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GRI: focusing on the evolving violent Universe

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Abstract The Gamma-Ray Imager (GRI) is a novel mission concept that will provide an unprecedented sensitivity leap in the soft gamma-ray domain by using for the first time a focusing lens built of Laue diffracting crystals. The lens will cover an energy band from 200 - 1300 keV with an effective area reaching 600 cm^2. It will be complemented by a single reflection multilayer coated mirror, extending the GRI energy band into the hard X-ray regime, down to $\sim$10 keV. The concentrated photons will be collected by a position sensitive pixelised CZT stack detector. We estimate continuum sensitivities of better than 10^{-7} ph $\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{keV}^{-1}$ for a 100 ks exposure; the narrow line sensitivity will be better than 3×10^{-6} ph $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for the same integration time. As focusing instrument, GRI will have an angular resolution of better than 30 arcsec within a field of view of roughly 5 arcmin - an unprecedented achievement in the gamma-ray domain. Owing to the large focal length of 100 m of the lens and the mirror, the optics and detector will be placed on two separate spacecrafts flying in formation in a high elliptical orbit. R&D work to enable the lens focusing technology and to develop the required focal plane detector is currently underway, financed by ASI, CNES, ESA,

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and the Spanish Ministery of Education and Science. The GRI mission is proposed as class M mission for ESAs Cosmic Vision 2015-2025 program. GRI will allow studies of particle acceleration processes and explosion physics in unprecedented detail, providing essential clues on the innermost nature of the most violent and most energetic processes in the Universe.

Keywords gamma-ray astronomy · mission concepts · crystal lens telescope · multilayer-coated mirror telescope · Cosmic Vision 2015-2025

1 INTRODUCTION

Following 4 years of successful operations, INTEGRAL has significantly changed our vision of the gamma-ray sky [10]. The telescopes aboard the satellite have revealed hundreds of sources of different types, new classes of objects, extraordinary and puzzling views of antimatter annihilation in our Galaxy, and fingerprints of recent nucleosynthesis processes. With the wide fields of view of the IBIS and SPI telescopes, INTEGRAL is an exploratory-type mission [11] that allows extensive surveys of the hard X-ray and soft gamma-ray sky, providing a census of the source populations and first-ever all-sky maps in this interesting energy range. The good health of the instruments allows continuing the exploration during the upcoming years, enabling INTEGRAL to provide the most complete and detailed survey ever, which will be a landmark for the discipline throughout the next decades.

Based on the INTEGRAL discoveries and achievements, there is now a growing need to perform more focused studies of the observed phenomena. High-sensitivity investigations of point sources, such as compact objects, pulsars, and active galactic nuclei, should help to uncover their yet poorly understood emission mechanisms. A deep survey of the galactic bulge region with sufficiently high-angular resolution should shed light on the still mysterious source of positrons. And a sensitivity leap in the domain of gamma-ray lines should allow the detection of nucleosynthesis products in individual supernova events, providing direct insights into the physics of the exploding stars.

Technological advances in the past years in the domain of gamma-ray focusing using Laue diffraction have paved the way towards a new gamma-ray mission that can fulfil these requirements. Laboratory work and balloon campaigns have provided the proof-of-principle for using Laue lenses as focusing devices in gamma-ray telescopes [9, **?**,1, 7], and concept studies by CNES and ESA have demonstrated that such an instrument is technically feasible and affordable [6, **?**]. Complemented by a hard X-ray telescope based on a single-reflection multilayer coated concentrator, a broad-band energy coverage can be achieved that allows detailed studies of astrophysical sources at unprecedented sensitivity and angular resolution, from $\sim$ 10 keV up to at least 1 MeV.

Bringing our scientific requirements into the context of these technological achievements, we started a common effort to define the scenario for a future gamma-ray mission that we baptised the *Gamma-Ray Imager* (GRI). The GRI mission fits well into the framework of ESA's Cosmic Vision 2015-2025 planning, and it will provide a perfect successor for INTEGRAL in that it will considerably deepen the study of the phenomena unveiled by the observatory. In response to the first Announcement of Opportunity of the Cosmic Vision program, a class M mission proposal has been submitted recently to ESA. Figure 1 shows an artists view of the GRI mission deployed

