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"Continuing Studies in Support of Ultraviolet Observations of Planetary Atmospheres"

Principal Investigator: John T. Clarke

This program was a one-year extension of an earlier Planetary Atmospheres program grant, covering the period 1 August 1996 through 30 September 1997. The grant was for supporting work to complement an active program observing planetary atmospheres with Earth-orbital telescopes, principally the Hubble Space Telescope (HST). The recent concentration of this work has been on HST observations of Jupiter's upper atmosphere and aurora, but it has also included observations of Io, serendipitous observations of asteroids, and observations of the velocity structure in the interplanetary medium.

The observations of Jupiter have been at vacuum ultraviolet wavelengths, including imaging and spectroscopy of the auroral and airglow emissions. The most recent HST observations have been at the same time as in situ measurements made by the Galileo orbiter instruments, as reflected in the meeting presentations listed below. Concentrated efforts have been applied in this year to the following projects:

- The analysis of HST WFPC 2 images of Jupiter's aurora, including the Io footprint emissions. We have performed a comparative analysis of the Io footprint locations with two magnetic field models, studied the statistical properties of the apparent dawn auroral storms on Jupiter, and found various other repeated patterns in Jupiter's aurora.

- Analysis and modeling of airglow and auroral Ly α emission line profiles from Jupiter. This has included modeling the auroral line profiles, including the energy degradation of precipitating charged particles and radiative transfer of the emerging emissions. Jupiter's auroral emission line profile is self-absorbed, since it is produced by an internal source, and the resulting emission with a deep central absorption from the overlying atmosphere permits modeling of the depth of the emissions, plus the motion of the emitting layer with respect to the overlying atmospheric column from the observed Doppler shift of the central absorption. By contrast the airglow emission line, which is dominated by resonant scattering of solar emission, has no central absorption, but displays rapid time variations and broad wings, indicative of a superthermal component (or corona) in Jupiter's upper atmosphere.

- Modeling of the observed motions of the plumes produced after the impacts of the fragments of Comet S/L-9 with Jupiter in July 1994, from the HST WFPC 2 imaging series.

Listed on the following pages are the publications in refereed journals resulting from this work, and abstracts of talks at meetings that have been given during the period of this grant.

John T. Clarke

6 July 1998

Publications:

"Evidence for Supersonic Turbulence in the Upper Atmosphere of Jupiter", C. Emerich, L. Ben Jaffel, J.T. Clarke, R. Prangé, R. Gladstone, J. Sommeria, & G. Ballester, *Science, 273*, 1085 (1996).

"Far-UV Imaging of Jupiter's Aurora with HST/WFPC 2", J.T. Clarke, and 20 co-authors, *Science, 274*, 404 (1996).

"Time-Resolved Observations of Jupiter's Far-UV Aurora: Comparison of WFPC2 and IUE", G.E. Ballester, J.T. Clarke, and 20 co-authors, *Science, 274*, 409 (1996).

"Analysis of Jovian Auroral H Ly-α Emission (1981-1990)", W.M. Harris, J.T. Clarke, M.A. McGrath, and G.E. Ballester, *Icarus, 123*, 350 (1996).

"Simultaneous Spectroscopy and Imaging of the Jovian Aurora with the Hopkins Ultraviolet Telescope and the Hubble Space Telescope", P.F. Morrissey, P.D. Feldman, J.T. Clarke, B.C. Wolfven, D.F. Strobel, S.T. Durrance, and J.T. Trauger, *Astrophys. J. Lett., 476*, 918 (1997).

"Detection of Self-Reversed Lyman α Lines from the Jovian Aurorae with the Hubble Space Telescope", R. Prangé, D. Rego, L. Pallier, L. Ben Jaffel, C. Emerich, J. Ajello, J.T. Clarke, & G.E. Ballester, *Astrphys. J. Lett.*, 484, L169 (1997).

"The Pele Plume (Io): Observations with the Hubble Space Telescope", J. Spencer, P. Sartoretti, G.E. Ballester, A. McEwen, J.T. Clarke, & M. McGrath, *Geophys. Res. Lett., 24*, 247 (1997).

"Asteriod Trails in HST WFPC 2 Images: First Results", R. Evans and 23 co-authors incl. J.T. Clarke, *Icarus*, 131, 261 (1998).

