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The IUE Archives delivered to the World Scientific Community

An advanced data archive and distribution system for astrophysics

Ultraviolet Radiation

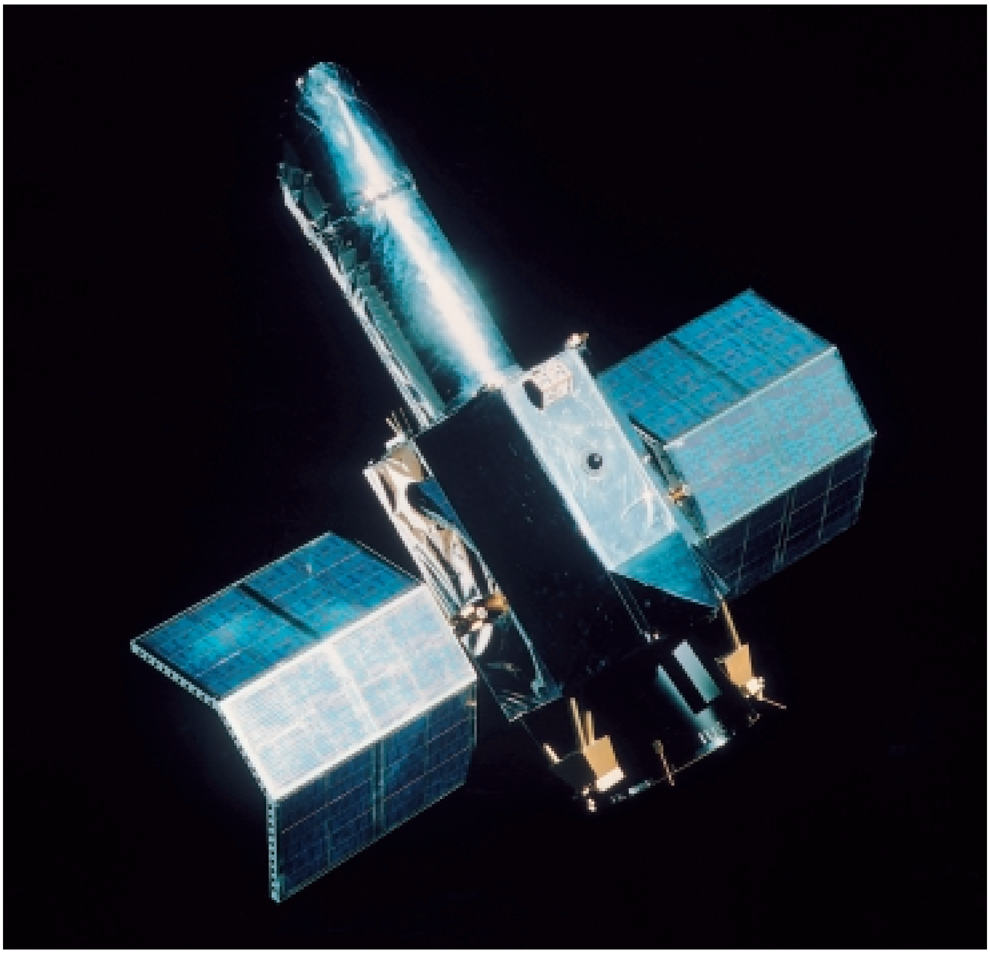
Ultraviolet light, or radiation, cannot be detected by the human eye, but is extremely harmful for the human skin. Luckily, the Earth's ozone layer, which lies between 15 and 40 km above the Earth's surface, protects us from it. This protection is, however, a disadvantage for astronomers. Because most ultraviolet (UV) light cannot reach the ground, the wealth of information that it contains about astronomical objects in the heavens cannot reach ground-based telescopes either. Therefore, only when UV telescopes were placed above the Earth's atmosphere could the ultraviolet Universe be studied for the first time.

Different kinds of light (electromagnetic radiation at different wavelengths) carry different sorts of information about the astronomical objects. Although all objects emit light at all wavelengths, their emissions peak at different wavelengths depending on such features as their temperature or the degree of ionisation of the atomic elements. Cool material (from –100 to about 700 deg C), for instance, emits mostly at infrared wavelengths and hence is best observed with infrared telescopes. Sources at temperatures from 800 to 10 000 deg C peak in the optical domain – the kind of light that the human eye can see – and thus can be observed with optical telescopes. Typical temperatures for the ultraviolet range between 10 000 to 100 000 deg C. Ultraviolet-bright sources are therefore hot stars, accretion disks and, in general, violent shocks in the Universe. The X-ray and gamma-ray domain extends to even more energetic objects.

