White Paper on Comparative Planetary Exospheres

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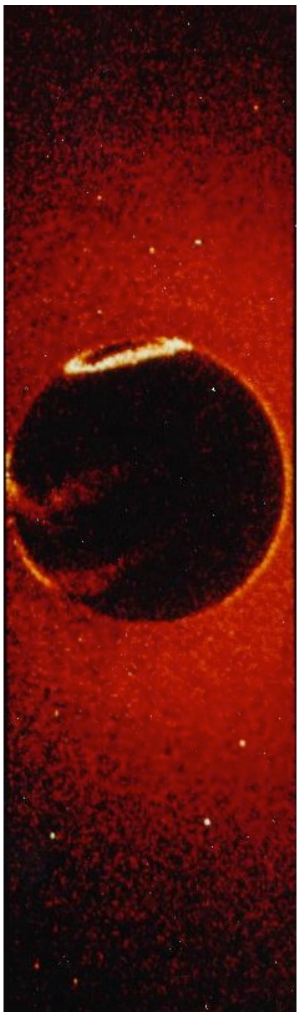

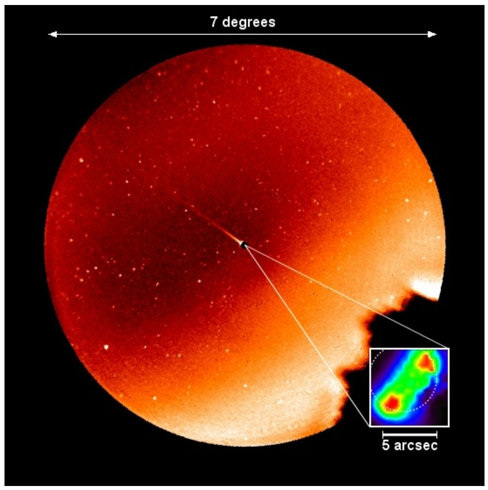

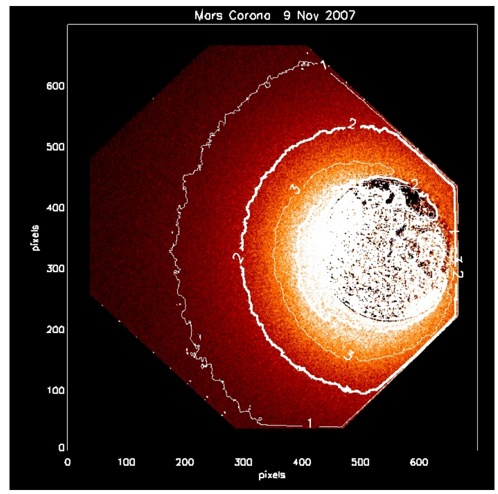

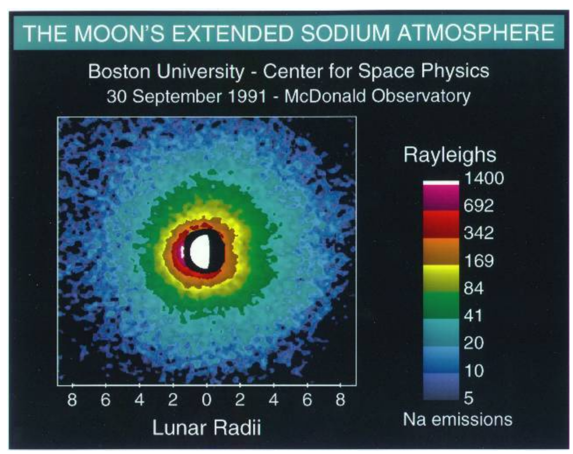

Figures: From left, images of the exospheres of the Earth (H Ly alpha emission), Mercury Na D line emission), Mars (H Ly alpha emission), and the Moon (Na D line emission).

Introduction and Justification:

Planetary exospheres form the boundary between the planetary atmosphere and the space environment. These regions encompass the interaction with the solar wind and are the source of atmospheric escape. Exospheres consist of neutral atoms and molecules that are collisionless on ballistic, satellite, and escaping trajectories. They are commonly greatly extended compared with the planet's radius (and decreasing "g"). They are subject to complex interactions via charge exchange with solar wind protons, radiation pressure from solar emissions, and tidal effects from other gravitating bodies, while the source is determined by the properties of the underlying atmosphere or surface (e.g. Mercury).

Our understanding of the detailed physics of the Earth's exosphere can be greatly improved by studying other objects in the solar system where the conditions are very different in terms of the strength of gravity and the magnetic field, the intensity of solar radiation, and the size scale of the extended exospheric species.

This white paper proposes enhanced ground-based observations of the extended regions of other planets and satellites and a space-based mission that could greatly improve our knowledge at a modest cost. In addition to the Earth, the resulting improved understanding of exospheres can be applied to the cases of exo-planets, where super-Earths or Jovian planets exist much closer to stars than in our solar system. These systems are believed to undergo much more rapid escape and evolution of their atmospheres due to the large energy inputs, but little of the detailed work of modeling these systems has yet been carried out.

Measurement Objectives:

In the appendix we briefly tabulate the main properties of Mercury, Venus, Earth, Mars, Jupiter, Io, Europa, Titan, Uranus, , Triton, and Pluto, and the important emissions that can be observed to reveal the state of the exosphere of each object.

