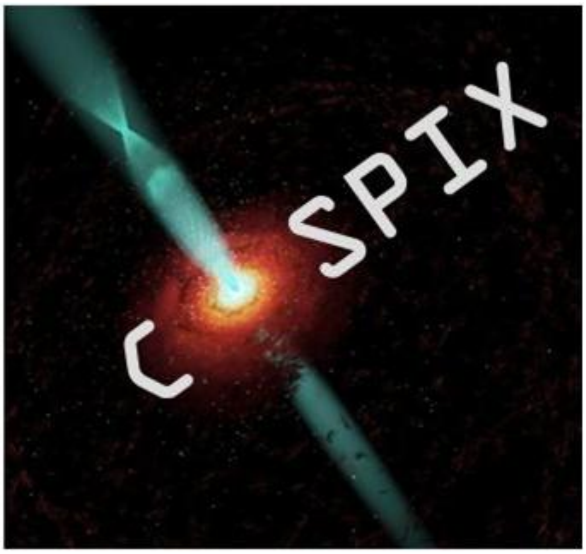

COSPIX

Compact Object Spectroscopy Polarimetry and Imaging in hard X-rays

A proposal in response to the

"Call for a Medium-size mission opportunity for a launch in 2022"

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Contact person : D[r] Philippe Ferrando CEA/DSM/Irfu/SAp – APC

Irfu / Service d'Astrophysique,
Bâtiment 709 Orme des Merisiers,
CEA Saclay,
91191 Gif-sur-Yvette, Cedex - France
Tel: +33 [0]1 69 08 44 38

Laboratoire Astroparticule et Cosmologie,
Bâtiment Condorcet,
10, rue Alice Domont et Léonie Duquet
75205 Paris Cedex 13 - France
Tel: +33 [0]1 57 27 60 59

e-mail : philippe.ferrando@cea.fr

Co-proposers , Science Team :

M. Arnaud	CEA/SAp-AIM, Saclay, FR
X. Barcons	IFCA/CSIC-UC, Santander, ES
V. Beckmann	APC, FACe, Paris, FR
D. Bomans	Astr.Inst., Bochum, DE
I. Caballero	CEA/SAp-AIM, Saclay, FR
F. Carrera	IFCA/CSIC-UC, Santander, ES
S. Chaty	CEA/SAp-AIM, Saclay, FR
J. Chenevez	DTU Space, Copenhagen, DK
R. Chipaux	CEA/SEDI, SAp, FR
F. Christensen	DTU Space, Copenhagen, DK
A. Claret	CEA/SAp-AIM, Saclay, FR
S. Corbel	CEA/SAp-AIM, Saclay, FR
J. Croston	Univ. Southampton, UK
E. Daddi	CEA/SAp-AIM, Saclay, FR
M. De Becker	Inst.Astr.Geo, Liege, BE
A. Decourchelle	CEA/SAp-AIM, Saclay, FR
D. Elbaz	CEA/SAp-AIM, Saclay, FR
M. Falanga	ISSI, Bern, CH
C. Ferrari	OCA, Nice, FR
C. Feruglio	CEA/SAp-AIM, Saclay, FR
A. Goldwurm	CEA/SAp-APC, Saclay, FR
D. Götz	CEA/SAp-AIM, Saclay, FR
C. Gouiffès	CEA/SAp-AIM, Saclay, FR
C. Hailey	Col. Univ., New-York, USA
M. Hernanz	ICE/CSIC, Barcelona, ES
I. Kreykenbohm	Ast.Inst.Uni.Erl., Bamberg, DE
P. Laurent	CEA/SAp-APC, Saclay, FR
O. Limousin	CEA/SAp-AIM, Saclay, FR
J. Malzac	CESR, Toulouse, FR
F. Mattana	APC, Paris, FR
A. Meuris	CEA/SAp-AIM, Saclay, FR
G. Miniutti	CAB/CSIC-INTA, Madrid, ES
K. Nalewajko	Nic.Cop.Astr.Ctr., Varsaw, PL
I. Negueruela	Dept Fisica, Univ.Alicante, ES
S. O'Dell	NASA/MSFC, Huntsville, USA
S. Paltani	ISDC, Geneve, CH
R. Petre	NASA/GSFC, Greenbelt, USA
P.-O. Petrucci	LAOG, Grenoble, FR
M. Pierre	CEA/SAp-AIM, Saclay, FR
G. Ponti	Univ. Southampton, UK
G. Rauw	Inst.Astr.Geo, Liege, BE
N. Rea	ICE/CSIC, Barcelona, ES
M. Renaud	LPTA, Montpellier, FR
J. Rodriguez	CEA/SAp-AIM, Saclay, FR
A. Rozanska	Nic.Cop.Astr.Ctr., Varsaw, PL
A. Santangelo	IAAT, Tübingen, DE
J.-L. Sauvageot	CEA/SAp-AIM, Saclay, FR
S. Soldi	CEA/SAp-AIM, Saclay, FR
M. Tagger	LPC2E, Orléans, FR
C. Tenzer	IAAT, Tübingen, DE
R. Terrier	APC, Paris, FR
G. Trap	CEA/SAp-APC, Paris, FR
P. Varnière	APC, Paris, FR
J. Wilms	Ast.Inst.Uni.Erl., Bamberg, DE
W. Zhang	NASA/GSFC, Greenbelt, USA
J. Zurita Heras	APC, FACe, Paris, FR

The technical and outreach parts of the proposal were also prepared by :

J. Martignac, F. Pinsard : CEA/SAp-AIM, Saclay, FR

J.-L. Robert : APC, Paris, FR

EXECUTIVE SUMMARY

The Compact Object Spectroscopy Polarimetry and Imaging in hard X-rays (COSPIX) mission is proposed to provide the community with an observatory able to address fundamental questions identified in two of the Cosmic Vision 2015-2025 science objectives:

1. The evolving violent Universe: trace the formation and evolution of the supermassive black holes at galaxy centres – in relation to galaxy and star formation. Examine the accretion process of matter falling into black holes by the spectral and time variability of X-rays and gamma-rays. Understand in detail the history of supernovae in our Galaxy.

2. Matter under extreme conditions: probe general relativity in the environment of black holes and other compact objects, and investigate the state of matter inside neutron stars.

Precise hard X-ray observations of black holes is the key information needed for answering these questions, for two reasons. The first is visibility: at energies above 10 keV, we expect to find the elusive massive black holes (obscured in soft X-rays) believed to play a major role in galaxy formation and needed to understand the cosmic X-ray background at its peak energy of 30 keV. The second is the astrophysics of these objects: observations of this part of the spectrum, coupled with the soft X-ray band, are critical for understanding the way matter is processed in strong gravity fields, via the formation of disks, very hot coronae, or relativistic jets.

COSPIX will provide exquisite data on obscured supermassive black holes up to redshift of ~ 1, resolving 70 % of the Cosmic X-ray background at its energy peak. COSPIX will perform spectral measurements over the dynamical time scales in black hole systems, making crucial tests of the geometry between the illuminating source (corona, jet) and the reflector (accretion disk) in supermassive black holes, and providing clues about the change of state in stellar mass black hole systems. Thanks to its wide energy band, COSPIX will unambiguously measure, via the Fe line shaped by relativistic effects, the spin for a hundred of supermassive black hole systems, thereby unveiling the black hole growth history.

Being an observatory, COSPIX will also contribute to other fundamental questions of astrophysics. It will probe particle acceleration mechanisms in all of Nature's accelerators; in shocks of all scales, that of supernovae but also that of stellar winds and of radio-galaxy lobes, in jets of blazars, as well as in the strong magnetic fields of pulsars. Observations of these accelerators will give crucial clues in the quest of the origin of cosmic rays. In addition to accurate spectroscopy and excellent imaging, COSPIX will also perform polarimetry measurements at an unrivaled accuracy level, providing new and sometimes unique clues about emission processes and source geometry. COSPIX will reveal details about supernova explosive nucleosynthesis and the explosion mechanism itself, via accurate measurements of the radioactive ^{44}Ti yield in several supernovae. COSPIX will provide the precise measurements of the non-thermal particle component of clusters of galaxies, needed to perform accurate mass determinations and to understand their evolution.

In order to fulfill these objectives, COSPIX is proposed as an observatory type mission, with large throughput, excellent angular resolution, and accurate timing across the entire 0.3 to 100 keV band, along with precise polarimetry in hard X-rays. COSPIX will rely on focusing optics throughout its energy band, with hard X-ray performance in a regime far surpassing that of the first hard X-ray missions with focusing optics, NuSTAR and Astro-H, to be flown in the next years.

A launch year of 2020-2022 is perfectly suited for several reasons. In the high energy observatories timeline, COSPIX will come after the probable end of the large European observatories XMM–Newton and INTEGRAL, the probable end of Chandra at soft X-rays, and the end of both NuSTAR and (probably) Astro–H, leaving the domain with virtually no observation facility. After 2020, the soft X-ray band will be covered by IXO if selected, probably from the middle of the decade, but no hard X-ray mission is in an advanced study phase.

The throughput of COSPIX can be obtained only using a long focal length telescope. The scientific payload concept relies on a single telescope, using lightweight focusing optics that provide area close to ten times that of the upcoming missions at 50 keV, coupled to a focal plane assembly providing high spatial and spectral resolution, with low background. The focal length is 33 m.

The COSPIX mission proposal has a solid technical basis. On one side of the telescope, the model detector payload is a slight evolution of the Simbol–X one; after that project was stopped at the beginning of phase B, all the payload detector elements have continued to be developed in the laboratories to a high level of maturity. The model optics payload is in the direct line of the developments being performed for the L-class mission IXO, on Silicon Pore and on Slumped Glass Optics, with partial heritage from NuSTAR for the latter, but with less stringent requirements on angular resolution. All payload elements, detector and optics, have TRL of minimum 3, and are on a development track for reaching TRL 5 well before the end of 2014.

The long focal length is a novelty. For the length needed by COSPIX, two approaches can be envisioned: a deployable mast or formation flight. In this proposal, it is demonstrated that formation flight is feasible using the available technology, with considerable margin. This option was chosen as it is the one for which the proposing team has the most solid experience based on Simbol–X studies, and for which now there is a strong heritage from flying missions (PRISMA). The critical formation flight elements have also a TRL of minimum 3, and can be easily brought to TRL 5. But using formation flight is not mandatory for the science. It might be the case that the proposed payload can be implemented with a deployable mast, an option which could be the object of a trade-off study during the assessment phase.

The mission will be launched by a Soyuz from Kourou and positioned in L2. The L2 orbit offers very stable conditions, ideal for the thermal point of view, but also for minimizing the deformation of the telescope during observations (whatever the technology), as the gravity gradient between the two ends of the telescope is very small. From the scientific point of view, L2 offers uninterrupted observation conditions, without perturbations due to radiation belts, so that arbitrarily long observations can be scheduled.

COSPIX is conceived as an observatory, in a similar way that XMM–Newton and INTEGRAL are. The observation program will be selected following Calls for Observations, and distributed to the community with the dedicated analysis software. Target of Opportunities observations will also be implemented. The minimum lifetime required for ensuring that the major scientific objectives are met is 3 years of scientific observation; an extension to 5 years is desirable for this observatory type mission and can be implemented within the consumable budget of formation flight at L2.

The cost of the mission, with the assumption that ESA is providing the optics payload with a contribution of NASA, is well within the allocated amount for the M3 mission.

The COSPIX mission is proposed by a large community of astrophysicists from eight European countries, and from United States, dedicated to design the instrument needed in the next decade to efficiently attack or solve an important part of the Cosmic Vision questions, through exceptional performance in the hard X-ray domain. COSPIX will be available to the worldwide astronomical community, for observing a large variety and number of sources. There is no doubt that beyond answering the questions well identified today, its large throughput, and its high spectral, polarimetry, and imaging capabilities will be the key to answering new questions which will be raised by the upcoming missions, and to make new discoveries.

INTRODUCTION

The opening of the X and gamma-ray windows in the sixties, thanks to satellite borne instruments, has started a new era in astrophysics. Extremely energetic and violent phenomena were discovered and found to be ubiquitous in the Universe, and the existence of compact objects, in particular of black holes, was unveiled. Since then the importance of the role of the black holes of all masses in the Universe has been realized to a point that their study is central in two themes of the Cosmic Vision science objectives : Q3.3 "*matter under extreme conditions*", and Q4.3 "*the evolving violent Universe*".

The COSPIX mission is designed to provide direct insights into these two major questions. COSPIX will give the measurements needed to understand how matter is organized and behaves around black holes and how these extreme objects influence their environments on a very large scale; and the measurements needed to find the still elusive obscured massive objects in the center of galaxies. In addition, COSPIX will address other major problems in contemporary astrophysics, as the understanding of acceleration processes at shocks of all sizes (those of supernovae, but also at larger scales those of Active Galactic Nuclei radio lobes) in relation with the origin of cosmic-rays, or as the definitive characterization of the debated non-thermal X-ray energy content of clusters of galaxies, with its effect on their mass estimate and dynamical evolution.

To do so, COSPIX is proposed as an observatory type mission, operating from below 0.5 keV to about 100 keV. The full energy range is covered by a single telescope featuring a very large throughput and high angular resolution optics, coupled to a compact focal plane assembly, with excellent imaging and spectroscopy over the full range. In addition, it will provide unique polarimetry measurements in the hard X-ray domain, adding important new diagnostics tools at energies for which the non-thermal processes dominate.

At the time of this proposal, the hard X-ray domain is covered by simple imagers (as IBIS/ISGRI on the ESA INTEGRAL mission), orders of magnitude less sensitive and accurate than the powerful focusing instruments in soft X-rays (as XMM–Newton). The situation should change dramatically in the coming years with the launch of the American NuSTAR and the Japanese Astro–H missions, which will carry the first focusing telescopes in hard X-rays. But their relatively poor angular resolution (45" and 100" respectively) and low effective area in hard X-rays (~ 300 cm^2 at 30 keV) will leave the above scientific questions for some of them fully, for others partly, unanswered, due to confusion, or lack of sensitivity.

COSPIX is designed to have performance, not only several orders of magnitude better than the present instruments, but also several fold better than NuSTAR and Astro–H. This is illustrated by the comparison of effective area and sensitivity between these missions (Fig. 1). This, together with its angular resolution well below 20 arcseconds, and its sensitive polarimetry measurement capability, gives to COSPIX the scientific performance improvements needed for a mission after NuSTAR and Astro–H, not only for the above well-defined questions, but also for the unexpected ones that undoubtedly will come from these missions.

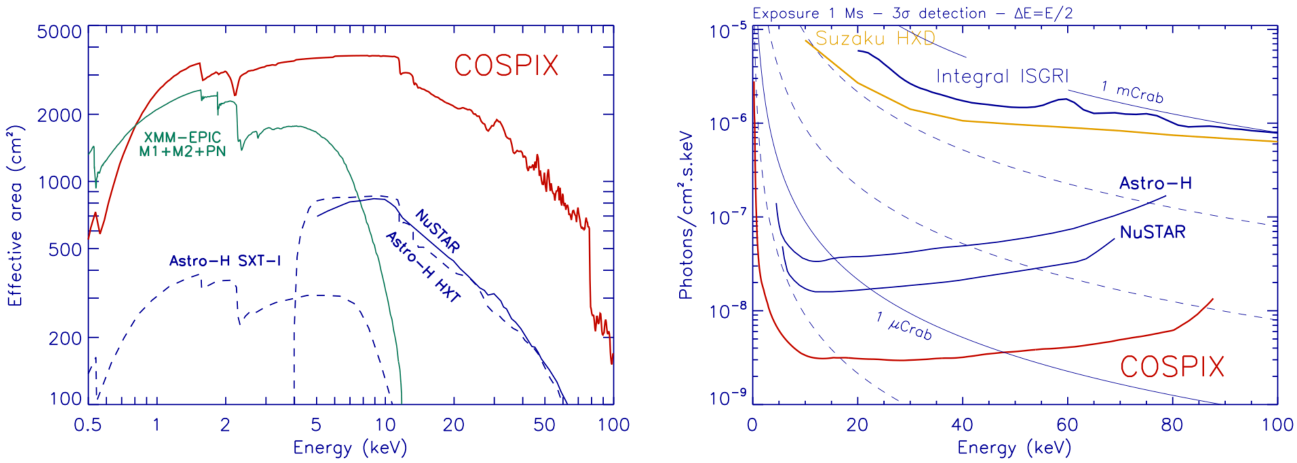


Fig.1. Left: *Effective areas of COSPIX, Astro-H HXT and SXT-I, NuSTAR, and XMM–EPIC (all 3 cameras summed).* ***Right****: Continuum sensitivities of COSPIX, for point sources compared to flying missions and to the forthcoming NuSTAR and Astro-H missions (all evaluated for extraction region of PSF side, from published instrumental data)*

The detailed science objectives are given in the next section, which finishes by a table of scientific requirements. This is followed by more technical sections, for which the model payload and the mission profile and its possible implementation heavily build on the Simbol–X studies. These were stopped in the beginning of phase B but allowed to reach a high TRL level. It is not possible to have a collecting area much larger than the upcoming missions without using long focal length optics. We propose here to use formation flight, for which we had the most extensive studies proving the feasibility of the mission, and a high TRL level. But using a deployable mast might also be a possibility, and we propose to look into this trade-off in details during the assessment phase.

The last sections deal with the operations of COSPIX, corresponding to an observatory type mission opened to the full community, the technology development requirements and the preliminary programmatic and costs, showing that indeed COSPIX can fly at the very beginning of the next decade within the allocated budget, and a program of communication and outreach intending to make this mission known and appreciated well beyond the astrophysics community it will serve.

SCIENTIFIC OBJECTIVES AND REQUIREMENTS

COSPIX addresses two of the fundamental questions of the ESA Cosmic Vision Program: the evolving violent Universe and the matter under extreme conditions. The way this is done by COSPIX is described in detail below, in the first two sections. The other important fields that COSPIX addresses, particularly that of particle acceleration, are described in the next sections. Finally, we provide the scientific requirements which are deriving from these scientific goals.

I. The Evolving Violent Universe

Black Hole Census, Cosmic X-ray Background and Obscured Accreting AGN

Active Galactic Nuclei (AGN) play a key role in the course of galaxy formation and evolution through interaction with their host galaxies. The Cosmic X-ray Background (CXB) is the fossil of the emission by accretion in the Universe. Its spectrum (Fig. I.1 left) tells us that most accretion in the Universe takes place in obscured environments (Fabian & Iwasawa 1999 MNRAS 303 L34) and matching its energy density to the local Super Massive Black Holes (SMBH) mass density reveals that current surveys miss about half the existing AGN (probably the most obscured ones). Hence, to understand the cosmic history of accretion and its influence on galaxy formation it is mandatory to find and characterize the population of obscured and heavily obscured AGN.

However, this population is so far only loosely constrained. If the column density (N_H) does not exceed a few times 10^{24} cm^{-2} the nuclear radiation is still visible above 10 keV and the source is called “mildly” Compton thick (CT). If $N_H > 10^{25}$ cm^{-2} (“heavily” CT) the entire spectrum is depressed by Compton recoil. In both cases, a strong iron line (Equivalent Width = 1–2 keV) and a Compton reflection continuum, peaking around 30 keV, are almost invariably observed. All present X-ray surveys miss most of the highly obscured, but still strongly accreting objects, even deep surveys below 10 keV are inefficient to detect them (e.g. Tozzi *et al.* 2006 A&A 451 457). The handful of objects so far discovered in hard X-rays (Swift/INTEGRAL, Beckmann *et al.* 2009 A&A 505 417), may represent just the tip of the iceberg as they belong to the very local Universe, while highly obscured objects may well be common at high redshift (e.g. Fabian 1999 MNRAS 308 L39; Silk & Rees 1998 A&A 311 L1; Gilli *et al.* 2007 A&A 463 79).

