HOPKINS ULTRAVIOLET TELESCOPE

ASTRO-1 MISSION

Preliminary Science Report

NASA Contract NAS 5-27000

Prepared by

Arthur F. Davidsen
Principal Investigator

29 April 1991

Table of Contents

I. Introduction

The Hopkins Ultraviolet Telescope (HUT) was finally flown aboard the Astro-1 mission on the space shuttle *Columbia* from 2 December to 9 December 1990, a successful launch having been achieved on the nineteenth scheduled launch date. Despite several significant problems encountered during the mission, HUT performed nearly flawlessly throughout nine days in orbit, and obtained the first sub-Lyman α far ultraviolet spectra (912 Å $\leq \lambda \leq$ 1850 Å) of a large sample of astronomical sources ranging from solar system objects to stars, nebulae, galaxies, and quasars. In addition, HUT obtained pioneering extreme ultraviolet spectra ($\lambda <$ 912 Å) of a small number of objects that are close enough to earth to be detectable in spite of the high opacity of the interstellar medium at these wavelengths.

A total of 31 different targets selected to be of prime interest to HUT were observed, and HUT spectra of 77 objects in all were obtained on Astro-1. This is a substantial body of unique and highly significant astronomical data. At least a dozen scientific papers are already in preparation based on HUT data, and perhaps 40-50 papers will ultimately result from our analysis. Our first paper reporting results from HUT is scheduled to appear in *Nature* in late May 1991 (see Appendix A).

II. HUT Performance

The HUT instrument performed nearly flawlessly during the flight of Astro-1. The single hardware anomaly that occurred was caused by a misaligned switch on the shutter doors of the telescope. A simple change to the software allowed the doors to work normally. None of the other error messages recorded are believed to be caused by hardware. Several minor software changes were made during the flight to improve performance. As these changes were anticipated in the design of the software, they were simple to implement.

The throughput or efficiency of HUT was determined in flight by measurement of the spectrum of the hot DA white dwarf G191-B2B and comparison of the data with a stellar model calculation for the star. The resulting effective area curve has a shape that is similar to the one determined in the laboratory several years before the mission, but the overall level is about 30 percent lower. This result was very satisfactory, given all the inherent difficulties in calibrating in this spectral region and the potential for serious degradation during the many long delays experienced by Astro-1.

Difficulties experienced with the Instrument Pointing System (IPS), especially early in the mission, prevented us from ever carrying out the in-flight focus and alignment of HUT. However, the instrument was evidently in good focus, since the data obtained were quite excellent.

It should be emphasized, however, that the performance of the IPS caused considerable degradation of the quantity and quality of data obtained by HUT. In addition to losing many planned targets completely, due in many cases to failure of the IPS to acquire the field, many of the observations which were apparently successful are severely compromised by poor tracking (i.e., the targets were constantly drifting and jittering in and out of the HUT spectrograph aperture). This has at least four negative effects on the HUT data, namely: (1) loss of signal-to-noise ratio in the spectra; (2) loss of ability to detect short time-scale variability in the sources; (3) loss of precision in the final flux calibration of HUT spectrophotometry; and (4) loss of spectral resolution (smearing due to image motion within the aperture).

III. Preliminary Overview of Data Obtained by HUT on Astro-1

A summary of the quantity of data obtained by HUT on the Astro-1 mission is provided in the following tables. Table III.1 gives the results for astronomical objects (targets) of primary interest to the HUT Team. Table III.2 gives the results for all the IPS targets, including WUPPE and UIT primary targets as well as HUT targets. Much of the data obtained by HUT on targets specified by the other teams is also of great value and high interest. It is, however, in most cases, not relevant to the scientific programs of greatest priority for the HUT Team.

TABLE III.1: HUT Performance on HUT Prime Targets

	Planned (Pre-Mission)	Actual	Percent Accomplished
Number of Targets	44	30	69 %
Number of Pointings	86	45	54 %
Total Observation Time (ksec)	146	63	43 %

TABLE III.2: HUT Performance on All IPS Targets

	Planned (Pre-Mission)	Actual	Percent Accomplished
Number of Targets	153	77	50 %
Number of Pointings	238	106	45 %
Total Observation Time (ksec)	387	142	37 %

The average length of the planned pointings was about 1900 seconds, while the average length realized during the mission was about 1400 seconds.

A complete list of all HUT prime target observations, in time-ordered sequence, is given in Table III.3. The identifier in the left-most column is usually H for HUT, but in some cases was ascribed to another team for accounting purposes. The second column, labelled JSCI-ID, gives the Astro unique identifier for each observation. The remaining columns are self-explanatory.

Table III.4 gives a time-ordered sequence listing of all IPS pointings throughout the Astro-1 mission. The columns are the same as those in Table III.3. The column labelled "Approximate Observation Time" lists very preliminary values for all non-HUT prime targets. These times will be updated later. Note that this list includes several observations which yielded only airglow data for HUT.

Table III.3: List of Pointings - HUT Prime Targets

I	JSCI-ID	Name 1	Name 2	Plan Start	Ap[a]	GMT start	GMT end	Obs Time
H	8116-11	NGC4151		35.0136	7	337:17:56:18	337:18:21:19	100 s
H	3503-11	HR1099	HD22468	39.1769	7	337:22:06:01	337:22:44:01	1800 s
H	8202-31	NGC1068		45.2186	7	338:04:27:14	338:04:52:19	60 s
H	2801-11	ALF-AUR	CAPELLA	52.7961	1	338:12:09:21	338:12:35:27	1100 s
H	2801-12	ALF-AUR	CAPELLA	54.5000	1	338:13:45:59	338:14:02:21	600 s
H	4412-10	CYGLOOPA		64.9725	2	338:23:54:17	339:00:24:01	1700 s
H	2509-10	G191B2B		68.3327	1	339:03:15:05	339:03:48:29	1600 s
U	8307-11	M87	NGC4486	77.8078	2	339:12:52:31	339:13:07:33	600 s
H	8407-13	0558-504	PKS	79.5606	7	339:14:31:06	339:14:40:12	540 s
H	6314-24	NGC1399		86.7319	2	339:21:51:12	339:22:01:36	300 s
H	8424-13	3C273	1226+023	88.5153	7	339:23:25:22	340:00:08:56	1400 s
H	2801-13	ALF-AUR	CAPELLA	89.6217	7	340:00:44:29	340:01:00:50	700 s
H	3814-10	HER-X-1	HZ-HER	93.4717	7	340:04:22:04	340:04:52:55	1700 s
H	8415-13	1700+64		94.1500	7	340:05:00:42	340:05:39:57	2000 s
H	4413-10	CYGLOOPB		95.2897	2	340:06:07:30	340:06:43:34	2000 s
H	2533-10	HZ43		114.8394	7	341:01:55:09	341:02:02:09	80 s
U	6314-11	NGC1399		118.5019	2	341:05:37:41	341:06:03:31	1400 s
U	6314-12	NGC1399		120.0292	2	341:06:59:14	341:07:36:19	2040 s
U	6314-13	NGC1399		121.5561	2	341:08:25:56	341:08:57:59	1650 s
H	8512-12	Q1821		122.8475	7	341:09:39:16	341:10:31:51	3000 s
H	8512-13	Q1821		124.4025	7	341:11:14:16	341:11:59:37	2600 s
H	2533-11	HZ43		134.5432	3	341:21:37:07	341:21:48:07	300 s
H	1204-40	JUPITER		135.5472	2	341:22:20:27	341:23:04:07	2300 s
H	4104-10	NGC1535		136.8697	2	341:23:48:55	342:00:17:55	1400 s
H	8116-13	NGC4151		141.7531	7	342:04:38:27	342:05:22:48	2300 s
H	4212-13	IC63		144.3452	2	342:07:12:35	342:07:51:35	1920 s
H	8202-33	NGC1068		145.9063	7	342:08:46:19	342:09:29:07	2400 s
H	8623-14	2155-304	PKS	156.1914	7	342:19:01:14	342:22:50:09	760 s
H	3218-10	UX-UMA		156.9383	1	342:19:41:23	342:20:31:23	2400 s
H	0010-14	BD284211		157.8547	1	342:20:50:55	342:20:56:55	250 s
H	3218-20	UX-UMA		158.4625	1	342:21:16:23	342:22:08:23	2200 s
H	8623-16	2155-304	PKS	159.5744	7	342:22:41:07	342:22:50:09	150 s
U	8202-34	NGC1068		161.1395	1	342:23:57:38	343:00:43:58	2760 s
U	6308-21	M49	NGC4472	162.1639	2	343:01:04:09	343:01:18:09	660 s
H	9319-10	A665		168.0167	6	343:07:47:54	343:08:23:20	1900 s
H	3213-20	Z-CAM		175.0757	1	343:13:59:44	343:14:33:44	1900 s
U	6308-22	M49	NGC4472	177.3628	2	343:16:17:48	343:16:23:49	90 s
H	8424-14	3C273	1226+023	178.4633	7	343:17:17:21	343:17:59:21	2200 s
H	8101-10	MKN335		185.4247	7	344:00:22:44	344:00:58:22	1850 s
H	3212-13	C48D1557		186.3786	7	344:01:27:06	344:01:35:56	340 s
H	1204-50	JUPITER		187.3793	2	344:02:10:42	344:03:02:30	2930 s
H	3208-11	U-GEM	HD64511	190.3647	1	344:05:10:36	344:05:45:13	1840 s
H	4406-12	N49A+B		198.2695	2	344:13:23:55	344:13:38:57	780 s
H	3227-31	SS-CYG	HD206697	199.0472	7	344:14:04:56	344:14:29:57	1400 s
H	1112-20	C-LEVY		200.	2	344:14:53:34	344:15:13:34	1220 s

