SEMINAIRE DE PROSPECTIVE SCIENTIFIQUE 2014

APPEL A IDEES

INTITULE DU PROJET

ASTROMEV

THEMATIQUE PRINCIPALE A LAQUELLE SE RATTACHE LA PROPOSITION

Astronomie et Astrophysique

THEMATIQUES SECONDAIRES

Physique fondamentale, Gravitation, Astroparticules

Soleil, Héliosphère, Relations Soleil-Terre, Magnétosphères terrestre et planétaire

RESPONSABLE SCIENTIFIQUE

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The remaining of this letter of intent is written in English, as being shared with our foreign collaborators. The complete list of scientists supporting the MeV roadmap described below is given on page 9 of the document.

1. A ROADMAP FOR THE MEV DOMAIN

The variety of scientific topics that can be addressed in the MeV domain (0.1 – 100 MeV) is comparable to that accessible with gamma-rays above 100 MeV (see Fermi). In addition line emission mechanisms either from nuclei, neutron capture and antimatter annihilation can be also studied in the MeV range. Questions such as the cosmic-ray origin especially in the MeV-GeV range, its propagation, the nucleosynthesis, the physics of pulsars and relativistic jets (gamma-ray bursts, microquasars, blazars), and the origin of galactic positrons can all be tackled with observations in the MeV domain. Moreover these observations can also contribute to the advancement of fundamental physics, solar or atmospheric physics.

However, the MeV domain (100 keV - 100 MeV) lags far behind compared to its neighbors (X-rays and gamma rays of high or very high energy). This delay is largely due to instrumental difficulties specific to this domain. The lack of a mirror to form images on a large field of view and focus on a small radiation detector is probably the biggest handicap. Above a few MeV, pair creation is a very specific signature of a photon and provides immediate information about its incident direction. At lower energies, however, Compton scattering takes over and the corresponding signature in the detectors can be confused with charged particle interactions, while reconstructing the incident direction becomes harder. In addition, the interaction of photons with matter attains its minimum near 1 MeV so that photons at that energy are particularly difficult to detect. Finally, MeV is the domain of nuclear γ-ray lines, which makes it extremely interesting but gives it a strong instrumental background due to the activation of irradiated materials in space.

Although remarkably successful in the field of hard X-rays and 511 keV and having produced the first solid results in gamma polarimetry, the INTEGRAL satellite has failed to outperform significantly the CGRO/COMPTEL sensitivity beyond 1 MeV.

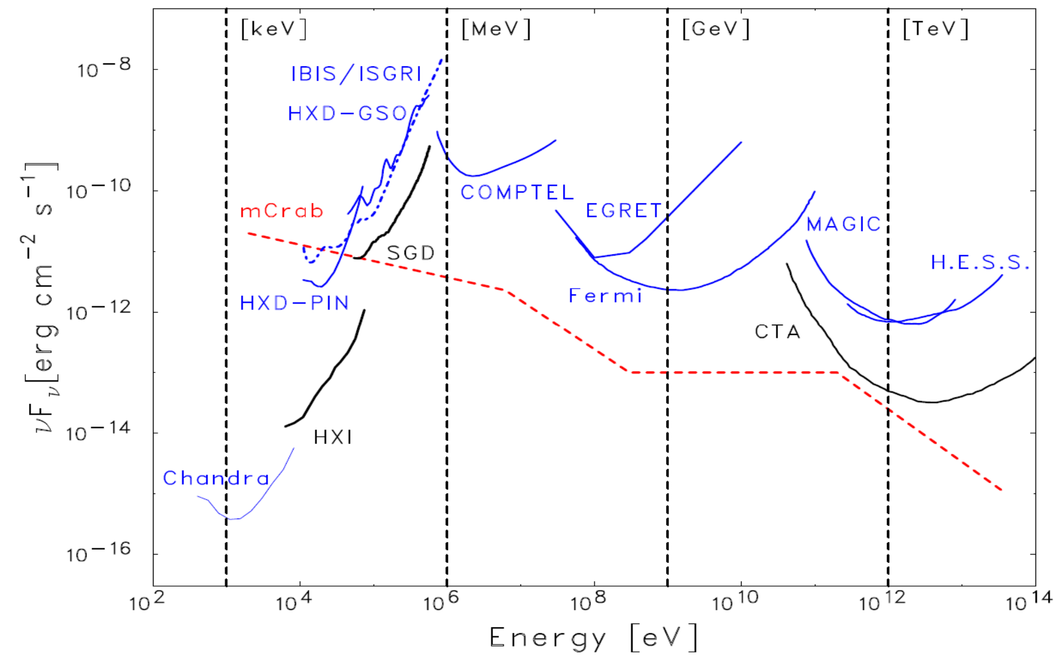

Figure 1 *Point source sensitivity of different X and γ-ray instruments (Takahashi et al. 2012). The curves for Chandra/ACIS-S, Suzaku/HXD (PIN, GSO), INTEGRAL/IBIS and ASTRO-H (HXI, SGD) are given at 3σ for 100 ks. The COMPTEL and EGRET sensitivities are given for the observing time accumulated during the whole CGRO mission (~9 years). The Fermi/LAT sensitivity is given at 5σ for a high Galactic latitude source with a 1 year observing time (Atwood et al. 2009). For MAGIC (Carmona et al. 2011), H.E.S.S. (Aharonian et al. 2006) and CTA (Actis et al. 2011) the sensitivities are given at 5σ for 50 hours.*

Since the end of the CGRO mission, many experimental designs have been proposed to surpass the performances of its instruments. This is particularly the case of the Fermi mission (2008-...) which allowed progress by a factor of 30 in sensitivity compared to the CGRO/EGRET instrument (1991-1999) which itself surpassed COS-B (1975-1982) by the same factor. We note here an improvement of three orders of magnitude in just over three decades.

With the same success, the MeV domain would have been covered by a telescope 30 times more sensitive than CGRO/COMPTEL since a few years and 1000 times more sensitive than COMPTEL in 2023. This did not happen and will not happen largely for the instrumental reasons explained above, but also because the scientific community has not managed to completely gather around a large project as in the case of Fermi. An action in this direction has been attempted in the United States at the beginning of the previous decade (Advanced Compton Telescopes) but without success, 4 experimental concepts appearing equally appealing. Experimental work continues in US with the Tiger and NCT balloon experiments. In Germany, a prototype of the MEGA telescope has been built and tested but the project was stopped in 2007. In Japan, the planned mission ASTRO-H will slightly improve the situation below 1 MeV with the SGD instrument. At ESA level, GRI was proposed for M2 and the tender for M3 resulted in three competing proposals for a MeV telescope, two in France (DUAL, CAPSiTT) and one in Germany (GRIPS). There is however little doubt that current technologies can help improve the sensitivity by two orders of magnitude in sensitivity with regard to COMPTEL.

That France has produced two of the three M3 proposals for MeV telescopes is not so surprising if one bears in mind that France with COS-B, GRANAT/SIGMA and INTEGRAL (SPI and IBIS) played a major role in gamma-ray astronomy. The French γ-ray community is undoubtedly by far the largest in Europe. However the ESA debriefing made clear that although the experimental gamma-ray community is very much alive… it does not know what the best instrumental concept is. In other words, ESA will not choose between instrumental concepts, this choice has to be made by the experts of the gamma-ray community.

It is therefore essential as a first step to bring the community, particularly in France, around a process to converge to a single instrumental concept.

This process just began with a 2-day workshop in January 2013 to define the scientific objectives in the MeV domain and the instrumental performances required to fulfill them. In parallel with the R & D lines already underway, the thinking will continue with simulation activity till an upcoming workshop (~June 2013) dedicated to the selection of an experimental design that could best meet the scientific needs expressed during the January workshop. The rest of the year 2013 will be devoted to the design optimization in order to be ready when the next AO for an M class mission (M4) will be issued by ESA. It is commonly agreed that with a maximum payload mass of 100 kg, the Myriade French microsatellites are not adapted for a general purpose gamma-ray telescope. ESA may not be the only agency offering launching opportunities for 2-ton class experiments and bilateral collaborations may also be considered.

2. R&D ACTIVITIES IN FRANCE

A number of R&D activities are or have been pursued in several laboratories that will allow the community to be at the forefront of the technological developments:

→ Laue lens at IRAP (CNES), Peter von Ballmoos responsible

→ Harpo, a time projection chamber at LLR (IN2P3): Denis Bernard responsible

→ LaBr3 as an imaging calorimeter for a Compton telescope at CSNSM (labex P2I0): Vincent Tatischeff responsible

→ CdTe strip and pixel hybrids at AIM (CEA, CNES): Olivier Limousin responsible

→ Silicon DSSD for the scatterer of a Compton telescope at IPNO (labex P2I0): Nicolas de Séréville responsible

→ Silicon DSSD for the scatterer of a Compton telescope at APC (CNES): Philippe Laurent responsible

→ Silicon DSSD for the scatterer of a Compton telescope at APC (labex UnivEarthS): François Lebrun responsible

→ Germanium DSSD for the detection plane of a gazing incidence telescope at IRAP (CNES): Jean-Pierre Roques responsible

In addition balloon experiments are considered to achieve targeted scientific goals:

- Engaged: NCT (Nuclear Compton Telescope) in US with a contribution from IRAP (Pierre Jean) and a financial support of the CNES. NCT will be launched in balloon flight in spring 2014.
- Envisioned: small Compton telescope on a CNES balloon to measure the Crab polarization at ~100 keV and raise the subsystem TRL to the level (5) requested by ESA at the end of the study phase.

