8th International Conference on Position Sensitive Detectors (PSD8),1st - 5th of September 2008

X- and gamma-ray detector development for space applications

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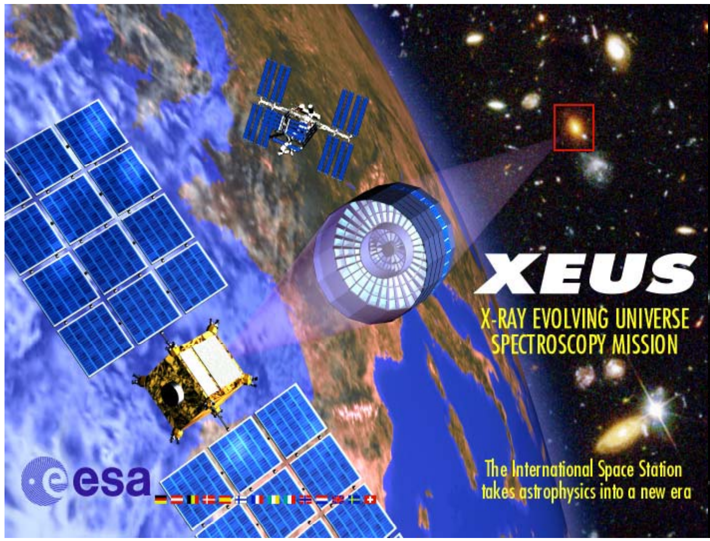

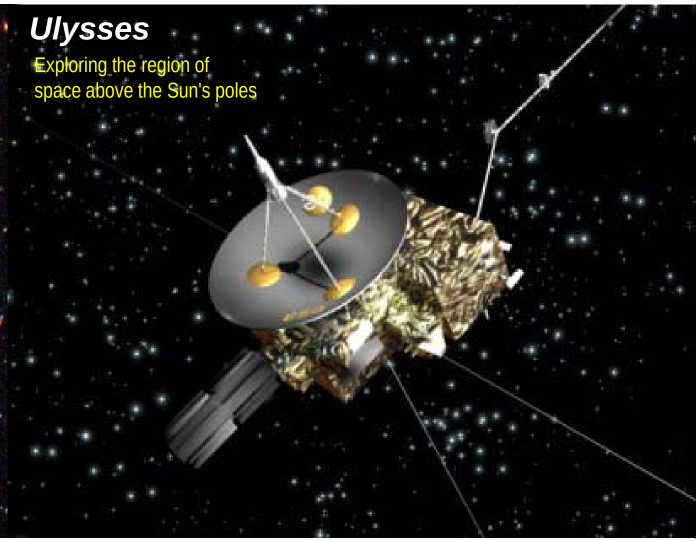

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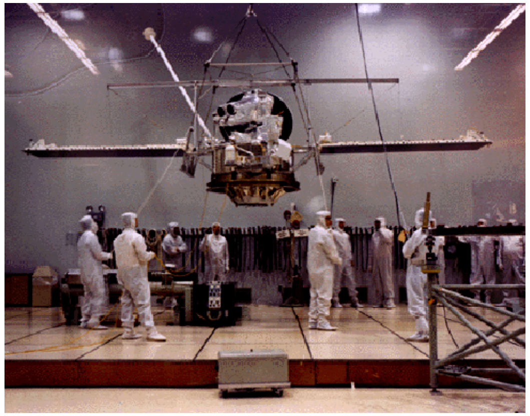
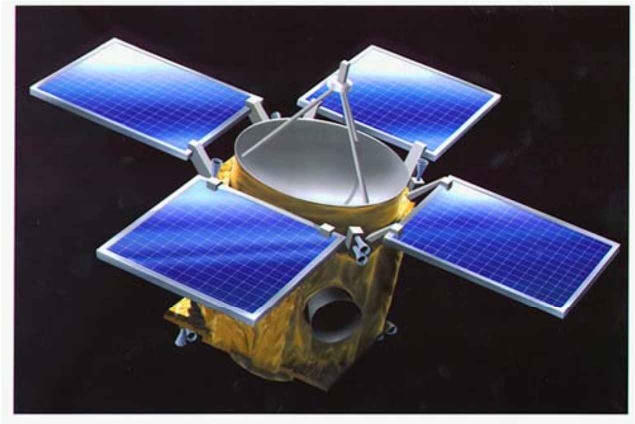
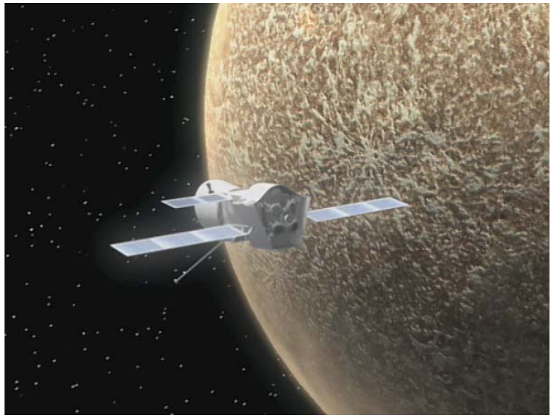
Advanced Concepts and Technology Preparation

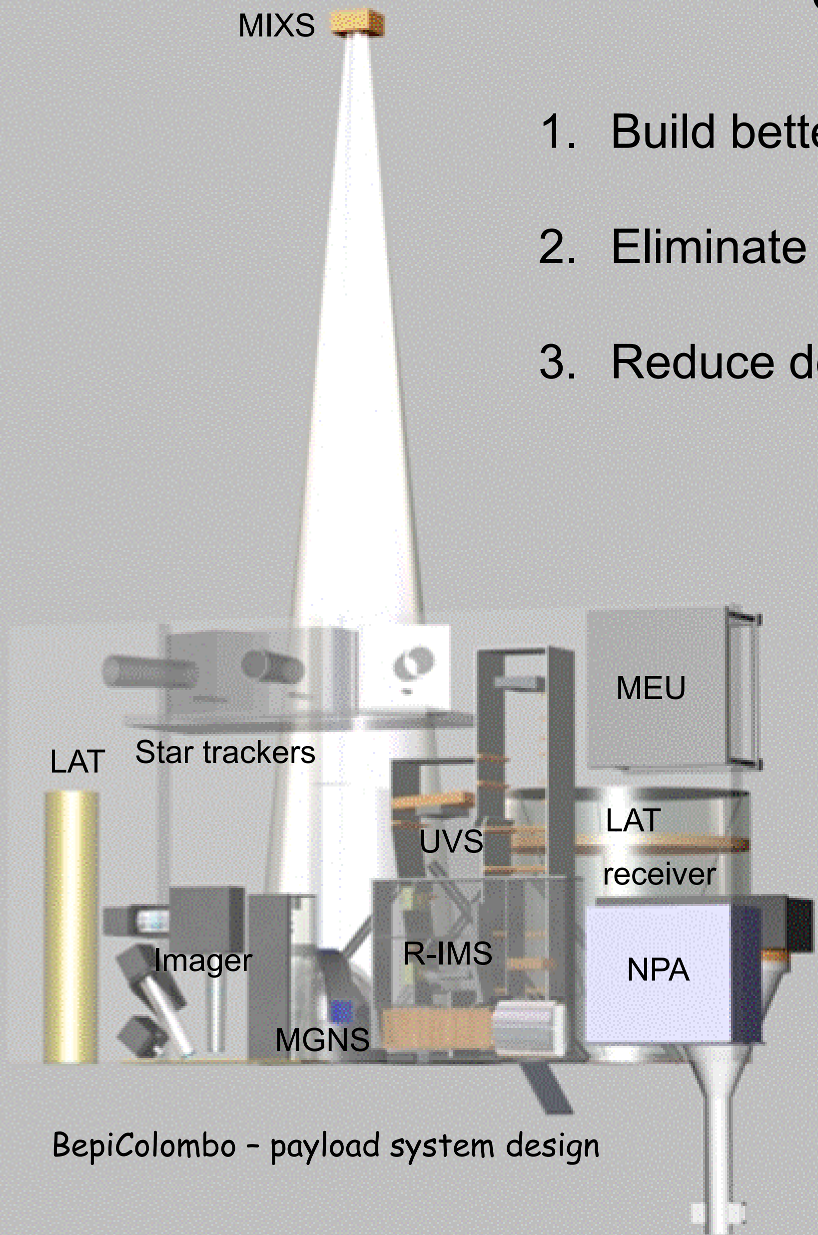
Instrumenting the present and next generation of spacecraft

The problem

Bottom line – instruments get smaller and resource starved – but loss in performance unacceptable

Mariner 10	NEAR	BepiColombo
		
30 years ago 6 instruments 79.4 kg, 100 W TLM = 117.6 kbps	15 years ago 5 instruments 56 kg, 94 W TLM = 27 kbps	Now 12 instruments 50 kg, 100 W TLM = 51 kbps
13 kg, 17 W, 20 kbps	11 kg, 19 W, 5.4 kbps	4 kg, 8 W, 4 kbps

Solution I



BepiColombo – payload system design

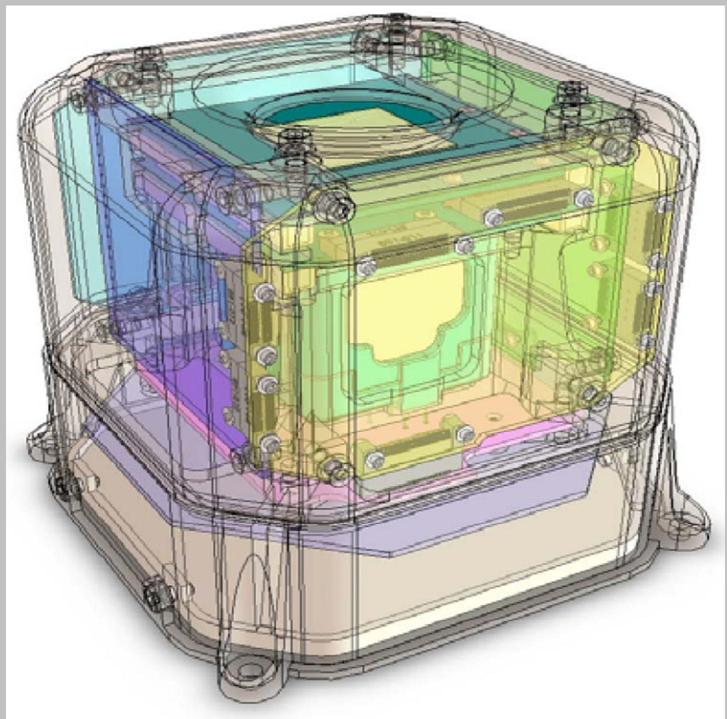
1. Build better detectors
2. Eliminate ancillary support equipment
3. Reduce dependence on spacecraft resources

