Final Report: A Comprehensive Analysis of Io's Atmosphere and Torus (NAG5-4932 and NAGW-2484)

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This final report describes the results of our NASA/Planetary Atmospheres program studying the atmosphere of Jupiter's moon Io and the plasma torus which it creates. Io is the most volcanically active body in the solar system, and it is embedded deep within the strongest magnetosphere of any planet. This combination of circumstances leads to a host of scientifically compelling phenomena, including (1) an atmosphere out of proportion with such a small object, (2) a correspondingly large atmospheric escape rate, (3) a ring of dense plasma locked in a feedback loop with the atmosphere, and (4) a host of Io-induced emissions from radio bursts to UV auroral spots on Jupiter. This proposal seeks to continue our investigation into the physics connecting these phenomena, with emphasis on Io's atmosphere and plasma torus. The physical processes are clearly of interest for Io, and also other places in the solar system where they are important but not so readily observable.

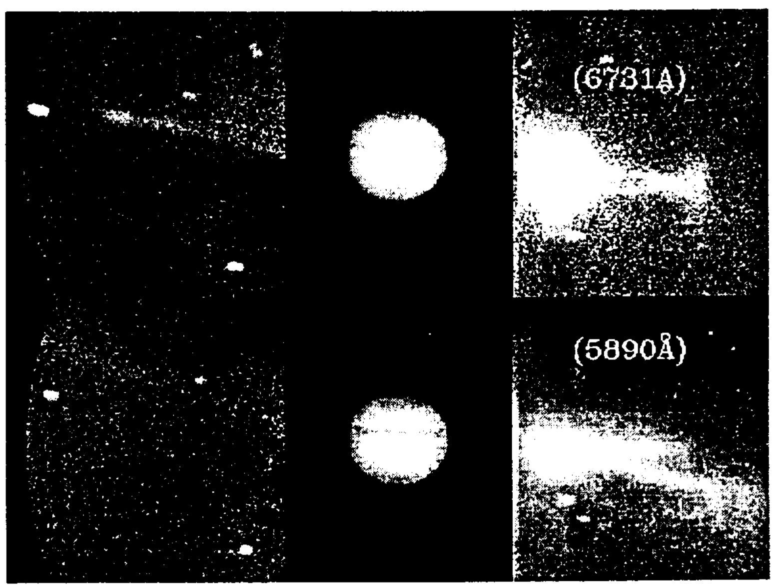

Figure 1: Groundbased images of Io's escaping atmosphere (bottom) and the resulting torus of plasma encircling Jupiter (top). The bottom image shows neutral sodium; the appearance of the cloud reflects the many processes which cause atmospheric escape. The top image shows S^+; the structure reveals the combined effects of mass and energy supply. The ring is tilted due to the tilt of Jupiter's magnetic field. These observations were made in collaboration with J.T. Trauger.

Twenty-five years of groundbased observations and a handful of interplanetary and Earth-orbiting spacecraft have given an adequate general picture of Io's atmosphere and torus (reviewed by Spencer & Schneider 1996). Io's volcanism pumps sulfur dioxide and other species onto the surface and into its atmosphere. These materials escape Io's weak gravity by several mechanisms and form extended "neutral clouds" around Io orbit (Figure 1, bottom). The atoms and molecules are ionized by the plasma, and are swept into a ring by Jupiter's rapidly rotating magnetic field (Figure 1, top). The plasma, along with its concomitant electric and magnetic fields has a remarkably strong interaction with Io, leading to a variety of excitation and escape processes in Io's atmosphere. Thus the torus and atmosphere form a tightly coupled system which must be studied as a whole.

Results of the Final 3 Years

Atmospheric Escape. Escape on Io is mostly directly observable through sodium observations. Our observations of high-speed escape from Io have identified a new escape process: ionospheric loss driven by the electrodynamic interaction of Io with Jupiter's magnetosphere. This result stems from Wilson's thesis work under this grant; it has been accepted for publication in JGR-Planets (Wilson & Schneider 1999). Furthermore, long-term observations supported by the current grant have paid off in identifying a "dual nature" of Io's sodium cloud. Atmospheric loss is sometimes dominated by the high-speed escape as described above. At other times, escape is dominated by the brute force impact of plasma on the atmosphere, resulting in slower escape. This result arose from the collaboration with Mendillo and Wilson at Boston University, and was made possible by combining their large-scale observations and our close-up images of the sodium cloud. Those results have been submitted to Icarus (Wilson, Mendillo, Baumgardner, Schneider and Trauger 1999).

Finally, we have gotten our first close-up look at the ionospheric escape process with Galileo. It matches all predictions from the Wilson & Schneider mechanism. Furthermore, the image shows that escape is confined to an area much smaller than Io's diameter, indicating that the ionosphere is restricted to low latitudes. This result (the work of graduate student Burger under this grant, before JSDAP funds were available) has been submitted to Science (Burger & Schneider 1999).

Torus Structure and Energetics. Our thorough observations of the S^+ torus yielded the best 3-d description of the torus brightness and structure (Schneider and Trauger 1995). For example, we answered the 20-year-old question of what property of the torus is responsible for making half of the torus up to four times brighter than the other. We showed it can be attributed to a vertical compression of plasma on one side (from lower ion temperatures) resulting in higher emission rates. We then sought insights into the mechanism causing this asymmetry. We mined the existing dataset for clues, and discovered that the large difference in ion temperatures offers a natural tests of energy supply theories. The observations and accompanying theory were published in Schneider *et al.* 1997. Based on the new theory, we made simultaneous observations with Galileo, HST, EUVE and Mt. Wilson. The large scope of the project has make progress slow, but the results will be submitted by July (Schneider, Kueppers, McGrath, Trauger, Hall, in preparation).

In general, observations of torus structure (density, temperature, composition, etc.) ultimately lead to insights on the processes which form the torus. For example, Volwerk *et al.* 1997 suggested that densities were 5-10× higher than our view; this would have substantially altered torus energy supply theories. We refuted their claims in Kueppers & Schneider 1997.

Publications Supported by this Grant

Burger & Schneider 1999, "Galileo's Close-up View of Io's Sodium Jet", submitted to Science.

Kueppers, M. and N. M. Schneider, "The density of the Io plasma torus ribbon", *Geophys. Res. Lett.,* 25, no. 14, 2757-2760, 1998.

Schneider, N.M., J.T. Trauger, "The Structure of the Io Torus", *Astrophys. J. 450*, 450-462, 1995.

Schneider, N. M., M. H. Taylor, F. J. Crary, J. T. Trauger, On the nature of the λ_{III} brightness asymmetry in the Io torus, *J. Geophys. Res.*, 102, 19823-19833, 1997.

Schneider, Kueppers, McGrath & Hall, "A Multi-Wavelength Study of Energy Flows in the Io Torus", in preparation.

Spencer, J.R. and N.M. Schneider, "Io on the Eve of the Galileo Mission", *Ann. Rev. Earth Plan. Sci. 24*, 125-90, 1996.

Wilson, Mendillo, Baumgardner, Schneider & Trauger 1999, "The Dual Nature of Io's Sodium Clouds", submitted to Icarus.

Wilson & Schneider 1999, "Io's Sodium Directional Feature: Evidence for Ionospheric Escape", accepted for publication in JGR (Planets).