THE INTERNATIONAL ULTRAVIOLET EXPLORER (IUE)

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Abstract. The International Ultraviolet Explorer (IUE) was launched into a geosynchronous orbit on 26 January 1978. It is equipped with a 45-cm mirror and spectrographs operating in the far-ultraviolet (1150–2000 Å) and the mid-ultraviolet (1900–3200 Å) wavelength regions. In a low-dispersion mode, the spectral resolution is some 6–7 Å. In a high-dispersion echelle mode, the resolution is about 0.1 Åat the shortest wavelength and about 0.3 Åat the longest. It is a collaborative program among NASA, ESA and the British SERC. The IUE is operated in real time 16 hours a day from NASA Goddard Space Flight Center near Washing ton, D.C. and 8 hours daily from ESA's Villafranca groundstation near Madrid, Spain. By the end of 1989, 1870 papers, using IUE observations, have been published in refereed journals. During the same period, over 1700 different astronomers from all over the world used the IUE for their research.

1. Introduction

The International Ultraviolet Explorer (IUE) was launched on a Delta rocket into an eccentric geosynchronous orbit on 26 January 1978. The IUE is a collaborative project of NASA, ESA and the British SERC (Science and Engineering Research Council). It is operated in real time 16 hours daily from NASA Goddard Space Flight Center in the suburb of Washington, D.C. and 8 hours a day from ESA's Villafranca groundstation near Madrid, Spain. The satellite observatory is equipped with a 45-cm aperture primary mirror and spectrographs operating in the far-ultraviolet (1150–2000 Å) and the mid-ultraviolet (1900–3200 Å) wavelengths. The IUE was originally designed for a 3- to 5-year mission. (Cf. Boggess et al. 1978)

From the outset, the IUE was planned as a guest observer facility. Astronomers from any country in the world may submit their proposals to use the IUE. Users have come to Goddard and Villafranca science operations centers from every continent of the world, with the inevitable exception of the Antarctica. In all, over 1700 different astronomers have come through the first twelve years of its operation. This represents a significant fraction of the astronomers of the world, particularly those in the U.S and Europe.

The total number of scientific papers from IUE observations published in refereed journals came to 1870 at the end of 1989. A list of refereed IUE papers is published from time to time in the IUE Newsletter.

Themes of research with the IUE have encompassed from solar system objects, such as planets, satellites, asteroids and comets, the interstellar and intergalactic media, and all manner of stars, including Cepheids, X-ray binaries, novae and superno vae, to external galaxies, including star burst galaxies, active galactic nuclei and quasars. The brightest star observed was Sirius at −1.4 magnitude and the faintest a 21st magnitude object. (Actually, Venus was observed at −4.0 magnitude

Y. Kondo (ed.), Observatories in Earth Orbit and Beyond, 35–40.

TABLE I
SPACECRAFT

Mass	462 kg
Dimensions	
Length	417 cm
Width	145 cm
Main Body Shape	Octagonal
Orbit	
Semi-Major Axis	42162 km
Perigee	27616 km
Apogee	43953 km
Eccentricity	0.1937
Inclination	29.76 degrees
Mean Orbital Velocity	3.1 km/sec
Data Rates	
Downlink	2249.80 Mhz (S-Band); PCM Split
Phase Uplink	148.98 Mhz (UHF)
Ranging	136/86 Mhz (VHF)
Downlink Data Rates	40–12.5 Kbits/sec (uncoded or convolved)
Science Data Rates	Maximum rates 3 images per hour; 1 image consists of 768 by 768, 8-bit pixels (= picture elements)

but it is not very bright in the ultraviolet and is therefore not suitable for examining the dynamical range.)

2. Scientific Highlights

Highlights of research with the IUE have been reviewed in a multi-authored volume edited by Kondo et al. (1987 and 89) and in a review article by Kondo, Boggess and Maran (1989). The book contains 31 chapters but even that was not enough to cover ade quately the many astronomically significant results from the IUE. The proceedings of several IUE symposia, quoted in the latter article are also excellent sources of information. In the fol lowing, a few selected examples of IUE highlights will be briefly reviewed.

