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Scientific/technical/management section (15 pages)

New discoveries made in recent observations at Venus and Mars and new laboratory data on key reaction rate coefficients enable comparative studies of the effects of meteoroids on multiple planets.

1 – What meteoroids do to ionospheres

All planets and satellites in the solar system sweep through interplanetary dust as they move along their orbital paths. When dust particles, known as meteoroids, enter an atmosphere at orbital speeds, they are decelerated and ablated. Meteoroid ablation deposits exotic species like Mg and Fe into planetary upper atmospheres (Grebowsky et al., 2002; Murad and Williams, 2002). As these metallic species can be ionized during ablation, by sunlight's ultraviolet photons, or by charge exchange with existing atmospheric ions, meteoroids affect the structure, chemistry, dynamics, and energetics of planetary ionospheres (Figs 1-3).

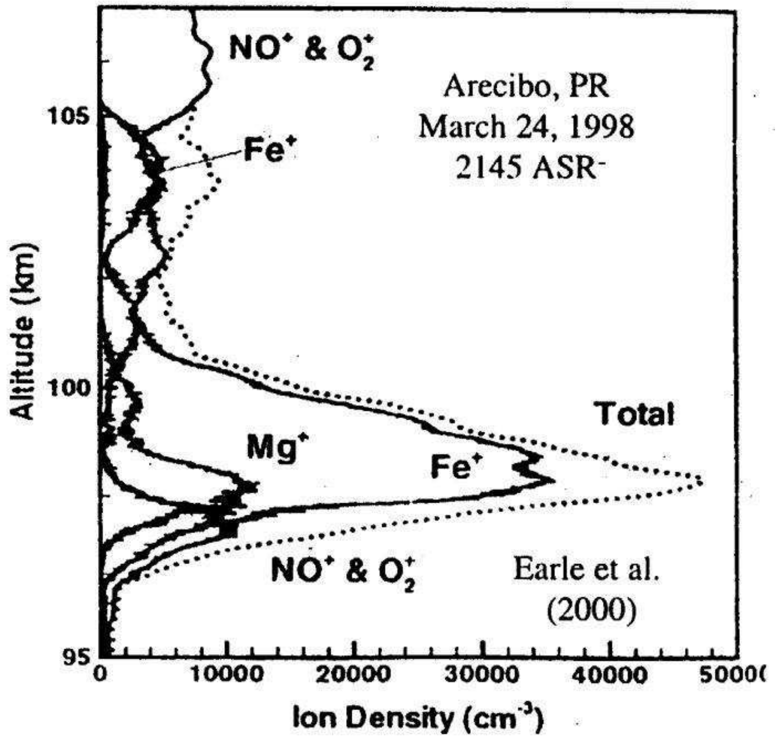

***Figure 1*. *Earth*.** *Meteoric ion densities measured above Puerto Rico by a rocket-borne mass spectrometer. In these post-sunset measurements (2145 local time), photo-produced plasma (NO^+ and O_2^+) at these E region altitudes is sparse. Note the narrow width (about 2 km) of the meteoric layer. In this instance, meteoric densities are extremely large. The typical density measured by rocket flights is 10^3 cm^{-3}. The intense variability in meteoric densities cannot be reproduced by models. Figure 8.11 of Grebowsky and Aikin (2002).*

The ablation of meteoroids disrupts the quiescent state of an ionosphere by introducing exotic metallic species into an environment dominated by species derived from low mass constituents like N_2, O_2, or CO_2. In particular, metal species tend to form atomic ions (e.g. Mg^+), whereas typical atmospheric ions are low-mass molecular species like O_2^+. Since atomic ions cannot dissociatively recombine like molecular ions, they tend to be long-lived and a slow production rate of atomic ions can maintain a significant plasma population. This is illustrated in Fig. 1.

Motivated by terrestrial findings, scientists have long sought to find meteoric layers on Venus and Mars, but were restricted by limited electron density data and non-existent compositional data at the relevant altitudes. Definitive detections for Venus and Mars were made by Patzold et al. (2009) and Patzold et al. (2005), respectively, with several strong possibilities suggested earlier by Witasse and Nagy (2006) and Fox (2004a), respectively (Figs 2-3). On all three planets, meteoric plasma forms narrow layers below the main peaks of their ionospheres.

Unsurprisingly, observations of metal ions are more extensive for Earth than for Venus or Mars. Compositional profiles have been obtained by 50 sub-orbital rocket flights with *in situ* mass spectrometers (Grebowsky and Aikin, 2002). They consistently show a metal ion layer a few km wide located between 90 km and 100 km (Fig 1). The strong variability in observed layer properties cannot be reproduced by current terrestrial models. On both Venus and Mars, meteoric layers occur sporadically, not continuously – at least at the 10^3 cm^{-3} detection limit of radio occultation experiments. Models have yet to explain this sporadic occurrence, which could be caused by external factors like meteoroid flux variations or internal factors like wind patterns.

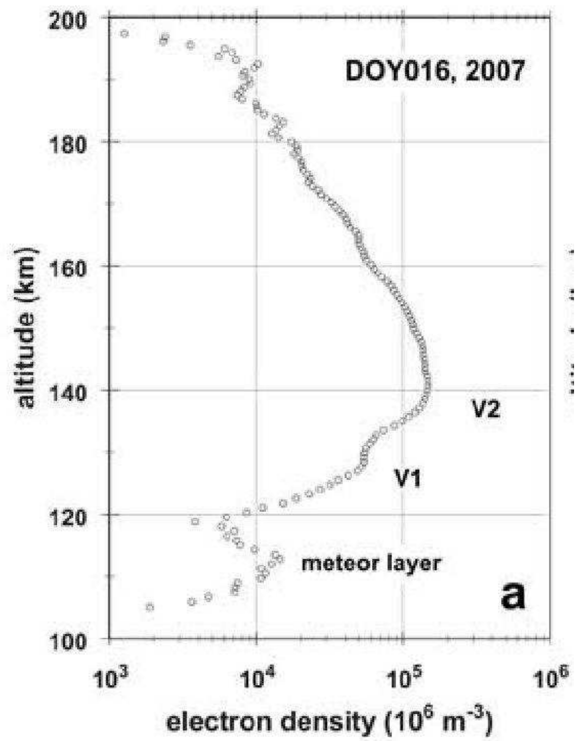

Figure 2. ***Venus***. *Meteoric layer seen in the dayside ionosphere of Venus on day 16 of 2007 by the Venus Express radio occultation experiment. The meteoric layer occurs at 110 km altitude and has a peak density of* 10^4 cm^{-3}. *It is distinctly separated from the main photochemical layers V1 and V2 of the ionosphere, which are produced by solar soft X-rays and extreme ultraviolet photons, respectively. These photochemical layers contain molecular* O_2^+ *ions, which behave very differently from the atomic* Mg^+ *ions in the meteoric layer. Meteoric layers on Venus and Mars are broader (~10 km) than on Earth. Meteoric layers are only observed sporadically on Venus and Mars, but are ubiquitous on Earth. However, ion densities on Earth are highly variable. Perhaps Venus layers are also ubiquitous, but are rarely strong enough to detect. Figure 2 of Patzold et al. (2009).*

The interaction of meteoroids with atmospheres relates to several important topics in planetary science. These include cometary activity, the dynamics of dust in space, the delivery of organic materials to planets, and collision hazards for spacecraft. From an ionospheric perspective, meteoric plasma offers a probe into an important altitude region (Schunk and Nagy, 2000; Bauer and Lammer, 2004). Meteoric plasma is most abundant at relatively low altitudes where ion chemistry is more complex, where ionization due to protons from solar energetic particle events is greatest, and where ionospheric disruption of radio wave propagation may occur. It also introduces novel chemical pathways and non-standard plasma sources into the ionosphere.

