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FLIGHT PROGRAM TO STUDY SPACECRAFT/ATMOSPHERIC INTERACTIONS

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Arizona Airglow Experiment (GLO): Flight Program to Study Spacecraft/Atmosphere Interactions

The Arizona Airglow Experiment (GLO) used a Space Shuttle-borne spectrograph and imager suite to study the atmosphere from 60 to 400 km and the *in situ* interactions between the Space Shuttle and the ionosphere. Published reports include data on thruster interactions with the ionosphere, nascent dayglow and night airglow of the atmosphere, and metal atom and ion emissions in the thermosphere.

Two essentially identical GLO instruments were constructed and flew a total of six times on board 5 separate shuttle flights, with real-time ground control from NASA Goddard Space Flight Center in Greenbelt, MD. Each shuttle flight provided a unique set of orbital parameters affecting the ionospheric observations, so a much greater dataset was obtained than would have been possible if the flights had been identical. The experiment returned over 50 gigabytes of hyperspectral data, where spectral and altitude dimensions are recorded directly from the detectors, and distance along flight track is accumulated over time for each orbit.

Flight parameters for each mission are summarized in Table 1, showing the shuttle orbit and atmospheric observations for each GLO. The shuttle orbit alignment is shown in Figure 1. The first GLO flight on STS-53 closely followed the terminator, and provided excellent viewing of the dawn and dusk atmospheres. The remaining GLOs flew orbits that crossed the terminators sharply, providing various combinations of time-of-day and observable latitude. GLO-5 and GLO-6 flew together on STS-85 (see Figure 2), and their views were arranged to provide (i) greater dayglow tangent height coverage than that afforded by a single machine, (ii) different angles through the night airglow atmosphere to provide multiple height resolutions, or (iii) near-stereo viewing to aid in 3-dimensional projections of the atmosphere. For the latter, one GLO viewed typically ahead of the shuttle track and the other viewed behind the track to scan the same patch of ionosphere from two angles with only a short time difference. The STS-85 end-of-mission summary is included as Appendix 1.

Table 1. GLO Flight Parameters

GLO-	1	2	3	4	5 & 6
STS-	53	63	69	74	85
Orbital Inclination	57°	51°	28°	51°	57°
Lat at Local Noon	57°N	48°S	10°N	43°N	45°N
Dates on Orbit	2-9 Dec 92	3-11 Feb 95	7-18 Sep 95	12-20 Nov 95	7-19 Aug 97
Limb View Hours	30	50	120	50	>300
Sunlit L. V. Hours	25	30	70	40	200
Fractional moon	0.56-0.99	0.17-0.86	0.97-0.31	0.73-0.04	0.25-1.0
A_p Index	2-12	2-30	3-39	3-10	5-16
F10.7 solar flux (10^{-22} W/cm^{2}Hz)	112-116	79-84	68-72	71-75	76-84
Tangent Height km	80-330	80-400	80-400	80-400	80-300
Spectrograph Slit	Parallel	--- Parallel Night, Vertical Day ---			
Data Focus	Terminator	Near Global	Equatorial	Near Global	Near Global