2.1. Galactic Halos

IUE observations of hot stars in the Magellanic Clouds showed absorption due to C II and other neutral or low-ionization atoms and absorption due to C IV and other highly ionized atoms, which were caused by the gas outside the galactic disk. Galactic halo gases were thus discovered. Most of the gas seems to be relatively

TABLE II
INSTRUMENTS

Telescope	
Type	Ritchey-Chretian
Aperture	45 cm
Focal Ratio	f/15
Image Quality	2 arc sec
Spectrograph	
Type	echelle
Wavelength Ranges	
short	1150–2000 Å
long	1900–3200 Å
High Dispersion	resolving power = 10,000 or, 0.1 to 0.3 Å
Low Dispersion	about 7 Å
Apertures	3 arc sec and 10 × 20 arc sec

TABLE III
SPACECRAFT AND INSTRUMENT STATUS AS OF 1 JUNE 1990

Gyroscopes	originally 6* gyros, 2 operational gyros since 1985, 1-gyro control system developed
Slewing	3 reaction wheels in use; 1 back-up never used in orbit
Solar Panels	decreasing output 2–4 % a year
Batteries	2 fully functional batteries
Computers	2 onboard computers 8K standard configuration
Spectrograph Cameras	short wavelength primary – operational (SEC Vidicons) s.w. redundant – non-operational long wavelength primary – operational l.w. redundant – back-up at reduced sensitivity
Fine Error Sensors	FES No. 2 – operational
(or Star-Trackers)	FES No. 1 – operational, back-up

* The IUE was designed to be operated with a minimum of 3 gyro scopes; we started with 3 redundant gyroscopes for a projected 3 to 5 year mission. After the third gyroscope failure, we de veloped a 2-gyro spacecraft control system, which was placed in service after the fourth gyroscope failure in 1985. A 1-gyro control system has since been developed in case it is needed. A zero-gyro control system is a theoretical possibility that may yet be developed.

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cool and exists within several hundred parsecs of the disk. The higher temperature gas exhibits different velocity distribution from that of the cooler gas and its scale height based on C IV observations is several kiloparsecs.

2.2. Mass Loss from Stars

Early ultraviolet observations from rockets and previous satellites showed mass loss primarily from hot stars. The IUE has been used to observe just about all types of stars. The IUE's capability to observe much fainter stars at a high resolu tion has made it possible to extend such observations to all manner of stars; they are effectively all losing matter from its surface and that includes hot white dwarfs with relatively low surface gravity. Such universal mass loss from virtually all kinds of stars will affect the evolutionary processes in those stars and will influence the replenishment of the interstellar media.

2.3. Mass Flow in Binary Stars

Until the advent of the satellite observatories that provided the ultraviolet spectra of interacting binary stars, the exact manner of mass flow in them has been unclear. Since the mass flow is governed by a hydrodynamic or a magnetohydrodynamic processes further complicated by the three- body problem, theoretical models were not entirely adequate in predicting the evolutionary processes in interacting binaries. The IUE has made it possible not only to observe vastly more such binaries but, more importantly, to observe a number of binaries following its orbital phase. As a result, the wholly conservative mass flow idea that had currency in the Sixties through the mid-Seventies was shown to be wrong. According to the IUE data, some of the matter flowing out of one of the two components leaves the binary system while a fraction of the gas is apparently accreted by its companion creating a hot region. Such synoptic observations are also unraveling the physical processes involved in novae and other cataclysmic binaries.

2.4. Comets

The IUE has been used every year to observe a number of periodic comets as well as newly discovered ones. One interest ing example of the latter type was the 1983 comet IRAS-Araki- Alcock, in which strong emission spectral features due to molecu lar sulfur were unexpectedly discovered. The comet's close approach to Earth apparently made their serendipitous detection possible. The sulfur molecular bands, never observed before, have not since been detected in any other comet. The presence of the sulfur molecules is thought to be closely tied to the proc esses in the protosolar system nebula in which comets were formed.

A prime example of periodic comets observed with the IUE was Halley's comet. The IUE was the first telescope to observe the comet from outside the Earth's atmosphere in 1985 and was also the last to do so in August 1986. Based on the OH emission lines observed near the comet's perihelion passage, Halley was dumping water into space at the rate about 10 tons per second. When the tragic accident of Space Shuttle Challenger made the Astro mission to observe the comet impossible, the IUE provided the complementary ultraviolet observations in support of the Halley flyby missions Giotto, Vega 1 and 2, Suisei.