3. WORKSHOP SCIENTIFIC PERSPECTIVES IN THE MEV DOMAIN

(APC, 15-16 JANUARY 2013)

The January workshop gathered about 50 scientists, mainly French, with some foreigners recognized for their expertise in a topic that MeV astronomy could advance. During these two days of intense work, two dozen of scientific objectives have been presented and their instrumental performance requirements have been expressed and discussed. All the presentations given during the workshop are accessible at the following webpage:

https://indico.in2p3.fr/conferenceTimeTable.py?confId=7243#all.detailed

At first sight, it appeared that the science accessible to a general purpose MeV telescope is as broad as that addressed by Fermi and it is difficult to pinpoint a single topic that would be emblematic. If we try to fit them in the Cosmic Vision scheme, most of them are related to theme 4.3 "the evolving violent universe" which list 3 objectives:

1. Trace the formation and evolution of the super-massive black holes at galactic centers – in relation to galaxy and star formation – and trace the life cycles of chemical elements through cosmic history
2. Examine the accretion process of matter falling into black holes by the spectral and time variability of X-rays and gamma-rays, and look for clues to the processes at work in gamma-ray bursts
3. Understand in detail the history of supernovae in our Galaxy and in the Local Group of galaxies

The particle acceleration (Supernovae, Superbubbles, Sun), the RC propagation, the pulsars and pulsar wind nebulae emission mechanisms do not fit easily in the Cosmic Vision program but are very interesting topics where the MeV window can have a decisive impact on the multi-wavelength picture.

Two talks presented the state of the art in MeV instrumentation addressing all relevant imaging techniques: coded mask telescopes, gamma-ray lens, Compton telescopes, pair telescopes, Compton and pair telescopes and time projection chambers.

The participation was very active and it was clear that there was a consensus around the idea that working out together a single instrument concept is the only viable alternative. In that sense, this workshop was a great success. This gives hope that gamma-ray astronomy may be more successful in the upcoming selections.

The main outcomes of the workshop are therefore the adhesion of the participants to a common strategy and the performances requirements of each scientific topic. The following table summarizes these requirements. The scientific case and justification for the performance requirements are given topic by topic in the annex.

Theme	Field-of-view (FWHM)	Angular resolution (FWHM)	Spectral resolution (ΔE/E @ Energy)	Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	Cont. sensitivity ($cm^{-2}s^{-1}keV^{-1}$ ΔE=E,, 3σ, 1 Ms)	Timing performance	Polarimetric capability (Minimum Polarization Fraction in Crab source in 1 Ms)	Real-time data ?
Galactic center		<0.2°	3-5 % @ 4.4 MeV	< 10^{-5} @ 4.4 and 6.2 MeV	< 5 10^{-12} erg cm^{-2} s^{-1} over the whole range			
511 keV	>60°	<1°	0.2% @ 511 keV	~ 10^{-6} @0.5 MeV	~ 10^{-8} (0.17-0.5 MeV) ~2x 10^{-9} (0.7-2 MeV)			
SN Ia			0.3%		10^{-7}			
Core collapse SN	90°		0.3%	10^{-6} @ 847 keV 10^{-7} @ 415 keV	10^{-7} @ 100 keV			
^{44}Ti	180°	1°	0.3 % @1.157 MeV	~ 10^{-6} @1.157 MeV				
Classical novae	> 180°		1-2%	6x 10^{-7} @1.3 MeV	10^{-5} 50 – 150 keV			
Continuum emission from Novae	> 180°			<4. 10^{-12} @ 100MeV				
High-energy ISM	120°	10°	10%		10^{-6} – 10^{-7}			
Nuclear gamma-ray lines from Cosmic rays	100°	1°	2% @ 5 MeV	10^{-5} @ 5 MeV	2x 10^{-8} (1-8 MeV)			
Gamma-ray binaries	60°	0.1-0.5°			10^{-9} (1-100 MeV)			
Gamma-ray lines form X-ray binaries			0.5% @ 511keV 1% @ 1.5 MeV 0.5% @ 2.2 MeV	10^{-6} @ 511 keV 7x 10^{-7} @ 1.5 MeV 10^{-6} @ 2.2 MeV				
Black Holes and accreting objects	1° ?	0.1°			10^{-9} @ 1 MeV	0.1 s	10% @ 1 MeV	

Theme	**Field-of-view (FWHM)**	**Angular resolution (FWHM)**	**Spectral resolution (ΔE/E @ Energy)**	**Line sensitivity (@ Energy) (units $cm^{-2}.s^{-1}$, 3σ, 1 Ms)**	**Cont. sensitivity (units: $cm^{-2}s^{-1}keV^{-1}$ ΔE=E,, 3σ, 1 Ms)**	**Timing performance**	**Polarimetric capability (Minimum Polarization Fraction in Crab**	**Real-time data ?**
Gamma-Ray Bursts	>180 °	0.5°	<10% @ 300 keV		5-6x10^{-8} @ 1 MeV	<10 µs	<10%	yes
Active Gal. Nuclei	60°	1- 2°	10% @ 1 MeV		5x10^{-8}			
Magnetars and isolated pulsars	120°	0.1-0.2°	<10%		30x comptel	50 µs	1%	
Pulsar wind nebulae		<0.003° < 1°			3 10^{-9} @ 1 MeV	3 ms	0.2%	
Supernova remnants superbubbles		0.05°	<10%	3x10^{-5}	3x10^{-6}			
Starburst galaxies	120°	0.1°			4 10^{-12} @ 100 MeV			
The SUN at high energy		<0.05 °	1-2 % @ 5 MeV	10^{-6} @ 1 MeV		1 ms		
Terrestrial γ-ray flashes	90°	0.05-0.1°	10%			<1 µs		
Long lived radioactive isotopes	40°	<3°	0.16 %	10^{-7} – 6 10^{-7}				
Dark matter annihilation or decay	1°	0.1-1°	10^{-6}	10^{-6} @ 511 keV	10^{-6} – 10^{-7} @ 1 MeV			
Limits of modern physics	180°	0.05°	10%			1 s	5 %	

4. SCIENTISTS SUPPORTING THIS MEV ROADMAP

AMATI, Lorenzo	INAF - IASF Bologna	Bologna, Italy
BALLET, Jean	CEA/SAp	Saclay
BECKMANN, Volker	APC/CNRS	Paris
BERNARD, Denis	LLR	Palaiseau
BUDTZ-JØRGENSEN, Carl	DTU Space	Lyngby, Denmark
BYKOV, Andrei	Ioffe Institute	St.Petersburg, Russia
CELESTIN, Sebastien	University of Orleans	Orleans
CHABOT, Marin	IPN Orsay	Orsay
CLARET, Arnaud	CEA-Saclay	Gif sur Yvette
COLLMAR, Werner	MPE	Garching, Germany
CORDIER, Bertrand	CEA-Saclay IRFU/SAP	Gif sur Yvette
DAIGNE, Frédéric	IAP	Paris
DE SEREVILLE, Nicolas	IPNO	Orsay
DUBUS, Guillaume	IPAG	Grenoble
FEINSTEIN, Fabrice	LUPM	Montpellier
FOGLIZZO, Thierry	CEA-Saclay	Gif sur Yvette
FRASCHETTI, Federico	University of Arizona	Tucson, USA
GALLANT, Yves	LUPM	Montpellier
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GOLDWURM, Andrea	APC - CEA/IRFU/SAp	Paris
GOUIFFES, Christian	CEA/SAp	Gif-sur-Yvette
HAMADACHE, Clarisse	CSNSM	Orsay
HAMMACHE, Fairouz	IPNO	Orsay
HENRI, Gilles	IPAG-Observatoire de Grenoble	Grenoble
HERMSEN, Willem	SRON	Utrecht, Netherland
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ISERN, Jordi	ICE_CSIC/IEEC	Barcelona, Spain
JEAN, Pierre	IRAP	Toulouse
KATSANEVAS, stavros	APC/CNRS	Paris
KIENER, Jurgen	CSNSM	Orsay
KNÖDLSEDER, Jürgen	IRAP	Toulouse
KRETSCHMER, Karsten	APC/CNRS	Paris
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LAVALLE, Julien	LUPM	Montpellier
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TATISCHEFF, Vincent	CSNSM	Orsay
TERRIER, Régis	APC/CNRS	Paris
VILMER, Nicole	LESIA-Paris Observatory	Paris
VON BALLMOOS, Peter	IRAP	Toulouse
VUILLAUME, Thomas	IPAG	Grenoble
ZDZIARSKI, Andrzej	N. Copernicus Astronomical Center	Warsaw, Poland

ANNEX

Scientific objectives
And
Performance requirement justification

THE GALACTIC CENTER IN THE MEV RANGE

Scientific summary :

The Galactic Centre harbors the closest supermassive black hole to Earth and is therefore a fundamental laboratory to understand the physics of these objects and their interaction with their environment. An emission coincident with the Galactic Centre position is observed all over the high energy domain and understanding its origin is crucial. Because of the extreme density of potential high energy emitters in the region a good angular resolution is mandatory.

