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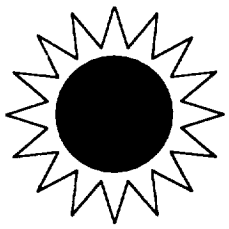

HIGH ALTITUDE OBSERVATORY **53 Years • 1940-1993**

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March 31, 1994 8 f

NASA Scientific and Technical Information Facility
Accessioning Dept.
800 Elkridge Landing Rd
Linthicum Heights, MD 21090

SUBJECT: FY1993 Annual Report for NASA Grant NAG 5 676 (FINAL REPORT)

Dear Sir:

This suborbital program has been a very successful program over the past three years at the University of Colorado (CU), National Center for Atmospheric Research (NCAR), University of California at Berkeley (UCB), and Boston University (BU). There were two rocket flights from the White Sands Missile Range, one in 1992 and one in 1993 as NASA 36.098 and 36.107 respectively. We met the minimum success criteria for NASA 36.098 as only the CU/NCAR instruments were able to make good solar and airglow measurements. The problems associated with the power switching for the UCB/BU instruments were solved, and we met comprehensive success criteria for NASA 36.107 as all instruments made good solar and airglow measurements. The rocket payload includes 5 solar instruments and 1 airglow instrument from CU/NCAR and 1 solar instrument and 2 airglow instruments from UCB/BU. These instruments are described by Woods *et al.* [*Optical Engineering*, 33, 438-444, 1994] and Vickers *et al.* [*SPIE Proceedings*, 1745, 132-139, 1992]. Of these nine instruments, six instruments were fabricated for these rocket flights. The remaining part of this report only discusses the CU/NCAR program. Supriya Chakrabarti, as PI for the UCB/BU program, is responsible for reporting the UCB/BU program status.

We have completed all the calibrations for all instruments and have all usable data in irradiance or brightness units. The intercomparison between results from different instruments and results to models is underway, so the results presented here should be considered preliminary.

To get a perspective on the solar activity for our rocket flights, the Ottawa 10.7 cm solar flux is shown in Figure 1 along with the dates for our rocket flights. Both NASA 36.098 and 36.107 occurred during moderate solar activity during the descending phase of solar cycle 22. Combining results from the 5 solar instruments plus those from UARS SOLSTICE (PI: Gary Rottman), we are able to compile solar irradiance spectra at approximately 0.1 nm resolution from 0.1 to 200 nm. This part of the solar spectrum is most important for upper atmospheric research because it is the dominant energy source for the atmosphere above 60 km. Figure 2 shows the solar irradiance results for October 4, 1993. We are also involved with the international Solar Electromagnetic Radiation Study for solar cycle 22 (SOLERS-22) (Chair: Dick Donnelly and Claus Fröhlich) which studies the solar variability and makes recommendations of solar reference spectra. We have formatted our rocket measurements in the recommended SOLERS-22 intervals, as listed in Table 1, and will be submitting these measurements for consideration as reference spectra for the SOLERS-22 program. We have not yet performed a detailed comparison of the CU/NCAR solar measurements to the UCB/BU measurements but plan to start this comparison in the near future. We have however done comparison to proxy models of the solar irradiance. In Figure 3, the comparison to the

Hinteregger proxy model is shown. The top panel in Figure 3 indicates significant systematic differences by factors of 2 at many wavelengths between the measurement and model, and the bottom panel, which has the ratio of the 1992 to 1993 results plotted, indicates the solar variability predictions by the Hinteregger proxy model are within the 30% uncertainty of the proxy model. However, there are variability differences between the measurement and model that warrants changes to the model. Two papers are now in preparation that will give the details of these solar results. This research of the solar EUV irradiance and its variability is being done primarily by Tom Woods, Scott Bailey, Gary Rottman, and John Worden.

