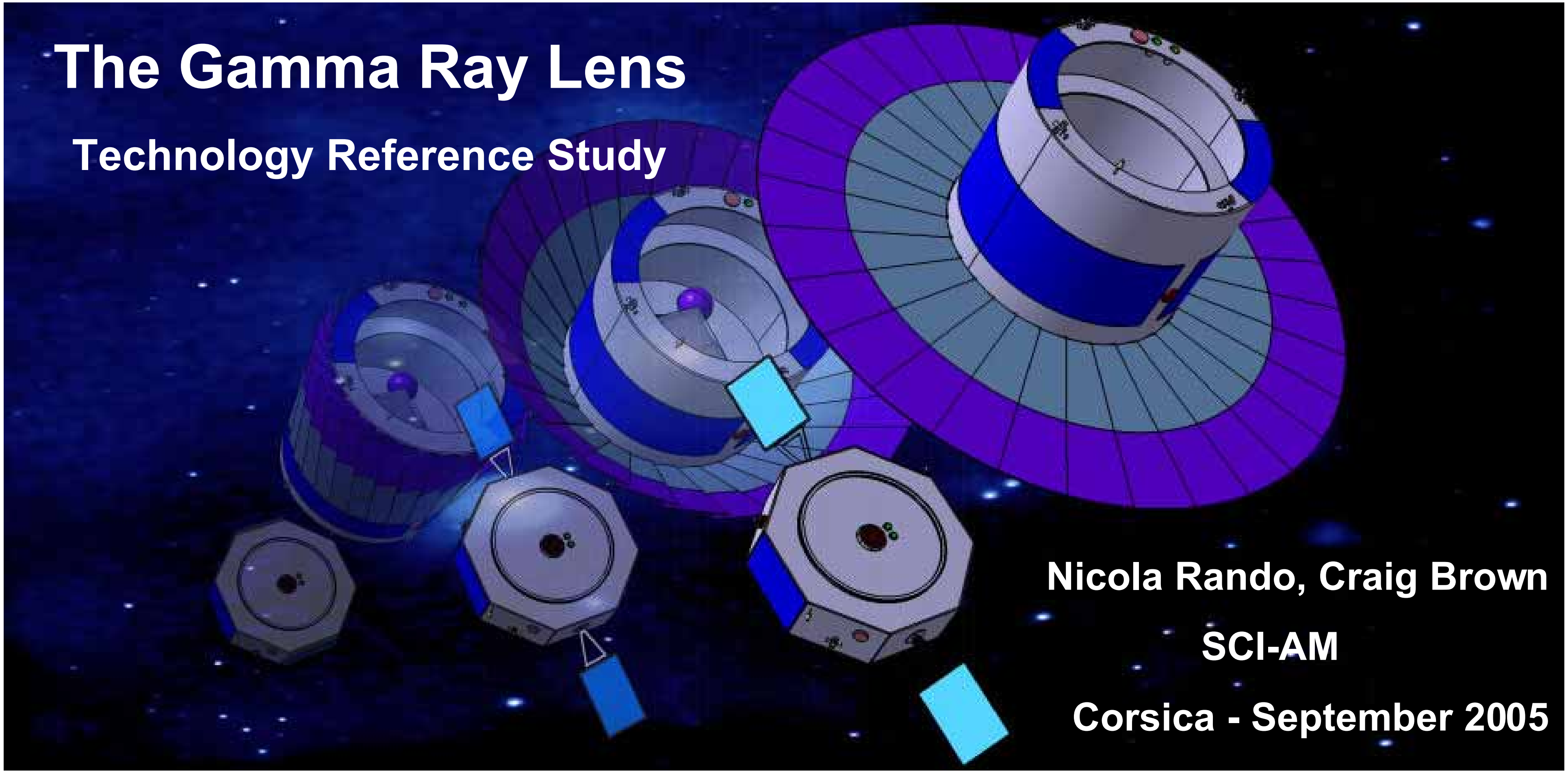


The Gamma Ray Lens

Technology Reference Study

Nicola Rando, Craig Brown

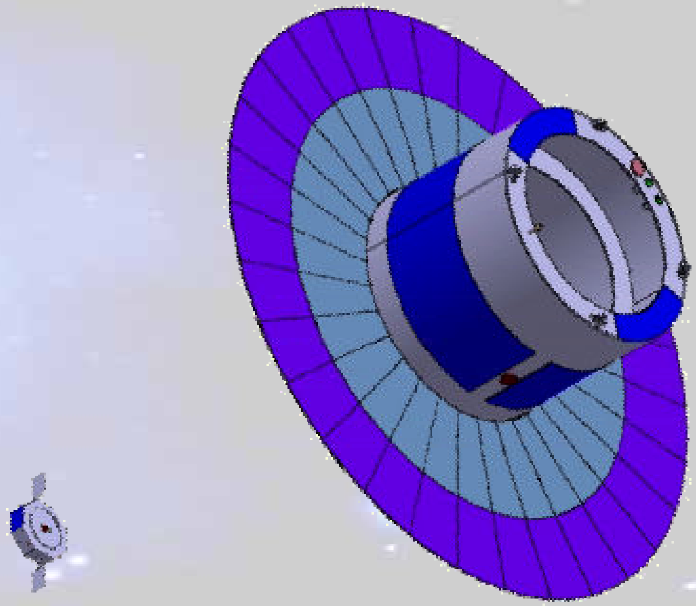
SCI-AM

Corsica - September 2005

Science Payloads & Advanced Concepts Office

Presentation Summary

- Technology Reference Studies
- Science Goals
- Design Drivers
- SF-2B & A5-ECA scenario
- Future work - Conclusions



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Technology Reference Studies

- **Internal ESA exercise carried out by SCI-A – system level**
- **Hypothetical future missions (not part of ESA science programme)**
- **Based on preliminary science goals, used as reference**
- **Objectives:**

  - **Essential mission definition / learning tool**
  - **Establish technical drivers and requirements**
  - **Identify critical technologies for future missions as to construct a coherent technology development plan**

Proved as very useful tool in all space science disciplines

(Venus Entry Probe / Jupiter Moon Explorer / Solar Polar Orbiter / etc.)

Gamma Ray Lens

- First iteration - internal SCI-AM exercise
- System level, as to allow preliminary definition
- Assuming significant step forward wrt INTEGRAL
- Exercise decoupled from programmatic considerations
- Emphasis on focusing optics technologies (critical to enhance effective area): maturity & accommodation.

Reference Science Objectives

Assumed primary target for the GRL:

SNe Ia	511 keV e^+e^-
847 keV line (^{56}Co)	Compact Objects
Long rise time ~60 days	Galactic Binaries
Long half life ~77 days	Supernovae
Relatively strong line	Galactic Centre
Flux ~10^{-5}-10^{-7} ph.cm^{-2}s^{-1}	Flux ~10^{-4}-10^{-8} ph.cm^{-2}s^{-1}

Other lines of Interest:

158, 481, 812 keV from SNe Ia, 478 keV (Classical Novae),