The COSPIX main contribution in this field will be the discovery and the characterization of the sources making the strongest contribution to the peak of the CXB around 30 keV. Some of these sources may be already present in deep Chandra and XMM–Newton surveys, as well as in deep mid-infrared surveys, however **only sensitive observations at 30 keV can 1) univocally identify them as hard X-ray sources and strong contributors to the CXB; 2) quantify their volume density as a function of the Cosmic time; 3) constrain the physics and the geometry of the obscuring matter**. For example, luminous quasars

(QSOs) may follow a different formation and evolution pattern than lower luminosity Seyfert galaxies. Thus also the build up and evolution of the obscuring gas could be dramatically different in high and low luminosity AGN and getting information on the real N_H distribution and on the gas covering fraction would result vital.

In order to complete the census of SMBH by searching for hard X-rays from highly obscured AGN, trying to cover as much as possible the luminosity-redshift plane, COSPIX will perform:

1. A spectral survey of previously known moderately obscured QSOs up to redshift z ~ 1.
2. Deep observations to search for faint Compton thick AGN up to redshift z ~ 1, which will also derive the obscuration history of AGN.
3. A survey of candidate CT AGN selected using their infrared emission in Spitzer/Herschel surveys.

Compton thick QSOs up to z ~ 1

A few moderately obscured ($N_H \leq 10^{24}$ cm^{-2}), high luminosity QSOs have been discovered by previous X-ray satellites. Current X-ray spectra are rather poor, and the uncertainties on the column densities are large. Some of these objects may even be CT but current data cannot tell for sure. COSPIX spectra will easily distinguish between Compton thin and Compton thick AGN. For a moderately bright ($L_X = 10^{44}$ erg/sec) Compton thick AGN at redshift z = 1, the absorbing column density can be determined with an error of 25 % within a 100 ks observation. Thus COSPIX can and will for the first time detect and measure Compton thick AGN up to cosmologically relevant redshifts, both through serendipitous surveys and targeting candidates from XMM-Newton and Chandra Surveys.

Deep surveys

The resolution of the CXB at the energy where it peaks is one of the main goals of the COSPIX mission. COSPIX holds the key to uncover and detect directly most SMBH accretion luminosity in the Universe. Fig. I.1 middle shows the predicted 10–40 keV number counts per square degree. COSPIX will reach flux limits indicated by the vertical dashed line in the left panel in a ~ 200 ks observation, thus allowing the detection of more than 25 sources per COSPIX field in the 10–40 keV band (~ 15 for 100 ks). About one fourth of these sources should be highly obscured AGNs. Most of them will be Seyfert 2 galaxies, but one or two sources per field should be high luminosity type 2 QSOs.

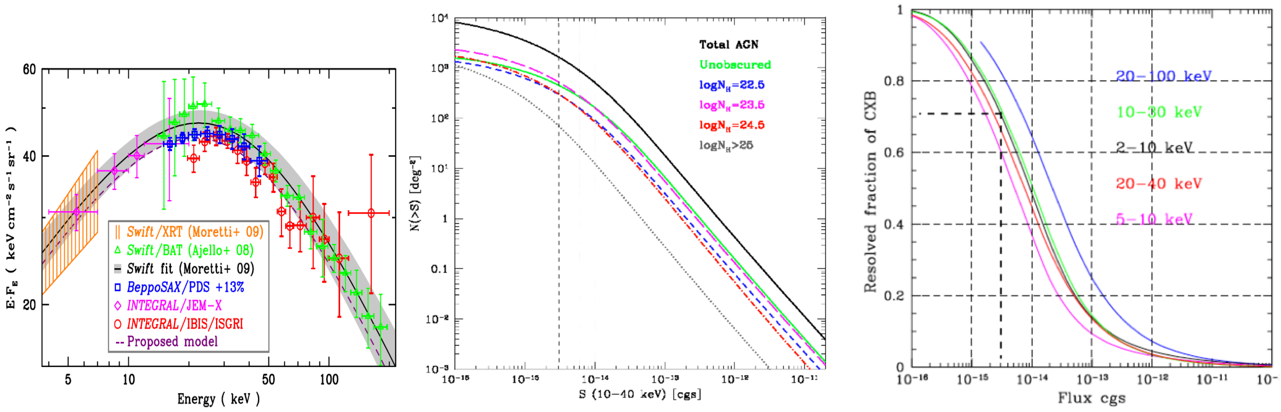


Figure I.1: ***Left panel***: *CXB spectrum derived by different recent missions (Turler et al. 2010 A&A 512 49). The black line shows a cut-off power law model fit with a peak at 29 keV with the uncertainty area in grey.* ***Middle panel***: *Expected number of sources per square degree as a function of flux limit. The dashed vertical line indicates the flux limit reached in a 200 ks COSPIX observation, resulting in about 2000 sources per deg^2 and ~ 25 in the field of view.* ***Right panel***: *resolved fraction of the CXB as a function of flux limit in different energy bands. At the confusion limit, COSPIX will resolve 70 % of the CXB at its peak around 30 keV.*

The right panel of Fig. I.1 shows the resolved fraction of the CXB as a function of flux. Taken at face value, the plot implies that at the 200 ks COSPIX flux limit 70 % of the CXB is resolved in sources (compared to a resolved fraction of much less than 5 % in current Swift and INTEGRAL surveys; Sazonov *et al.* 2007 A&A 462 57, Paltani *et al.* 2008 A&A 485 707). This fraction, easily achievable with COSPIX, is comparable or even larger than that already resolved by XMM and Chandra between 5 and 10 keV. In a deep 1 Ms exposure, our simulations show that COSPIX would be able to measure the X-ray spectral characteristics of the faintest detectable sources up to z ~ 3 and down to L(2–10 keV) less than a few 10^{44} erg/s, telling apart unabsorbed, Compton thin and CT objects with high significance, and recovering the intrinsic absorption with less than 20 % uncertainty for Compton thin objects.

Infrared selected Compton Thick AGNs

A quantitative, complete assessment of the demography of highly obscured AGN with intermediate-to-high luminosity (the so called type 2 QSOs) is still lacking because building up complete samples of highly obscured, high luminosity QSOs with homogeneous selection criteria is difficult and time-consuming, due to the large area that must be covered.

Complementary selection criteria combining far to near infrared to optical photometry, have been successful in pinpointing candidate obscured AGN. In particular, highly obscured AGN and QSOs can be selected by requiring extreme values of the 24 µm to optical flux ratio and red colors, which are demonstrated to be reliable proxies of high luminosity and high obscuration (Fiore *et al.* 2008 ApJ 672 94). For example, the SWIRE survey, covering with medium-deep MIPS and IRAC photometry about 50 deg^2 of the sky, provides a good opportunity to build up such a complete sample of highly obscured QSOs. COSPIX observations of the brightest SWIRE sources with faint optical counterparts can easily probe their obscured nuclei. These sources are expected to host the most luminous and obscured AGN in the high redshift Universe. The combination of X-ray and infrared information can be used to measure the number density of highly obscured QSOs. By joining this sample to those obtained from the deep fields, and from the serendipitous survey, we will be able to determine the evolution of the obscured AGN population, a step forward in completing the census of SMBH through Cosmic time.

Fig. I.2 shows two COSPIX simulations of Compton Thick AGNs : one in the local Universe for which all components are very accurately measured, and an extreme SWIRE source at z ~ 1 showing that its Compton thick nature is clearly detectable (the X-ray normalization was estimated scaling the 24 µm flux with the observed ratio in the high luminosity highly obscured QSO IRAS 09104+4109).

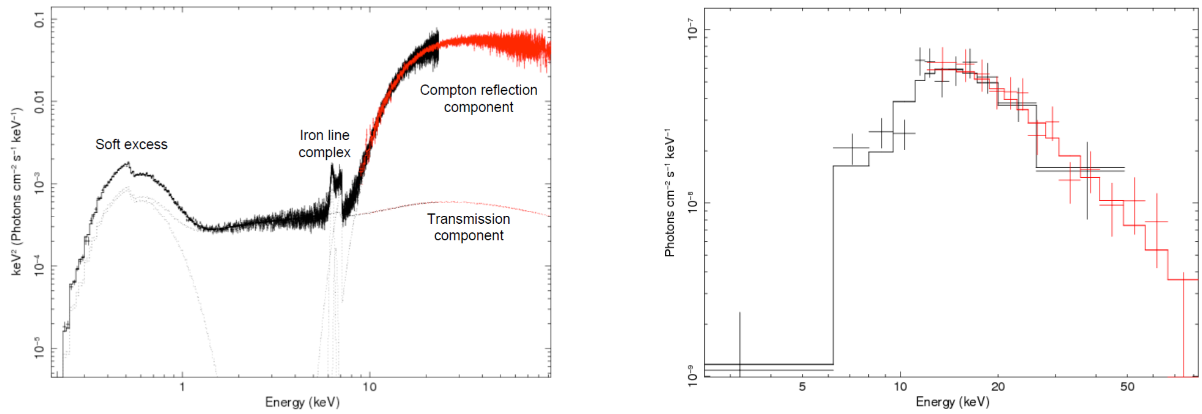


Figure I.2: ***Left panel***: *Simulated spectrum of a COSPIX 100 ks observation of a local (z=0.02) Compton Thick AGN with transmission component (1% of the absorbed one), thermal component (kT = 0.1 keV), iron line complex and a luminosity L(20-40 keV) = 5 10^{43} ergs/s.*
Right panel: *Same for a 200 ks exposure of a highly obscured Compton Thick AGN at z = 1 with properties similar to local QSOs* like IRAS 09104+4109, placed at z = 1 (N_H = 2 10^{24} cm^{-2}, F(20-40 keV) = 2 10^{-14} ergs/s/cm^2, index Γ=2).

Accretion and Ejection physics

Accretion of material onto an object as result of gravitational attraction is the most important energetic process in the Universe as it powers most types of astrophysical sources and acts at different scales. Understanding such a fundamental phenomenon is crucial for understanding the evolution of the Universe as a whole. The most extreme manifestation of accretion and related phenomena such as relativistic ejections and outflows, occurs in the huge potential well of black holes (BH), either the super-massive ones as in AGN, or the stellar mass ones as in X-ray binaries (XRB). Since the bulk of radiated energy is emitted in the X-ray and hard X-ray bands, COSPIX will provide fundamental advances in the domain of accretion and ejection physics from the detailed studies of X-ray accreting sources. The main results expected in this field will concern: the physics of accretion flows and associated radiation processes, the relativistic effects from accretion in strong gravity regime, the physics of ejection and outflow processes.

Accretion and ejection physics in AGN and Galactic Black Holes

A large fraction of the accretion energy in accreting systems is dissipated in the innermost regions of the accretion flow that, in luminous systems, takes the form of a thin accretion disc. Gravitational energy is radiated away as quasi-blackbody emission – peaking in the UV/EUV in AGN and in the soft X-rays in XRB – and powers a central corona or the base of a compact jet, responsible for a power law continuum in the X-rays that extend well above several tens of keV. The X-ray continuum irradiates the dense disc flow which produces a reflection spectrum rich in emission lines – most notably the iron line at ~ 6-7 keV – and characterized by a broad hump-like structure around 30 keV (the so-called Compton hump) and a soft component below ~ 2 keV in excess to the extrapolation at low energy of the high energy continuum (Fig. I.2 left, I.3). Most of the BH accreting systems also show different flavors of particle ejections and outflows that clearly bear a link with accretion process and system physical conditions. But this general picture if far from being complete as there are several different interpretations for the different emission components, and the origin of the jets and their link to the accretion power are not understood either.

The origin of the primary X-ray emission is still highly debated. One hypothesis is that it is due to Comptonization of soft (optical-UV) seed photons from the accretion disk by a population of hot (10^9 K) thermal electrons, the so-called **corona**. Apart from the uncertainties concerning the possible different origin, geometries, locations and physical conditions of the putative corona, a totally alternative interpretation links the component rather to a **compact jet via a substantial contribution of synchrotron emission**. This interpretation is motivated by the strikingly tight correlation between radio and X-ray emissions in galactic BH in hard state (Corbel *et al.* 2003 A&A 400 1007) that demonstrates an intimate coupling between these two wave-bands and their associated components (compact jets and inner accretion flow). This correlation seems present also in AGN (Falcke *et al.* 2004 A&A 895 903), once a mass scaling factor is included, implying that something fundamental links these components in accreting BH systems.

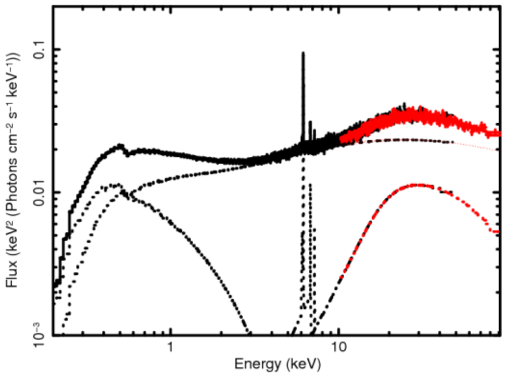


Fig. I.3: *Simulated COSPIX spectrum of a typical Seyfert galaxy in 50 ks. The primary continuum, the reflection component (iron line, hump at 30 keV) and the soft X-ray excess are clearly visible in the broad 0.1-100 keV COSPIX energy range.*

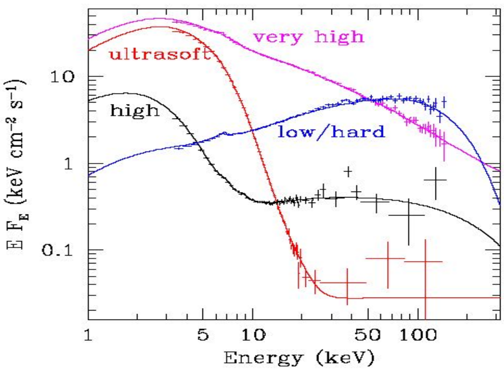


Fig. I.4: *1-150 keV spectra of a typical micro-quasar (Cyg X-1) during different spectral states, when various components dominate the spectra at different epochs.*

The origin of the **soft X-ray excess** is also still highly debated: it could be the **comptonized tail of the accretion disk** by a second population of electrons, characterized by a smaller temperature (10^7 K) and higher optical depth ($\tau \sim 10$) than the one at the origin of the primary continuum. It could also result from relativistically blurred ionized **reflection or absorption** (Crummy *et al.* 2006 MNRAS 365 1067; Gierlinski & Done 2004 MNRAS 349 L7). BH XRB display, in addition, a complicated set of different states (high-soft, intermediate, low-hard, etc.) in which different components dominate (Fig. I.4) and show, at specific X-ray state transitions, powerful relativistic ejections, usually observed at radio to infrared (IR) wavelengths.

Each of these interpretations implies a different relationship between the different energy bands of the broad band high-energy spectrum. To make a significant advance in this field more sensitive broad band X-ray measurements as well as optical/UV/radio and X-ray simultaneous monitoring are needed to disentangle the various components. Only a telescope like COSPIX with large effective area over the whole 0.1-100 keV domain will be able to explore these relationships in BH systems. The polarization mode will also allow to measure, for bright sources, the polarization fraction and to establish the role of synchrotron emission in the primary component.

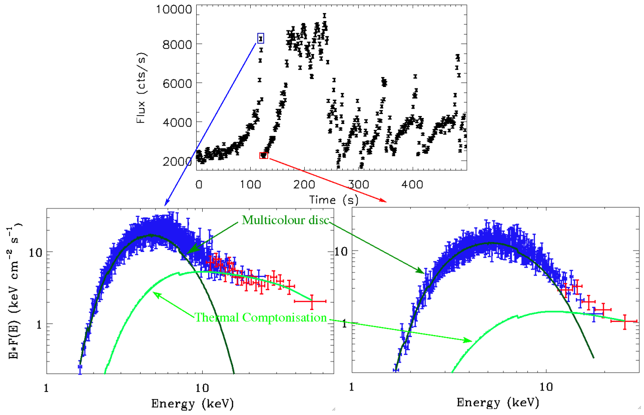


Fig. I.5 ***Top****: X-ray light curve of GRS 1915+05 over a 500 s interval showing the large dynamic range of variability. The first spike is thought to trigger a relativistic ejection.* ***Bottom****: Source simulated spectra from 1s COSPIX observations at the top and bottom of the spike. Here, the major changes occur at energies above 10 keV due to changes in the corona.*

Moreover, the presence of important **spectral and flux variability**, observed, in some cases, (Ponti *et al.* 2004 A&A 417 451) on time scales as short as the dynamical time scale for SMBH is also a major issue. In particular, the reflection models predict that the reprocessed disc reflection must respond to the fast continuum variation with a short time delay associated with the light travel time between the irradiating source and the reprocessing disc. A first detection of such delays (called **reverberation delays**) has been reported recently in one extreme object with XMM-Newton, supporting the reflection interpretation for the soft excess.

COSPIX will permit to study simultaneously, with high precision and on time scale as short as the dynamical one for the SMBH, the variability of the different spectral components of radio-quiet AGNs and BH XRB spectra (primary continuum, soft X-ray excess, iron line, reflection bump). Thanks to the wide bandpass and hard X-ray sensitivity COSPIX will enable us to study simultaneously the variability properties of all components in bright AGN providing a definitive test for the reflection interpretation in the local Universe. Time-resolved spectroscopy enabling to constrain the reflection intensity at the few percent level will be possible in the whole bandpass down to ~ 4 ks in AGN with fluxes ≥ 2 10^{-11} erg cm^{-2} s^{-1} (2–10 keV), that is in ~ 60 local type 1 AGN (or down to ~ 2 ks in the brightest ~ 20 AGN). Notice that the orbital timescale at 6 gravitational radii (the ISCO for a non-rotating black hole) is ~ 5 ks (~ 50 ks) in a typical 10^7 (10^8) $M_\odot$ BH.

XRBs on the other hand display much shorter timescales due to the smaller BH mass (Rodriguez *et al.* 2008 ApJ 675 1449) and COSPIX will allow to explore the microquasars physical processes and their evolution over their characteristic time scales: the free fall time scale (seconds), tracing the evolution of the corona whose emission peaks at 10-100 keV, and the viscous time scale (min to hours) tracing the evolution of the disc (0.5-5 keV). This is shown by the simulations of 1s exposure observations of GRS 1915+105 (Fig. I.5).

The super-massive black hole at the Galactic Center

The Galactic Center hosts the super-massive black hole closest to us, associated to the radio/IR/X-ray source **Sgr A***, which with its 4 10^6 $M_\odot$ **links the SMBH in AGN to the stellar mass size BH of XRB**. Sgr A* is also extremely dim: with a total luminosity of ~ 10^{-8} times its Eddington value it represents the **prototype of an accreting BH in quiescence**, in a regime of low accretion rate and very low radiation efficiency. One of the key features of Sgr A* is that it displays X-ray and IR flares at rates of ~1 per day, during which the X-ray luminosity can increase by a factor (F) of 200 on timescales of hours. These flares offer a unique possibility to study processes that occur at few gravitational radii from a SMBH horizon in optically thin conditions.

While the Sgr A* flare IR emission can now be ascribed to synchrotron emission, the origin of X-rays, detected with Chandra and XMM, is not yet understood. This is due to the uncertainties on the spectral slope, to the non detections of spectral changes and of spectral shape above 10 keV, which hamper the identification of the non-thermal radiation mechanism at work (synchrotron or Compton) (Dodds-Eden *et al.* 2009 ApJ 698 676), of the heating and cooling mechanisms, including the role of adiabatic expansion. COSPIX will provide crucial sensitive measurements of X-ray spectra of Sgr A* flare up to 60 keV for medium/soft flares and up to 100 keV for bright hard ones, will determine slopes even for weak flares, will measure the high-energy break (and therefore electron maximum energy) (Fig. I.6) and will detect spectral changes giving crucial hints on the heating/cooling mechanisms. Such measurements, along with simultaneous multi-wavelength observations, will constrain several physical parameters (electron energies, magnetic field, emitting region) and will tell us whether the acceleration takes place in the accretion flow or in a compact jet. Given the diffuse and point-like sources emission that surrounds Sgr A*, only a sensitive instrument with angular resolution better than 20" (HEW) and broadband capability as COSPIX can carry out this experiment. Recently X-ray flaring activity has been detected also from the nucleus of M31 (Li *et al.* 2010 arXiv1011.1244) confirming that Sgr A* behavior is likely common to other quiescent local SMBH.