The other aspect of this suborbital program is the study of the thermospheric airglow, namely the photoelectron excited emissions from N_2 and O. The focus for this research is to develop a model of the thermospheric airglow that incorporates the measured solar EUV spectral irradiance and the latest laboratory cross sections for photoelectron creation / cascade and excitation of the N_2 Lyman-Birge-Hopfield (LBH) and OI 135.6 nm emissions by electron collision. This model was initially developed by Scott Bailey and Stan Solomon in 1992. Now that the calibrations for the rocket airglow instrument are completed, this thermospheric airglow model is just now being validated and refined. Figure 4 shows the comparison of the N_2 LBH (2,0) and (4,0) bands, those two bands being bright and isolated from other emissions, and the O emissions at 130.4 and 135.6 nm. Our thermospheric airglow model does not include the calculations for the O 130.4 nm emissions which are optically thick, solar resonance emissions, but the results from Randy Gladstone and Supriya Chakrabarti models of the O 130.4 nm emissions are included in this figure. Our measurements of this O 130.4 nm emission has been sent to Supriya Chakrabarti and Jim Vickers for more detailed analysis at Boston University. Scott Bailey's dissertation, as well as a paper in preparation about these rocket airglow results, will focus on the measurements and models of the N_2 LBH and O 135.6 nm emissions.

We report in Listing 1 the papers, presentations, and students that have been supported by the NASA Grant NAG 5 676. Several more papers and presentations based on the rocket measurements made in 1992 and 1993 are planned but will be supported by our new rocket program that starts in April 1994. With this new rocket program, we will additionally support John Worden, a graduate student at the University of Colorado. John Worden has worked on our NASA Guest Investigator grant to study the San Marco solar measurements and to develop improved proxy models of the solar EUV irradiance. This San Marco grant ends in April 1994. We have finished the analysis of the solar measurements from the San Marco satellite, but John needs an additional year to complete his proxy model and his dissertation based on this proxy model. The development of solar proxy models was proposed as part of our new rocket program.

We thank NASA Headquarters and NASA Wallops, and all of its subcontractors, for supporting this very successful rocket program. We look forward to our continued collaboration with our new rocket program.

Sincerely,

Thomas N. Woods

Dr. Thomas N. Woods
Principal Investigator

LISTING 1. Papers, Presentations and Students Supported by NASA Grant NAG 5 676.

Papers Published

Woods, T. N., G. J. Rottman, S. Bailey, and S. C. Solomon, "Vacuum-ultraviolet instrumentation for solar irradiance and thermospheric airglow", *Optical Eng.*, **33**, 438-444, 1994.

Woods, T. N., S. Bailey, S. C. Solomon, and G. J. Rottman, "Far ultraviolet and extreme ultraviolet rocket instrumentation for measuring the solar spectral irradiance and terrestrial airglow", *SPIE Proceedings* , **1745**, 140-148, 1992.

Papers In Preparation

Woods, T. N., G. J. Rottman, S. Bailey, and S. C. Solomon, "Solar vacuum ultraviolet irradiance measurements in 1992 and 1993", *J. Geophys. Res.*, to be submitted, 1994.

Bailey, S. M., T. N. Woods, C. A. Barth, R. Korde, L. R. Canfield, S. C. Solomon, and G. J. Rottman, "Solar Irradiance from 2 to 30 nm on October 4, 1993", *J. Geophys. Res.*, to be submitted, 1994.

Bailey, S. M., S. C. Solomon, and T. N. Woods, "Response of the Lyman-Birge-Hopfield Bands of N_2 in the Dayglow to Variations in the Solar Flux", *J. Geophys. Res.*, to be submitted, 1994.

Presentations

Woods, T. N., S. Bailey, S. Solomon, G. Rottman, and J. Worden, Recent solar EUV irradiance measurements, *Front Range Am. Geophy. Union* , p. 16, Feb. 14-15, 1994.

Bailey, S., T. N. Woods, C. A. Barth, G. J. Rottman, and S. C. Solomon, Solar soft x-ray flux measured from a sounding rocket, *Front Range Am. Geophy. Union* , p. 5, Feb. 14-15, 1994.