Thanks to the study of the ultraviolet Universe, astronomers now have a different and more complete view of the Solar System and of the space between stars and galaxies. They have been able to delve into the surroundings of black holes, and to understand phenomena such as supernovae and novae explosions much better than ever before. But they also know that the Universe's UV show has only just begun !

Facts about the IUE Project

LIFETIME IN ORBIT:	18.7 years, uninterrupted until September 1996
ORBIT:	Geosynchronous, 32 000 km x 52 000 km
OPERATIONS:	Two observatories (VILSPA in Spain; GSFC in USA)
TELESCOPE:	45 cm, f/15 Ritchey-Chretien Cassegrain
LAUNCH:	Delta rocket on 26 January 1978 from Cape Canaveral (671 kg)
SCIENCE INSTRUMENTS:	2 spectrographs for the UV; imager for fine stabilisation
	2 resolutions at 18 km/s and 800 km/s
DATA COLLECTED:	110 033 spectra of 11 054 different objects extending over a brightness range of 10 billion, including comets, planets, stars, galaxies, and quasars.
SPECIAL CHARACTERISTICS OF THE MISSION:	
	UV observations outside the Earth's atmosphere
	Analogous to ground-based observatories
	Exceptionally short responses for special phenomena (1 hour)
	Heavily used data-archive from start of mission
UTILISATION OF DATA:	
	Five spectra continue to be retrieved each hour
	3585 publications in the professional refereed literature use data from IUE
	More than 500 PhD theses have used data from IUE



The IUE spacecraft in orbital configuration with its hexagonal fixed solar panels fully deployed. The skewed front end of the telescope prevented direct light from the Sun and Earth from entering the scientific instrumentation

The IUE Satellite

The International Ultraviolet Explorer (IUE) was the first space observatory ever launched. Although some earlier rocket flights and satellite missions – TD-1 from ESA, Copernicus from NASA and the ANS mission from NASA and SRON – had already shown that the detection of UV radiation would provide valuable new information, IUE was the first mission that could be operated as a true space facility for the whole astronomical community. It was IUE that marked the real beginning of UV astronomy, and in so doing it also helped to make astro-physicists aware of the great advantages of pursuing science in space.

IUE also holds the record for the longest lifetime of any space observatory to date. An ESA/NASA/UK project, it remained operational until September 1996, more than 13 years longer than originally planned. A team of 50 astronomers and engineers operated it from ESA's Satellite Tracking Station in Villafranca, near Madrid (Spain) and NASA's Goddard Space Flight Center in Maryland (USA). More than 2000 investigators made observations, with the possibility – rare for space missions – to react quickly to unfolding astronomical events and change the mission observation plans accordingly. IUE took more than 110 000 spectra of 11 000 different objects, each of which has already been used at least six times by the astronomical community.

INES – IUE's Legacy for the Astronomy of the Future

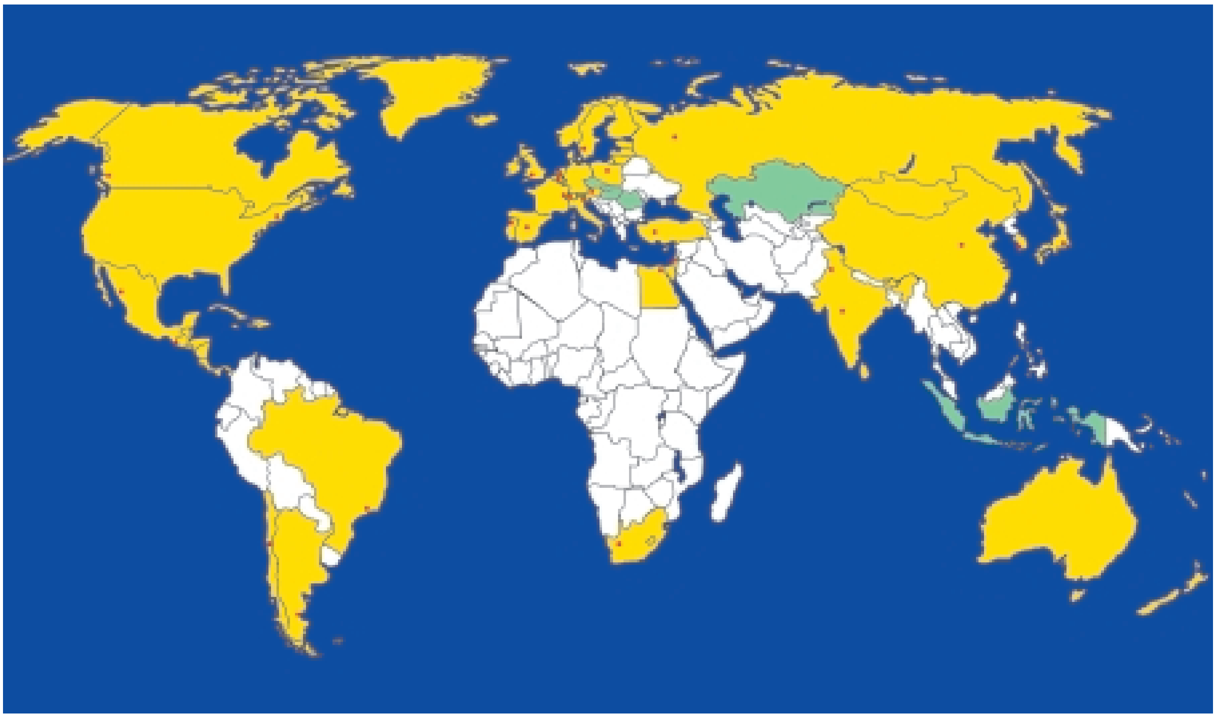
The IUE archie was the first astronomical data archive accessible on line – back in the days when the World Wide Web didn't even exist – and it now stores almost two decades' worth of UV astronomy: more than 110 000 spectra from 11 000 objects. Could IUE have left a better legacy? To allow this gold-mine of discoveries to be fully exploited in the future, ESA has created INES, a system to make IUE data accessible all over the World.