Key questions in this area are whether any or all of the following planet-specific factors have significant bearing on the ionospheric effects of meteoroids – meteoroid flux, background ionospheric chemistry, planetary magnetic field and its influence on motion of plasma, dynamics of the neutral atmosphere, especially eddy diffusion, and scale height of the neutral atmosphere. Also, are meteor showers important? There is a long-standing debate about how annual meteor showers affect Earth's ionosphere, with current data not showing a clear signal. Since the importance of shower versus sporadic meteoroids will differ from Earth at other planets, meteor shower signals may be clearer at Venus or Mars, especially as Venus has no seasonal variations.

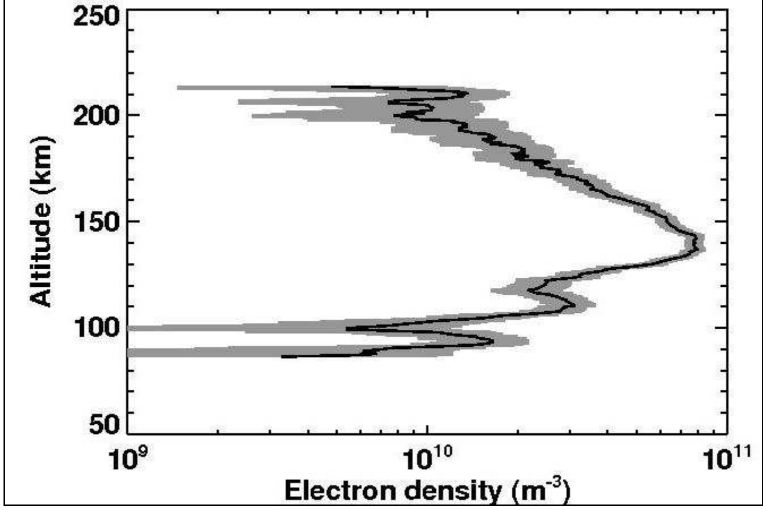

Figure 3. ***Mars****. Meteoric layer at 90 km in the dayside ionosphere of Mars (Mars Global Surveyor radio occultation experiment). Grey regions show* 1σ *uncertainties. The two higher ionospheric layers (110 km and 140 km) are analogous to the V1 and V2 layers on Venus. They contain* O_2^+ *ions, are photochemically controlled, and are produced by solar soft X-rays and extreme ultraviolet photons, respectively. Figure 2 of Withers et al. (2008a).*

2 – Outline of proposed investigation

The goal of this proposal is to use data and models to compare meteoric layers on Venus and Mars in order to investigate what physical processes, planet-specific conditions, and meteoroid influx properties are responsible for similarities and differences in the observed characteristics of these layers.

Our efforts will commence with a survey of the typical properties of observed meteoric layers on Venus, along the lines of our past work at Mars (Withers et al., 2008a), that will include a search for trends linking observable characteristics to external factors such as solar zenith angle (**Task A: Comparison of basic observed properties at Venus and Mars**). The results of this **Task** and our prior Mars work will serve as benchmarks for subsequent numerical modeling. Next, we will update an existing one-dimensional model for the production, transport, and loss of meteoric plasma on Venus and Mars (**Task B: Initial application of model for Venus and Mars**). We will then compare predicted layers to those observed, simulate variations with solar zenith angle, and calculate the lifetime of meteoric plasma. Finally, we will explore how meteoric layer properties vary due to plausible variations in expected meteoroid influx properties (**Task C: Effects of variations in meteoroid influx at Venus and Mars**). The analysis of meteoric layer observations is a potential tool for constraining the meteoroid flux at the orbits of Venus and Mars, which can provide better understanding of the solar system dust environment and its connections to the population and dynamical evolution of small bodies.

3 – Available observations of meteoric layers

Radio occultation observations of ionospheric electron density profiles are the primary resource for studying layers of meteoric plasma in extraterrestrial planetary atmospheres. For Venus, 322 profiles are available from Venus Express (VEX) (Fig. 2). Patzold et al. (2009) found 21 meteoric layers in a sample of 118 early VEX profiles. We have access to all VEX profiles since PI Withers is a Co-I on this instrument team. For Mars, 5600 profiles are available from Mars Global Surveyor (MGS) (Fig 3), 557 from Mars Express (MEX), and ~100 from Mariner 9.

Withers et al. (2008a) found 71 meteoric layers in the MGS profiles, Patzold et al. (2005) found 10 in an early subset of MEX profile, and Withers et al. (in preparation) found an additional 65 in an ongoing survey of the full MEX dataset and 7 in the Mariner 9 profiles. The MGS profiles are publicly available at the PDS and we have access to all MEX profiles since PI Withers is a Co-I on this instrument team. We have digital copies of the Mariner 9 profiles, which we got as microfilmed tables from the NSSDC and are in the process of preparing for delivery to the PDS.

4 – Available numerical model of meteoric layers

In this work, we shall update an existing one-dimensional model for the production, transport, and loss of meteoric plasma on Venus and Mars. This model was initially applied at Mars by Pesnell and Grebowsky (2000, 2001) and Grebowsky et al. (2002) and at Venus by Grebowsky et al. (2002) and Pesnell et al. (2004). Due to competing projects, the Venus work was not fully published. The predictions of Pesnell and Grebowsky for Mars are sufficiently similar to data (Fig. 4) for us to conclude that the model is basically sound, although published results over-estimate the layer width and do not explain the layer's sporadic occurrence. Their predictions are generally consistent with the contemporaneous work of Molina-Cuberos et al. (2003).

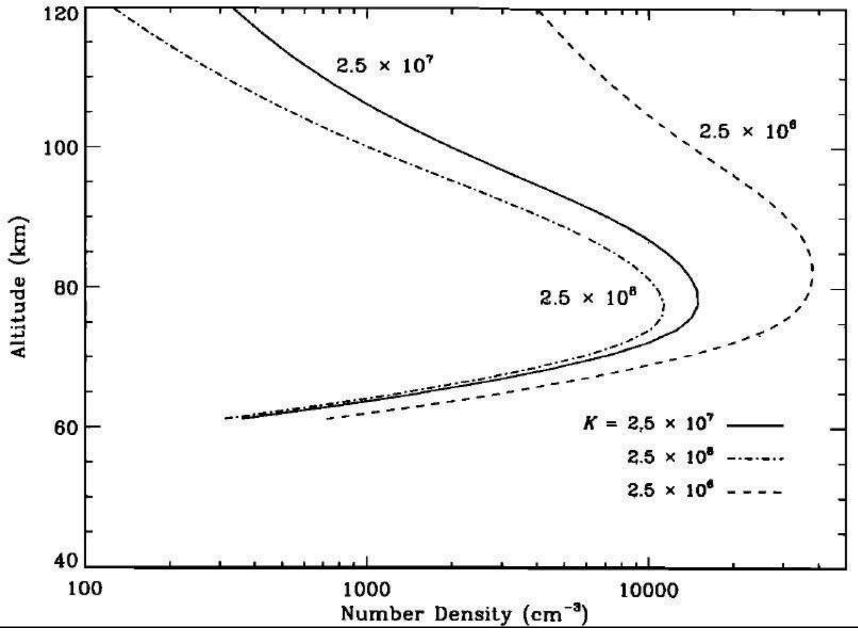

Fig 4. ***Mars****. Simulated* Mg^+ *profiles at Mars for three values of the eddy diffusion coefficient, K, in units of* $cm^2\ s^{-1}$*. K = 2.5E6 (dashed), 2.5E7 (solid), and 2.5E8 (dot-dashed). On Earth, peak density is approximately inversely proportional to K (Plane, 2004). That trend is not reproduced here on Mars, although peak density does decrease as K increases. Figure 7 of Pesnell and Grebowsky (2000).*

The early work of Pesnell, Grebowsky, Molina-Cuberos, and colleagues suffers from two drawbacks. Firstly, it precedes the first observations of meteoric layers on Venus and Mars, and is consequently unconstrained by direct measurements. Secondly, it precedes important laboratory work on key rate coefficients by John Plane and colleagues at the University of Leeds, UK. Minimal laboratory work on reactions involving metal species in a carbon dioxide atmosphere had been performed until Plane's research group focused on this area a few years ago (e.g. Woodcock et al., 2006; Whalley and Plane, 2010; Whalley et al., 2011). Hence Pesnell and Grebowsky were forced to use estimated rate coefficients for some key reactions. For example, they assumed a rate coefficient of 10^{-30} $cm^6\ s^{-1}$ for $Mg^+ + 2CO_2 \rightarrow MgCO_2^+ + CO_2$, which is the main pathway for the conversion of atomic metal ions into molecular ion species that rapidly dissociatively recombine. Whalley and Plane (2010) measured a value of 10^{-28} $cm^6\ s^{-1}$, two orders of magnitude larger.