Judge, P., G. Rottman, R. Roble, V. Tisone, and T. N. Woods, Solar EUV variability measurements from lunar observations with EUVE, *Front Range Am. Geophy. Union* , p. 9, Feb. 14-15, 1994.

Bailey, S. M., S. C. Solomon, and T. N. Woods, Recent rocket measurements of the FUV airglow and EUV solar irradiance, *Am. Geophy. Union* , **74 (43)**, 460, 1993.

Woods, T. N, J. Worden, G. J. Rottman, S. C. Solomon and G. Schmidtke, Observed variability of the solar EUV irradiance, *The Sun as a Variable Star,* IAU #143, Boulder, 198, 1993.

Solomon, S. C., S. M. Bailey, and T. N Woods, Thermospheric airglow response to the solar ultraviolet irradiance, *The Sun as a Variable Star,* IAU #143, Boulder, 183, 1993.

Bailey, S. and T. Woods, Calibration of multiple diffraction orders at SURF-II, Ninth Workshop on the Vacuum Ultraviolet Calibration of Space Experiments, Boulder, CO, March 10-11, 1993.

Bailey, S., T. N. Woods, S. C. Solomon, and G. J. Rottman, The Solar EUV irradiance comparison experiment, *EOS Transactions, Am. Geophy. Union* , **73 (14)**, 225, 1992.

Students

Scott Bailey, a graduate student at the University of Colorado, has worked on this rocket program from June 1991 to the present. He has also worked on Charles Barth suborbital program at University of Colorado in 1993. Scott has worked primarily on the solar XUV photodiodes and the FUV airglow experiment. His PhD dissertation, which is expected to be completed in about one year, is about the measurements and models of the N_2 LBH and O 135.6 nm emissions as well as the solar EUV irradiance effects on these emissions using the data from NASA 36.098 and 36.107.

Vanitha Sankaran, an undergraduate student at the University of Arizona at Tuscon, worked on this rocket program during the summer of 1993. She was involved with the NCAR minority Summer Employment Program (SEP). She worked primarily on the calibration of the solar avalanche photodiode spectrometer and the analysis of the XUV image from NASA 36.098. She wrote a report on her results as part of the NCAR SEP program.

Table 1. SOLERS 22 Wavelength Intervals

SOLar Electromagnetic Radiation Study for solar cycle 22 (SOLERS 22) is an international STEP program to help establish solar minimum and maximum reference spectra for solar cycle 22. The following is the SOLERS 22 suggested wavelength intervals for these reference spectra. The data are from NASA 36.017 (Oct. 4, 1993).

