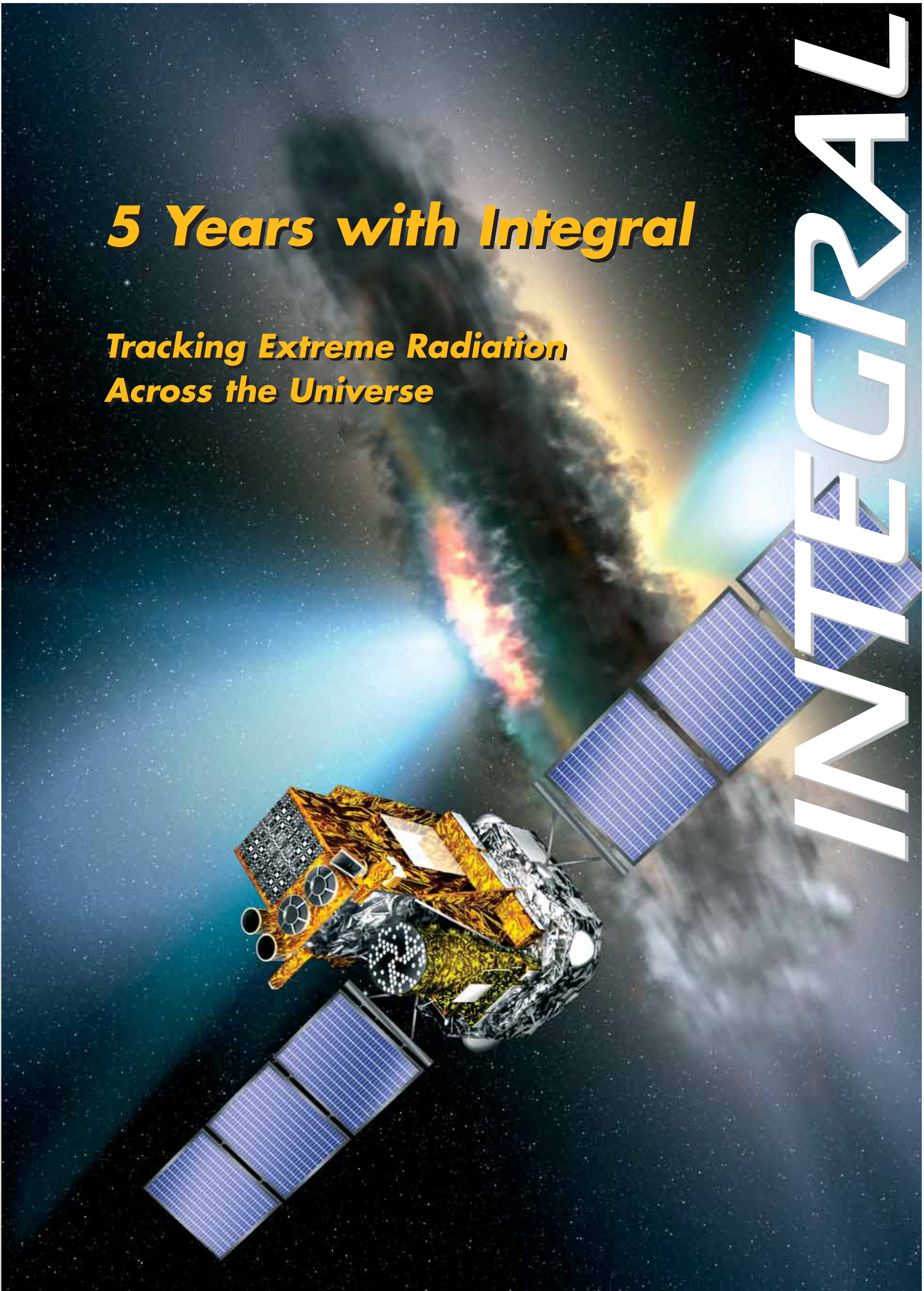
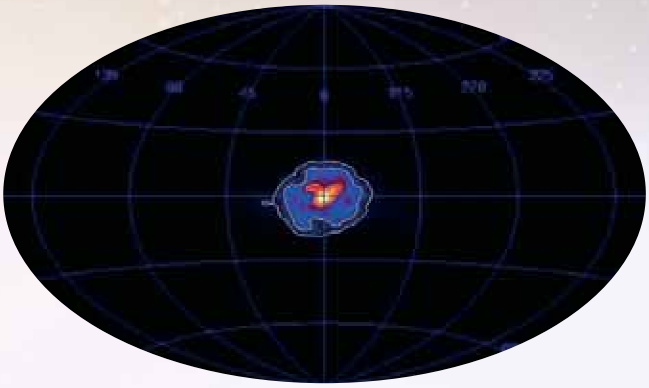
esa