The GC region is also the site of intense star formation and particle acceleration. There is now good evidence that the central 200 pc are pervaded by low energy cosmic-rays thanks to H_3^+ measurements. The measurement of the sub GeV cosmic-ray content can then be performed thanks to possible nuclear excitation lines and by separating the hadronic and leptonic contributions with spectral measurements in the range of tens of MeV. For the latter point, in the absence of clear spectral signatures, a good angular resolution is important to really separate diffuse processes from individual objects.

Scientific interest :

Physics of the supermassive black hole, particle acceleration and diffusion. The community involved in GC physics is large and some progress is really needed in the high energy range.

Justification of required performance :

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)		Not really constraining since the region of interest is 2° in diameter
Angular resolution (FWHM, deg)	<0.2°	For 4.4 and 6.2 MeV line, the emission will be detected with angular size beyond the degree so that this constraint can be alleviated for this specific topic
Spectral resolution (ΔE/E @ Energy)	3-5% @ 4.4 MeV	
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	$<10^{-5}$ @4.4 and 6.2 MeV	Note: over > 1 deg.
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	<5 10^{-12} erg/cm^2/s over the whole range	Sensitivity for possible Sgr A* flares would be quite high since they last ~ 1h and their peak flux is about 10^{-11} erg/cm^2/s. The sensitivity is given in energy flux since it is a general constraint on the energy range
Timing performances	No constrains	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)		
Real-time data ?		

511 keV EMISSION FROM POSITRON ANNIHILATION

Scientific summary : Positrons annihilate by emitting two photons of 511 keV and a continuum in the sub-MeV to >MeV range ; the latter emission depends on whether they form ortho-positronium (observations suggest that Galactic positrons do so, at the 95 % level) and on the speed of positrons at the time of their annhilation. Positron annihilation emission from the Galaxy is the first and strongest gamma-ray line detected so far, but its galactic distribution (with a bulge/disk ratio greater than unity) differs from those at any other wavelength. From the theoretical point of view it is unclear what are the main sources of positrons (conventional, like SNIa or Low-mass X-ray binaries, or more « exotic », like the Galactic black hole - which is notoriously inactive today- or even candidate dark matter particles) ; furthermore, positrons may propagate for several 10^5 yr far away from their sources before annihilating (depending on still poorly understood properties of Galactic ISM and magnetic fields), making it difficult to infer positron sources from the observed gamma-ray emission.

Scientific interest : Identifying the sources of positrons is of great interest for the astrophysics of stellar explosions (SNII) and of compact objects (X-ray binaries, pulsars, etc.) . Clarifying all aspects of positron propagation is of interest for cosmic-ray physicists (reacceleration processes), plasma physicists (low energy particles in a turbulent, magnetized medium) and for understanding the large scale configuration of the Galactic magnetic field.

Justification of required performance : A large field of view is required to perform a deep Galactic Survey, including regions of low surface brightness. A sub-degree angular resolution is needed to resolve the inner bulge and detect possible point sources. A line sensitivity of 10^{-6} cm^{-2} s^{-1} is necessary to detect low surface brightness regions (outside the Galactic plane) and enhanced emission from inner Bulge and star forming regions (e.g. Cygnus, spiral arms) and the LMC (which will be detected for the first time).

Performance parameter	**Goal value**	**Remarks and notes**
Field-of-view (FWHM, deg)	>1 sr	Wide-field instrument to perform a deep Galactic Survey, including regions of low surface brightness
Angular resolution (FWHM, deg)	<1	Detailed mapping of Galactic plane, including possible enhanced emission from inner Bulge and point sources.
Spectral resolution ($\Delta E/E$ @ Energy)	0.002 @ 511 keV	To detect Doppler effect due to Galactic rotation (intrinsic width of narrow line ~1 keV
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	~ 10^{-6} @0.5 MeV	To detect low surface brightness regions (outside the Galactic plane) and enhanced emission from inner Bulge and star forming regions (e.g. Cygnus, spiral arms) and the LMC
Continuum sensitivity (in which energy band?) (cm^{-2} s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	~ 10^{-8} @ 0.17 – 0.5 MeV ~ 2×10^{-9} @ 0.7 – 2 MeV	Continuum emission from Ortho-positronium and (perhaps) in-flight annihilation in the 0.3-0.5 (and 0.5-2) MeV ranges
Timing performances		
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)		
Real-time data ?		

GAMMA-RAY EMISSION FROM TYPE Ia SUPERNOVAE

Scientific summary : The amount and distribution of radioactive isotopes produced in thermonuclear supernovae, SNIa and the different subtypes, strongly depend on the stellar configuration at the onset of the explosion, on the ignition process and on the propagation mode of the flame. This means that the gamma-rays produced by these isotopes can be used as a diagnostic tool for the explosion. The most abundant products being ^{56}Ni and its radioactive chain for which reason the detection of their lines, including the annihilation one is of the maximum interest.

Scientific interest : Stellar Physicist, including Nuclear Astrophysicis (late stages of stellar evolution, physics of Coulomb plasmas, explosive nucleosynthesis…). Galactic and extragalactic Astrophysics (chemical evolution of galaxies, galactic winds, galactic distances…) and Cosmology (Dark energy)

Justification of required performance : Lines are very broad, from 5 to 10% and the Ni ones display an important time dependence. Since SN explosions cannot be predicted, the instrument has to be able to study in detail the nearby ones, <20 Mpc, and to provide the gross features of the most distant.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)		
Angular resolution (FWHM, deg)		
Spectral resolution ($\Delta E/E$ @ Energy)	~0.003	In case of nearby supernovae Lines are broad ~ 20-40 keV
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)		
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	~ 10^{-7}	To detect a significant number of SNIa/year Range 0.1 to 2 MeV
Timing performances		
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)		
Real-time data ?		

SUPERNOVAE AND RADIOACTIVITY

Scientific summary : Core collapse supernovae produce most of the intermediate mass and heaviest elements in nature and dominate energy input to the galaxy, yet the mechanism of their explosion is not well understood. High-energy observations can clarify their nucleosynthesis, dynamics, possible jet formation, and stellar mass-loss. For relatively nearby core-collapses, lines from ^{56}Co and ^{57}Co can be measured, and would be enhanced by jets and/or dynamical mixing of core material outward. Extended time coverage and/or detailed spectroscopy of the lines can clarify these conditions. Ejecta/circumstellar matter interactions can produce hard X-ray continuum emission and clarify presupernova mass-loss. Very sensitive line measurements could probe, e.g., ^{26}Al production and dynamics in the Vela supernova remnant, and r-process nucleosynthesis in galactic remnants. Observations of large quantities of ^{56}Co would show that pair instability supernovae can occur in the recent universe (a la SN 2006gy.)

Scientific interest : Stellar evolution and nucleosynthesis, nuclear astrophysics, and supernova observers at all wavelengths would be interested in the results of such a mission.

Justification of required performance :

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	>2 ster	For continued monitoring and discovery of unpredictable (e.g., csm) emission. Sensitive, narrow field instruments could achieve objectives for known SNe.
Angular resolution (FWHM, deg)	Not essential	
Spectral resolution ($\Delta E/E$ @ Energy)	1000 km/s (E/ ΔE ~ 300) at 847 keV	For discriminating location of radioactivity from spectroscopy.
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	10^{-6} $cm^{-2}.s^{-1}$ at 847 keV 10^{-7} $cm^{-2}.s^{-1}$ at e.g., 415 keV	For ^{56}Co, ^{57}Co, ^{44}Ti objectives For r-process ^{126}Sn, e.g.
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	10^{-7} cm-2 s^{-1} keV^{-1} at 100 keV	For SN ejecta/CSM interactions
Timing performances	Not applicable	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	Not applicable	
Real-time data ?	Not applicable	

^{44}TI LINE EMISSION FROM YOUNG SNRS

Scientific summary : Only a few radioactive nuclei are accessible to gamma-ray astronomy. Among them, ^{44}Ti is thought to be exclusively produced in supernova explosions of all types, during the early stages, and emits 3 lines at 67.9, 78.4 and 1157 keV during its decay ^{44}Ti → ^{44}Sc → ^{44}Ca with a lifetime of ~ 85 yrs. It is therefore an unvaluable tool for constraining the physical parameters governing the SN explosion and for finding previously-unknown young SN remnants in the Galaxy. So far, ^{44}Ti lines have been detected directly in only two SNRs (Cas A and SN 1987A), and indirectly in one other SNR (G1.9+0.3, through the ^{44}SC X-ray line emission). In order to explain the observed ^{44}Ca solar abundance, the required ^{44}Ti yield, derived from several Galactic Chemical Evolution models, is incompatible with the non-detection of any young SNR (besides Cas A) in the Galaxy by past and current gamma-ray instruments (HEAO-3, SMM, COMPTEL, INTEGRAL/IBIS).