λ Interval		ID	Flux	Err (%)
0.05	0.10		7.347 (4)	30.00
0.10	0.20		7.560 (3)	30.00
0.20	0.40		1.065 (4)	30.00
0.40	0.80		3.194 (6)	30.00
0.80	1.60		1.778 (6)	50.00
1.60	2.30	O k-shell	6.874 (6)	25.00
2.30	3.20	N k-shell	2.656 (7)	25.00
3.20	4.40	C k-shell	2.426 (7)	25.00
4.40	6.00		2.064 (8)	25.00
6.00	8.00		3.539 (8)	25.00
8.00	10.00		3.095 (8)	50.00
10.00	15.00		3.293 (8)	50.00
15.00	20.00		5.590 (9)	50.00
20.00	25.00		3.502 (9)	50.00
25.00	30.00		2.632 (9)	50.00
25.60	25.60	He II, Si X	1.528 (9)	50.00
28.40	28.40	Fe XV	1.790 (9)	50.00
30.00	35.00		4.373 (9)	17.87
30.30	30.40	He II, Si XI	6.692 (9)	14.98
33.50	33.50	Fe XVI	3.902 (8)	17.54
35.00	40.00		2.115 (9)	13.86
36.80	36.80	Mg IX	1.783 (8)	11.99
40.00	45.00		1.103 (9)	14.19
45.00	50.00		1.228 (9)	10.51
46.50	46.50	Ne VII	2.257 (8)	9.51
49.90	49.90	Si XII	2.252 (8)	7.34
50.00	55.00		1.414 (9)	8.57
55.00	60.00		1.222 (9)	7.44
55.40	55.40	O IV	4.860 (8)	6.02
58.40	58.40	He I	1.080 (9)	5.06
60.00	65.00		1.193 (9)	7.97
61.00	61.00	Mg X	5.275 (8)	5.89
62.50	62.50	Mg X	2.350 (8)	8.00
63.00	63.00	O V	1.240 (9)	5.49
65.00	70.00		8.160 (8)	11.12
70.00	75.00		1.063 (9)	10.07
70.30	70.30	O III	2.618 (8)	7.43
75.00	80.00		2.303 (9)	7.85
75.90	76.20	O V	1.210 (8)	9.00
76.50	76.50	N IV	3.770 (8)	9.00
77.00	77.00	Ne VII	2.600 (8)	9.00
78.00	78.00	Ne VII	1.540 (8)	8.00
78.80	79.00	O IV	7.790 (8)	8.00
80.00	81.00		5.178 (8)	8.00
81.00	82.00		6.331 (8)	7.93
82.00	83.00		8.488 (8)	7.93
83.00	84.00		8.960 (8)	7.31
83.40	83.40	O II, O III	8.131 (8)	7.31
84.00	85.00		1.053 (9)	7.77
85.00	86.00		1.346 (9)	7.36
86.00	87.00		1.305 (9)	7.36
87.00	88.00		1.586 (9)	7.52
88.00	89.00		1.951 (9)	8.06
89.00	90.00		2.579 (9)	8.77
90.00	91.10		3.359 (9)	9.07
91.10	92.00		1.846 (9)	8.94
92.00	95.00		2.070 (9)	10.36
95.00	95.00	H I (Ly-δ)	5.338 (8)	10.71
95.00	100.00		1.493 (9)	14.12
97.20	97.20	H I (Ly-γ)	8.800 (8)	14.00
97.70	97.70	C III	7.870 (9)	14.00
99.00	99.20	N III	9.352 (8)	14.59
100.00	102.70	O2 limit	9.749 (8)	18.52
102.60	102.60	H I (Ly-β)	4.890 (9)	20.00
103.20	103.20	O IV	3.620 (9)	30.00
103.70	103.70	O IV	2.700 (9)	30.00
102.70	105.00		4.480 (8)	40.00
105.00	110.00		2.402 (9)	40.00
108.50	108.50	N II	5.291 (8)	40.00
110.00	115.00		7.567 (8)	40.00
115.00	120.00		2.500 (8)	40.00
117.50	117.50	C III	2.787 (9)	40.00
120.00	125.00		1.932 (10)	6.09
120.60	120.60	Si II	6.875 (9)	6.29
121.60	121.60	H I (Ly-α)	4.547 (11)	5.19
125.00	130.00		9.635 (9)	7.14
130.00	135.00		7.439 (9)	6.86
130.20	130.60	O I	1.059 (10)	5.19
133.50	133.60	C II	1.363 (10)	5.67
135.00	140.00		1.300 (10)	6.47
139.40	140.30	Si IV	5.995 (9)	5.44
140.00	145.00		1.801 (10)	6.06
145.00	150.00		2.930 (10)	5.63
150.00	155.00		4.488 (10)	5.34
154.80	155.10	C IV	1.327 (10)	5.76
155.00	160.00		6.937 (10)	5.10
160.00	165.00		1.108 (11)	5.92
165.00	170.00		1.815 (11)	5.70
165.60	165.70	C I	2.200 (10)	5.55
170.00	175.00		3.387 (11)	5.56
175.00	180.00		6.258 (11)	5.43
180.00	185.00		1.008 (12)	5.18
180.80	181.70	Si II	6.620 (10)	5.16
185.00	190.00		1.526 (12)	5.26
190.00	195.00		2.191 (12)	5.23
195.00	200.00		3.210 (12)	5.19