[a] Apertures:
1. 26.8 × 30" (elliptical)
2. 9.4" × 116" (rectangular)
3. 27.7" × 30.0" (elliptical)
4. 160" × 174" (elliptical)
5. 16.9" × 116" (rectangular)
6. 17.1" × 116" (rectangular)
7. 16.8" × 18.4" (elliptical)

TABLE III.4: List of Pointings - All IPS Targets

I	JSCI-ID	Name1	Name2	Plan Start	Ap [a]	GMT Start	GMT End	Obs Time
H	8116-11	NGC4151		35.0136	7	337:17:56:18	337:18:21:19	100 s
H	3503-11	HR1099	HD22468	39.1769	7	337:22:06:01	337:22:44:01	1800 s
H	2417-13	21VUL	HD192518	40.3210	7	337:23:16:30	337:23:30:31	480 s
H	8202-31	NGC1068		45.2186	7	338:04:27:14	338:04:52:19	60 s
H	4416-10	SN1987A	LMC	48.0969	7	338:07:08:24	338:08:03:06	1680 s
H	2801-11	ALF-AUR	CAPELLA	52.7961	1	338:12:09:21	338:12:35:27	1100 s
H	2801-12	ALF-AUR	CAPELLA	54.5000	1	338:13:45:59	338:14:02:21	600 s
W	2107-20	ALF-CAM	HD30614	60.7097	7	338:19:55:36	338:20:11:36	462 s
U	5108-10	M92	NGC6341	61.4772	2	338:20:39:30	338:20:48:31	360 s
W	2307-21	THT-MUS	HD113904	63.1092	7	338:22:05:31	338:22:13:31	360 s
H	4412-10	CYGLOOPA		64.9725	2	338:23:54:17	339:00:24:01	1700 s
U	9305-12	PERSEUS	A426	66.6544	6	339:01:48:23	339:02:11:24	1380 s
W	4516-13	SK69-239	HD269902	67.5858	7	339:02:38:31	339:02:52:31	430 s
H	2509-10	G191B2B		68.3327	1	339:03:15:05	339:03:48:29	1600 s
W	4207-11	ETA-CARH	HD93308	70.2592	7	339:05:37:31	339:05:48:49	540 s
U	6106-10	SMC-A	SMCSNR	71.0667	2	339:06:07:19	339:06:18:19	600 s
U	8113-10	NGC2992	A245	71.6103	7	339:06:31:08	339:07:05:10	1600 s
U	4414-10	CRABNEB	NGC1952	72.8703	6	339:07:52:28	339:08:25:29	1600 s
W	4557-10	HD197770		74.0533	7	339:08:58:40	339:09:11:26	600 s
U	6216-10	M81	NGC3031	74.6217	1	339:09:50:30	339:09:56:37	720 s
W	2302-20	EZ-CMA	HD50896	76.0683	7	339:11:08:00	339:11:29:03	800 s
U	8307-11	M87	NGC4486	77.8078	2	339:12:52:31	339:13:07:33	600 s
W	2102-10	KAP-CAS	HD2905	78.7822	7	339:14:03:22	339:14:07:22	2800 s
H	8407-13	0558-504	PKS	79.5606	7	339:14:31:06	339:14:40:12	540 s
U	5104-11	M79	NGC1904	80.5144	7	339:15:29:52	339:15:32:53	980 s
W	4516-12	SK69-239	HD269902	82.5542	7	339:17:35:34	339:17:58:04	1080 s
U	5104-12	M79	NGC1904	83.5669	2	339:18:25:28	339:19:01:38	2220 s
H	6314-24	NGC1399		86.7319	2	339:21:51:12	339:22:01:36	300 s
W	2133-10	P-CYG	HD193237	87.6494	7	339:22:32:12	339:23:09:08	600 s
H	8424-13	3C273	1226+023	88.5153	7	339:23:25:22	340:00:08:56	1400 s
H	2801-13	ALF-AUR	CAPELLA	89.6217	7	340:00:44:29	340:01:00:50	700 s
W	4530-10	HD99264		90.4272	7	340:01:22:50	340:01:47:37	1200 s
W	2122-10	HD45677		91.2150	7	340:02:02:10	340:02:39:34	900 s
U	7310-10	M100	NGC4321	92.0056	1	340:02:52:10	340:03:07:33	450 s
U	6205-10	M74	NGC628	92.5378	6	340:03:30:08	340:04:02:26	450 s
H	3814-10	HER-X-1	HZ-HER	93.4717	7	340:04:22:04	340:04:52:55	1700 s
H	8415-13	1700+64		94.1500	7	340:05:00:42	340:05:39:57	2000 s
H	4413-10	CYGLOOPB		95.2897	2	340:06:07:30	340:06:43:34	2000 s
U	9202-11	AB1367		96.1036	2	340:07:01:14	340:07:23:14	1350 s
W	2401-10	ALF-HYI	HD12311	96.7764	7	340:07:36:09	340:08:11:58	1300 s
U	4448-10	VELASNRE		97.6469	2	340:08:36:06	340:08:50:08	870 s
W	2235-11	PI-AQR	HD212571	98.3908	7	340:09:17:22	340:09:37:54	200 s
U	7205-10	M82	NGC3034	98.9819	1	340:09:50:46	340:10:22:00	1354 s
W	4211-10	NGC7023	HD200775	100.0617	7	340:11:03:23	340:11:36:23	1800 s
H	2533-10	HZ43		114.8394	7	341:01:55:09	341:02:02:09	80 s
U	6314-11	NGC1399		118.5019	2	341:05:37:41	341:06:03:31	1400 s
U	6314-12	NGC1399		120.0292	2	341:06:59:14	341:07:36:19	2040 s
U	6314-13	NGC1399		121.5561	2	341:08:25:56	341:08:57:59	1650 s
H	8512-12	Q1821		122.8475	7	341:09:39:16	341:10:31:51	3000 s
H	8512-13	Q1821		124.4025	7	341:11:14:16	341:11:59:37	2600 s
W	0606-11	GAM-GEM	HD47105	126.2947	7	341:13:08:44	341:13:37:52	1440 s
W	0606-12	GAM-GEM	HD47105	127.8200	7	341:14:47:47	341:15:19:35	1380 s
W	4416-32	SN1987A	LMC	131.1864	7	341:18:05:17	341:18:39:55	1860 s
U	6105-13	M31	NGC224	132.1800	2	341:19:06:51	341:19:36:51	1680 s

[a] See footnote to Table III.3.

(continued on next page)

TABLE III.4: List of Pointings - All IPS Targets (cont.)

