Outstanding Mysteries of the Uranian Magnetosphere. I. J. Cohen[1], G. B. Clark[1], P. Kollmann[1], D. L. Turner[1], [1]The Johns Hopkins Applied Physics Laboratory (11100 Johns Hopkins Road, MS 200-E254, Laurel, MD 20723).

Introduction: Current understanding of the magnetosphere of Uranus [1] is largely limited to in-situ information gathered during the January 1986 flyby of the system by the Voyager 2 spacecraft [2]. Launched on August 20, 1977, the Voyager 2 spacecraft carried a comprehensive payload comprising both in-situ particles and fields and remote sensing instruments as it took advantage of a "once-in-a-lifetime" cosmic alignment to conduct a "Grand Tour" of all of the Giant planets in our solar system: Jupiter, Saturn, Uranus, and Neptune [3]. Despite multiple calls for further exploration of Uranus – and its sister world Neptune – these "Ice Giant" planets remain woefully underexplored [4], despite the fact that they represent a significant stepping stone in understanding the range of environments to be expected from exoplanets [5].

This first glimpse of Uranus revealed myriad surprises and provided observations that have led to countless new questions about the solar system's seventh planet. Perhaps most significantly, the Voyager 2 flyby revealed that Uranus boasts an offset and the most highly tilted – 60º from the rotational axis – intrinsic magnetic field in the solar system [6]. This, combined with the significance of higher-order non-dipole terms and the planet's high obliquity (its rotational axis is nearly parallel to the ecliptic plane) results in one of the most complex magnetospheric configurations and unique solar wind interactions in the solar system [1]. Given its complicated and dynamic topology, which is driven by significant variations at both daily and seasonal timescales, it remains unclear how plasma is sourced, transported, and accelerated throughout the system and thus whether Uranus' magnetosphere more closely resembles Earth – as a solar wind-driven system – or Jupiter, which is dominated by internal processes [7]. Early results seemed to suggest the presence of Earth-like dynamics [8], but seem inconsistent with the lack of heavy ion species [9-10] expected in a solar wind-driven system.

Another mystery arising from the Voyager 2 observations at Uranus centers on what were determined to be surprisingly intense electron radiation belts [11]. Notably, the energetic populations at Uranus were observed to be very similar to Earth [12], despite the fact that Voyager 2 found very low densities of plasma in the system [13] from which the radiation belts could be populated [7]. Coincidentally, the inner magnetosphere of Uranus was also the location where Voyager 2 measured the most intense whistler-mode wave emissions that it saw at any of the Giant planets [13]. However, transformational advances in understanding of magnetospheric processes afforded by observations from subsequent missions at several planets – e.g., Earth (Van Allen Probes, Polar, THEMIS, MMS), Juno (Galileo, Juno), & Saturn (Cassini) – provide a new lens through which to reanalyze Uranus' magnetosphere.

New analyses of Voyager 2 observations in the Uranian magnetosphere have revealed a significant source of energetic (~300 keV to ~2 MeV) ions in the region between the moons Miranda and Ariel. Consideration of multiple potential sources concludes that the presence of an active ocean world (most likely Ariel) is a potential explanation. Alternative sources considered – e.g., magnetospheric injections and CRAND - cannot explain the location, sustained severe pitch angle gradients, or energies observed in the LECP measurements. However, a potential moon source at Ariel could plausibly source plasma that could give rise to ion-mode electromagnetic waves, unable to be seen by Voyager 2 instruments, that could result in both sufficient energization and the observed steep pitch angle gradients. Unfortunately, it is very difficult to definitively determine the source of these energetic particles given the extremely limited – in capability, quantity, and system coverage – in-situ particle and waves measurements of the Uranian magnetosphere. In particular, composition measurements of ion species – both mass and charge state – in the thermal and suprathermal (10s to 100s keV) energy ranges are lacking, which could help identify particle sources and acceleration processes. Likewise, field measurements at the relevant frequencies required to assess ion-mode wave processes are missing. More comprehensive in-situ observations of the particle and fields environment are required to definitively determine the actual cause of this curious energetic particle source.

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