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The Imager on INTEGRAL (*)(**)

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Summary. — The EIDOS gamma-ray Imager has been proposed in response to the INTEGRAL Announcement of Opportunity issued on the 1st July 1994. Through a combination of different detector technologies, it provides high-quality imaging of celestial gamma-ray sources in the energy range between 20 keV and 10 MeV combined with high continuum sensitivity, high sensitivity to both narrow and broadened gamma-ray lines and good spectral resolution. The instrument also offers sensitive polarimetry of gamma-ray sources. The scientific objectives of this instrument are vast and range from studies of the most compact Galactic objects through to the structure of the Galaxy and on to active galactic nuclei. Careful attention has been taken to ensure that the design of the EIDOS Imager is compatible with the mission requirement for a Galactic Plane Survey.

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1. – Introduction

The intimate relationship that γ-rays have with nuclear and particle processes provides a direct means to explore the most energetic phenomena which occur in nature and enables some of the most fundamental questions of physics and astrophysics to be addressed. Particle collisions, radioactivity, matter/antimatter annihilation and nuclear excitation are all directly related to the production of γ-rays with unique and powerfully diagnostic emission characteristics. Precise information is provided on the detailed geometry, energetics and physics of the underlying systems that power celestial sources. Unlike most other wavebands, γ-rays are not secondary reprocessed photons and are thus

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able to probe these fundamental driving forces directly. This attribute is further aided by the extreme penetrating power of the γ-ray photons.

INTEGRAL consists of two main instruments operating in the γ-ray range, one optimized for imaging and the other for spectroscopy. The payload comprises also two monitors, one operating at X-ray energies and the other in the optical window. The overall INTEGRAL payload has been carefully designed to address the imaging, accurate positioning and spectroscopy of celestial objects. As in most other wavebands, the full measurement capability of fine- and large-scale imaging together with fine and broad-band spectroscopy is not technically possible within a single instrument. Two separate and co-aligned instruments, which may be regarded as effectively one telescope, are necessary to provide the full diagnostic information. The Imager and Spectrometer have been conceived and designed as a fully complementary pair.

EIDOS will provide the complement of fine imaging, source identification, polarimetry and maintains spectral sensitivity to broadened lines and the continuum. The Spectrometer will provide narrow-line sensitivity and maintains an extended source imaging capability. In conjunction with the Spectrometer, EIDOS will employ these powerful diagnostic capabilities to a range of celestial objects of all classes ranging from the most compact galactic systems, through violent explosive events, to the structure of the Galaxy and on out to extragalactic objects and then cosmological implications. The major advance in observing capability, when applied for the first time to the direct study of nuclear and particle processes within celestial objects, offers the chance of a new and radically altered perception of the underlying physics. As in other cases when "new" astronomical windows have been opened onto the Universe, important discoveries will be made, fundamental questions can be answered.

2. – Scientific objectives and capabilities

The scientific objectives of INTEGRAL include galactic and extragalactic astrophysics.

The Galactic Centre and Bulge house some of the most active objects in the hard–X-ray and soft–γ-ray band, one of the few windows available for observations through the intervening gas and dust. EIDOS will be able to provide a high-quality continuum and spectral line measurement in a moderate exposure of 10^4 s, locating the emission coming from the various transient and persistent sources discovered by previous experiments, with a precision better than 1 arcmin (see table I).

The study of compact objects with EIDOS is an important objective of the mission. Virtually all types of compact objects are significant sources of high-energy emission ranging from white dwarfs (Cataclysmic Variables) to neutron stars (isolated and in binary systems) and black holes (transients). The fine imaging capability of EIDOS will ensure accurate source location and identification and the high sensitivity will allow any broad-line spectral features, hard tails and the underlying continuum emission associated with a particular source to be studied in great detail.

The observation of the γ-ray lines produced by the nuclear transitions from the de-excitation of decay products and the annihilation of positrons produced in various nucleosynthesis sites, such as supernovae (present and historical) is another important scientific objective of EIDOS. For instance, the ^{44}Ti mean life of $\sim$78 years is sufficiently long that the associated lines (0.068, 0.078 and 1.156 MeV) from recent supernovae will appear as "hot spots" when the Galactic Plane is imaged by EIDOS. The Galactic Plane constitutes

TABLE I. – *Key* EIDOS *performance parameters.*

Energy range	20 keV–10 MeV
Detection area	2500 cm^2
Spectral resolution ($\Delta E/E$ FWHM)	6% at 100 keV, 6.5% at 1 MeV
Angular resolution (FWHM)	$16'$ at 100 keV, $19'$ at 1 MeV
Point-source location (20σ source)	$1'$
Field of view	9 square degrees (fully coded)
	150 square degrees (1/2 coded)
Continuum sensitivity	2.3×10^{-7} ph cm^{-2} s^{-1} keV^{-1} at 100 keV
	6.2×10^{-8} ph cm^{-2} s^{-1} keV^{-1} at 1 MeV
Line sensitivity	4.1×10^{-6} ph cm^{-2} s^{-1} at 100 keV
	2.1×10^{-5} ph cm^{-2} s^{-1} at 1 MeV (broad line)
Polarimetry sensitivity	$\sim$10 mCrab, $\phi \leq 1°$
Timing accuracy	0.1 ms

the core program of INTEGRAL which will aim to the study of the γ-ray emission in the ^{26}Al line at 1.8 MeV which the Imager will map at arcminute level.