74, 102 and 170 keV (Compton backscattering)

Science Requirements

Parameter	**Requirement**
Energy Band	425-522 keV, 825-910 keV, 50-200 keV
Effective Area	~ 10000 cm^2 @511 keV, 5000 cm^2 @ 847 keV
Angular Resolution	Arc-minute
Energy Resolution	2 keV @ 600 keV
Line Sensitivity	~ 5x10^{-7} ph.cm^{-2}s^{-1}
Continuum Sensitivity	~ 10^{-8} ph.cm^{-2}s^{-1}keV^{-1}
Typical Integration Time	~ 10^6 s @ 511 keV, 2x10^5 s for SNe Ia
Sun Restraint Angle	30º half cone (based on XEUS)
Nom. Mission Lifetime	10 year

ESLAB symposium

- **Target established from catalogued position (e.g INTEGRAL), from orbit or ground based observations.**
- **Imaging not a priority – point sources (tbc) – time evolution of fluxes + spectroscopy**

Design drivers (1)

Focusing optics

Laue Crystals:

- Capable of higher energies – truly in the gamma ray regime → key technology
- Small energy band-pass (~ 60 keV) → suited for line emission, not for continuum
- Very small FOV (~ 30’’) → more suited for point sources, not for imaging

Graded Multilayer Mirrors:

- Capable of larger energy band-pass – Potential interest for continuum emission
- Advanced coatings applied to existing optics geometry, e.g. XMM-Newton, XEUS
- Efficient at hard X–ray energies (< 200 keV at present stage)

Design drivers (2)

➢ Laue lens assembly

Crystals mounted in concentric rings - Each crystal ring focuses a different peak energy to the focal point – R ~ 3 to 5 m (depending on LV fairing)

Large number of crystals, crystal alignment, large mass, deployable structure

➢ Formation flying:

Imposed by long focal distance of focusing optics (f ~ 500 m)

Relaxed ACS requirements wrt VIS/NIR optics (+/- 1cm lateral, +/- 50 cm on axis)

➢ Focal plane:

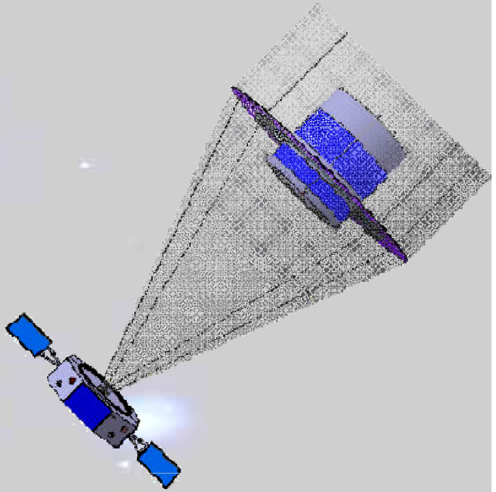
Spectrometer (imaging assumed to be lower priority) – not requiring cryogenics

High energy resolution and stopping power – radiation hard

Pixellated detector to improve background rejection – anticoincidence system

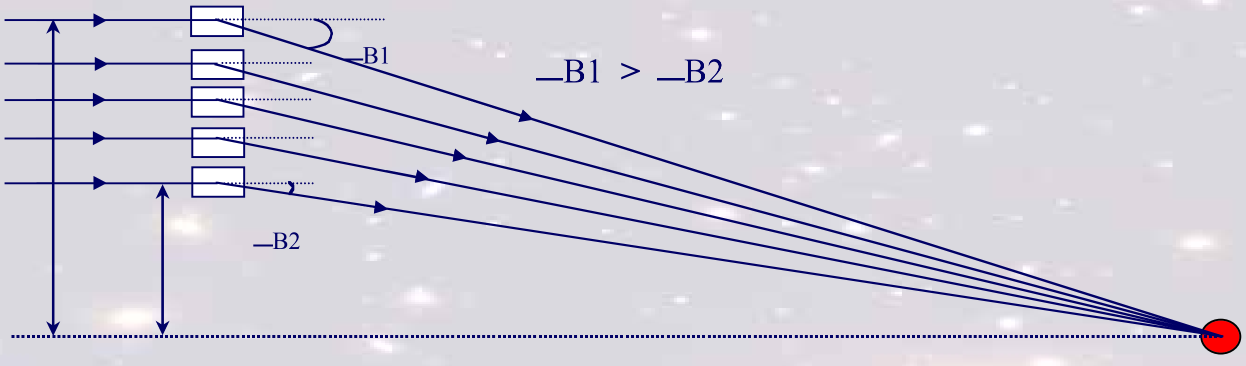
GRL TRS work plan

- Effective Area & Sensitivity model created (Laue)
- 2 different scenarios investigated (both at L2):
  - *Soyuz-Fregat (2B)*
  - *Ariane 5 (ECA)*



- Preliminary analysis of both scenario’s
- Ariane 5 scenario chosen for further investigation
- Further spacecraft definition and mass budgeting
- Further work required and potential TDAs extracted

Gamma Ray Lens - Crystal Rings



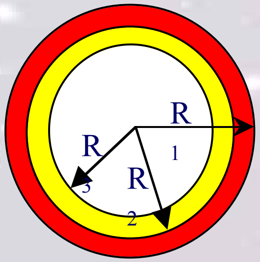
$$2d\sin\theta_B = n\frac{hc}{E} \Rightarrow 2d\theta_B = \frac{hc}{E}$$