This can be achieved by;

- Highly Integrated Payload Suite philosophy

Solution II

1. Build better detectors
2. Eliminate ancillary support equipment
3. Reduce dependence on spacecraft resources

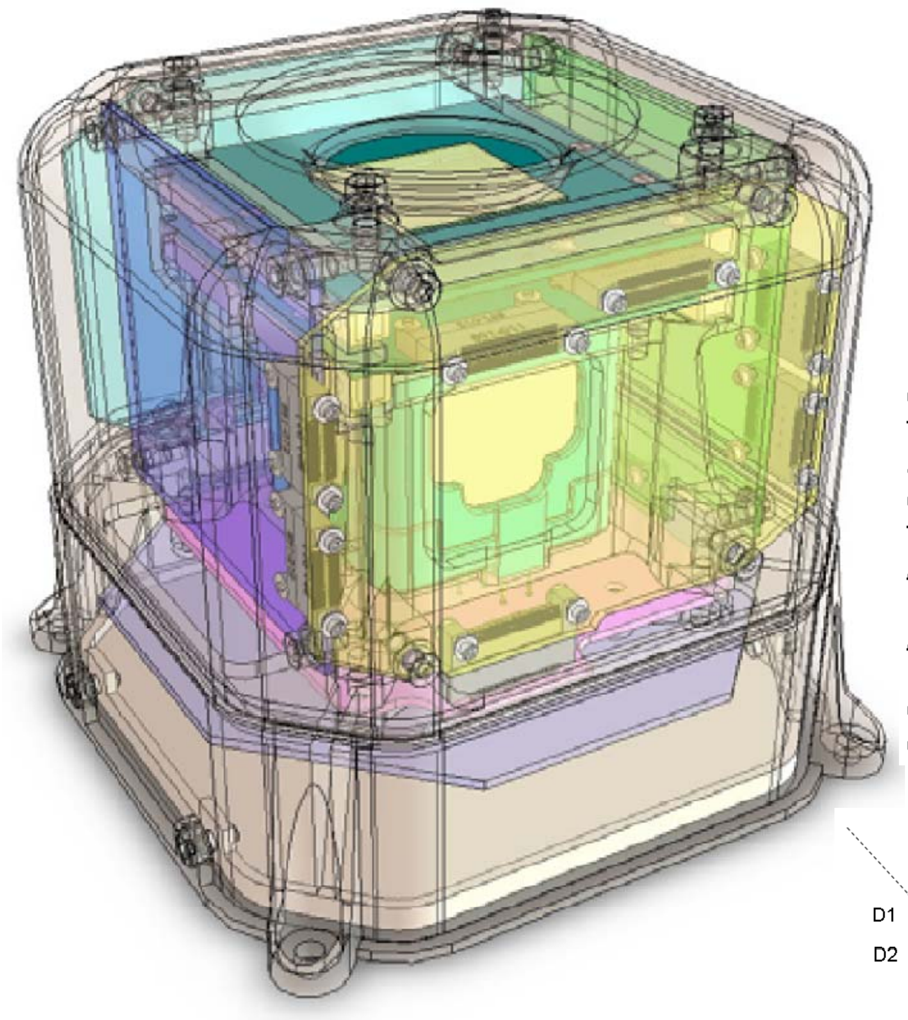


The Multifunctional Spectrometer
Mass ~ 1.4 kg, Power ~ 5.0 W

This can be achieved by;

- Highly Integrated Payload Suite philosophy
- Miniaturization

Multi-Functional Spectrometer (MFS) to be flown on Alphasat

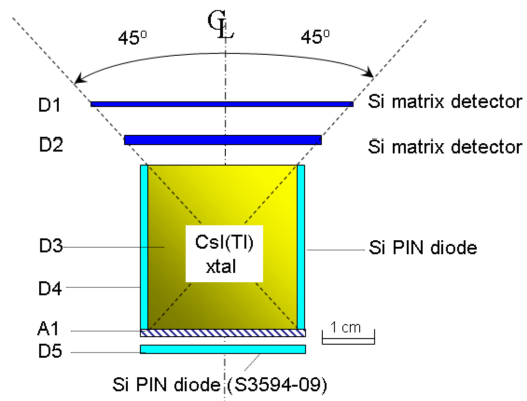


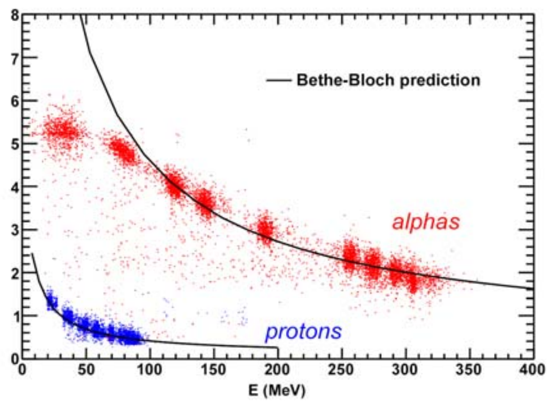
MFS specifications largely driven by SEP characteristics

Particles	e, p, α, ions, gamma-rays
Ion separation	H, D,T,^{3}He,^{4}He,C,N,O

	Electrons	Protons	Alphas	Gamma-rays
Energy range	1-20 MeV	1-200 MeV	5-400 MeV	0.1-3 MeV
Energy Resolution	20%	5%	5%	10%

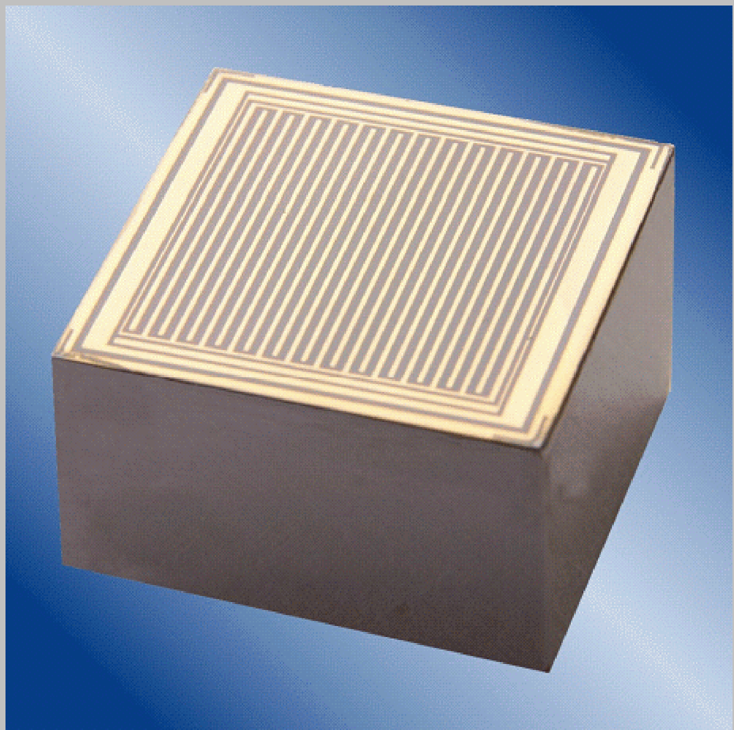
Count rate	up to 10^{6} cps (spectral), 10^{7} cps (integral above 1 MeV)
Time resolution	1 sec
Sensitive FOV	> 6 ster
Geometric factor	> 30 cm^{2} ster
Telemetry rate	<100 bps
Accommodation	< 1L
Mass	5 kg
Autonomous operation	7 days
Processor	LEON-II
Output	SpaceWire/ **MIL-STD-1553** (configurable)
Configuration	single unit





Solution III

1. Build better detectors
2. Eliminate ancillary support equipment
3. Reduce dependence on spacecraft resources

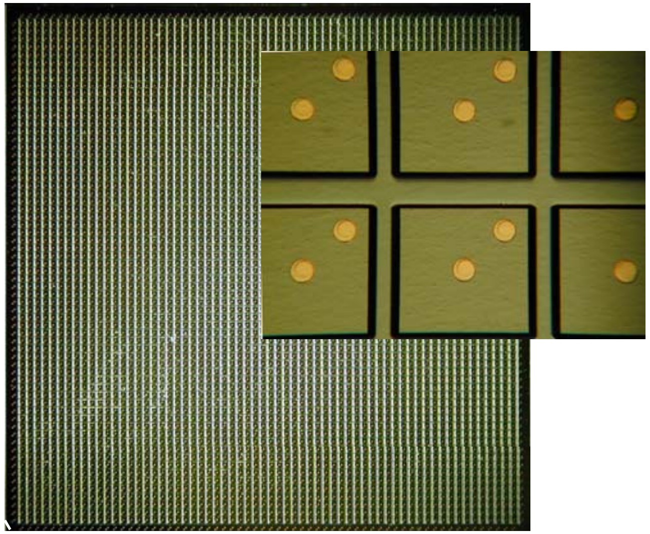


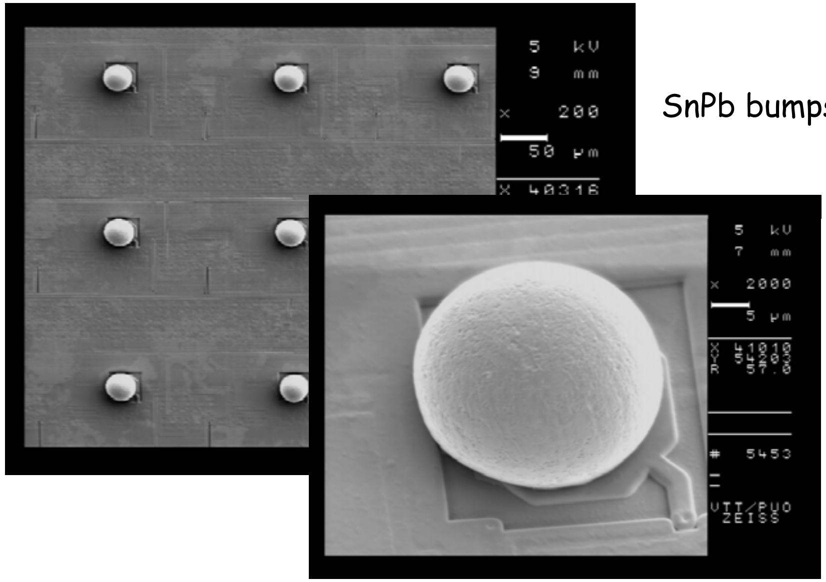
15x15x11mm³ CdZnTe Coplanar grid

This can be achieved by;