However, use of this rate coefficient in a model by Whalley and Plane (2010) led to predicted meteoric ion densities on Mars that are ten times smaller than typically observed (Fig 5). This is paradoxical – the model with the unquestionably better rate coefficients makes worse predictions. There are no obvious ways in which the Whalley and Plane (2010) model is weaker than the Pesnell and Grebowsky (2000) model. Resolving this paradox is an aim of this proposal. Since Plane's group had not at that time finished its entire program of laboratory measurements, the model of Whalley and Plane (2010) was not able to replace all the rate coefficients estimated by Pesnell and Grebowsky (2000) with measured values. Perhaps the correction of errors in one of the remaining estimated rate coefficients, such as the rate of dissociative recombination of $MgCO_2^+$, can enhance the too-small densities predicted by Whalley and Plane (2010). Alternatively, imperfect meteoroid influx rates or eddy diffusion coefficients might be the cause.

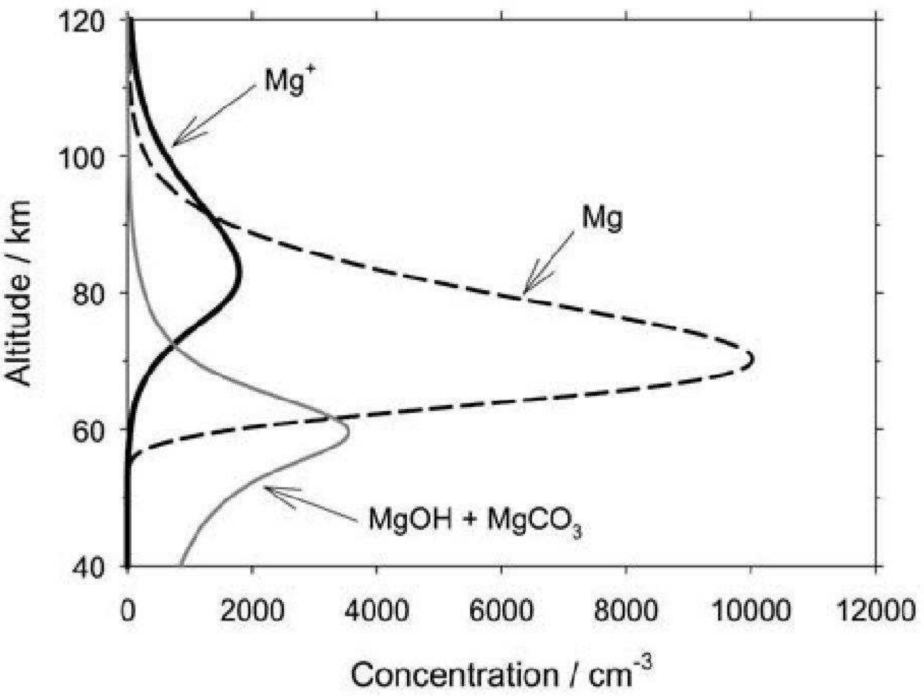

Figure 5. ***Mars****. Simulated vertical profiles of selected Mg species in the atmosphere of Mars. The peak altitude is 10 km lower than typically observed and the peak density is 10 times smaller than in typical* <u>*detections*</u> *of meteoric layers. It is possible that a weak layer is ubiquitous, but only sporadic strong layers are detected. Figure 11 of Whalley and Plane (2010).*

The basic lifecycle of meteoric ions is as follows. They are produced by ionization during ablation, photo-ionization, and charge exchange. They are destroyed by transport downwards into denser regions of the atmosphere where atomic metal ions (e.g. Mg^+) undergo three-body reactions to form molecular ions that are quickly neutralized by dissociative recombination with an electron. Since the chemistries of the ionospheres of Venus and Mars are so similar, the same model framework can be used for each planet, although many inputs will be planet-specific. The basic structure of this model is as follows:

- Assume vertical profile for neutral atmospheric density, temperature, and composition. Some relatively minor species may need to be included if they are chemically important.
- Assume incident velocity of meteoroids and flux as a function of meteoroid size.
- Simulate ablation of meteoroids in the atmosphere.
- Assume a fixed background profile of the densities of typical atmospheric ions.
- Simulate the steady-state chemistry and transport of meteoric neutral and ion species using a system of chemical reactions and specified molecular and eddy diffusion coefficients. This

will generate vertical profiles of the number densities of individual species of meteoric neutral atoms and ions.

Meteoroids contain many chemical elements. In this model, we shall initially simulate the lifecycle of only one of them, Mg. This is a common metal in meteoroids and tends to dominate metal ion densities measured on Earth by mass spectrometers (e.g. McNeil et al., 2001; Grebowsky et al., 2002; Grebowsky and Aikin, 2002). To first order, its behavior will be representative of all metal species. Other metal species, such as Fe, will be included if early results suggest that their absence is causing order-of-magnitude errors in the results.

We will assume neutral atmospheric properties from Hedin et al. (1983), Krasnopolsky and Parshev (1983), and Yung and DeMore (1999) for Venus and the Mars Climate Database (http://www-mars.lmd.jussieu.fr/) for Mars. We will initially assume a meteoroid size and velocity distribution from the sources cited in Pesnell and Grebowsky (2000) and Molina-Cuberos et al. (2003). This will be revisited in the later stages of this project. We will simulate the ablation of meteoroids in the atmosphere using the CABMOD model of Collaborator Plane and Co-I Janches (Vondrak et al., 2008), which permits differential chemical ablation and produces element-specific ablation profiles of atoms and ions (Janches et al., 2009). This is an advance on the model used by Pesnell and Grebowsky (2000), which assumed that ablated material shared the composition of the parent meteoroid. Inclusion of differential ablation alters the deposition profile of Mg and related species, shifting the peak altitude. We do not plan to fully integrate the chemistry of the normal ionosphere and the meteoric ion species, which would add unnecessary complexity. Instead, we will impose a fixed background profile of “normal” atmospheric ions that influences the chemistry of metal species. One obvious inconsistency that results is that charge exchange between neutral metal atoms and O_2^+ ions, which is a source of metal ions, does not consume the O_2^+ ions. Nevertheless, this approximation was judged reasonable by Pesnell and Grebowsky (2000) and Molina-Cuberos et al. (2003) and we will use this as our starting point. As our work progresses, we will examine the relevant time constants to test this approximation, so that we can then make any necessary changes.

The rate of production of meteoric ions by ablation is provided by CABMOD. The rate of production of meteoric ions by photoionization is calculated using a solar spectrum, attenuation by the neutral atmosphere, and ionization cross-sections of the neutral metal species, where these inputs are specified in Pesnell and Grebowsky (2000) and Molina-Cuberos et al. (2003). The rate of production of meteoric ions by charge exchange is calculated using a system of chemical reactions and associated rate coefficients. The chemical reaction schemes are described by Pesnell and Grebowsky (2000) and Molina-Cuberos et al. (2003). Note that Pesnell and Grebowsky (2000) estimated rate coefficients for some important reactions: $Mg^+ + 2CO_2 \rightarrow MgCO_2^+ + CO_2$, $MgCO_2^+ + CO_2 \rightarrow Mg^+ + 2CO_2$, and $MgCO_2^+ + e \rightarrow Mg + CO_2$. We shall update these coefficients using laboratory results from Collaborator Plane. The relative importance of ablation, photoionization, and charge exchange for producing metal ions is important to determine, since it influences the qualitative behavior of meteoric ion layers. If ablation is dominant, then production will occur at all locations, but may vary seasonally with meteoroid influx rates. If charge exchange or photoionization is dominant, then production will cease on the nightside, but will have minimal seasonal variations.