I	JSCI-ID	Name1	Name2	Plan Start	Ap [a]	GMT Start	GMT End	Obs Time
U	0301-13	BR-EARTH		133.0753	2	341:19:49:21	341:20:13:21	500 s
U	6105-14	M31	NGC224	133.6267	2	341:20:36:37	341:20:58:37	1130 s
H	2533-11	HZ43		134.5432	3	341:21:37:07	341:21:48:07	300 s
H	1204-40	JUPITER		135.5472	2	341:22:20:27	341:23:04:07	2300 s
H	4104-10	NGC1535		136.8697	2	341:23:48:55	342:00:17:55	1400 s
W	0658-21	HD25443		138.3591	7	342:01:38:03	342:01:51:03	540 s
W	0658-22	HD25443		139.8861	7	342:02:53:07	342:03:28:14	1980 s
U	6203-11	NGC253		141.1508	1	342:04:03:23	342:04:17:30	650 s
H	8116-13	NGC4151		141.7531	7	342:04:38:27	342:05:22:48	2300 s
U	3607-11	L2PUP	HD56096	143.2551	7	342:06:06:35	342:06:33:36	1480 s
H	4212-13	IC63		144.3452	2	342:07:12:35	342:07:51:35	1920 s
H	8202-33	NGC1068		145.9063	7	342:08:46:19	342:09:29:07	2400 s
W	2109-12	ALF-ORI	HD39801	149.1716	7	342:12:07:05	342:12:43:05	1840 s
U	6602-13	NGC891		150.4814	2	342:13:21:47	342:14:03:49	1680 s
W	4503-11	HD62542		153.8962	7	342:16:55:40	342:17:29:40	1750 s
W	2107-21	ALF-CAM	HD30614	155.1296	7	342:17:55:30	342:18:38:40	2400 s
H	8623-14	2155-304	PKS	156.1914	7	342:19:01:14	342:22:50:09	760 s
H	3218-10	UX-UMA		156.9383	1	342:19:41:23	342:20:31:23	2400 s
H	0010-14	BD284211		157.8547	1	342:20:50:55	342:20:56:55	250 s
H	3218-20	UX-UMA		158.4625	1	342:21:16:23	342:22:08:23	2200 s
H	8623-16	2155-304	PKS	159.5744	7	342:22:41:07	342:22:50:09	150 s
U	8202-34	NGC1068		161.1395	1	342:23:57:38	343:00:43:58	2760 s
U	6308-21	M49	NGC4472	162.1639	2	343:01:04:09	343:01:18:09	660 s
U	5103-21	NGC1851		162.8814	6	343:01:45:04	343:02:17:28	1440 s
U	5107-12	M13	NGC6205	163.7281	1	343:02:51:19	343:03:00:19	300 s
U	9305-13	PERSEUS	A426	167.2766	1	343:06:33:30	343:06:47:32	500 s
H	9319-10	A665		168.0167	6	343:07:47:54	343:08:23:20	1900 s
W	4518-13	HD37903		170.5016	7	343:09:16:22	343:09:54:16	1400 s
W	0658-23	HD25443		171.8730	7	343:10:46:05	343:11:26:05	1930 s
W	2609-13	G70D8247	GRW	173.1782	7	343:11:59:51	343:12:47:51	2600 s
H	3213-20	Z-CAM		175.0757	1	343:13:59:44	343:14:33:44	1900 s
U	9305-15	PERSEUS	A246	176.3308	2	343:15:13:37	343:15:56:37	1870 s
U	6308-22	M49	NGC4472	177.3628	2	343:16:17:48	343:16:23:49	90 s
H	8424-14	3C273	1226+023	178.4633	7	343:17:17:21	343:17:59:21	2200 s
U	6140-11	M32/N206		179.4086	2	343:18:31:53	343:18:54:29	1200 s
U	5105-10	M3	NGC5272	180.2925	7	343:19:11:27	343:19:30:27	850 s
U	6119-11	M33	NGC598	180.9050	1	343:19:47:57	343:20:28:23	2240 s
W	2235-12	PI-AQR	HD212571	182.2113	7	343:21:03:35	343:21:42:35	1970 s
W	2102-11	KAP-CAS	HD2905	184.0669	7	343:22:59:59	343:23:32:00	1740 s
H	8101-10	MKN335		185.4247	7	344:00:22:44	344:00:58:22	1850 s
H	3212-13	C48D1557		186.3786	7	344:01:27:06	344:01:35:56	340 s
H	1204-50	JUPITER		187.3793	2	344:02:10:42	344:03:02:30	2930 s
U	8303-11	NGC1316		188.6899	2	344:03:29:33	344:04:13:34	2300 s
U	5116-11	OMG-CEN	NGC5139	189.5811	2	344:04:28:24	344:04:50:24	750 s
H	3208-11	U-GEM	HD64511	190.3647	1	344:05:10:36	344:05:45:13	1840 s
U	7404-11	NGC2146		191.7992	1	344:06:39:16	344:07:11:17	1645 s
U	6216-11	M81	NGC3031	193.3488	1	344:08:09:26	344:08:42:26	1540 s
W	2109-13	ALF-ORI	HD39801	194.8995	1	344:09:39:22	344:10:18:22	2120 s
W	3115-11	HD200775		196.0483	7	344:10:51:18	344:11:38:18	2460 s
H	4406-12	N49A+B		198.2695	2	344:13:23:55	344:13:38:57	780 s
H	3227-31	SS-CYG	HD206697	199.0472	7	344:14:04:56	344:14:29:57	1400 s
H	1112-20	C-LEVY		200.	2	344:14:53:34	344:15:13:34	1220 s

IV. Data Products and Data Quality

During the flight of Astro-1, the HUT Telemetry Experiment Ground-Support Equipment (TEGSE) captured $\sim$ 90% of the data transmitted from the Shuttle in real-time and playback modes. About 1.6% of the captured data frames contained errors which made them unsuitable for further processing. The majority of these were rejected in real time by the TEGSE software, but $\sim$0.5% had to be weeded out in the post-flight analysis software. The vast majority of the missing data and bad frames came from time segments where the data were being dumped from the Payload Flight Data Recorder (PFDR). So far this has not had a deleterious impact on our scientific analysis since we transmit our spectra in a cumulative mode to guard against such dropouts. The missing data will severely hamper our efforts to perform high-time-resolution analysis of targets to look for flickering or rapid variability.

As of April 15, 1991, the project has taken delivery of 105 HUT Spacelab Experiment Channel Tapes (SECT) from the Space Lab Data Processing Facility. These tapes contain 199 hours of data, and represent all the processed science data we expect to receive from NASA for the flight. The only significant missing science data is the 10 minute time segment covering the eclipse of the cataclysmic variable UX UMa when the Payload Recorder was incorrectly configured for HUT data storage.

We have also received a complete set of IMCS SECT tapes covering 202 hours, 204 hours of data on the Spacelab I/O Channel Tapes (SICT), and 203 hours of the Spacelab Ancillary Data Tapes (SANC). A complete set of Orbiter Ancillary Data Product tapes from Johnson Space Flight Center has been delivered, and 7 of 9 Spacelab Post-Mission Ancillary (SPMA) tapes are in house. Once the final two tapes in the SPMA series are delivered, we will have a complete set of data for Astro-1.

We have performed a comparative analysis of a 15 hour time segment from our TEGSE quick-look tapes and from the SLDPF-processed SECT tapes. The SLDPF processing recovers more frames, but the extra frames are invariably corrupted in some way. Again, the vast majority of these bad data frames are from time segments when the data were dumped from the PFDR. The playback data are bad $\sim$6.8% of the time. In contrast, the real-time data have very high quality — only 0.2% of the frames in this 15-hour time interval were bad.

In summary, the data quality is not as good as we had expected. This can be attributed completely to the failure of the High Data Rate Recorder (HDRR) and the subsequent reliance on the PFDR, which did not perform up to the expected quality standards. While the lower data quality will not compromise any of our results making use of time-integrated spectra, the large number of missing frames will severely hamper our ability to perform high-time-resolution analysis of bright sources.