Another recent key discovery on the Sgr A* activity is that **it likely underwent a giant outburst that rose its X-ray luminosity by a factor of 10^6 in the past**, few hundred years ago. Traces of this event are found in the X-ray emission of molecular clouds (MC) of the region. Recent measurements of variability in different MC of both the neutral iron Kα line at 6.4 keV with XMM (Ponti *et al.* 2010 ApJ 714 732) and of the high energy continuum above 20 keV with INTEGRAL (Terrier *et al*. 2010 ApJ 719 143), both key features of hard X-ray reflection by cold material, have given preliminary constraints on the past outburst. However measurements of the continuum were possible only for the Sgr B2 MC. The most spectacular variability with apparent superluminal propagation of the 6.4 keV line has been measured in a MC close (15') to Sgr A (Fig. I.6 middle), a region too confused for INTEGRAL. COSPIX will in the coming years at the same time monitor the 6.4 keV and the reflected continuum at high energy from all the illuminated MC of the central molecular zone with unprecedented precision (Fig I.7 right) providing a detailed spectrum of the original outburst and tight constraints on the activity of Sgr A* (periods and luminosity). This will be possible because COSPIX will derive the 3D MC distribution from polarization measurements of the MC reflected continuum, whose polarized fraction vary from 100 % to 0 % depending on the angle (Φ) between the line of sight and the SgrA*-MC direction (Churazov *et al.* 2002 MNRAS 330 817). For example, the MC G011-011 (Ponti *et al.* 2010) has a 20-40 keV flux of ~ 10^{-4} ph/cm^2/s and therefore with an exposure of 100 ks we expect to detect a polarization fraction of 7 % or larger, from which we can derive angles $\Phi > 15°$ providing a quite accurate 3D localization of the cloud.

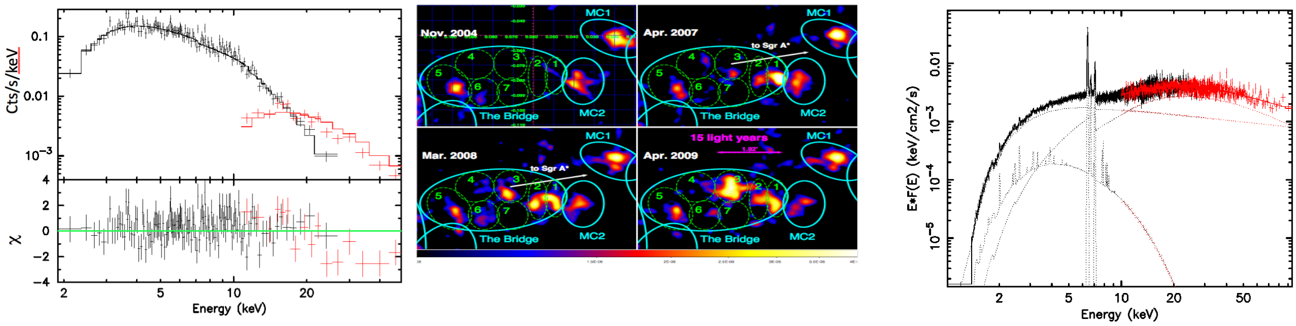


Fig. I.6: ***Left***: *Simulated COSPIX spectrum of a 2 hr, F = 50, Sgr A* soft flare, with a break at 20 keV, compared to the best fit power law. The break is clearly visible in the residuals. A proper fit gives the break energy within ± 5 keV and the slope index within ± 0.02.* ***Middle***: *XMM images at 6.4 keV from MC at 15' from Sgr A* at different epochs showing superluminal propagation. COSPIX will map also the reflected continuum above 10 keV with the same angular resolution.* ***Right***: *Simulation of a 100 ks COSPIX spectrum of G 011-011, another MC at 15' from Sgr A*.*

Relativistic jets and their effect on the environment: blazars and AGN jets

About 10% of AGNs produce relativistic jets emitting prominent non-thermal radiation across the electromagnetic spectrum. In **blazars**, one of the jets is closely aligned with the line-of-sight and its emission is strongly boosted by relativistic Doppler effect thus completely dominating the nuclear emission. Blazars spectra are composed of two broad components. The low-energy one is explained by the synchrotron emission of relativistic electrons. The high-energy one can arise either from the inverse-Compton (IC) up-scattering of some seed radiation on electrons or from emission processes involving relativistic hadrons. The spectral properties of blazars depend on their radio luminosity, they form a continuous sequence (Donato *et al.* 2001 A&A 375 739) from low luminosity BL Lac objects to high luminosity Flat-Spectrum Radio Quasars (FSRQs).

With its broad spectral coverage, **COSPIX can detect the high-energy end of the synchrotron component in BL Lac sources and the low-energy end of the IC component in FSRQ sources.** In the second case, the low-energy part of the particle distribution can be probed, which is inaccessible in other bands. There is a scattered evidence that FSRQs can have very hard spectra in the hard X-ray band, which challenges the hadronic models for high-energy emission (Sikora *et al.* 2009 ApJ 704 38). Moreover, the location of the luminosity peak of the IC component in FSRQs is poorly constrained. COSPIX will have unprecedented sensitivity in the hard X-ray band up to about 100 keV and hence it will measure the spectra of a large number of blazars even at high redshifts.

Detected polarization degrees up to 40 % have provided the strongest argument for the synchrotron nature of the radio, mm and NIR-opt-UV emission in blazars. **Polarimetric measurements of blazars in the hard X-rays with COSPIX** will provide a significant new insight into the structure of their emitting region. The synchrotron emission from BL Lac sources is expected to be significantly polarized while the emission from FSRQ sources is expected to be un-polarized, if produced by IC up-scattering of un-polarized external radiation on isotropic distribution of electrons (Poutanen 1994 ApJS 92 607). Hence, detection of significant polarization in FSRQs would challenge our understanding of the high-energy emission component.

The mechanical energy input via **AGN jets and lobes** into their galaxy, group and cluster environments is now thought to play a crucial role in regulating the gas properties within galaxy groups and clusters, and in driving galaxy evolution (McNamara & Nulsen 2007 ARA&A 45 117). However, physical conditions within AGN jets, their energetic and the feedback process remain poorly understood, due to the poor diagnostic power of the radio synchrotron emission by which they are primarily studied.

With its unprecedented sensitivity and spatial resolution in the hard X-ray regime, COSPIX will detect the X-ray inverse-Compton radio-lobe emission from scattering on the Cosmic Microwave Background (CMB) which will allow determining radio-lobe magnetic field and total energy content (Croston *et al.* 2005 ApJ 626 733). To date, this X-ray component has only been unambiguously detected from the population of powerful FRII radio galaxies; while it is the low-power FRI radio galaxies that are thought to dominate AGN feedback in the local Universe. COSPIX will detect and resolve ~ 100 FRI radio galaxies, with ~ 20 objects having sufficiently high count rates and well-matched angular sizes for detailed mapping of the spatial structure of the magnetic field and electron distributions (Hardcastle & Croston 2005 MNRAS 363 649). It will also detect ~ 100 FRII radio galaxies, determining the electron energy distribution over ~ 2.5 orders of magnitude in energy for the first time. About 50 objects are well suited for spatial studies and detailed investigations of curvature in the low-energy electron population to test particle acceleration models. COSPIX will enable enormous progress in this field by allowing us to identify the maximum energy to which particles can be accelerated in a range of environments, from the relativistic shocks in FRII hotspots to the inner jets of FRI radio galaxies (Hardcastle *et al.* 2007 ApJ 670 81) and the bow shocks surrounding expanding radio-galaxy lobes, which appear to behave similarly to supernova remnant shells (Croston *et al.* 2009 MNRAS 395 1999). The high-energy cut-off in all of these environments is expected to fall within the COSPIX energy band, and the X-ray synchrotron fluxes in this band are predicted to be high enough to allow their identification for the first time in tens of nearby objects. Also, COSPIX has the resolution needed to map in a handful of well-studied objects (e.g. Centaurus A, Pictor A) their spatial variation in the cut-off so as to characterize the dependencies of particle acceleration behaviour on environment and shock conditions.

II. Matter under extreme conditions

Relativistic effects from accretion in the strong relativity regime of black holes

Accretion in very compact objects allows us to also explore gravitation in the strong field limit and determine black hole parameters. **Relativistic effects** shape the emission produced close to the black hole horizon and in particular the iron emission line and overall reflection spectrum of compact accreting sources. This emission then encodes in its feature profile and variability crucial physical parameters, providing a unique tool with which to study the geometry, velocity, irradiation radial profile, and dimensions of the innermost accretion flow close to the black hole event horizon (or the neutron star surface). Assuming that the innermost disc radius corresponds to the Innermost Stable Circular Orbit (ISCO), the black hole spin can be determined. **Black hole spin** encodes the accretion history of super-massive black holes. Steady accretion inevitably leads to highly spinning black holes, whereas short-lived accretion episodes of matter with random angular momentum vectors produce low spin. Measuring the black hole spin distribution in a significant sample of AGN then provides a picture of black hole growth and evolution. Since stellar-mass black holes cannot accrete enough mass/angular momentum to significantly affect their spin during their lifetime, spin measurements there carry information on the progenitor collapse and black hole formation.

Current X-ray observations with XMM-Newton and Suzaku have demonstrated the huge potential of relativistic iron line studies in accreting systems. However, a precise measurement of the black hole spin – and other relevant parameters – is hampered by the relatively limited bandpass (XMM) and sensitivity at hard X-ray energies (Suzaku HXD) introducing large uncertainties in the underlying continuum modeling.

COSPIX represents a large improvement due to the significant increase of effective area at iron energies and, perhaps most importantly, to the huge step forward in hard X-ray sensitivity above 10 keV with respect to any previous X-ray mission. COSPIX broadband capabilities permit an exquisite continuum modeling and, in particular, a precise determination of the reflection strength via the direct measurement of the Compton-hump intensity at ~ 30 keV. This translates into smaller uncertainties in the relevant relativistic parameters with respect to current capabilities. A COSPIX black hole spin survey of bright AGN will distinguish between slow and fast rotators providing crucial information on the accretion history of local black holes. Assuming a standard iron line and associated reflection, a 200 ks COSPIX exposure will constrain the black hole spin at the 30 % level at fluxes of ~ 1 10^{-11} erg cm^{-2} s^{-1} in the 2–10 keV band. Of the order of 100 Seyfert 1 to 1.5 are available for this study from the Swift/BAT AGN 22-month catalogue.

Matter under extreme conditions in Neutron Stars

Neutron stars (NS) are fundamental targets to explore matter under extreme conditions since they have the highest known matter densities in nature, utterly beyond the densities produced in terrestrial laboratories. Understanding the properties at nuclear densities and determining its equation of state (EOS) has been one of the most challenging problems in the contemporary astrophysics. To date through the complexity of Quantum Chromo Dynamics uncertainties in high-density regime, several and widely different EOS have been predicted, each of which imply a different NS radius for a given mass. COSPIX will determine the mass-radius relationship for a few dozens of NS of various masses with distinct methods.

Thermonuclear flashes on accreting neutron stars, observed as Type I X-ray bursts, offer a powerful probe of the conditions inside the dense interior of the neutron star. These bursts can temporarily exceed the Eddington luminosity and may thus eject nuclear burning ashes, which may engender absorption features in their spectra. Super-expansion bursts are more likely to occur in Ultra-compact X-ray binaries that accrete He-rich stellar material at low rates (Cumming 2003 ApJ 595 1077). As suggested by Weinberg *et al.* (2006 ApJ 639 1018) photoionization edges corresponding to the H-like states of ^{58}Fe at 9.2 keV, ^{59}Co at 9.9 keV, ^{60}Zn and ^{62}Zn at 12.2 keV are expected and should be detected by COSPIX. Indeed, their models predict equivalent widths larger than 600 eV for these species when ejected from the neutron star. Moreover, ^{32}S is expected to produce a photoionization edge at 3.5 keV from the base of the photosphere that, due to general relativity effects, should be detectable by COSPIX around 2.65 keV. The identification of these edges would uniquely provide a direct measure of the **gravitational redshift at the surface of the neutron star**, and thus constitute **a probe of the ultra-dense matter equation-of-state**.

The space-time geometry around neutron stars is similar to that described by the Schwarzschild metric of non-rotating black holes. All relativistic effects discussed for black hole systems are observed in neutron stars as well. In particular broad relativistic iron and oxygen lines have been detected from accreting neutron stars (Strohmayer *et al.* 2006 astro-ph/0301544). A measure of the inner disc radius is then obtained, which directly places a clean upper limit on the neutron star radius. By combining this information with mass estimates, relativistic iron lines provide an additional method to constrain the equation of state of the supranuclear density matter in neutron stars. For a dozen of accreting millisecond pulsars the pulse timing profile is also distorted due to these relativistic effects, i.e. light bending, redshift, and lensing effects. Modeling the pulse profile of ms pulsars obtained with COSPIX with a relativistic ray-tracing model where the only free parameters are the NS mass and radius will allow independent measure of these parameters due to the instrument excellent timing resolution (better than 100 μs) and energy-resolved fast timing. COSPIX measurements of NS mass and radius will hence distinguish among the allowed EOS models.

The best objects to study the **most extreme magnetic fields of the Universe**, those that **exceed the electron quantum critical field of B=4.4×10^{13} Gauss,** are Magnetars (Mereghetti 2008, A&ARv 15 225), isolated highly magnetized neutron stars that appear either as Anomalous X-ray Pulsars (AXP) or as Soft Gamma-ray

Repeaters (SGR) and that are powered by magnetic energy. The COSPIX mission will allow scientists to study in particular the AXPs hard tails that extend to a few hundred keV (Götz *et al.* 2006 A&A 449 L31) and whose nature is still unclear. With exposures as short as 20 ks COSPIX will characterize the entire spectrum of AXPs and study through their variable states (Rea *et al.* 2009 MNRAS 396 2419) the relationship between the thermal and the non-thermal components. Another unique possibility for COSPIX is the direct measure of the magnetic field of Magnetars through the detection of absorption lines in the hard X-ray domain in SGR burst spectra. Some of these detections have been tentatively claimed in the past (Ibrahim *et al*. 2007 Ap&SS 308 43), and simulations show that they would be easily obtained with COSPIX, then providing the only model independent measurement of the magnetic field of Magnetars. COSPIX will also study **Isolated Neutron Stars** (pulsars) with less extreme magnetic fields, which will provide constraints on the emission mechanism and geometry in the pulsar magnetosphere.

Measurements of **cyclotron lines in the hard X-ray spectrum of X-ray Pulsars (XRP)** also provide a direct measurement of the highest NS magnetic fields, since the line energies for fields in excess of 10^{12} G are expected in the hard X-ray range. Cyclotron lines have been observed in more than a dozen XRP (Coburn *et al*. 2002 ApJ 580 394). These lines vary in shape, depth, and width over the pulse (Schönherr *et al*. 2007 A&A 472 353) depending on the physical parameters like plasma geometry, electron temperature and density. The XRP high quality spectra that will be obtained by COSPIX will constrain the parameters of cyclotron lines and the underlying continuum in unprecedented detail. Simulated COSPIX spectra of some of the known cases with exposures as short as ~ 5 ks prove that the line positions can be determined with a relative accuracy of ~ 0.2 %, and a 100 ks will allow to perform accurate phase resolved spectroscopy in at least 10 phase bins and to determine the cyclotron line energy with relative accuracy of ~ 0.15 % in every bin.

III. Acceleration Processes

Acceleration in SuperNova Remnants

Supernova remnants (SNR) are expected to be the main source of Galactic cosmic rays. Their ability to accelerate particles to very high energies has been testified by observations of X-ray synchrotron emission at their shocks (ASCA, Chandra and XMM-Newton) and very high energy GeV-TeV emission (HESS, Fermi). However, a number of fundamental issues stay unresolved like the evidence of proton acceleration, the level of efficiency of the acceleration process and its dependence on the magnetic field amplification and orientation (Drury *et al*. 2001 SSRv 99 329). Assessing the nature and spatial distribution of the emission above 10 keV is necessary to resolve a number of pending questions and characterize the electrons accelerated at the highest energy in supernova remnants.

The X-ray spectrum of a SNR sums the contributions from various emission mechanisms: thermal bremsstrahlung from the highest temperature shocked ambient medium, synchrotron emission at the forward shock, non-thermal bremsstrahlung at the interface between the shocked ejecta and ambient medium. Spatially resolved broad band X-ray spectroscopy encompassing the emission above and below 10 keV, is needed to disentangle those contributions, which dominate at different energies and locations (Fig. III.1).

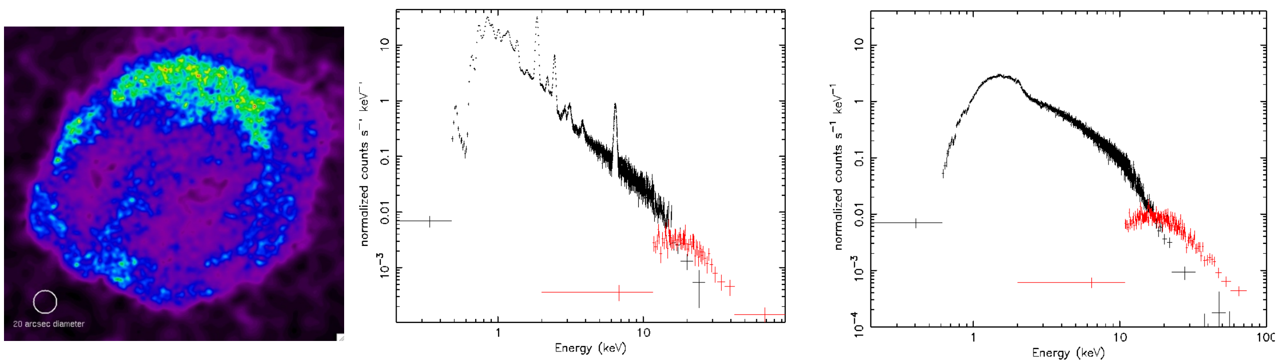


Fig. III.1: *COSPIX simulations of Kepler's SNR for 50 ks exposure time and a signal to noise of 5.* ***Left****: 20-40 keV HED adaptively smoothed image. Simulated spectrum of a region of 20'' diameter where both thermal and synchrotron emission are contributing* ***(middle)*** *and where synchrotron only is present* ***(right)****.*

The full characterization of the synchrotron X-ray emission up to tens of keV is required to derive what is the particle maximum energy (if the magnetic field is known) through the measurement of the X-ray cut-off frequency, what is the spectral shape of this cutoff, where particle acceleration occurs preferentially (where the magnetic field is parallel or perpendicular to the normal of the shock), what is the level of magnetic field amplification and what is the dependence of the maximum energy with the field orientation.

A fundamental quest is to establish evidence for ion acceleration in supernova remnants, to determine how efficient cosmic-ray acceleration is and what fraction of the shock energy can be tapped by the cosmic rays. Pion decay emission arising from the collision of accelerated protons with protons is expected in the GeV-TeV band (Drury *et al.* 1994 A&A 287 959). But the emission is contaminated by the contribution of the inverse Compton emission. Characterizing precisely the synchrotron emission of electrons constrains the inverse Compton TeV emission of those same electrons, as well as the curvature of the particle spectrum (Berezhko & Ellison 1999 ApJ 526 385), which holds the signature of proton acceleration.