5 Years with Integral

Tracking Extreme Radiation Across the Universe

INTEGRAL





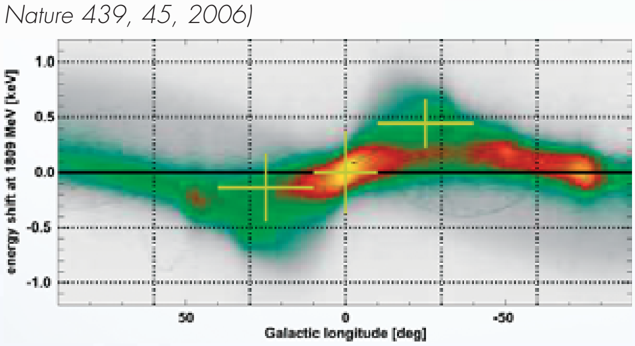
The centre of the Galaxy shines brightly in gamma-rays with a specific energy of 511 keV. This is the energy released when an electron encounters its antimatter particle counterpart, the positron. It is not yet known what creates the antimatter. The image shows the full sky at 511 keV. (J. Knödlseder et al., A&A 441, 513, 2005.)

The atoms that make us

The Universe we live in contains more than 100 different types of atoms, known as elements, such as iron, oxygen and hydrogen. Whereas hydrogen and helium were created from the Big Bang, stars are continuously synthesising the other elements. In this process of building elements, stars release energy – and it is this energy that keeps them shining. Then, at the end of a massive star's life, the energy released in the explosion builds further elements.

Some of these elements are radioactive and as they decay into stable 'isotopes', they release gamma-rays. Each isotope has a characteristic energy that it releases. They are known as gamma-ray lines and Integral can detect them, allowing astronomers to investigate the composition of the cosmos.

The Galaxy looks strangely kinked in this image, composed of the gamma-rays given out by the radioactive isotope of aluminium-26. The curves are produced by the Doppler effect and show how the Galaxy is rotating. The rotation introduces a small but observable shift in the energy of the line emission – exactly as measured by Integral. (MPE; R. Diehl et al. Nature 439, 45, 2006)



Integral has made giant strides in the study of the radioactive isotope aluminium-26. This is produced inside massive stars and released into space when they explode, or by stellar winds from those stars. By surveying the entire Galaxy for this isotope, Integral has enabled scientists to calculate that every 50 years, on average, a supernova explodes somewhere in our Galaxy.