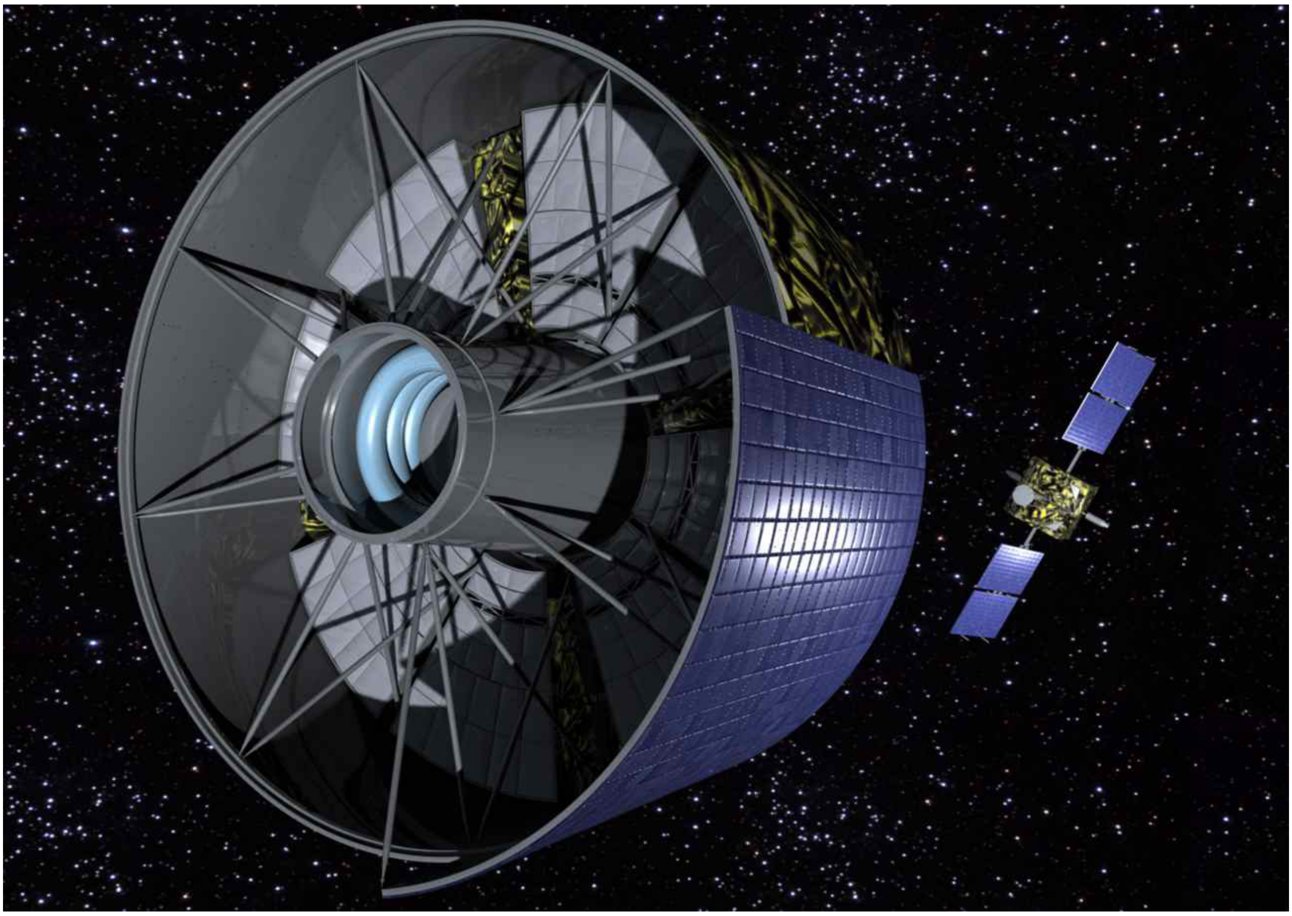

Fig. 1 The GRI mission deployed in space. GRI is composed of two spacecrafts flying in formation at a distance of 100 m. The Optics Spacecraft (front) carries the Laue crystal lens and the multilayer coated single reflection mirror payloads that concentrate incoming hard X-rays and soft gamma-rays onto a focal spot situated 100 m behind the spacecraft. The Detector Spacecraft (back), carrying the detector payload, is placed at the location of the focal spot to collected the concentrated photons.

in space. The image is based on the GRI mission concept study conducted by Thales Alenia Space in the context of the GRI Cosmic Vision proposal.

2 GRI SCIENCE

Many fundamental questions of modern astrophysics are related to the extremes of our Universe: extreme energies that drive powerful stellar explosions and accelerate particles to macroscopic energies, extreme densities that modify the laws of physics around the most compact objects known, and extreme fields that influence the matter in a way that is unexplorable on Earth. The Gamma-Ray Imager (GRI) will explore these extremes via focused observations in the hard X-ray and soft gamma-ray bands. For the first time ever in this domain, focusing technologies will be employed to concentrate high-energy photons onto a small focal spot. Focusing will bring the long awaited sensitivity leap, lifting the veil of the extreme Universe. The main science questions that GRI will address and that drive the mission design are:

- **How do supernovae explode?** GRI will measure gamma-ray line and continuum light curves and line shapes of radioactive decay products in thermonuclear explosions. This will unveil the Type Ia supernova explosion mechanisms and provides the key to understand the variety of the SN Ia phenomena. Furthermore, the GRI observations will provide a calibration of the SN Ia luminosities as required for accurate measurements of the cosmic acceleration.
- **What is the origin of the soft gamma-ray background radiation?** GRI will determine the spectral properties of accretion and jet dominated AGN (continuum shapes, cut-off energies). The characterisation of AGN high-energy spectra will constrain their contributions to the cosmic background radiation, and will probe their radiation physics.
- **What links jet ejection to accretion in black hole and neutron star systems?** GRI will measure spectral properties during state transitions, determine the polarization of the emission, and search for annihilation signatures. These measurements will reveal how the state transitions are triggered. Furthermore they will constrain the system geometries, and determine the nature of the emitting hot plasma.
- **How are particles accelerated to extreme energies in the strongest magnetic fields?** GRI will perform phase resolved spectroscopy of pulsars and determine the polarization of the high-energy emission, constraining thus the geometry of pulsar magnetosphere. Moreover, GRI will measure the spectral properties of magnetars, determining their acceleration physics and probing QED effects in the strongest known magnetic fields.

In addition to these main objectives, GRI will also detect radioactive decay products in nearby novae or young supernova remnants, constraining their nucleosynthesis and stellar physics. Positron-electron annihilation signatures constitute an important diagnostics tool of particle populations that GRI will search for in a variety of objects such as galactic compact objects, pulsars, supernovae and supernova remnants. Particle acceleration phenomena can further be studied in supernova remnants, galaxy clusters, and gamma-ray bursts. And GRI also has the potential to constrain or even detect the products of dark matter annihilation and/or decay.

Figure 2 shows three science simulations for GRI. The left panel shows the observed spectrum for thermonuclear supernovae (SN Ia) at distances of 10 Mpc and 20 Mpc for an observing time of 1 Ms. A delayed detonation model has been assumed and the spectra have been simulated for 90 days after the explosion where the gamma-ray line intensities are at maximum. The most important lines arise from the radioactive decay of ^{56}Ni and ^{56}Co, and from electron-positron annihilation, and all of them can be clearly distinguished by GRI. GRI will measure such spectra for about 5 events per year.

