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Final Technical Report

Particle Excitation, Airglow and H_2 Vibrational Disequilibrium in the Atmosphere of Jupiter

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Summary

The EUV emission produced by particle excitation of the hydrogen atmopsheres of Jupiter and Saturn is examined using model calculations to determine the nature of the energy deposition process and the effect of such processes on atmospheric structure. Research supported by this grant has been conducted in a number of closely related tasks, which range from examination of phenomenologically related processes on Saturn and Titan in addition to Jupiter, to analysis of experimental laboratory data required to allow accurate modeling of emissions from hydrogenic atmospheres.

1) A major accomplishment in the program is completion of work which advances a new explanation of the hydrogen H Lyα bulge in Jupiter's emission from the equatorial region.[1] The explanation diverges drastically from earlier work, because detailed analysis of the Voyager EUV spectrum shows that the abundance of atomic hydrogen is constant in magnetic longitude. Earlier explanations depend on a bulge in H abundance, in direct conflict with these results. The explanation advanced here as the only plausible possibility, is a combination of collisional transfer of H(2s) atoms into the H(2p) state and recombination of H_2^+ and H_3^+ in an asymmetric ionosphere. The proposed mechanisms have far reaching importance because the processes imply that the ionosphere and upper atmospheric heating must be controlled by solar simulated exospheric particle excitation generated mostly from an internal energy source. Saturn appears to show a very similar deposition process,[2] but with different physical manifestations due to a higher degree of symmetry in the magnetic field, and a lower gravitational field.

2) The same high altitude energy deposition processes occurring on Saturn produces a substantial flux of atomic hydrogen with energies surrounding the atmospheric escape value of 5.5 - 6 eV. According to this work the flux is sufficient to produce

the extended hydrogen cloud surrounding Saturn and extending beyond the orbit of Titan. It is proposed that Saturn, rather then Titan is the major source of the extended cloud. The atomic hydrogen detected at the rings of Saturn may originate predominantly from the same source.

3) A cross calibration has been obtained between the Pioneer 10 EUV photometer and the Voyager EUV spectrometers,[3] thus providing a direct measure of the temporal morphology of Jupiter between a minimum (1973/74) and a maximum (1979) in solar activity. The results indicate a strong apparent dependence of Jupiter auroral and equatorial EUV emission rates on the major solar cycle. It appears that the radiative power of the Io torus also follows this cycle with a similar order of magnitude variation.

4) Atomic and molecular data required for the research program have been obtained,[4] in continuing collaborative work. Detailed analysis of laboratory data has been essential to the successful modeling of atmospheric phenomena.

5) An extrapolation of conditions in the upper atmospheres of Jupiter and Saturn has produced a predicted condition at Uranus in terms of excitation and hydrogen escape rates that may be observed at Voyager-Uranus encounter.

Research Tasks Conducted in the Present Grant

Details beyond the following descriptions are available in earlier proposals and reports in the program.

a) The Lyα Bulge on Jupiter

The early work on this phenomenon recognized its importance as a process unique to Jupiter. The observational evidence immediately eliminated any simple explanation

for the correlation of the equatorial H Lyα brightness with system III (λ_{III}) magnetic longitude. All of the previous studies (see Appendix A) considered solutions surrounding the basic assumption that the bulge was caused by solar resonance scattering in a substantial asymmetry in the abundance of atomic hydrogen. However the production of atomic hydrogen requires energy, about 15 eV per neutral pair, and evidence for the deposition of the necessary amount has not been forthcoming. The analysis discussed in Appendix A in fact has shown that the bulge in atomic hydrogen required by earlier suggested mechanisms does not exist. The explanation of the phenomenon according to Appendix A lies mostly with the preferential collisional transfer of H(2s) atoms into the H(2p) state in the quiet sector region of the lower magnetosphere. The nature of the proposed process is therefore totally different from earlier published descriptions, because it does not involve the deposition of large amounts of energy in a particular region of λ_{III} longitude, and requires no strong asymmetry in the abundance of atomic hydrogen. Thus the bulge phenomenon internally, as described here, does not involve the transfer of significant amounts of energy and from this narrow point of view is not a matter of direct importance in Jupiter's budget. On the other hand the process creating the ingredients for the emission asymmetry is of extreme importance to the understanding of the upper atmosphere and magnetosphere. According to the present analysis the bulge phenomenon can appear only in a particle excited exosphere. This particle excitation process controls the production of ionospheric particles, neutral hydrogen, and probably the upper atmospheric temperature. Evidently it is also the dominant source of the H^+, H_2^+ and H_3^+ ions loading the magnetosphere throughout the region to the ~80 R_J bow shock. The H Lyα bulge in this description is therefore an outcrop of a process which is a controlling influence on the upper atmosphere and magnetosphere. Although the bulge can be explained in quantitative terms through models of the observed effects, the underlying mechanisms for the generation of particle energy and heat deposition is very difficult to explain

