level at which to approximate the fully general expression. For instance, first order or higher in (v/c), are gravitational redshift effects significant? The second challenge is to represent the motions of the DSN and spacecraft antenna with the appropriate level of accuracy in a SPICE framework. For instance, can the motion of the DSN antenna be adequately represented by a point at the stated latitude, longitude and radial distance that rotates relative to Earth's center of mass at the canonical rate about the canonical axis? Or do variations in the length of day and polar wander have to be considered? Are motions as small as antenna motion with respect to its stated latitude, longitude and radial distance due to plate tectonics significant? Such apparently tiny factors are typically considered in radio occultation investigations (Pätzold, 2010, pers. comm.).

3.2 - Task B (Step 2 - Determine the ray bending angle from frequency residual, spacecraft trajectory and DSN antenna location)

The simplest possible expression relating the frequency residual df to the ray bending angle α is df/f = αv/c, where f is frequency, v is the speed of the spacecraft with respect to the DSN antenna, and c is the speed of light (Hinson et al., 1999; Withers, 2010). Using these two simple expressions, the ratio of the frequency residual df to the vacuum Doppler shift Δf is α. Measuring the frequency residual associated with 1 μrad of bending in the Mars ionosphere therefore requires calculation of the vacuum Doppler shift to an accuracy of 1 part in $>10^6$, which explains why highly accurate representations of the motion of the DSN antenna with respect to a defined inertial frame are needed.

Again, the expression given here is too simple an approximation for practical use. More general expressions exist in many papers and textbooks (e.g., Fjeldbo et al., 1971; Hinson et al., 1999). However, the expressions are often reported using specialized coordinate frames that are not easily generalizable or that assume idealized 2D geometries. The first challenge here is to write the many published expressions in frame-independent vector representations. The second challenge is to identify the appropriate level at which to approximate the fully general expression.

3.3 - Task C (Step 3 - Derive a vertical profile of refractive index from a vertical profile of ray bending angle using an Abel transform relationship)

Refractive index μ and ray bending angle α are related by an integral relationship known as an Abel transform (Hinson et al., 1999).

$$\ln \mu_j = \frac{-1}{\pi} \int_{a=a_j}^{a=\infty} \ln \left(\frac{a}{a_j} + \sqrt{\left(\frac{a}{a_j}\right)^2 - 1} \right) \frac{d\alpha}{da} da$$

Equation 1.

where a is effectively the radius of closest approach of the ray path to the planet and the subscript j labels a particular ray path (equivalent to a particular time at the receiver). The first challenge here is the optimal extension of the measured vertical profile of dα/da, which cannot extend above the spacecraft's apoapsis altitude, to the infinite altitudes required by this equation. Is it best to extend with a string of zeroes or assume a functional form that gradually transitions from a finite value at the top of the actual profile to zero at infinite altitudes? The second challenge is working with real, noisy data, to which the derivative dα/da is especially sensitive. What smoothing or averaging techniques are most suitable for minimizing the effects of Gaussian noise or plausible systematic errors? How do uncertainties in dα/da propagate through the integral relationship to uncertainties in μ?

4 - Sustainability

Several pathways are available for sustaining and strengthening the Boston University radio occultation group that will be seeded by the effort proposed here. Growth will depend on opportunities grasped. In particular, a significant funded role in a flight mission is the next critical step forward.

Flight instruments: We intend to collaborate with colleagues on proposals to NASA for involvement in missions, including participating scientist roles in missions with radio occultation investigations (e.g., Cassini, New Horizons), facility science investigations in missions with selected payloads that are capable of performing radio occultation observations but have no radio occultation team (e.g., MAVEN, Mars Trace Gas Orbiter, Dawn, Messenger), and instrument teams in missions whose payloads are not yet selected (e.g., JEO and JGO spacecraft of the EJSM project, Discovery, New Frontiers, future NASA Mars orbiters). NASA also supports US-based scientific contributions to selected non-NASA missions at a similar range of levels. Note that even comets and atmosphere-less bodies like the Moon, Mercury, and asteroids may have detectable ionospheres, making them suitable targets for radio occultation investigations.

Reduction of existing datasets: Several low-level datasets exist that we will have the capability to transform into high-level data products. We may propose to NASA and other R&A programs to exploit existing low-level data products from MEX, MRO, and Cassini. The MEX low-level data products have already been discussed. Although MRO does not have an official radio occultation investigation, the MRO project has elected to perform approximately one occultation per day (several hundred as of October 2010) under the direction of JPL's Sami Asmar, who is a collaborator on this proposal. High-level ionospheric profiles have not been produced from these observations. Cassini has archived low-level occultation data products only, and analysis of data from the dense, spherical neutral atmosphere of Titan is a potential starting point.

