Science prospects with INTEGRAL

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Abstract. With the launch of ESA’s INTEGRAL satellite in October 2002, a gamma-ray observatory will be placed in orbit providing a multiwavelength coverage from a few keV up to 10 MeV for the study of high energy phenomena in the universe. Among the major scientific objectives of INTEGRAL are the study of compact objects, and in particular of microquasars, stellar nucleosynthesis, high energy transients, particle acceleration and interaction processes, and galactic diffuse emission. In this review I will expose the science prospects of INTEGRAL in the above mentioned fields.

1. The INTEGRAL observatory

Due to continuing progress in instrumentation, the field of gamma-ray astronomy has become a new complementary window to the universe. With the upcoming INTEGRAL satellite, foreseen for launch in October 2002, ESA provides a gamma-ray observatory to the scientific community that combines imaging and spectroscopic capacities in the 20 keV to 10 MeV energy range. INTEGRAL is equipped with two gamma-ray telescopes, optimised for high-resolution imaging (IBIS) and high-resolution spectroscopy (SPI), supplemented by two X-ray monitors (JEM-X) and an optical monitor (OMC). With respect to precedent instruments, the INTEGRAL telescopes provide enhanced sensitivity together with improved angular and spectral resolution.

1.1. The instruments

IBIS is optimised for high angular resolution imaging of X- and γ-rays in the 20 keV to 10 MeV domain, and is therefore called the imager of the INTEGRAL observatory. Its detector system consists of two layers where the upper one (ISGRI) acts as hard X-ray detector that is sensitive to radiation in the 20–300 keV domain, while the lower one (PICsIT) absorbs the more energetic γ-ray photons in the 100 keV - 10 MeV energy range. A tungsten mask placed at about 3.1 meters above the detector provides an angular resolution of about 12’ within a fully coded field of view (FOV) of 9° (the partially coded FOV extends to 30°). The usage of CdTe and CsI(Tl) detectors allows only for a moderate energy resolution of ~ 6%, making IBIS primarily an instrument for studying point-like continuum sources.

SPI is optimised for high spectral resolution imaging of X- and γ-rays in the 20 keV to 8 MeV energy range, and is therefore called the spectrometer on INTEGRAL. Its detector system consists of 19 hexagonally shaped germanium detectors cooled to an operational temperature of 85 K, which provide an excellent...
spectral resolution of \( \sim 0.3\% \), well suited for detailed studies of gamma-ray lines. A coded mask placed 1.7 meters above the detector plane provides a moderate angular resolution of 2.5° within a fully coded FOV of about 15° (the partially coded FOV extends to \( \sim 33° \)). Although SPI provides only a poor angular resolution, the usage of rather large mask elements makes it well suited for studying diffuse emission. Since the continuum sensitivity of SPI is comparable to that of IBIS, it provides a perfectly complementary instrument for disentangling point-source and diffuse emission contributions along the galactic ridge (see section 4.1).

Two identical X-ray monitors (JEM-X) extend the energy range of SPI and IBIS to soft X-rays (3−35 keV). They are also based on the coded mask principle and offer an angular resolution of 3′, a fully coded FOV of 4.8°, and a partially coded FOV of 13.2°. An optical monitor (OMC) provides simultaneous coverage in the visible V band of the central part (5°) of the FOV. Timing is possible with 1−10 s resolution which allows linking the highly variable X- and \( \gamma \)-ray emission of compact objects to the visible wavelength range.

Figure 1 compares the expected sensitivities of IBIS, SPI, and JEM-X to those of precedent hard X-ray and gamma-ray telescopes. Obviously, INTEGRAL will provide unprecedented continuum sensitivity in the energy range from a few tens of keV up to a few MeV. In particular, IBIS has a much better angular resolution than the OSSE telescope aboard \( CGRO \) (12′ versus 4°), allowing precise localisation (and hence identification) of gamma-ray sources (SIGMA had a similar angular resolution, yet its limited sensitivity did allow only the detection of bright sources). Concerning gamma-ray lines, SPI is expected to provide a major breakthrough with respect to precedent missions. Not only is the sensitivity improved by an important factor, but the combination with the extremely high energy resolution will allow for the first time detailed line profile studies in the gamma-ray domain.