2.5. Supernova 1987A

When the report of the discovery of SN1987A in the Large Magellanic Cloud reached Goddard on February 24, the IUE was the only telescope in the world capable of observing it immediately. When the first exposure was read down by telemetry, the supernova was still so bright in the ultraviolet that the next exposure had to be shortened substantially. It was bright enough for high resolution observations, and the spectra obtained provided first valuable information on the interstellar and intergalactic matter between the solar system and an object in the Large Magellanic Cloud.

The far-ultraviolet flux subsided by three orders of magnitude over the next four days, diminishing effectively to zero in short wavelengths and revealing the spectra of the two relatively faint hot stars in the same direction as the superno va. The in-depth analysis of the pre-supernova image of this area by Walborn et al. (1987) showed that there had actually been three stars present. The analysis of the IUE far-ultraviolet spectrum showing the two remaining stars enabled Sonneborn, Altner and Kirshner (1987) in the U.S. and Gilmozzi et al. (1987) in Europe to establish that it was the blue supergiant star SK-69°202 that exploded as a supernova. It was the first time in history that the progenitor of any supernova had been identified.

It was speculated that the blue supergiant had once been a red supergiant. After shedding its outer atmospheres it had become a blue supergiant. If this interpretation was correct, we should expect the illumination of the ejected envelope from the red supergiant. Emission lines of various ionized atoms, such as the N V lines and the forbidden lines of C III, which became observable in the summer of 1987 reached their peak intensities some four hundred days after the original brightening, placing the location of the gaseous shell previously ejected from the red supergiant at about one light year or less.

2.6. Active Galactic Nuclei

Investigation of the active galactic nuclei took a step forward when it became possible to observe these objects in all wavelengths, from the X-ray to the ultraviolet, optical, infrared to radio wavelengths. Since these objects are variable, unless we obtain simultaneous synoptic observations at all wavelengths, it is impractical to formulate a viable model for the source of its immense energy. The first such observations were made in 1978 for MK 501 with HEAO-1, IUE, the 5-meter Hale Telescope at Palomar Mountain, the 2.5-meter at Mt. Wilson, the 92-meter telescope at Green Bank and the 48- meter telescope at Algonquin.

The latest such observations were made on NGC5548 with the IUE at a 4-day interval over an 8-month period. Some radio, infrared, optical and X-ray observations were also made during this period. These evenly-spaced observations yielded very good fluctuation power density spectra, which were quite steep during this epoch, being roughly proportional to the inverse square of the frequency. The largest amplitude variations were observed in the shortest wavelengths; the spectrum was harder when brighter in agreement with the thermal interpretation of the far ultravio let excess. Variability was much slower than what could be expected from the orbital period of the putative accretion disk. A close synchrony was observed between the ultraviolet and opti cal variations; the optical maximum lagged by about two days or less.

NGC 4151 was also observed synoptically over 62 days at frequent intervals. A prevailing variability timescale of 23 days was observed. The ultraviolet flux changes were as much as by a factor of 3.5, with doubling times of about 7 days and halving times of some 12 days. The shapes of the light curves were unusual.

3. Concluding Remarks

The IUE satellite has uniquely important roles to play in the era of new space missions such as the Hubble Space Telescope and ROSAT in addition to its many versatile normal roles as a guest observer facility. It is the only observatory currently operating in space suitable for systematic observations of the variabilities in astrophysically important objects, such as active galactic nuclei and novae. Its flexibility for scheduling makes it an essential component in any coordinated multi-wave length observing campaign requiring ultraviolet data.

The prospects for its continued operation over the next few years are good, thanks to the dedicated efforts of the Resi dent Astronomers, Telescope Operators, spacecraft support engi neers, especially the guidance and control system engineers at Goddard, and numerous other support personnel.

Processing of the spectra for the IUE Final Data Archive, in which its already good quality will be optimized, is scheduled to start in early 1991. This will further enhance the value of the IUE archive that contained more than 70,000 spectra in early 1990.

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