$$F = \frac{R}{\tan(2\theta_B)} \Rightarrow 2\theta_B = \frac{R}{F}$$

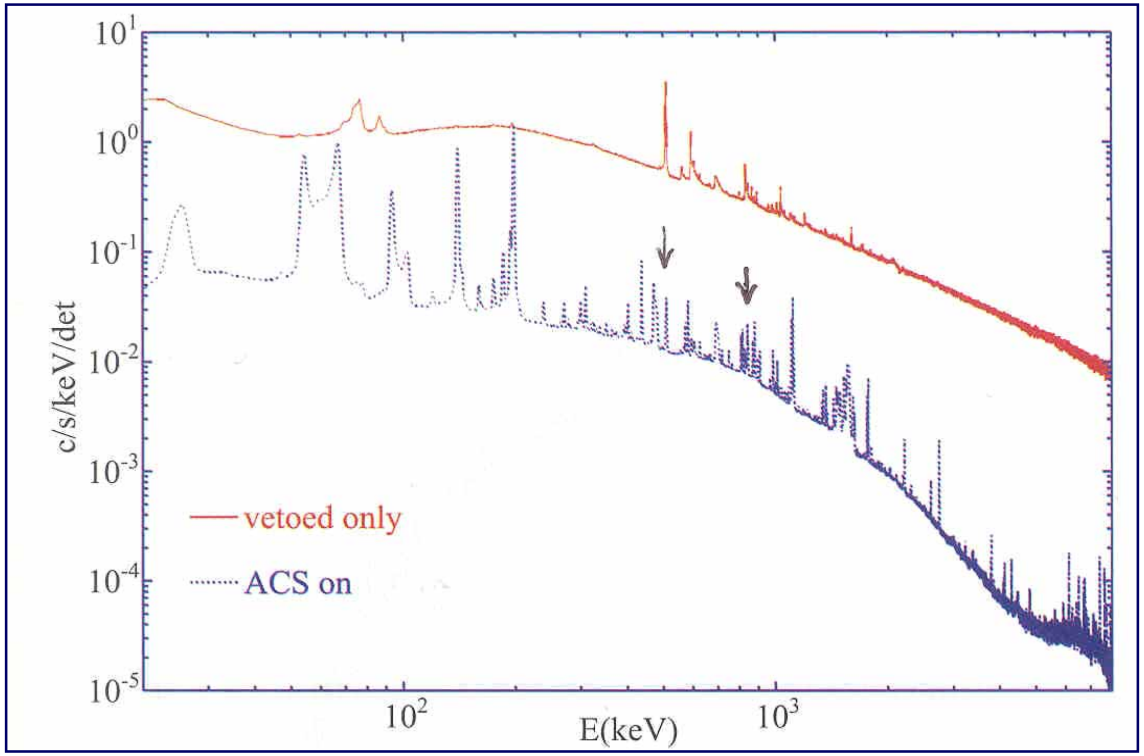
$$\therefore \frac{Rd}{F} = \frac{hc}{E} \Rightarrow E = \frac{Fhc}{Rd}$$

For small _B and n=1

- Crystalsmounted in concentric rings
- 2 energy bands over ~70 rings (Ge + Cu)
- Each crystal ring focuses a different peak energy to the focal point



Sensitivity analysis



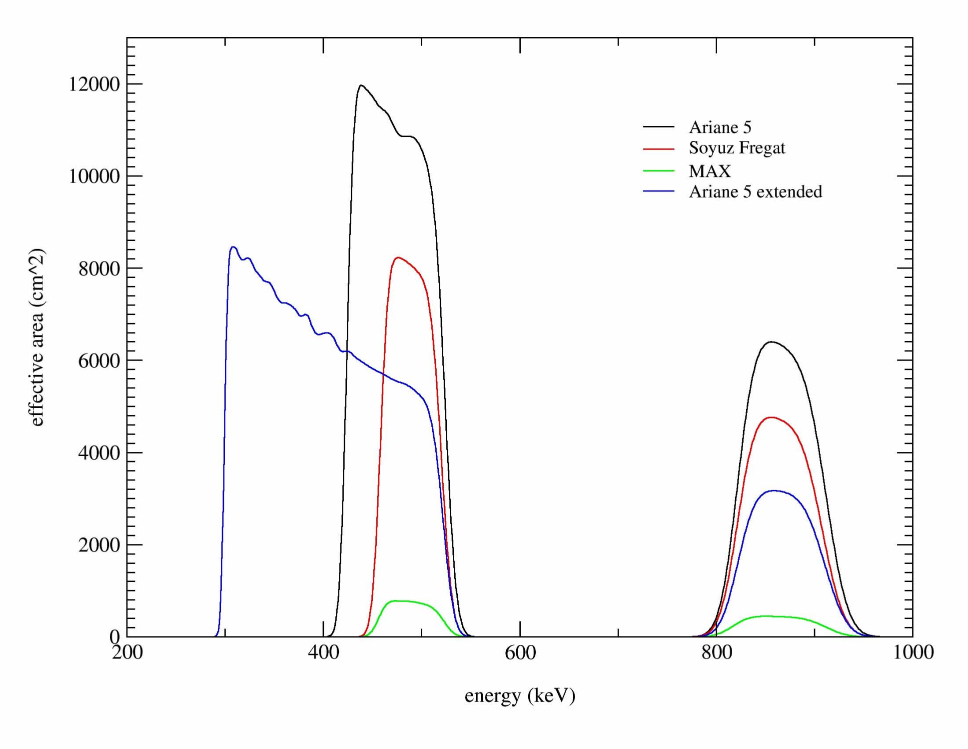
Main assumptions:

- Background as INTEGRAL/SPI
- Ge detector: δE = 0.4% FWHM
- Detector thickness = 3 cm
- Integration time: 10^6 sec
- PSF radius = 1 sigma