Recommendations / Mission Description:

A significant step toward improving the impact of comparative studies on the field of heliophysics would be achieved by the NASA Heliophysics R&A programs specifically soliciting/prioritizing such studies. Despite such studies falling within the scope of current R&A programs, experience has shown that proposals that go beyond the single planet Sun-Earth Connection are rarely rated highly.

Greatly expanded ground-based observations of planetary and satellite exospheres would improve our understanding of the detailed physics of their many interactions. A more comprehensive time series of measurements would allow us to study the dependence of exospheric densities and distributions with other parameters, i.e. solar wind strength, solar radiation, tidal forces, and the conditions in the lower atmosphere (the source). Ground-based observations can resolve exospheric properties with a resolution of ~ 1 arc sec, with some limits due to light scattering in the Earth's atmosphere (e.g. faint exospheric emissions next to the bright limb of the planet). We propose that 1 or more 1-meter class telescopes be outfitted with the needed instrumentation and dedicated to observations of planetary exospheres. Since the needed aperture is modest, existing telescopes no longer in active use for other observations could be modified to accomplish this. Since time coverage is an important parameter, it would be best if at least 2 telescopes with a wide range in longitude could be employed.

In addition, a small Earth-orbiting visible/UV telescope would permit higher resolution images of the key species, including simple atoms at UV wavelengths, with much lower scattered light than possible from the ground. This would provide measurements close to each planet's exobase, the source region of the atoms. In round numbers, visible imaging with a 6 inch aperture would provide ~ 0.5 arc sec imaging with a several arc min field of view of Na, K, and other species. Far-UV imaging with an ~30 cm aperture would provide similar resolution, field of view, and a higher sensitivity to the fainter emissions. Prior phase A studies of the proposed JMEX mission have shown that the resolution, pointing stability, data rates, etc. fit easily within SMEX mission parameters. A bore-sited two telescope system would in fact be significantly simpler, lower risk, and lower cost than the previously proposed JMEX mission. To keep this white paper short, we will not include all the specific data for such a mission, but we will be happy to provide more details if asked.

Summary:

In summary we propose comprehensive observations of planetary and satellite exospheres, including:

- Including comparative planetary exospheres in the stated priorities for proposals to NASA and NSF

- Supporting comprehensive ground-based observations of planetary exospheres, either with existing facilities or new telescope(s), including the development of the appropriate focal plane instrumentation

- Including in the next SMEX AO a priority for comparative planetary exospheres with a spacebased telescope payload.

Body	Species Observed	Scale Height	Extent Observed	Loss rates	Reference
Mercury	H (1216Å)	1330 km (day) 230 km (night)	0.4 R_M	<8.0e23 s^{-1} (Jeans)	Hunten et al., in *Mercury* 1988
	He (584Å)	330 km (day) 57 km (night)	1 R_M	3.0e22 s^{-1} (Photo-ionization)	Hunten et al., in *Mercury* 1988
	Na (5891Å & 5897Å)	150 km (supra-thermal)	1500 R_M	$\leq$1.3e24 s^{-1} (Radiation Pressure (Varies))	Killen et al., *Planet Space Sci.* 1999; Schmidt et al., *Icarus* 2010
	Ca (4227Å)	0.3-0.5 R_M(supra-thermal)	3.5 R_M	?	Killen et al., *Icarus* 2005; Vervack et al., *Science* 2010
	Mg (285Å)	0.4-2.0 R_M(supra-thermal)	3.5 R_M	?	Killen et al., *Icarus* 2010; Vervack et al., *Science* 2010
Venus	H (1216Å)	1000 km (supra-thermal)	8 R_V	2.0e25 s^{-1} (Jeans)	Delva et al., *GRL* 2009; Galli et al., *JGR* 2008
	O (1304Å)	20 km (day)	0.8 R_V	2.0e25 s-1 (Charge Exchange)	Nagy et al., *Ann. Geophys.*1990; Galli et al., *JGR* 2008
Earth	H (1216Å)	6.2 km	15 R_E	1.4e27 s^{-1} (Jeans)	Hunten, in *Atmospheres of the Solar System*, 2002
	O (1304Å)	10.9 km	?	?	Chamberlain, in *Phys. Aurora and Airglow* 1961
Mars	H (1216Å)	740 km (day) 230 km (night)	4.0 R_M	1.3e26 s^{-1} (Jeans)	Anderson and Hord, *JGR* 1971; Clarke et al., *DPS* 2009
	He (584Å)	185 km (day) 85 km (night)	?	7.0e23 s^{-1} (Jeans)	Krasnopolsky and Gladstone, *JGR* 1996.
	H_2	370 km (day) 115 km (night)	?	3.3e24 s^{-1} (Jeans)	Krasnopolsky and Feldman, *Science* 2001.
Titan	H (1216Å)	900 km	0.7 R_T	6.95e26 s^{-1} (Jeans)	Hedelt et al., *Icarus* 2010
	H_2	?	?	5.0e27 s-1 (Hydrodynamic)	Strobel, *Icarus* 2008
	CH_4	?	?	2.0e27 s-1 (Hydrodynamic)	Strobel, *Icarus* 2008
Triton	H (1216Å)	0.7 R_T	?	2.0e28 s-1 (Jeans)	Hunten, in *Atmospheres of the Solar System*, 2002
	N	70 km	?	2.0e27 s-1 (Jeans)	Hunten, in *Atmospheres of the Solar System*, 2002
Pluto	N_2	15-30 km	?	0.4-6.7e27 s-1 (Hydrodynamic)	Strobel, *Icarus* 2008