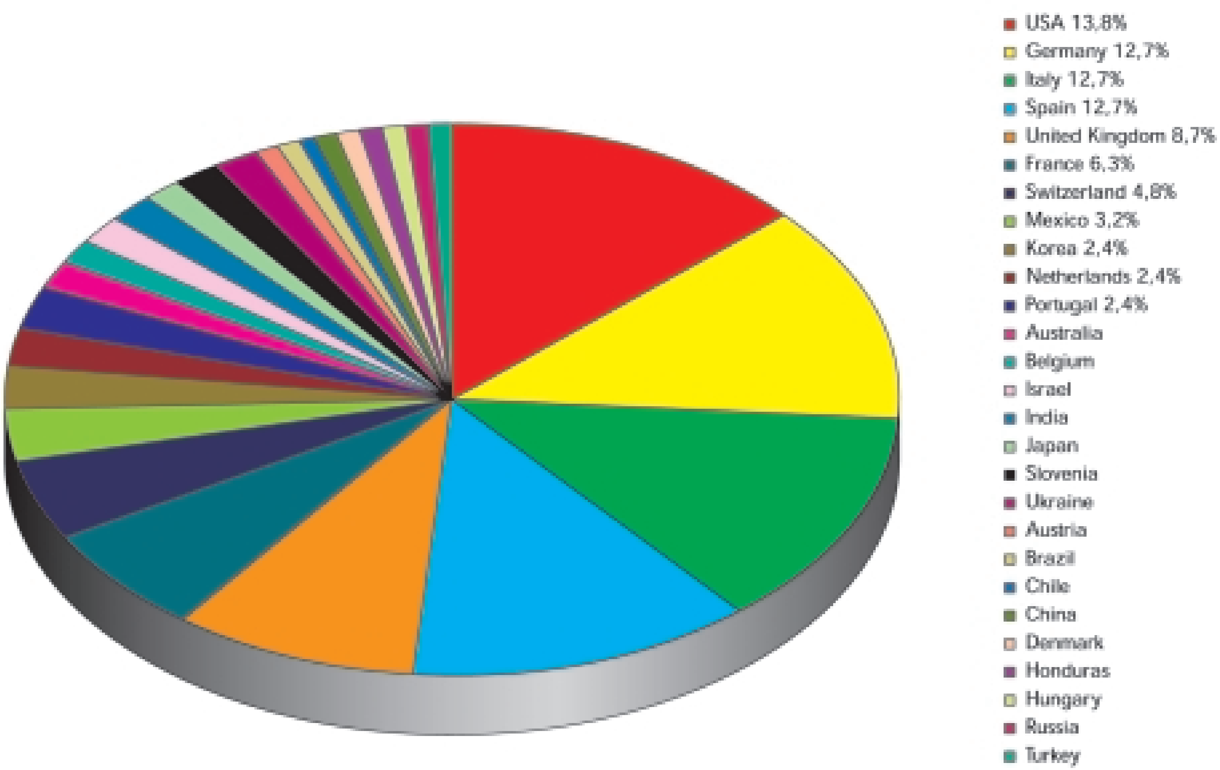
The INES (IUE Newly Extracted Spectra) System is a complete astronomical archive and data-distribution system. Its production and release to the community represents the final activity by ESA in the context of the IUE project.