Figure 1. Launch Dates

NASA

21.101 Nov. 10, 1988
F10.7 = 145

36.054 June 20, 1989
F10.7 = 220

36.098 Oct. 27, 1992
F10.7 = 170

36.107 Oct. 4, 1993
F10.7 = 120

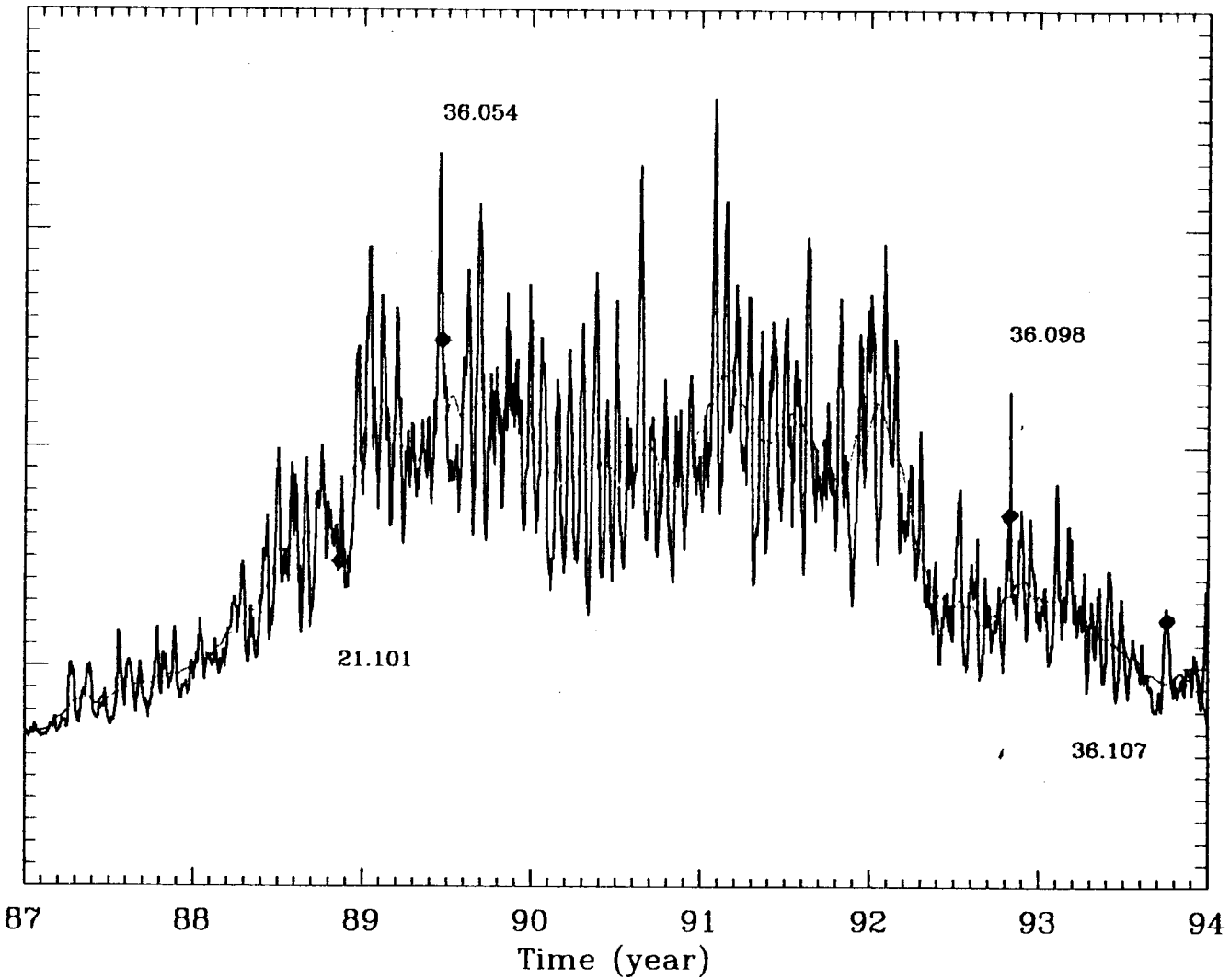

Figure 2. Solar VUV Spectrum

This solar spectrum is based on rocket and UARS SOLSTICE measurements on Oct. 4, 1993.