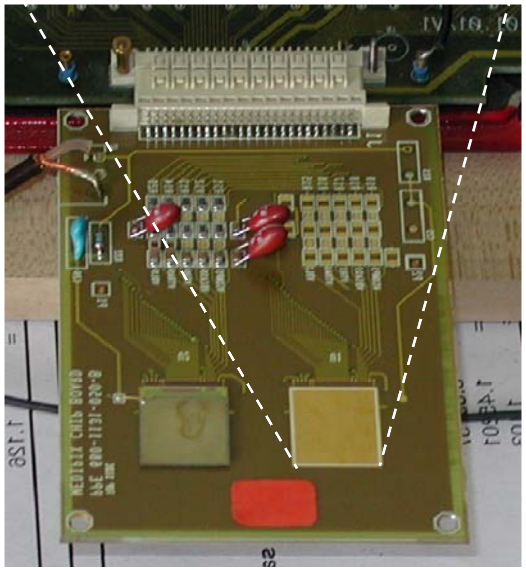
- Highly Integrated Payload Suite philosophy
- Miniaturization
- Advanced technologies

GaAs 64x64 imager development (using MEDIPIX I)

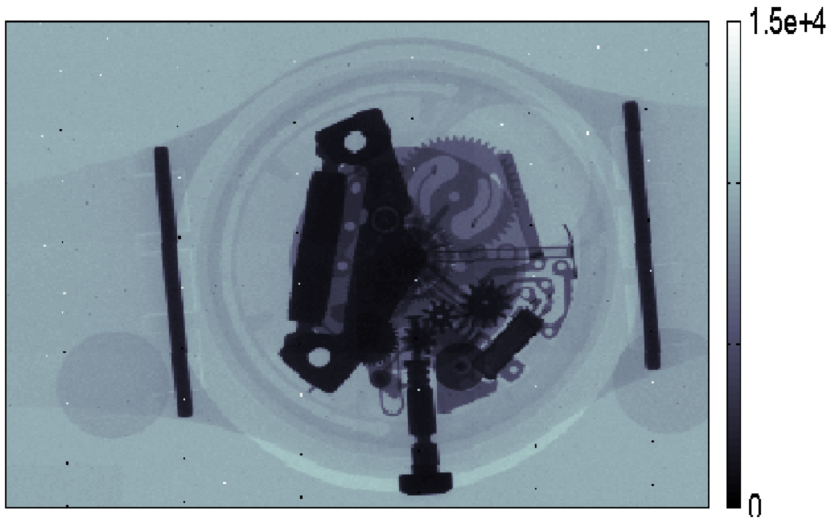




SnPb bumps



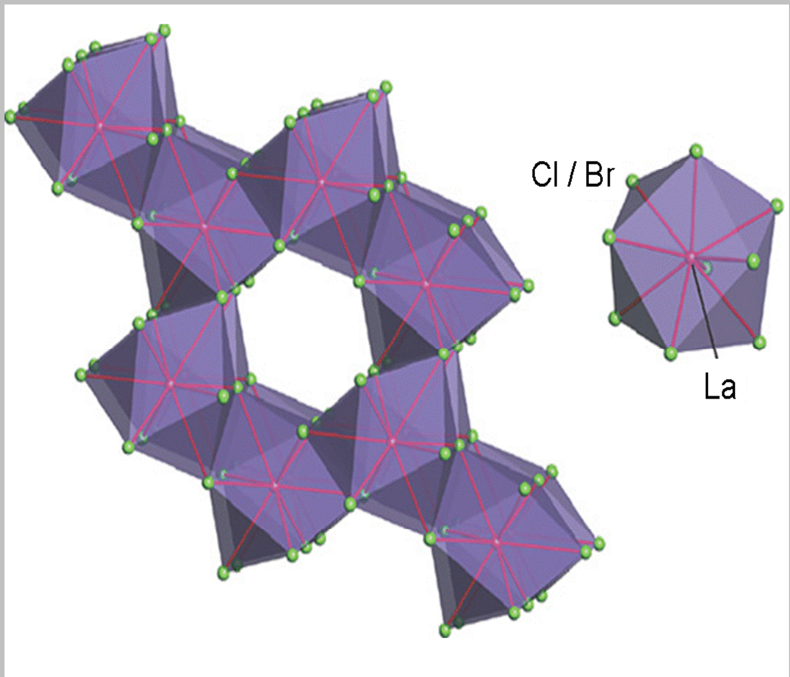
flip-chip bump-bonded and mounted
on the MUROS daughter board



X-ray image taken with a Mo target (17.4 keV)

Solution IV

1. Build better detectors
2. Eliminate ancillary support equipment
3. Reduce dependence on spacecraft resources



Lanthanum halide growth study

This can be achieved by;

- Highly Integrated Payload Suite philosophy
- Miniaturization
- Advanced technologies
- Targeted or new materials

Materials under development

InAs	III-V
InSb	III-V
GaN	III-V
GaAs	III-V
B_4C	III-IV
Ge	IV
SiC	IV-IV
TlBr	III-VII
CdZnTe,	II-VI
CdMnTe	II-VI
$LaBr_3:Ce^{3+}$	
$LaCl_3:Ce^{3+}$	
LuI_3	
$CeBr_3$	

New detector development activities

Activity	Material	Mission
Remote sensing γ-ray spectrometer	$LaBr_3$,$LaCl_3$	BepiColombo/ SolO
XRF planetary spectroscopic imager	GaAs	Cosmic Vision
Solar Monitor	GaAs	BepiColombo
Low bandgap hi-res X-ray detector arrays	InAs, InSb	XEUS
High resolution, minimally resourced γ-ray	HPGe	Near earth, Lunar
Small γ-ray probe	TlBr/CdMnTe	JME
Extreme environment X-ray/particle detectors	SiC, GaN, C	JME, JSE, SolO
UV detectors	GaN, C	SolO, JME, IHEP
Large γ-ray imaging detection plane	TlBr, CdZnTe	GRL TRS
Direct neutron detection	B_4C	BepiColombo
New scintillation materials	$CeBr_3$,$Lu3Al_5O_{12}$	Cosmic Vision

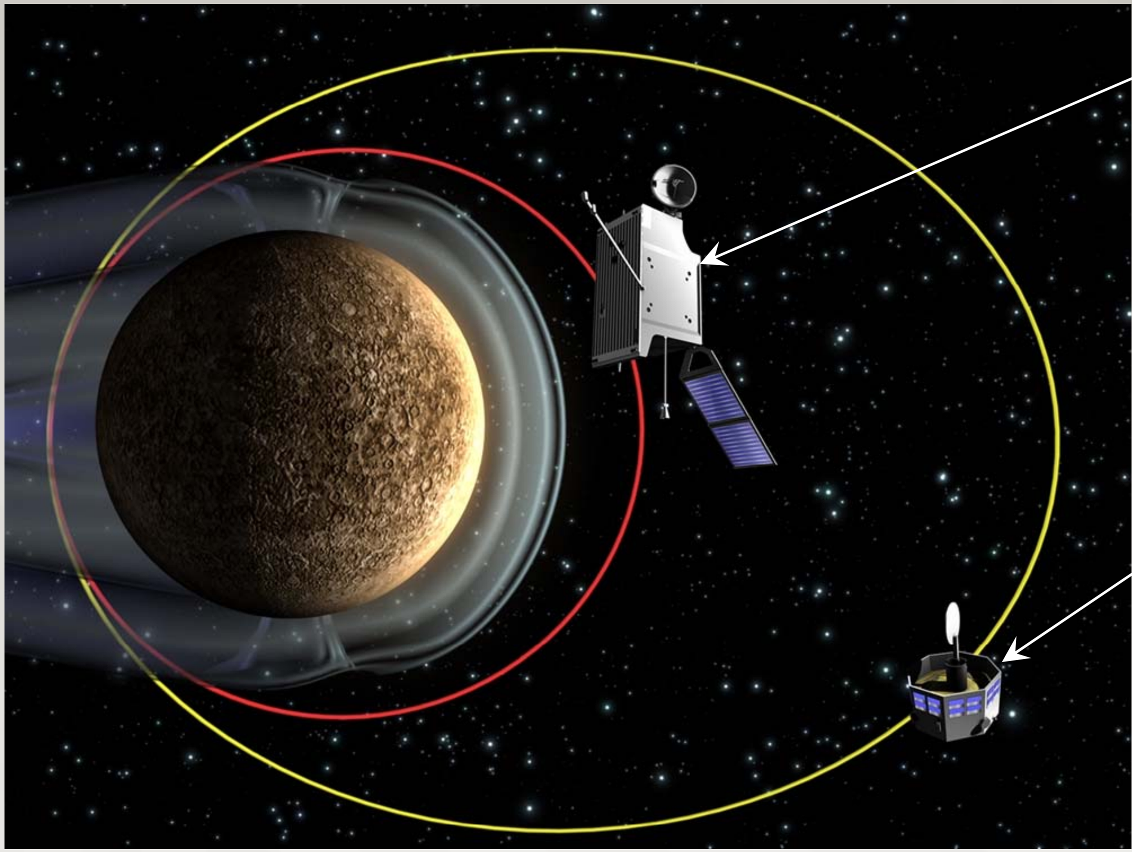
BepiColombo An Example

An Interdisciplinary
Mission to the Planet Mercury

MISSION OBJECTIVES:

- Investigate the origin and evolution of a planet close to its parent star
- Investigate Mercury as a planet: its form, interior, structure, geology and composition
- Verify Mercury's vestigial atmosphere (exosphere): composition and dynamics
- Study Mercury's magnetized envelope (magnetosphere): structure and dynamics
- Determine the origin of Mercury's magnetic field
- Test Einstein's theory of general relativity

BepiColombo at Mercury



Mercury Planetary Orbiter (MPO)

- polar orbit optimized for study of the planet itself
- 400 x1500 km
- 2.3 hr period

Mercury Magnetospheric Orbiter (MMO)

- polar orbit optimized for study of the magnetosphere
- 400 x12000 km
- 9.2 hr period