Archives are essential for all space projects. They contain information based on observations that in most cases cannot be repeated, and are an excellent tool for the study of variable phenomena. The data acquisition rate of a mission is usually too fast for the community to digest instantaneously. Archives allow to re-use many times previously acquired astronomical data for different scientific purposes. Moreover, for many didactic purposes archives are a precious source of high quality data that have never before been available to students.

INES contains the complete data set obtained in 18.7 years of ultraviolet spectroscopy from space with the IUE satellite. All data are in a format that allows direct scientific analysis without the need for specialised data reduction. With the release of INES, a quarter of a century in which the IUE project has played a major role in astrophysics comes to an end.

This map shows the broad distribution of the INES system for scientific access to ultraviolet spectra. The countries in yellow are active INES users, with the locations of the National Host institutes marked by red dots. Those in green have no National Hosts, but local scientists are supported by the Principal Centre at LAEFF





Geographical distribution of INES users in 1999

Since INES is a unique historical reference archive, a special effort has been made to:

- ensure easy access to and use of the data – the archive distribution system has been designed with an up-to-date configuration, suitable for the tools available at most research institutes, universities and schools around the World
- limit the need for specialised project knowledge or expertise to be able to use the data effectively.
- organise the data in such a way that further innovations can be easily implemented on top of the INES system, without affecting its native functionality
- minimise maintenance costs associated with the archival support.

Throughout the IUE project's history, special attention has been paid to the distribution of the observations to the scientific community at large. The expertise acquired with the first on-line astronomical data archive, ULDA, implemented as early as 1985 by the ESA/IUE Project, has been used in the design of INES

The distribution system is structured into three levels:

- a Principal Centre at the LAEFF/INTA, at ESA's Villafranca station near Madrid, with a data mirror at the Canadian Data Center CADC in Victoria, Canada
- currently 20 National Hosts, and
- an unlimited number of end-users.

The Principal Centre contains the complete database and is the core of the distribution system. It provides access to information not available at the National Hosts. It is also intended to maintain and develop the system in co-ordination with the worldwide community of scientists. The National Hosts provide easy local access to the main archive, of which they carry a subset. Requests to retrieve spectra are automatically resolved locally or forwarded to the Principal Centre.

The whole process of data retrieval is fully automated and totally transparent to the end user. The availability of a significant number of National Hosts, plus the Principal Centre with its mirror site in Canada, avoids local connectivity problems and thereby helps to guarantee uninterrupted data availability.

Science with IUE

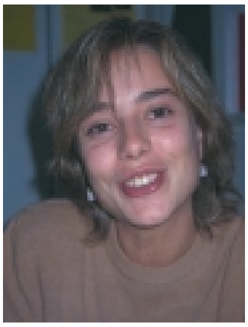
From Jovian Auroras to Black Holes

IUE entered and left astronomy observing the same object – the very bright star Capella, in the Auriga constellation – but with a time-lapse of 18.7 years in between. For all of that time it was the World's ultraviolet 'eye in the sky', a 'periscope' providing access to a Universe that remains inaccessible to all of us who live beneath the Earth's life-sustaining atmosphere. Astronomers could not have dreamt of a better facility. IUE, the maximum theoretical lifetime of which was originally no more than 5 years, has made key contributions in so many fields of astronomy. Its discoveries, whether closer to home in the Solar System or in far distant extragalactic space, have often been the seeds for new fields of study and research and new generations of astronomers.

For instance, IUE provided the first systematic study of how a comet's activity varies during its journey through the Solar System. IUE also first detected the existence of auroras on Jupiter, and studied how they change with respect to the 11-year-long solar cycle. Still further afield, IUE allowed the first direct detection of the halo in our galaxy – a great amount of very hot matter on the outskirts of the Milky Way – and measured the size of a black hole in the core of an active galaxy. The only high-redshift quasar to be studied in the UV was also discovered with IUE.

As the first space observatory built and the first to be located at more than 30 000 km from Earth, IUE could be operated as easily as a ground-based telescope. Its orbit and operational characteristics made it flexible enough to react quickly to astronomical events, as well as to perform long and uninterrupted observations of the same object. As a result, supernovae could be observed for the first time just a few hours after the initial explosion, and objects that vary on time scales of days, such as the stellar winds in hot stars, are now much better understood.

IUE was also the first space observatory to participate in multi-wavelength observations, both with other astronomical satellites and with ground-based telescopes. Above all, however, the satellite's exceptionally long lifetime has allowed astronomers to witness events that they never thought they would, such as the metamorphosis of a very old star to a beautiful planetary nebula, a central star surrounded by illuminated gas and dust. By analysing all of IUE's observations of the old star, the researchers were able to track the spectacular changes that it had suffered in less than two decades.



Dr Eva Verdugo, INSA
ISO Archive Analyst.
'Studying and using the data in the IUE Archive to make my PhD thesis has been wonderful training for working with the instruments of the future'.