Scientific interest : Nuclear astrophysicists (explosive nucleosynthesis and the origin of ^{44}Ca in the Galaxy) and astroparticle community (search for previously unknown young Galactic SNRs, thought to be PeV CR accelerators).

Justification of required performance :

A FOV as wide as possible will be needed to perform a Galactic Plane Survey. A 10^{-6} cm^{-2} s^{-1} line sensitivity shouldreveal a dozen of Galactic SNR and probe ^{44}Ti yields of 10^{-5} M_{o} in Tycho and Kepler type Ia SNRs, as indirectly measured in G1.9+0.3. A spectral resolution of 0.003 will allow us to measure Doppler velocities of 10^3 km s^{-1}, lower than shock speeds usually found in very young SNRs ($v_{Cas\ A}$ ~ 6.10^3 km s^{-1}), and hence to constrain the dynamics of ^{44}Ti-emitting regions.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	~ 2π sr	Wide-field instrument to perform a deep Galactic Plane Survey
Angular resolution (FWHM, deg)	~ 1	To mitigate the source confusion along the Galactic Plane
Spectral resolution (ΔE/E @ Energy)	0.003 @ 1.157 MeV	To measure Doppler velocities in SNR ejecta of ~ 1000 km s^{-1}
Line sensitivity (@ Energy) (cm^{-2}.s^{-1}, 3σ, 1 Ms)	~ 10^{-6} @1.157 MeV	To detect >10 young Galactic SNRs in the ^{44}Ti 1.157 MeV line emission
Continuum sensitivity (in which energy band?) (cm^{-2} s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)		
Timing performances		
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)		
Real-time data ?		

CLASSICAL NOVAE EXPLOSIONS

Scientific summary: In classical nova explosions γ-rays are expected from positron-electron annihilation; positrons are emitted by the β+-unstable short-lived isotopes 13N and 18F (lifetimes 862s and 158min, respectively), and to a lower extent by 22Na. Therefore, prompt emission consisting of a 511 keV line plus a continuum below this energy (with a cut-off at 20-30 keV) is expected, with very short duration. In addition, γ-ray lines at 478 keV (7Be decay in CO novae, lifetime 77 days) and 1275 keV (22Na decay in ONe novae, lifetime 3.75 years), are expected to last a couple of months and years, respectively.

Scientific interest: The detection of the prompt γ-ray emission from novae is an important challenge, which would strongly constrain theoretical models. The duration of the emission, its intensity and the width of the line are clear indicators of the dynamical properties of the envelope and the efficiency of convective mixing.The detection of the long duration γ-ray lines from novae is another interesting goal.

Justification of required performance: A FOV as wide as possible will be needed to detect the 511 keV line and the continuum below, since it has very short duration and appears before the optical discovery of the nova. On the other hand, detection of the 1275 keV only needs pointed observations.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	Very broad (511 keV line and continuum) no restrictions (478 and 1275 keV lines)	511 keV line and continuum below it can only be detected by « a posteriori » analysis of the data ; monitoring of the « whole sky »
Angular resolution (FWHM, deg)	No constrains	
Spectral resolution (ΔE/E @ Energy)	1-2%	Lines are broad with delta_E/E=1.5%
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	6 10^{-7} ph/cm2/s (for t_obs=1Ms) @ 1275keV 10^{-5} ph/cm2/s @ 511 keV (for **t_obs=1 hour**)	Detection of novae up to 5 kpc (1275 keV) ; only ONe novae ; 1/year approx. Broad line (1.5%) Detection of novae up to 5 kpc
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	(50-150) keV ≈10^{-4} ph/cm2/s/keV TBC (for **t_obs=1-2 hour**)	
Timing performances	not needed	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	not needed	
Real-time data ?	not needed	

CONTINUUM EMISSION FROM PARTICLE ACCELERATION IN NOVAE

Scientific summary : A galaxy such as our own naturally accelerates particles up to very high energies and at very high rates, compared to current human experiments. This flux of so-called cosmic rays permeates the interstellar medium and reaches any region of the galaxy. The processes by which this happens are only partially understood. The main source candidates are supernovae, through the shocks driven by their remnants in the environment, but several other powerful astrophysical objects probably contribute. These phenomena often have long evolutionary time scales, and observing them can only provide snapshots of the acceleration process, under different initial and boundary conditions. Getting a global understanding from that is thus a challenging exercise. Novae can be highly valuable here because they are to some extent nothing else than scaled-down supernova explosions, occurring much more frequently and having relatively short evolution time scales. Three novae have been detected at ~GeV energies with the Fermi/LAT (V407 Cyg, Nova Sco 2012, and Nova Mon 2012), thus opening a new dimension for cosmic ray studies.

Scientific interest : This topic should interest the large community involved in cosmic ray and particle acceleration studies, which makes up a sizable fraction of the astroparticle community. In terms of observations, particle acceleration in novae shows up predominantly in the radio, X-Ray, and gamma-ray bands, and so collaboration with the corresponding communities will be possible.

Justification of required performance : The physical modelling of the data on V407 Cyg indicates that observations in the 1-100MeV can constrain the efficiency of particle acceleration at the shock, as well as the nature of the particle radiating gamma-rays. Achieving that would require an extension of the GeV sensitivity of the Fermi/LAT instrument down to <10MeV.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	A few sr	Can be much less if instrument is to work from external triggers (optical or else…).
Angular resolution (FWHM, deg)		Not a concern, provided it does not complicate the extraction of the useful signal.
Spectral resolution (ΔE/E @ Energy)		Not a concern, but required by nuclear gamma-ray lines studies of the same novae.
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)		Not applicable.
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	$<4.10^{-12}$ @ 100MeV	Goal is a flat sensitivity of $<6.10^{-11}$ $erg/cm^2/s$ over 1-100MeV band, in order to discriminate inverse-Compton from pion decay spectrum.
Timing performances		Not applicable.
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)		Not applicable.
Real-time data ?		Not applicable.

MEV ASTRONOMY OF THE HIGH-ENERGY INTERSTELLAR MEDIUM

Scientific summary :

The MeV photon energy range is critical to understanding interstellar radiation from cosmic-ray interactions. Since it is below the pion-decay range, it is free from the hadronic component, and is instead sensitive to bremsstrahlung and inverse-Compton emission from cosmic-ray electrons and positrons. Inverse Compton emission is dominant down to about 100 keV, as has been shown using INTEGRAL SPI data. In the MeV region, the only available data are from COMPTEL, which show an apparent excess over the expection from interstellar processes, possibly due to populations of unresolved point sources. The leptonic component is relevant also to the Galactic synchrotron radiation which is a foreground for CMB studies by Planck as well as being of great intrinsic interest. Recent determinations of the ionization rate of clouds using chemistry indicate a high level due to MeV protons: this has consequences for the expected nuclear excitation lines and star formation. The Fermi Bubbles are enormous structures at GeV energies, and their origin will be better revealed with MeV observations due to their probably leptonic nature. Fermi-LAT may be extended down to at most 20 MeV, with limited angular and energy resolution, and a complemenary sky survey with comparable sensitivity below this energy is essential for the astrophysical interpretation.

Scientific interest : Cosmic-rays, radio and cosmology (Planck foregrounds), star formation (ionization), Galactic centre, AGN/starburst activity (Fermi bubbles).

Justification of required performance : Complete sky coverage is essential for large-scale diffuse emission, so that a large FWHM is desirable. The sensitivity must be sufficient to complement Fermi (>50 MeV) and not more than a factor 10 worse for 0.1-30 MeV. The values given are based on an improvement of 10-100 over COMPTEL and SPI.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	π	Need to cover whole sky (4π) but this is not a FWHM. Can be built up from many observations, even in case of a narrow field instrument. But a wide field is better for this goal.
Angular resolution (FWHM, deg)	1^o	
Spectral resolution ($\Delta E/E$ @ Energy)	10 %	Need to resolve positronium which is a competing process in the 200-500 keV range and must be distinguished from non-thermal emission.
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	-	
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1} sr^{-1}, ΔE=E, 3σ, 1 Ms)	10^{-6}-10^{-7}	Units are intensity (sr^{-1}), appropriate to extended emission. This is 10-100 better than SPI, COMPTEL.
Timing performances	-	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	-	
Real-time data ?	-	

NUCLEAR GAMMA-RAY LINES FROM LOW-ENERGY COSMIC RAYS

Scientific summary : High ionization rates of molecular hydrogen in diffuse interstellar clouds point to a distinct low-energy cosmic-ray (LECR) component. Such a hadronic component below a few hundred MeV per nucleon produces efficiently nuclear γ-ray line emission in the 0.1-10 MeV range by interactions with the interstellar gas and dust. A detection of this emission would give the clearest evidence of LECRs that escape direct observations due to the solar modulation. The objective is to detect the strongest lines, i.e. at 4.4 and 6.1 MeV from ambient ^{12}C and ^{16}O, respectively, and to map the total gamma-ray line emission from the inner Galaxy in the 0.1-10 MeV range.

