The JEM-X instruments on the INTEGRAL satellite

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Modern astronomers uses the entire electromagnetic spectrum to learn about the cosmos. Europe's next major scientific satellite, INTEGRAL, is designed to make astronomical observations in hard X-rays and gamma rays, the most energetic forms of electromagnetic radiation. INTEGRAL carries four instruments which have been selected to complement each other to give the best global view of the cosmic sources of gamma-rays. One of the four instruments, the Joint European Monitor for X-rays, JEM-X, has been provided by a collaboration of European laboratories with a strong Nordic contribution.
The role of JEM-X is to provide accurate positions for new sources through its fine images, and to cover the hard X-ray energy range from 3 to 35 keV. This will provide a good energy overlap with the two gamma-ray instruments which covers the range from 20 keV to 8 MeV.

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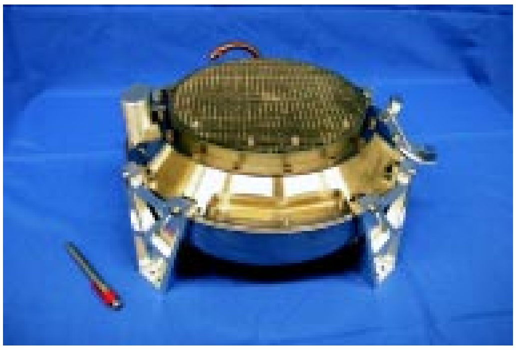
The scientific case for INTEGRAL

The stars which shines in X- and gamma-rays are very different from ordinary stars like our Sun. The Sun shines steadily, with only small changes in luminosity over long periods of time. X- and gamma-ray stars, on the other hand, are frequently extremely variable - exhibiting dramatic changes in luminosity in hours, minutes and even in seconds. The dramatic difference in stability is a reflection a huge difference in size for the two types of stars. Surprisingly, the stars which emit the high energy radiation are much smaller than the normal stars. The Sun is more than a million km across, an X-ray star only a few tens of km!

The Sun draws its energy from the conversion of hydrogen to helium deep in the Solar interior - any time variability in this process is effectively damped out in the long diffusion time for the radiation before it arrives at the solar surface. In contrast to this, the energy release from most X-ray stars, comes about because matter is transferred (accreted) from a neighbor star to the very compact X-ray star. and is compressed and heated to extreme temperatures during this infall. The solar surface has a temperature of 6000 degrees and emits visible light, whereas the matter trapped in orbit around the compact objects is heated to temperatures of many millions degrees and then emits X- and gamma-rays

Hard X-rays and gamma-rays are therefore a telltale signature for the astronomers where to look for these peculiar compact objects, the neutron stars



One of the two JEM-X detectors now orbiting the Earth on-board INTEGRAL. The detectors have been build in Finland with major contributions from Italy and Denmark.
Photo: DSRI

and black holes. A lot of unexplored territory in physics can now be studied in the strong gravitational fields surrounding compact stellar objects.

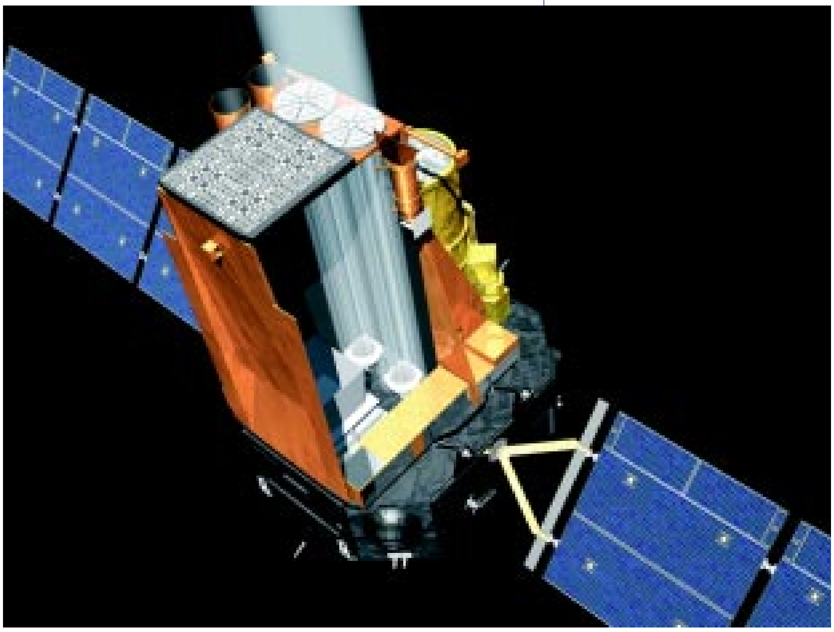
One other process which produces gamma-rays is important in the cosmos - the decay of radioactive nuclei. As already mentioned ordinary stars converts hydrogen to helium, but other nuclear processes occur as well in the stellar interiors through which the stars form all the other, heavier chemical elements - carbon, oxygen, iron - all the way up to uranium. Many of the newly formed elements are radioactive and must go through one or several radioactive transmutations before they end up as stable elements. Many of these decays emit gamma-rays with characteristic energies - a detailed study of the energy spectrum of the cosmic gamma-rays can therefore tell us about the places and the processes which have formed the building blocks for our Solar system, our planet, and even for ourselves.