The main chemical loss process for atomic metal ions like Mg^+ is a three body reaction with two CO_2 molecules to form $MgCO_2^+$ which rapidly neutralizes via dissociative recombination. Neutral Mg reacts with a range of O and C-bearing neutrals to eventually form $MgCO_3$, which is heavy and stable. The ultimate sink for Mg is $MgCO_3$ falling out of the atmosphere. The continuity and momentum equations that determine the concentration of each meteoric species are:

$$\frac{\partial N_i}{\partial t} = P_i - L_i - \frac{\partial (N_i v_i)}{\partial z} \quad \text{Eqn 1}$$

$$\begin{aligned} v_i = &-D_i \left(\frac{1}{N_i} \frac{\partial N_i}{\partial z} + \frac{1}{H_i} + \frac{1}{T} \frac{\partial T}{\partial z} \right) \\ &-K \left(\frac{1}{N_i} \frac{\partial N_i}{\partial z} + \frac{1}{H} + \frac{1}{T} \frac{\partial T}{\partial z} \right) \end{aligned} \quad \text{Eqn 2}$$

where i is an index labeling a species, t is time, z is altitude, N-i is the species' number density, P-i is its chemical production rate, L-i is its chemical loss rate, v-i is its vertical velocity, D-i is its molecular diffusion coefficient, H-i is its individual scale height, K is the eddy diffusion coefficient, H is the bulk atmospheric scale height, and T is temperature. We will obtain molecular and eddy diffusion coefficients from von Zahn et al. (1983), Krasnopolsky and Parshev (1983), and Yung and DeMore (1999) for Venus and the sources cited by Pesnell and Grebowsky (2000) and Molina-Cuberos et al. (2003) for Mars. Solution of Eqns 1-2 requires the imposition of boundary conditions, two per metal species. A reasonable set of boundary conditions for ions is photochemical equilibrium (i.e. densities influenced by chemical production and loss, but not transport) at the lower boundary and diffusive equilibrium (i.e. zero velocity) at the upper boundary (Molina-Cuberos et al., 2003). For metal-bearing neutrals, a prescribed abundance (Pesnell and Grebowsky, 2000) or a sink reaction for polymerization into meteoric smoke particles (Whalley and Plane, 2010) can be a lower boundary condition. Pesnell and Grebowsky (2000) found that their results were not sensitive to the lower boundary condition. Diffusive equilibrium gives an upper boundary condition. This is a 1-D steady state model, so computational resource requirements are not large.

The assumption of steady state chemistry must be justified. In unfortunate omissions, neither Pesnell and Grebowsky (2000) nor Molina-Cuberos et al. (2003) reported time constants for the major processes in their steady state simulations, or inferred plasma lifetimes. In their Fig 12, Whalley and Plane (2010) predict Mg^+ lifetimes of about 1 day in Martian meteoric layers. Hence the notion of "a steady state simulation at the subsolar point" is somewhat questionable for Mars. Not fatally flawed, but not perfect either. For slowly-rotating Venus, matters are much more reasonable. Therefore we will begin with this steady state assumption in order to get a feel for the diurnal behavior of the system, but will be willing to introduce time dependence with a time-implicit integration scheme later on if it is deemed necessary.

5 – Task A: Comparison of basic observed properties at Venus and Mars

One should never run a complicated model without knowing what results to expect from the model. The basic properties (occurrence rate, altitude, plasma density, width, shape, relationship to other ionospheric layers) of meteoric layers have been characterized for Mars (Withers et al., 2008a), but not for Venus. We wish to know what the analogous results for Venus are before we launch headlong into numerical modeling. This will be accomplished here in **Task A**.

We will focus on basic trends. For instance, Withers et al. (2008a) found correlations between the altitude, width, and electron density of meteoric layers on Mars (Fig 6), but did not explain their cause. Here we will test whether similar behavior occurs on Venus, and in **Task B** we will use the model to develop potential explanations. We will pay attention to possible dependences on the solar zenith angle (which controls some production mechanisms). We will also address comparisons between planets. For instance, Patzold et al. (2009) found a typical meteoric layer altitude of 110-115 km for Venus, while the Pioneer Venus sounder probe found a pressure of 0.1 Pa at 112 km (Seiff et al., 1980). Withers et al. (2008a) found a typical meteoric layer altitude of 87-97 km for Mars, while the Viking Lander 1 found a pressure of 0.01 Pa at 92 km (Seiff and Kirk, 1977). Is this order of magnitude difference in the pressure level at which meteoric layers occur on Venus (0.1 Pa) and Mars (0.01 Pa) supported by more detailed analysis? If so, why do these layers occur at different pressures on different planets?

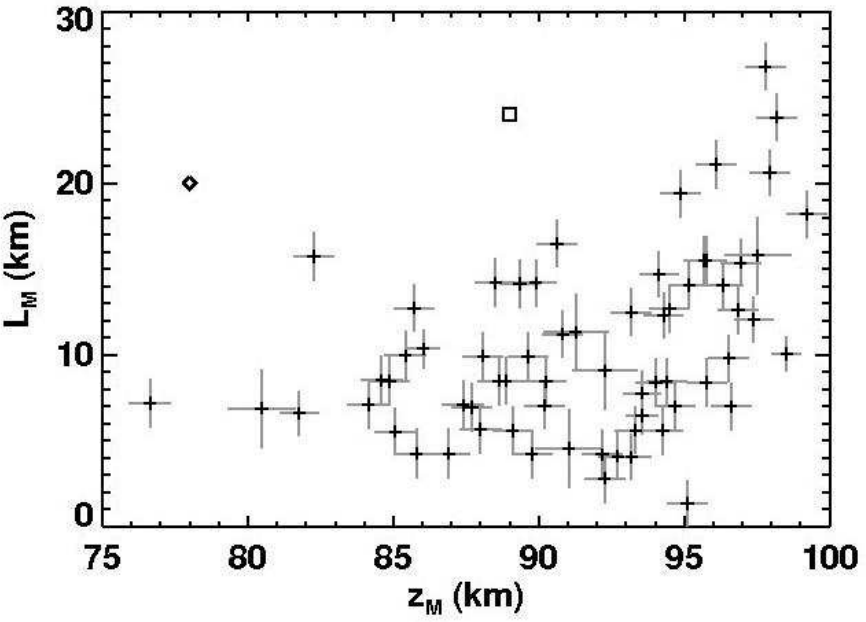

*Figure 6. **Mars**. Distribution of peak altitude (zm) and width (Lm) for meteoric layers on Mars. Grey arms on the crosses show 1σ uncertainties. Diamond: Pesnell and Grebowsky (2000). Square: Molina-Cuberos et al. (2003). Altitude and width are positively correlated (r=0.40). Do any similar correlations exist for Venus? What is the cause of this correlation? Fig. 5 of Withers et al. (2008a).*

The **Objectives** of **Task A** are:

Obj. A.1 To determine the basic properties of meteoric layers on Venus
Obj. A.2 To compare the basic properties of meteoric layers on Venus and Mars

These **Objectives** will be met by completion of the following **Investigations**:

Inv. A.1 Find the occurrence rate of meteoric layers in VEX density profiles (**Obj. A.1**)
Inv. A.2 Measure the mean and standard deviation of the altitude, plasma density, and width of meteoric layers that are present in VEX electron density profiles (**Obj. A.1**)
Inv. A.3 Characterize shapes of meteoric layers in VEX electron density profiles (**Obj.A.1**)
Inv. A.4 Characterize any relationships between properties of the Venus meteoric layer and the other ionospheric layers found at Venus (**Obj. A.1**)
Inv. A.5 Compare the Venus results of **Inv. A.1-4** to the Mars results of Withers et al. (2008a), including any dependence on magnetic field conditions (**Obj. A.2**)
Inv. A.6 Develop preliminary physical hypotheses to explain the results of **Inv. A.1-5** (**Obj. A.2**)

Models of terrestrial meteoric layers rely on wind shear in a strong and inclined magnetic field to organize ions into narrow layers (e.g. Carter and Forbes, 1999). The ionospheres of Venus and Mars are magnetized at times, but their magnetic environments are highly variable with position and solar wind conditions. In **Inv. A.2**, we will see if magnetic fields at Venus and Mars influence their meteoric layers. Nevertheless, we will not address the effects of magnetic fields on plasma motion in our numerical simulations since their importance for meteoric layers on Venus or Mars has not yet been demonstrated. We wish to understand the basic behavior of meteoric plasma properly first before introducing this complexity.