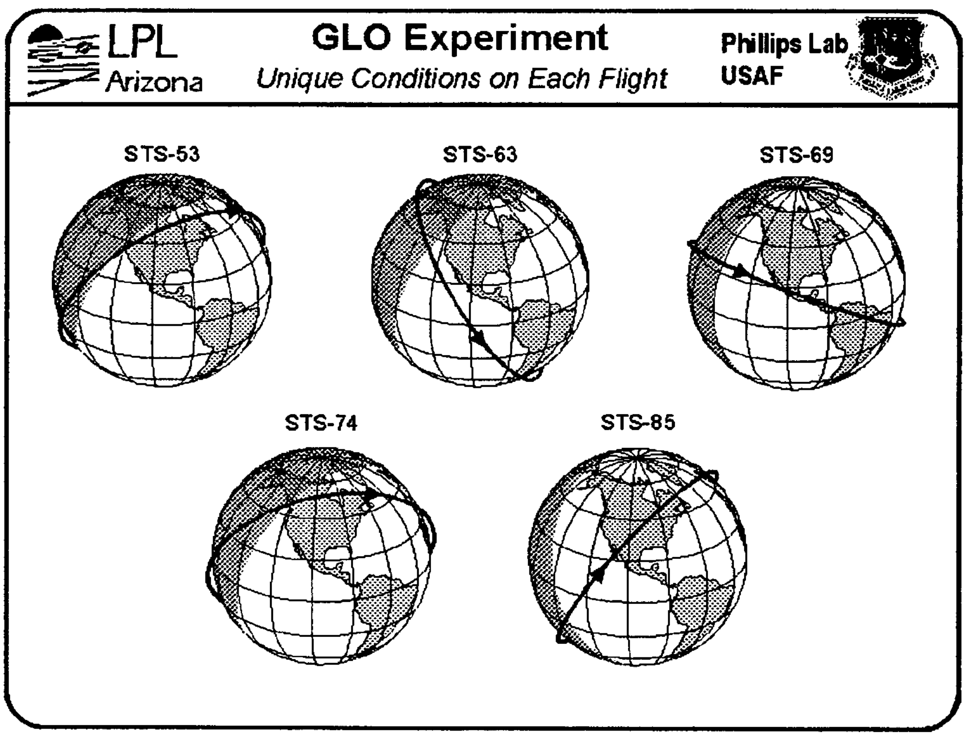

Figure 1. Orbit tracks showing latitudinal extent and relation to terminator for the five Space Shuttle missions.

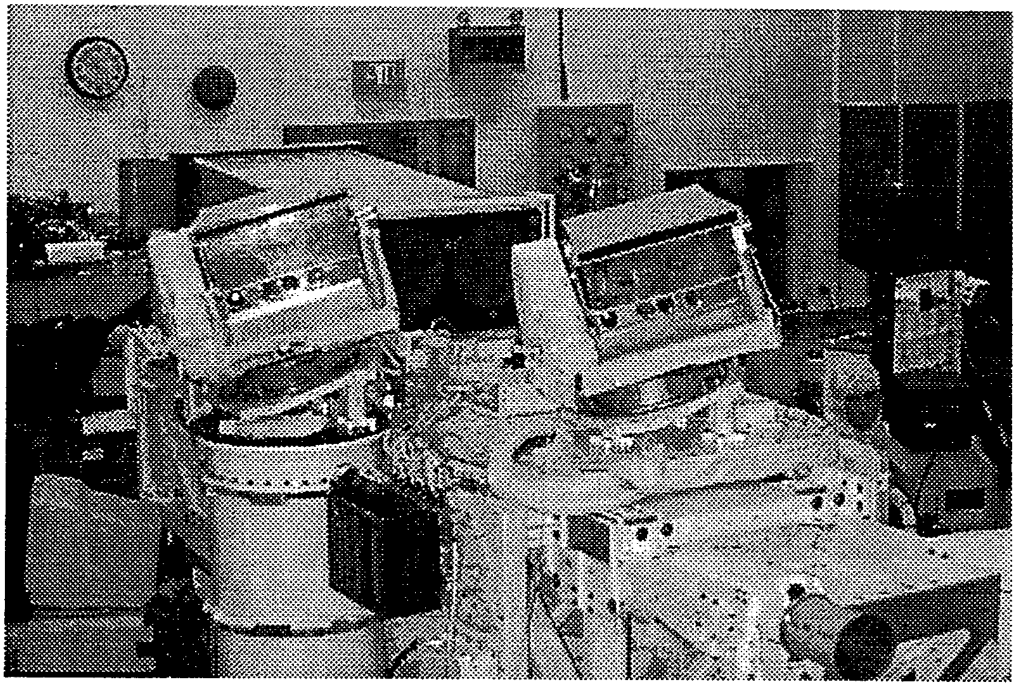

Figure 2. GLO-5 and GLO-6 being integrated onto the IEH2 Hitchhiker bridge in preparation for the STS-85 flight.