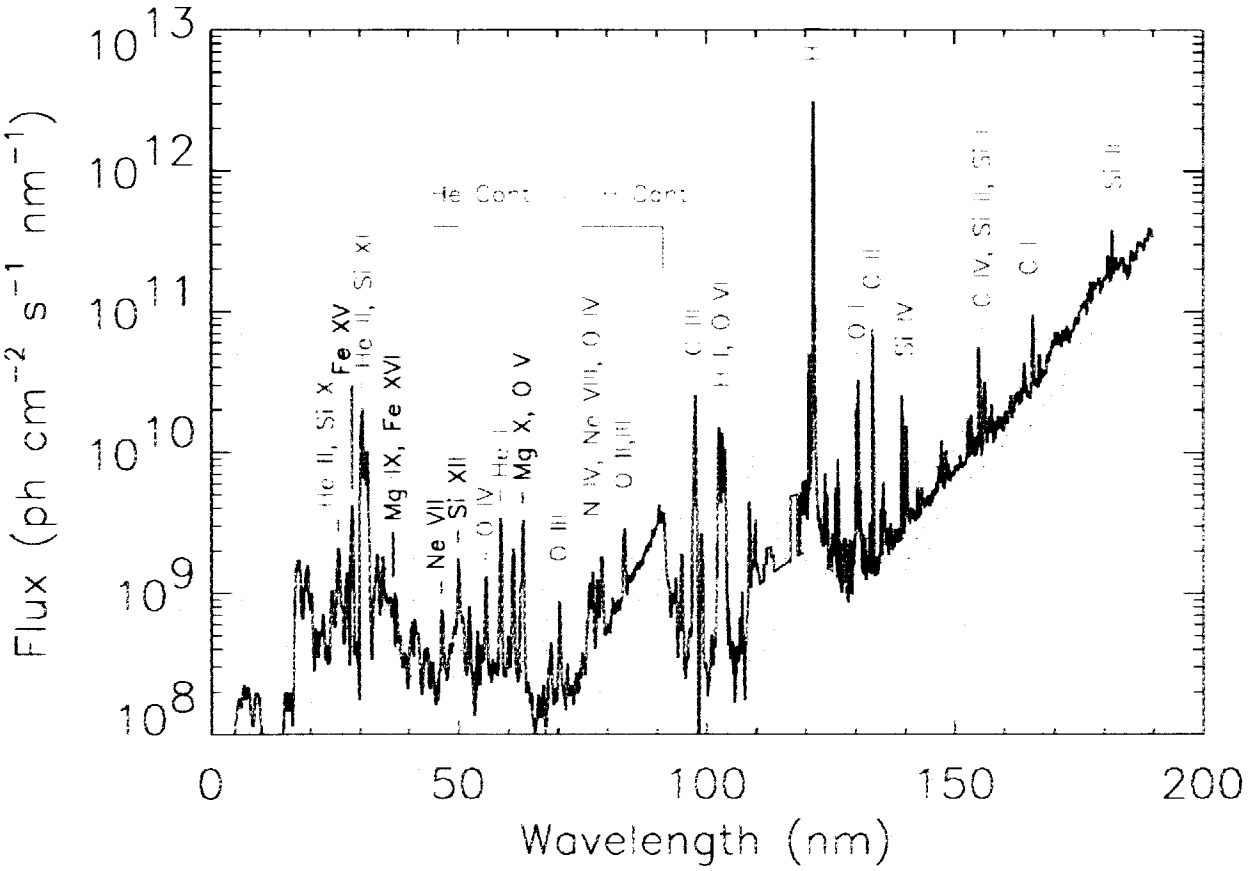

Figure 3. Comparison to Solar Proxy Model

Comparison of NASA 36.098 (Oct. 27, 1992) and NASA 36.107 (Oct. 4, 1993) measurements of the solar spectral irradiance to the results from the Hinteregger *et al.* [1981] F10.7 proxy model.