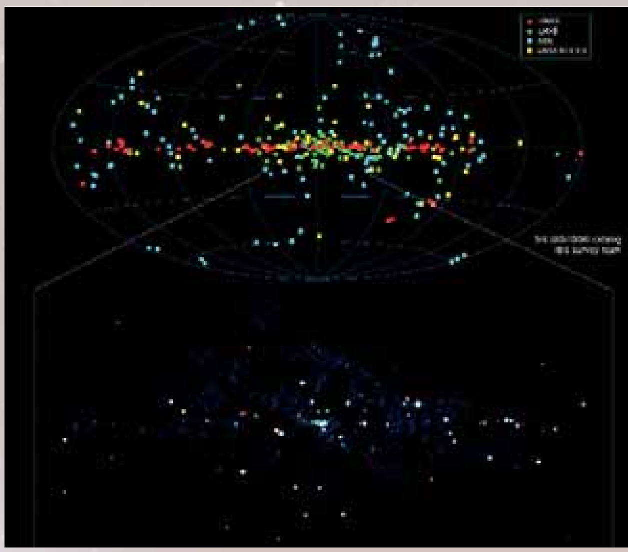
One of the key discoveries by Integral involves a mystery at the centre of the Galaxy. Here, a certain gamma-ray line is not coming from atoms but from antimatter. In particular, the antimatter counterpart of the electron, known as a positron, has been pinpointed as being responsible. The Integral results clearly show that something is producing vast quantities of positrons in the centre of the Galaxy.

When these antiparticles come into contact with electrons, they annihilate each other, creating gamma-rays of a highly specific energy, 511 keV, corresponding to the mass of both particles according to Einstein's famous equation $E = mc^2$.

According to the emission seen by Integral, some 1.5×10^{43} positrons are being annihilated every second. This raises the question: how can such vast numbers of particles be generated every second, and how would these sources be distributed over the sky to match the gamma-ray map? As yet, the answer is completely unknown but a number of candidate sources have been proposed. These include: supernovae, micro-quasars, winds from rapidly rotating (millisecond) pulsars, and light dark-matter particles.

The densest objects in the Universe

Integral has now observed almost all of the sky, looking for celestial objects that emit gamma-rays. These gamma-ray energies are not just lines but cover a broad band. Within months of beginning work, Integral had solved a 30 year-old mystery by showing that the broadband



The red and green boxes represent dense objects discovered by Integral in our Galaxy. The blue spots are supermassive black holes in the distant Universe. The yellow spots are so-far unidentified sources of gamma-rays; their distribution suggests that they are probably dense objects within the Milky Way. (IBIS Survey Team, A. Bird et al., ApJS 170, 175, 2007)

gamma-ray emission seen towards the centre of the Galaxy was produced by a hundred individual sources. No other space observatory had been able to resolve them before.

Astronomers went on to compile a catalogue of close to 500 gamma-ray sources from all over the sky, most of them new discoveries. Many are neutron stars, created when massive stars explode. At the end of such a star's life, not all of its mass is thrown into space. In the centre of the explosion, a compact object just 20 km across is created. Squeezed into this small sphere is about the same amount of matter as in our Sun.

When a neutron star spins at the right angle, it can sweep a 'searchlight' beam of radiation towards Earth's. Integral sees this radiation; and astronomers call the sources pulsars. Integral has now shown that a rare class of anomalous X-ray pulsars (AXPs) generate magnetic fields a thousand million times stronger than the strongest steady magnetic field achievable in a laboratory on Earth. Such bodies are also called 'magnetars', the most magnetically active bodies in the Universe.

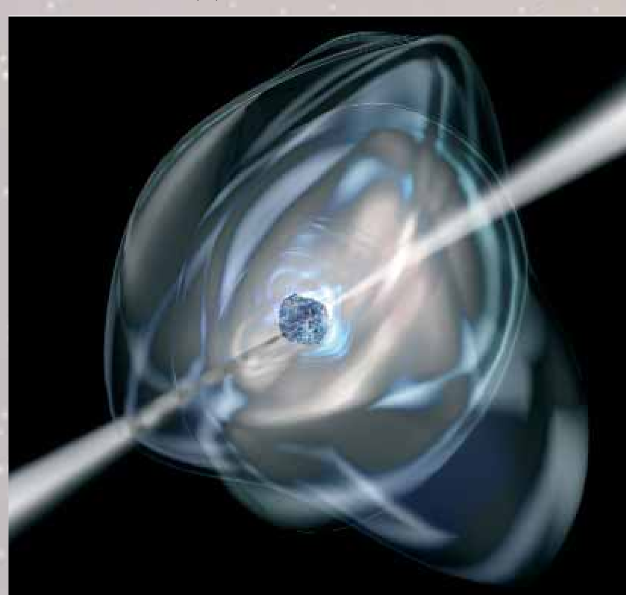
In another study, Integral revealed that a sub-class of X-ray binary stars, previously thought to be extremely rare, is actually common in our Galaxy. Each of these 'supergiant fast X-ray transients' consists of a compact object, either a neutron star or a black hole, sucking matter from an enormous supergiant star. Integral has now confirmed eight of them and has identified 15 more candidates. The stars suddenly rise in brightness, pour out gamma-rays for a few tens of minutes and then fall back into quiescence. Integral has also shown that some suffer recurrent outbursts. For comparison, most other known transient X-ray binary systems display longer outbursts, lasting weeks or months.