Dr Willem Wamsteker, ESA
IUE Project Scientist
'IUE set the standards against which future projects will be judged; being involved in it has been both a privilege and a very exciting experience'.

Prof. Mudumba Parthasarathy, IIA
Scientist ISRO, India
'For scientists in countries like India, the availability of the IUE data through INES has been a major boost to making UV astronomy data accessible to us. No other system makes it so easy to use such data for new scientific discoveries'.

Prof. Klaas S. de Boer, University of Bonn
Director Sternwarte, Germany
'Having worked with the IUE and its data from the very beginning, I find it remarkable how the project has maintained a dynamic structure through until the end. ESA's delivery of INES represents a magnificent finale to the quarter-century-long IUE Project'.

Exposing the progenitor of a supernova

Thanks to the rapid response of IUE through the Target of Opportunity programme, the supernova 1987A (SN 1987A) was observed just a few hours after its discovery. The eight years of IUE observations of this object have allowed the compilation of the most complete data set ever showing the evolution of a supernova in the ultraviolet. Figure 3 shows the development of the UV spectrum of SN 1987A during the first month. It can be seen that the flux decreased by a factor 1000 in just the first three days.

In addition to the studies of SN 1987A itself, showing for instance the existence of materials in the photosphere moving at velocities of up to 40 000 km/s, it is worth noting that IUE data made it possible to pinpoint the star that had suffered the explosion: the blue supergiant Sk-69 202. It was the first time that a progenitor of a supernova had been exposed, and challenged current theories of stellar evolution.

The circumstellar ring structure around the supernova, seen in direct images with the Hubble Space Telescope only in 1991, had already been detected with IUE just a few months after the outburst. Also, observations of the UV echoes, originating when interstellar dust located close to the line-of-sight between SN 1987A and the observer, is illuminated by the explosion, have allowed the spectrum of the supernova at the time of the explosion to be reconstructed, indicating extremely high temperatures.

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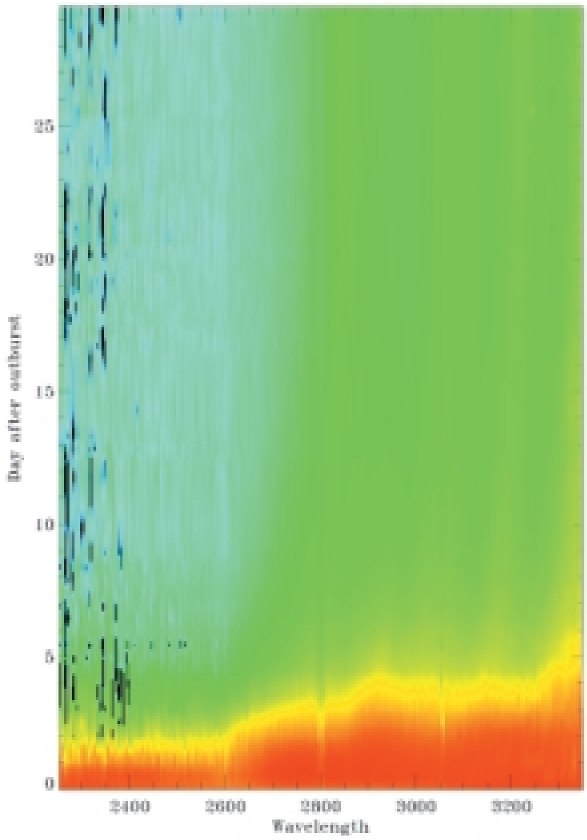

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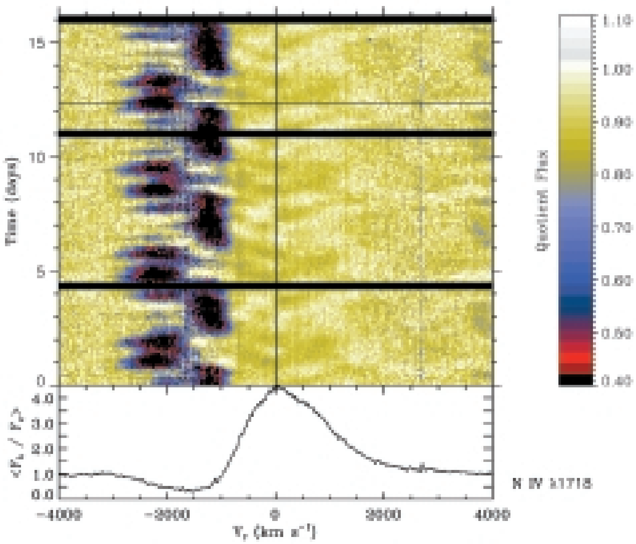

Hot stellar winds

Hot stars are characterised by strong winds, which eject huge amounts of mass at several thousands of kilometres per second. This mass loss, which occurs on time scales varying from hours to days, has a tremendous impact on the life of the star. Non-stop observations taken over several days are essential to understand the mechanisms powering these winds. The example in Figure 4 corresponds to a 'Wolf Rayet' star, an evolved massive hot star with even higher velocities and mass-loss rates.