1.2. Mission profile

\( INTEGRAL \) is an observatory-type mission with a nominal lifetime of 2 years and a (plausible) extension up to 5 years. Most of the observing time (65 – 75%) is awarded to the scientific community through a standard AO process, the remaining time is reserved as guaranteed time for the PI institutes, Russia and NASA for their contributions to the program, and to ESA/ISOC and the mission

\[ \text{Figure 1. Comparison of } INTEGRAL \text{ continuum (left) and line (right) sensitivities to the performances of precedent instruments.} \]
scientists. During the guaranteed time, the so-called Core Program is executed which is composed of
- weakly galactic plane scans (GPS) with the primary aim of detecting transient sources,
- the galactic centre deep exposure (GCDE) which aims in studying the source population and diffuse emission distributions in the central galactic radian,
- target of opportunity (ToO) follow-up observations,
- and a deep exposure of the Vela region during the first year of the mission.

2. Legacy

Although various $\gamma$-ray telescopes have preceded the INTEGRAL observatory in its quest for unveiling the high-energy universe, two missions have particularly influenced the design and the performance parameters of the INTEGRAL telescopes: the French/Russian telescope SIGMA on the GRANAT satellite and the telescopes COMPTEL and OSSE on NASA’s Compton Gamma-Ray Observatory (CGRO).

GRANAT has been launched in December 1989 from Baikonour, Kazakhstan, using a Proton rocket, and has successfully been operated during 8 years (INTEGRAL will be lift into orbit in an identical scenario). The SIGMA telescope was based on the coded mask principle and covered the hard X-ray to soft $\gamma$-ray band from 35 keV - 1.3 MeV. With an angular resolution of $13^\prime$ and a $4.7^\circ \times 4.3^\circ$ FOV, SIGMA detected more than 30 sources which are all associated to compact objects, such as persistent black hole candidates (BHCs), X-ray novae, Type I X-ray busters, accreting and isolated pulsars, and Active Galactic Nuclei (AGN). Most of these sources are highly variable, and a substantial fraction only shows transient emission. Consequently, regular repeated observations are needed to study their time variability, and search scans are required to unveil new transient sources, which largely motivated the inclusion of the GPS in the INTEGRAL mission profile. In addition, SIGMA observations showed that the inner Galaxy is densely populated with sources, and a good angular resolution (as implemented in IBIS) is mandatory to avoid source confusion, and to allow for source counterpart identification.

CRGO has been launched in April 1991 by NASA’s space shuttle, and remained in orbit during 9 years after which the satellite was deorbited in a spectacular manoeuvre. COMPTEL consisted of a Compton telescope and covered the energy range from 750 keV - 30 MeV with a moderate angular ($4^\circ$) and energy (9%) resolution. Amongst its most important achievements were the first survey of the entire sky in this energy domain, providing maps of diffuse $\gamma$-ray line (1.809 MeV) and continuum emission. In addition, pulsars, AGNs, BHCs, Gamma-Ray Bursts (GRBs), and supernova remnants (SNRs) have been detected [1]. The OSSE telescope consisted of collimated ($3.8^\circ \times 11.4^\circ$) scintillator crystals with moderate (7%) energy resolution, and extended the energy band covered by CRGO to lower energies (50 keV - 10 MeV). OSSE provided the first map of the 511 keV positron annihilation radiation from the central galactic radian, but it also detected $\gamma$-ray lines in the nearby SN 1987A supernova remnant. It also observed numerous galactic and extragalactic compact objects and provided a precise measurement of the diffuse hard X-/soft $\gamma$-ray continuum emission of the galactic ridge. Both COMPTEL and OSSE have revealed that diffuse $\gamma$-ray emission extends over angular scales of several degrees, which set the resolution scale and FOV of SPI. These telescopes also showed that diffuse $\gamma$-ray emission extends over the entire galactic plane with pronounced enhancements towards the central radian, which
motivated the inclusion of the GPS and GCDE in the INTEGRAL core program in order to build-up a substantial exposure of these important regions over the mission lifetime.

3. Compact objects

3.1. Black-hole candidates, X-ray novae, microquasars

The class of black hole candidates (BHC) divides into persistent sources and soft X-ray transients, also called X-ray novae. The persistent sources are all high-mass X-ray binaries (HMXB), the prototype being Cyg X-1, while X-ray novae are low-mass X-ray binaries (LMXB). X-ray novae typically reach their maximum luminosity within a few days, from where on the luminosity regularly declines on a few weeks timescale. Recurrence intervals for X-ray novae are in the range 1 – 50 yr, which suggests an underlying population between 200-1000 black-hole binaries within the Galaxy [2, 3]. Due to its improved sensitivity with respect to precedent instruments, IBIS has the potential to detect them all, improving considerably our knowledge about their distribution and characteristics.