Radioactive nucleosynthesis products in supernova remnants: ^{44}Ti

Young SNR will also be observed with COSPIX in order to study the formation of elements. With a lifetime of 85 yrs, ^{44}Ti provides a direct way to study the radioactive nucleosynthesis products arising from the deeper layers of the supernova and provides constraints on the explosion mechanism. The radioactive decay lines associated to ^{44}Ti have been measured uniquely in the Cassiopeia A (Cas A) SNR, notably with Beppo-Sax and INTEGRAL (Renaud *et al.* 2006 ApJ 647 L41). Its intensity implies a large energy and asymmetries in the explosion (Young *et al.* 2006 ApJ 640 891). A key issue is to determine the location within the ejecta and the velocity of this radioactive element produced during the first stages of the supernova explosion. COSPIX will be able to perform these measurements in Cas A and in G1.9-0.3 (Fig. III.2), the youngest known SNR in the Galaxy (Reynolds *et al.* 2009 ApJ 695 L149). ^{44}Ti is expected to be detectable in all young supernova remnants. Measurement of the abundance and distribution in other young remnants (as e.g. SN 1987A) will provide important constraints on the explosion mechanism; in particular, for massive progenitors, on the mass-cut between the compact remnant and the ejecta.

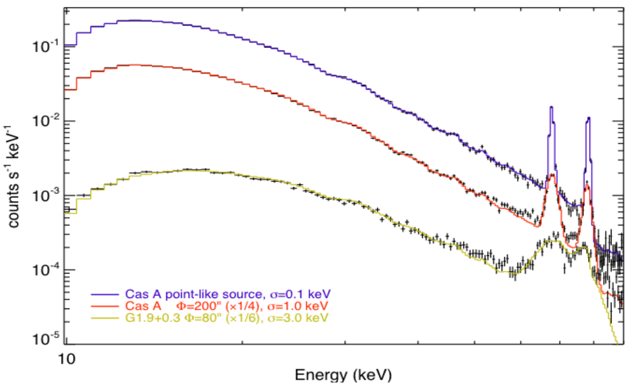


Fig. III.2: *Spectra of simulated 100 ks COSPIX observations of Cas A and G1.9+0.3. Two scenarios are considered for Cas A: a static point-like source (blue) and an extended source of 200" diameter (Φ) (red) with an average velocity of 4000 km/s. A 3σ velocity resolution of ~2000 km/s is estimated. For G1.9+0.3, a ^{44}Ti-emitting region velocity of ~14000 km/s, of total ejected mass of 3 10^{-5} $M_\odot$ is assumed.*

Acceleration in Pulsar Wind Nebulae

Pulsar Wind Nebulae (PWN), the extended bubbles inflated by the wind of radio pulsars, are powerful emitters of non-thermal X-ray radiation (Gaensler & Slane 2006 ARA&A 44 17). The pulsar electron-positron wind interacts with the surrounding medium and forms a relativistic shock, which accelerates particles up to PeV energies, the highest energy particles associated with astronomical discrete sources. Since hard X-rays from PWN are closely linked to the post-shock distribution, COSPIX will allow studying the diffusive acceleration in the (poorly understood) relativistic shocks. Besides the morphological and spectral studies, COSPIX will map for the first time the *polarimetric* properties of PWN in hard X-rays.

Despite the highly dynamical nature of PWN they were considered steady emitters. Significant flux variability of the overall Crab nebula has been recently reported both in X-rays (long-term, Wilson-Hodge *et al.* 2010 arXiv/1010.2679) and in GeV gamma-rays flares (Abdo *et al.* 2010 arXiv/1011.3855). The measured X-ray variability, on the order of 3.5% yr^{-1}, is compatible with the one predicted by MHD simulations (Volpi *et al.* 2008 A&A 485 337). Data also suggest a possible quasi-periodicity on a ~ 3 year timescale, still in agreement with the expected MHD timescale of the outflow and of the entangled magnetic

Fig. III.3: *Chandra image of the inner part of the Crab nebula. The grey spot shows the COSPIX 20" diameter point spread function.*

field downstream the shock (Camus *et al.* 2010 MNRAS 400 1241), however alternative explanations exist (Spitkovsky & Arons 2004 ApJ 603 669). COSPIX will be sensitive to flux differences as low as 0.5% Crab in 10-80 keV and 2.5% Crab in 50-80 keV in only 50 ks. With longer exposures, it will detect the variability on PWN with flux of a few mCrab. With short observations, COSPIX will firmly establish PWN quasi-periodicities. This will allow to test whether the timescales and the RMS intensities are linked to the crossing time of the magnetosonic waves.

According to MHD simulations, the polarization fraction in PWN is very high, close to the theoretical maximum (~77%), and the polarization angle is mostly parallel to the pulsar spin axis (Del Zanna *et al.* 2006 A&A 453 621). This prediction has been recently confirmed by INTEGRAL, which discovered polarization in the Crab non pulsed 100 keV-1 MeV emission, aligned with the pulsar rotation axis (Dean *et al.* Sci 2008 321 1183, Forot *et al.* 2008 ApJ 688 L29). COSPIX polarization measurements will open a new window on the geometry and magnetic configuration of the wind. Because of the short lifetime of the electrons radiating in hard X-rays, the energy-dependence of the polarization will also probe for the first time the amplitude of the magnetic turbulence on length-scales of 0.1-10 parsec. In a 30 ks observation, COSPIX will detect polarization in the Crab for a fraction as low as 1% (in the 25-40 keV band), allowing to phase-resolve the polarization of the Crab pulsar and to spatially resolve the polarization along the nebula (~ 4' diameter) (Fig. III.3). The measure of the polarization fraction will be possible to a level above 8% (50 ks) for 10 mCrab sources as the Vela nebula and PSR B1509-58/MSH 15-52, and above 30% (100 ks) for the dozen faint PWN detected by INTEGRAL with typical flux of a few mCrab. This will allow probing the magnetic field configuration in more evolved and diffuse PWNe.

Non-thermal emission of galaxy clusters

Deep radio observations have pointed out the existence of diffuse radio sources in galaxy clusters (radio "halos" and "relics"; see e.g. Ferrari *et al.* 2008, SSRv, 134, 93), related to the presence of magnetic fields (~ μG) and cosmic ray electrons (E~GeV) in the intracluster volume. The effects of this intracluster non-thermal (NT) component on galaxy cluster formation and evolution have been largely neglected in the last years. Only recently the astrophysical community has realized the need of characterizing more precisely the physical properties of the cluster NT component to study its effects on galaxy cluster mass estimate and dynamical evolution (e.g. Laganà *et al.* 2010 A&A 510 76). Galaxy clusters form hierarchically via the collapse and merger of smaller structures. Cluster mergers are possibly responsible for electron acceleration and seed magnetic field compression and amplification in the intracluster volume. The origin and evolution of the intracluster NT component is however strongly debated. More precise measures of magnetic field intensity and structure and of cosmic ray energetics are required.

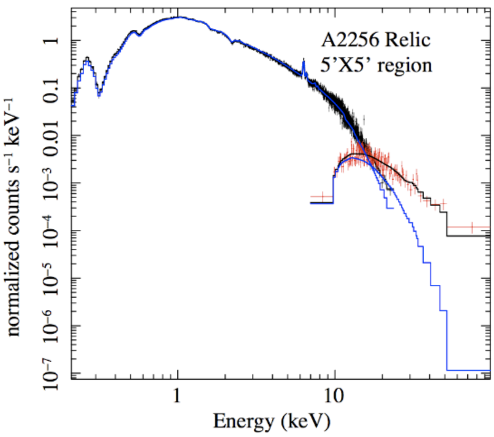


Fig. III.4: *Spectrum of a simulated COSPIX observation of a 5×5 arcmin^2 region in the A2256 galaxy cluster radio relic (Low Energy Detector in black, High Energy Detector in red). The thermal emission was estimated from ROSAT and Chandra data. The Inverse Compton emission was assumed as a power law with 0.8 index and 20-80 keV flux of 5 10^{-12} ergs/s/cm^2, mostly originated in the relic, with ~ 1/3 of the total flux in the integration region. The black line is the (MEKAL+PL) model. The blue line is the best fit isothermal model to simulated data. The IC emission is unambiguously detected at 20 σ level and its slope and normalization measured with an accuracy of ± 1.5 % and ± 5 % respectively.*

Non thermal inverse Compton hard X-ray (HXR) radiation is expected from interaction of CMB photons and intracluster relativistic electrons. Up to now detection of X-ray non-thermal emission from galaxy clusters has been matter of debate due to the absence of instruments with the required spectro-imaging capabilities in the HXR band. Our simulations (Fig. III.4) show that COSPIX has the capabilities to unambiguously detect the NT HXR emission from galaxy clusters hosting typical diffuse cluster radio sources. The angular resolution of COSPIX is a minimum requirement to discriminate point sources from the extended cluster emission. When combined with radio data, observations of the HXR cluster emission allows to constrain the energy spectrum of relativistic particles (e.g. Arnaud 2008 MSAIt 79 170) and the intensity of intracluster magnetic fields (Eq. 13 in Ferrari *et al.* 2008 SSRv 134 93). Note the importance of combining COSPIX observations with data from new generation radio telescopes (e.g. LOFAR, LWA, EVLA, ASKAP, MeerKAT, SKA...) that are opening a new era for non-thermal cluster studies.

Other relevant science objectives of COSPIX and synergies with other facilities

Thanks to its high performance in a very broad energy band and its spectral, imaging and polarimetry capabilities the COSPIX mission will provide many other invaluable results virtually in all fields of modern high-energy astronomy for a very large astrophysical community. All the large variety of galactic and extragalactic compact objects, from low/high mass X-ray binaries (L/HMXB) to cataclysmic variables (CV), will be important targets for the mission but COSPIX will also explore diffuse sources, hot plasmas and stars thanks to its unique ability to study and disentangle thermal and non-thermal components.

For example studies CV with COSPIX will lead to determination of the mass of white dwarfs (WD), which is another crucial measurement **since it determines the final fate of such stars and if they are scenarios of type Ia supernovae.** The properties of the thermal plasma falling onto a WD depend on its mass: the larger the mass, the stronger the accretion shock and the larger the reached temperature and the energy of the photons emitted, up to some tens of keV. Therefore **COSPIX would be crucial to determine the masses of WDs in CVs**, especially in the most interesting cases where they are potential SNIa (e.g., in post-outburst classical or recurrent novae, once accretion is re-established). Another important experiment will be to explore the hard X-ray component of the **afterglow emission of Gamma-Ray Bursts (GRB)** that will provide new insights in the models of the shock of the GRB ultra-relativistic fireball with the interstellar medium. COSPIX will also detect and measure the inverse Compton hard X-ray emission from a large sample of **colliding wind binaries** (systems harboring two massive early-type stars whose stellar winds generate hydrodynamic shocks) covering a wide range of their orbital and physical parameters. This will shed new light on particle acceleration in such shocks over a different part of the parameter space (magnetic field strength, local plasma density, shock properties, optical radiation) than for supernova remnants, and will thus allow quantifying the overall contribution of colliding wind binaries to the cosmic ray production. Finally COSPIX will explore the non-thermal activity of the **Sun, active stars, Young Stellar Objects and protostars**, which are known to present different level of persistent and flaring hard X-ray emission.

As has been mentioned through this detailed scientific section, a number of the COSPIX research subjects will benefit from observations performed at other wavelengths by new generation instruments. For example the James Webb Space Telescope will provide a wealth of data on candidate Compton Thick AGNs which will be observed by COSPIX; the European-Extremely Large Telescope will monitor several supermassive black holes as can be done today only on SgrA*, giving with X-rays strong constraints on flaring activity; the Cerenkov Telescope Array will look to the very high energy component of SNRs and PWNs, probing with hard X-ray observations cosmic rays acceleration; the Square Kilometer Array will measure the radio emission of clusters of galaxies constraining with X-rays their non-thermal energy content.

Scientific Requirements Table

Req. #	Parameter	Value
SR-1	Energy band	0.3 – > 80 keV
SR-2	On-axis continuum sensitivity	$\leq 2\ 10^{-15}$c.g.s. (~ 0.1 μCrab) ; 10–40 keV band, 3 σ in 1 Ms
SR-3	On axis line sensitivity @ 68 keV	$< 10^{-7}$ ph cm^{-2} s^{-1} ; 3 σ in 1 Ms,
SR-4	Minimum Detectable Polarisation	< 0.7 % ; 20–40 keV, 3 σ in 100 ks, for 100 mCrab source

Req. #	Parameter	Value
SR-5	Field of view @ 30 keV	diameter ≥ 6 arcmin (goal 9 arcmin)
SR-6	Angular resolution (H.E.W.)	≤ 10 arcsec @ E < 10 keV ≤ 20 arcsec (goal 15 arcsec) @ E = 30 keV
SR-7	On-axis effective area:	≥ 400 cm^2 @ 0.5 keV ≥ 2000 cm^2 @ 1 keV ≥ 3500 cm^2 @ 10 keV ≥ 1800 cm^2 @ 30 keV ≥ 600 cm^2 @ 75 keV
SR-8	Spectral resolution	E/ΔE = 40-50 in 6-10 keV ; E/ΔE = 65 @ 68 keV
SR-9	Detectors background	< 2 10^{-4} cts $s^{-1}cm^{-2}keV^{-1}$ for HED and LED
SR-10	Absolute timing accuracy	100 µs (50 µs goal)
SR-11	Time resolution	50 µs
SR-12	Absolute pointing reconstruction	~ 3 arcsec (goal 2 arcsec) radius, 90%
SR-13	Mission duration	3 years (goal 5), after commissioning and calibration
SR-14	Total number of pointings	> 2000 (goal > 3000)

SR-1, **broad-band coverage**: starting well below 1 keV, is necessary to constrain and cleanly separate different continuum and absorption spectral components. Extending the band largely above 75 keV is important to cover the ^{44}Ti line and to constrain efficiently the high energy cut-offs in AGN's spectra.

SR-2, continuum sensitivity in hard X-rays: needed to resolve a very large fraction, ~ 70 %, of the Cosmic X-ray Background at its peak energy. It is also needed in order to accumulate meaningful spectra in variable objects in a duration comparable to their dynamical time-scales.

SR-3, line sensitivity in hard X-rays: needed to achieve the mapping of the ^{44}Ti line in Cas A and other Galactic young SNRs, and search for ^{44}Ti emission in SN1987A.

SR-4, minimum detectable polarisation: ensures accurate measurements of the probable reflected component of the past Sgr A* activity on molecular clouds, mapping of the Crab nebula, and open sensitive window for finding polarization expected in blazars and binaries.

SR-5, field of view: a large FOV is needed for deep surveys targeted to the resolution of the Cosmic X-ray Background, as well as for the study of acceleration in extended sources (clusters of galaxies, supernovae remnants, jets), and of binary systems in close by galaxies.

SR-6, angular resolution: necessary for both reaching the required sensitivity and avoid source confusion. Also necessary for resolving features like radio-galaxy hot spots and lobes and supernovae remnants, and to avoid confusion in complex and crowded regions like the Galactic Centre, star-formation regions etc...

SR-7, effective area: in order to meet the above sensitivity requirement and to ensure an adequate spectral capability across the entire energy band the minimum telescope effective area is needed as indicated.

SR-8, spectral resolution: needed to separate different absorption and emission spectral components at low energy, including the Fe line, and characterize at high energy the 68 keV, and possibly 78 keV ^{44}Ti lines.

SR-9, detectors background: ensures the required sensitivity on axis for point sources, and allows sensitive mapping of extended sources with low surface brightness.

SR-10, absolute timing accuracy: needed to perform absolute phase determination of e.g. ms pulsars, and compare with radio data, requires an absolute timing accuracy of at least 100 µs (50 µs goal), obtained after on ground processing.

SR-11, time resolution: implied by the SR-10 requirement.

SR-12, pointing reconstruction: needed to fully exploit the required angular resolution, and for correlation with other wavelengths. Obtained after on-ground processing.

SR-13, mission duration: the minimum to ensure that all the scientific goals of the mission are met to an acceptable level. The mission being an observartory, and the potential targets being very numerous and for some of them very variable, an increase of the mission duration will allow to increase the science return.

SR-14, number of pointings: in accordance with the very large number of potential targets, and the observatory type of the mission.

MISSION PROFILE

The mission profile is driven by the following top level requirements.

Firstly, COSPIX is a telescope observing celestial sources. It is operated in a pointing mode, with observation times which can range from a few kiloseconds to several hundreds of kiloseconds. In addition, the full sky should be accessible at least once during the mission.

COSPIX is an observatory, with an observation program that will be regularly uploaded according to scientific selections, and mission constraints. As a lot of sources are variable in time, it is highly desirable for source variability studies to minimize possible interruptions during an observation sequence. A high elliptical orbit is necessary for that reason. Moreover, the stability of the focus (whatever the technology, i.e. mast or formation flight) is also much easily ensured at large distances from the Earth, i.e. again at least on highly elliptical orbits.

On the other hand, there is no scientific necessity, during routine observations, to have a continuous link with the Earth. The spacecraft can be operated autonomously, following an observation program that will be regularly uploaded.

Finally, the full scientific data should be downloaded regularly, with a suggestion of one communication session per day. In case the full scientific data could not be downloaded daily, it is nevertheless necessary to download with this periodicity at least quick look data, a set of monitoring data set prepared onboard.

According to these constraints and according to the mission study detailed in the "Spacecraft Requirements and Spacecraft Key factors", the elements of the mission can be specified as required.

I. Launcher requirements

The mission study shows that the required scientific performances can be met with a system of 2.06 tons of wet mass, including contingency and system margins (0.49 tons of margins total). This mass budget fits perfectly with the performance of the **Soyuz Fregat vehicle**, launched from **Kourou**.

However, there is no special requirement on the launcher.

II. Orbit requirements

The orbit must offer the possibility of long observations and stable environmental conditions with a minimum of gravity gradient between the two ends of the telescope.

A **Lissajous orbit around L2** is consequently the preferred orbit. It offers the most stable environmental conditions. This also minimizes the amount of cold gas propellant needed to maintain the formation flight configuration (if this technology is adopted). Alternatively, for a given cold gas mass at launch, this ensures the longest possible lifetime of the mission.

Otherwise, a Highly Elliptical Orbit could probably be considered but appears less desirable a priori.

III. Ground segment and communication requirements

The ground segment should have an operational part. Its role will be to ensure manoeuvres of the spacecraft and commands, both for spacecraft and instrument. It will be responsible for uploading the observation program as well as monitoring the instrument health. Finally, it will be responsible for downloading full science data and quick-look data.

The ground segment should also have a scientific part, with a role described in the "Science operations and archiving" section.

Contacts with COSPIX should be made daily for full scientific data download. This is consistent with the sizing of scientific data volume, telemetry, and onboard memory described in the proposal. Other periodicities can be considered for full scientific data download, provided that at least quick-look data are downloaded once per day.

COSPIX should have the capability to cope with at least one telecommunication failure without stopping the observation program and without losing data. Consequently, it must have enough mass memory to store the corresponding scientific data, and to guarantee a sufficiently long observation program.

Observations should not be interrupted during the contact with the Earth and the scientific data download.

The sources observed by COSPIX are different in nature and intensity. Moreover, a lot of them are intrinsically time-varying. The amount of scientific data generated between two download periods will thus be variable. Most of the observations will be on low brightness sources, generating a low amount of data. The communication requirements with the ground are driven by the less frequent observations of very strong sources. The data corresponding to such strong sources (intensity of several Crab) that will be observed for a relatively short time (typically 10 ks or less) can be downloaded in a few standard contact sessions. It is estimated that these conditions are met with the following requirements:

• Scientific data volume: **3 GBytes/day**

• Telemetry rate and time: **1.6 Mbits/s during 4 hours**

These requirements can be met by the use telecommunication in **X band with a 15 m ground antenna**.

There is no request on the location of the antenna.

IV. Operational mode

COSPIX is an observatory, working in pointing mode during celestial observations.

COSPIX will have an observational program for given sources to be pointed. The program includes the associated duration of the observations and the instrument observation mode (described in the payload section).

In nominal operations, COSPIX will run autonomously the observational program stored onboard.

In addition the mission will have the capability to observe a Target of Opportunity (ToO) on trigger from alerts given by the community. A desirable response time for ToO is 24 hours from the trigger.

COSPIX will have standard emergency modes in case of problems.

COSPIX will have an instrument safe mode, in case of occurrence of solar flares, triggered by the COSPIX payload (monitor of count rate). In entering this mode, the calibration wheel will be closed and the observation interrupted. The observation will be resumed at the end of the solar flare, also monitored by the COSPIX payload.