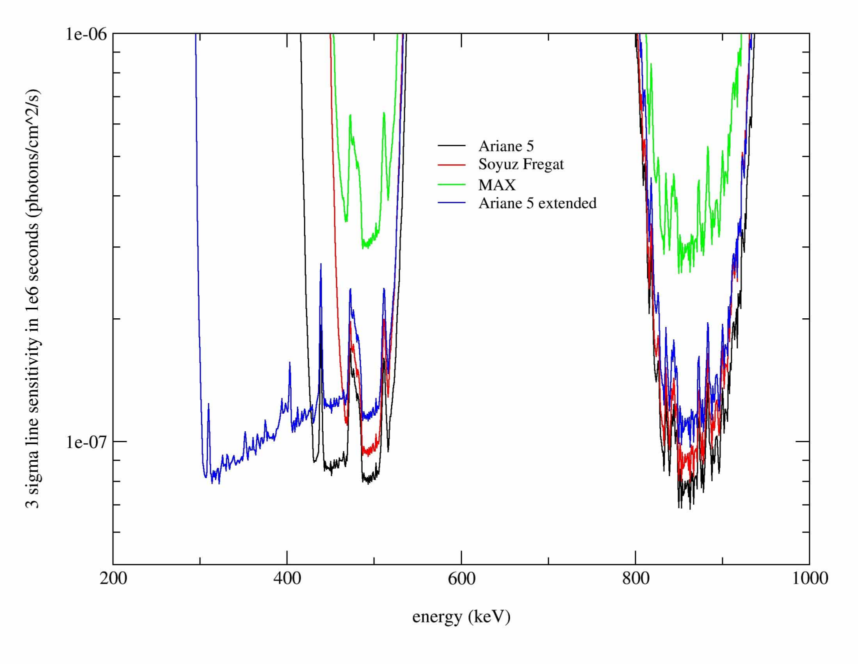
Validated reproducing MAX results (reported at Integral workshop 2005)

The Study Results

Effective Area



Sensitivity



Soyuz Fregat Scenario

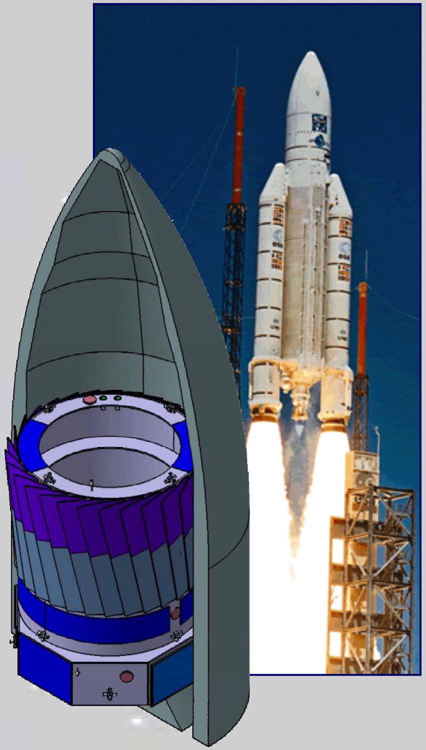
- R = 3.6 m, Ge + Cu → F = 436 m
- OSC ~2010 kg, DSC ~1200 kg
- Soyuz to L2 = 2050 kg
- 2 spacecraft, 2 launches

Pros: Lower scale, fewer crystals, lower cost, achieves the Sne-Ia observational requirements.

Cons: Dual launch complexity, more limited science capability, no expansion possible (Laue optics only, OSC is mass limited).

Ariane 5-ECA Scenario

- ➢ R = 4.5m, Ge + Cu → F = 504 m
- ➢ OSC ~3600 kg, DSC ~1300 kg, Tot = 4900 kg
- ➢ A5 to L2 = 6800 kg (ECA)
- ➢ 2 spacecraft, single launch



Pros: All science requirements met. Significant scope for payload expansion – either increased effective area or increased bandwidth. Also addition of other payloads. Simpler operations through single launch.

Cons: larger cost, larger # of crystals, more complex deployment mechanism

Comparison

SF : A_{eff} ~7400 cm^2 @ 511 keV, ~4800 cm^2 @ 847 keV

S ~ 1-2 x 10^{-7} $ph.s^{-1}cm^{-2}$ (3 sigma)

A5 : A_{eff} ~10800 cm^2 @ 511 keV, ~6400 cm^2 @ 847 keV

S ~ 7 x 10^{-8} to 1 x 10^{-7} $ph.s^{-1}cm^{-2}$ (3 sigma)