The diagram shows how the gas velocity, as derived from the displacement of the dark absorption lines, varies periodically. It does so on two time scales of approximately one and four days, reaching peak values of 3000 and 1500 km/s, respectively. The co-existence of these two periodicities reflects the complex interaction phenomena occurring in the outermost regions of these stars.

Chasing a comet

Observations of comets have been one of the most challenging tasks with IUE, due to the intrinsic difficulty of tracking such fast-moving objects. However, comets were observed with IUE from the very beginning of the mission. IUE was able, for instance, to discover new molecules never seen before in the nuclei of comets and, most importantly, it was often able to follow these objects all along their path from very far away until their closest approach to the Sun. This allowed astronomers to analyse for the first time the changes in the comet's water-vapour production as it gets heated up more and more by the Sun's ultraviolet radiation. Figure 5 shows how the emission due to OH radicals produced by the decomposition of water increases as comet P/d'Arrest approaches the Sun. From the analysis of this emission, we can estimate the comet's water loss, which is about 20 l/s when it is 300 million km from the Sun, increasing to 1200 l/s when it is 100 million km closer. When at its closest to the Sun, the comet loses an amount of water equal to that in an Olympic-sized swimming pool every 30 minutes.

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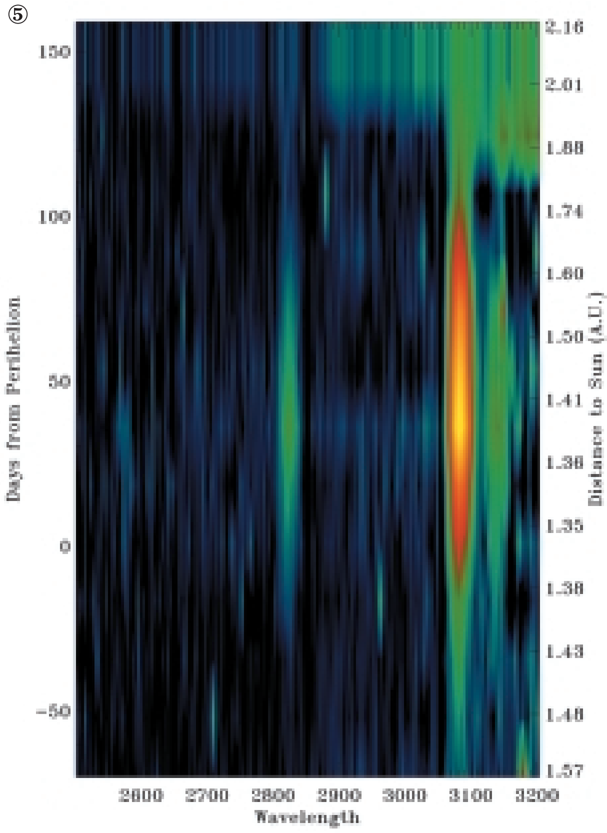