V. A Sample of Topics under Investigation

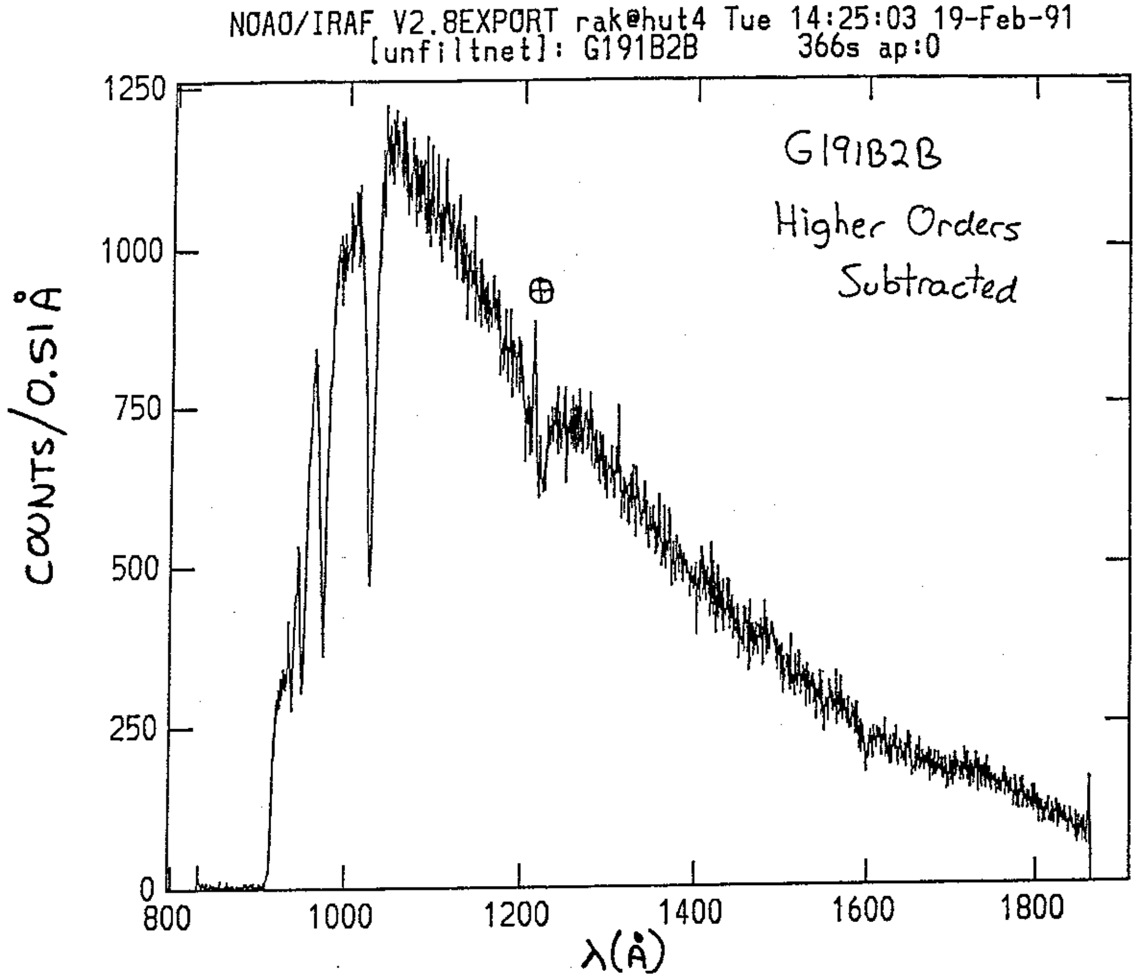
In this section I describe very briefly just a few of the many topics currently being investigated with HUT data. Any results quoted should be regarded as strictly preliminary. Details of these investigations and others will be presented in several papers which are in preparation (see Section VII and Appendix B). The first completed paper reporting results from HUT and Astro-1 has been accepted for publication in *Nature*. The manuscript is included here as Appendix A.

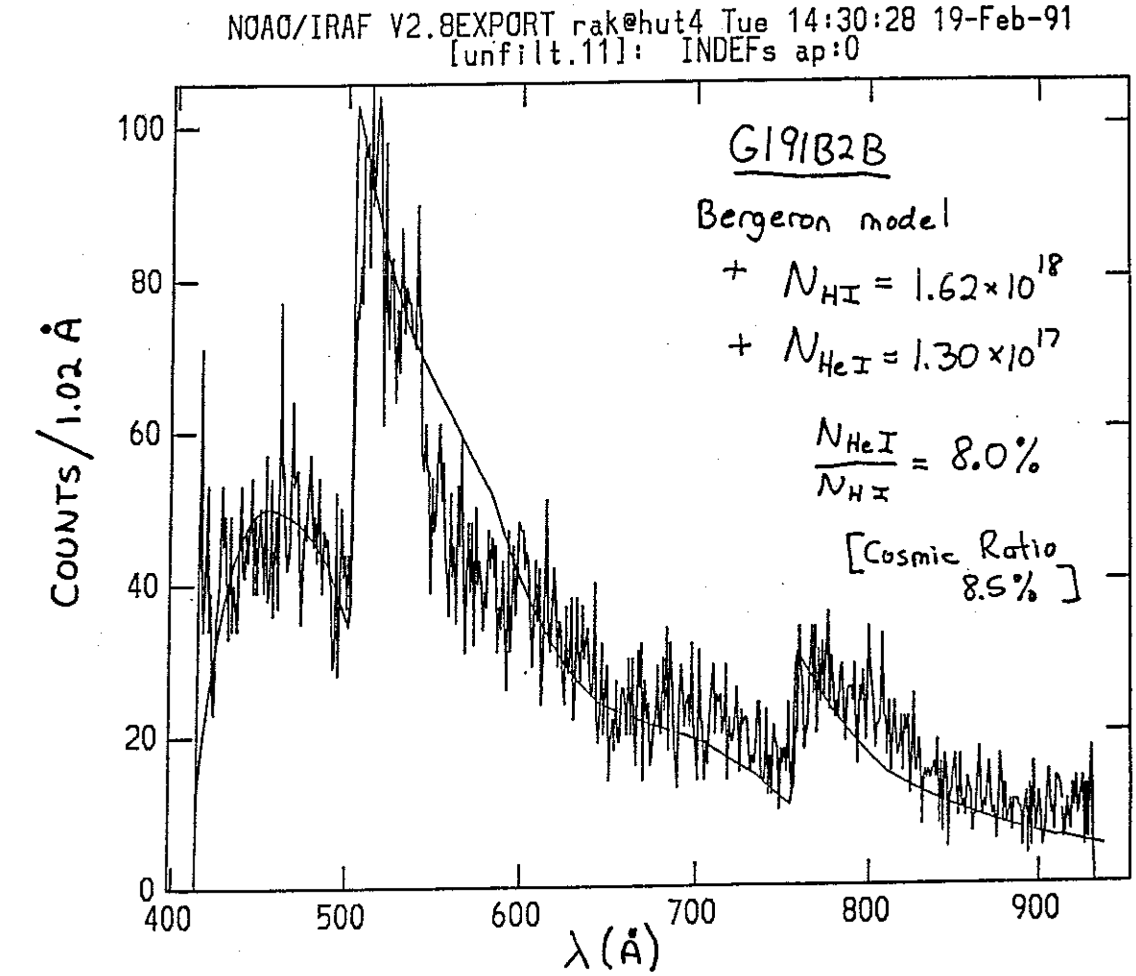
V.1 EUV Observation of the Hot White Dwarf G191-B2B

In addition to its unique capabilities in the primary far ultraviolet bandpass of 912-1850 Å, HUT also provided new capabilities for spectroscopic observations at extreme ultraviolet wavelengths below 912 Å. Using a thin film EUV-transmitting filter to reject far ultraviolet radiation, HUT was able to observe (in higher grating orders) the sub-912 Å radiation from targets hot enough to radiate at these wavelengths and near enough to be visible through the photoelectric opacity of hydrogen and helium in the interstellar medium. During the Astro-1 mission, HUT carried out such EUV observations of two of the three hot white dwarf stars known (from low resolution Voyager observations) to be visible at 500 Å. A highly successful observation was made of the DA white dwarf G191-B2B; a very short but potentially usable observation was made of the DA white dwarf HZ43.

The principal goal of the EUV white dwarf program was to study the physical conditions in the local interstellar medium by measuring the column densities of neutral hydrogen and neutral helium along the line of sight toward these EUV-emitting stars. The neutral hydrogen column is measured by observing the rise in the stellar flux toward shorter EUV wavelengths away from the hydrogen ionization edge at 912 Å; the helium column is measured directly by the strength of the helium ionization edge observed at 504 Å. The magnitude of the neutral column densities indicates the spatial extent of the interstellar cloudlet which surrounds the solar system (which in turn lies in the midst of a low density million degree 100 pc radius bubble). In addition, the ratio of the neutral column densities, when compared with the known cosmic abundances of the elements, reveals the relative ionization of these two principal constituents of the interstellar medium.