6 – Task B: Initial application of model for Venus and Mars

To date, the models of Pesnell and Grebowsky (2000), Molina-Cuberos et al. (2003), and Whalley and Plane (2010) have made only cursory investigations of meteoric ion phenomena on Mars. Venus has been neglected almost entirely. These groups have published a handful of representative profiles, leaving topics as fundamental as how meteoric ion densities depend on incident meteoroid flux, meteoroid velocity, or solar zenith angle untouched. None of these models have been adjusted or tuned to reproduce observed meteoric layers, nor used to explore why meteoric layers are observed only sporadically, not ubiquitously, on Venus and Mars. These papers did not report the time constants of various processes, which are essential for any intuitive feel for the behavior of the system. We will remedy some of these deficiencies in **Task B**.

We concentrate in this **Task** on seeing exactly how well the model predictions match observations and on exploring solar zenith angle (SZA) effects. The properties of the main ionospheric layers on Venus and Mars are completely dominated by SZA dependences, and the rates of production of metal ions by photoionization and charge exchange will also be strongly influenced by SZA. Withers et al. (2008a) attempted to quantify SZA effects in their study of MGS electron density profiles, but were somewhat impeded by the dependence of SZA on Ls and latitude in their dataset. They found occurrence rates of 0.3%, 0.6%, and 1.7% for SZA ranges of 70^o-75^o, 75^o-80^o, and 80^o-85^o, respectively. This may simply be an observational bias: when background electron densities decrease with increasing SZA, near-constant meteoric plasma densities become more detectable. Or it may be a real physical trend produced by effects as yet undetermined. Or it might simply be an artifact of non-uniform sampling within the MGS dataset. Our simulations in **Task B** will help interpret such observational results.

The **Objectives** of **Task B** are:

Obj. B.1 To update the model of Pesnell and Grebowsky (2000)
Obj. B.2 To compare predictions of meteor layer characteristics to observations
Obj. B.3 To simulate variations in meteor layer characteristics with solar zenith angle

These **Objectives** will be met by completion of the following **Investigations**:

Inv. B.1 Reproduce the results of Pesnell and Grebowsky (2000) for Mars to verify model performance (**Obj. B.1**)
Inv. B.2 Incorporate better rate coefficients and ablation (CABMOD) into the model and adapt the model to Venus, with simple switches to change between the two planets (**Obj. B.1**)

Inv. B.3 Run the Venus and Mars models at a solar zenith angle of 75°, for which many meteoric layers have been seen on both planets, and compare results to observations (**Obj. B.2**)
Inv. B.4 If this initial comparison is grossly unsatisfactory, make reasonable adjustments to model input parameters until results improve (**Obj. B.2**)
Inv. B.5 Run the Venus model at solar zenith angles of 0°, 15°, …, 120° (**Obj. B.2, B.3**)
Inv. B.6 Run the Mars model at solar zenith angles of 0°, 15°, …, 120° (**Obj. B.2, B.3**)
Inv. B.7 Interpret the predicted dependence of meteor layer characteristics on SZA in terms of physical properties and processes (**Obj. B.3**)
Inv. B.8 Compare the suite of simulations against observations (**Obj. B.2**)
Inv. B.9 Determine the effects of SZA on meteoric layer occurrence rate in VEX, MEX, and Mariner 9 observations and physically interpret any trends (**Obj. B.3**)

In order to properly understand the physics of meteoric layers, we will identify the most important time constants that control the simulated behavior of the system. Our focus in this **Task** is on basic reproducibility of observations and solar zenith angle effects, not attempting to vary every model parameter simultaneously. These simulations will involve fixed meteoroid fluxes, neutral atmospheres, and background ionospheres (except for simple SZA dependence in the background ionosphere). These are the quantities that may be tuned in **Inv. B.4**.

7 – Task C: Effects of variations in meteoroid influx at Venus and Mars

A long-term goal of our research program is to see if extraterrestrial meteoric layer observations can be used to determine the meteoroid flux away from 1 AU. In order to attempt this in the future, we will require a clear understanding of how meteoric layer properties depend on the meteoroid flux. This is our focus in **Task C**. On Earth, effects of exciting annual meteor showers on meteoric layers have not yet been detected. Perhaps circumstances on Venus or Mars are different. Withers et al. (2008a) reported that the occurrence rate of meteoric layers in MGS profiles from Mars had a possible dependence on season (Ls), which might imply a role for meteor showers. However, their results were obscured by the dataset's simultaneous variations in SZA and latitude and it is probably premature to regard them as a definitive confirmation of seasonal effects. Venus, which we will study in **Task A**, is a perfect test case. Venus has a low obliquity and eccentricity, which eliminate atmospheric seasonal and heliocentric effects. Thus seasonal variations in occurrence rate on Venus, if detected, must be due to variations in meteoroid influx rate.

The flux incident at a particular geographic location on a planet depends on both the true flux in that region of the solar system and the position and motion of that planetary location relative to the flux. The meteoroid influx onto a planet is not the same at all locations on the planet. Firstly, meteoroid fluxes may be anisotropic and bombard one hemisphere more than another. Secondly, the orbital and rotational motion of the planet causes aberration in the meteoroid fluxes. Consider the well-known tendency for meteors to be most impressive at dawn, not dusk, on Earth, which is caused by the dawn terminator moving towards incident meteoroids and the dusk terminator receding from them.

On Earth, most meteoroids are sporadics (rather than associated with particular showers). Sporadics are not isotropic. They come predominantly from six apparent sources that are tens of degrees across (called the helion, anti-helion, north apex, south apex, north torodial, and south torodial sources). Their locations are fixed in an Earth-centered coordinate system that is defined by the two vectors of Earth's velocity and the Earth-Sun line. The flux of sporadic meteoroids at Earth consequently depends on which of these apparent sources is above the horizon, which is the primary cause for seasonal variations in rates observed at a fixed location on Earth. We shall extend this population of sporadic meteoroids to Venus and Mars, then simulate how the meteoroid flux depends on geographic location, and how this affects meteoric layer properties.