Probably the most characteristic spectral signature of BHCs is the hard power-law tail that extends to energies $\geq 200$ keV. The tail is generally interpreted as evidence for Comptonisation of soft photons associated with an accretion disk by a semi-relativistic plasma. The tail often obeys an exponential cut-off that shifts to lower energies with increasing luminosity, probably as result of enhanced Compton cooling. Yet, actual models have difficulties to explain the extended tails observed in Cyg X-1 or GRO J0422+32 that reach up to MeV energies [4, 5]. Here, better observational data is needed in the few 100 keV to MeV region that allows a better determination of the spectral shape.

There is increasing evidence that the hard X-ray emission produced by accretion onto stellar mass black holes is always associated to the production of relativistic jets [6]. Early radio observations with the VLA interferometer of NRAO of several SIGMA sources were actually very successful and lead to the identification of the radio counterpart of X-ray Nova Oph 1993, the finding of radio jets in two persistent hard X-ray sources (1E 1740.7-2942 and GRS 1758-258), and the discovery of GRS 1915+105 as the first superluminal radio source in the Galaxy. This illustrates the importance of scheduling contemporaneous X-/\gamma-ray and radio observations, a possibility that is offered by INTEGRAL through the GPS and GCDE observations that are well planned in advance and provide the highest likelihood in detecting new transient sources.

The study of outburst phenomena is important since it generally reflects a change in the accretion rate, hence it provides an excellent laboratory to study accretion physics and the formation mechanism of relativistic jets. Multi-wavelength observations of the microquasar GRS 1915+105, for example, have been interpreted as ejection of the plasma corona in form of collimated jets as result of a shock that has been formed due to the refill of the accretion disk [6]. Yet, the matter content in the jets (normal plasma made of electrons and protons or a pair plasma made of electrons and positrons, or a mixture of both) is still an open question, which may be resolved by the detection of annihilation features during jet ejection. Transient line features that might be indicative of pair annihilation have been reported in 1E 1740.7-2942, Nova Muscae, and GRO 1655-40 [8-11], yet contemporaneous observations by OSSE and SIGMA of an outburst of 1E 1740.7-2942 gave contradictory results [11]. Hopefully, with its good sensitivity and spectral resolution, INTEGRAL will clarify the situation.
3.2. Type I X-ray bursters

Type I X-ray bursters are interpreted as thermonuclear explosions at the surface of weakly magnetised neutron stars, and are associated with LMXBs. They typically occur at intervals of hours to several days, and show characteristic spectral changes which are interpreted as photospheric temperature changes during the outburst [11]. In particular, the observations of Eddington-limited bursts provide important insight into parameters of neutron star binaries, such as estimates of the distance, neutron star radii, average luminosities, and accretion rates [12]. With the improved sensitivity of IBIS, INTEGRAL will increase the sample of known X-ray bursters, and will allow detailed studies of their characteristics and their galactic distribution. In particular, the new class of X-ray bursters that has been revealed recent by BeppoSAX observations [12] is in the focus of INTEGRAL observations, which should improve our knowledge about the proportion of black-hole to neutron star systems in our Galaxy.

3.3. Pulsars

Pulsars are highly magnetised rotating neutron stars that spin-down due to particle acceleration processes in their magnetosphere, which are most directly probed in the X- and γ-ray domain [13]. However, it is not yet clear in which region of the magnetosphere electrons (or positrons) are accelerated and whether processes like magnetic pair production and photon splitting are relevant or not. As prototype of an isolated pulsar, the Crab pulsar shows a pulse shape transition in the hard X-ray to soft γ-ray domain which possibly indicates the presence of different emission components [14]. In general, turn-overs in the hard X-ray domain are expected, which potentially help to distinguish between the different pulsar models [13]. With the good sensitivity in this transition region, INTEGRAL will shed new light on the origin of the different pulse components.

In the X-ray domain, most pulsars are accreting binaries where the mass flow is confined at the magnetic poles. Shocks in the accreting column heat the matter up to γ-ray temperatures, which results in highly variable sources of hard X-/soft γ-ray photons. In the extreme magnetic fields ($B \gtrsim 10^{12}$ G) that characterise most accreting X-ray pulsars, the energy of the electrons is quantified in Landau levels, leading to resonant scattering that induces cyclotron absorption line features at energies $E = 11.6 \times n \times B_{12}$ keV, where $n$ is a positive integer number and $B_{12}$ is the magnetic field strength in units of $10^{12}$ Gauss. Consequently, the determination of the cyclotron line energies allows for a direct measurement of the magnetic field strength. Here INTEGRAL is particularly powerful since it fully covers the energy domain of cyclotron features (many precedent instruments were not sensitive enough in the hard X-ray band to reliably determine multiple harmonics of the same cyclotron feature). In particular, thanks to its high spectral resolution, SPI will probe the geometrical conditions of the emission by detailed cyclotron line shape measurements [15].