Integral has also discovered a completely new class of high-mass X-ray binaries, known as 'highly absorbed X-ray binaries'. The compact object is only faintly seen because it is deeply cocooned in matter streaming off the supergiant companion star. However, Integral's sensitivity to gamma-rays of a few tens of keV and above has allowed it to detect about 25 of these celestial objects. The first, called IGR J16318-4848, was discovered on 29 January 2003.

Giant black holes

Another primary source of gamma-rays in the Universe are giant black holes. Each lives in the centre of a galaxy and, if it is swallowing gas from its surroundings, it will cause gamma rays to stream out from the centre of the galaxy.

An anomalous X-ray pulsar.



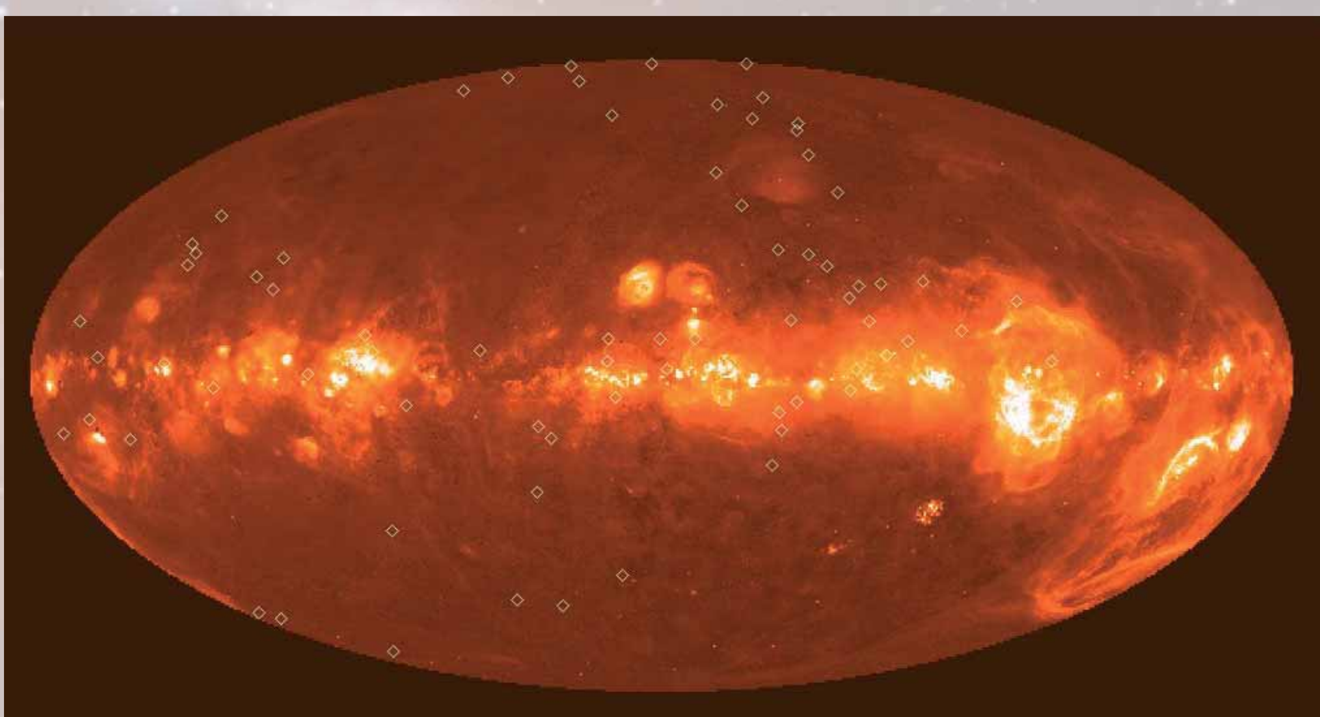
Integral used the Earth to mask out gamma-rays from the distant Universe. In this way, the drop in gamma-rays allowed scientists to measure how much high-energy radiation is coming from distant supermassive black holes.