Scientific interest : Astroparticle physics: extension of the cosmic-ray spectrum to low energies, cosmic-ray acceleration and propagation; nuclear astrophysics: synthesis of the light elements Li-Be-B by LECRs; astrochemistry: ionization and heating of molecular clouds.

Justification of required performance : The diffuse emission is certainly concentrated in the Galactic plane with a longitudinal profile following roughly the H_2 column density with eventual concentrations around acceleration sites. A large field-of-view is necessary for the observation of diffuse emission, ideally covering the inner Galaxy ($|l| < 60^o$). Energy resolution of the order of the width of the strongest lines at 4.4 and 6.1 MeV, Δ E ~ 100 keV. Angular resolution of the order of the Galactic latitude profile of the emission, about 1^o. The 4.4-MeV narrow line brightness from the inner Galaxy is expected to be in the range $(0.2 – 2)\times10^{-5}$ cm^{-2} s^{-1} sr^{-1} and the broadband emission (in the 1 – 3 and 3 – 8 MeV ranges) is about ten times brighter.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	2 sr	
Angular resolution (FWHM, deg)	1	
Spectral resolution (ΔE/E @ Energy)	0.02 @ 5 MeV	
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	~10^{-5} @ 5 MeV	Diffuse emission. To detect the line from the inner Galaxy.
Continuum sensitivity (in which energy band?) (cm^{-2} s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	2 10^{-8} @ 1-8 MeV	Diffuse emission. To map the broadband emission from the inner Galaxy.
Timing performances	-	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	-	
Real-time data ?	no	

GAMMA-RAY BINARIES

Scientific summary : Gamma-ray binaries are composed of a massive star and a compact object. Gamma-ray binaries have been detected from radio up to TeV gamma-rays but most of their emission is radiated in the 1-1000 MeV band, hence their name. Five systems are currently known but their Galactic population could reach several 100s. MeV observations offer the best chance to find such systems, otherwise inconspicuous at other wavelengths. Their emission from radio to VHE is variable along the orbit. Periodic MeV emission has been recently reported from one COMPTEL source, in phase with the X-ray and TeV gamma-ray emission but in anti-phase with emission in the GeV range. The variability lightcurve and the spectral shape in the MeV domain provide information on the origin of the accelerated particles, the efficiency of the acceleration process, and the amplitude of the magnetic field. Gamma-ray binaries are thought to be powered by the spindown of a young pulsar, whose relativistic wind interacts with the stellar wind of its stellar wind on spatial scales much smaller than in pulsar wind nebulae. Gamma-ray binaries offer novel ways to probe pulsar physics and, more generally, to study the formation of relativistic outflows from highly-magnetized, rotating objects.

Scientific interest : The interested communities are high-astrophysicists working on binaries, colliding winds, particle acceleration, magnetized outflows, and pulsars. There is also strong interest from the VHE gamma-ray community.

Justification of required performance :

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	~1 sr	perform monthly scans of Galactic Plane to search for new binaries (variable sources).
Angular resolution (FWHM, deg)	0.1-0.5	0.1deg to allow identification of mwl counterpart with MeV data. 0.5deg enough if identification left to VHE gamma-ray follow-up (assuming all are VHE sources).
Spectral resolution ($\Delta E/E$ @ Energy)		
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)		
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	1-100 MeV range 10^{-9} cm^{-2} s^{-1} keV^{-1} @ 1 MeV	Comparable to Fermi/LAT sensitivity in a nu Fnu plot.
Timing performances		Periodic signal expected on orbital timescale (days-months).
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)		Might have variable, periodic polarisation.
Real-time data ?		

GAMMA-RAY LINE EMISSION FROM X-RAY BINARIES

Scientific summary :

Accretion disks and jets in X-ray binary systems are sources of high energy particles that should produce gamma-ray lines when they interact with their environment. The gamma-ray lines are emitted either by neutron capture or by annihilating positrons. These processes may happen in the atmosphere of an accreting neutron star or in the atmosphere of the companion star. The most intense lines expected are : (a) The 511 keV from misaligned microquasars when jets that are inclined with respect to the X-ray binary orbital plane hit the atmosphere of the secondary. Positrons from the jet annihilate and produce a narrow 511 keV line emission in the secondary atmosphere. (b) The gravitational redshifted 2.2 MeV line from the atmosphere of accreting neutron stars. Neutrons are produced by He spallation in the neutron star atmosphere. The 2.2 MeV line is emitted when n are captured by H. The escaping 2.2 MeV photons are redshifted due to the strong gravitational field. (c) The 2.2 MeV line from the atmosphere of companion of close X-ray binaries. Neutrons escape the accretion disk where they are produced by spallation. A fraction of these neutrons produce a 2.2 MeV line emission by neutron capture in the companion atmosphere.

Scientific interest :

(a) The measurement of the 511 keV line flux allows to determine the nature of jets (leptonic/hadronic). (b) The detection of the gravitational redshift of the 2.2 MeV line from accreting neutron stars leads to an estimate of the mass to radius ratio and provides a strong constraint on the equation of state of neutron stars. (c) The observation of the 2.2 MeV flux yields constraint on accretion models.

Justification of required performance :

Good spectral performance is required to accurately measure the characteristics (centroid, width) of these gamma-ray lines. We do not expect source confusion.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	-	
Angular resolution (FWHM, deg)	-	Point sources
Spectral resolution (ΔE/E @ Energy)	0.5% @ 511 keV 1 % @ 1.5 MeV 0.5% @ 2.2 MeV	1.5 MeV line : 1% due torotational broadening of a gravitational redshifted 2.2 MeV line.
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	10^{-6} @ 511 keV 7 10^{-7} @ 1.5 MeV 10^{-6} @ 2.2 MeV	1.5 MeV line flux estimated for Sco X-1 (2.8 kpc) 2.2 MeV line : typical flux from closest candidate sources when the accretion rate is large.
Continuum sensitivity (in which energy band?) (cm^{-2} s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	-	
Timing performances	-	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	-	
Real-time data ?	-	

MEV EMISSION OF BLACK-HOLE BINARIES FROM JETS & ACCRETION

Scientific summary : Both inflows and outflows in accreting black-hole binaries can produce continuum MeV emission. Relativistic electrons appear to be present in accretion flows in both hard and soft spectral states. MeV tails due to their Compton emission have been discovered in Cyg X-1 and a number of other sources. Jets of those systems are known to contain relativistic electrons and can produce MeV emission via both synchrotron and Compton processes. Future observations in the MeV range will allow us to understand both the jets and accretion flows in those systems.

Scientific interest : Emission due to Compton upscattering of blackbody photons have been discovered in the soft state of Cyg X-3 at >0.1 GeV. The way this emission continues to lower energies is of major importance for understanding the jet structure. In Cyg X-1, strong polarization has been discovered in 0.3-3 MeV range, implying it originates from the jet in that system. Current upper limits at >0.1 GeV already constrain the magnetic field and the distance of the emitting region in the jet.

Justification of required performance : For this subject, we concentrate on understanding of known sources. Thus, we need high sensitivity more than a wide field of view. Angular resolution of 0.1 deg is important to distinguish contributions of various sources. The sensitivity of 10^{-3} keV/(cm^2 s) is needed to measure spectral contributions from accretion and jets, and to distinguish between them. Confirmation of the polarization of Cyg X-1 at ~1 MeV is crucial to determine whether the jet indeed contributes in that range.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	A narrow field of view and high sensitivity	Detailed studies of individual sources
Angular resolution (FWHM, deg)	~ 0.1	To mitigate possible source confusion.
Spectral resolution (ΔE/E @ Energy)		Not important for continuum studies
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)		
Continuum sensitivity (in which energy band?) (cm^{-2} s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	EF(E) sensitivity of 10^{-3} keV/(cm^2 s)	To accurately measure the accretion and jet contributions in several black-hole binaries
Timing performances	0.1 s at 1 MeV	To distinguish between the jet and accretion origin of MeV emission
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	10% at 1 MeV	To distinguish between the jet and accretion origin of MeV emission
Real-time data ?		

GAMMA-RAY BURSTS (GRBS) : MEV EMISSION AND PERSPECTIVES

Scientific summary : The study of GRBs will greatly benefit from new observations in the MeV domain, improving upon the results obtained by *Fermi*. GRB exhibit complex light curves and spectra. Before *Fermi*, most SEDs of GRB prompt emission were described by the phenomenological Band function, a non-thermal component made of two smoothly connected power laws and peaking at an energy E_{peak} which can reach, especially for short GRBs (SGRBs), several hundreds of keV up to a few MeV. *Fermi* observations have shown deviations from this simple picture, with the detection of an extra power law above a few (tens of) MeV. In one burst, GRB 090926A, this non-thermal component shows a spectral break possibly due to $\gamma\gamma$ opacity within the jet. In a few cases, thermal photospheric emission has been also detected below 100 keV. Good capabilities for time-resolved spectroscopy over a broad energy range are thus required to understand the physics at work in GRB jets. Polarimetry would bring additional constraints on the mechanisms responsible for energy dissipation, and on particle acceleration and emission processes in the prompt and early afterglow phases (e.g., synchrotron / Inverse Compton, internal / external shocks). It would also help to infer the jet energy content (kinetic / thermal / magnetic) and the geometry of the magnetic field.