3.4. Active Galactic Nuclei

Active Galactic Nuclei (AGN) are believed to consist of an accreting supermassive black hole, where the central region is populated by a hot electron corona surrounded by an extended molecular cloud torus. Depending on the viewing angle, different types of AGNs may be observed [16]. Most AGNs detected above
~ 50 keV are either blazars (radio-loud AGNs viewed along the relativistic jet), or radio-quiet Seyferts (AGNs without strong jet emission).

Blazars show important flaring activity on timescales of days and less, and obey a characteristic spectral turnover at MeV energies. In the X-/γ-ray domain, blazar emission is generally interpreted as inverse Compton radiation generated by relativistic electrons on soft photons. At soft X-ray energies, a synchrotron component from relativistic electrons and eventually a thermal accretion disk component may contribute. The most pertinent questions on which INTEGRAL may shed new light is the nature of the primary accelerated particles in the jet (leptons or hadrons) and the origin of the soft photons in leptonic jets (synchrotron self compton or external Compton scattering). Eventually, the detection of positron annihilation features by INTEGRAL may reveal information about the jet composition.

Radio-quiet Seyferts are generally only detected up to a few 100 keV, showing a thermal Comptonisation spectrum with an exponential cut-off. The emission source is typically located above the surface of the accretion disk, by which it is Compton reflected. Yet, the origin of the incident primary radiation is much less understood. Key observables, that will be provided by INTEGRAL, are the spectral shape at hard X-ray/soft γ-ray energies (break or cut-off) to determine the origin of the radiation. In addition, the contribution of non-thermal processes, such as jet emission, can be constrained. High-energy observations can determine the fraction of non-thermal processes, such as the acceleration of electrons (or electron-positron pairs) to relativistic energies. This results in a high-energy tail that is either due to Compton scattering by relativistic electrons or due to electron-positron annihilation from pair cascades.

INTEGRAL may also play a fundamental role in establishing the evolutionary link between galaxy mergers and AGNs. It is believed that galaxy mergers and interactions lead to infrared luminous galaxies which harbor AGN that are fueled and uncovered as the dust settles. In the optical domain, dust obscuration hides the potential AGN which prevents the verification of this scenario. In contrast, due to the penetrating nature of γ-rays, INTEGRAL observations may reveal the hidden AGN in infrared luminous galaxies.

3.5. Gamma-ray bursts

Owing to the large FOVs of IBIS and SPI, about 12 γ-ray bursts per year are expected to be detected by the instruments on INTEGRAL. Although no onboard burst localisation is foreseen, the realtime telemetry allows for a rapid burst localisation with arcmin precision within a typical alert time of ~ 30 seconds after burst occurrence. For this purpose, a special Integral Burst Alert System (IBAS) has been installed at the Integral Science Data Centre (ISDC). If the burst occurs in the (smaller) FOV of the optical monitor aboard INTEGRAL, a rapid reconfiguration procedure of the OMC has been foreseen in order to obtain images in the visible band around the estimated burst location. Thus INTEGRAL may provide itself optical counterpart identifications, although the small OMC FOV (5° × 5°) make such events probably rather rare.

With an effective area of ~ 3000 cm², the SPI anticoincidence shield, operating above ≤ 100 keV, provides an excellent large area detector that may also be used for GRB detection. It is expected that it may detect several hundred bursts per year, which will be dated to 50 ms accuracy. By adding this timing information to that of other satellites in the interplanetary network of GRB
detectors, it is expected to localise GRBs to within an area of 8 square arcminutes.

4. Diffuse emission

4.1. Galactic continuum emission

Measurements of the galactic continuum emission in the hard X-ray/soft \( \gamma \)-ray band is inherently difficult because of the presence of numerous transients and variable discrete sources in the galactic plane, and the fact that X-/\( \gamma \)-ray telescopes either have large fields of view and no imaging capabilities, or have imaging capability but no diffuse emission sensitivity. INTEGRAL, with its complement instruments IBIS (high angular resolution) and SPI (good diffuse emission sensitivity), provides an unprecedented combination that finally will allow for an accurate separation of point source and diffuse emission components.