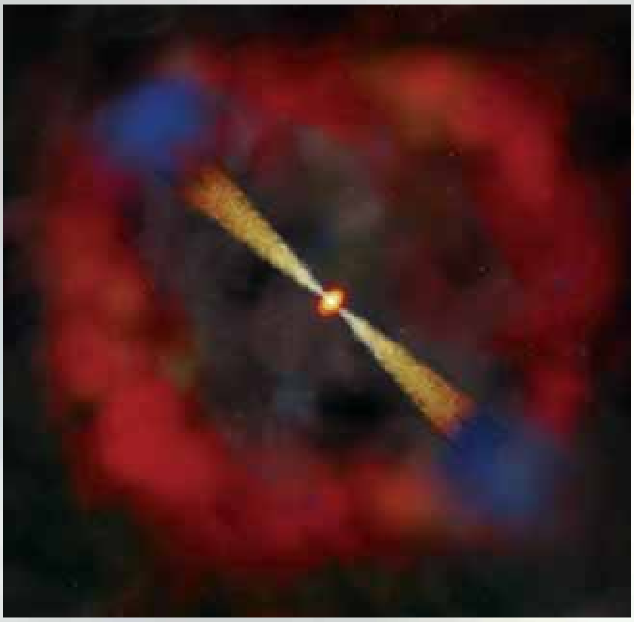
Supermassive black holes are thought to sit in the centre of every galaxy. Some are surrounded by dusty tori of matter that feed them. Superheated gas streams away in jets, saved from being swallowed by the black hole.

Integral has already seen about 100 of the brightest supermassive black holes in other galaxies. These are just the tip of the iceberg and the number is increasingly rapidly as Integral searches distant space for more. Astronomers believe there are tens of millions of active black holes spread throughout space, all pumping out gamma rays.

Integral has also been on a quest to find supermassive black holes hiding in nearby galaxies but has found surprisingly few. Either the black holes are better hidden than scientists realised or they are lurking only in younger celestial objects, which populate the more distant Universe.

This all-sky map shows hydrogen gas in the local Universe, obtained by composing data from three recent ground-based surveys (WHAM, VTSS and SHASSA). The hidden black holes detected by Integral are located in the diamond shapes.
(D. Finkbeiner/ESA, Integral, V. Beckmann, ISDC Geneva)





What a gamma-ray burst might look like up close. The two jets of gamma rays shoot off into space. If one happens to point to Earth, Integral sees it. (CXC/M. Weiss)

It is believed that the huge number of galaxies spread throughout the Universe are together responsible for creating a diffuse background glow of gamma-rays, seen over the entire sky. To untangle this faint glow from the other sources of background gamma-rays, such as the material of the spacecraft itself or the contribution from our own Galaxy, Integral used the Earth as a giant shield. Astronomers watched the number of telltale gamma-rays from the distant Universe dwindle to zero and then return, as our planet blocked (and unblocked) the sky view.

By measuring the fall in the gamma-ray flux once Earth had blocked Integral's view and by allowing for Earth's atmospheric emission, the astronomers precisely gauged the gamma-ray background.