The INTEGRAL satellite

The INTEGRAL satellite is specifically designed for the study of the questions discussed above and it carries four instruments which together form a space observatory of unparalleled sensitivity and precision.

The two largest instruments are both gamma-ray telescopes: SPI, the gamma-ray spectrometer, and IBIS, the gamma-ray imager. The spectrometer has limited angular resolution, only 13x13 pixels, but sufficient spectral resolution to identify individual nuclear lines and perform accurate measurements of cosmological redshifts for extragalactic sources. The gamma-ray imager on the other hand has moderate spectral resolution but with its 128x128 pixels sets new standards for the detail of the gamma-ray images.

Two smaller instruments: JEM-X, the X-ray monitor and OMC, the optical monitor complements the gamma-ray instruments. Their function is to provide even better imaging (256x256 and 1024x1024 pixels respectively) of the source fields than available from IBIS, and, in the case of JEM-X, also to provide simultaneous information about the luminosity of the gamma-ray sources in the hard X-ray band. Observations made by previous missions have demonstrated that some gamma-ray sources may temporarily «hide» their luminosity to the gamma-ray telescopes by switching their emission between the gamma-ray and the hard X-ray regime - simultaneous observations in the two bands are therefore essential for the interpretations of the results.

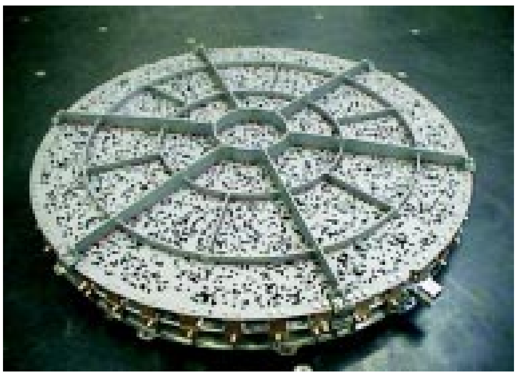


Cut-away illustration of INTEGRAL in orbit, illustrating the working of the “coded-mask” cameras. The complex software needed for the analysis of the JEM-X data have been provided by Denmark, Poland, Sweden and Switzerland.
Figure: ESA

The JEM-X instrument

The scientific requirements for the X-ray monitor called for an instrument covering an energy range from 3 to 35 keV with a field of view of 5° or more. X-ray mirror systems could not be designed to fulfill such requirements, and a „coded mask“ camera option was chosen instead. The design of the coded mask camera is similar to the classical pinhole camera, but the single pinhole is replaced by a mask with many pinhole arranged in a specific pattern. Behind the mask is a position sensitive X-ray detector which will detect a characteristic shadow pattern, dependent on the position of the X-ray source within the field of view.

The advantage of the multiple pinholes (more than 5000 in the case of JEM-X) is a large increase in sensitivity, the drawback is that the images of all the sources in the field of view interferes with each other and has to be disentangled through a complex software system. Even so, the ability of coded mask cameras to handle several tens of sources simultaneously has already been demonstrated. All three X- and gamma-ray instruments on INTEGRAL uses this type of camera.