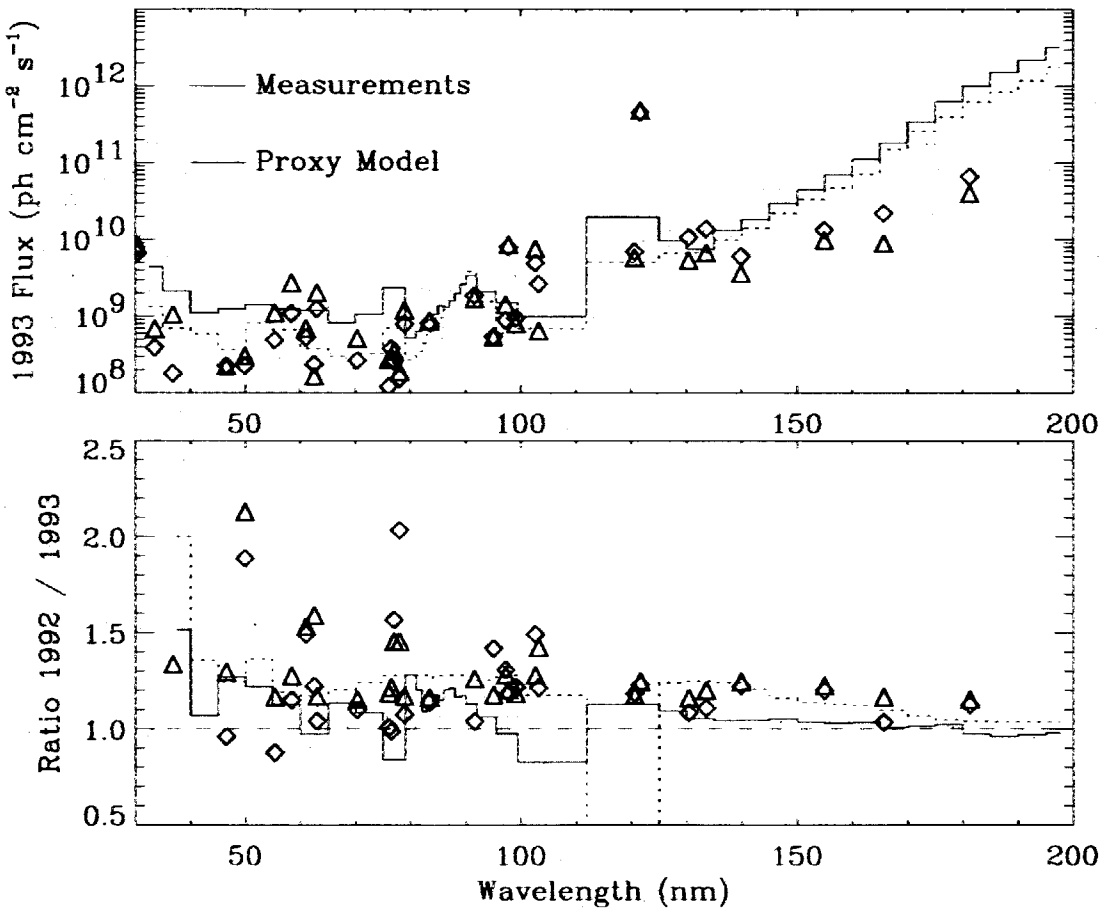

Figure 4. Comparison of Airglow Measurements to Model

The thermospheric airglow measurements are shown as symbols and the model results as lines.