Pointing Integral at the Earth was a risky proposition that required plenty of planning. The spacecraft is not designed to look at such a bright object because its star-trackers that tell it where it is pointing become confused. To solve this, the control team pointed Integral in a direction where the Earth would eventually cross and then turned off the star-trackers, letting the gyroscopes hold the spacecraft stable for 10 hours.

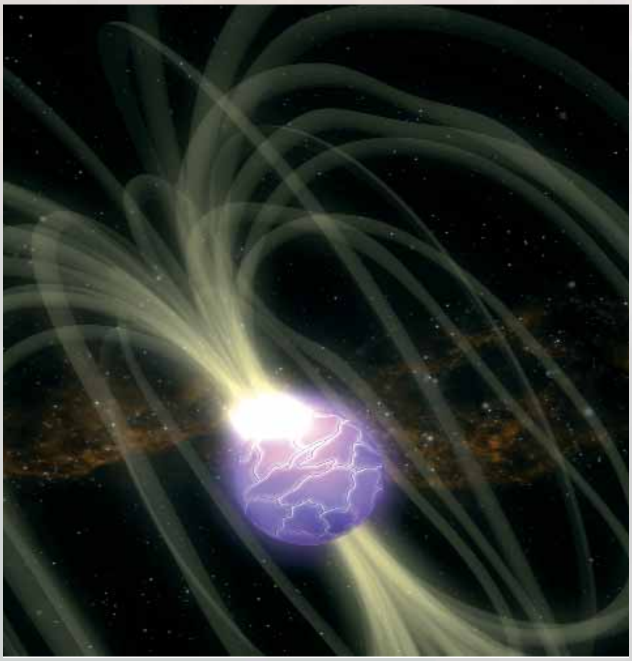
During that time, the Earth drifted across Integral's view, blocking the gamma-rays coming from millions of distant black holes. The information will allow astronomers to understand the origin of the highest energy background radiation and, possibly, provide new clues on the growth of supermassive black holes since the early Universe.

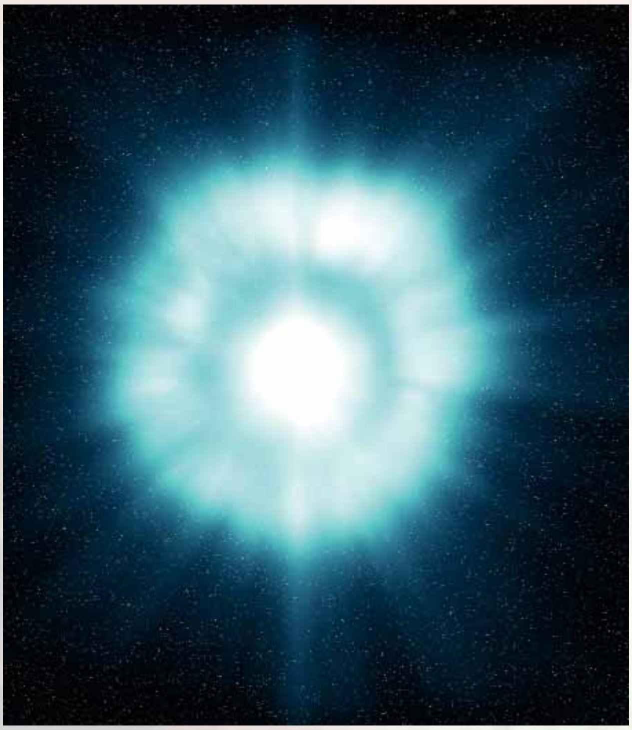
Mysterious Bursts

Once every day or so, a burst of gamma-rays washes through the Solar System. They can last anything from a hundredth of a second up to hundreds of seconds or even longer. They become, briefly, the brightest objects in the gamma-ray sky, but are never seen to repeat. These colossal explosions are triggered when compact objects such as neutron stars or black holes collide. They are also triggered when incredibly powerful supernovae, called hypernovae, explode.