The mid panel shows Seyfert spectra with different cut-off energies for a flux of 3 mCrab in the 2-10 keV energy range. The simulation clearly demonstrates the GRI capability to measure the high energy cut-off up to highest energies with unprecedented

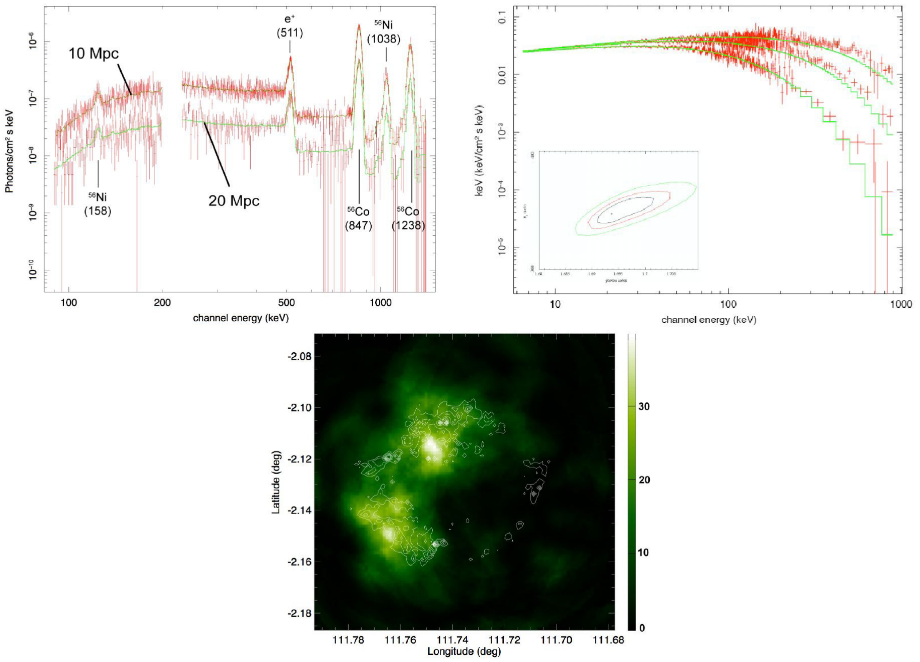

Fig. 2 GRI science simulations: *Left panel:* Type Ia supernova spectra obtained for events at 10 Mpc and at 20 Mpc, respectively. *Mid panel:* AGN spectra for different cut-off energies. *Right panel:* Image of the (assumed) spatial distribution of ^{44}Ti in the Cas A supernova remnant.

accuracy in a 100 ks observation, crucial to determine the contribution of these objects to the extragalactic diffuse background.

The right panel shows the image that GRI will obtain for a 1 Ms observation of the Cas A supernova remnant in the 68 keV decay line of ^{44}Ti. The observation has been simulated by assuming that the ^{44}Ti is distributed similar to Si, as mapped by Chandra observations (white contours). Clearly, the GRI observation will allow to localise the radioactive material in the supernova remnant, providing important insights into the dynamics and symmetry of the explosion that took place 320 years ago!

3 GRI MISSION

3.1 Mission profile

The GRI mission is composed of two spacecrafts that will be launched by a single Soyuz Fregate-2B launch from Kourou. The optics spacecraft (OSC) carries a multilayer coated single-reflection mirror and a Laue crystal lens that focus incoming gamma-rays onto a focal spot situated at a distance of 100 m. The detector spacecraft (DSC) carries a position sensitive detector, and will be placed in the focal spot to collect the concentrated gamma-rays. Figure 3 illustrates the GRI mission profile. Both satellites will be launched stacked in a circular 300 km parking orbit (a similar to the configuration that has been proposed and validated for the Simbol-X and XEUS missions). The heavier OSC will be placed at the bottom, and will be supported by the Soyuz-Fregate standard adapter (1194-SF). The lighter DSC will be placed on top of the OSC. For this purpose the OSC is equipped with a support cone with a DSC interface diameter of 937 mm. With an overall mass budget of 2340 kg, and including the necessary S/C adapter, the GRI total launch mass (including margins) amounts to 2327 kg, leaving a performance margin of 13 kg with respect to the launcher performances