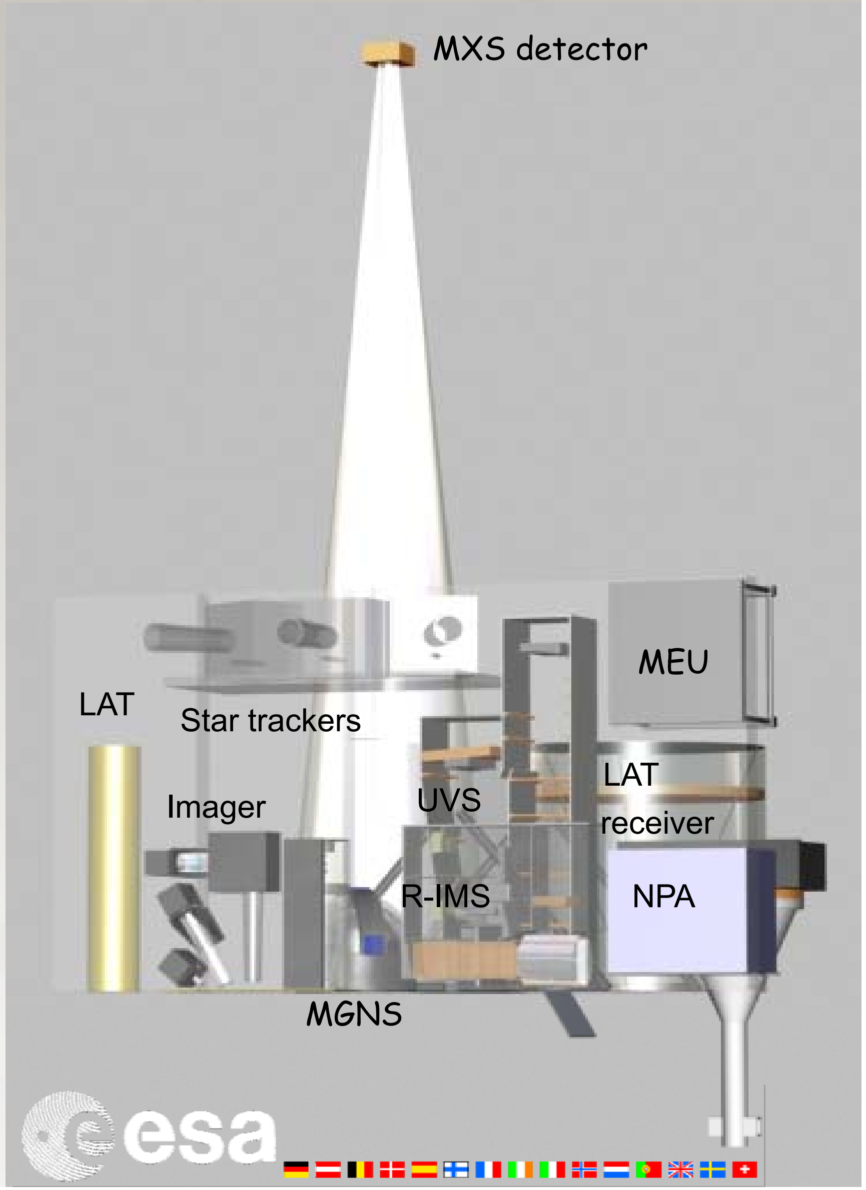
- a natural north-south rotation of the orbits' major axis will favour the science coverage of the planet

The BepiColombo Project (how its put together)

- **ESA provided:**
  Mission design, MPO spacecraft, Mercury Transfer Module, integration and test, launch, overall cruise operations, MPO operations at Mercury (Overall ESA budget 665 M€)

- **JAXA provided:**
  MMO spacecraft and its operations at Mercury

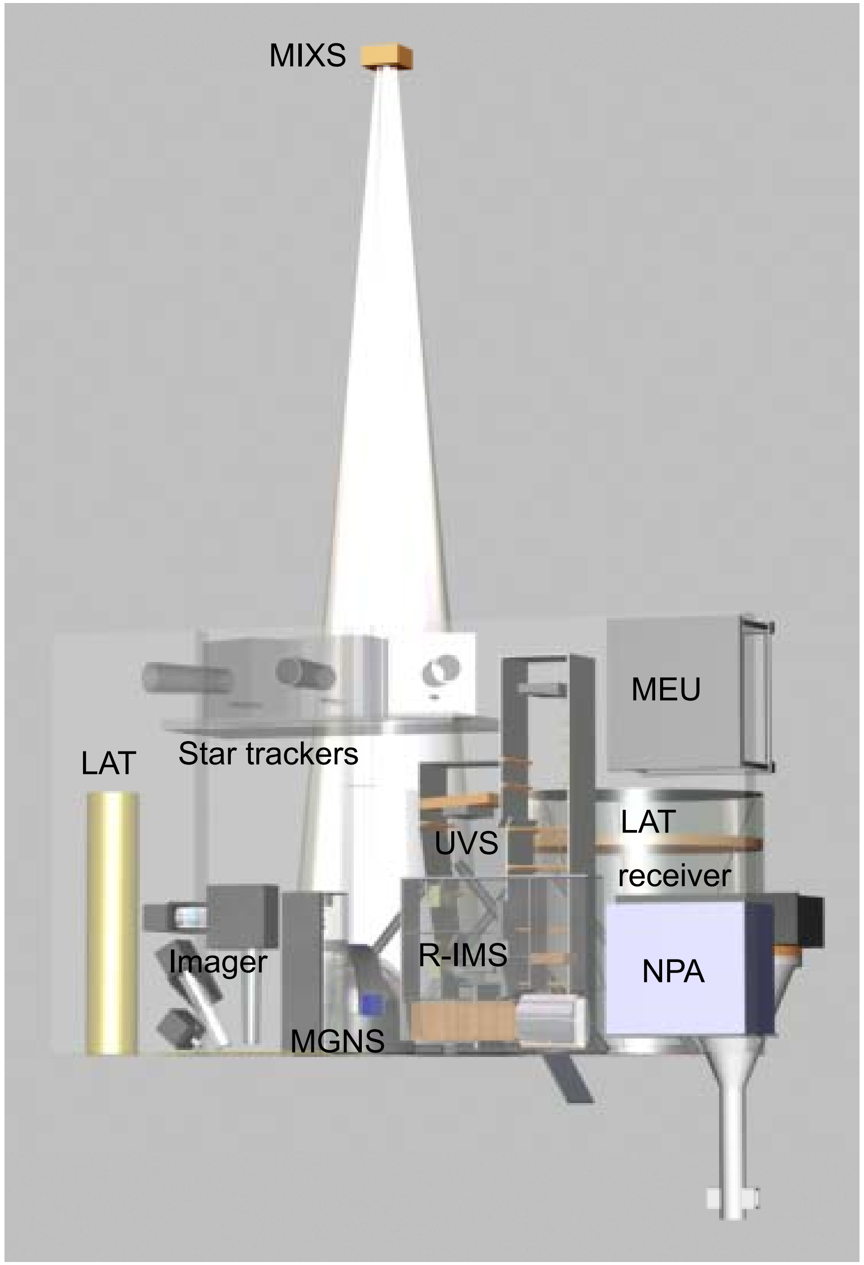
- **National funding**:
  - MPO scientific instruments: 10 European and 1 Russian
  - MMO scientific instruments: 4 Japanese and 1 European



Technology development and BepiColombo

- HIPS √
- Miniaturization √
- New Technology √
- Use of new materials √
  - XRS - GaAs
  - SXM – GaAs
  - GRS - $LaBr_3$
  - IMS - HgCdTe

Nr.	Instruments	Mass (kg)	Power (W)	Heat load
1	HRC	1.10	1	4.8
2	S-CAM	0.55	1	0.3
3	L-CAM	0.34	1	0.0
4	VN-IMS	0.80	7	3.6
5	R-IMS	2.20	3	2.7
6	UVS	1.65	2	0.0
7	MXS/SXM	2.10	5	4.8
8	MGNS	3.00	3	0.5
9	LAT	5.53	(20)	3.4
12	NPA	1.80	3	0.1
10	RSE	6.70	10.6	0.0
11	MAG	4.15	2	0.0
13	Platform	3.00	0	0.0
14	2CPU	3.00	20	0.0
15	CPPS	0.70	11.7	0.0
16	Harness	1.68		0.0
	Subtotal	38.3	70.3	20.3
	Contingency	7.7	14.1	14.1
	Total	45.9	84.4	34.4

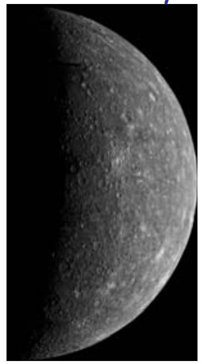


The geochemical package

MIXS
MGNS

Moon

Mercury

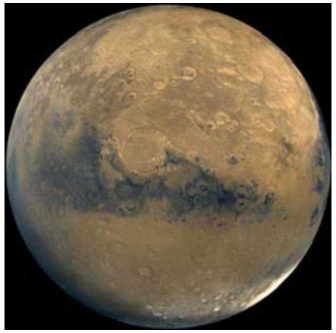


Remote sensing and Planetology

1. Surface composition provides information on the planet bulk composition. Bulk composition helps to understand where and how the planet forms.

   ➔ **Planet Origin**

Mars



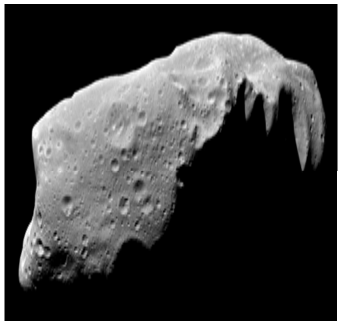
2. Surface composition also provides information on how a planet has evolved since its formation.