Scientific interest : The GRB community at large would be interested in this topic, which is also important in several fields in astrophysics and fundamental physics.

Justification of required performance : Sensitive time-resolved spectroscopy between 100 keV and 100 MeV should be complemented by polarimetry as a function of energy down to a polarization degree of 5-10%. A wide field of view and excellent localizations are needed to provide many useful GRB alerts. An angular resolution of a few tens of arcmin would provide arcmin positions to robotic optical telescopes on ground (while redshift measurements with the largest optical telescopes need arcsecond positions). Detection and localization performance might be optimized for SGRBs / harder spectra to enhance searches for gravitational wave counterparts.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	$>2\pi$ (a few sr)	As large as possible, to monitor the sky and to provide many GRB triggers.
Angular resolution (FWHM, deg)	A few tens of arcmin	Would provide arcmin positions, but arcsecond positions are needed for follow-up observations by large optical telescopes...
Spectral resolution ($\Delta E/E$ @ Energy)	$\leq$10% @ 300 keV	Accurate E_{peak} measurement. Should not be less than ~10% at other energies (0.1-100 MeV).
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)		
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	5.10^{-5} in 1 s (LGRBs) 2.10^{-4} in 100 ms (SGRBs) At 1 MeV	For time-resolved spectroscopy in the 0.1-100 MeV range: identification of spectral components and their time evolution.
Timing performances	$\leq$10 μs	Low deadtime needed for sensitive timing analysis, especially for SGRBs.
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	$\leq$10%	As a function of energy, to distinguish spectral components.
Real-time data ?	Yes	To promptly (within a few tens of s) disseminate GRB alerts, positions, and preliminary spectral analyses (e.g., SGRBs with high E_{peak}).

ACTIVE GALACTIC NUCLEI IN THE MEV DOMAIN

Scientific summary: Many of the Active Galactic Nuclei (AGN) emit most energy in the MeV domain. This is not only true for blazars, in which a relativistic jet is pointing at the observer, but also for the newly detected class of gamma-ray bright non-blazar sources, like Fermi/LAT detected star burst galaxies and radio galaxies. So far, a dozen AGN have been detected in the MeV range. A deeper survey in this domain will provide a rich sample of more than 1000 AGN. This will allow to determine the energy output of AGN, will constrain the physics involved in blazars and other MeV emitting AGN, and possibly also detect radio quiet Seyfert galaxies (i.e. supposedly non-beamed sources). Doubtlessly the jump from now 14 known AGN in the MeV range to more than 1000 extragalactic sources will provide the potential for unexpected discoveries, but at the same time a rich science outcome is guaranteed. The survey will also provide an unprecedented view on the extragalactic gamma-ray background and the AGN sample will give insight into what dominates this background.

Scientific interest: The AGN community is strongly interested in this topic, not only the colleagues working on blazars (who will derive the true energetics and physical modeling in this energy range), but especially also the groups working on non-beamed sources. At the same time, the community working now on Fermi/LAT and AGILE will naturally participate in the MeV studies.

Justification of required performance: In order to detect more than 1000 AGN in a five year mission, the following parameters are required

Performance parameter	Goal value	Remarks and notes
Field-of-view (deg^2)	6600	2 sr
Angular resolution (FWHM, deg)	1-2	This allows to distinguish gamma-ray sources. If identification with optical counterpart (without further information) is the goal, then this should be rather 0.1-0.2 degrees.
Spectral resolution ($\Delta E/E$ @ Energy)	0.1 @ 1 MeV	To determine spectral shape
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	---	No lines expected in AGN spectra
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	$5\ 10^{-8}$	For the survey science, the product of field of view and sensitivity is crucial, thus a larger field of view would then require a less sensitive instrument
Timing performances	----	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	---	Polarization is not the major science driver.
Real-time data ?	---	

GAMMA-RAY EMISSION FROM MAGNETARS AND ROTATION-POWERED PRS

Scientific summary : Magnetars and strong-B-field pulsars harbour magnetic fields above the QED limit. It is still not clear what processes in such extreme fields produce the non-thermal soft gamma-ray emission, nor do we understand the connection between the pulsar and magnetar population. In the last two years two SGRs have been found with field strengths below B_{QED}. A high-B-field radio-quiet rotation-powered pulsar, PSR B1846-0258, triggered by a timing glitch, behaved for 60 days like an SGR (outburst with short magnetar-like bursts), increasing simultaneously also its soft gamma-ray flux. A radio-emitting magnetar, AXP 1E1547-0548, created after a timing glitch a hard X-ray/soft gamma-ray pulse decaying over one year. The spectra of non-thermal pulsed and unpulsed persistent emissions from AXPs extends until at least 300 keV, but there are no measurements in the 300 keV – 10 MeV band to allow discrimination between the exotic theories aiming to explain these emissions. A recent study of all rotation-powered pulsars detected in the 20-200 keV band (only 15 in total due to the lack of sensitive observations at soft gamma-ray energies) shows that it comprises of young, energetic mainly radio-quiet or radio-dim pulsars, most of them not seen by Fermi. This appears to be a sample of pulsars peaking in luminosity at MeV energies, ideal targets for characterization with future more sensitive observations in this band, which would allow one to perform complete pulsar population studies.

Scientific interest : (Astro)physicists studying with magnetar bursts the physics of the neutron star interior; with bursts and persistent emission the physics under the extreme conditions of the neutron star magnetosphere.

Justification of required performance : An instrument with sensitivity 30x Comptel will be able to study the outbursts and persistent soft gamma-ray emissions from magnetars, mentioned above, in great detail. Namely, the persistent pulsed emission from three AXPs is at 100 keV a factor of >2 stronger than that of the Vela PSR; the flux from AXP 1E1547-0548 reaches in outburst the level of PSR B1509- 58, already detected with Comptel. Non-thermal emission has been detected from millisecond pulsars below 30 keV and with Fermi/LAT above 100 MeV. Simple interpolation shows that their characteristics can be measured at MeV energies if in addition a timing accuracy < 50 µs can be reached. Polarization would also be unvaluable.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	A few sr	To monitor any magnetar outburst in the Galaxy
Angular resolution (FWHM, deg)	0.1 – 0.2	To avoid source confusion for measuring total emission in sky maps (unpulsed from magnetars, PWN around PSRs)
Spectral resolution (ΔE/E @ Energy)	< 10 %	
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)		
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	30 × COMPTEL	To energies down to ~100 keV for PWNe, 0.1-10 MeV for magnetars and 0.1-30 MeV for PSRs
Timing performances	< 50 µs	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	1 %	
Real-time data ?		

PULSAR WIND NEBULAE IN THE MEV DOMAIN

Scientific summary : In Crab Nebula, dramatic variability (GeV flares) observed near cutoff of synchrotron spectrum; cutoff energy determined by balance of acceleration with cooling losses. Synchrotron spectrum in X-rays and above consistent with Fermi acceleration at relativistic shocks, although questions remain about magnetisation regime. In most other young PWNe, with lower magnetic fields, maximum acceleration energy set by confinement criterion, $r_{Larmor} < \varepsilon\ R_{shock}$ (with ε~0.3) ; implies synchrotron cutoff in MeV domain for typical parameters, but currently little or no data above ~100 keV. Measurement of spectral cutoff would yield constraints on particle transport in relativistic shock acceleration, and magnetic field in inner PWN (shedding light on "σ problem"). Possible MeV variability around the synchrotron cutoff energy could illuminate the physics of Crab GeV flares. Measurement of the synchrotron polarisation near cutoff can give a unique view of the magnetic geometry of the acceleration region.

Scientific interest : In addition to PWN observers and modelers, of interest to particle acceleration theorists and simulators : PWNe are unique laboratories for relativistic shock acceleration, with resolved (at lower energies), quasi-steady geometry. Also of interest to cosmic-ray community, clarifying plausible role of PWNe as dominant sources of primary high-energy cosmic-ray positrons (and electrons).

Justification of required performance : Detection of bright PWNe other than Crab Nebula and measurement of their spectral cutoffs would ideally require reaching a sensitivity $\nu F_\nu \sim 3 \times 10^{-12}$ erg/cm^2/s, throughout the MeV domain given their $\Gamma \sim 2.1$ spectral indices. Resolving their emission region would require an angular resolution of ~10 arcsec or better ; angular resolution < 1 degree (to be quantified further) will be required to overcome source confusion in the Galactic plane. A modest spectral resolution of ~10% will be adequate to characterise cutoffs. Separating PWN from pulsed emission requires a timing resolution better than a few ms (for young pulsars) throughout their energy range (as well as contemporaneous ephemerides from other frequencies). High polarisation fractions (~50%) expected, but next highest PWN flux after Crab is about 5 milliCrab (for MSH 15-52) ; equivalent MPF is thus ~0.002(?).