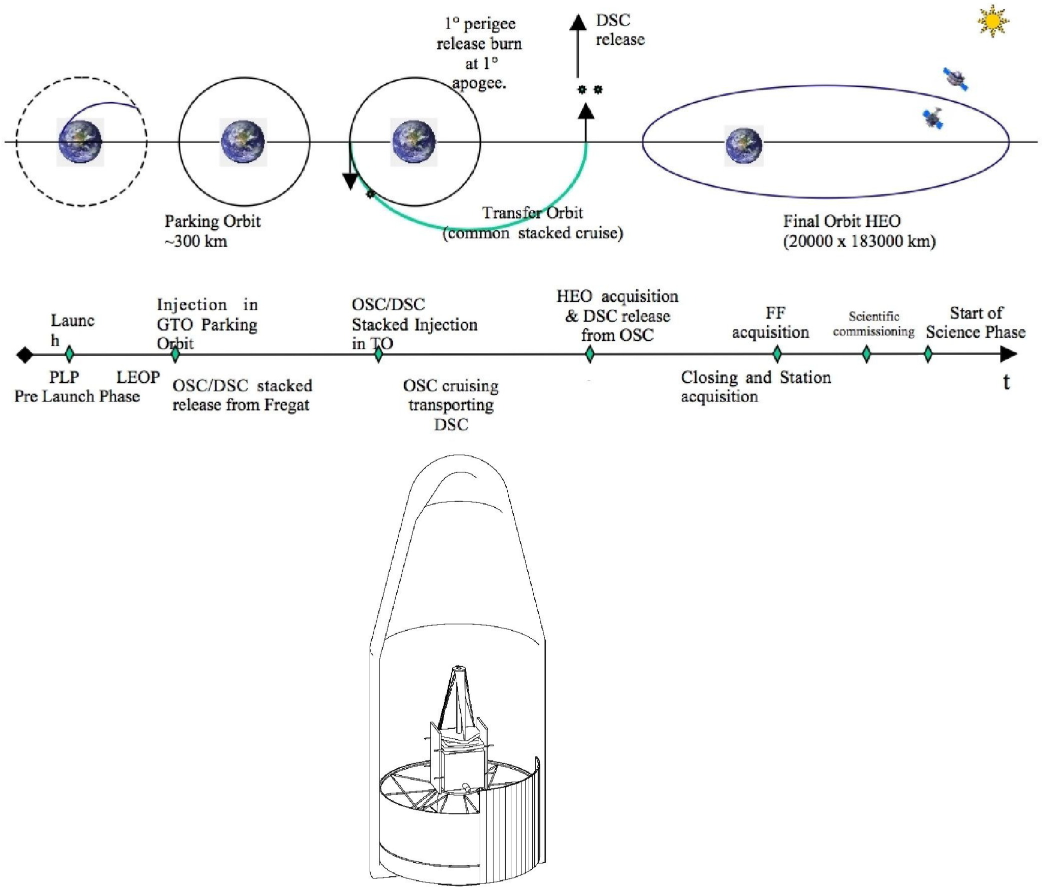

Fig. 3 GRI mission profile (*left*) and launch configuration (*right*).

Using the OSC propulsion system, the satellites are then injected stacked into a transfer orbit to reach a final highly eccentric orbit (HEO). A HEO operational orbit with perigee between 15000 - 20000 km provides the best conditions for mission maintenance, formation flying control, ground station link as well as scientific efficiency. The apogee of the orbit will be at 183000 km, leading to a revolution period of 4 days (the orbit is identical to that proposed and validated for the Simbol-X mission). Once in final orbit, both satellites will be separated, acquire the Sun, and put into formation. After a scientific commissioning phase, a science phase of 3 + 1 years will follow.

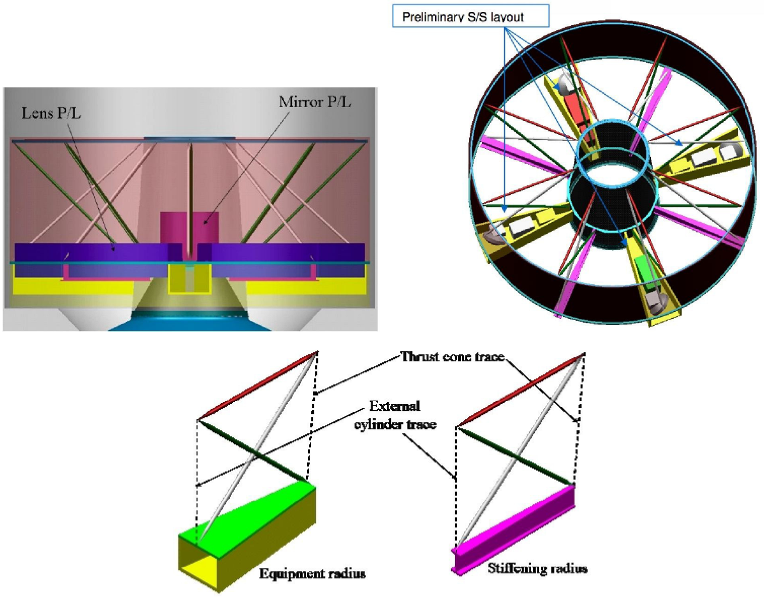

Fig. 4 Overview over the OSC design. From left to right: OSC configuration, preliminary sub-systems layout, and radius.

3.2 Optics Spacecraft

For the optics spacecraft (OSC) we propose a specific satellite development that aims in the maximization of the surface area usable for the collection of gamma-rays, while satisfying the launch and operational constraints of the GRI mission. A specific OSC design study in the context of the Cosmic Vision proposal has been performed by TAS-I Turin. While the OSC requires a dedicated solution, the S/C can be equipped with standard equipment at sub-system level, with advantages in terms of cost and reliability. The OSC preliminary design concept is based on XEUS heritage for the wheel geometry and truss support structure. It consists of a thrust cone, four equipment radius, four stiffening radius, eight sets of reinforcement rods and an external cylindrically drum to close the load flux (cf. Fig. 4). The thrust cone reaches from the launcher interface ring through the OSC to the DSC interface ring, allowing for the launch of both S/C in a stacked configuration. The four equipment radius host the main S/C sub-systems.

In order to have the electrical power generation compatible with the constraints of the OSC geometry, a system based on solar photovoltaic cells mounted on the OSC drum has been considered. The cells have been sized for a Sun aspect angles of ±20°. To allow also larger solar aspect angles, required for the survey of supernovae, a specific mode has been considered where all systems are powered from battery with autonomy of 2-3 hours. In this case, the solar aspect angle can be extended to ±80°.

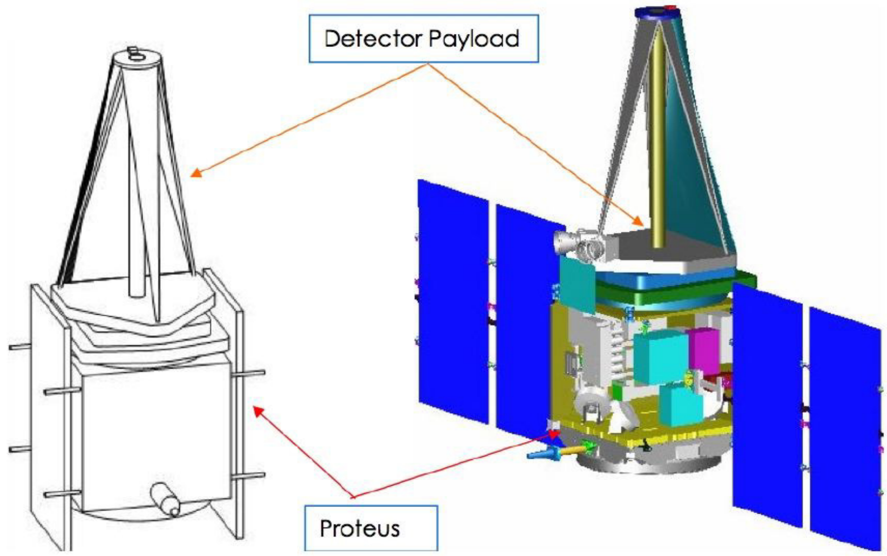

Fig. 5 DSC with integrated payload.