Includes Graded Multi-layers Optics for 50-200 keV range

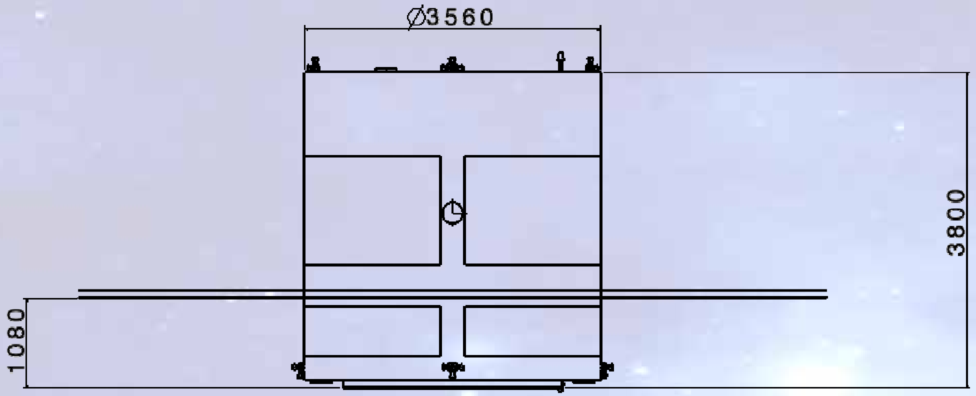
Significant opportunity for P/L expansion

A5 scenario selected for additional TRS work

OSC Configuration Design Drivers

Configuration Design Driver	Design Solution
Deployment mechanism for the large diameter circular lens	Novel deployment mechanism – folded and locked on long, cylindrical spacecraft bus
Large mass concentration on the lens ring	Support/stiffening rings used before deployment during launch
Temperature gradient & misalignment control of the optics	MLI covering the Laue lens and Silicon Pore Optic, complemented by active temperature control
Unobstructed Graded Multi-layers optics (additional lens)	Bus is a cylindrical ring with the Graded Multi-layer Optics (GMO) supported inside
30° sun angle restriction during observation	• GaAs and Si solar panels providing adequate power in all orientations • Omni-directional communication capability No direct sunlight on the Ge detectors
2624 Ariane 5 adapter	Diameter of bus to accommodate this.

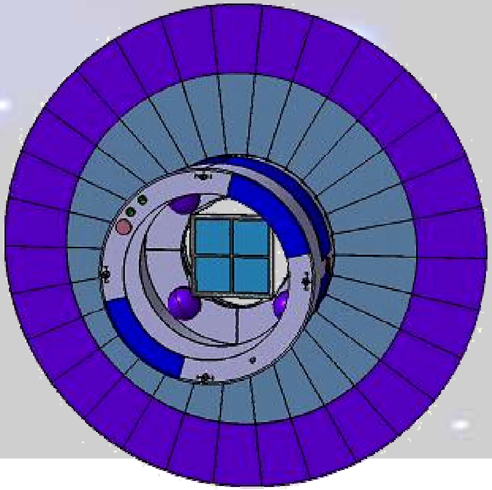
The Optic Spacecraft



- 9m diameter lens
  - 184988 Ge crystals
  - 64582 Cu crystals

  80 % P.F.
- Additional Graded Multilayer Optics

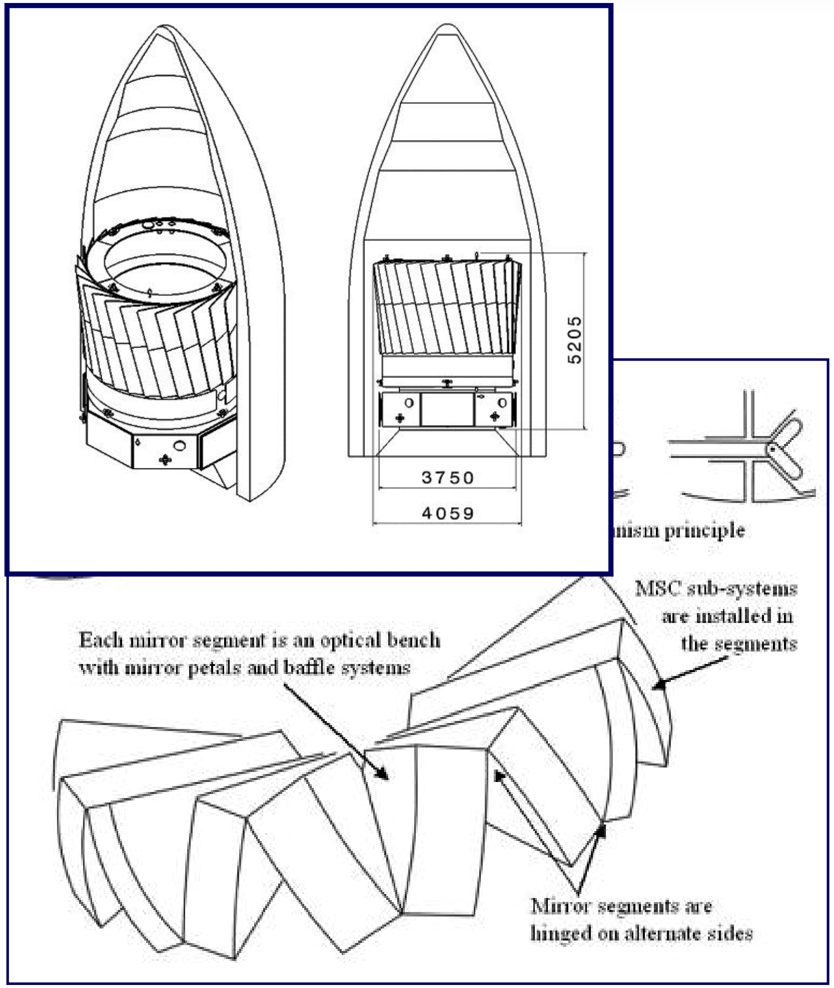
- More passive of the 2 spacecraft
- 3 Axis stabilised
- Omni-directional com with DSC
- Crystals and GMO covered in MLI