V. Mission Lifetime

The mission lifetime should be three years after the commissioning and calibration phase. However, the goal is to reach a five years mission. Part of the commissioning and calibration phase can be done during the transfer to L2.

VI. Special requirements

There is no special requirement.

VII. Critical issues

There is no critical issue.

COSPIX PAYLOAD

I. Overview of all proposed payload elements

The COSPIX telescope is basically built using a classical Wolter I optics focusing X-rays onto a focal plane detector system. The gain in the maximum energy that can be focused is achieved by having a 33 m focal length. Since this cannot fit in a single spacecraft, due to the limited size of fairings, the mirror and detectors will be flown on two separate spacecrafts in a formation flight configuration. The COSPIX mission will have then two payloads, the mirror and the detector ones, one on each satellite.

II. Summary of mirror payload key resources and characteristics

II-1. Description of the measurement technique

The COSPIX mirrors are accurate approximations of Wolter I optics typically used in X-ray astronomy, working in grazing incidence as currently used for XMM/Newton and Chandra. Because the optics properties entirely rely on the total reflection phenomenon, which is characterized by a very large reflectivity at grazing angles until a critical angle beyond which the reflectivity falls rapidly down to almost zero, conventional single layers coatings limit the maximum energy and field of view (FOV). In order to increase both parameters, the mirrors will be coated with multi-layers, which exploit Bragg diffusion in addition to total reflection.

II-2. Mirror conceptual design and key characteristics

The COSPIX mirror will mix two mirror technologies, Silicon Pore Optics (SPO) and Glass optics (GOp). The GOp will be inserted in the SPO and will ensure the high energy response of the telescope. The SPO external mirror will offer more than 3500 cm² effective area at 10 keV. Similarly to XMM/Newton, both mirrors will have sieve plates in order to minimize the stray light due to out of FOV X-ray sources. A concept view of the COSPIX mirror is given in Figure 1.

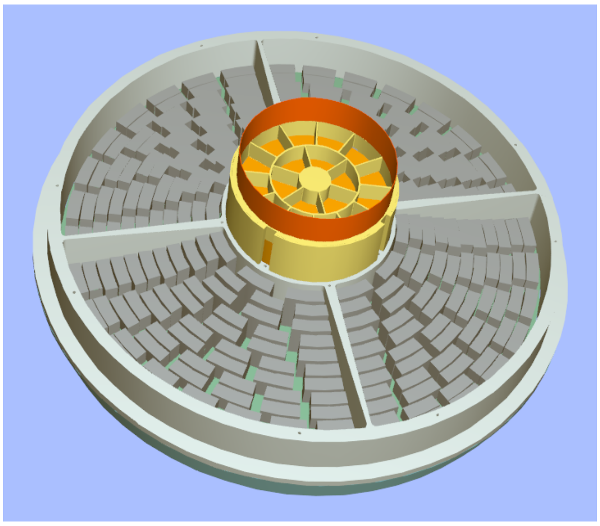
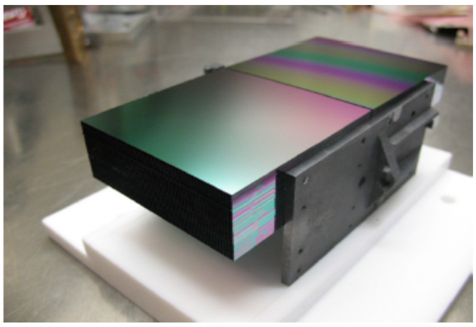


Figure 1: *Concept view of the X-ray mirror assembly made of SPO and GOp.*

II-2-a Silicon pore optics

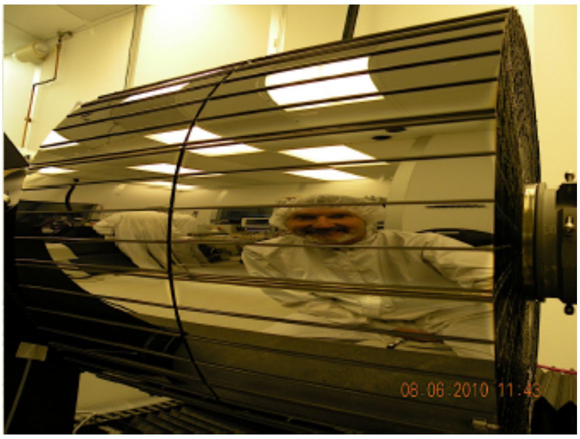
Silicon pore optics (SPO) are made of silicon mirror plates diced from standard silicon wafers. The plates are ribbed on one side (called the back side). The front side is used for the reflection of X-rays. Then the ribbed plates are bonded to form a stack. Doing do, a stack forms a set of concentric conical surfaces. In order to approximate a Wolter-I system, two stacks are placed one after the other in such a manner that two SPO stacks form a cone-cone system. A two-stack system is called a Mirror Module (MM). In a cone-cone system made with SPO, the spacing between consecutive reflecting surfaces is dictated by the thickness of the silicon wafers, and is therefore (almost) constant across the optics. Consequently, the length of the silicon plates along the optical axis increases as their radial position decreases. The SPO technology has been under development at ESA for the International X-ray Observatory mission (IXO).



SPO Mirror Module

II-2-b Glass optics

The glass optics technology has also been under development for IXO. It has been successfully adapted for making hard X-ray mirror assemblies for NASA's NuSTAR mission, scheduled for a launch early 2012. The mirror substrates are thin sheets of flexible glass, which start out as flat sheets. The glass is heated in an oven and slumped over precisely polished cylindrical quartz mandrels to achieve the right curvature. The slumped mirror segments are then coated with a multilayer process. The optics are built from the inside out, shell upon shell, spaced apart by graphite spacers and held together by epoxy.



NuSTAR FM Glass Optics

II-2-c Optics key characteristics

The table below gives the key characteristics of the two optical modules foreseen for COSPIX.

	SPO	*GOp*
Number of Shells	470	370
Multilayer coating composition	Pt/C	Pt/C

***Table 1**: Key parameters of the COSPIX glass and silicon pore optics mirrors.*

II-3. Performance assessment

First computations made for the SPO and for the Glass Optics lead to the mirror performances in Table 2, for a mirror configuration as described in part II-2-c, which shows that the COSPIX scientific requirements will be met.

II-4. Resources: mass, volume, power, telemetry

The mass and volume of the mirror payload is given in Table 3. The total mirror mass is 394 kg (with 10% margin for Si or Glass and 20% margin for mounting system). It is included into an overall cylinder of 1124 mm of diameter and 750 mm height.

SR	Parameter	Required	SPO	GOp
7	Effective area @ 1 keV (cm^2)	**≥ 2000**	3517	965
7	Effective area @ 10 keV (cm^2)	**≥ 3500**	3327	951
7	Effective area @ 30 keV (cm^2)	**≥ 1800**	1295	897
7	Effective area @ 75 keV (cm^2)	**≥ 600**	28	613
5	FOV @ 30 keV (at 50%)	**≥ 6'**	4'	6'
6	Angular Resolution < 10 keV	**≤ 10"**	≤10"	≤10"
6	Angular Resolution @ 30 keV	**≤ 20"**	≤20"	≤20"
1	Energy range (keV)	**0.3–80**	0.3 - 80	0.5 – 100

***Table 2**: Performances of the COSPIX mirrors with respect to the scientific requirements.*

	SPO	GOp
Inner Diameter (mm)	500	100
Outer Diameter (mm)	1124	500
Height (mm)	280	750
Mass of Mirror Segments (kg)	259	70
Mirror Assembly Mass, including both glass and structure (kg)	274	120

***Table 3**: Mirror geometry and mass budget.*

II-5. Pointing and alignment requirements

These requirements, being common to mirror and payload satellites, are discussed in section IV.

II-6. Operating modes

N/A

II-7. Specific interface requirements: configuration needs, thermal needs

As the mirror payload should be shielded against the solar flux, baffles are included in the design and mass estimates. Doors should be also foreseen in order to protect the COSPIX mirror against contamination. Mirror performances are dependent on their temperature, so a thermal regulation will be provided by the mirror satellite platform in order to maintain the temperature gradient through the whole mirror to less than 0.5 °C.

II-8. Calibration

The SPO and GOp will be calibrated at each stage of their production, for the different models of the mirror payload (QM, FM). Efficiency and angular resolution will be checked, using dedicated calibration facilities such as Panter in Germany, the CSL in Belgium, or X-ray beam lines at Columbia University, NASA/GSFC or NASA/MSFC.

II-9. Current heritage and TRL

The two optics of the COSPIX mirror inherit from studies made for the IXO satellite, both in USA and in Europe. According to NASA/GSFC, Glass Optics development in view of the COSPIX performances, tighter than NuSTAR ones, is actually at TRL 4. The technology development from TRL 4 to TRL 5/6 is already underway, in synergy with the IXO mirror technology development. SPO is under development through an ESA contract. Currently, several activities are running in parallel, to be completed in 2011; these will result in first vibration and thermal tests of mirror modules (MM) to achieve TRL 5.

II-10. Procurement approach

II-10-a Silicon pore optics

The SPO is developed through the ESA technological development program. Obviously COSPIX can benefit from the continuation of this program, as the current technology plan is largely coherent with the requirements of COSPIX. In case this program is discontinued, a similar program will be implemented for the COSPIX needs. Before 2015, the process development consists of two major phases: reaching TRL 5 and producing a breadboard. This breadboard would consist of one petal populated with 9 MM, fully representative of the final MM including multi-layer coating, the rest filled up with mass dummies.

II-10-b Glass optics

The glass substrates will be manufactured at GSFC using an existing facility that is being used for NuSTAR. It will be upgraded and available for COSPIX by the end of 2011. Then the substrates will be coated with multilayers both in Denmark and New York City, as the NuSTAR substrates are being done.

II-11. Critical issues

We have identified the following critical issues for which we foresee dedicated technical development activities:

a. The mounting and alignment process of the two mirrors.
b. The required FOV is at the limit of the current technology.

III. Summary of detector payload key resources and characteristics

III-1. Description of the measurement technique

The COSPIX focal plane (FPA) is designed to detect single photons focused by the mirror in the energy range from 0.3 up to 100 keV. To do so, the FPA is equipped with two superimposed semiconductor based imaging spectrometers, LED (Low Energy Detector - Si) and HED (High Energy Detector - CdTe). Both are embedded into an active and passive shield system, ACD (Anti Coincidence Detector). LED and HED will measure the interaction position, energy deposit, and arrival time of each incoming X-ray. The LED detector, based on Silicon Active Pixel Sensor imager technology, will operate in the low energy range from 0.3 up to 40 keV, whereas the HED, CdTe based imager, will cover the 8 to 100 keV range. Combining coincidence data of the two detectors will allow using the FPA as a hard X-ray Compton Polarimeter. A collimator will be placed on top of the FPA to stop all photons coming out of the mirror field of view. ACD will allow detecting charged particles of the space environment, avoiding a significant loss of sensitivity due to induced background on LED and HED. The whole payload system will be calibrated in flight by means of two radioactive sources mounted on a calibration wheel (CW). A protective enclosure surrounds the detector assemblies to provide environmental protection and to block stray light.

III-2. Detector Payload conceptual design and key characteristics

FPA design is completely inherited from the Simbol-X Detector Payload Phase A studies and scaled to COSPIX geometry. Figure 2 illustrates the FPA arrangement. Warm electronics boxes are not represented here. However, the system counts four independent electronics boxes on the payload, all connected to primary power bus from S/C:

a. DPU (Digital Processing Unit) hosts the onboard computer and manages TM/TC and data packets via Space Wire links (SpW) from detectors electronics and to the S/C.
b. CE (Control Electronics) hosts CW and Thermal Control (TC) electronics for thermal regulation of FPA. CE has a SpW link to DPU.

c. DE (Detector Electronics) hosts HED, ACD electronics and Event processor electronics (EPE). DE has a SpW link to DPU.
d. LESE (see III-2-a) has its own electronics box and has a data link to DE.

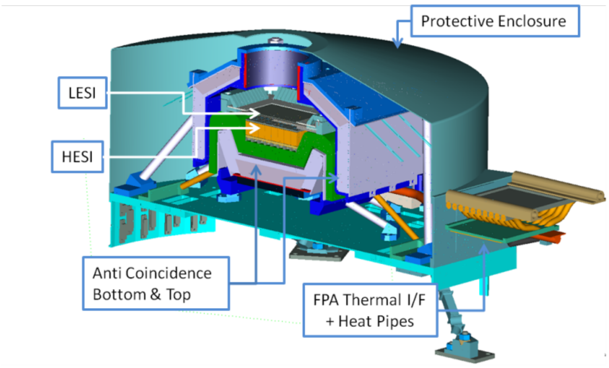
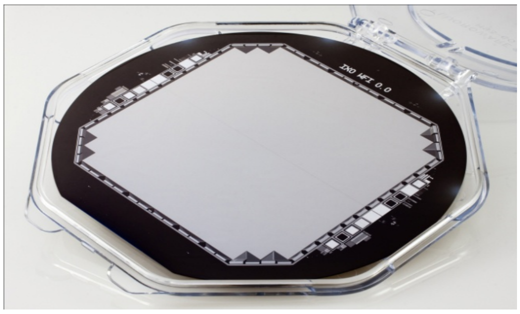


Figure-2: *FPA layout.*

III-2.a The Low Energy Detector (LED) description and characteristics

LED operates from 0.3 up to 40 keV range. It consists of 10 × 10 cm² silicon monolithic imager with a double-sided process. At the backside, it has a DEPFET active pixel sensor array, composed of 32768 macro-pixels. Pixels pitch is 520 µm for 3-fold sampling of a 10 arcsec mirror PSF. At the front side, the entrance window is divided in 32 square shaped pixels, 16.6 mm pitch, used for particle trigger above 10 keV. LED is electronically separated in five individual regions: four at the back, one on top. The LED consists of 4 main parts:

a. The Low-Energy Spectro-Imager (**LESI,** picture hereafter) is the LED pixelated anode (backside). LESI is a matrix which performs precise measurement of energy and position of the photons incoming from the mirrors. The matrix is permanently read out in a rolling shutter mode. Each pixel is readout every 192 µs thanks to optimized distribution of front-end electronics and control front-ends, enabling parallel readout strategy and eventually fast readout window mode (64 µs).
b. The Low-Energy Spectro-imager Electronics (**LESE**) which includes ADCs, sequencers, and event pre-processing unit for corrections and pattern recognition (tracks suppression, multiple events management). LESE fits into a dedicated electronic box on the payload. It is connected to primary power of S/C and uses SpW for data interface to the DE.



LESI module

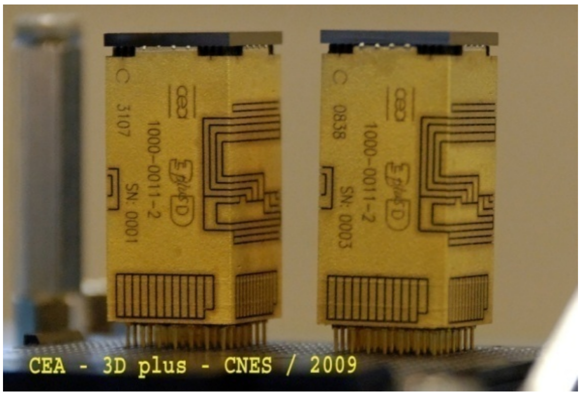
c. The Low-Energy Trigger (**LET**), which is the LED segmented cathode. The LET is a self-trigger system to get accurate time of arrival of particles. It is used for coincidence analysis with the HED for Compton event detection and for anticoincidence with the ACD events for background rejection (see III-2-c).
d. The Low-Energy Trigger Electronics (**LETE**) includes analog front-end ASIC of LET, ADC and associated sequencer. LETE fits into a small electronics box mounted on the FPA housing and is connected to LESE (SpW and regulated power links).

III-2.b High Energy Detector (HED) description and characteristics

HED operates between 8 and 250 keV. It fully covers the mirrors high-energy capabilities. It consists of a 10 × 10 cm² assembly made of 8 × 8 CdTe elementary detection units based on Caliste technology (see picture below) developed at CEA in the frame of Simbol-X. Caliste modules are distributed on 8 fully independent hard X-ray cameras (MACSI). MACSI also includes a massive thermal drain used to facilitate cooling and is terminated by a digital interface since the interconnection termination boards support ADCs and sequencers in addition to regulated power lines. Each Caliste module is equipped with 256 pixels monolithic Schottky CdTe diode, 12 mm by side, 2 mm thick (97 % efficiency at 80 keV) and houses 8 multichannel analog front-end chips (IDeF-X HD). Pixels pitch is 780 µm for 4-fold sampling of a 20 arcsec mirror PSF above 10 keV. The HED consists of 2 parts:

a. The High Energy Spectro-Imager (**HESI**) is the assembly of CdTe based Caliste units. HESI has 16384 individual channels readout in a self-triggered mode. Pixels are distributed in a 128 × 128 array. HESI performs precise measurement of energy, position and arrival time of the single photons incoming from the mirrors.

b. The High Energy Spectro-imager Electronics (**HESE**). HESE holds 8 boards insuring power distribution and SpW data link to the 8 MACSI sub-units of HESI. HESE digital blocks perform timing corrections for HED events and pattern recognition. HESE fits into the DE box on the payload.



Two Caliste modules

III-2.c Anti-coincidence System (AS) description and characteristics

The anticoincidence system provides accurate tagged time trigger (100 ns) for particles crossing the detectors or matter close to the detectors, which generate internal background. It is fully opaque to photons up to 200 keV, outside of the FOV and self-absorbs secondary fluorescence photons (passive graded shield). The active part of the system shows more than 99 % efficiency for passing-through minimum ionizing particles. The maximal residual level of background due to particle environment is 2.10^{-4} ph/cm^2/s/keV. The AS is spread in 3 parts:

a. The Anticoincidence Detector (**ACD**) is made in two parts (integration constraints), the upper and the lower AC. The AC includes a mechanical structure, an active and a passive shield. The passive shield is made with a sandwich of metals. The active shield is made of 13 scintillator tiles, 8 for the upper AC and 5 for the lower ones. Optical fibers are glued on scintillator and used for light collection.

b. The AC Detector Assembly (**ACDA**) includes 4 photomultipliers (ACPHD) and their individual associated Front End Electronic (ACFEE). A set of 2 ACPHD (main and redundant) read out the upper AC while 2 others (main and redundant) read out the lower AC optical fibers.

c. The AC Detector Electronics (**ACDE**) boards support analog interface to ACDA, digital electronic, housekeeping and power supplies. ACDE fits into the DE box on the payload.

III-2.d Calibration wheel

The Calibration Wheel (CW) will integrate two radioactive sources. CW will have a position to close the FPA during non-observation phases or periods of strong solar activities, and open position during observations. CW Electronics (CWE) send/receive commands and housekeeping's data. CWE boards fits into the CE electronics box on the payload.

III-2-e Detector Payload main detectors key characteristics

The table below gives the key characteristics of the COSPIX Detector Payload:

DP Parameters	LED		HED
Dimension (cm²)	10 x10		10 x 10
Number of pixel	32768	32	16384
Pixel size (µm)	520	16640	780
Filling factor	100 %	98 %	90 %
Time tagging (µs)	192	1	1
Required operating Temperature (°C)[1]	-50		-40

[1]: this temperature is required to maintain the COSPIX energy resolution requirements over the whole mission duration. The performance loss is mainly due to the irradiation by protons. This value has been computed assuming 10^9 protons/cm² after 5 years.

Table 4: *Key parameters of the COSPIX detector payload main detectors*

III-3. Performance assessment of the Detector Payload

Simbol-X Phase A studies and additional computation made by the 3 detectors teams lead to the following Detector Payload performances, for the configuration as described in part III-2, which shows that the COSPIX scientific requirements will be met.