"HST/GHRS Observations of the Velocity Structure of the Interplanetary Medium", J.T. Clarke, R. Lallement, J. Bertaux, H. Fahr, E. Quemerais, & H.Scherer, *Astrophys. J., 499*, 482, (1998).

"Ballistic Reconstruction of Ejecta Motion Subsequent to the Impact of Shoemaker-Levy 9 Fragments A and G with Jupiter", K.L. Jessup, J.T. Clarke, G.E. Ballester, & H.B. Hammel, submitted to *Icarus* (1998).

"Analysis of the H Lyman α Emission Line Profile from Jupiter's Aurora", D. Rego, J.T. Clarke, L. Ben Jaffel, G.E. Ballester, R. Prangé, & J. McConnell, submitted to *Icarus* (1998).

Meeting Abstracts:

"HST/WFPC 2 Images of Jupiter's UV Aurora Simultaneous with GALILEO Measurements", J.T. Clarke, G. Ballester, & J. Trauger, *EOS Suppl., 77*, no. 22, W72 (1996).

"WFPC 2 and IUE Observations of Jupiter's UV Aurora", G. Ballester, J.T. Clarke, J. Trauger, & W. Harris, *EOS Suppl., 77*, no. 22, W74 (1996).

"High Resolution FUV Spectro-Imaging of the Jovian Aurora", R. Prangé, L. Pallier, C. Emerich, D. Rego, J.T. Clarke, G. Ballester, D. Southwood, P. Zarka, & L. Ben Jaffel, *EOS Suppl., 77*, no. 22, W74 (1996).

"Saturn's Far-Ultraviolet Aurora", J.T. Trauger, R. Evans, J.T. Clarke, & G. Ballester, *EOS Suppl., 77*, no. 22, W75 (1996).

"HST/WFPC 2 Images of Jupiter's UV Auroral Emission from Io's Magnetic Footprint", J.T. Clarke, G. Ballester, J. Trauger, & J. Connerney, *EOS Suppl., 77*, no. 22, W78 (1996).

"Follow-up HST/WFPC 2 Imaging of Jupiter to Track the Absorbing Material from S/L 9 Impacts", J.T. Clarke, M. Vincent, H. Hammel, & R. West, *EOS Suppl. 77*, no. 22, W78 (1996).

"Initial Jupiter Atmosphere Results from the Galileo Ultraviolet Spectrometer Experiment", W.R. Pryor, and 11 co-authors incl. J.T. Clarke, *B.A.A.S., 28*, 1137 (1996).

"HST Observations of Jupiter's UV Aurora Simultaneous with GALILEO Measurements", J.T. Clarke, G. Ballester, D. Rego, J. Trauger, K. Tobiska, W. Pryor, L. Ben Jaffel, J. Ajello, X. Liu, *B.A.A.S., 28*, 1145 (1996).

"Jovian Auroral H Lyman α Observations with the HST GHRS", D. Rego, J.T. Clarke, L. Ben Jaffel, *B.A.A.S., 28*, 1145 (1996).

"A Probable Mechanism for H and H_2 Escape from the Atmosphere of Jupiter", C. Emerich, L. Ben Jaffel, R. Prangé, J.T. Clarke, G. Ballester, J. Sommeria, and G.R. Gladstone, *B.A.A.S., 28*, 1145 (1996).

"Characteristics of Io's Far-UV Neutral Oxygen and Sulfur Emissions Derived from Recent HST Observations", G.E. Ballester, J.T. Clarke, D. Rego, M. Combi, N. Larsenn, J. Ajello, D.F. Strobel, N.M. Schneider, and M. McGrath, *B.A.A.S., 28*, 1156 (1996).

"Meridional Spreading of the SL-9 Debris as Imaged in the Ultraviolet with WFPC 2", M.B. Vincent, J.T. Clarke, R.A. West, H.B. Hammel, *B.A.A.S., 28*, 1149 (1996).

"Saturn's Far-Ultraviolet Aurora", J.T. Trauger, J.T. Clarke, G. Ballester, and R. Evans, invited talk at *Magnetospheres of the Outer Planets*, p. 43 (1997).

"HST Images and Spectra of Jupiter's Aurora During GALILEO Orbits G1 and G2", J.T. Clarke, G. Ballester, J. Trauger, L. Ben Jaffel, J.-C. Gérard, R. Gladstone, H. Waite, J. Ajello, W. Pryor, and K. Tobiska, *Magnetospheres of the Outer Planets*, p. 45 (1997).