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)		Sources known from other energies
Angular resolution (FWHM, deg)	< 0.003 < 1	To resolve MeV emission region To overcome confusion with nearby sources
Spectral resolution ($\Delta E/E$ @ Energy)	0.1	
Line sensitivity (@ Energy) (cm^{-2}.s^{-1}, 3σ, 1 Ms)		
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	~ 3 x 10^{-9} @ 1 MeV	Ideally going as E^{-2} throughout range
Timing performances	< few ms	To distinguish PWN from pulsar
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	0.2%	50% polarisation for a 5 mCrab source
Real-time data ?		

SUPERNOVA REMNANTS AND SUPERBUBBLES

Scientific summary : MeV regime observations provide an unique information on the physical processes and the chemical/isotope composition of supernova remnants (SNRs). Both compact sources (pulsar and their wind nebulae) and extended supernova shells can be detected in the continuum MeV emission. In young supernova remnant Cas A the continuum MeV regime emission of a flux about 3 10^{-6} cm^{-2} s^{-1} MeV^{-1} at 1 MeV is expected in models of leptonic cosmic rays injection. Detection of the flux would constrain the cosmic ray injection models. Supernova remnants interacting with molecular clouds e.g. IC 443, are the brightest Fermi SNRs. Apart from pion decay emission, relativistic bremsstrahlung component may contribute. MeV observations are the unique probe to constrain the leptonic contribution and also to study the SNR interaction with dense clumps in a molecular cloud. Collective action of fast stellar winds of young massive stars and supernovae in OB associations are producing superbubbles – large caverns filled with hot gas and enhanced cosmic ray population. Broad line-like features with estimated fluxes of about 3 10^{-5} cm^{-2} s^{-1} MeV^{-1} were reported by the COMPTEL team in their study of the diffuse emission from the central galactic radian (Bloemen et al in 4th Compton symposium, AIP Conference Proceedings, v. 410, pp. 1074-1078 (1997)). Nuclear-interaction line emission from superbubbles are expected with the level flux of above 3 10^{-7} cm^{-2} s^{-1} MeV^{-1} at 4-6 MeV for distant superbubbles, while the extended local bubbles (loops) might be observable.

Scientific interest : Cosmic ray origin issues are of interest for a broad community. Nuclear line studies are of interest for interstellar processes researchers.

Justification of required performance :

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)		
Angular resolution (FWHM, deg)	a few arcmin	To study molecular clumps
Spectral resolution (ΔE/E @ Energy)	About 10%	Narrow line widths are about 100 keV
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	3 10^{-5} cm^{-2} s^{-1}	
Continuum sensitivity (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	3 10^{-6} cm^{-2} s^{-1} MeV^{-1} @ 1 MeV	
Timing performances	No	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	No	
Real-time data ?	no	

DIFFUSE EMISSION FROM COSMIC RAY AND INTERSTELLAR MEDIUM INTERACTIONS IN EXTERNAL STAR-FORMING GALAXIES

Scientific summary : Our Galaxy is permeated by a fluid of relativistic particles called cosmic rays (CRs). These nuclei, electrons, and positrons are most likely energized by violent events such as supernova explosions and pulsar winds. Yet, CRs are not only a side-product of such phenomena, they also contribute to the physical and chemical evolution of the Galaxy. As such, it is crucial to understand how they interact with the different components of the interstellar medium (ISM). This is made possible by different radiation mechanism such as Bremsstrahlung, synchrotron,…, that basically trace these interactions. Performing such studies in our Galaxy is complicated by line-of-sight accumulation. Looking outside, towards neighboring star-forming galaxies may cast a new light on the role of cosmic rays in a galaxy.

Scientific interest : This topic should interest the community involved in cosmic ray acceleration and propagation, as well as the people concerned with galaxy evolution. In terms of observations, the CRs-ISM interactions show up predominantly in the radio, millimeter, and gamma-ray bands and so collaboration with the corresponding communities will be possible.

Justification of required performance : The physical modelling of observations of several star-forming galaxies, ranging from radio to GeV and TeV gamma-rays, does not unambiguously tell how cosmic-ray transport proceeds. Making the distinction between several scenarios would require an extension of the GeV sensitivity of the Fermi/LAT instrument down to <10MeV.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	A few sr	To ensure a large coverage of many objects, but can be only 10-15° if pointed observations.
Angular resolution (FWHM, deg)	0.1°	To resolve the SMC and LMC
Spectral resolution (ΔE/E @ Energy)		Not a concern.
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)		Not applicable.
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	$<4.10^{-12}$ @ 100MeV	Goal is a flat sensitivity of $<6.10^{-11}$ $erg/cm^2/s$ over 1-100MeV band, in order to discriminate different transport scenarios.
Timing performances		Not applicable.
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)		Not applicable.
Real-time data ?		Not applicable.

THE SUN IN THE MEV DOMAIN

Scientific summary : The Sun is an efficient particle accelerator during flares. Energetic electrons (>20 keV to 100 MeV) produce a strong X-ray/γ-ray continuum via bremsstrahlung radiation in the solar atmosphere. Energetic ions (a few MeV/nuc to GeV/nuc) produce through nuclear interactions with the solar atmosphere a complete spectrum of γ-ray lines (deexcitation prompt lines from e.g. $^{12}C^*$ at 4.44 MeV and $^{16}O^*$ at 6.2 MeV but also a neutron capture line at 2.2 MeV: n + H → D + 2.2 MeV line) and also for the most energetic ions γ-ray emission (in the 100 MeV range) from pion decay radiation. The most recent observations of solar flares at high energies have been performed with the solar dedicated mission RHESSI. A few solar flares have also been observed by INTEGRAL/SPI (through the anticoincidence shield and by the shield itself). Observations are also obtained right now with FERMI. There is still a limited number of flares with well observed gamma-ray line spectra (~30), still a limited number of events observed at 100 MeV (~20). There are still many unresolved questions on the link between electron and ion acceleration in flares, on the angular distributions of accelerated electrons and ions,… which all need observations with a higher line sensitivity, a good spectral resolution and potentially polarization measurements (in the continuum above a few hundred keV). After a solar flare, the Sun is predicted to produce γ-ray emission through radioactive decay (e.g. lines at 847 and 1434 keV from the decay of ^{56}Co and ^{52}Mn, respectively). The detection of these lines would provide additional information on energy spectra and composition of flare-accelerated particles, as well as on mixing processes in the solar atmosphere. These lines have been searched for with RHESSI, after large flares, but with no success.

Scientific interest : Solar physicists interested by high energies and nuclear astrophysicists interested in solar flares

Justification of required performance : An energy resolution of 1% to 2% at ~5 MeV is required to measure the Doppler profiles of the C and O lines

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)		Can be potentially pointed to the Sun?
Angular resolution (FWHM, deg)	Arc min ?	
Spectral resolution (ΔE/E @ Energy)	1% to 2% at ~5 MeV	
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	~10^{-6} @ 1 MeV	To detect delayed gamma-ray lines in the aftermath of large flares
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)		
Timing performances	<1ms	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)		Interesting in the continuum above 100 keV (not too many observations)
Real-time data ?		

TERRESTRIAL GAMMA-RAY FLASHES

Scientific summary: Terrestrial gamma-ray flashes (TGFs) are high-energy photons originating from the Earth's atmosphere in association with thunderstorm activity. TGFs were serendipitously discovered by BATSE detectors aboard the Compton Gamma-Ray Observatory. TGFs have also been detected and further studied by the RHESSI, AGILE and Fermi satellites. Their emission extends up to 100 MeV and exhibits an e^+e^- annihilation line. TGFs were utterly unexpected and as of now they are not fully understood. They are believed to be the product of particles acceleration inside T-storms. As they are produced in the Earth's atmosphere, they potentially have a tremendous impact on our understanding of thunderstorms and atmospheric electrodynamics in general.

Scientific interest: Atmospheric and Space Electricity Physicists, Atmospheric Physicists, Space Plasmas Physicists, High Energy Astrophysicists.

Justification of required performance: TGFs have peculiar characteristics due to their specific production mechanisms in the atmosphere (the low energy spectral cutoff) and the proximity of their sources to the detectors (a few hundreds of kilometers). Recent results by Fermi-GBM show that they are very short (50-500 microseconds) and usually so intense that effects of detector deadtime and pile-up are issues to be avoided. Their position being unpredictable, a large field of view (>90°) is required and very good localization capabilities will help correlate them with other simultaneous phenomena in thunderstorms. Detection and identification of relativistic electrons associated with TGFs are of great importance.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	~90°	Pointed towards Earth
Angular resolution (FWHM, deg)	~0.05°-0.1°	0.05° corresponds to a distance of ~1 km at the source location as seen from a low Earth orbit
Spectral resolution (ΔE/E @ Energy)	10%	
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	-	
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	Not restrictive	0.01-100 MeV range
Timing performances	Dead time < 1 microsec	Total duration is typically 50-500 microsec
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	-	
Real-time data ?	no	

LONG-LIVED RADIOACTIVE ISOTOPES

Scientific summary :

The radioactive isotopes ^{26}Al and ^{60}Fe are produced and ejected into the interstellar medium by massive stars. With lifetimes on the order of 10^6 years, comparable to the evolutionary time scales of the OB associations and the stars contained within, the isotopes' presence traces the regions where massive stars formed recently. The nuclear origin of the gamma-ray lines emitted in the decay of these tracers allows the measurement of the hot component of the interstellar medium occurring in superbubbles, unbiased by the ionisation state of the gas. The gas carrying the radioactive tracers interacts with neighbouring molecular gas, where new star formation episodes can be triggered.