Scientific research on relevant planetary environments: We intend to propose to NASA and other R&A programs to conduct scientific research on planetary environments relevant to the measurement capabilities of radio occultation investigations (e.g. structure and dynamics of neutral atmospheres and ionospheres). These activities might include theoretical modeling and analysis of data products from instruments that are not radio occultation investigations, as well as analysis of high-level data products from radio occultation instruments.

5 - Personnel

Principal Investigator Paul Withers: Assistant Professor Withers has substantial experience using data, supported by modeling, to explore the atmosphere and ionosphere of Mars. He has worked with aerobraking accelerometer experiments for MGS, Odyssey, and VEX (Venus), entry accelerometer experiments for Huygens (Titan), Spirit, Opportunity, and Phoenix, and radio occultation experiments for MEX and VEX (Venus). He has used SPICE in the development of two radio occultation instrument proposals and in the processing and PDS archiving of several aerobraking and entry accelerometer datasets (ODYA_1001, MERIMU_2001, PHXASE_0002).

Postdoctoral Researcher (TBD): A preferred candidate for the postdoctoral researcher position has not been identified. We desire a recent PhD recipient with experience either in analysis of data concerning planetary atmospheres/ionospheres or with relevant instrumentation, such as a radio wave instrument used to characterize a terrestrial, space, or planetary environment. Experience in both scientific and engineering fields would, of course, be highly desirable. US institutions that train graduate students with these skills include Arizona, Berkeley, Caltech, Colorado, Cornell, Michigan, UCLA and others (science), and Georgia Tech, Iowa, MIT, Stanford and others (instrumentation / engineering). Several international institutions also train suitable students.

Collaborator Sami Asmar: Asmar, the supervisor of JPL's Radio Science Systems Group, has managed scientists and engineers in radio occultation experiments through the design, implementation, operations, data acquisition and analysis stages. He has been a Co-Investigator or Team Member on 8 radio science investigations, including Co-PI for BepiColombo radio science, Deputy Project Scientist for the GRAIL mission, and Instrument Manager for Cassini and Juno radio science investigations.

Collaborator Martin Pätzold: Pätzold leads the MEX and Rosetta radio science investigations. He is or has been a team member on radio science investigations for VEX, Stardust, New Horizons, Galileo, Giotto, and Ulysses.

Collaborator Silvia Tellmann: Tellmann is a Co-Investigator on the MEX, VEX and Rosetta radio science investigations. She leads the data processing of MEX radio occultation observations.

6 - Work plan for 24 month duration of project

Foundations (Months 01-03): Complete ongoing literature review. Acquire relevant data (various levels of MEX and MGS data products, SPICE trajectory kernels) and become familiar with data formats, data quality, and data coverage.

Task A (Months 04-09): Find general, frame-independent expression for vacuum Doppler shift in frequency (Δf) in terms of relative motion of transmitter and receiver. Understand possible approximations and their consequences/impact. Define requirements for software tool. Develop software tool. Verification and validation. Numerical investigation of how uncertainties in required inputs determine uncertainties in output products.

Task B (Months 10-15): Find general, frame-independent expression for ray bending angle (α) in terms of frequency residual (df) and relative motion of transmitter and receiver. Understand possible approximations and their consequences. Define requirements for software tool. Develop software tool. Verification and validation. Numerical investigation of how uncertainties in required inputs determine uncertainties in output products.

Task C (Months 16-21): Investigate solutions to the vertical extension problem. Investigate techniques for smoothing $d\alpha/da$. Develop software tool. Verification and validation. Numerical investigation of how uncertainties in required inputs determine uncertainties in output products.

Synthesis (Months 22-24): Define requirements for interfaces between the tools developed for Tasks A-C as a step towards an end-to-end system for radio occultation observations. Identify any unresolved problems and develop possible strategies for resolving them in future work. Locate other low-level radio occultation datasets for which high-level data products have not been archived and explore the feasibility of producing high-level data products in future work. If the results of this capacity-building activity are suitable for scientific publication, then a manuscript will be prepared.

The postdoctoral researcher will have primary responsibility for these tasks. PI Withers will manage all aspects of this proposed effort and deliver required reports. He will coordinate communication between personnel, monitor progress, and supervise the postdoctoral researcher. He will also be responsible for the professional development of the postdoctoral researcher. The Collaborators will provide directions to key papers, monographs, and reports concerning radio occultation investigations; critiques of evolving ideas and techniques; and interfaces to the capabilities and skills of the JPL Radio Science Systems Group and the Cologne radio science group.