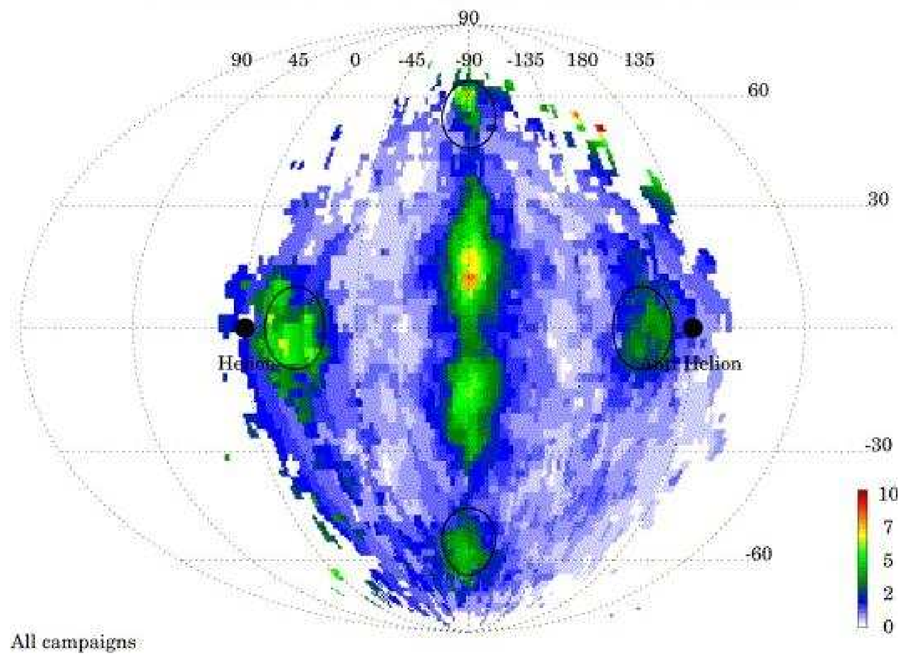

Fig 7. ***Earth****. Distribution of meteor radiants seen by the Jicamarca Radio Observatory, Peru. Colors indicate number of meteors observed per square degree. Coordinates refer to an Earth-centered frame with the Sun at 0^o longitude and 0^o latitude and the ram direction at -90^o longitude and 0^o latitude. The six sources of sporadic meteoroids are apparent. Fig 8 of Chau et al. (2007).*

There are few direct measurements of meteoroid fluxes at Venus and Mars. Terrestrial models of fluxes from the six sporadic sources (Gardner et al., 2011; Fentzke and Janches, 2008; Janches et al., 2006) can be extrapolated to Venus and Mars using reasonable assumptions. Data from spacecraft dust detectors are consistent with uniform spatial density of meteoroids and simple dynamics suggests speeds inversely-proportional to the square-root of heliocentric distance. Assuming the same angular distribution as at Earth and accounting for gravitational focusing provides sufficient information to extrapolate to Venus and Mars. This is our baseline approach.

We would prefer to use fluxes from a serious dynamical model, but such models have focused solely on Earth. One of the best is that of Nesvorny et al. (2011a, b), which is based on IRAS observations of the zodiacal cloud. It predicts that 85-95% of the dust in the inner solar system comes from Jupiter family comets, with the remainder from the asteroid belt and Oort Cloud comets. Most of the dust, which drifts towards the inner solar system due to Poynting-Robertson drag, has masses in the range 1-10 μg. Dust enters Earth's atmosphere around 14 km s^{-1}. Nesvorny, Janches, and Plane are currently working to reconcile this dynamical model with radar observations of meteors. The radar data are invaluable, but plagued with mass- and velocity-dependent detection biases that must be fully understood before model-data agreement can be declared. For example, radars, which are most sensitive to fast, heavy meteoroids, report a typical entry speed near 30 km s^{-1} and a smaller total mass flux than this model. The Nesvorny group, here represented by Collaborator Janches, plans to develop their model so that it can be used beyond Earth (proposals are pending). If this model can provide predicted fluxes at Venus and Mars by the final year of this project, then we shall use them. If the model cannot, then our baseline approach of extrapolating from Earth is fine for the purposes of this exploratory project.

No discernible impact of meteor showers on terrestrial meteoric layers has yet been convincingly detected above other sources of variability (Kopp, 1997; Grebowsky et al., 1998; Grebowsky and Aikin, 2002), although numerical models predict that metallic ion column densities should increase by two orders of magnitude during a meteor storm comparable to the 1966 Leonids (Carter and Forbes, 1999; McNeill et al., 2001). Shower meteoroids, although visibly prominent, are not a major fraction of the incident mass at Earth. The same may be true at Venus and Mars, although that has not been proven. We will simulate a few idealized meteor shower and meteor storm cases to see how the narrower meteoroid speed, direction, and size distributions and significantly elevated fluxes of showers affect meteoric layers. Our fluxes will be taken from McAuliffe (2006, PhD thesis supervised by Collaborator Christou), who explored the ablation of shower meteoroids at Venus and Mars.

The **Objectives** of **Task C** are:
Obj. C.1 To search for observational indications of seasonal variations in meteoric layer occurrence rates at Venus and Mars
Obj. C.2 To simulate variations in meteoric layers at Venus and Mars due to variations in meteoroid influx

These **Objectives** will be met by completion of the following **Investigations**:
Inv. C.1 Determine seasonal variations in meteoric layer occurrence rates in VEX, MEX, and Mariner 9 observations and physical interpretation of trends (**Obj. C.1**)
Inv. C.2 Conduct sensitivity study for how Venus and Mars meteoric layers change when size, speed, and flux of meteoroids change (**Obj. C.2**)
Inv. C.3 Perform a suite of simulations for Venus and Mars with different meteoroid fluxes appropriate for different seasons (Mars only) and locations on the planetary surfaces (**Obj. C.2**)
Inv. C.4 Simulate meteor showers and meteor storms on Venus and Mars (**Obj. C.2**)
Inv. C.5 Analyze the results of **Inv. C.3**, compare to the results of **Inv. C.1**, and interpret the findings (**Obj. C.1-2**)

For **Inv. C.3**, we shall conduct simulations at Mars at 60^{o}N (representative of most MGS observations) and the equator (more useful for general circumstances) at local times of dawn, midday, dusk, and midnight (0, 6, 12, and 18 hours). Conditions at these 8 geographic locations will be simulated for at least 4 places along the planet's orbit for a total of 32 or more cases. Only one season is required at Venus due to its low obliquity and eccentricity. Simulations for meteor showers and meteor storms will be performed at a small number of selected latitudes, local times, and orbital positions.

Recent work (Weigert et al., 2009) surprisingly suggests that only a small number of comets with particular orbital characteristics are significant sources of sporadic meteoroids. This raises the possibility that the sporadic meteoroid fluxes at Venus and Mars might be produced by other comets and hence be significantly different from Earth, rather than just a straight-forward scaling. If our model fails spectacularly at Venus or Mars, then we might have demonstrated that simply extrapolated meteoroid fluxes are inappropriate. This would be a positive finding.

8 – Anticipated results and broader impact

At the conclusion of this project, we expect to have developed a clear sense of the ways in which meteoric layers on Venus and Mars are observationally similar to each other and ways in which they differ. Also, we expect to have used our numerical model to determine how and why properties of these layers vary in response to changing conditions, as well as to have identified underlying physical reasons for the similarities and differences between the two planets. We will have the capability to constrain (at least to some degree) planetary and meteoroid properties, such as eddy diffusion coefficient and meteoroid flux, from past and future observations of meteoric layers, turning meteoric layers from an interesting observational curiosity into a diagnostic tool.

We plan to produce one peer-reviewed manuscript per year during the course of this project. These manuscripts will focus on physical characteristics of Venus meteoric layers and comparisons to prior results from Mars (**Task A**), simulations of meteoric layers on Venus and Mars using measured values of key rate coefficients and a range of solar zenith angles, including direct comparison to observations (**Task B**), and predictions of how variations in meteoroid flux affect observable meteoric layer occurrence rates and properties (**Task C**).

We have considered how best to disseminate the benefits of this modeling capability into the wider scientific community. We will place tabulated and documented model output for a representative series of simulations online at the conclusion of this project. It would be premature at this stage for us to specify exactly which simulations will be archived. Our archetype is Steve Bougher’s archive of selected thermospheric general circulation model simulations (http://aoss-research.engin.umich.edu/tgcm_planets_archive/). We recognize that the greatest benefits to planetary science (and to our own reputations and careers) come from an open policy regarding data products. PI Withers has demonstrated a strong commitment to data archiving and sharing throughout his career, delivering several atmospheric datasets to the PDS.

One of the major positive outcomes of this project will be the professional development of a graduate student. The graduate student will have deep knowledge of the workings of a powerful numerical model, a tool which will have the capacity for application to a wide range of future projects after their graduation. The development of intellectual links between the graduate student and NASA GSFC is also positive for both parties. In addition, successful completion of this project will result in Collaborator Plane and Co-Investigator Janches, who are international expert on the behavior of metal species in Earth’s atmosphere, becoming more deeply enmeshed in the planetary science community and thus likely to continue to apply their expertise in the field of planetary science afterwards.