(Appendix A). It is without a doubt the single most important factor influencing the condition of the upper atmosphere-magnetosphere system and should be the subject of intensive study in future work.

b) Long Term Temporal Morphology at Jupiter;

Pioneer 10 vs. Voyager

Appendix A also briefly discusses the changes in Jupiter's emissions over the 1973 - 1979 time period. Uncertainties in relating observations in 1973 to the later encounters stem mostly from questions of relative calibration of the observing instruments. Part of this year's research program has been devoted to establishing the relative sensitivites of the Pioneer 10 (P10) and Voyager EUV instruments. The primary results of this work are being published in a paper by Shemansky, Judge and Jessen (see references in Appendix A). The sensitivites of the instruments have been related through common observations of the interstellar medium. The results indicate that the apparent intensities from the P10 instrument in the long wavelength channel must be multiplied by a factor of 4.4 in order to place the two instruments on the same calibration scale. The H Lyα emissions from Jupiter calculated on this basis are more than an order of magnitude weaker in 1973 at solar minimum than they were at Voyager encounter in 1973. This result gives strong support to the conclusion in Appendix A that solar photons act as a stimulus to internally generated energy deposition at Jupiter. By implication, Saturn behaves in a very similar manner. These results provide a basis for model calculations aimed at simulating conditions on the outer planets as a function of major solar cycle. This work also impacts research programs on the morphology of the Io plasma torus.

c) The Atomic Hydrogen Torus in Saturn's Magnetosphere

Last year's proposal for continuing research in this program discussed work that suggested the neutral torus at Saturn and the ring atmosphere were mostly supplied from Saturn's exosphere rather than local sources or Titan. The escape of atomic hydrogen from Saturn was calculated on the basis of a phenomenologically similar process as that described for Jupiter in Appendix A. The results of this work published orally by Shemansky and Smith (see references, Appendix A) remain valid subsequent to the detailed study of hydrogen reactions in Appendix A. However, work on this important question for Saturn has not proceeded over the past year because of limited time resources. It remains an important part of the research program that must receive attention. An important factor in this study is the role played by Titan. The upper atmosphere of Titan requires a substantial research program as a separate subject, although atomic data in the EUV for nitrogen has vastly improved since the time of encounter, research in this area has not proceeded because of resource limitation.

d) Uranus

The recent preparations for Voyager encounter with Uranus have stimulated some unpublished research (Shemansky and Smith) assuming that upper atmospheric energy deposition processes analogous to those at Jupiter and Saturn also take place on Uranus. The basic major difference in physical conditions at Uranus is the much lower gravitational field. This allows substantially more of the dissociated hydrogen to escape, giving Uranus a comet-like character. It is then possible that the Uranus magnetosphere may be heavily loaded with protons, given the proper conditions. The accompanying table gives a rough projection of rates. Although, as the table data indicate, the estimated loss rate is not significant for total atmospheric evolution consi-

derations, it is many orders of magnitude larger than previous estimates based on satellite or other sources.

Exobase Production Rates and Escape of Atomic Hydrogen

$$e + H_2 \rightarrow H(n\ell) + H(n\ell) + e$$

$$\rightarrow H(n\ell) + H^+ + 2e$$

$$\rightarrow H_2^+ + 2e$$

Dissociation Production (s^{-1})	1.6×10^{30}	3×10^{29}	2×10^{28}?
Rate ($cm^2\ s^{-1}$)	5.1×10^9	1.7×10^9	5×10^8?
HI escape energy (eV)	19.	6.	2.
Escape yield (%)	0	~15	~80
Loss Rate (kg yr^{-1})		2.4×10^9	8×10^8?
Loss Lifetime for 200 km am H_2 (yr)			10^{11}
Exobase ion density (cm^{-3})		2×10^4	2×10^4

These estimates exclude auroral activity

e) Atomic and Molecular Data

Developments in atomic and molecular data have played a strong role in allowing the research in this project to move forward. The major work establishing the importance of higher H_2 Rydberg series band systems and providing meaured cross-sections has been completed (Appendix B). Further research having a broad effect on cross-section measurements in general is described in Appendix C. Ongoing work in collaboration with the authors of Appendix B is in progress relating to the triplet system of H_2 and improvements in accuracy of transition probabilites of the higher H_2 Rydberg band systems.

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