In the continuum energy range where INTEGRAL is most sensitive (few tens of keV to few MeV), the galactic ridge emission is composed of (1) transient discrete sources, (2) the positron annihilation line and 3 photon continuum, (3) a soft \( \gamma \)-ray component (\( \lesssim 300 \) keV) of uncertain origin, and (4) a hard \( \gamma \)-ray component (\( \gtrsim 500 \) keV) which is likely due to interaction of cosmic-rays with the interstellar medium. The origin of the soft \( \gamma \)-ray component is certainly one of the key questions that will be addressed by INTEGRAL. If it is made of hard, discrete sources, IBIS should be able to unveil at least some of them. However, it may turn out that the soft \( \gamma \)-ray component is intrinsically diffuse, likely due to low-energy cosmic ray electrons that undergo Bremsstrahlung while encountering the interstellar medium.

4.2. Positron annihilation signatures

The 511 keV gamma-ray line due to annihilation of positrons and electrons in the interstellar medium has been observed by numerous instruments. At least two galactic emission components have been identified so far: an extended bulge component and a disk component. Indications of a third component situated above the galactic centre have been reported, yet still needs confirmation.

The galactic disk component may be explained by radioactive positron emitters, such as \(^{26}\)Al, \(^{44}\)Sc, \(^{56}\)Co, and \(^{22}\)Na. The origin of the galactic bulge component is much less clear, and will be one of the key-questions addressed by INTEGRAL. SPI will provide a detailed map of 511 keV emission from the Galaxy. Using this map, the morphology of the galactic bulge can be studied in detail, and the question on the contribution of point sources to the galactic bulge emission can be addressed. In particular, the ratio between bulge and disk emission, which is only poorly constrained by existing data, will be measured more precisely, allowing for more stringent conclusions about the positron sources of both components. The 511 keV map will also answer the question about the reality of the positive latitude enhancement, which may provide interesting clues on the activity near to the galactic nucleus.

The 511 keV line shape carries valuable information about the annihilation environment which will be explored by SPI. The dominant annihilation mechanism sensitively depends on the temperature, the density, and the ionisation fraction of the medium, and the measurement of the 511 keV line width allows the determination of the annihilation conditions. Observations of a moderately broadened 511 keV line towards the galactic centre indicate that annihilation in the bulge...
mainly occurs in the warm neutral or ionised interstellar medium \cite{21}. By making spatially resolved line shape measurements, SPI will allow to extend such studies to the entire galactic plane, complementing our view of galactic annihilation processes.

With its good continuum sensitivity, SPI will also be able to detect the galactic positronium continuum emission below 511 keV. The intensity of this component with respect to that of the 511 keV line carries complementary information about the fraction $f$ of annihilations via positronium formation, probing the thermodynamical and ionisation state of the annihilation environment \cite{22}.

### 4.3. Galactic 1.809 MeV line emission

The COMPTEL telescope aboard CGRO has provided the first all-sky map of the distribution of the radioactive $^{26}$Al isotope that, with a lifetime of $\sim 10^6$ years, is an unambiguous proof that nucleosynthesis is still active in our Galaxy \cite{23}. The 1.809 MeV $\gamma$-ray decay line map shows the galactic disk as the most prominent emission feature, demonstrating that $^{26}$Al production is clearly a galaxywide phenomenon. The observed intensity profile along the galactic plane reveals asymmetries and localised emission enhancements, characteristic for a massive star population that follows the galactic spiral structure. By refining the knowledge about the 1.809 MeV emission distribution, SPI will provide a unique view on the star formation activity in our Galaxy.

A precise determination of the 1.809 MeV latitude profile by SPI will provide important information about the dynamics and the mixing of $^{26}$Al ejecta within the interstellar medium. High velocity $^{26}$Al has been suggested by measurements of a broadened 1.809 MeV line by the GRIS spectrometer \cite{24}, although this observation is at some point at odds with the earlier observation of a narrow line by HEAO 3 \cite{25}. In any case, the propagation of $^{26}$Al away from its origin should lead to a latitude broadening with respect to the scale height of the source population, and the observation of this broadening may allow the study of galactic outflows and the mass transfer between disk and halo of the Galaxy. The excellent energy resolution of SPI will easily allow to decide whether the 1.809 MeV line is broadened or not, and the improved angular resolution and sensitivity with respect to COMPTEL will allow to determine the scale height of the galactic $^{26}$Al distribution much more precisely.