Integral has been instrumental in studying these gamma-ray bursts. Because of their unpredictable nature and the speed at which they fade, rapid follow-up is essential. Although Integral was not originally conceived to be a

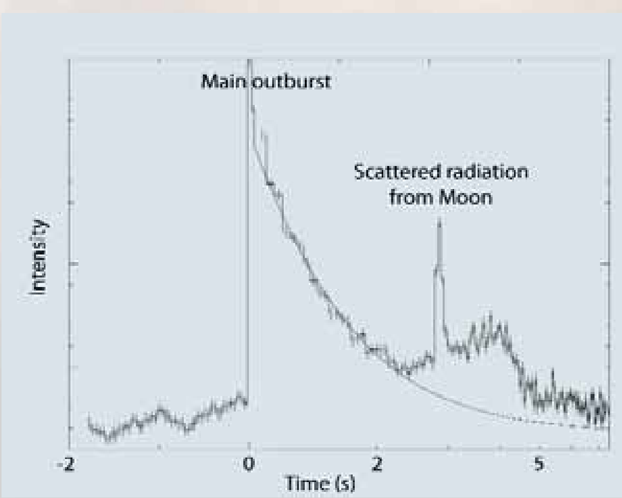
A magnetar is a neutron star with an exceptionally strong magnetic field. On 27 December 2004, SGR 1806-20 released a gigantic burst of gamma-rays that struck Integral from 50 000 light-years away. (NASA)





burst watchdog, scientists realised that it could perform this task if assisted by powerful software. Now, Integral can alert astronomers within seconds.

The gamma-ray source SGR 1806-20 underwent a giant outburst, or explosion, on 27 December 2004. The graph shown here is a 'light curve', plotting the intensity of the gamma-ray radiation (number of photons) detected by Integral as a function of time (seconds). The peak of the curve corresponds to the outburst itself (indicated at '0' seconds). The radiation emitted in the outburst was scattered by the Moon and detected by Integral about 3 seconds later, as shown in the second (weaker) peak plotted here. (Aapted from S. Mereghetti et al., ApJ 624, L105, 2005)



ESA set a new record for speed and accuracy with the Integral Burst Alert System (IBAS) on 3 December 2003, when a burst was detected, localised and an alert was sent to astronomers in 18 seconds. The rapid follow-up on 3 December allowed astronomers to conclude that this event, called GRB 031203, is one of the closest cosmic gamma-ray bursts on record. It exploded in a galaxy less than 1300 million light years away. GRB 031203 is also the faintest burst observed. Usually, the fainter an object, the further away it is but not so in this case. In fact, if GRB 031203 had been further away, it would have been lost to sight. This suggests that an entire population of weaker bursts has so far gone unnoticed.

The system went through the same routine with another burst on 6 January 2004, completing the alert in just 12 seconds.

It is not only traditional gamma-ray bursts that Integral has been studying. On 27 December 2004, at 21:30:26 GMT, Integral was hit by a huge wave of gamma-rays. It was the strongest flux of gamma rays yet measured by any spacecraft – stronger than any radiation burst from the Sun. It was even possible for Integral to measure the radiation that bounced off the Moon, reaching its detectors some time later because of the additional journey.
Remarkably, the body responsible for this massive outburst was a neutron star with an extremely strong magnetic field, magnetar SGR 1806-20. It is located on the other side of our Milky Way at a distance of about 50 000 light-years. Thanks to this outburst, astronomers now think that some gamma-ray bursts might come from similar magnetars in other galaxies.

Integral has been able to take images of gamma-ray bursts, even if the telescope was not pointing in the right direction. When GRB 030406 exploded unexpectedly in April 2006, Integral was observing another part of the Universe, about 74 times the diameter of the Full Moon away. Nevertheless, astronomers reconstructed an image of the event. The trick was in using the radiation that passed through the side of Integral's imaging telescope and struck the detector.