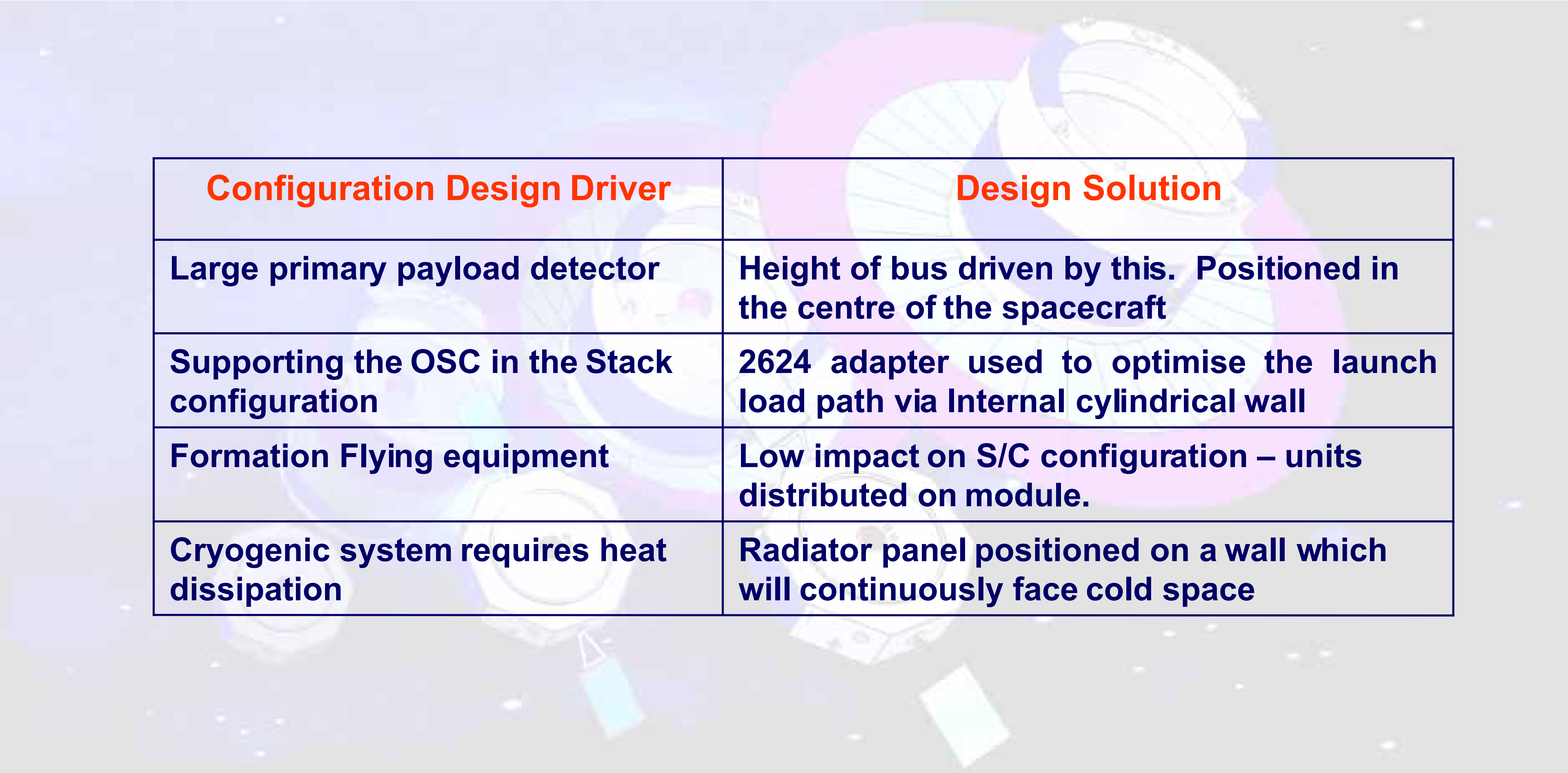
Deployment mechanism

- **Design drivers**
  - Segmented in petals (30)
  - Inter-crystal alignment
  - AIV/AIT, calibration facility
  - Large mass (launch lock)
  - Minimise T gradients to avoid lens distortion (MLI)
  - Simple spring-latch

Dedicated study is required

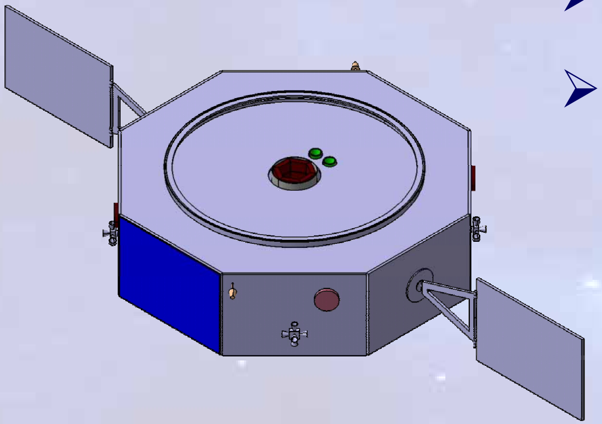


DSC Configuration Design Drivers

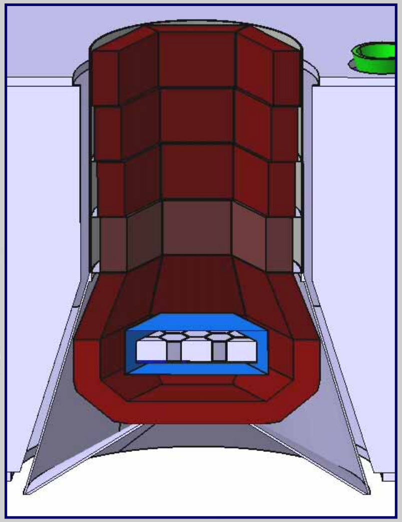


Configuration Design Driver	Design Solution
Large primary payload detector	Height of bus driven by this. Positioned in the centre of the spacecraft
Supporting the OSC in the Stack configuration	2624 adapter used to optimise the launch load path via Internal cylindrical wall
Formation Flying equipment	Low impact on S/C configuration – units distributed on module.
Cryogenic system requires heat dissipation	Radiator panel positioned on a wall which will continuously face cold space

The Detector Spacecraft



- More active of the 2 spacecraft (FF)
- Designed for launch stack configuration:
  - Diameter and strength to support the OSC during launch
  - Inner cylindrical wall to optimise load path



- Payload is a spectrometer based on SPI INTEGRAL
- 52 Ge detectors @80K and 405cm^2, BGO ACS.

Future Work and TDAs

Key Mission	Driver	Future Work