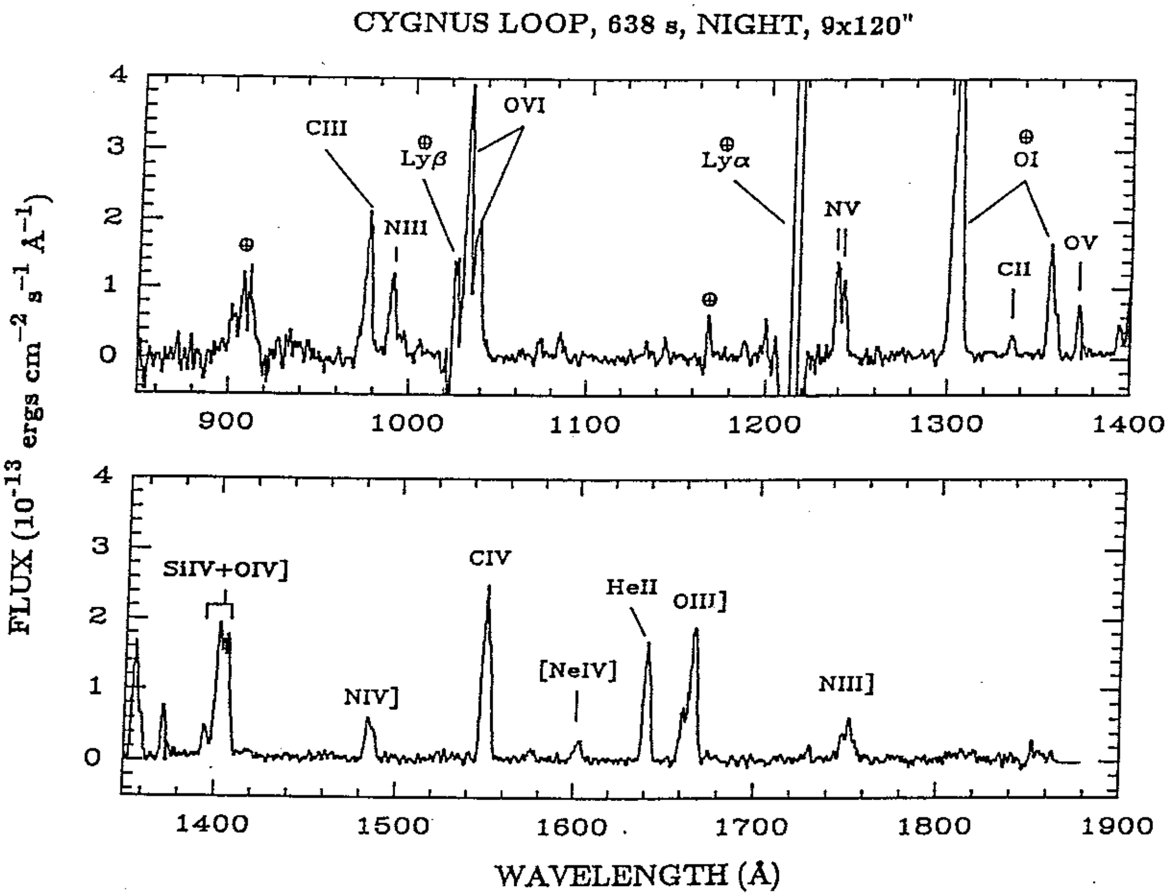
A preliminary analysis of the G191-B2B spectrum indicates that the cloudlet surrounding the sun can extend no more than about five pc in the direction of G191-B2B; more significantly, the neutral hydrogen to helium ratio is seen to be the straight cosmic abundance ratio. This latter result is actually somewhat surprising, as several lines of argument had led to a widespread view that in the local interstellar medium, the hydrogen was substantially ionized, and the helium much less so. Interpreted as evidence for very little ionization of either constituent, our result implies a surprisingly low pressure for the local interstellar medium. Alternatively, if we conclude that the hydrogen and helium are ionized equally, significant constraints are placed on the nature of the ionization source, as various candidate ionizing sources would not ionize the two equally. We intend to explore the ramifications of our measurement in more detail; we will, when the instrument's background and calibration are more precisely characterized, determine these properties of the interstellar medium along the line of sight to HZ43 as well.


NOAO/IRAF V2.8EXPORT rak@hut4 Tue 14:25:03 19-Feb-91
[unfiltnet]: G191B2B 366s ap:0
G191B2B
Higher Orders
Subtracted
COUNTS/0.51 Å
λ(Å)
0
250
500
750
1000
1250
800
1000
1200
1400
1600
1800


NOAO/IRAF V2.8EXPORT rak@hut4 Tue 14:30:28 19-Feb-91
[unfilt.11]: INDEFs ap:0
G191B2B
Bergeron model
+ N_HI = 1.62×10^18
+ N_HeI = 1.30×10^17
N_HeI / N_HI = 8.0%
[Cosmic Ratio 8.5%]
COUNTS/1.02 Å
λ(Å)
0
20
40
60
80
100
400
500
600
700
800
900

V.2 Radiative Filament in the Cygnus Loop

Two positions in the Cygnus Loop were observed by HUT during Astro-1, one corresponding to a nonradiative filament on the northeast X-ray rim of the remnant and the other corresponding to a radiative filament on the eastern edge, but within the bright optical filaments. The spectrum shown in Figure X is a preliminary reduction of a 638 s portion of the radiative filament data from orbital night. Although a "nightglow" spectrum has been subtracted, a number of faint residual airglow lines are still present in the data because the line of sight at this point was looking back across the bright earth limb. A preliminary flux calibration has been applied, as has a correction for interstellar extinction, so the data shown represent a reasonable approximation of the true intrinsic relative line intensities. The strength of O VI $\lambda\lambda$1032,1038 with respect to other high ionization lines such as N V λ1240 and C IV λ1550 is surprisingly high for a radiative filament. C III λ977 and N III λ991 from the remnant are also visible in the sub-Ly α region. Comparison with theoretical shock models such as those of Hartigan, Raymond, and Hartmann (1987, *Ap. J.*, **316**, 323) indicates that the shock velocity must be near 170 km s^{-1} in this radiative filament. This is a significantly higher velocity than has been suggested for other radiative filaments in the Cygnus Loop. Because of the strength of the O VI emission in this filament, the importance of far UV line emission in the evolution of SNRs such as the Cygnus Loop may need to be reassessed. This will be discussed further in an upcoming paper (Blair *et al.* 1991, *Ap. J. Letters*, in preparation).



V.3 The Spectrum of the Planetary Nebulae NGC 1535 from 912-1830 Å

A 1400-second observation of the planetary nebula NGC 1535 was obtained during the Astro-1 flight. Observing time was divided about equally between the bright (m_V=12.2) central star and the nearby nebulosity. The HUT 9" x 116" slit was used and was manually offset by the payload specialist midway during the observation. The resolution was 3.5-4.0 Å.

The observation of the central star shows a bright UV continuum as well as strong nebular emissions of He II (λ1640) and C IV (λ1549). The continuum is consistent with model atmospheres of about 70,000 K and extinction of $E_{(B-V)}$=0.1. Such a high temperature is consistent with a Zanstra temperature of 65,000 K derived from He II (λ4686) but greatly at variance with a similarly derived temperature of 38,000 K using Hβ. One explanation of this discrepancy involves the existence of a stellar wind providing flux not accounted for in the stellar models below the He II (λ228) ionization edge. Strong P-Cygni line profiles at N V (λ1240), O IV (λ1340), O V (λ1370) as well as the strongest, O VI (λ1035), confirm the existence of this wind with a velocity of about 2000 km/s. The existence of such a strong O VI P-Cygni line was predicted by Adam and Köppen (1985)[1] by postulating that the stellar wind was very hot, about 250,000 K. An alternative to the hot wind model is provided by Pauldrach *et al.* (1988)[2] who believe that such P-Cygni profiles of high ionizing states may be produced by a reduced optical depth effect due to the presence of the high velocity stellar wind. A detailed comparison of these two alternative models with the HUT data should permit the confirmation of the hot or cold wind models.