"Characteristics of Jupiter's Ultraviolet Aurora from Time Series Observations with WFPC 2", G.E. Ballester, J.T. Clarke, J. Trauger, L. Ben Jaffel, R. Gladstone, H. Waite, J.-C. Gérard, J. Ajello, W. Pryor, and K. Tobiska, *Magnetospheres of the Outer Planets*, p. 46 (1997).

"Simultaneous Extreme Ultraviolet and Far Ultraviolet Observations of Jupiter Aurora by GALILEO Orbiter", J. Ajello, W. Pryor, K. Tobiska, D. Shemansky, C. Hord, S. Stephens, I. Stewart, J. Clarke, J. Gebben, W. McClintock, C. Barth, and B. Sandel, *Magnetospheres of the Outer Planets*, p. 46 (1997).

"Characteristics of Io's Far-Ultraviolet Emissions Derived from HST Observations", G.E. Ballester, J.T. Clarke, M. Combi, D.F. Strobel, N. Larsenn, J. Ajello, N. Schneider, D. Rego, and M. McGrath, *Magnetospheres of the Outer Planets*, p. 95 (1997).

"HST Observations of Jupiter's UV Aurora", J.T. Clarke, invited talk at *Spring AGU meeting*, (1997).

"Jupiter Aurora Results from the GALILEO Ultraviolet Spectrometer Experiment", W.R. Pryor, C. Hord, C. Barth, I. Stewart, W. McClintock, K. Simmons, J. Ajello, K. Tobiska, R. West, G.

James, D. Shemansky, B. Sandel, and J. T. Clarke, *Spring AGU meeting*, (1997).

"Observations of Planetary Aurora", J.T. Clarke, invited talk at 1997 DPS meeting, *B.A.A.S., 29*, 982 (1997).

"Io's Far-UV Emissions as Observed with HST and IUE", G.E. Ballester, J.T. Clarke, M. Combi, D. Strobel, N. Larsen, M. McGrath, M. Lenigan, J. Ajello, N. Schneider, & D. Rego, *B.A.A.S., 29*, 980 (1997).

"HST/FOS Observations of Io in the Near UV", K.L. Jessup, G.E. Ballester, J.T. Clarke, D. Strobel, N. Schneider, M. McGrath, M. Combi, J. Ajello, J. Luhmann, & X. Zhu, *B.A.A.S., 29*, 980 (1997).

"Observations of Short Time Scale Variability of the Jovian UV Aurora and Simulation of Morphological Patterns", J.C. Gérard, D. Grodent, V. Dols, R. Gladstone, H. Waite, J.T. Clarke, G. Ballester, & J. Trauger, *B.A.A.S., 29*, 996 (1997).

"Ultraviolet Spectroscopy of Jupiter's Auroras from GALILEO", W.R. Pryor and 12 co-authors incl. J.T. Clarke, *B.A.A.S., 29*, 997 (1997).

"HST Observations of Jupiter's Aurora Simultaneous with GALILEO Measurements", J.T. Clarke and 10 co-authors, *B.A.A.S., 29*, 997 (1997).

"Observations of the Pele Plume (Io) with the HST", J.R. Spencer, G. Ballester, P. Sartoretti, A. McEwen, J.T. Clarke, & M. McGrath, *B.A.A.S., 29*, 1001 (1997).

"HST Observations of [OI] Emissions from Io in Eclipse", J.T. Trauger, K. Stapelfeldt, G. Ballester, J.T. Clarke, & the WFPC 2 Science Team, *B.A.A.S., 29*, 1002 (1997).

"Jovian UV Albedo and Center-to-Limb Profiles as Observed by IUE and WFPC 2", M.B. Vincent, J.T. Clarke, G. Ballester, W. Harris, & T. Livengood, *B.A.A.S., 29*, 1008 (1997).

"HST/GHRS Observations of the Velocity Structure of the Interplanetary Medium", J.T. Clarke, R. Lallement, J.-L. Bertaux, E. Quemerais, H. Fahr, and H. Scherer, *IAGA Symposium 4.10*, IUGG XXII General Assembly, p. 437, August (1997).

"HST Observations of Jupiter's UV Aurora", J.T. Clarke, *IAGA Symposium 4.10*, IUGG XXII General Assembly, p. 446, August (1997).