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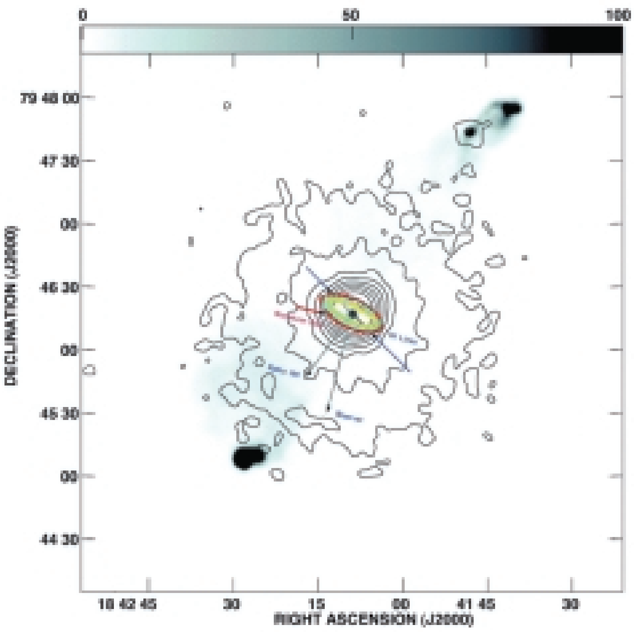
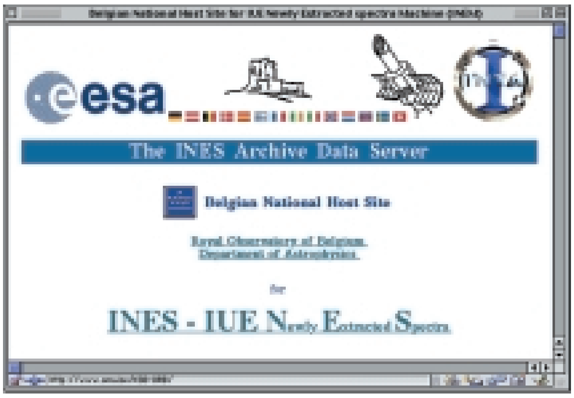
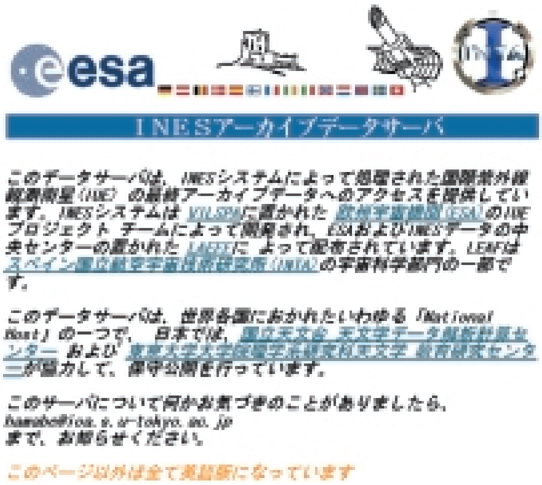


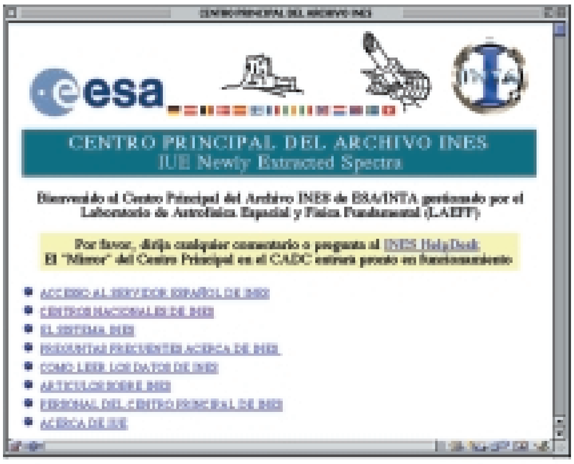
Feeding a black hole

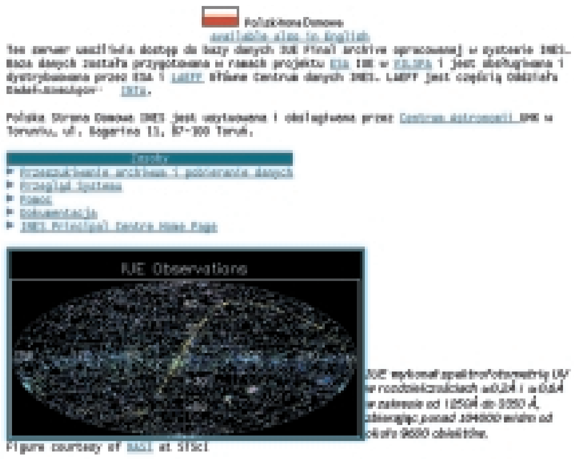
To explain eruptions seen in galaxies, theorists blamed giant black holes. Observations tallied with, but did not prove, the idea that a black hole 'eats' gas from a flat, incandescent 'dinner plate' surrounding it, called an 'accretion disk'. In 1997, these conjectures became reality: it was announced that the accretion disk in galaxy 3C390.3 was one-fifth of a light-year across, and 1500 times wider than the black hole at its centre.

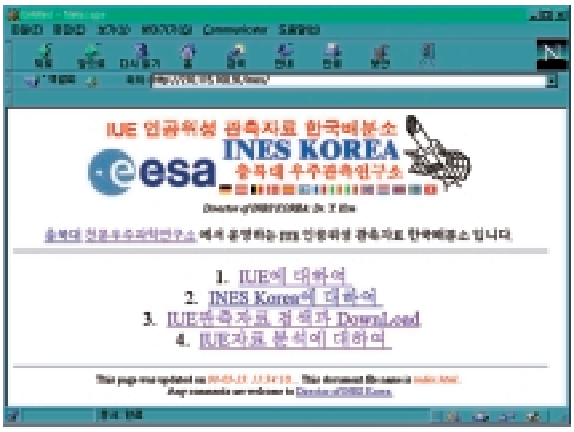
IUE examined that galaxy 39 times over a 14-year period. The scientists also consulted observations by five X-ray satellites. Whenever the black hole consumed a larger morsel than usual the galaxy flared up, but light took more than a month to reach the edge of the accretion disk. This delay served to measure the width of the disk. By studying the motions of the gas, astronomers also calculated the fate of an unlucky star captured by the hole. Shredded by the intense gravity, its gas would swirl twice around the black hole before disappearing into its maw after 150 years.