3.3 Detector Spacecraft

For the detector spacecraft (DSC) we propose the utilization of the TAS-F PROTEUS satellite, a multi-purpose platform developed for the so-called mini satellites family that is flight proven with the successful launch of the JASON-1 and COROT satellites. The use of the qualified PROTEUS platform for GRI leads to reduced risks, cost minimization, and simplifies the qualification and AIT sequence. The robust and reliable PROTEUS structure is composed of an aluminium rod assembly forming a cube (1 m long) stiffened by sandwich panels. It acts as primary structure and guarantees the transfer of main loads from payload to launcher through a fully machined aluminium frame. The PROTEUS structure was qualified on former programs for payloads up to 300 kg and is thus fully compliant with the payload mass of 120 kg. The payload telemetry of 120 kbps is compatible with the PROTEUS standard capability.

3.4 Formation flying metrology

The GRI telescope is split into two satellites: the OSC carrying the lens and the mirror and the DSC maintains actively an accurate formation flight (position and orientation) with respect to the OSC at the focal length of 100 m. For the observation, the formation flight maintains an inertial pointing towards the source, requiring an absolute accuracy of 10 arcsec. The OSC is in charge of controlling its attitude using Reaction Wheels, which are unloaded by the chemical propulsion system. The precision of the star trackers will allow to determine the effective OSC pointing to an accuracy of 3 arcsec.

The GRI formation flying control is based on the relative position measurement performed by the metrology devices. On the basis of the measured relative OSC/DSC

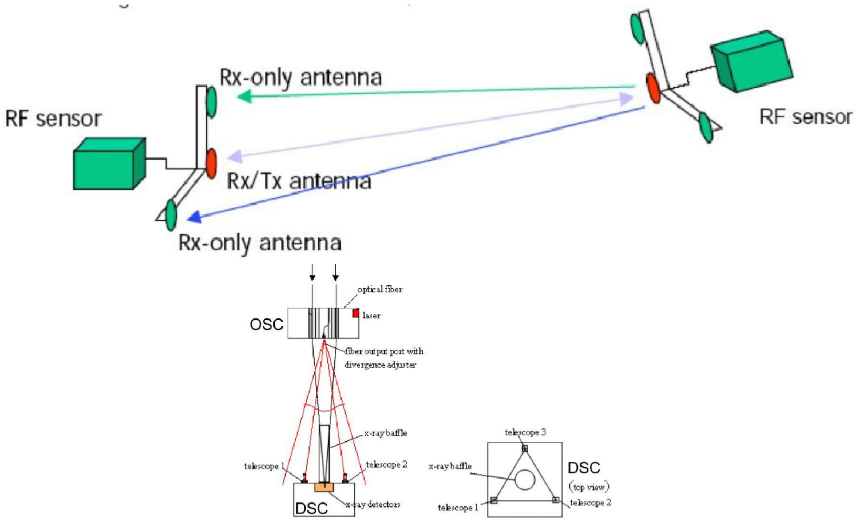

Fig. 6 Formation flying metrology of GRI. *Left panel:* RF metrology and mounting scheme. *Right panel:* HDOM metrology and mounting scheme.

position, the DSC onboard computer elaborates thanks to dedicated software the alignment and attitude errors to be compensated by the means of cold gas thrusters.

Reorientation to a new science target is performed by slewing the OSC and translating and slewing the DSC in order to maintain its focal position. Typically, 20° rotations are performed in roughly 2 hours, with a cold gas reserve for 800 target changes.

Two types of metrology systems are foreseen: RF metrology and optical metrology. The proposed RF sensor has been designed by TAS-F and belongs to the coarse metrology sensors family, providing longitudinal ranging measurements and bearing angles for azimuth and elevation determination. The RF metrology offers also an inter-satellite data-link (ISL), which will be used for HK data transfer from OSC to DSC, OSC commanding and time coordination (bi-directional throughput of 10 kbps). The following equipment is foreseen: On the OSC, a total of 6 antennae are installed, where 3 are facing the DSC in formation flying condition, and 3 are facing opposite to provide 4π coverage for safety reasons. Symmetrically, 6 antennae are installed on the DSC, 3 facing the OSC and 3 on the opposite side. Each set of 3 antennae are placed in a L shape configuration (Fig. 6).

A Hexa-Dimensional Optical Metrology (HDOM) system provides the 3D position and 3D orientation of the DSC relative to the reference frame of the OSC. The HDOM, developed by TAS-I, has been considered for GRI because of the robustness in luminous environments, allowing for very wide solar aspect angles of ±80° as required for the supernova survey. The HDOM system elements are split between the two satellites (Fig. 6). The relatively weak requirements of the GRI mission leave generous performance margins.

4 GRI PAYLOADS

The GRI payload is composed of a Laue crystal lens, a multilayer-coated single-reflection mirror and a focal plane detector. The lens and the mirror are placed on the OSC while the focal plane detector is placed on the detector spacecraft DSC.

4.1 Laue lens payload

The Laue lens payload consists of a broad-band gamma-ray lens based on the principle of Laue diffraction of photons in mosaic crystals. Each crystal can be considered as a little mirror which deviates gamma-rays through Bragg reflection from the incident beam onto a focal spot. Although the Bragg relation $2d \sin\theta = nhc/E$ implies that only a single energy E (and its multiples) can be diffracted by a given crystal, the mosaic spread $\Delta\theta$ that occurs in each crystal leads to an energy spread $\Delta E \propto (\Delta\theta)E^2$ (d is the crystal lattice spacing, θ the Bragg angle, n the diffraction order, h the Planck constant, c the speed of light and E the energy of the incident photon).