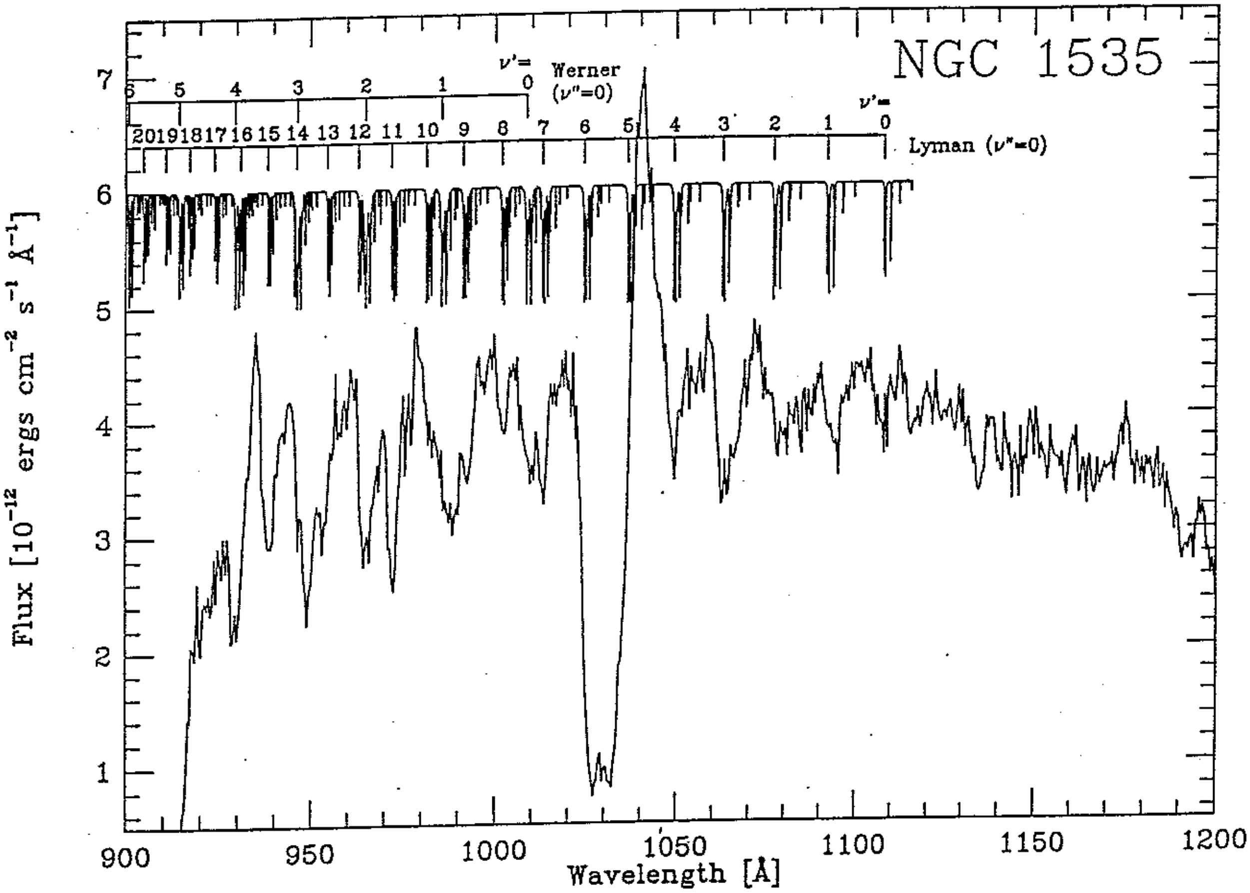
Below 1150 Å, the characteristic absorption pattern of H_2 is clearly seen. Comparison with models indicates a column density of about 4×10^{18}cm^{-2} and a temperature of about 100 K. Currently we are continuing to refine these parameters and trying to determine whether the H_2 is of interstellar origin or is local to the planetary nebula.

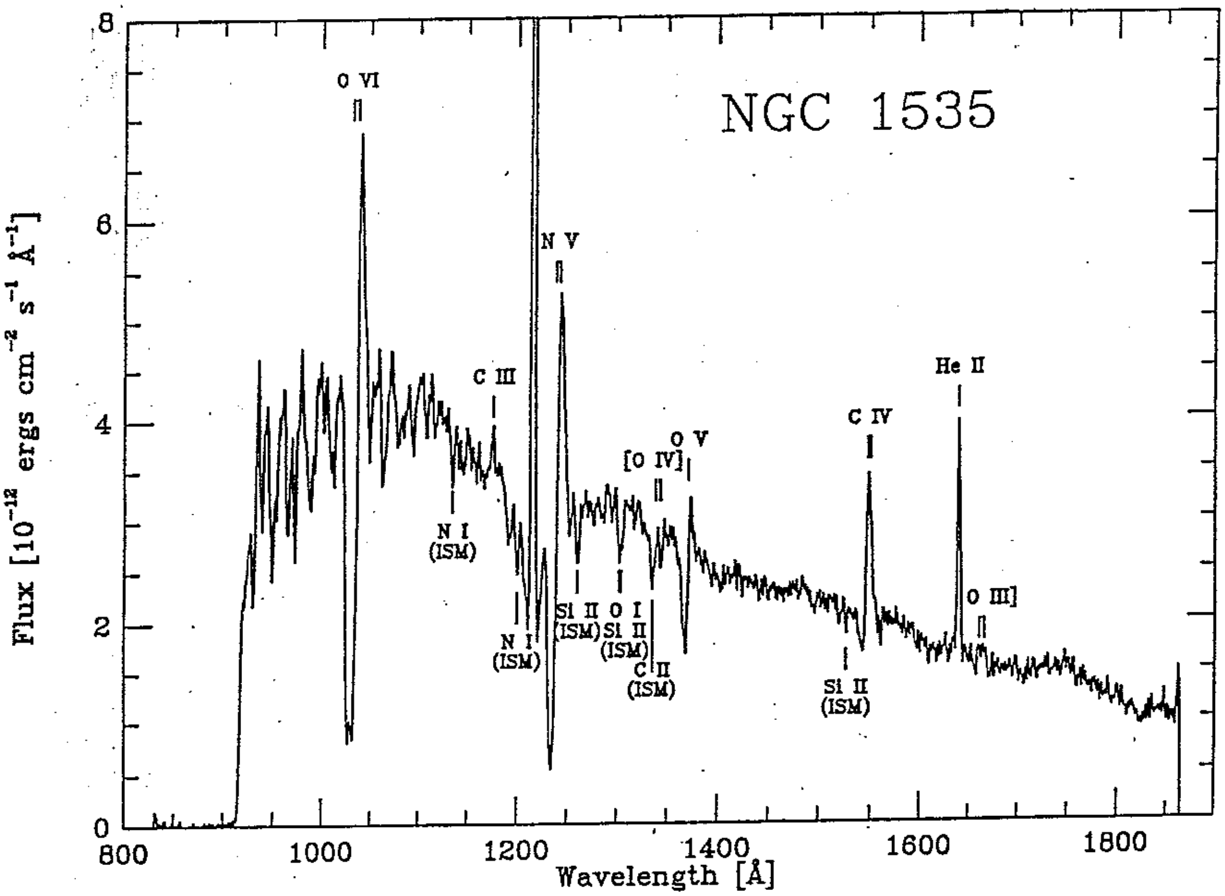
Nebular spectra obtained at the end of the HUT observation show many emission features including He II (λ1640, λ1085), C III (λ1177), C IV (λ1549), N IV (λ1487), O III (λ1663), and below 1000 Å C III (λ977) and N III (λ991). There are in addition several as yet unidentified nebular emission lines. Longward of 1216 Å the expected two photon continuum is also clearly seen. Analysis of these features in conjunction with IUE and optical data will be used to characterize better both the nebular conditions and composition.

References -

[1] Adam, J., and Köppen, J. 1985, *Astr. Ap.*, **142**, 461.

[2] Pauldrach, A., Puls, J., Kudritzki, R., Mendez, R., and Heap, S. 1988, *Astr. Ap.*, **207**, 123.