Data analysis efforts included the development of the SIBYL code to manipulate GLO data, evaluation of thruster-atmosphere interactions, identification of atmospheric morphology, and validation/verification of atmospheric compensation codes. The latter work tested codes, which were developed by the Air Force Research Laboratory and its contractors using Modtran4 atmospheric simulations to remove the effects of atmospheric components and scattering from the measured radiance in hyperspectral data. The resulting reflectance spectral cubes are then available for use as inputs to AFRL data categorization routines.

Ground-based observation of the ionosphere was also performed during RF-heater excitation experiments. A prototype dual-spectrograph system was assembled to demonstrate the importance of full visible range spectral observations during ionospheric excitation experiments, such as those planned for the Air Force HAARP site in Gakona, AK. The prototype was fielded during the January 1998 RF-heater campaign at Arecibo, PR, and returned positive identification of molecular bands during ionospheric excitation events. These molecular bands had not been previously predicted by the ionospheric heating community.

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Appendix 1:

STS-85

THE ARIZONA AIRGLOW EXPERIMENT

GLO-5 AND GLO-6

END-OF-MISSION REPORT

SUBMITTED BY: Lyle Broadfoot, P.I.
University of Arizona

The science operations of the GLO-5 and GLO-6 experiments on board STS-85 have been a spectacular success! The two GLO instruments performed spectral and imagery measurements on several optical data targets:

Target	# orbits	Comment
ionospheric dayglow	73	43 in "preferred" attitude
ionospheric night airglow	68	all in good attitudes
Aurora Australis	12	some ground-to-deep-space scans
planets, stars (calibration data)	20	pointing/detector response checks
Perseid meteor shower metals	68	data set in night airglow
Hale-Bopp comet	5	
cometary OH	3	
space vehicle glow	2	
OMS engine firings	2	2 events at altitude change
"Near-stereo" viewing	20	1 at 90° others at 40° angle
SEH, CRISTA coordinated scans	30	

Both GLO instruments performed flawlessly, with better-than-expected thermal responses and no serious anomalies. GLO observations occurred in all of the shuttle's routine attitudes, and a total of 25 gigabytes of ITM (Ionosphere, Thermosphere, Mesosphere) data were recorded, rivaling the total for GLO-2, -3, and -4 on STS-63, -69, and -74 in 1995. Lessons learned from, and instrument upgrades since, those flights significantly improved both the operation of and scientific return from the instruments.

The GLO instruments are essentially identical imaging spectrographs. Each contains a spectrograph suite covering 120 - 930 nm in several steps, using Intensified Charge Coupled Device (ICCD) detectors. Detector chips are chosen for best sensitivity in each of several wavelength regions. The GLOs also include filtered imagers that are dedicated to monitoring OH, O_2, and O in the airglow. A low-light-level video camera is on-board to assist in pointing the instrument, and all optics are co-aligned and boresighted to a single view-center. On GLO-6, an EUV diode is also mounted to support the SEH solar-viewing experiment.

Dayglow and airglow measurements were performed in two modes: (i) spectrograph slit perpendicular to the earth limb, and (ii) slit near-parallel to the earth limb. The first mode was accessed during -YLV, -XLV, and +XLV attitudes. With the long axis of the spectrograph slit perpendicular to the limb, the GLOs record altitude-resolved optical data. For dayglow measurements, the two GLOs operated with their Fields-Of View (FOV) stacked, to provide continuous coverage from about 100 to 300 km tangent height at the earth limb. For night airglow, one GLO was positioned with its FOV parallel to the limb to provide maximum sensitivity with a narrow height range. The other GLO had its FOV tilted to provide about 40 km of viewing height at the limb, to provide simultaneous coverage of the 70 to 110 km region in which the important airglow features are found. The GLOs each collected 43 orbits of dayglow and 38 orbits of airglow in this mode.

The slit-nearly-parallel mode is the only mode accessible during -ZLV (bay-to-earth) attitudes. Here, the 15° wedges that tilt the scan platforms forward allowed GLO to maintain the 40 km range in tangent heights during the day. Without the wedges, no useful data would have been collected during Day periods in the bay-to-earth attitudes. At night, airglow measurements proceeded as described above for the other attitudes. Each GLO collected 30 orbits of dayglow and 30 orbits of airglow in the bay-to-earth attitudes.