Placing the crystals on concentric rings around an optical axis, and the careful selection of the inclination angle on each of the rings, allows then to build a broad-band gamma-ray lens that has continuous energy coverage over a specified band. Since large energies E_1 imply smaller diffraction angles θ, crystals diffracting large energies are located on the inner rings of the lens. Conversely, smaller energies E_2 imply larger diffraction angles and consequently the corresponding crystals are located on the outer rings.

The lens payload consists of a set of 8 petals, each of which is interfacing at 3 points with the OSC (one point on the thrust cone, one on an equipment radius and one on a stiffening radius). This concept (illustrated in Fig. 7) is inspired from the XEUS MSC design, and allows a good lens payload modularity, with advantages in terms of feasibility, testability and production. Each petal has an opening angle of 36.4° and a length of 121 cm, and is composed of a SiC frame and support structure. Each petal will be divided into 22 sub-sectors that hold the crystal modules. Two options for the assembly of crystals on these modules are currently under study in dedicated industrial studies (CNES funded: contractor TAS-F Cannes; ESA funded: contractor TAS-I Milano).

4.2 Multilayer coated mirror

The payload consists of a multilayer coated single reflection mirror that acts as a concentrator for hard X-rays comprised in the energy band from 10 to 300 keV. We propose to use the high performance Si-pore optics developed by ESA within the XEUS mission concept to realize a light-weight mirror substrate [2]. Onto this substrate, depth graded multilayer coatings will be applied which act as broad band Bragg reflectors [5]. The basic principle of the mirror is very analogous to the principle used for the Laue lens payload, making use of the Bragg relation. Instead of using crystalline planes, however, the mirror employs depth graded multilayer coatings.

The mirror design is based on nested pore optics similar to that proposed for XEUS. With respect to the XEUS mission, however, the GRI mirror is significantly simplified. Firstly, instead of an approximated Wolter geometry only a single reflection

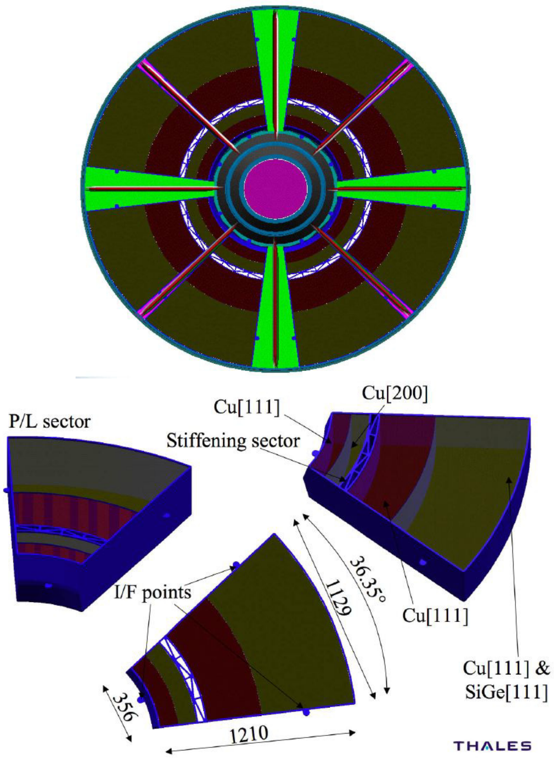

Fig. 7 Overview over the lens payload.

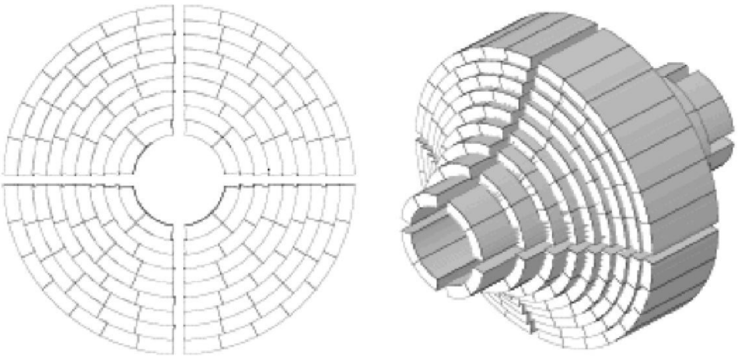

Fig. 8 Schematic representation of the mirror payload.

is used, leading to a simple concentrator with relaxed alignment constraints. Secondly, the mirror dimensions are much smaller than those foreseen for XEUS, leading to a simplified petal design providing less obscuration and simplified mounting. Thirdly, the imaging capabilities are relaxed to 10 arcsec instead of the XEUS goal of 2 arcsec, relaxing further the precision requirements for the optics.

The mirror module consists of 86 petal units. Each of these X-ray Optical Units (XOUs) needs to be aligned independently and is mounted together by special CeSiC brackets allowing for this alignment. Due to the fixed spacing of the Si wafers the inner shells need to be longer to make an effective use of the aperture. It is thus required to align several XOU's to the required precision along the optical axis. This petal structure is schematically shown in Fig. 8.

4.3 Detector

As baseline for the GRI focal plane detector, we propose a pixel CZT detector operating at room temperature that combines high detection efficiency, good spatial and good spectral resolution [4]. Instead of CZT crystals the usage of CdTe crystals could be envisioned for more effective signal compensation or improved spectroscopic performance, e.g. by the use of p-i-n contacts. Alternatively, a cooled high-purity Ge strip detector could provide an improved spectral resolution and better background rejection capabilities that potentially increase the scientific performances of GRI [12]. However, the Ge detector option implies active cooling and eventually detector annealing cycles that increase the complexity of the payload.