9 – Relevance to NASA

“[The Planetary Atmospheres program’s] broad objectives include the determination of compositions, dynamics, energetics, and chemical behaviors of planetary atmospheres”. This proposal fits squarely within the scope of PATM due to its investigation of how meteoroids alter the vertical structure and chemical composition of two planetary ionospheres.

Careful reading of the PATM call for proposals confirms that data analysis components of PATM proposals are not restricted to datasets in the PDS. Proposals to analyze PDS data are encouraged, but proposals to analyze non-PDS data (elements of **Task A**) are not forbidden. Forbidding such proposals would obviously create difficulties for many proposals concerning ground-based observations of planetary atmospheres. If our interpretation of PATM policies is erroneous, then we will restrict our funded efforts to analysis of only published figures and archived datasets, setting aside spacecraft datasets that are not yet publicly available. ~200 Venus profiles from Pioneer Venus Orbiter and the Veneras have been published in the literature.

10 – Personnel

This investigation will be carried out by PI Paul Withers, a BU PhD student, Co-Investigator Joe Grebowsky (NASA GSFC), Co-Investigator Diego Janches (NASA GSFC), Collaborator Tolis Christou (Armagh Observatory, UK), and Collaborator John Plane (Leeds University, UK).

Paul Withers, professor of astronomy at Boston University, will be responsible for the success of this investigation and for compliance with all reporting requirements. He has characterized the physical characteristics and occurrence rates of Martian meteoric layers using Mars Global Surveyor electron density profiles, and has also explored possible explanations for their sporadic occurrence (Withers et al., 2008a). He has also investigated possible seasonal trends in the occurrence rate of Martian meteoric layers (Withers et al., 2007, 2008b), examined old datasets to find additional instances of meteoric layers on Venus and Mars (Withers et al., 2009; Withers et al., in preparation), and made significant contributions to the development of Boston University's 1-D Mars Ionosphere Model (Mendillo et al., 2011, Lollo et al., 2012; Matta et al., 2012; and many conference presentations by Withers). He will mentor a graduate student, who will conduct the day-to-day work on this project.

Joe Grebowsky, researcher at the NASA Goddard Space Flight Center, has decades of experience studying the ionospheres of Venus and Mars, and studying the effects of meteoroids on atmospheres throughout the solar system (Grebowsky et al., 1998, 2002; Grebowsky and Aikin, 2002; Pesnell and Grebowsky, 2000, 2001). He is currently the MAVEN Project Scientist. He will ensure that the Boston University personnel have access to the numerical model of Pesnell and Grebowsky (2000), provide perspective on terrestrial meteoric layer phenomena, and contribute to the interpretation of our results.

Diego Janches, researcher at the NASA Goddard Space Flight Center, has studied the influx of material onto Earth from space and its ablation using meteor radars and chemical models (Janches and Chau, 2005; Janches et al., 2006, 2009; Vondrak et al., 2008). Recently, he has contributed to the development of a dynamical model for solar system meteoroids (Nesvorny et al., 2011a, b). He will supply meteoroid size and velocity distributions for Venus and Mars at a range of orbital positions and geographic locations, provide perspective on terrestrial meteoric layer phenomena, work with the meteoric layer model, particularly the CABMOD ablation component, and contribute to the interpretation of our results.

Tolis Christou, astronomer at Armagh Observatory, United Kingdom, uses meteor camera observations and dynamical models to study the solar system dust environment (Christou, 2004, 2010; Christou et al., 2007, 2008). He is an expert in the meteoroid flux in the inner solar system. He will ensure that our assumed shower meteoroid fluxes at Venus and Mars are reasonable.

John Plane, professor of atmospheric chemistry at the University of Leeds, UK, has experience in laboratory studies of chemical kinetics and numerical modeling that are relevant to studies of meteoric layers (e.g. Plane and Hellmer, 1995; Rollason and Plane, 2001; Plane et al., 2003; Plane, 2004; Vondrak et al., 2008; Whalley and Plane, 2010). He and his research group will collaborate with Co-I Janches to convert meteoroid influx rates into vertical profiles of the production rates of neutral and ionized metal species using the CABMOD ablation model. They will also provide laboratory measurements of selected rate coefficients, advise on the accuracy of all rate coefficients, and contribute to the interpretation of our results.

David Nesvorny, researcher at Southwest Research Institute, Boulder, uses numerical models to study solar system dynamics. He is an expert on the dynamics and fluxes of meteoroids (e.g., Nesvorny et al., 2011a, b). He will support Co-Janches in the provision of meteoroid fluxes.

The budget includes support for the graduate student to travel to one large-scale scientific conference per year (most likely Fall AGU or CEDAR), which is essential for their professional development and future employment, and to travel to NASA/GSFC once per year, which is required in order to ensure effective interactions between the BU and GSFC personnel, smooth functioning of the model, and full understanding of the predicted variations in meteoroid flux. Withers, Christou, Grebowsky, Janches, Plane, and Nesvorny routinely attend the same scientific conferences in connection with other funded projects and we intend to use those serendipitous meetings for discussions of this project. In addition to targeted phone and email conversations that will occur as needed by the graduate student’s progress, PI Withers will also schedule telecons involving all personnel every few months to discuss recent accomplishments, near-term plans, and long-term directions. Discussions amongst the core funded personnel (Withers, graduate student, Janches) will occur monthly.

11 – Work plan

Requested levels of effort are 1 summer month per year for PI Withers, 12 months per year for the graduate student, and 2 months per year for Co-I Janches. In addition, PI Withers can also mentor the student and conduct research during the academic year.

Task A will be conducted by the graduate student (14 months total effort). **Task B** will be conducted by the graduate student (11 months total effort) and Co-I Janches (3 months total effort). The graduate student and Co-I Janches will jointly complete **Inv. B.1-4**, then the graduate student will complete **Inv. B.5-9**. Task C will be conducted by the graduate student (11 months total effort) and Co-I Janches (3 months total effort). The graduate student will perform most of **Task C**. Co-I Janches will concentrate on generating meteoroid fluxes for the planned suite of simulations, but will also support the completion of the simulations. PI Withers will supervise the graduate student and the intellectual direction of the project during all **Tasks**. **Tasks A and B** will be initiated together, with efforts on **Task B** limited to **Inv. B.1-2** until **Task A** is well in hand. **Task C** will commence after the completion of **Tasks A and B**.

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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