The capability of simultaneous detections of optical and γ-ray emission from γ-ray bursts in the field of view of EIDOS, with the Optical Monitor, will allow the identification of the bursts which fall in the partially coded field of view (several per year).

The study of extragalactic objects (Seyfert, Quasars, BL Lacs, other galaxies, and clusters) is one of the most important scientific objectives of EIDOS. γ-rays carry away the dominant fraction of the emitted energy from active galactic nuclei, and the deep broad-band sensitivity level associated with the imaging capability of the Imager will increase our knowledge of the mechanisms responsible for the emission, of the physical condition of the objects, and of the identification of the sources, and will offer the possibility to determine the low-energy γ-ray luminosity function and the $\log N$- $\log S$, and to evaluate the contribution of AGNs to the Cosmic Diffuse Background at these energies.

3. – The Imager

EIDOS is based very closely on the extensive studies carried out for the Imager during the INTEGRAL Phase-A [1]. It employs a coded mask in conjuction with an actively shielded, three-layer position-sensitive γ-ray detector.

The detector is highly modular and consists of three planes (two of which are identical) and each plane consists of 24 triangular modules. Within each module there are 120 detector cells (in the front plane these are "hexacells", each containing 6 distinct pieces of CdTe). The modularity is important in making the development, construction, qualification and testing of a complex system praticable. The stack of three planes is surrounded by a BGO scintillator veto shield (also modular) which is operated in anticoincidence with the CsI detector elements. The entrance aperture has a tantalum tube collimator to reduce the effects of the diffuse γ-ray background.

The coded mask is made from 1.5 cm thick tungsten elements sandwiched between carbon-fibre–reinforced plastic honeycomb panels. This provides $>70\%$ opacity even in the difficult region between 2 and 3 MeV. The mask element size has been chosen to be 15.67 mm (across flats) so that, with a distance of 3.25 m between the Imager detector and the mask, the telescope will have an angular resolution of $19'$ FWHM, and by centroiding,

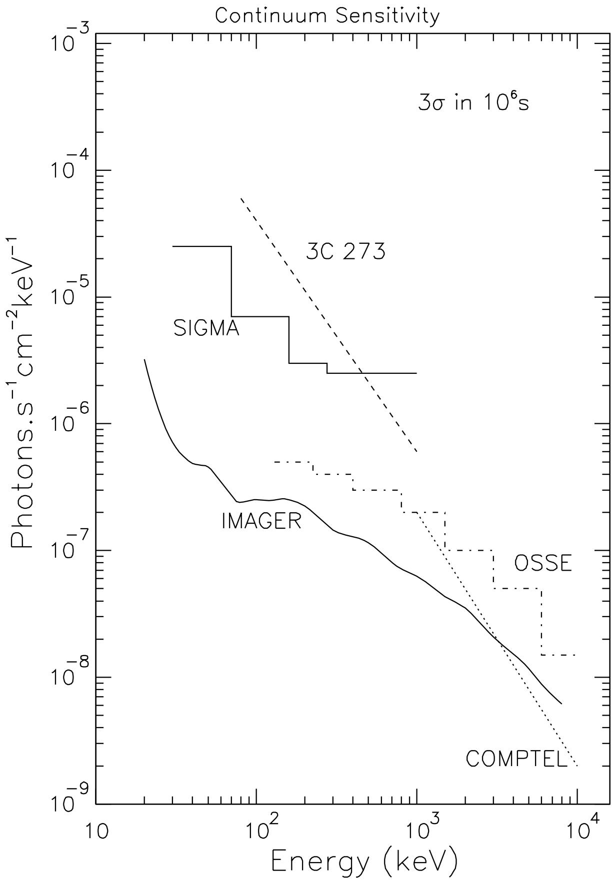

Fig. 1. – Continuum sensitivity of EIDOS compared with what achieved by other instruments working in the same energy range.

source positions may be located to typically 1′. The size of the mask has been chosen to provide a fully coded field of view of 9 square degrees and exposes 150 square degrees of the sky with more than 50% coding.

4. – Detector performance

The key performance parameters (detection efficiency, background noise, and sensitivity) of EIDOS have been estimated using a combination of Monte Carlo modelling and laboratory tests.

The use of CdTe and CsI ensures a detection efficiency always greater than 50% throughout the whole energy range from 20 keV up to 8 MeV. The energy resolution is around 6% both at 100 keV (with CdTe) and at 1 MeV (with CsI). Particular care has been given to the minimization of background noise. Several techniques have been envisaged: the tantalum collimator and the reduction down to 2 mm of the top CdTe plane for energies less than 200 keV; identification of multiple events attainable with the 3d discrete detection element structure which also gives the possibility of reconstructing the kinematic of the Compton events.

Figure 1 shows the continuum sensitivity curve of EIDOS compared to what has been achieved by other instruments operating in the same energy range. It is important to note the broad-band capability of EIDOS, which enables to cover the range between the low-energy limit of SIGMA up to the upper energy range of OSSE. The resulting sensitivity is a few times better than OSSE but with an angular resolution that is of the order of what achieved by SIGMA which has a sensitivity a factor of 30 worse.

REFERENCES

[1] INTEGRAL Collaboration, *Phase-A Study, INTEGRAL Report on the Phase-A Study*, ESA SCI(93)1 (1993).