The GRI focal plane baseline detector is based on a position sensitive spectrometer made of 4 stacked CZT layers, surrounded by CZT side walls. The stack is composed of a 5 mm thick top layer, optimized for photoelectric absorption in the 10-250 keV band, and three bottom layers, each one 20 mm thick, to grant a total detection efficiency of better than 75% for photons below 1 MeV. In our preliminary design, the top layer is composed of 129 CZT crystals divided into 33024 pixels of 0.8×0.8 mm^2 in size. Each of the (identical) bottom layers is composed of 688 CZT crystals divided into 8384 pixels of 1.6×1.6 mm^2 in size. The crystals of the bottom layers are placed vertically, so that the interaction path for the photons amounts to 20 mm within a single crystal. In contrast to the top layer, that is biased in planar field configuration, the crystals of the bottom layers are biased in planar transverse field (PTF) configuration, resulting in small charge collection lengths of 1.6 mm, granting a good spectral resolution. The detector stack is directly exposed to the source photons focused by the lens and mirror optics, while the side wall detectors are used to collect scattered photons from the primary beam in order to maximize the full energy absorption efficiency. In our preliminary design, the side walls are made of 1344 CZT crystals divided into 4032 pixels of 6.4×6.4 mm^2 in size. The side wall has a thickness of 10 mm, and the crystals are again biased in PTF configuration. The entire detector is surrounded by a segmented veto shield made of 44 BGO modules (thickness 10 mm), which are read out through optically coupled new generation photomultiplier tubes (PMTs). On top of the detector, a baffle made of a sandwich of materials with decreasing Z (e.g. W, Sn, Cu) will allow an efficient reduction of the diffuse cosmic background for energies up to 100 keV.

Figure 9 shows the preliminary design of the GRI detector payload. The high detector segmentation will allow on the one hand for precise localisation of the photon interaction locations and for Compton polarimetry, and on the other hand for effective background rejection exploiting Compton kinematics event reconstruction techniques. Our preliminary detector design consists of 62208 individual CZT pixels and 44 PMTs.

Each CZT pixel, grouped in homogeneous families according to position, will be read out individually using a low-power charge pre-amplifier coupled through a multiplexing unit to a flash ADC. This functionality should be integrated into dedicated

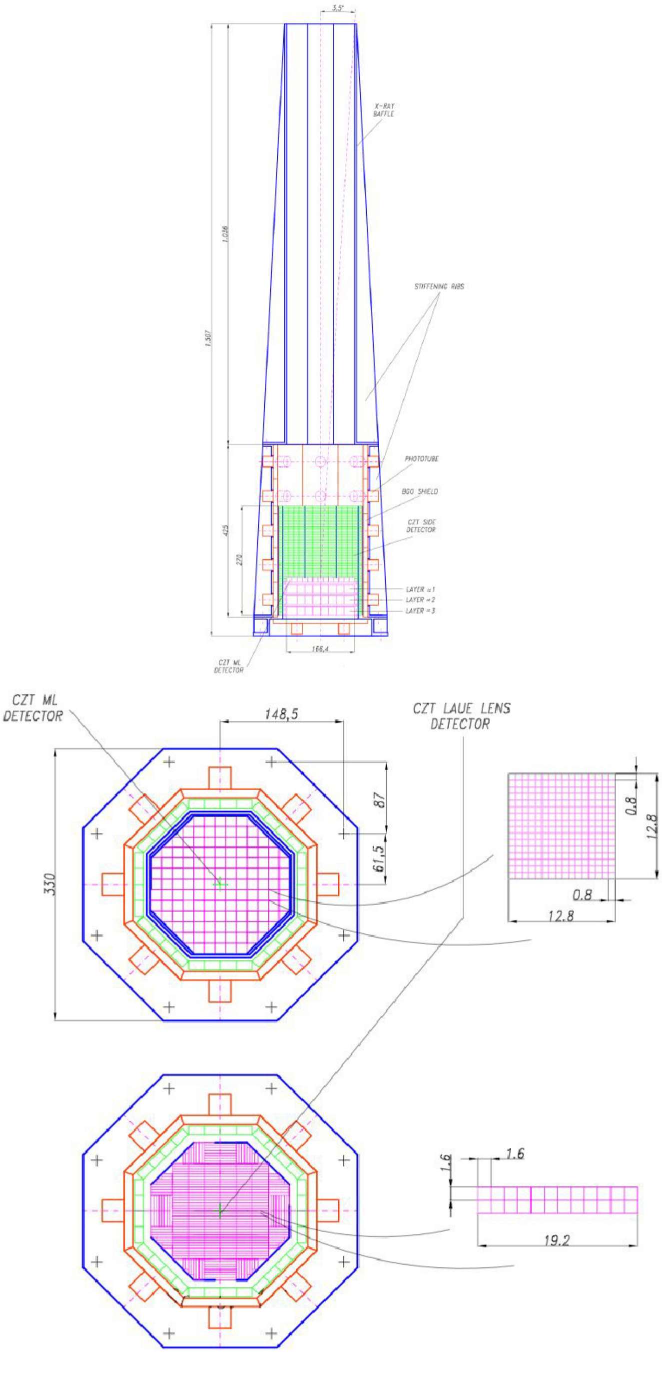

Fig. 9 Schematic representation of the detector payload.

multichannel ASICs. The ASIC outputs will be collected in the Instrument Control Unit (ICU) where a FPGA based digital processing unit provides the event characterisation (total energy deposit, interaction position, time tagging and coincidence analysis for Compton kinematics reconstructions and polarimetry analysis). The onboard event processing will lead to a significant data reduction that allows to minimize the telemetry downlink rate.