- **Withers** (2011) Attenuation of radio signals by the ionosphere of Mars: Theoretical development and application to MARSIS observations, Radio Science, 46, RS2004, doi:10:1029/2010RS004450.
- Lillis, Brain, England, **Withers**, Fillingim, and Safaeinili (2010) Total electron content in the Mars ionosphere: Temporal studies and dependence on solar EUV flux, Geophysical Research Letters, 115, A11314, doi:10.1029/2010JA015698
- Opgenoorth, Dhillon, Rosenqvist, Lester, Edberg, Milan, **Withers** and Brain (2010) Dayside ionospheric conductivities at Mars, Planetary and Space Science, 58, 1139-1151
- **Withers** (2010) Prediction of uncertainties in atmospheric properties measured by radio occultation experiments, Advances in Space Research, 46, 58-73
- **Withers** (2009) A review of observed variability in the dayside ionosphere of Mars, Advances in Space Research, 44, 277-307
- Paetzold, Tellmann, Haeusler, Bird, Tyler, Christou and **Withers** (2009) A sporadic layer in the Venus lower ionosphere of meteoric origin, Geophysical Research Letters, 36, L05203, doi:10.1029/2008GL035875
- **Withers**, Mendillo, Hinson, and Cahoy (2008) Physical characteristics and occurrence rates of meteoric plasma layers detected in the martian ionosphere by the Mars Global Surveyor Radio Science Experiment, Journal of Geophysical Research, 113, A12314, doi:10.1029/2008JA013636
- **Withers** (2008) Theoretical models of ionospheric electrodynamics and plasma transport, Journal of Geophysical Research, 113, A07301, doi:10.1029/2007JA012918
- Christou, Vaubaillon, and **Withers** (2007) The dust trail complex of comet 79P/du Toit-Hartley and meteor outbursts at Mars, Astronomy and Astrophysics, 471, 321-329
- Mendillo, **Withers,** Hinson, Rishbeth, and Reinisch (2006) Effects of solar flares on the ionosphere of Mars, Science, 311, 1135-1138
- **Withers** (2006) Mars Global Surveyor and Mars Odyssey Accelerometer observations of the martian upper atmosphere during aerobraking, Geophysical Research Letters, 33, L02201, doi:10.1029/2005GL024447
- Fulchignoni and 42 colleagues, including **Withers** (2005) In situ measurements of the physical characteristics of Titan's environment, Nature, 438, 785-791, doi:10.1038/nature04314
- **Withers** and Mendillo (2005) Response of peak electron densities in the martian ionosphere to day-to-day changes in solar flux due to solar rotation, Planetary and Space Science, 53, 1401-1418, doi:10.1016/j.pss.2005.07.010
- **Withers**, Mendillo, Rishbeth, Hinson, and Arkani-Hamed (2005) Ionospheric characteristics above martian crustal magnetic anomalies, Geophysical Research Letters, 32, L16204, doi:10.1029/2005GL023483
- **Withers**, Bougher, and Keating (2003) The effects of topographically-controlled thermal tides in the martian upper atmosphere as seen by the MGS Accelerometer, Icarus, 164**,** 14-32
- **Withers** and Neumann (2001) Enigmatic northern plains of Mars, Nature, 410, 651
- Lorenz, Lunine, **Withers**, and McKay (2001) Titan, Mars and Earth: Entropy production by latitudinal heat transport, Geophysical Research Letters, 28, 415 – 418

Biographical Sketch for Co-I Joe Grebowsky

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NASA/GSFC, Mail Code: 695, Greenbelt, MD 20771
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Recent Positions and Appointments

Present - MAVEN Project Scientist
2006 - Member Planetary Atmospheres Review Panel
2005 - Radiation Belt Storm Probe Mission Deputy Project Scientist
2004 - Member NASA Mars Aeronomy Working Steering Committee
2003 - Deputy Project Scientist, Living With a Star Geospace Missions
2002 - Member JGR- Planets Editor Search Committee
2000 - Member of Geospace ITM review panel
1998 - Program Scientist at GSFC for NASA's Sun Earth Connections Theory Program
1997 - Project Scientist for Geospace Electrodynamic Connections mission
1995-1997 - Assisted R. Carovillano in managing NASA's Magnetosphere Physics program
1994-1996 - Member NASA ITM MOWG
1993-1994 - Deputy Project Scientist for TIMED
1992-1993 - Coinvestigator on Pioneer Venus Orbital Ion Mass Spectrometer Team

Selected Publications

"Seasonal Variations of Magnesium Atoms in the Mesosphere-Thermosphere", J. Correira, A. C. Aikin, J. M. Grebowsky, W. D. Pesnell, and J. P. Burrows, Geophys. Res. Lett.,35, L06103, doi:10.1029/2007GL033047, 2008.
"Temporal Evolution of the Vertical Content of Metallic Ion and Neutral Species", A.C. Aikin, J. M. Grebowsky, J. P. Burrows, J. Correira, W.D. Pesnell, J. Atmos.-Solar Terr. Phys., 67, 1238-1244, 2005.
"Satellite Measurements of the Atmospheric Content of Metallic Ion And Neutral Species", A. C. Aikin, J. M. Grebowsky, and J. P. Burrows, Adv. Space Res., 33, 1481-1485, 2004"
"Watching Meteors on Triton" Pesnell, W. D., J. M. Grebowsky and A. L. Weisman, Icarus, 169, 482-491, 2004.
"In-situ Meteoric Ion Measurements", J. M. Grebowsky, A. I. Aikin, chapter in Meteors in the Earth.s Atmosphere, ed.: E. Murad and I. P. Williams, U. Cambridge Press, New York, Chapter 8, pp. 189-214, 2002.
"Meteoric Material - an Important Component of Planetary Atmospheres", J. M. Grebowsky, J. Moses, W. D. Pesnell, in Comparative Aeronomy, Geophysical Monograph 130, ed. Mendillo, Nagy, Waite, American Geophysical Union, 235-244, 2002.
"Meteoric Ions in the Ionosphere of Jupiter", Kim, Y. J., W. D. Pesnell, J. M. Grebowsky and J. L. Fox,, Icarus, 150, 261-278, 2001.
"Meteoric Ions in Planetary Ionospheres", W. D. Pesnell and J. M. Grebowsky, Adv. Space Res., 27, 1807-1814, 2001.
"Meteoric Magnesium Ions in the Martian Atmosphere", W. D. Pesnell and J. M. Grebowsky, J. Geophys. Res., 105, 1695-1708, 2000.

Biographical Sketch for Co-I Diego Janches

Diego Janches, Ph.D.

Goddard Space Flight Center (GSFC)/National Aeronautics and Space Administration (NASA)

Related Experience Summary

2008-Present	Southern Argentine Agile Meteor Radar (SAAMER), Designed, deployed, operate and manage radar in Tierra del Fuego, Argentina
2010-Present	Deployment of remote stations for meteor orbital studies with SAAMER, August 2010
2010-Present	King George Island Meteor Radar, Designed, deployed, operate and manage radar in King George Island, Antarctica
2004-Present	Logistical, educational and scientific planning for the relocation of the Advanced Modular Incoherent Scatter (AMISR)
2004-Present	Develop modeling of the Meteor Input Function

Employment History

2010-Present	Research Astrophysicist, Space Weather Lab, GSFC/NASA
2005-2010	Senior Research Associate, CoRA, NWRA
2004-2005	Research Associate, CIRES, University of Colorado
2003-2004	Research Associate, Arecibo Observatory, Cornell University
2001-2003	NSF/CEDAR Postdoc, Arecibo Observatory, Penn State University
1/2001-8/2001	Postdoctoral Scholar, Swedish Institute for Space Physics
1996 - 2000	Graduate Research Assistant, Electrical Eng., Penn State University
1993 - 1996	Graduate Research Assistant, Astronomy and Astrophysics, Penn State Univ.

Education

2000	Ph.D., Electrical Engineering, The Pennsylvania State University
1997	M.Sc., Astronomy and Astrophysics, The Pennsylvania State University
1993	Licenciatura, Physics, Universidad de Buenos Aires

Selected Relevant Publications

Gardner, C.S., X. Chu, P.J. Espy, J.M.C. Plane, D.R. Marsh and D. Janches, 2011, Seasonal variations of the mesospheric Fe Layer at Rothera, Antarctica (67.5S, 68.0W), J. Geophys. Res., 116, D02304, doi:10.10129/2010JD014655.

Janches, D., L. P. Dyrud, S. L. Broadley, and J. M. C. Plane (2009), First observation of micrometeoroid differential ablation in the atmosphere, Geophys. Res. Lett., 36, L06101, doi:10.1029/2009GL037389.

Fentzke, J. T., D. Janches, and J. J. Sparks (2009), Latitudinal and seasonal variability of the micrometeor input function: A study using model predictions and observations from Arecibo and PFISR, J. Atmos. Solar Terr. Phys., 71, 653-661.

Fentzke, J. T., and D. Janches (2008), A semi-empirical model of the contribution from sporadic meteoroid sources on the meteor input function in the MLT observed at Arecibo, J. Geophys. Res., 113, A03304, doi:10.1029/2007JA012531.

Janches, D., C. Heinselman, J. Chau, A. Chandran, and R. Woodman (2006), Modeling the global micrometeor input function in the upper atmosphere observed by high power and large aperture radars, J. Geophys. Res., 111, A07317, doi:10.1029/2006JA011628.