SR	Parameter	Required	LED	HED
1	Energy range (keV)	**0.3 – 80**	0.3 – 40	8 – 250
8	E/ΔE FWHM @ 6 keV	**40**	46	-
8	E/ΔE FWHM @ 68 keV	**65**	-	75
11	Time resolution (µs)	**50**	1	1

Table 5: *Performances of the COSPIX detector payload with respect to the scientific requirements*

III-4. Resources: mass, volume, power, telemetry

III-4.a Mass budget

The Detector Payload mass budget best estimate is derived from the Simbol-X studies and scaled to the COSPIX mission. Result is summarized in the table here after:

Sub-System	*Mass (kg)*	*Margin (%)*	*Mass incl. margin (kg)*
FPA			
HESI	2.2	15	2.53
LESI+LET	1.2	15	1.38
LED+HED Mech. Struct.	6	15	6.9
ACD+ACDA	44	15	50.6
FPA Protective Enclosure	13.5	15	15.52
Thermal IF & Heat Pipes	3.25	15	3.73
Connectors/ Harness/ …	4	20	4.8
Calibration Wheel / Collimator			
CW	3	25	3.75
Collimator Segmented Tube + Shielding	10	20	12
Collimator Structure	18	20	21.6
Electronic boxes			
DE	7	15	8.05
LESE	7	15	8.05
CE	4.2	15	4.83
DPU	5	15	5.75
Harness	10	25	12.5
Systems			
Passive Radiator + Heat Pipes + Thermal IF	10.3	20	12.36
RF Antennas	1.5	15	1.73
Total	**150.15**		**176.05**

Table 6: *Detector Payload mass budget*

III-4.b Power budget

Sub-System	*Nominal mode (W)*
LESE	62
DE	59.9
CE	9.7
DPU	7.5
Total	**139.1**
Total 20% margin incl.	**167**

Table 7: *Electrical power budget*

The power consumption breakdown is given in the table 7.

III-4.c Volumes

Derived from the SIMBOL-X studies, the budget below is given taking into account the COSPIX new electrical function implementation. Warm electronic boxes design (thermal & mechanical) benefits of the last developments done on PACS and SPIRE, two instruments onboard the Herschel satellite:

Sub-System	*Dimensions (L × l × h) [mm]*
FPA	700 (diameter) × 350
Collimator (struct incl.)	3080 Height from stable P/F 1300 × 1300 Footprint on stable P/F
CW	400 (diameter)*90
DE	300 × 230*170
LESE	300 × 230*170
CE	240 × 230*100
DPU	220 × 230*115

Table 8: *Subsystem volumes.*

III-4.d Telemetry budget

The COSPIX Detector Payload total telemetry budget is given below for a 1 Crab source:

Direction	*Data flow*	*Data Rate*
Downstream	Scientific Data & HK	1.74 Mbps
Upstream	S/S Commands	<0.1 Mbps

Table 9: *Telemetry budget*

III-5. Pointing and alignment requirements

These requirements, being common to mirror and payload satellites, are discussed in section IV.

III-6. Operating modes

mode	***LED***	***HED***	***AS***	***CW***
off	off	off	off	off
safe	on, HK only	on, HK only	on, HK only	Close
idle	on, HK only	on, HK only	on, HK only	Off
Cal.	on, full frame	on, full science	on, full science	Cal Source 1 or 2
nominal	on, full frame	on, full science	on, full science	Open
window	on, window	on, full science	on, full science	Open

Table 10: *COSPIX payload operating modes*

The operating modes of the COSPIX detector payload are given in Table 10.

III-7. Specific interface requirements: configuration needs, thermal needs

The FPA detector must be cooled down in the range of -50°C to optimize the performances all along the mission. A radiator mounted on the Detector S/C (S ~ 0,6 m²) will be connected to the instrument through heat pipes. The thermal I/F will be at -60°C and will drive 32.5 W (including 20 % margin and parasitic loads).

III-8. Calibration

The COSPIX detector payload and its sub-systems will be calibrated with radioactive sources, at each step of the development (EM, QM, FM). These calibrations will be used to verify the performances of the system and to improve the payload numerical mass model, which will compute the expected performance of the mission; they will be updated with dedicated in-flight calibrations.

III-9. Current heritage and TRL

The current TRL level of the different COSPIX Detector Payload subsystems are the following:

Subsystems		***current TRL***
LED	LESI	4
	LESE	4
	LET	3
	LETE	3
HED	HESI	4
	HESE	4
AS	ACD	4
	ACDA	3
	ACDE	3
CW	CW	6
	CWE	6
DPU	DPU	4

Table 11: *Current COSPIX DP TRL level*

As already noticed, the COSPIX Detector payload inherit totally from the Simbol-X phase A studies. Some of the parts of the Simbol-X detector payload were already at TRL 5. The LET/LETE is a new system, which was not foreseen for Simbol-X. However, building blocks were operated in a laboratory environment; therefore it has been assigned a TRL 3.

III-10. Procurement approach

LED and HED, including associated electronics are unique technologies that enable large surface sensors in the COSPIX range and must be procured by MPE/HLL (D) and CEA (F) respectively. All other sub-systems may be delivered alternatively by industry in Europe or by space laboratories of the COSPIX consortium. For instance, Calibration Wheel and collimator tube and structure are considered to be delivered by ISDC (CH) while ACD could preferably be under responsibility of APC/Paris (F). Radiator and thermal chain could preferably be under responsibility of the S/C prime contractor. DPU could preferably go to a laboratory that would be involved in the science performance and calibrations.

III-11. Critical issues

We have identified the following critical issues for which we foresee dedicated technical development activities:

a. The segmented electrodes with associated on-chip collimator at the entrance window of the LED. This technology is certainly at a lower TRL than the rest of LED system and special care is needed.
b. Radiation tolerance data are missing at the moment on several full custom ASIC, for LED, HED and ACD. Dedicated work is programmed to overcome this issue in a short term scale.
c. The interface of HED with HEDE is fully digital and requires a full custom ASIC with a TRL 4 at the moment. However, alternative solutions exist with commercially available parts and different system architecture that would necessitate much shorter harnesses and analog interface, constraining implementation at payload level.

III-12. References

P. Lechner, L. Andricek, U. Briel, *et al.*, 2008, "The low energy detector of Simbol-X", SPIE 7021, 10.1

Meuris A. *et al.*, 2009, "Micro hard X-ray camera: from Caliste 64 to Caliste 256", TNS, 56, 4.1835

IV. Summary of key resources and characteristics at instrument level

We call "instrument" the assembly of the mirror + detector payload satellite to form the X-ray telescope. This telescope is somewhat virtual, as there is no solid link between mirror and detectors spacecraft. Like a classical telescope, anyway, some parts of the design and of the performance cannot be computed without considering the two satellites as a whole. These peculiarities will be described below.

IV-1. Instrument conceptual design and key characteristics

IV-1.a Absolute pointing reconstruction and angular resolution

The required absolute pointing reconstruction is 3 arcsec (goal 2 arcsec), at the 90% confidence level (SR12) and the angular resolution (HEW) should be around 10-20'' depending on energy (SR 6). These pointing reconstruction and angular resolution requirements imply constraints on the alignment and pointing of the whole system, mirror + detector satellites. System studies made for the Simbol-X telescope lead to the requirement given below, updated for COSPIX.

IV-1.b Polarimetric capabilities

Photons focused by the mirrors can be detected in the Detector Payload as Polarimetric events. These events correspond to photons making a Compton scattering in the LED followed by detection in the HED. These events are registered by looking at temporal coincidence between these two detectors, the LED time tagging being measured by the LET. The temporal window will be around 1 µs. COSPIX will act as a Compton polarimeter, the principle of which being based upon the asymmetry of Compton scatterings. Indeed, the Compton scattering cross section is maximal for photons scattered at right angle to the direction of the incident electric vector. This leads to an asymmetry in the azimuthal profile S of scattered events with a π period:

$$S = \bar{S} \times \left[1 + a.\cos\left(2\left(\varphi - \varphi_0\right)\right)\right]$$

where φ is the Compton scattering azimuthal angle modulation and a is the modulation factor. We can retrieve two others parameters of astrophysical importance from this equation:

- the polarization fraction : PF = a/a_{100} (a_{100} is the modulation for a 100 % polarized source; this is a parameter intrinsic to the detectors).
- the polarization angle : PA = $\varphi_0 - \pi/2 + n\pi$

IV-1.c Diffuse sky background rejection

In order to reach the required level of background on the detectors, out of the FOV diffuse sky background should be carefully minimized. This background component is stopped by the collimator on the detector payload satellite, and by a circular sky shield on the mirror satellite. An "instrument" system tradeoff is the choice of the geometry of the collimator/sky shield combination.

It must answer the following requirements:

- no vignetting (FOV sources should not be blocked, even if both satellites are moving relative to each other).
- screen + collimator block diffuse X-ray light (no "holes")
- screen + collimator should have a minimal mass.

The optimal configuration reached for COSPIX is given in the table below, for a segmented cylindrical collimator (see figure 3) and a circular sky shield:

Optimal Configuration	
Sky shield Diameter (m)	3.5
Collimator length (m)	3.08
Collimator diameter (cm)	22.4
Sky shield mass (kg)	33.2
Coll. Shield mass (kg)	7.4
Shield Total Mass (kg)	40.6

Table 12: *Collimator/Sky shield geometry and mass budget*

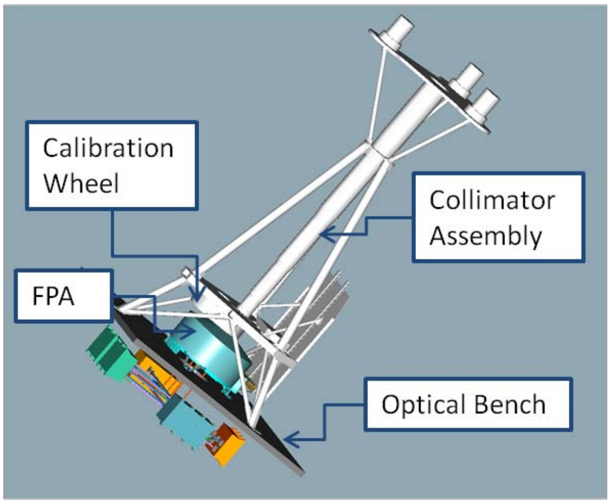


Figure 3: *Overall Detector Payload*

IV-2. Performance assessment

IV-2.a Absolute pointing reconstruction and angular resolution

COSPIX is a pointed telescope, which is required to be able to perform very long uninterrupted observations (100 ks or more) on the same target. The necessity to have a good and stable image quality, as well as to keep the full field of view inside the detector area, dictates the requirements on the formation flight stability. In order to obtain the required absolute pointing reconstruction and angular resolution, the mirror satellite should point to X-ray sources with a 20 arcsecond accuracy.

The pointing direction should be reconstructed on Earth with less than three arcseconds accuracy (SR 12). The payload satellite then aligns to the mirror satellite. Alignment requirements between the two satellites are given below (updated for COSPIX):

1. lateral total control requirement must be better than ± 1cm.
2. longitudinal position vs to best focus ± 1cm.
3. knowledge (monitoring) of the relative positions of the two spacecraft must be known within about ± 0.5 mm.

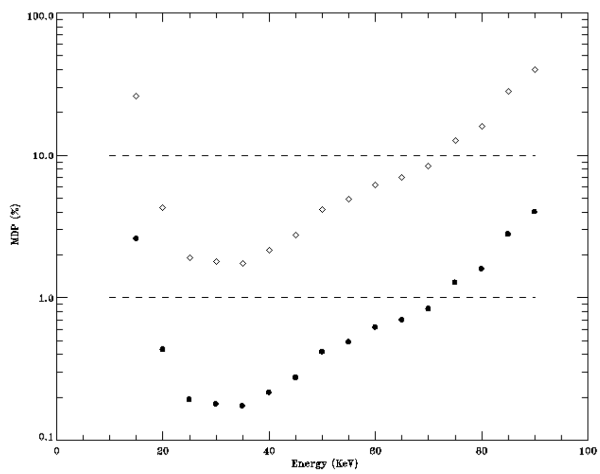


Figure 4: *COSPIX MDP*
for a 100 mCrab intensity source

IV-2.b Polarimetric capabilities

Figure 4 gives the minimum polarization fraction (MDP) detectable by the COSPIX detector payload design described above, through the mirrors, in function of energy. The white dots correspond to an observing time t_{obs} of 10 ks, whereas the black ones correspond to t_{obs} = 1 Ms. We see that we fulfill the requirement of a MDP less than 0.7 %, between 20 and 40 keV (SR 4).

IV-2.c Diffuse sky background rejection

Thanks to collimator and sky shield design described in IV.1.a, first computation have shown that the COSPIX background due to diffuse out of the FOV emission should be much less than the required background level of is $2\ 10^{-4}$ ph/cm^2/s/keV (SR 9). This result will be consolidated in the future by Monte-Carlo simulations.

IV-3. Calibration and other specific requirements

In addition to in-process X-ray testing of the optics modules (§II-8) and of the detector payload and its subsystems (§III-8), we will conduct extensive X-ray testing of the flight mirror assembly with ground-equipment detectors and with the flight detector. These tests will verify the functionality of the flight X-ray system and calibrate the performance of the flight-model X-ray optic alone and in combination with the flight-model detector: an end-to-end test.

For the flight-optic and end-to-end calibration, we plan to use NASA's XRCF (X-Ray and Cryogenic Facility), at the Marshall Space Flight Center (MSFC). This X-ray beam line has an approximately 520 m length and a 1.46 m diameter, which allows full illumination of the COSPIX the 1.3 m diameter flight optic. Accommodating COSPIX's 33 m focal length will require modification of the facility. In addition, extending the XRCF's energy range into the hard X-ray band will necessitate additional X-ray sources and ground-support detectors. The Mission of Opportunity proposal to NASA for US participation in COSPIX will include the upgrade and calibration at the XRCF. The telescope will be also fully calibrated in-flight by observations of well-known X-ray point sources (e.g. Crab) and diffuse emission.

IV-4. Critical issues

No critical issues are identified at the instrument level.

SYSTEM REQUIREMENTS AND SPACECRAFT KEY FACTORS

Given the scientific driver similarities, the COSPIX spacecraft key issues proposed here after are derived from the Simbol–X mission studies, which were performed by CNES & ASI up to the beginning of phase B, with parallel industrial contracts to TAS and EADS. These studies have resulted in a consolidated knowledge of the problematics and solutions. It is shown in this section that the COSPIX mission is feasible with this formation flight option. But as mentioned in the beginning of the document, it might be possible that the mission is also feasible with a deployable mast. Thus is not discussed here because of the lack of consolidated knowledge at the proposers level; obviously, a trade-off between the two options could be open during the study phase.

In formation flight, one satellite carries the collimator and the detection module (Detector Spacecraft: DSC), the other one carries the main mirror used to focus the X-rays (Mirror Spacecraft: MSC). The distance between the two satellites roughly corresponds to the instrument focal length. Each satellite includes a generic service module (SVM), specifics products to ensure formation flight stability and measurement accuracy and a dedicated payload module.

In launch configuration, the two satellites may be preferably mounted one over the other, the launcher interface being provided by the MSC through a ∅ 1666 mm ring (see Figure 1). The same interface diameter must be used for the interface between both satellites. The satellites dimensions must be consistent with the Soyuz fairing, with a 3 meter high collimator mounted on the top of the DSC and a 3.5 m diameter sky-shield. With the proposed preliminary design, the spacecrafts wet masses with adapter (~ 2 060 kg, including 487 kg of contingency and system margin) are compliant with the Soyuz launcher capacity for a direct injection into L2 trajectory (2 100 kg).

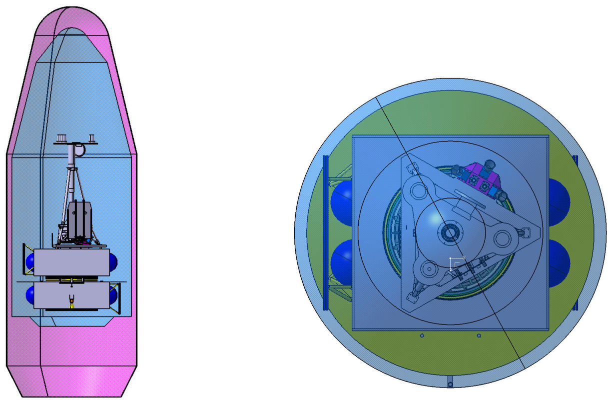


Figure 1: *Composite spacecraft in launch configuration*

I. Attitude and orbit control

The propose baseline for the COSPIX orbit is a Lagrange L2 point. The satellites line of sight, perpendicular to the sun-satellite direction, will be able to point any star in a 20° × 360° sky strip (see illustration of Figure 2) at a given time period.

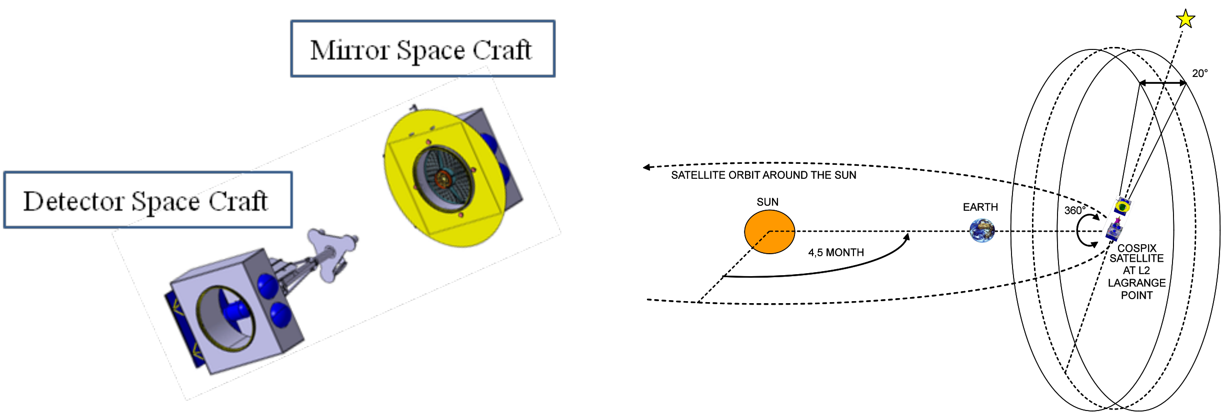


Figure 2: *Satellite configuration and observation concept*

One of the important parameters of the science requirements is the Line Of Sight restitution. Given the flying configuration the absolute pointing values at the two spacecraft levels should be as follows:

• Mirror Spacecraft: ± 20 arcsec (acceptable error on mirror vignetting)

• Detector Spacecraft: ± 2 arcmin (no vignetting of field of view due to collimator entrance)

As in Simbol–X mission, the spacecrafts will be 3-axis stabilized and controlled using a coarse stage for large manoeuvre and orbit control and a fine stage for observation. The coarse mode could be compatible for instance with Astrium's Astrobus concept for attitude control and trajectory correction coupled with a gyro / star tracker / reaction wheels technologies. The fine attitude control system aims at maintaining the formation flight stability during the observations. It could be composed of the following equipments:

- a fine star tracker set mounted on each satellite to give 2 absolute attitude measurements and one relative attitude information,
- a RF sensing set (called FFRF) with 2 sets of 3 RF antennas (1 set on each satellite) to ensure the Formation Flight stability during the transient phases and,
- an optical sensing set (called FFOS) with a set of diode on the MSC and a camera on the DSC to control and measure accurately the position during observations.

The MSC is pointed very accurately and is passive while the active control is performed on the DSC through cold gas propulsion. The required performances are consistent with the ones predicted for the Simbol-X mission (with a similar focal length), which guarantees formation flight feasibility and the attitude reconstruction at the scientific requirement level.