   ➔ **Planet Evolution**

3. Comparative studies helps us to understand how and why planets differ from each other.

   ➔ **Comparative Planetology**

Asteroid



remote sensing - ground truth

Determining surface composition - remote sensing

	Sampling Depth	Excitation source	Relative data Quality	Surface Resolution (S/C altitude)	Element sensitivity
X – ray	100 μm	Solar X-rays	Good if flare	1/10 – 1/3[1]	Fe Na Mg Al Si P S K Ca Ti
γ – ray	~ 20 cm	Cosmic-rays Secondary Neutrons	Poor	1/3	H O Na Mg Al Si S Cl K Ca Ti Cr Th U Fe
neutrons	~ 1 m	Cosmic-rays	Good	1/2	(Fe, Ca, Ti, REE) (H REE) <A>

	Instrument Design	Instrument Operation	Data Reduction	Signal Sensitivity	Data Interpretation
X – ray	Moderate	Moderate	Moderate	Moderate	Moderate
γ – ray	Can be Complex	Can be Complex	Complex	Very Good	Simple
neutrons	Simple	Simple	Moderate	Moderate	Difficult

[1]spatial resolutions of 200m can be achieved with the proposed MIXS

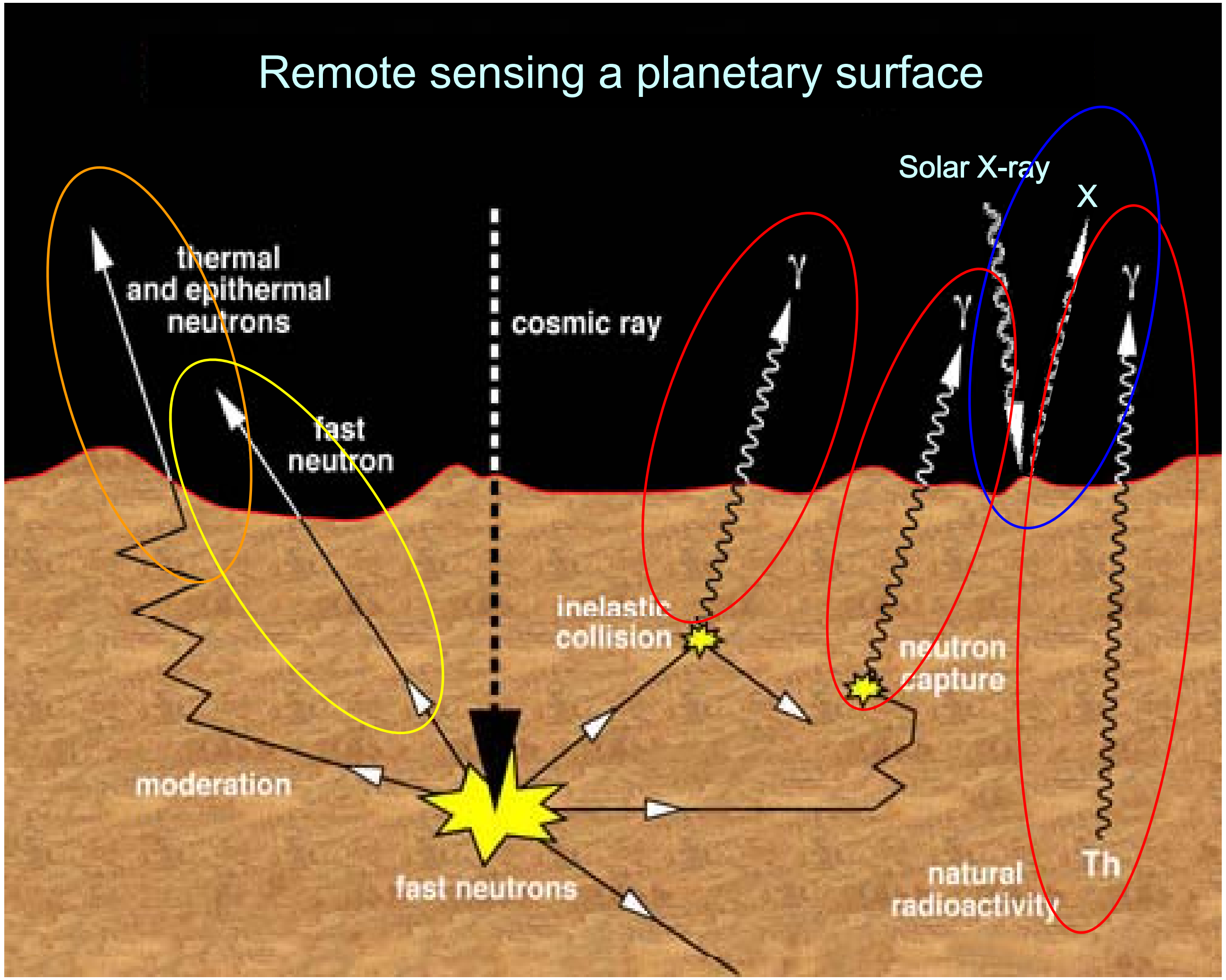
X/gamma-ray/neutron remote sensing

PHYSICS:

Solar X-rays impinge on planetary surface and fluoresce characteristic X-rays from the top ~100 microns of the regolith

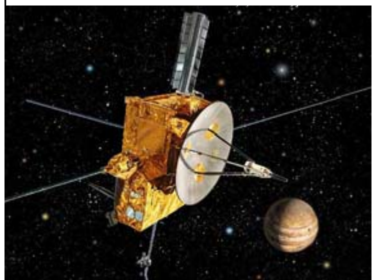
Galactic Cosmic Rays interact with the regolith producing neutrons, gamma-rays and X-rays in the 1-3 meters subsurface layer

Their flux and energy spectra are characteristic of the elementary composition of the subsurface. The neutrons are particularly moderated by hydrogenous matter



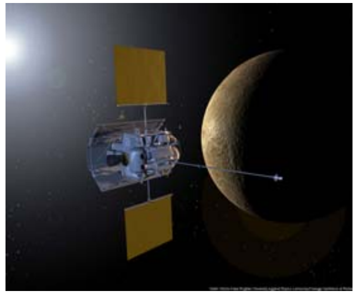
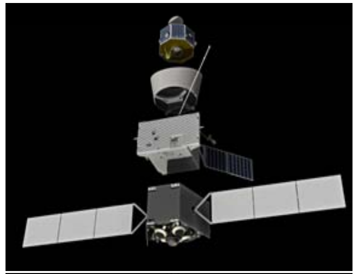
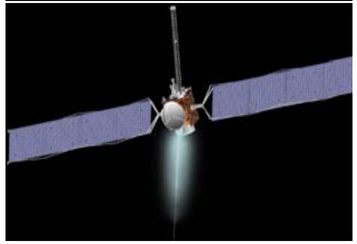
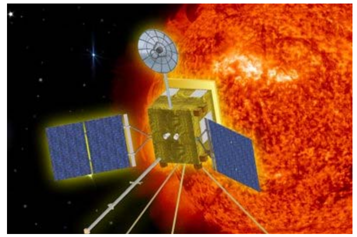
Geochemical packages on Planetary Missions




Mission	GRS	XRS	NS	PS
• Past missions				
– Phobos	CsI	yes	Stilben,plastic	yes
– Lunar Prospector	BGO/BC454		BC454	
– Near	NaI/BGO	gas		
– Mars Observer	HPGe/BC454		BC454	
– Mars Odyssey	HPGe		BC454,Stilben,plastic	CsI
• Current missions				
– Ulysses	CsI/GRB			Plastic
– Messenger	HPGe/BGO	gas	GS20,BC454	
• Missions in implementation				
– Dawn	CZT/BGO		BGO,BC454, G20	
– Phobos Grunt	$LaBr_3$		BC454,Stilben,gas	
– Solar Orbiter	$LaBr_3$		BC454	plastic
– BepiColombo	$LaBr_3$	Si	BC454,Stilben,gas	CsI

GRS=gamma-ray spectrometer
XRS=X-ray spectrometer
NS=neutron spectrometer
PS=particle spectrometer

GRS - Specific requirements for BepiColombo

produce a large volume gamma-ray detector with:

- High γ-ray detection efficiency in the MeV region (300 cm^3)

  (SCI-RD ε > 14% FEPE @ 1 MeV). Achieved through use of high density materials (i.e., > 5 g cm^{-3})

- High energy resolution above 1 MeV ($\leq$3% FWHM @662 keV)

  ΔE SCI-RD driven. Achieved through using scintillation materials with high light output (>50,000 ph/MeV) – low light non-proportionality, low readout noise (< 20 phe rms)

- Environmentally robust

  Achieved using inorganic scintillators - Hardness > 2 Mho, Radiation tolerance > 10^4 Gy, low activation susceptibility (< 3 ct cm^{-3} s^{-1}), low phosphorescence, annealing possibility *via* thermal or optical bleaching means

- Inert

  Room or elevated temperature operation (-10°C to +30°C) , no high voltages, no special EMC, cleanliness or handling requirements, no moving parts

- Minimally resourced

  No services (e.g., cooling, vacuum, calibration sources, radiation or magnetic shielding), no maintenance, 4 kg, 4W, 1 L – above all simple

Scintillators - Basic Properties

	Light O/P [photons/keV]	Decay Time [ns]	Emis. Wavelength [nm]	Density [g/cm^3]
NaI(Tl)	38	250	415	3.7
CsI(Tl)	54	1000	550	4.5
BaF_2	10	0.7/630 fast/slow	220/310 fast/slow	4.9
$LaCl_3$(Ce)	49	28	350	3.8
$LaBr_3$(Ce)	66	16	380	5.1

FWHM energy resolution at @ 662 keV

NaI(Tl) $\Delta E/E \sim 6\%$
$LaCl_3$ $\Delta E/E \sim 4\%$
$LaBr_3$ $\Delta E/E \sim 3\%$
CdZnTe $\Delta E/E \sim 2\%$ *(after correction for carrier recombination)*

History - $LaBr_3$ development program

Project driven consortium formed between ESA, Cosine BV, Delft TU, Saint Gobain

Requirements for sensor for MGNS

- ≤ 3% FWHM energy resolution at 662 keV
- 300 cm^3 detection volume, ε_p> 14% @ 1 MeV
- Minimum resourced – 4.5 kg, 5W, 100 bps, no cooling