4.4 Performance assessment

The lens and mirror payload performances have been evaluated by dedicated simulation software based on ray tracing techniques. The critical performance parameters for these payloads are the expected effective area and focal spot characteristics as function of energy. For the detector payload, the most critical properties are the instrumental background and detection efficiency (which is limiting the sensitivity) and the spectral resolution (which is limiting the energy resolution). The instrumental background rates for GRI have been estimated using the measured background for the IBIS/ISGRI detector, reduced by a factor of 4 as result of a better shielding and a lighter spacecraft mass (this shielding improvement is justified by the improvement achieved on INTEGRAL/SPI with the active BGO shield). The relevant background rates depend on the focal spot size on the detector. For a mirror HPD of 10 arcsec a focal spot size of 0.2 cm^2 is expected, resulting in an active detector volume of 0.1 cm^3. For a lens HPD of 30 arcsec a focal spot size of 3.2 cm^2 is expected, resulting in an active detector volume of 21 cm^3. The expected GRI performances are summarized in Fig. 10.

5 CONCLUSIONS

The gamma-ray band presents a unique astronomical window that allows the study of the most energetic and most violent phenomena in our Universe. With ESA's INTEGRAL observatory, an unprecedented global survey of the soft gamma-ray sky is currently performed, revealing hundreds of sources of different kinds, new classes of objects, extraordinary views of antimatter annihilation in our Galaxy, and fingerprints of recent nucleosynthesis processes. While INTEGRAL provides the longly awaited global overview over the soft gamma-ray sky, there is a growing need to perform deeper, more focused investigations of gamma-ray sources, comparable to the step that has been taken in X-rays by going from the EINSTEIN satellite to the more focused XMM-Newton observatory.

Technological advances in the past years in the domain of gamma-ray focusing using Laue diffraction techniques have paved the way towards a future gamma-ray mission, that will outreach past missions by large factors in sensitivity and angular resolution. Complemented by a hard X-ray telescope based on a single-reflection multilayer coated concentrator, a broad-band energy coverage can be achieved that allows detailed studies of astrophysical sources at unprecedented sensitivity and angular resolution, from ~ 10 keV up to at least 1 MeV. We have developed a mission concept, named the *Gamma-Ray Imager*, that combines both technologies in a promising new observatory. Industry studies, conducted primarily by Thales Alenia Space and COSINE, have demonstrated that GRI is feasible and affordable within an ESA class M mission envelope. GRI is composed of two spacecrafts that will be launched by a single Soyuz Fregate-2B launch from Kourou. The optics spacecraft (OSC) carries the multilayer coated single-reflection mirror and the Laue crystal lens that focus incoming gamma-rays onto a focal spot situated at a distance of 100 m. The detector spacecraft (DSC) carries the position sensitive detector, and will be placed in the focal spot to collect the concentrated gamma-rays. The estimated continuum sensitivity is better than 10^{-7} ph $\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{keV}^{-1}$ for a 100 ks exposure; the narrow line sensitivity will be better than 3×10^{-6} ph $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for the same integration time. These sensitivities may be compared to those achieved today by INTEGRAL for the same exposure times: 3×10^{-6} ph $\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{keV}^{-1}$ at 100 keV (ISGRI) and 1×10^{-4} ph $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at 847 keV (SPI). With these unprecedented performances, a factor of more than 30 better than existing mission, GRI will allow to study particle acceleration processes and explosion physics in unprecedented depth, providing essential clues on the intimate nature of the most violent and most energetic processes in the Universe.

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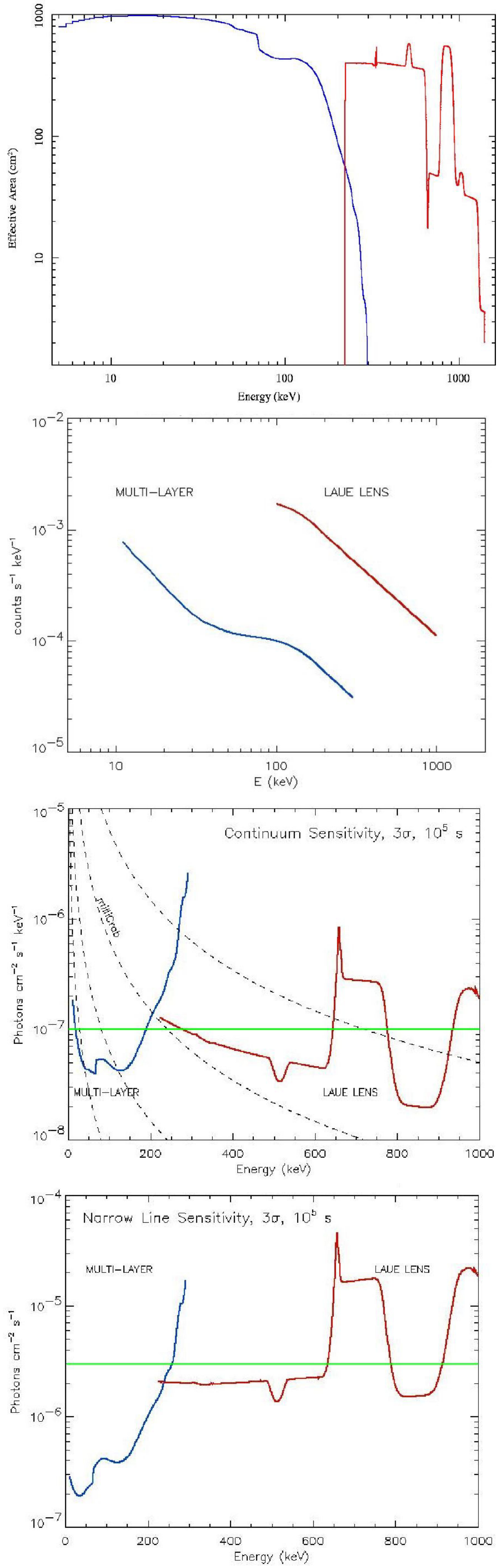

Fig. 10 Expected GRI performances. Blue lines indicate the performances of the multilayer