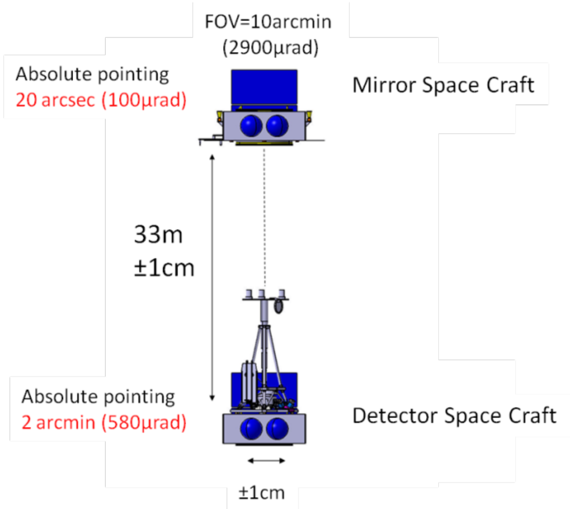


Figure 3: *Formation Flight requirements*

The propellant budget for manoeuvres (orbit control, target acquisition, spacecraft orientations once per day for science telemetry download) must be estimated for mission duration of 3 + 2 years.

II. Architecture/On-board data handling and telemetry

The proposed hardware architecture of the DMS features is based on a state-of-the-art Leon3 central computer (OBC) in charge of the spacecraft command/control and an input/output management unit (RIU) for development flexibility. The OBC interfaces with most of spacecraft units via a redounded MIL-STD-1553B Bus. On the DSC, a dedicated "SpaceWire" bus has to ensure an efficient data rate between the OBC and FPA detectors. Like on the Simbol-X design, the FFRF antennas used for Formation Flight could be also used for command/control transmissions between the 2 satellites.

The generic SVM can be derived from a generic European product line including:

- two solar arrays, a Li-Ion battery and PCDU for power supply,
- a Leon3 based OBC, a remote interface unit for specific module command and MIL-STD-1553 B + SpaceWire buses for data handling,
- RF communication for satellites control in X band (TM/TC),
- an Astrix 120 class gyro, sun sensors, Reaction Wheels, a high precision APS star-tracker and an hydrazine propulsion module with four tanks for AOCS,
- a modular PUS compliant on board software.

The data are processed at payload level and stored on board in a dedicated mass memory. The onboard memory does not induce any problem due to technology limitation. A minimum of **200 Gbit memory** is implemented to compensate the data volume acquisition variation along the days and offer a stabilized mean telemetry data rate for ground operation simplification.

During the visibilities and thanks to simultaneous write/read memory capacity, the science data can be downloaded toward the Earth. With a downlink data rate of **1.6 Mbps**, **4 h visibility** will be necessary to transmit the **3 Go science data** needed per day with a **15 m ground antenna**.
A work plan can be uploaded every day. Each plan is available during at least 1 week to ensure a sufficient spacecraft autonomy in case of ground station anomaly.

III. Mission operations concept (ground segment)

The mission operations and ground segment concepts are detailed in the "Mission Profile" and "Science Operations" sections.

Regarding the lifetime, given the scientific requirement of three years of observation, with the launch campaign, the LEOP, the cruise phase and the In Orbit Tests (part of which being run during cruise) and initial calibrations, the minimal needed lifetime is about **3 years and 3 months**. Compared to HEO orbit, the L2 Lagrange point is more stable and may allow increasing the lifetime up to **5 years**, with the same propellant tanks configuration.

IV. Spacecraft concept and estimated overall resources (mass and power)

The satellites structures have to ensure the needed stiffness to withstand the launch loads while carrying all the equipments. For the two satellites, the main structure could be classically composed of a cubic box linked to a central cylinder by shear walls. In such a configuration, the launch loads are supported by the central cylinder; side walls are used to carry the equipments, propulsion tanks and solar panels. On the MSC, the mirror main cylinder is linked to the satellite central cylinder through a conical adapter. The interface with the launcher ring (∅ 1666 mm) is ensured by the central cylinder. The top floor is used to carry the disc-shaped sky shield and the set of RF antennas dedicated to the formation flight control. On the DSC, the payload base plate must ensure the interface between the top floor and the payload assemblies (collimator and focal plane mainly). The Collimator tube is mounted in the centre of a structure called Collimator Tower. As in Simbol-X, this structure is foreseen to support in addition the RF antennas dedicated to the formation flight control and the passive radiator used to cool down the detectors. The LOS module (fine star trackers) is directly mounted on the optical bench (payload base plate) to minimize the thermo-elastic contribution and thus improve the attitude restitution performances.

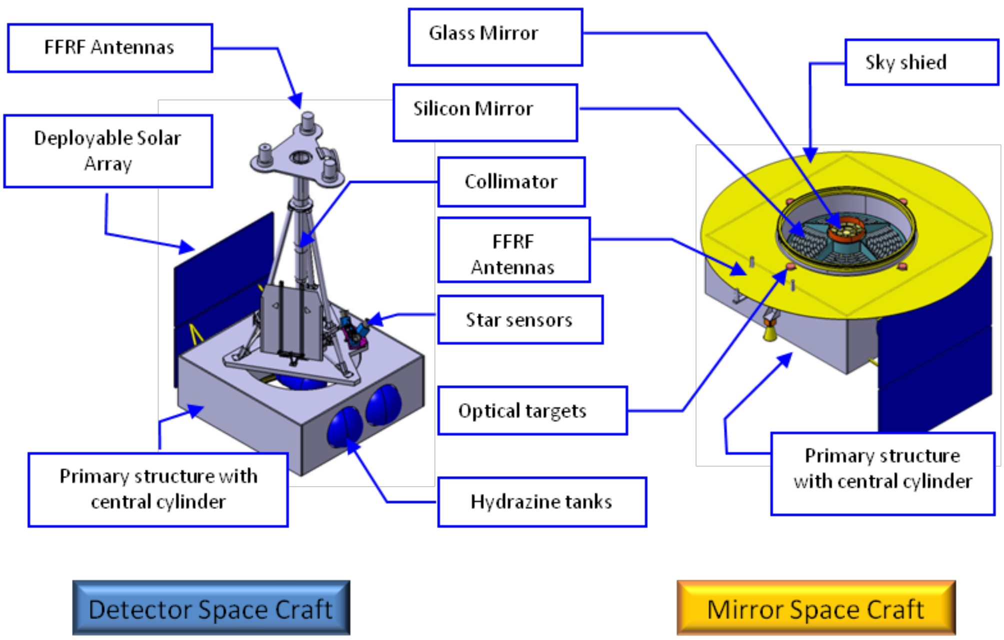


Figure 4: *DSC and MSC overall layout*

The thermal sub-system design has to take into account the specific mission configuration at L2 where the Sun can always illuminates the same satellite side. A passive concept using heat pipes is used to transfer the heat from the spacecraft sun side to the satellite cold side and thus balance the global satellite thermal budget. The focal plane assembly which is operated at -50°C (-60°C at the FPA interface) must be controlled through passive radiator oriented toward the cold sky, on the anti-sun spacecraft side.

The table of budgets below is derived from the Simbol–X phase A study. We take into account the improvements foreseen for COSPIX, which mainly concern (regarding resource aspects) the increase of the detector size, and the largest optical effective area on the mirror side. The new orbit (Lagrange L2 versus HEO in case of Simbol–X) has been also taken into account.

	Detector Spacecraft	*Mirror Spacecraft*	*Launch Composite*
Payload dry mass	176.7 kg*	459.2 kg	635.9 kg
Service module dry mas	384.4 kg	317.8 kg	702.2 kg
Contingency	74.9 kg	108.3 kg	183.1 kg
System margin (20%)	127.2 kg	177.1kg	304.3 kg
Total dry mass	763.2 kg	1062.3 kg	1825.5 kg
Cold gaz propellant	26.0 kg	0.0 kg	26.0 kg
Hydrazine propellant	54.0 kg	55.0 kg	109.0 kg
Total wet mass	**843.2 kg**	**1171.3 kg**	**1960 kg**
Launch vehicle adapter			100.0 kg
Total Launch Mass			**2060.5 kg**

** formation flight metrology systems included on top of detector payload mass*

***Table 1:** Composite mass budget*

The power management and regulation could be performed by an off-the-shelf Power Conditioning & Distribution Unit (PCDU). The electrical power is generated by the solar array based on standard technology and is conditioned with Array Power Converter (APR) driven by the Maximum Power Point Tracker (MPPT) logic. The table below summarizes the needed resources as electrical power, data rate and mass memory.

Parameter	***Budget***
Power	< 800 W (even during data transmission) on the two satellites, including 170 W for the Detector payload and a maximum of 100 W for the Mirror thermal balance.
Science Data per day	3 GBytes with a 1.6 Mbits/s data rate (15 m diameter antenna ground network) during 4-hour visibility (On board system could go up to 8.5 Mbits/s with a 35 m ground antenna)
Mass Memory	≥ 200 Gbits

***Table 2:** Power, Mass memory and TMI data rate*

V. Specific environmental constraints (EMC, temperature, cleanliness)

V-1. Thermal environment

V-1-a LOS restitution

Two items are potentially very sensitive regarding thermal environment. For the collimator there are two different aspects. The first one can be described as the field of view defined by the collimator aperture. A collimator deformation can produce a vignetting, a problem solved by increasing the collimator aperture with respect to the value for a perfectly rigid structure. Current collimator sizing (coupled to the sky shield on the MSC) has been done taking into account the deviations of the attitude control with respect to a perfect pointing. The second aspect, more critical, will be the attitude control between the two satellites and the LOS restitution. On the collimator side, the thermo-elastics deformations must be compatible with RF antennas position accuracy and/or deviation. On the optical bench side, the thermo-elastic deformations must be also compatible with the requirements on the LOS restitution: a first estimate gives a maximum acceptable deformation of **100 µm** between star trackers and detectors. This budget has to be shared between the

Detector Payload and the Detector Spacecraft, and could imply a thermal regulation of the optical bench by the platform.

V-1-b. Operating temperatures

The table below summarizes the different operating temperatures and stability relative to the main components of the payload. All the temperatures are given at the interfaces.

Operating Temperatures at interfaces	*T min (°C)*			*T max (°C)*			*T° stability / Max gradient*
	Operating	*In orbit non operational*	*Start up*	*Operating*	*In orbit non operational*	*Start up*	
FPA	-60	-65	-65	-55	+40		±0.5°C / 3h
Electronic Boxes	-15	-35	-30	+45	+60	+50	-
Mirror	+19	-	-	+21	-	-	0.5°C

Table 3: *Operating Temperatures*

V-2. EMI-EMC environment

The current option is to manage the EMI-EMC aspects at the payload level. A special care will be put on the detection electronic chain grounding scheme.

V-3. Cleanliness

The cleanliness at FPA level will be insured by the protective enclosure mounted around the detector and the Calibration Wheel (CW) in closed position. In order to prevent CW and Focal Plane particle contamination a cover is foreseen on the top of Collimator. Due to the fact that the Protective Enclosure is not hermetically sealed, heating lines have to be provided during the launch phase and out gazing procedure has to be implemented before cooling down and switching on the detectors.
On the mirror side (for the slumped glass mirror) it is foreseen to mount two protections, one in each side. Once deployed, those protections could be used as sun shield devices.

VI. Special requirements

There is no special requirement.

VII. Current heritage and TRL

The SVM itself can be based on a number of off-the-shelf European platform, and all elements have a TRL higher than 7. The communication system can be reused from GAIA, except for the mechanically steerable X-band antenna, which is available off-the-shelf. The interface ring between the two spacecrafts and associated clampband is a standard Ø 1666 device.

Formation Flight will highly benefit from all predevelopment activities initiated in particular by CNES for Simbol-X, but also from the European PRISMA mission. For what concerns the Formation Flight hardware, the RF sensor has a strong heritage from the in-flight validated PRISMA one, with minor adaptations (number of antennas for instance). The optical sensor can be derived from an APS star tracker, and CNES had already started predevelopment activities, leading to a TRL 4. The cold gas propulsion bears heritage from GAIA.
Formation Flight in itself has been the subject of several predevelopment and breadboarding activities (plus some in-flight validation with RF sensor only on PRISMA), and a TRL of 3 to 4 can be claimed on the subject.

VIII. Proposed procurement approach

The SVM development follows a standard plan, and the proposed model philosophy will include a Structural Model (thermal representativeness not required due to the highly stable L2 environment) and a PFM.

IX. Critical issues

Formation Flight should be the subject of specific activities, including early assessment of performances first with a digital representative model and then on a specific test bench featuring representative hardware. This implies that predevelopment activities are to be led on the optical sensor to allow early availability of an Engineering Model.

SCIENCE OPERATIONS AND ARCHIVING

I. Science Operation Architecture

COSPIX is an X-ray space observatory operated by ESA and open to the international astronomical community. The telescope carried by two spacecrafts, both stabilized on 3-axis in formation flight, works in pointing mode, i.e. the telescope axis is oriented towards a predefined astronomical target and kept pointed for the duration of a predefined data recording time (exposure). The planning of the observations that reports the dates, pointing directions and spacecraft orientations and exposures for each approved observation, is defined in advance (typically once per year for a duration of 1 year). The expected typical average exposures are of 50-100 ks which implies typically 300-500 different observations per year, but certain targets may have to be observed for larger exposures (0.5-1 Ms). Such large exposures may have to be split in a sequence of shorter observations due to operational constraints. The planning will be optimized in order to reduce at the minimum the gas consumption and operations. Given the high variability of X-ray compact sources the planning may change on short notices because of the need of performing Target of Opportunity observations (ToO). Decided ToO implementation is expected to be performed with a typical delay of 1 day from the triggering alert.

Since ground–satellite connection is expected only once (for few hours) per day, the satellite will work mostly autonomously in routine phase with a predefined set of commands that are uploaded in advance. Except for this, the COSPIX operation concepts are expected to be similar to those of large X-ray observatories like XMM-Newton with the difference that no radiation belt passage nor ground station handover are foreseen and that the connection is expected to occur once a day only. At this connection the mission ground segment will dump the recorded telemetry, will perform health and safety checks, and will uplink the telecommands for future observations, subsequent maneuvers or for contingency operations.

The COSPIX observation planning is prepared by the mission ground segment based on a scientific planning decided by the community. The proposed mechanism for the definition of the scientific program is similar to the XMM and INTEGRAL ones, and is as follows. ESA will publish periodically, e.g. each year, a call for proposal of observations for a given period (Announcement of Opportunity, AO). The scientific community will respond to the call proposing scientific projects that make use of COSPIX observations. An independent committee of the community (the time allocation committee, TAC) select the most interesting and feasible observing projects and the science ground segment prepares then the observation planning from the selected community proposals.

This observing program is the Guest Observer (GO) program. Most of the available observing time shall be dedicated to the GO program. It is proposed that part of the available exposure time be dedicated to scientific projects proposed by the laboratories that participated to the mission development, in reward of their implication in the project. This is the guaranteed time (GT) program. The GT program will also ensure a fair return for national agency investments and will help to maintain involvement of instrument teams in post-launch activities of instrument health and calibration. GT program could be of the order of 20 % of the total available exposure time in the nominal phase (with a progressive reduction, e.g. 30 %, 20 % and 10 % in the 1st, 2nd and 3rd year of operations respectively) and will be 0 % in the extension phase.

II. Ground Segment and share of responsibilities

Mission operations and mission science operations will be carried out by the mission ground segment (GS). The GS is composed by a receiving ground station and a Mission operation center (MOC) that will be in charge of the spacecraft operations, a science operation center (SOC) that will carried out the activities linked to the definition of the observation planning and then one or a few science data centers (SDC) that will carry out science data processing and archiving. As for previous ESA missions like XMM and INTEGRAL the GS will be organized as follows.

The ground station network and MOC will handle all spacecraft operations such as telecommands uploading, reception of telemetry, housekeeping and data analysis for health and safety checks, real time operations with spacecraft and instruments. MOC will maintain the operational database of the mission, will receive the observation planning from SOC and will produce the detailed operational timeline. The MOC will deliver telemetry and associated files to the other GS parts.

The SOC will interface with the science community from the AO call to the end of the observations. This will include promoting the mission, publishing the AO, receiving the proposals from the community, maintaining a web interface that provide the log of performed observations and the long and short term observation schedules. The SOC will also organize and support the TAC meetings for the selection of the proposals and will then prepare the observing plan from the selected scientific program and the operational constraints, optimizing the plan in terms of gas consumption and operations. SOC will submit the program to MOC, handle MOC feedback and the interface with the observers (optimization of observation schedule, correlated observations with other observatories if needed, etc.) till the observation is performed. From this point the interface with the observers is handled by the SDC.

The SDC is in charge of the data processing, data delivery and archiving in addition to the mission archive at ESA. It will receive the whole telemetry and ancillary files/information from MOC and SOC and will perform routine science data processing with the goal of producing data products to deliver to the observers and to store in the archives. The SDC will be in charge to deliver to the observers the science data products, associated response and calibration files and the science analysis software needed by non-specialist observers to perform proper COSPIX data analysis with standard (non mission/instrument specific) astronomical tools. The SDC will therefore design, develop and maintain software pipelines to be run at the center and off-line analysis routines packages to be delivered to users for their customized data analysis.

The SDC will also perform, with the help of the instrument teams, some long term trend and in-flight calibration analysis in order to follow the performances of the instruments and update the response and calibration files needed to the data analysis.

Some level of quick look technical and scientific analysis will also be implemented at SDC, in order to monitor instruments and science data. However no real or near-real full time science analysis (of the type performed at the ISDC for the INTEGRAL mission) will be necessary since for the COSPIX small field of view the probability of discovery of new transient sources or GRB is small.

The ground station, MOC and SOC will be under responsibility of ESA, for example MOC tasks can be cover by the ESOC and SOC tasks by the ESAC. We propose that SDC on the other hand be set up by consortia of science laboratories, with strong participation of the instrument teams involved in the development of the telescope, and funded by national agencies or institutions. SDC tasks will be supervised by ESA through the SOC.

III. Archive approach

The raw data rate received from the spacecraft is about 3 GB per day. Including ancillary files and other metadata, the data product after the pipeline can increase by a factor of 3. The total volume over the mission nominal lifetime of 3 year may then reach about 10 TB. Raw telemetry will be stored at MOC. SDC will also store the telemetry files received by MOC and all the data products created by its pipeline processes. A copy of the SDC archive will be also maintained at the SOC. The data products generated by the SDC will be in standard astronomical format at the epoch of the operations (like FITS files today) for and easy access and use by the scientific community.

IV. Proprietary data policy

The proprietary data policy for COSPIX will be similar to the one implemented for XMM-Newton. Observers will have reserved data rights for given specified time (e.g. 1 year) from the moment the data products of their observation and analysis s/w are released to them by the SDC. After this time the data will be publicly available. The SDC will be responsible for timely provide the observers with their data, and implement the data right policy by accordingly restricting or opening the access to the archived data. GT program will follow the same rule. Data obtained during calibrations or unpredictable ToO (not subject to approved proposals) will be instead immediately made publicly available.

TECHNOLOGICAL DEVELOPMENT REQUIREMENTS

In this section, we present the technological development activities foreseen to reach the goal of TRL5 at any levels of COSPIX payload and satellites, both the payloads (optics and detectors) and mission and spacecraft, emphasizing formation flight. Most of these activities are already in progress. The development strategy is commented in the continuity of the current efforts in each laboratory of the COSPIX consortium and industry.

I. Payload technology challenges and technology development strategy

I.1. Mirrors Technological challenges

I.1.a Silicon Pore Optics mirrors TDA

The SPO technology development is currently financed by ESA and executed by a pan-European consortium of small and medium enterprises (SMEs) and scientific institutes. Currently several activities are running in parallel, to be completed in 2011; these will result in first vibration and thermal tests of MMs to achieve TRL 5. The further development plan for SPO foresees for 2011 to 2012/13, the full environmental qualification of mirror modules, the development of inner radii external baffles (sieve plates) at MM level, the development of Wolter-I type SPO modules. Dedicated studies will be also undertaken in order to enhance the FOV.

This plan does not yet include setting up a production facility in a rented part of a wafer fab (found e.g. around Enschede (NL), Munich (DE), Grenoble (F)), which requires about 200 m^2 of clean room floor space. In this rented facility the plate production, the coating and the stacking will be co-located, which requires installation of plate manufacture equipment, coating equipment, stacking robots and a number of operators.