Scientific interest :

In the nearby star forming regions Orion and Scorpius-Centaurus, the interaction between stellar outflow and surrounding molecular clouds can be observed by mapping the distribution of ^{26}Al in the interior and along the walls of the cavities in the interstellar medium.

By mapping the Galactic Plane, we can see at which locations in the spiral structure star formation happens and where the large-scale outflow from these regions transports matter, energy and momentum within the Galactic disc.

Justification of required performance :

If ΔE/E < 0.2% (comparable to SPI), we can resolve an additional degree of freedom (Doppler line broadening). Without this capability, improved angular mapping must compensate the lack of kinematic mapping, requiring higher sensitivity for resolving smaller features.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	40	Cover Sco-Cen, Orion, Cygnus
Angular resolution (FWHM, deg)	< 3	Superbubbles at 4 kpc
Spectral resolution (ΔE/E @ Energy)	0.16%	Detect Doppler broadening at 100 km s^{-1}
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	$6 \cdot 10^{-7}$ if ΔE/E < 0.2% 10^{-7} if ΔE/E > 0.5%	Detect Doppler broadening for 50 deg^2 regions resolve 20 deg^2 regions
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	no constraint	
Timing performances	no constraint	
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	no constraint	
Real-time data ?	no constraint	

DARK MATTER ANNIHILATION OR DECAY

Scientific summary : The fact that the matter content of the universe is dominated by a dark matter (DM) component is now well established, and observed from galactic to cosmological scales. DM is also the main ingredient of our current structure formation theory. Although departures from General Relativity might still partly explain current observations, the most appealing solution to the DM issue is the existence of new exotic and very long-lived or stable particles, which generically arise in extensions of the standard model (SM) of particle physics (PP). These may be related to specific and independent PP problems (e.g. neutrino mass, strong CP problem, unification of interactions, hierarchy problem(s), etc.), or elaborated on purpose (effective models, minimal approaches). The big advantage of the DM particle scenario is that it can be tested with currently operating or future instruments. For example, annihilation or decay products of DM in galaxies could be observed, which would help unveil the DM particle nature – while powerful constraints may come out if not, which could even exclude quite generic ideas. The mass range and specific properties allowed for these particles strongly depend on models and other constraints (e.g. the cosmological abundance), and, except for axion-like-particles, the relevant energy range for detection with astrophysical photons roughly goes from 10 keV (sterile neutrinos as warm/cold DM) to 1 TeV (supersymmetric candidates). Some candidates may annihilate or decay into photon lines (gamma+neutrino is typical for decays), which provides a clear signature. The MeV energy range is particularly interesting for those DM candidates which have been invoked to contribute the intense 511 keV line emission arising from the Galactic Center, whose full origin remains undetermined. Since the dominant part of this emission must come from positronium decay, electrons and positrons originating in DM annihilation or decay must be injected with MeV energies at most, constraining the DM mass range or the mass splitting in case of excited DM models (no strong mass constraint in the latter case). Annihilation into charged lepton pairs is prototypal for MeV astronomy since it is necessarily accompanied by final state radiation corrections which induce hard photon spectra, and therefore potentially observable signals whose intensity should somehow trace the DM distribution in targets. Beside spectral anomalies in the diffuse Galactic gamma-ray sky or toward the Galactic Center, another promising class of targets would be that of Dwarf Spheroidal (DSph) Galaxies orbiting the Milky Way, which are background-free DM dominated objects – the detection of a single such object would then have a tremendous impact. In this topic, MeV astronomical observations would still be strongly complementary to direct DM detection experiments, which are now able to probe DM couplings to electrons down to the MeV mass range, and to colliders like the LHC.

Scientific interest : Particle physicists working on aspects beyond the SM (BSM), who have long focused on the so-called hierarchy problem in the frame of supersymmetric or extra-dimensional theories, are more and more agnostic about the mass range one could expect for a DM particle, due to LHC results. Therefore, sub-TeV (even sub-GeV) new physics is now being investigated as potentially related to very high energy scales (e.g. neutrino mass, etc.). Moreover, the DM problem itself has acquired the status of full motivation for model builders. Part of this community will therefore be very enthusiastic as new observations are made available in this unexplored energy range. *A MeV instruments opens the possibility to test theoretically interesting and valid scenarios through indirect detection (sterile neutrinos, light axinos, pseudo-Nambu-Goldstone DM, etc.)*

Justification of required performance : For DM candidates decaying into gamma-ray lines (small part of available models) : very good energy resolution (% scale) may compensate for a low angular resolution. For other candidates, angular resolution becomes important to maximize the signal-to-noise ratio. Since sources are identified (GC, DSphs), the field of view is not a strong limit, provided significant observation time is available.

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	1	
Angular resolution (FWHM, deg)	0.1 - 1	0.1° corresponds to the angular size roughly encompassing nearby DSPhs
Spectral resolution ($\Delta E/E$ @ Energy)	10^{-6}	Energy dispersion induced by the velocity dispersion of DM particles in targets. Valid for DM candidates decaying into photon lines (e.g. sterile neutrinos)
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)	10^{-6} @ 511 keV	To detect the e+e- line emission from DSph. Comparable sensitivity required for direct decay into lines in this energy range
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, ΔE=E, 3σ, 1 Ms)	10^{-7} – 10^{-6} around 1 MeV	Sensitivity to detect continuous emission from DSphs
Timing performances		
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)		
Real-time data ?		

EXPLORE THE LIMITS OF MODERN PHYSICS

Scientific summary: One of the major goals of theoretical physics is to discover a theoretical framework for unifying gravity with the other three known forces, electromagnetism, and the weak and strong nuclear forces. A unified theory must be compatible with quantum theory at very small scales which correspond to very high energies. Even the goal of reconciling general relativity with quantum theory has been elusive and will likely require new concepts to accomplish. Quantum effects are expected to play a key role in determining the effective nature of space-time that emerges as general relativity in the classical continuum limit. A wide variety of suggested Planck-scale physics scenarios have explored the idea that Lorentz invariance (LI) may be only valid as an approximation, and have proposed the possibility of Lorentz Invariance Violation (LIV). One result of such assumptions is a modification of the dispersion relation that relates the energy and momentum of a free particle or photon. One of the consequences is that electromagnetic waves of opposite circular polarizations will propagate with different velocities, which leads to a rotation of linear polarization direction proportional to the propagation time and the square of the plane wave number k. Therefore, if polarization is seen in a distant source, it puts constraints on the parameter ξ which controls the rotation angle. Besides, the higher the wave number k, the stronger the rotation effect will be. Thus, the depolarizing effect of space-time induced birefringence will be most pronounced in the γ-ray energy range (Stecker, 2010). The best secure bound on this effect, $|\xi| < 10^{-14}$, was obtained using the observed polarized soft γ-ray emission from a Gamma-Ray Burst with Integral (Laurent et al, 2011). On the other hand, the absence of any detection or the observation of a systematic energy dependence of the polarization angle would be clear sign of the existence of the vacuum birefringence due to Lorentz invariance violation.

Scientific interest : this topic will interest astrophysicists (jet physics, GRB physics, AGN physics, …), cosmologists and theoreticians.

Justification of required performances : The main requirement is on the polarimetry sensitivity, as we need to measure precisely the angle difference between two energy bands. To observe Gamma-Ray Bursts, a large field of view would be, of course, preferable but LIV may be also measured from pointed observations of selected high redshift sources, such as blazars. Gamma-Ray Bursts have to be identified in optical in order to measure as precisely as possible their distance; an angular resolution of around 0.05° is then mandatory to get a more constrained GRB position with robotic telescopes and make a redshift measurement with on-ground bigger telescopes, such as CFHT. Also, as the possible intrinsic change of the polarimetric angle during the GRB duration may result in a null integrated signal, a timing resolution of the order of 1s is preferable to produce time-resolved polarimetry.

Performance parameter	Goal value	Remarks and notes
Field of view	180°	Smaller FOV is also possible
Angular resolution	~ 0.05° (GRB)	To mesure GRB position, less necessary for known sources (blazars).
Spectral resolution	10%	
Line sensitivity	N/A	
Continuum sensitivity		
Timing performances	1 s	To produce time-resolved polarimetry
Polarimetric capability	5 %	Sources seems to be strongly polarized, but a high sensitivity is mandatory to ensure a good polarization angle measurement
Real-time data	No	