Inferred from the SCI-RD

Major issues for $LaBr_3$ implementation

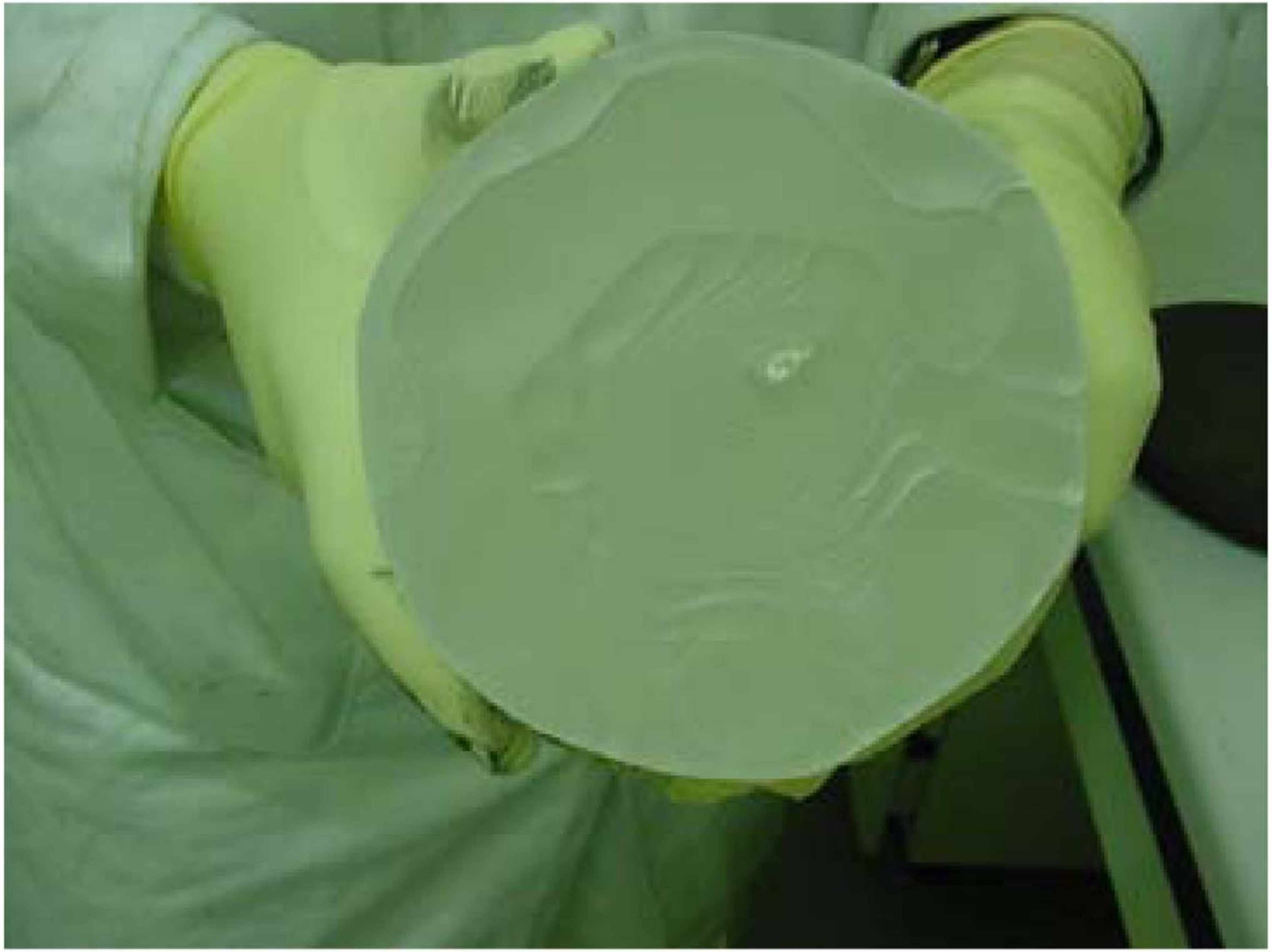
1. Cracking
2. Does resolution get worse with volume?
3. Radiation damage
4. Activation

BepiColombo Project required a favourable resolution of all issues

Issue 1. Growth problem - cracking

Run Y3B-24 - 5” x 5”

Run Y3B-28 - Single xtal



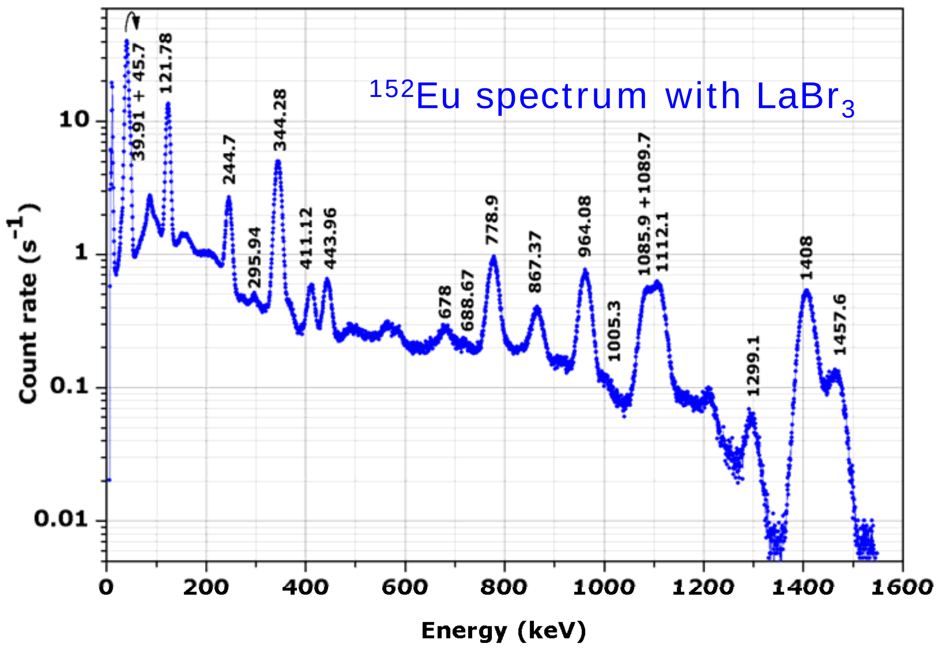
cosine | research

TUDelft Technische Universiteit Delft

SAINT-GOBAIN CRYSTALS

esa

Issue 2. Does resolution get worse with volume?