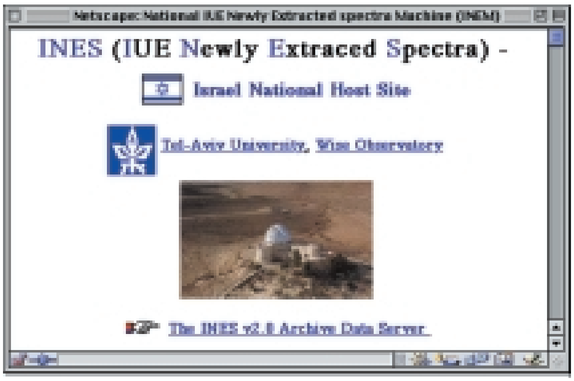












Translation: *The original text of this brochure is in English. The translations have kindly been provided by the National Host Managers.*

Summary information of INES National Host Institutes and URL addresses

Argentina: Observatorio Astronómico, Univ. Nacional de La Plata, Buenos Aires	*http://www.fcaglp.unlp.edu.ar/
Austria: Kuffner-Sternwarte, Vienna	http://www.kuffner.ac.at/ines/
Belgium: Royal Observatory of Belgium, Brussels	http://ines.oma.be/
Brazil : Instituto Astronomico e Geofisico, Sao	http://ines.iagusp.usp.br/ines/
Canada: CADC/DAO, Victoria B. C	http://204.174.103.197/
Chile : AURA/CTIO, La Serena	*http://www.ctio.noao.edu/
China,P.R.(National) : Centre for Astrophysics - USTC, Hefei	http://iue.cfa.ustc.edu.cn/ines/
Costa Rica: University of Costa Rica, San Jose	*http://www.efis.ucr.ac.cr/
Egypt: NRIAG - Helwan Observatory, Cairo	*http://www.frcu.eun.eg/
France : CDS - Observatoire de Strasbourg, Strasbourg	http://cdsweb.u-strasbg.fr/
India : Space Science Data Centre - ISRO HQ, Bangalore	*http://www.isro.org/
Indian Institute of Astrophysics - VBO, Alangayam	*http://www.iiap.ernet.in/
Israel : Wise Observatory, Tel Aviv University, Tel Aviv	http://wise-iue.tau.ac.il/
Italy : Osservatorio Astronomico di Trieste, Trieste	http://ines.oat.ts.astro.it/
Japan : National Astronomical Observatory, Tokyo	http://iue.mtk.nao.ac.jp/
Korea : Department of Astronomy and Space Science, Chungbuk	http://star91.chungbuk.ac.kr/ines/
Mexico :INAOE, Puebla	*http://www.inaoep.mx/
Netherlands : Sterrenkundig Instituut, Utrecht	*http://www.fys.ruu.nl/
Nordic countries : Uppsala Astronomical Observatory, Uppsala	*http://www.astro.uu.se/
Poland : Torun Center for Astronomy, Nicholas Copernicus University, Torun	http://ines.astri.uni.torun.pl/
Portugal : Centro de Astrofisica da Universidade do Porto, Porto	*http://www.astro.up.pt/
Russia : Institute of Astronomy of Russian Acad. Sci., Moscow	http://ulda.inasan.rssi.ru/
South Africa : South African Astronomical Observatory, Cape Town	*http://www.saao.ac.za/
Spain : LAEFF/VILSPA, Madrid. INES Principal Centre (also serving Germany)	http://ines.vilspa.esa.es/
Switzerland : Inst. d'Astronomie de l'Université de Lausanne, Chavannes-des-bois	*http://obswww.unige.ch/
Taiwan : Inst. of Physics and Astronomy, Chung-Li	*http://www.phy.ncu.edu.tw/
Turkey : Physics Department - METU, Ankara	*http://www.physics.metu.edu.tr/
United Kingdom : Rutherford Appleton Laboratory, Chilton	http://iuepc.bnsc.rl.ac.uk/ines/
USA : STScI, Baltimore	http://ines.stsci.edu/ines/

Notes: http: INES NH Node Link (installation completed and National Host fully operational)
*http: INES NH Institute Link (not yet operational)

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