The energy resolution of SPI of $\sim 2.5$ keV at 1.809 MeV converts into a velocity resolution of $\sim 400$ km s$^{-1}$, allowing for line centroid determinations of the order of 50 km s$^{-1}$ for bright emission features. Thus, in the case of an intrinsically narrow 1.809 MeV line, line shifts due to galactic rotation should be measurable by SPI \cite{22}. Although this objective figures certainly among the most ambitious goals of SPI observations, a coarse distance determination of 1.809 MeV emission features based on the galactic rotation curve seems in principle possible.

### 4.4. Galaxy intrachannel emission

Recent radio, EUV and X-ray observations suggest that clusters of galaxies contain large populations of non-thermal relativistic and/or superthermal particles \cite{27}. These particles may be produced by acceleration in cluster merger shocks, AGNs, and supernova explosions in cluster galaxies. 20 – 100 keV excess emission has been reported by BeppoSAX and RXTE at a level of about 2 mCrab from the Coma cluster, yet source confusion, in particular with the nearby Seyfert 1 galaxy
X Comae, make the precise flux level uncertain. With its high angular resolution and good sensitivity, IBIS is optimally suited to disentangle the various source contributions, and to allow a precise determination of the non-thermal intracluster emission. Hard X-ray observations of intracluster gas directly yield the mean strength of the magnetic fields and energy density of relativistic electrons.

5. Nucleosynthesis

5.1. Supernovae

Supernovae are the most prolific nucleosynthesis sites in the universe, producing a large variety of chemical elements that are ejected into the interstellar medium by the explosion. Among those are radioactive isotopes (such as $^{56}\text{Ni}$) that decay under gamma-ray line emission with lifetimes that are sufficiently long to allow escape in regions that are transparent to gamma-rays.

Type Ia events are easier to observe than the other supernova classes because they produce an order of magnitude more radioactive $^{56}\text{Ni}$ than the other types, and because they expand rapidly enough to allow the gamma-rays to escape before all the fresh radioactivity has decayed. From the SPI sensitivity and the observed type Ia supernova rates together with standard models of type Ia nucleosynthesis, one may estimate the maximum detectable distance for a type Ia event to about 15 Mpc and the event frequency to one event each 5 years [28]. Hence, during an extended mission lifetime of 5 years, SPI has statistically spoken the chance to detect one such event, which would provide important clues on the nature of the explosion mechanism.

5.2. Supernova remnants

Unveiling historic supernovae by searching for the $\gamma$-ray lines from the radioactive decay of $^{44}\text{Ti}$ is a further key science objective of INTEGRAL. The proof of principle has been achieved by the observation of 1.157 MeV $\gamma$-ray line emission from the 320 years old Cas A supernova remnant using the COMPTEL telescope [29]. Evidence for another galactic $^{44}\text{Ti}$ source (RX J0852.0-4622) has been found in the Vela region where no young supernova remnant was known before [30]. Given the marginal detection of the 1.157 MeV line from RX J0852.0-4622, a confirmation by SPI will be crucial for the further understanding of this object. $^{44}\text{Ti}$ line-profile measurements will provide complementary information on the expansion velocity and dynamics of the innermost layers of the supernova ejecta. The regular galactic plane scans and the deep exposure of the central radian that INTEGRAL will perform during the core program will lead to a substantial build-up of exposure time along the galactic plane, enabling the detection of further hidden young galactic supernova remnants through $^{44}\text{Ti}$ decay. The observed supernova statistics may then set interesting constraints on the galactic supernova rate and the $^{44}\text{Ti}$ progenitors. Indeed, actual observations already indicate that some of the galactic $^{44}\text{Ca}$ may have been produced by a rare type of supernova (e.g. Helium white dwarf detonations) which produces very large amounts of $^{44}\text{Ti}$ [31].
6. Conclusions

The list of INTEGRAL science prospects given above is by far not complete. In addition, studies of supernova remnants, Wolf-Rayet and Be stars, unidentified EGRET sources, cosmic background, $^{60}$Fe and nova nucleosynthesis, and the observation of nuclear interaction and neutron capture lines are on the menu of INTEGRAL science prospects, illustrating the richness of sources and the variety of information that can be obtained in the hard X- to soft $\gamma$-ray domain [32]. The combination of high angular resolution (IBIS) with excellent spectral resolution (SPI), covering the X-ray (JEM-X) to $\gamma$-ray band, provides a unique instrument configuration that has the potential to explore the high-energy universe far beyond the established horizon.

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