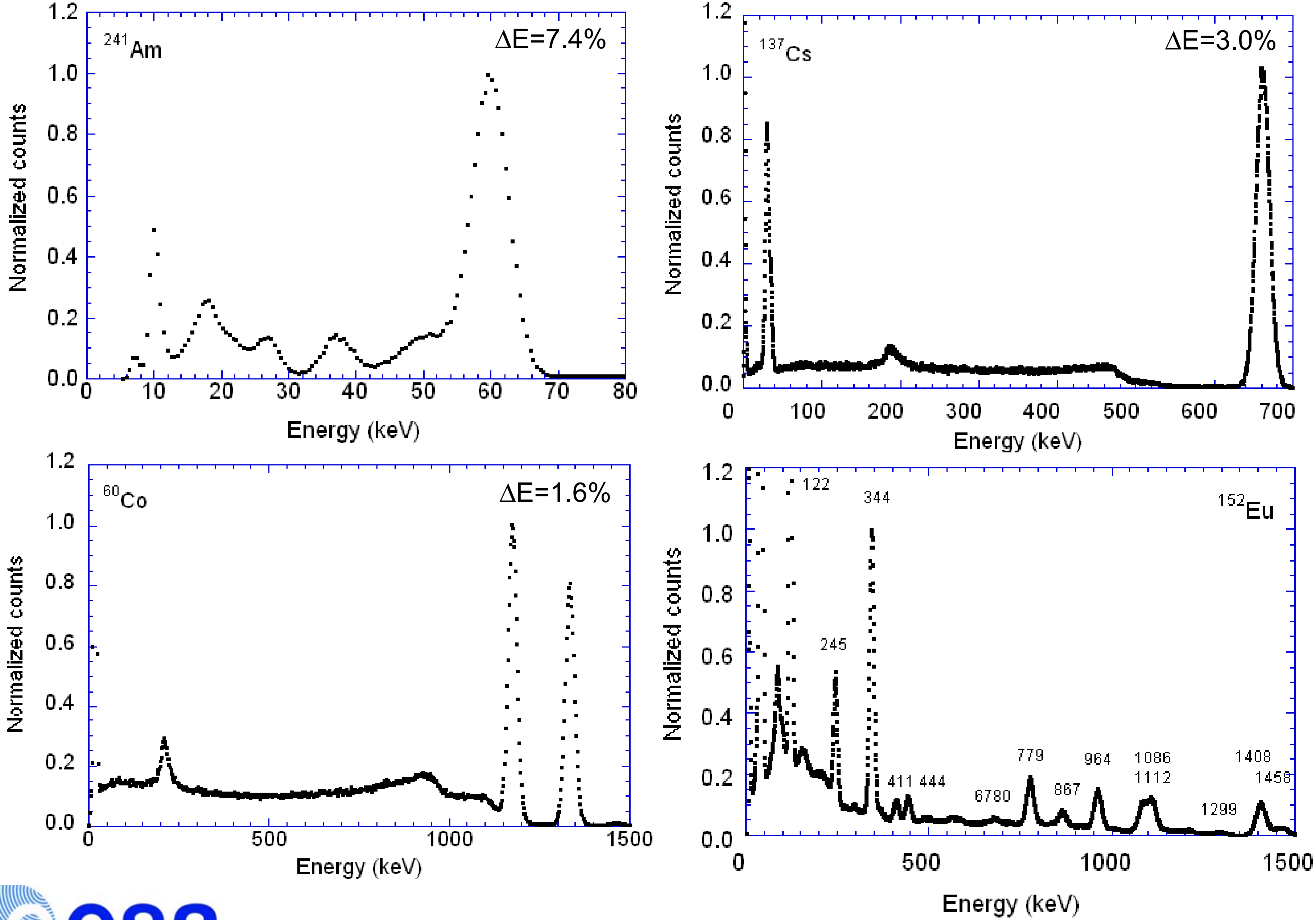


Advanced Concepts and Technology Preparation

$LaBr_3$ crystal growth evolution

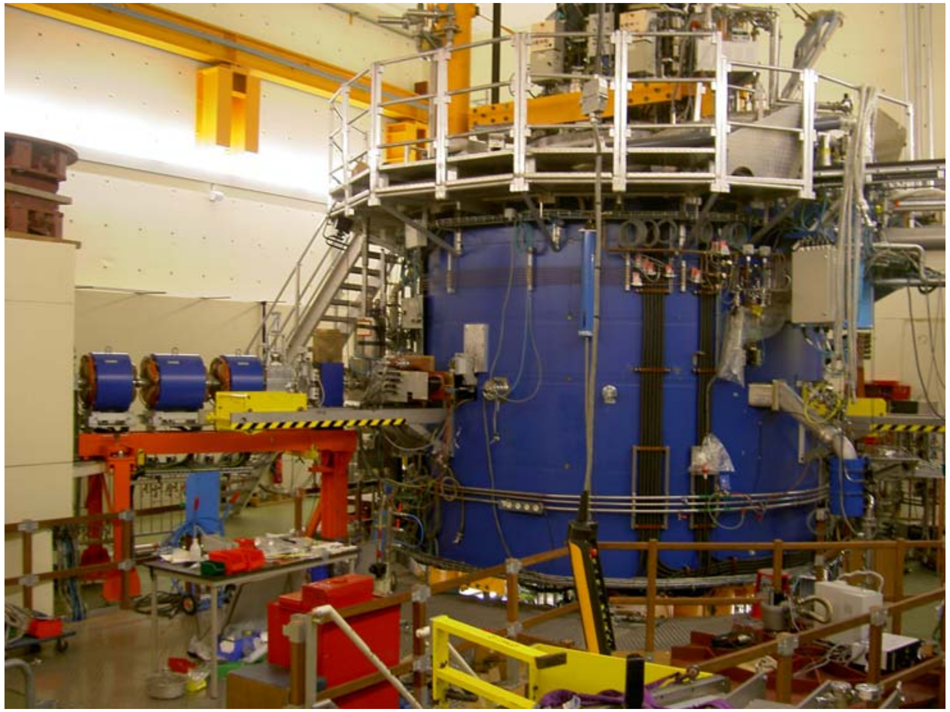
Crystal size Dia. x height cm^2	Volume cm^3	Volume increase factor	$\Delta E/E$ at 662 keV percent
0.3 x 0.3 x 1.0	0.90	1	3.2
1.3 x 1.3	1.73	1.9	3.4
1.9 x 1.9	5.39	6	3.4
2.5 x 2.5	12.27	14	2.8
3.8 x 3.8	43.10	48	2.8
5.1 x 5.1	103.0	114	3.0
5.1 x 7.6	155.2	172	3.0
7.6 x 7.6	347.5	386	2.8
10.2 x 7.6	462.7	514	3.0

3” x 3“ $LaBr_3$ crystal

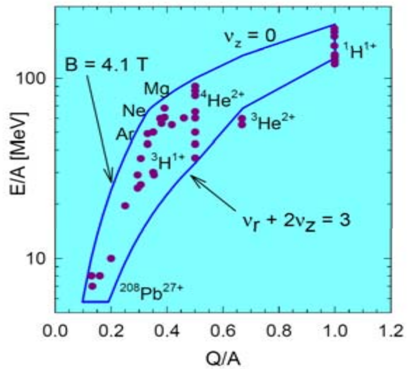


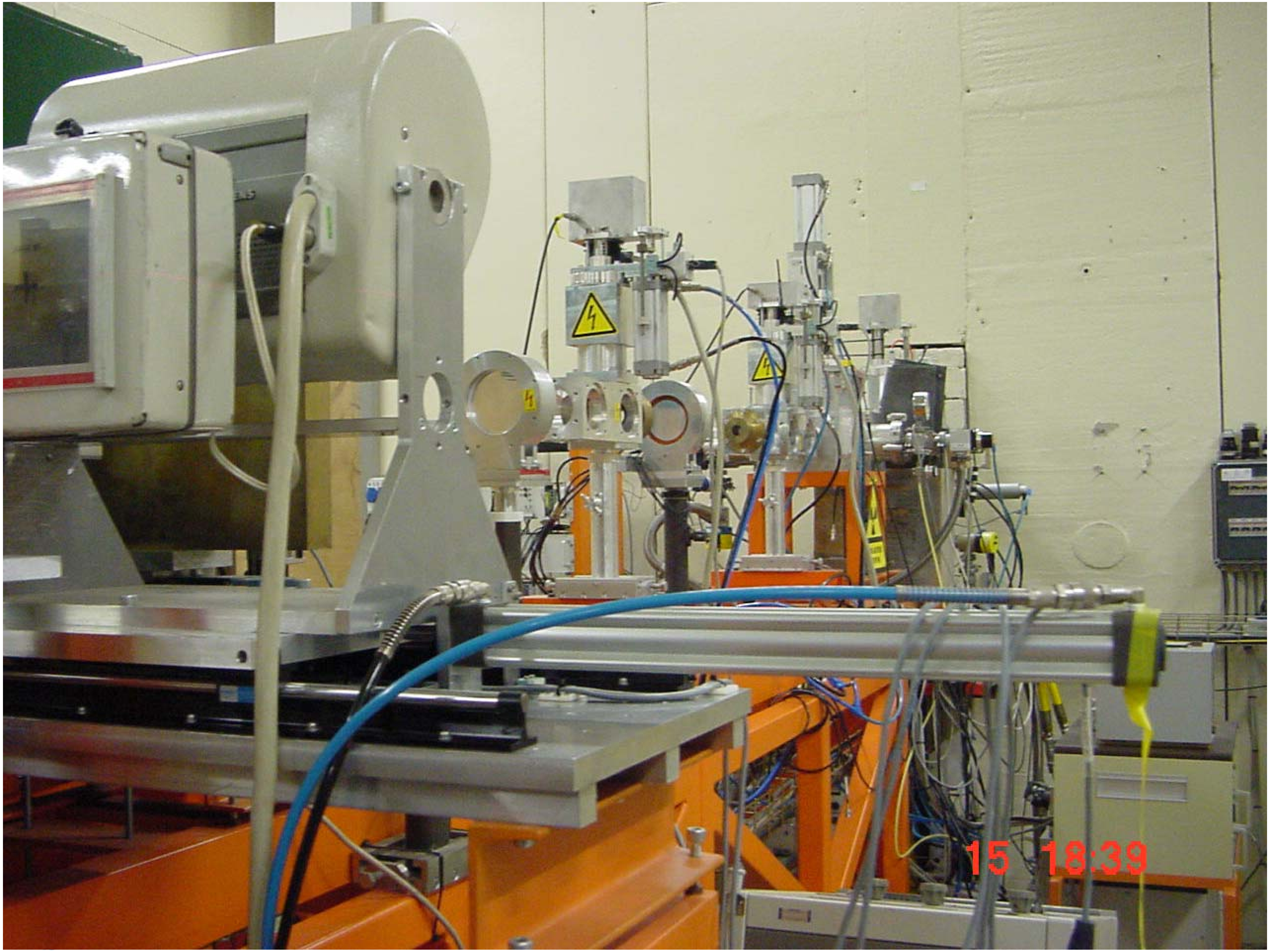
Issue 3. Does resolution get worse with radiation damage?

Assessment of space radiation effects at the Kernfysisch Versneller Instituut (KVI), Groninigen NL



- Protons - up to 200 MeV
- Alphas up to 400 MeV
- Ions up to $E/A = 600(Q/A)^2$
- Beam currents of up to10 nA

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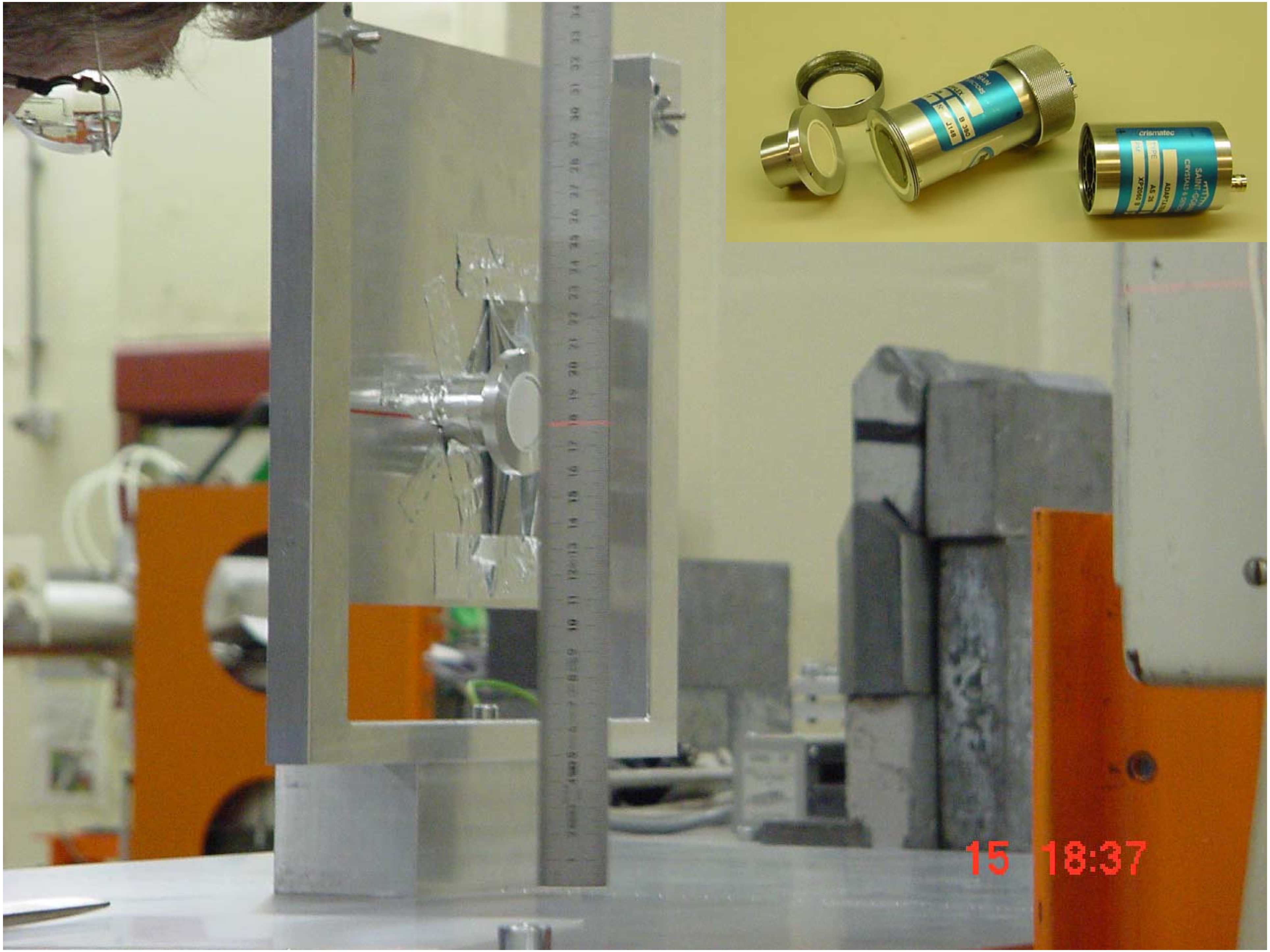
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Irradiations