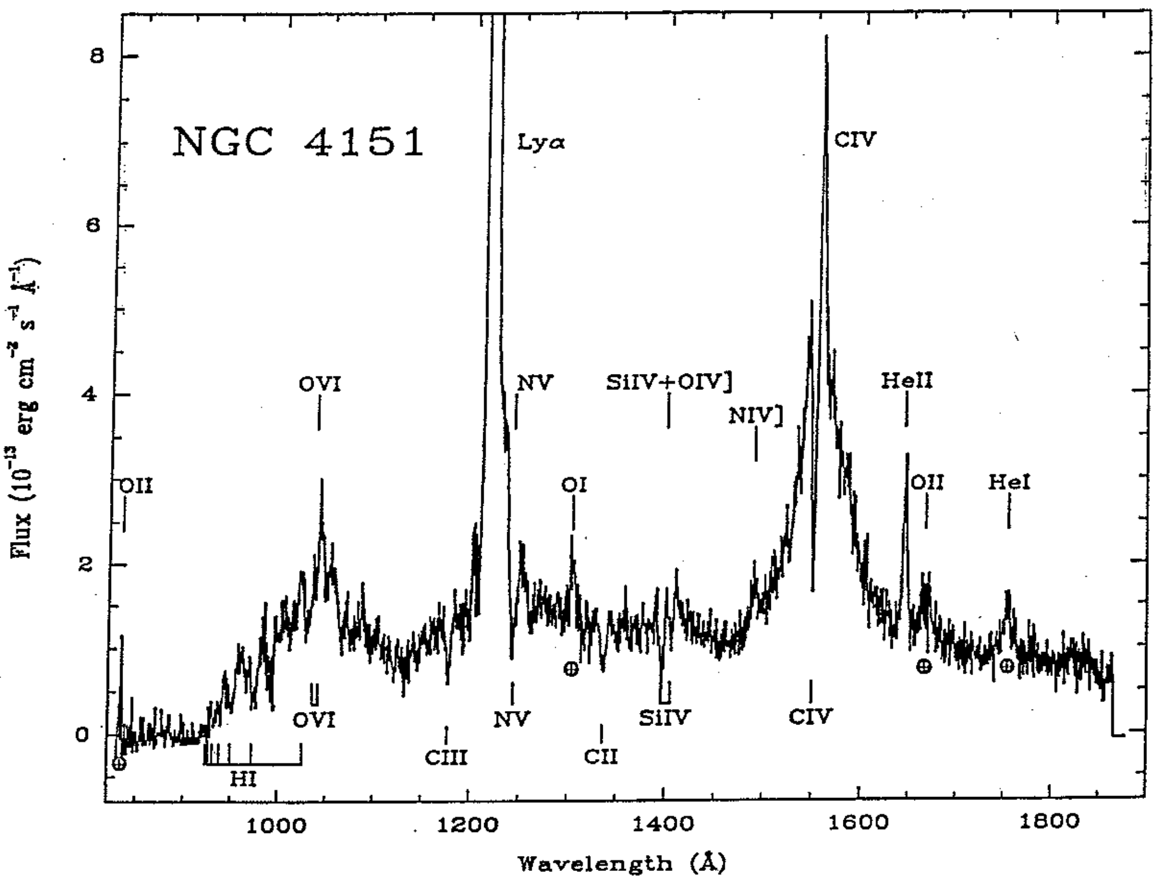

NGC 1535
Werner (ν''=0)
ν'=
Lyman (ν''=0)
Flux [10^{-12} ergs cm^{-2} s^{-1} Å^{-1}]
Wavelength [Å]


NGC 1535
O VI
N V
C III
N I (ISM)
Si II (ISM)
O I
Si II (ISM)
C II (ISM)
[O IV]
O V
C IV
Si II (ISM)
He II
O III]
Flux [10^{-12} ergs cm^{-2} s^{-1} Å^{-1}]
Wavelength [Å]

V.4 NGC 4151 in the Far Ultraviolet

The prototypical Seyfert 1 galaxy NGC 4151 was observed by HUT for ~2200 s on 8 December 1990. Approximately 2/3 of the observation was during the day portion of the orbit. The strongest dayglow lines have been removed from the spectrum shown in the following figure by differencing the night and day portions of the data. Weak airglow features which remain due to O I, O II and He I are marked. Geocoronal Ly α was subtracted empirically using a profile derived from observations through the same aperture of several faint targets with no detected emission in the vicinity of Ly α.

During our observation, NGC 4151 was slightly above the historical mean in continuum flux level ($f_{1450} = 1.6 \times 10^{-13}$ ergs cm^{-2} sec^{-1} $Å^{-1}$) and in the flux of broad C IV λ1549 ($\sim 3 \times 10^{-11}$ ergs cm^{-2} s^{-1}). The spectrum longward in wavelength from Ly α is typical of that observed on many occasions with the *IUE*. Shortward of Ly α, however, the continuum shows a pronounced dip centered on ~1125 Å, and then turns over sharply below 1000 Å. Narrow absorption lines are visible in all the highly ionized metallic species — C IV, Si IV, N V, and O VI. In addition, broad ($\sim$ 2000 km s^{-1}) hydrogen Lyman lines are seen in absorption slightly blue-shifted from the systemic redshift of NGC 4151. The emission line profiles exhibit many differences — C IV is unusually strong and broad with a weak central absorption feature; Si IV, N V, and O VI appear narrower with much stronger absorption components; and He II λ1640 and Ly α are dominated by emission from the narrow line region with little emission at the velocities seen in the C IV profile. From the ratio of narrow He II λ1640 to He II λ1085, we set an upper limit on the reddening of the narrow line region of E_{B-V}<0.14.



VI. More Examples of Data Obtained with HUT

This section intentionally left blank.

VII. Presentations and Papers on HUT Results

This section provides several tables listing all the papers (both written and oral), seminars, colloquia, and public talks on HUT and Astro-1 which are either completed or currently scheduled.

Table VII.1 concerns refereed journal publications. One paper has already been submitted and accepted for publication in *Nature*, and at least 13 other papers are in varying stages of preparation, mostly for *Astrophysical Journal Letters.*

Table VII.2 lists papers presented at various meetings. Four such papers have already been presented to organizations such as the AAS, the Washington Area Astronomers, and the American Physical Society. Some 17 additional papers are currently scheduled for upcoming meetings, including the American Astronomical Society (May), the American Geophysical Union (May), and various meetings of the International Astronomical Union, including the General Assembly (July-August).

Table VII.3 lists seminars and formal departmental colloquia being given on HUT and Astro-1 at various institutions around the country. At least 17 such presentations have already been made, including the astronomy (or physics and astronomy) colloquia at Johns Hopkins, Princeton, University of Washington, Berkeley, and Santa Cruz. At least 2 more seminars and colloquia are scheduled for the period through June 1991.

Finally, Table VII.4 lists talks and presentations made to a variety of non-specialists in astronomy. At least 23 such talks have already been given, and 4 more are currently scheduled.

TABLE VII.1

Papers Submitted on HUT Results

	Title	Journal	Submission Date	Authors
1.	"A Test of the Decaying Dark Matter Hypothesis Using the Hopkins Ultraviolet Telescope"	*Nature*	31 January 1991 (HUT Team)	Davidsen *et al.*

Papers in Preparation on HUT Results

	Working Title	Journal	Lead Author
1.	"Discovery of a Fast Radiative Shock Wave in the Cygnus Loop Using the Hopkins Ultraviolet Telescope"	*Ap. J. Lett.*	Blair
2.	"The Far UV Spectrum of the Seyfert Galaxy NGC 4151"	*Ap. J. Lett.*	Kriss
3.	"The Cataclysmic Variable Z Cam in Outburst"	*Ap. J. Lett.*	Long
4.	"Coronal Emission from Capella"	*Ap. J.*	Henry
5.	"The Hopkins Ultraviolet Telescope" [Instrument Paper]	*Ap. J. Lett.*	Davidsen
6.	"The UV Spectrum of the Giant Elliptical Galaxy NGC 1399"	*Ap. J. Lett.*	Ferguson
7.	"The Planetary Nebula NGC 1535 and Its Central Star"	*Ap. J. Lett.*	Bowers
8.	"EUV Observations of G191-B2B and the Local Interstellar Medium"	*Ap. J. Lett.*	Kimble
9.	"The Neutral Gas Cloud of Io"	*Ap. J. Lett.*	Durrance
10.	"HUT Spectroscopy of the Io Torus"	*Ap. J. Lett.*	Moos
11.	"UV-Bright Stars in Globular Clusters"	*Ap. J. Lett.*	Dixon
12.	"HUT Observations of Comet Levy (1990c)"	*Ap. J. Lett.*	Feldman
13.	"The Lyman Limit in Quasar 3C 273"	*Ap. J. Lett.*	Davidsen

TABLE VII.2

Papers Presented on HUT Results

	Meeting	Date	Presenter	Title
1.	AAS	17 January 1991	Davidsen *et al.* (HUT Team)	"First Results of the Hopkins Ultraviolet Telescope Aboard the Astro-1 Mission"
2.	Wash. Area Astron.	27 March 1991	Long	"The Hopkins Ultraviolet Telescope: First Results on Cataclysmic Variables"
3.	Wash. Area Astron.	27 March 1991	Kriss	"The Hopkins Ultraviolet Telescope: Neutrino Decay Radiation"
4.	APS (Invited Talk)	22 April 1991	Davidsen	"A New Window on the Universe: Far and Extreme Ultraviolet Spectroscopy with the Hopkins Ultraviolet Telescope"

Papers Scheduled on HUT Results

	Meeting	Date	Presenter	Title
1.	AAS (Invited Talk)	29 May 1991	Davidsen	"Highlights from the Hopkins Ultraviolet Telescope Aboard the Astro-1 Mission"
2.	AAS	29 May 1991	Blair	"Observations of a Bright Radiative Filament in the Cygnus Loop with the Hopkins Ultraviolet Telescope"
3.	AAS	29 May 1991	Kimble	"EUV Observations of G191-B2B and the Local Interstellar Medium"
4.	AAS	29 May 1991	Ferguson	"HUT Spectra of the Hot Stellar Components in the Elliptical Galaxy NGC 1399 and the Bulge of M31"
5.	AAS	29 May 1991	Feldman	"HUT Observations of Comet Levy (1990c)"
6.	AAS	29 May 1991	Moos	"HUT Spectra of the Io Torus"

(continued on next page)

Table VII.2 (cont.)