The budget includes travel for the postdoctoral researcher to 1 VEX/MEX two day radio science meeting per year (Year 1 at Stanford, Year 2 in Cologne). This will introduce the postdoctoral researcher to the radio occultation community and these meetings will serve as an excellent forum for discussing progress in this proposed effort. The European trip will be extended by several days to include focused discussions with Collaborators Pätzold and Tellmann. The budget also includes travel for the postdoctoral researcher to JPL for 1 week-long working visit with Collaborator Asmar per year. These multi-day face-to-face visits will be much more effective for trouble-shooting and brainstorming than telecons or brief sidebar discussions at other meetings, although routine interactions will occur regularly via email and telecons. No travel to scientific conferences is budgeted in this proposal as such travel is expected to be supported by the projects that support the postdoctoral researcher's other 0.67 FTE per year.

7 - Relevance to NASA

The NASA R&A program that this proposal is most relevant to is MDAP. It will create a group capable of producing high-level data products from existing low-level data products for MEX and MRO. This group will also be capable of enhancing the future scientific return of Mars orbital missions, such as MAVEN and Mars Trace Gas Orbiter, that do not currently plan to archive high-level radio occultation data products. From a broader perspective, this new group will be capable of assuming scientific leadership roles in a range of NASA missions throughout the solar system. Few other US groups have this capability and their long-term futures are not secured.

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MGS low-level data products, http://pds-geosciences.wustl.edu/missions/mgs/rsraw.html

MGS high-level data products, http://pds-geosciences.wustl.edu/missions/mgs/rsdata.html

MEX low-level data products, ftp://pds-geosciences.wustl.edu/mex/mex-m-mrs-1_2_3-v1/mexmrs_0735/data/level02/open_loop/dsn/dpx/m65rsr0l02_dpx_053651844_00.lbl

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Biographical Sketch for PI Paul Withers

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Education

- PhD, Planetary Science, University of Arizona 2003
- MS, Physics, Cambridge University, Great Britain 1998
- BA, Physics, Cambridge University, Great Britain 1998

Professional Experience

- Assistant Professor, Astronomy Department (Boston Univ.) 2010-present
- Senior research associate Dr. Michael Mendillo (Boston Univ.) 2007 – 2010
  Research associate Dr. Michael Mendillo (Boston Univ.) 2003 – 2007
  Analysis of ionospheric data from Venus, Mars and Earth, plus numerical modeling
- Graduate research assistant Dr. Stephen Bougher (Univ. of Arizona) 1998 – 2003
  Studied tides in the martian upper atmosphere. Played an advisory role in mission operations for Mars Global Surveyor and Mars Odyssey aerobraking

Selected Fellowships, Honors, and Awards

- NASA Early Career Fellowship 2009
- CEDAR Postdoctoral Fellowship from NSF for upper atmospheric research 2003
- 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

Membership of Committees and Working Groups

- DPS Nominating Committee 2008-present
- Mars Exploration Program Analysis Group (MEPAG) Goals Committee member 2008-present
- Mars Exploration Program Analysis Group (MEPAG) Mars Human Precursor Science Steering Group - Atmospheric Focus Team member 2004-2005

Selected Peer Reviewed Publications

- Opgenoorth and 7 colleagues, including **Withers** (2010) Day-side ionospheric conductivities at Mars, Planetary and Space Science, 58, 1139-1151, 10.1016/j.pss.2010.04.004
- **Withers** (2010) Prediction of uncertainties in atmospheric properties measured by radio occultation experiments, Advances in Space Research, 46, 58-73
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Biographical Sketch for Collaborator Sami Asmar

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Experience (1985-present, JPL):
Two decades of experience in Radio Science investigations from concept to completion. As the supervisor of the JPL Radio Science Systems Group, Asmar has managed scientists and engineers to conduct experiments through design, implementation, operations, data acquisition and analysis – including MGS and MEX radio occultations.

Science active research appointments:
• Co-Principal Investigator, BepiColombo Radio Science
• Co-Investigator & Deputy Project Scientist, GRAIL mission
• Co-Investigator, Huygens Doppler Wind Experiment
• Co-Investigator, Ulysses Radio Science Experiment
• Co-Investigator, Mars Express Radio Science Experiment
• Associate Team Member and Instrument Manager, Cassini Radio Science Team
• Associate Team Member, Dawn gravity science team
• Investigation Scientist & Instrument Manager, Juno Gravity Science

Current technical leadership positions:
• Supervisor of the Radio Science Systems Group
• Radio Science Lead in the Deep Space Network science office
• Initiative Leader of JPL's R&TD Advanced Radio Science Instrument Initiative including spacecraft-to-spacecraft links for radio occultations and surface scattering
• Study Lead of Radio Science community decadal studies

Selected Publications
• Anderson, J. D., et al. (2005) "Amalthea's Density is Less Than the Density of Water," Science, 308, 1291-1293.
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Experience:
Over two decades of experience in radio science investigations from concept to completion. Various positions at the University of Cologne since 1993, including Senior Research Scientist, University Lecturer, and acting Professor. Also Visiting Scientist at JPL and Visiting Assistant Professor at Stanford University.