Laue Crystals	Crystal growth, characteristics, mounting, packing factor, alignment	Crystal growth / large scale fabrication / mounting techniques
Graded Multi-layer Optics (e.g. SiPO)	Optics development, multilayer coating design for 50-200 keV	Design and characterisation of the Optics and multi-layers, Aeff
Background Rejection	'Better' ACS detectors, designing out intrinsic lines from S/C	Development of ACS materials (e.g LYSO & LuAP)
Polarisation	Noted as highly desirable by the Gamma-ray science community	Polarisation techniques, detector design
Formation Flying & Rendezvous	AOCS design	Establish formation flying package, including DSC propulsion issues
Metrology System	Calibration / alignment of lens	Address AIV/T, test facilities
PSF Size	Mosaicity, alignment, thermal control	Crystal mounting, deployment & thermal design/analysis
Mission Lifetime	10 yeas (+) desired	Dev. of rad hard detectors, LaI, LuI

Conclusions

- TRS extremely valuable exercise to appreciate mission drivers and critical technology requirements
- Large resources required to make a leap forward wrt INTEGRAL → escalation effect
- Need to explore performance of smaller scale missions (see literature/workshop)
- Effective area & background rejection are critical and need to be addressed in detail
- A number of technology developments identified as candidates for ESA planning
- Critical issue: maturity of optics technology