I.1.b Slump Glass Optics mirrors TDA

Due to NuSTAR previous developments, the GOp for COSPIX is currently at TRL 4/5. The technology development from TRL 4/5 to TRL 5/6 is already underway, in synergy with the IXO mirror technology development. The only significant difference between the NuSTAR mirror assembly, which will fly in 2012, and the COSPIX assembly is in the required angular resolution, COSPIX's being more than a factor of two more stringent. NuSTAR's angular resolution is limited by three factors. The first is the intrinsic shape of the glass substrate. The NuSTAR substrates are replicated off cylindrical mandrels because cylindrical mandrels are significantly easier to make, and therefore less expensive, than conical mandrels. For COSPIX we will use conical mandrels producing glass substrates with figure better than 10 arcseconds (two reflections) before multilayer coating. The second factor is coating stress that significantly distorts the intrinsic figures of the glass substrates. In the case of NuSTAR, most of these distortions are removed during the alignment and assembly process. The third factor is the accuracy of the alignment bar machining. There are well-defined means of addressing these other two limiting factors. When combined, we expect that reaching 20 arcsecond half-energy width to be straightforward. During the assessment phase we will develop an approach for significantly reducing or balancing the coating stress, so that the distortions of the finished mirror segments are negligible. The goal of this study is to develop a means of producing the multilayer-coated glass mirror segments with figures close to the 10 arcsecond figures the glass substrates have before coating. Then, we will adopt for COSPIX the mirror alignment and assembly technique that has been developed for IXO, which is currently capable of aligning and bonding 10 arcsecond mirror segments to make 12 arcsecond mirror modules, well within COSPIX specifications.

I.2. Detectors and electronics Technological challenges

I.2.a Low Energy Detector (LED)

LED LESI is based on mature and advanced monolithic DEPFET technology already at TRL 5 inherited from Simbol-X and BepiColombo and associated front-end circuits at TRL 4. Large-scale integration of such sensors is inheriting from IXO efforts. In the particular case of COSPIX, a double-sided process is desired to give a polarimetric capability to the instrument. It is necessary to implement an active and segmented entrance window (LET), which stands currently at TRL 3. Here the main challenge is to deposit on-chip thin collimators (on undepleted segmented electrodes gaps). On the other hand, cathode segmentation is on its way to TRL 5 from TRL 4 and must be adapted to the LED with a LESI at the opposite side. LETE is based on a strong heritage from IDeF-X ASICs. The input stage will be adapted to large input capacitance detector. Such design exists and a prototype will be realized in the next two years. This development is largely synergic with HED front-end development needs. In addition, further developments of LESI analog front-end are required for radiation tolerance tests on one hand (ASTEROID and SWITCHER will fly on Bepi Colombo 2014), and for speed improvement on the other hand (VERITAS chip development start in 2011). LESE warm electronics is currently at TRL 4. TRL 5 requires space-qualified parts and a dedicated standard thermal and mechanical design but is not a challenge.

I.2.b High Energy Detector (HED)

HED HESI relies on Caliste mature technology, which is currently at TRL 5 after Simbol-X efforts. Caliste current version must be scaled to the 780 µm pitch (900 µm and 580 µm pitch already exist) and will be equipped with a new chip (IDeF-X HD, under test) which still have to face radiation tolerance tests in the years 2011 (TID and SEL) and 2012 (SEU). Caliste will be integrated onto a demonstrator of MACSI camera. This development is on its way (currently TRL 4) and a prototype will be produced in 2013 with the scaled geometry from current design (5 cm long instead of 4 cm). MACSI will also be equipped with an integrated full-custom multi-channel parallel ADC on flex. A prototype already exists (Wilky) and must be scaled and evaluated from a radiation point of view. In addition, a development of full-custom sequencer is foreseen with a lower priority, as an option, to be used instead of the baseline commercial radhard FPGA. The same ADC and sequencer will be used for LED/LETE. Special care will be taken for SEU. This development will be initiated in 2011 and ended in 2013-14. HESE warm electronics is currently at TRL 4. TRL 5 requires space-qualified parts and a dedicated standard thermal and mechanical design but is not a challenge.

I.2.c Anticoincidence Detector (ACD)

ACD is inherited from Simbol-X studies. It stands at TRL 4 and will reach TRL 5 after Thermal test completion. The sensitive part will be scaled to the COPSPIX geometry, the architecture remaining the same. On ACDA side, the main challenge is to complete radiation environment tests (SEL and SEU) for the analog front-end electronics chips. In case of failure during these tests, a back-up solution based upon space-qualified components is also under development. This activity is on its way to TRL 5 and will be completed in 2012. A demonstrator of the full anticoincidence chain will be built during the years 2012 and 2013 and will undergo full set of environmental test to reach TRL 5.

II. Mission and Spacecraft technology challenges

Formation flight is a novel technology proposed for the satellite, although some heritage is available in Europe through the Simbol-X studies carried out in CNES and ASI until 2008, and the Swedish flight proven PRISMA mission.

In order to raise the TRL of the Optical sensor and of the formation flight system in itself, the following activities are proposed.

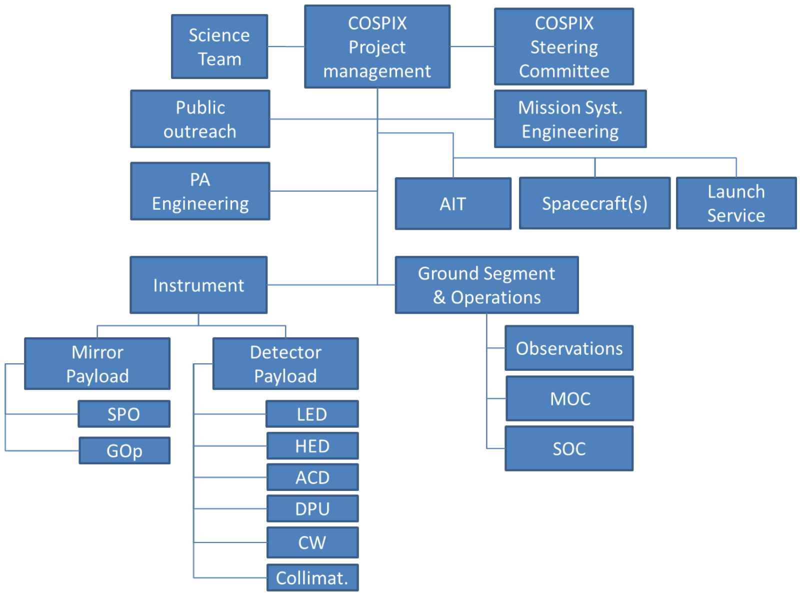
The optical sensor can be based e.g. on Sodern's Hydra APS Star Tracker. In order to reach a TRL 5 at the beginning of Phase B, the following activities shall be undertaken:

- Preliminary design, on the basis of the mission needs,
- Technological studies on critical items (e.g. diodes),
- Detailed definition of the overall sensor,
- Breadboard development in parallel to Detector satellite phase B1.

Formation flight relies on past R&D studies, and in particular R&D defined by CNES on Formation Flying Command & Control architecture, Formation Flight FDIR and guidance techniques. In order to guarantee a TRL 5, it is necessary to set up early in parallel with the definition study phase a full Formation Flight end-to-end simulator, which will be used to develop and validate all Formation Flight algorithms. This simulator will, once RF and optical sensors breadboards are available, be converted into a full-fledged Formation Flight validation bench.

PRELIMINARY PROGRAMMATIC / COSTS

I. Overall proposed mission management structure



A project organization chart for COSPIX mission is proposed as in the figure on the right. The COSPIX Project Management will be staffed by ESA to provide overall management and integration of the mission elements. ESA will competitively select an industry partner as prime contractor for development of the spacecraft and telescope integration. System engineers from across the mission flight and ground segments will be members of the mission system engineering team, and will work together to define interfaces and perform system level analyses. Engineers and managers across the mission, including all partner organizations, will also participate in requirement, design, and other key reviews at both the element and mission system level. The key stakeholders across the project team will form the COSPIX Steering Committee that will expedite resolution of issues across institutional boundaries.

II. Basic integration & verification approach and model strategy

At spacecraft and system level, the model philosophy is based on a Structural Model (SM) and a Proto Flight Model (PFM). At payload level, the models foreseen are the Structural and Thermal Model (STM), Engineering Qualification Model (EQM) and Flight Model (FM). As most of equipment's (except GOp) have modular design, spare units will be prepared to repair Flight units or refurbish EQM in a Flight Spare configuration.

III. Basic schedule

According the master schedule given below, the COSPIX launch date occurs lately in 2020. This is reachable thanks to the use of mature payload elements and parallel development of sub-elements of the mirror assembly. The program includes an end-to-end calibration at payload levels to be performed before AIT at S/C level. The critical path follows mirror assembly sub-system.

IV. Preliminary risk analysis

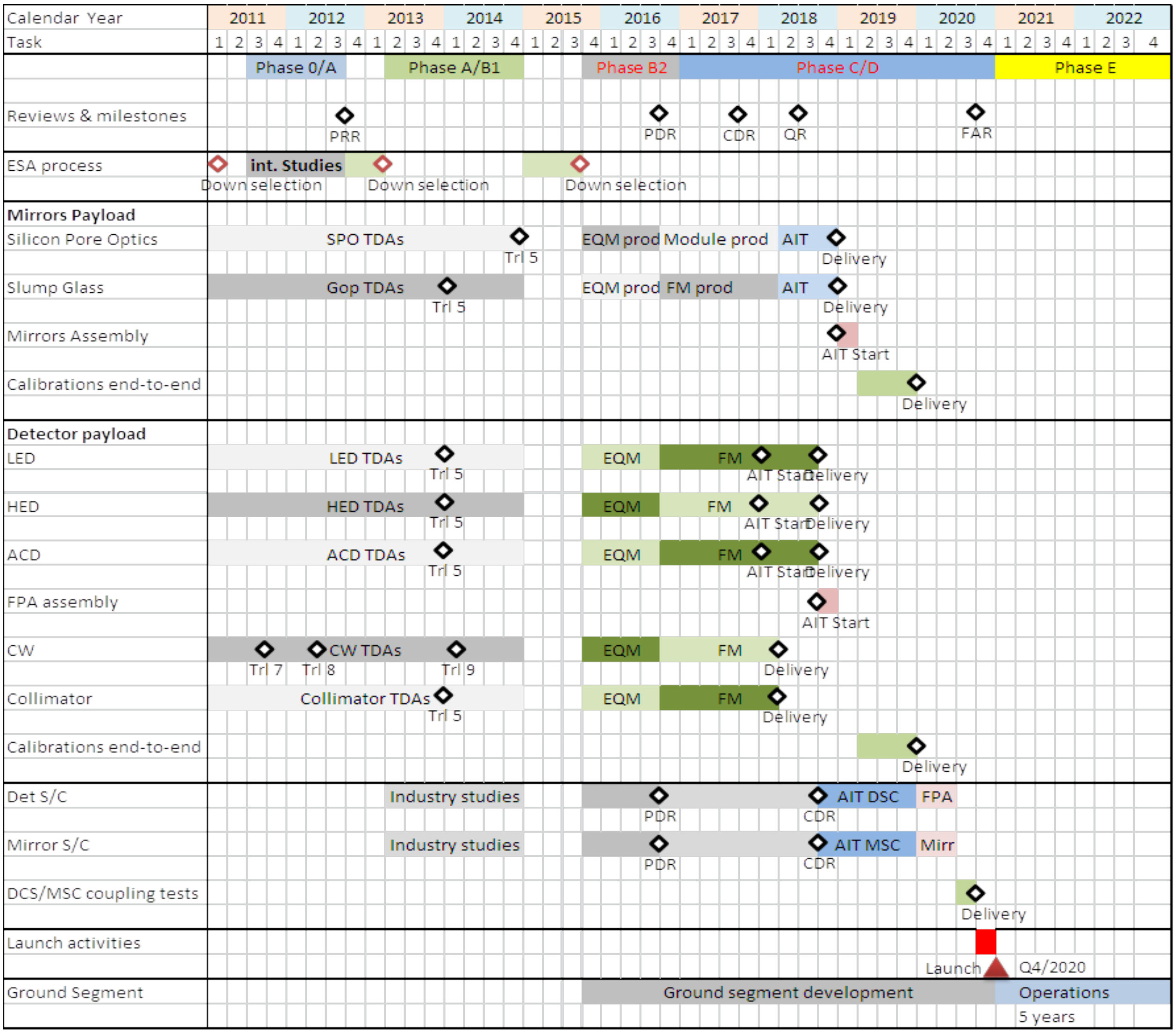
The top three missions risks are the following

1. Mirror delivery delay. The risk can be mitigated by early TDA's and parallel development of sub-mirrors.
2. If formation flight, or deployable mast, fails, it results in loss of the mission. Risk is mitigated by the use of proven technologies.
3. If the angular resolution is lower than required, the sensitivity will be affected proportionally, and a part of the science is lost proportionally. The risk is mitigated as the requirements stand well above the limits of the optics technology.

V. International Partners

The European countries, partners of the mission are essentially involved in the Detector Payload development and science.

The US participation is expected through NASA (GSFC, MSFC) for production of hard X-ray mirrors and end-to-end calibration campaign.



VI. ROM cost estimates

Total ESA costs, best estimates		
Launch vehicle (Soyuz)	75. M€	
Detector Spacecraft	110. M€	S/C Prime contractor
Mirror Spacecraft	40. M€	S/C Prime contractor
Flight in formation	20. M€	S/C Prime contractor
Prime contractor activities	25. M€	S/C Prime contractor
SiPO mirrors	23.5 M€	ESA, subcontracting
Operations	58.7 M€	20% acc. ESA requirements
ESA Project	29.4 M€	10% acc. ESA requirements
Total cost at Completion	381.6 M€	Margin is included

Total ESA member states nationally funded participation, best estimate		
Hardware, Software, Man Power	88. M€	Space labs and subcontractors
Science Data Center (SDC)	25. M€	
Total cost at Completion	113. M€	Margin is included

Total USA participation, best estimate		
GOp mirror assembly, Calibration facility and activities	51. M$ (~39 M€)	Fully assembled and qualified optics.

COMMUNICATION AND OUTREACH

The outreach project for COSPIX builds on some thoughts in the proponent laboratories about the scientific communication and its tools: how to reach the different audiences qualitatively, but also quantitatively; the audience must be much larger than the usual groups of amateur astronomers and of people passionate about science. The idea is thus to develop actions and tools adequate for an enlarged audience, including the young generation and the general public.

The goal of the project is to contribute to reinforce the interest of the new generations for the scientific studies, to satisfy the curiosity of the general public, and also to inform the scientific community at large about the results of the mission.

The mission is devoted to the emissions of the violent sources of the Universe in a large X-ray band. The educational perspectives that are envisioned in that domain are the following:

- popularize the non trivial nature of light as an electromagnetic radiation, and the different wavelengths,
- describe the sources of the violent Universe : exploding stars (supernovae), galaxies with a very bright nucleus (Active Galactic Nuclei), extremely dense objects (neutron stars, and black holes), merging of black holes and gamma ray-bursts,
- describe and explain how works an instrument in space research.

For these goals, it is proposed to build an interactive web site exhaustive on the scientific domains of COSPIX, a description and follow-up of the COSPIX space mission, its scientific environment, and the observed phenomena. This will have:

- high definition 3D movies explaining the mission,
- animated 2D educational videos and simulations about :
    - The detection in X-rays (grazing incidence mirror),
    - The formation flight (or deployable mast) technology,
    - The explosion of a star,
    - The formation of a compact object, black hole or neutron star.
- educational games, as cross words, texts to be filled up, enigmas, etc…
- a glossary, organized as a quiz,
- a COSPIX "be an astronomer focus", with :
    - Educational tools allowing the people to plan an observation, simulate the observation, measure astrophysical results as position of a source, is flux, its variability, and calculate from that parameters as the spin of black hole, in a graphic environment (in a way similar to the CLEA project developed at Gettysburg University)
    - An all you want to know section about Black Holes (types, horizon, environment,…)
- a X file, with "all you want to know about X-rays".

In addition, material as a "COSPIX tool-kit" will be produced more specifically towards teachers. It could contain electronic information (like photos, movies) on USB keys or CDs, and educational handouts on science and technology.

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

Reply to Attn of: Science Mission Directorate

NOV 1 2010

NASA has received a description of the following mission, which has been identified as a mission that will be proposed to the European Space Agency (ESA) for consideration as a Cosmic Vision mission, as well as a description of the mission's science objectives.

Mission: Compact Object Spectrometry, Polarimetry and Imaging in Hard X-rays (COSPIX)

Letter requested by: Robert Petre (NASA Goddard Space Flight Center)

NASA is aware of this proposal and acknowledges that its science objectives are aligned with the 2010 Science Plan for NASA's Science Mission Directorate (available at http://science.nasa.gov/about-us/science-strategy/).

This letter may be included in the proposal that is submitted to ESA. NASA has not provided ESA with a copy of this letter. NASA will enter into discussions with ESA about support of selected proposals at an appropriate time.

Sincerely,

Paul Hertz
Chief Scientist
Science Mission Directorate

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

Reply to Attn of: 660 November 29, 2010

Dr. Fabio Favata
SRE-C
ESA Headquarters
8-10 rue Mario Nikis
F-75738 Paris Cedex 15
Fabio.Favata@esa.int

Dear Dr. Favata,

I am pleased to affirm our great interest in partnering in the "COSPIX: Compact Object Spectroscopy, Polarization and Imaging in hard X-rays" proposal that will be submitted in response to the ESA call for a medium-size mission opportunity for a launch in 2022. The COSPIX mission concept is an exciting approach to applying the power of high resolution hard X-ray imaging together with spectroscopy and polarization to provide fundamental insights into the astrophysics of black holes and cosmic acceleration processes. The approach uses technology that we have pioneered and leverages off the enormous investment both NASA and ESA have made for the International X-Ray Observatory.

Scientists in the Astrophysics Science Division of the NASA Goddard Space Flight Center (GSFC) are world leaders in the science and technology proposed for COSPIX and enthusiastically support the mission objectives. We expect to support the study of this mission during the assessment phase, and will seek support from NASA Headquarters to participate and contribute technically to COSPIX should the mission move forward. I look forward to following the progress of this mission and will encourage its progress on the US side.

Sincerely,

William R Oegerle

Dr. William R. Oegerle
Director, Astrophysics Science Division
NASA/Goddard Space Flight Center
Greenbelt, MD 20771 USA

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA

State Secretariat for Education and Research SER
Swiss Space Office

CH-3003 Bern, SER

Prof. David Southwood
Director of Science
ESA Headquarters
8-10 rue Mario-Nikis
F-75738 Paris Cedex 15

Reference: 912.14 D2
Your Ref.:
Our Ref.: Bot
Official in charge: Oliver Botta
Bern, 26 November 2010

Call for Proposals for Cosmic Vision 2015-2025
Awareness of potential contributions from Switzerland to COSPIX

Dear Prof. Southwood

With this letter, the Swiss Delegation confirms its awareness of Swiss scientists being members of the proposing team of COSPIX, lead by Dr. P. Ferrando. The mission is an X-ray observatory, composed of two spacecraft, offering a large collecting area in the 30 keV range. The Swiss scientist Dr. Stéphane Paltani is a Co-Investigator of this team and has informed the Swiss Delegation about his foreseen contributions to the proposed international consortium of collaborators in FR, ES, BE and the U.S. With the potential to achieve sub-system level responsibility for the Swiss entities the development of the ground-segment and contributions to the flight hardware have been identified as potential contributions.
Should the mission proposal COSPIX be selected by ESA and be implemented as a mission in the Cosmic Vision 2015-2025 Programme, the Swiss Space Office in a very constructive way will enter procedures with the goal to support the development of aforementioned contributions with Swiss entities. Funding allocation would be on the request of the Co-I via the optional ESA Programme PRODEX, according to our national evaluation procedures

Sincerely

State Secretariat for Education and Research SER

State Secretariat for Education and Research SER
Oliver Botta
Hallwylstrasse 4, CH-3003 Bern
Phone +41 31 322 99 67, Fax +41 31 322 78 54
Oliver.Botta@sbf.admin.ch
www.sbf.admin.ch