Papers Scheduled on HUT Results (cont.)

Meeting	Date	Presenter	Title
7. AAS	29 May 1991	Henry	"HUT Observations of the Chromosphere of Capella"
8. AAS	29 May 1991	Kriss	"The Far UV Spectrum of the Seyfert Galaxy NGC 4151"
9. AAS	29 May 1991	Bowers	"Observations of the Planetary Nebula NGC 1535 with the Hopkins Ultraviolet Telescope"
10. AAS	29 May 1991	Dixon	"HUT Observations of UV-Bright Stars in Globular Clusters"
11. AAS	29 May 1991	Long	"Far UV Observations of SS Cyg and U Gem in the Low State with the Hopkins Ultraviolet Telescope"
12. AAS	29 May 1991	Durrance	"HUT Observations of Neutral Sulfur Emissions from Io"
13. AGU	28-31 May 1991	Feldman	"Ultraviolet Spectroscopy of the Terrestrial Airglow from Astro-1 with the Hopkins Ultraviolet Telescope"
14. AGU	28-31 May 1991	Feldman	"HUT Spectroscopy of the Io Torus"
15. Asteroids, Comets and Meteors Meeting	24-28 June 1991	Feldman	"HUT Observations of Carbon Monoxide in Comet Levy (1990c)"
16. IAU Gen'l Assembly XXI	22 July 1991	Davidsen	TBD (Invited Talk)
17. IAU Symp. 149	6 August 1991	Ferguson	"The Spectra of Normal Galaxies in the Far Ultraviolet"

TABLE VII.3

Seminars and Colloquia Presented on HUT Results

	Institution	Date	Presenter	Title
1.	STScI	25 January 1991	Long	"First Results from HUT"
2.	Johns Hopkins University	19 February 1991	Davidsen	"First Results from the Hopkins Ultraviolet Telescope"
3.	Princeton University	26 February 1991	Davidsen	"First Results from the Hopkins Ultraviolet Telescope"
4.	JHU CAS Seminar	26 February 1991	Kimble	"HUT Observations of G191-B2B and the Local Interstellar Medium"
5.	JHU CAS Seminar	26 February 1991	Blair	"Observations of Cygnus Loop with HUT"
6.	JHU CAS Seminar	5 March 1991	Long	"Observation of Cataclysmic Variables with HUT"
7.	U. of Washington	6 March 1991	Davidsen	"First Results from the Hopkins Ultraviolet Telescope"
8.	U. CA, Berkeley	7 March 1991	Davidsen	"First Results from the Hopkins Ultraviolet Telescope"
9.	U. CA, Santa Cruz	8 March 1991	Davidsen	"First Results from the Hopkins Ultraviolet Telescope"
10.	JHU CAS Seminar	12 March 1991	Feldman	"Comet Levy: IUE, HST & HUT"
11.	Johns Hopkins University	14 March 1991	Davidsen	"More New Results from the Hopkins Ultraviolet Telescope"
12.	APL	19 March 1991	Davidsen	"Astro-1: An Adventure in Space and Time"
13.	Boston U.	21 March 1991	Feldman	"Comet Levy: Observations from IUE, HST and HUT"

(continued on next page)

Table VII.3 (cont.)

Seminars and Colloquia Presented on HUT Results (cont.)

	Institution	Date	Presenter	Title
14.	JHU CAS Seminar	26 March 1991	Kriss	"HUT Observations of AGN"
15.	Pennsylvania State U.	28 March 1991	Long	"The Hopkins Ultraviolet Telescope: First Results on Cataclysmic Variables"
16.	Towson State U.	2 April 1991	Long	"The Hopkins Ultraviolet Telescope: First Results on Cataclysmic Variables"
17.	ST AGN Journal Club	25 April 1991	Kriss	"HUT Observations of Seyfert Galaxies and Quasars"

Seminars and Colloquia Scheduled on HUT Results

	Institution	Date	Presenter	Title
1.	Goddard Space Flight Ctr.	9 May 1991	Blair	"The Hopkins Ultraviolet Telescope: First Results on the Cygnus Loop"
2.	STScI	5 June 1991	Long	"The Hopkins Ultraviolet Telescope: First Results on Cataclysmic Variables"

TABLE VII.4

HUT Public Talks Presented

Audience	Date	Presenter	Title
1. JHU Exec. Comm. of the Board of Trustees	14 January 1991	Davidsen	"HUT and Astro-1: An Overview"
2. Fox 45 TV Program	24 January 1991	Blair and Davidsen	"Astro-1 and Astronomy from Space"
3. JHU Space Grant Consortium	12 February 1991	Durrance	"Astro-1: A Space Odyssey"
4. JHU Dept. Phys. & Astron.	14 February 1991	Durrance	"Astro-1: A Space Odyssey"
5. Baltimore JHU Alumni	6 March 1991	Feldman	"An Update on Space Astronomy"
6. JHU Community Conversations	7 March 1991	Durrance	"Astro-1: A Space Odyssey"
7. Havenwood Presbyterian Church	10 March 1991	Durrance	Presentation of Flag
8. JHU Wednesday Noon Series	13 March 1991	Durrance	"Astro-1: A Space Odyssey"
9. Washington JHU Alumni	13 March 1991	Durrance	"Astro-1: A Space Odyssey"
10. JHU Continuing Studies	16 March 1991	Durrance	"Astro-1: A Space Odyssey"
11. Havenwood Presbyterian Church	17 March 1991	Durrance	"Astro-1: A Space Adventure"
12. Lutherville Timonium Cub Scouts	21 March 1991	Durrance	"Astro-1: A Space Adventure"
13. Los Angeles JHU Alumni	27 March 1991	Durrance	"Astro-1: A Space Adventure"
14. Lincoln H.S., Los Angeles	27 March 1991	Durrance	"Astro-1: A Space Adventure"
15. "Eye on Tampa Bay" TV Show, Tampa, FL	1 April 1991	Durrance	30 minute live talk show
16. Tampa Palms Elem. School	8 April 1991	Durrance	"Astro-1: A Space Adventure" and Presentation

(continued on next page)

Table VII.4 (cont.)

HUT Public Talks Presented (cont.)

	Audience	Date	Presenter	Title
17.	City of Tampa	8 April 1991	Durrance	Presentation
18.	H.B. Plant H.S.	8 April 1991	Durrance	"Astro-1: A Space Adventure" and Presentation
19.	MD Science Center	18 April 1991	Durrance	"Astro-1: A Space Odyssey"
20.	92-WSTAR Radio	18 April 1991	Durrance	Interview on Astro-1 and HUT
21.	JHU Board of Trustees	22 April 1991	Davidsen and Durrance	"Success at Last for the Hopkins Ultraviolet Telescope"
21.	U. of CO Alumni	25 April 1991	Durrance	"Astro-1: A Space Odyssey"
22.	JHU Homecoming	27 April 1991	Durrance	"Astro-1: A Space Adventure"

HUT Public Talks Scheduled (cont.)

	Audience	Date	Presenter	Title
1.	JHU Continuing Ed.	4 May 1991	Blair	"Astro-1 and the Hopkins Ultraviolet Telescope: First Results"
2.	JHU Reunion Weekend	1 June 1991	Durrance	"Astro-1: A Space Odyssey"
3.	York Cty Parks Assoc.	15 June 1991	Durrance	"Astro-1: A Space Odyssey"
4.	JHU Alumni College	2-7 July 1991	Durrance	Lectures on Space and Astro-1