One of the two JEM-X pinhole masks. Each masks have about 5500 holes arranged in unique pattern to optimize the imaging properties. Spain have contributed the masks for all of INTEGRAL’s instruments.
Photo: DSRI

The other key element of JEM-X is the position sensitive detector. This new development, a microstrip detector, will be used in space for the first time on the INTEGRAL mission. It offers superior resolution both in energy and in position compared to earlier designs using wire grids.

The radiation environment in the INTEGRAL orbit is quite harsh, and therefore a rather conservative approach regarding the choice of on-board processors have been imposed by the INTEGRAL project. The JEM-X uses two MA1750 processors, both operating at 16 MHz, one is handling the more than 40 detector signals used in the processing of each photon, the other processor handles the command reception and the telemetry packing and formatting.

Prior to delivery the two JEM-X instruments have been through a long series of environmental tests and calibration runs. After delivery several additional tests and calibrations were carried out at satellite level. By the end of June 2002 the last test was successfully concluded and the satellite was prepared for shipment to the Baikonur cosmodrome in Kazakhstan from where INTEGRAL will be launched in the early morning hours of October 17. Then, after 9 years of hard work we look forward to see our instruments return exciting data!

The JEM-X consortium.

A number of European laboratories and firms have joined forces to design and build the two JEM-X instruments on INTEGRAL and to provide the data analysis software. Three Nordic countries have contributed significantly:

Denmark, through the Danish Space Research Institute have had the overall responsability for the design and development of the JEM-X instrument, and have on the technical side provided the instrument electronics, about half of the on-board software and the thermal design of the instrument.

Finland, through the University of Helsinki and the Metorex company have provided most of the mechanical parts for the detector vessel, and clean rooms for the detector assembly.

Sweden, through the Stockholm University have contributed to the development of the data analysis software. Other major contributors to this effort has been the University of Helsinki, the Copernicus Institute in Warszaw, the University of Valencia, the the Danish Space Research Institute and the INTEGRAL Science Data Center in Geneva.

On the hardware side JEM-X also contains major contributions from Spain (the coded masks) and from Italy (high voltage units, detector collimators and calibration sources).

The gamma rays.

The gamma rays detected by Integral are a million times more energetic than visible light. The shorter the wavelength, the higher the energy of the radiation is. Red light has a wavelength of 700 nanometres (0.000 000 7 metres, violet light of 400 nanometres. Integral studies radiation with a wavelength from only 0.2 to only 0.0008 nanometres

The energy of gamma rays is usually given in electronvolt or eV, a unit of energy used in particle physics. I eV is the change in energy of an electron when it is moved through a difference of potential of 1 volt. Visible light has an energy of 2 to 3 eV, the energy of X-rays is in the range of thousands of eV, that is, kiloelectronvolt or keV. Integral studies radiation in the energy range from 15 keV to 10 MeV (10 megaelectronvolt or 10 000 000 eV)

On earth, gamma rays are notorious as penetration radiation from radioactive materials. Some radioactive atoms occur naturally, others are produced in nuclear reactors. The gamma rays from outer space are blocked by the earth's atmosphere – fortunately, because this powerful radiation is lethal. In space there is a variety of mechanisms producing gamma radiation, mentioned can be decay of nucleons, nuclear interactions, annihilation between matter and antimatter, "Bremsstrahlung" which means slowing-down radiation, inverses Compton Scattering and synchrotron radiation.

Observing gamma rays is a difficult task. The gamma-ray protons from distant objects are rare, and with their penetrating power they cannot be focused by conventional mirror or lenses. No ordinary telescope can therefore focus this highest form of electromagnetic radiation and the scientists have therefore developed their own technique to detect the radiation, the coded mask technology. The coded mask is basically a pinhole camera, but with a larger aperture, that is, many pinholes to cope with the low gamma ray fluxes.

The first results.

The first months of operation after launch have demonstrated that, as expected, the INTEGRAL satellite will be capable of performing very detailed and accurate studies of the X- and gamma-ray sky. The first few gamma-ray bursts have been detected and quickly followed up with observations from the ground and from other satellites. Several new X-ray transients have been detected, one of which appear to be a very bright object shining through a thick cloud of obscuring material.

A black hole source have been studied in detail and the data is being analyzed to understand how the matter circling the black hole is being swallowed, and finally, the capability for extremely accurate timing measurements have been demonstrated through comparison of INTEGRAL X-ray observations of a fast spinning pulsar and radio observatons from the ground of the same source.