The Southern Aurora produced a superb target during STS-85. On about 8 separate orbits, intense auroral activity was measured from 100 - 300 km altitudes using the normal airglow method. During 4 of the inertial orbit attitudes, the aurora was measured as the earth limb swept through the FOV. On these orbits, the aurora were measured to their upper limits at several hundred kilometers altitudes.

GLO also performed measurements on stars to provide calibration data. Because stars are distant point sources, they are used to verify the co-alignment of each GLO's 12 detectors. Standard stars with well-known spectra, including Vega, Spica, Sirius, and Beta Centauri, are measured by the GLO instruments to provide spectral calibration of the instruments. The many inertial shuttle attitudes provided an excellent range of opportunities to calibrate the GLO instruments and scan platforms.

Because of the fortuitous launch on August 7, *Discovery* was on orbit during the Perseid meteor shower. This annual event lasts for several days, and August 12 is the peak of the ground-observable "shooting stars." Although meteor showers are a small portion of the total mass loading of the upper atmosphere by particles from space, the showers represent intense periods where the daily mass loading greatly exceeds the average. The Perseid meteor shower is expected to increase temporarily the natural metal layers near 90 km altitude by as much as 10 - 20%. The GLO instruments were able to scan this region before, during, and after the shower peak and will report on the average sodium layer density over the course of the mission.

The Hale-Bopp comet is a widely recognized target of opportunity for STS-85. As did several other experiments, the GLO instruments obtained spectra at Hale-Bopp's position during at least 4 orbits. The GLOs also attempted to measure electronically excited hydroxyl (OH) molecules that would be required by-products of "small comets". Post-flight data analysis will determine the scientific value of these data sets.

The GLO program historically has been interested in measuring thruster firings and effluents, as well as looking for the space vehicle glow phenomenon. During STS-85, the orbit adjust burns on Flight Day 11 were observed at multiple angles, looking especially for optical signatures of thruster gases downstream of the burns. Shuttle glow observation experiments were performed during several eclipse periods in the bay-to-earth configuration. GLOs also performed measurements in support of SEH and CRISTA: a solar Extreme UltraViolet diode on GLO-6 monitored solar output, and both GLOs supported CRISTA "Sprites" and thermospheric experiments. For each of these types of experiments, the data sets are small and will require post-mission analysis prior to commenting on their scientific value.

The GLOs also performed the definitive "near-stereo" viewing experiment. On prior GLO flights, only one instrument flew at a time. Although the scientific return from those earlier flights has been outstanding, the ionospheric data has always lacked an important dimension. The earlier data has shown altitude profiles along the shuttle flight track, yielding a 2-dimensional view of any selected spectral feature. With both GLOs on the same flight, we extend these measurements to include the depth dimension by pointing the instruments to view tangent points from different angles with only a short time delay between the measurements. The views were set to nearly 90° separation and viewed common points at 3 minute time delays. This data set will yield 3-dimensional (spatial) data on important atmospheric dynamics, such as the magnesium ion lines near 280 nm, which can be used as tracers for the earth's electric field.

The flight of GLO-5 and GLO-6 on STS-85 has been an absolute success! Both machines were completely nominal in performance. Ionospheric data included over 70 orbits of ionospheric data, dozens of stellar calibration points, and experiments focused on Jupiter, Hale-Bopp, cometary OH, shuttle glow, thruster firings, and coordinated observations with other STS-85 payloads. A key improvement to the instruments was the addition of a filter to remove second-order effects inside the ultraviolet spectrographs. This filter blocked interference from the oxygen 130.4 nm harmonic at 260.8 nm and allowed for GLOs' first positive identification of the strong iron ion emission line at 261.4 nm. Coupled with the magnesium ion lines at 280 nm and the sodium D lines at 589 nm, the iron data will greatly improve the understanding of metal cycling in the ionosphere. All results discussed here are from "quick-look" reduction of quality-control sampled data from each GLO. Far less than 1% of the total data set is available now, with the remainder being eagerly awaited.