Relevant experience:
- Principal Investigator, Mars Express Radio Science
- Principal Investigator, Rosetta Radio Science
- Co-Investigator, COROT
- Co-Investigator, Venus Express Radio Science
- Team Member, Stardust Radio Science
- Team Member, New Horizons Radio Science
- Team Member, Galileo Radio Propagation Experiment
- Co-Investigator, Giotto Radio Science
- Co-Investigator, Ulysses Solar Corona Experiment

Selected Publications:
- Häusler, B., M. Pätzold, G.L. Tyler, R.A. Simpson, M.K. Bird, V. Dehant, J.-P. Barriot, W. Eidel, R. Mattei, S. Remus, J. Selle, S. Tellmann and T. Imamura, "Radio science investigations by VeRa onboard the Venus Express spacecraft", Planet. Space Sci., 54, 1315-1354, 2006.
- Häusler B., M. Pätzold, G.L. Tyler, R.A. Simpson, D.P. Hinson, M.K. Bird, R.A. Treumann, V. Dehant, W. Eidel, S. Remus, J. Selle, and S. Tellmann, "Venus atmospheric, ionospheric, surface and interplanetary radio-wave propagation studies with the VeRa radio science experiment", ESA-SP-1295, 1-30, 2007.
- Hinson D.P., M. Pätzold, R.J. Wilson, B. Häusler, S. Tellmann and G.L. Tyler, "Radio occultation measurements and MGCM simulations of Kelvin waves on Mars", Icarus, 193, 125-138, 2008.
- Hinson, D.P., M. Pätzold, S. Tellmann, B. Häusler, G.L. Tyler, "The depth of the convective boundary layer on Mars", Icarus, 198, 57-66, 2008.
- Pätzold M., S. Tellmann, B. Häusler, D.P. Hinson, R. Schaa and G.L. Tyler, "A sporadic third layer in the ionosphere of Mars", Science, 310, 837-839, 2005.
- Pätzold, M., and 31 co-authors (also S. Tellmann), "Rosetta Radio Science Investigations (RSI)", Space Sci. Rev. 128, 599, 2007.
- Pätzold, M., B. Häusler, M.K. Bird, S. Tellmann, R. Mattei, S.W. Asmar, V. Dehant, W. Eidel, T. Imamura, R.A. Simpson and G.L. Tyler, "The structure of Venus middle atmosphere and ionosphere", Nature, 450, 657, 2007.

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Experience:
Retrieval of ozone abundance profiles from UV/visible nadir spectra recorded by GOME spacecraft. Applied these data processing skills to radio science data for Mars Express, Venus Express and Rosetta. Currently leading data processing effort for Mars Express radio occultation observations and deputy to Martin Pätzold in the Cologne radio science group.

Relevant experience:
- Co-Investigator, Mars Express Radio Science
- Co-Investigator, Rosetta Radio Science
- Co-Investigator, Venus Express Radio Science

Selected Publications:
- Häusler, B., M. Pätzold, G.L. Tyler, R.A. Simpson, M.K. Bird, V. Dehant, J.-P. Barriot, W. Eidel, R. Mattei, S. Remus, J. Selle, S. Tellmann and T. Imamura, "Radio science investigations by VeRa onboard the Venus Express spacecraft", Planet. Space Sci., 54, 1315-1354, 2006.
- Häusler B., M. Pätzold, G.L. Tyler, R.A. Simpson, D.P. Hinson, M.K. Bird, R.A. Treumann, V. Dehant, W. Eidel, S. Remus, J. Selle, and S. Tellmann, "Venus atmospheric, ionospheric, surface and interplanetary radio-wave propagation studies with the VeRa radio science experiment", ESA-SP-1295, 1-30, 2007.
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- Tellmann, S., M. Pätzold, B. Häusler, M.K. Bird and G.L. Tyler, "Structure of the Venus neutral atmosphere as observed by the radio science Experiment VeRa on Venus Express", J. Geophys. Res., 114, E00B36, doi:10.1029/2008JE003204, 2009.