Four irradiations planned, Incident proton beam will be modified to represent generic SEP spectrum with total fluences:

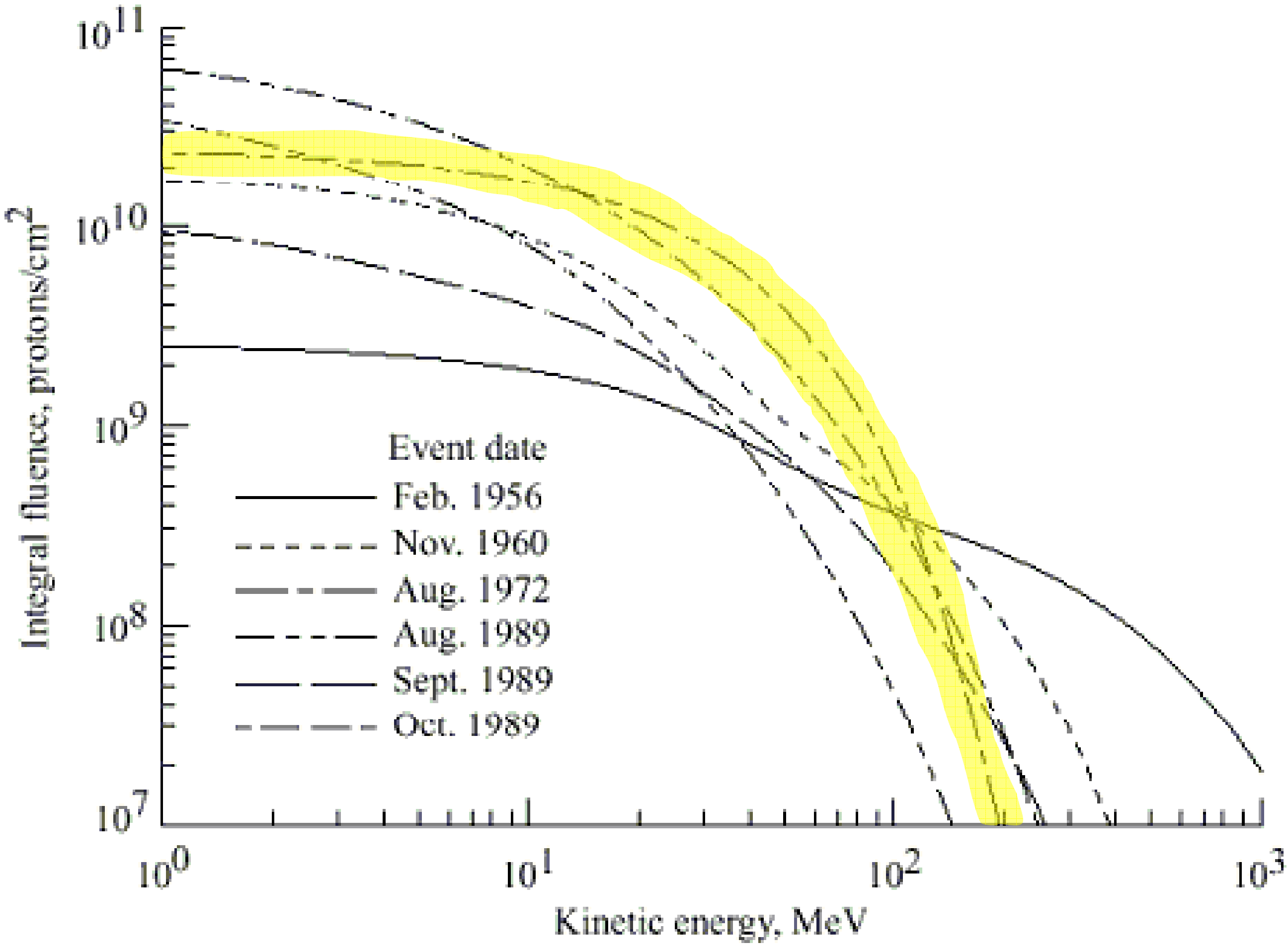
1. 10^{9} proton cm^{-2}
2. 10^{10} proton cm^{-2}
3. 10^{11} proton cm^{-2}
4. 10^{12} proton cm^{-2}

The crystals were tested before and after irradiations.

Simulating the energy spectrum

Using the August 1972 event as baseline

- Fluence 2 x 10^{10} protons cm^{-2} (>10 MeV) – reasonable chance of getting one at Mercury
- Spectrum covers high and low energy bands



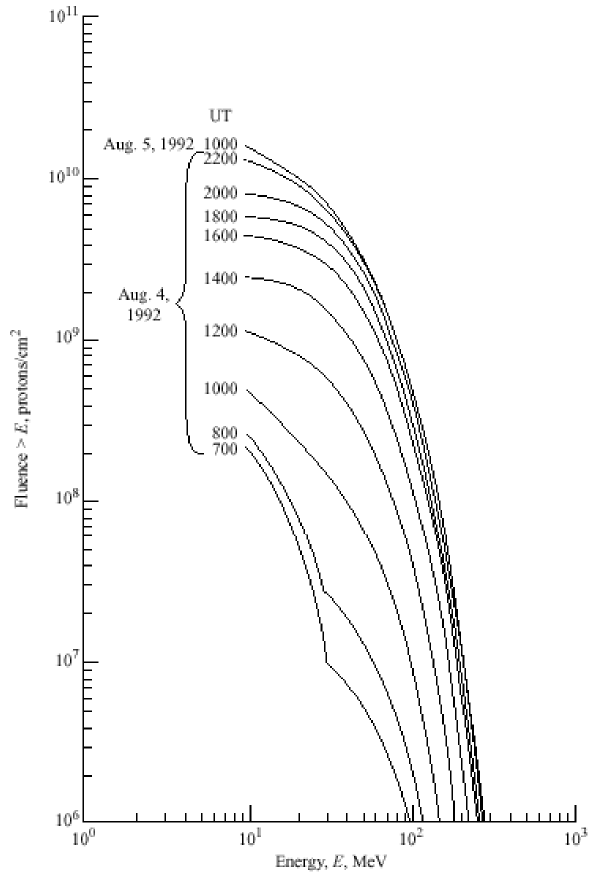
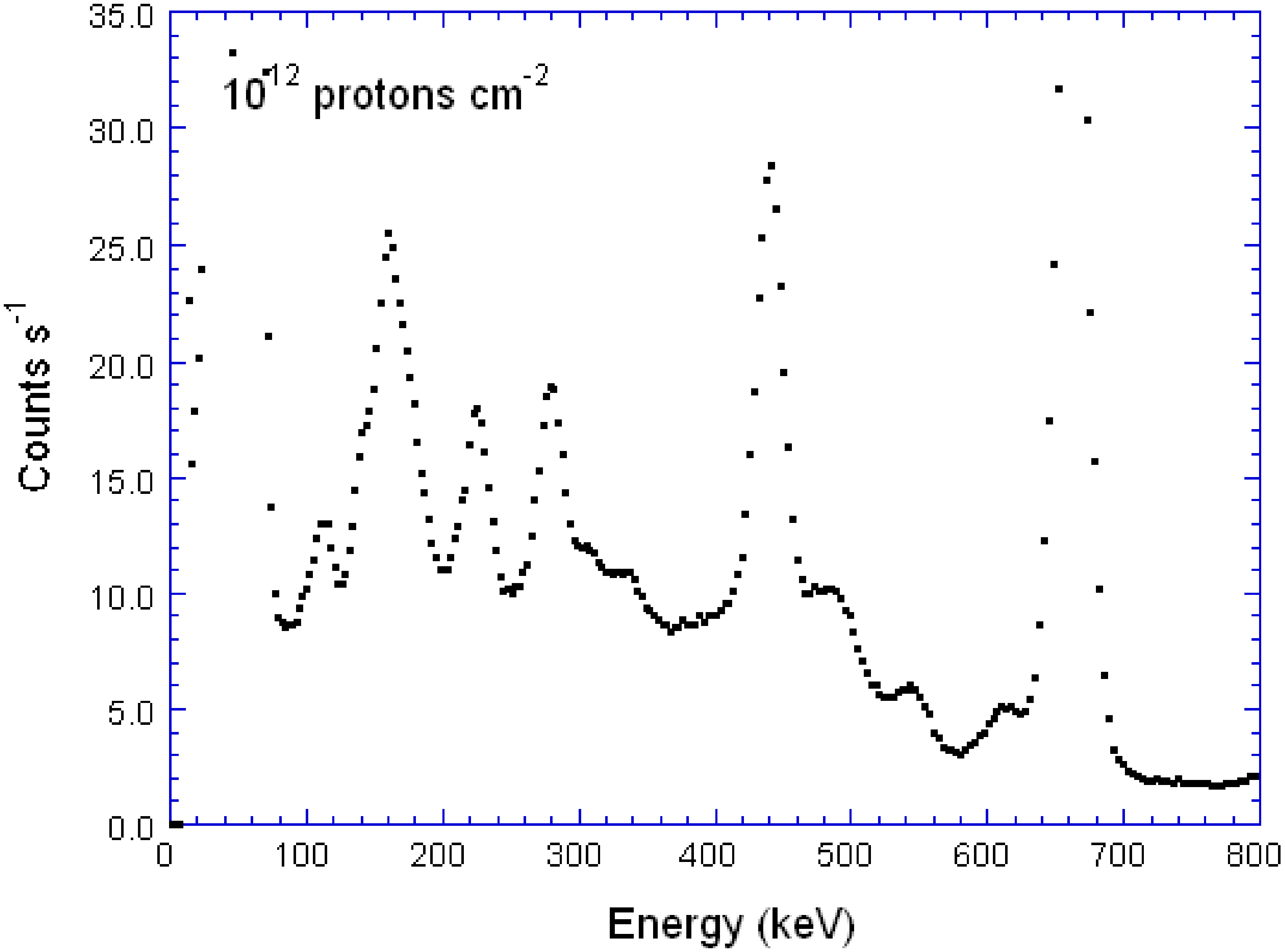


Figure 1. Fluence from August 1972 solar event as function of time and energy.

Wilson et al., NASA Langley (1997)

Issue 3. Does resolution get worse with radiation damage?



Summary resolution results

before irradiation

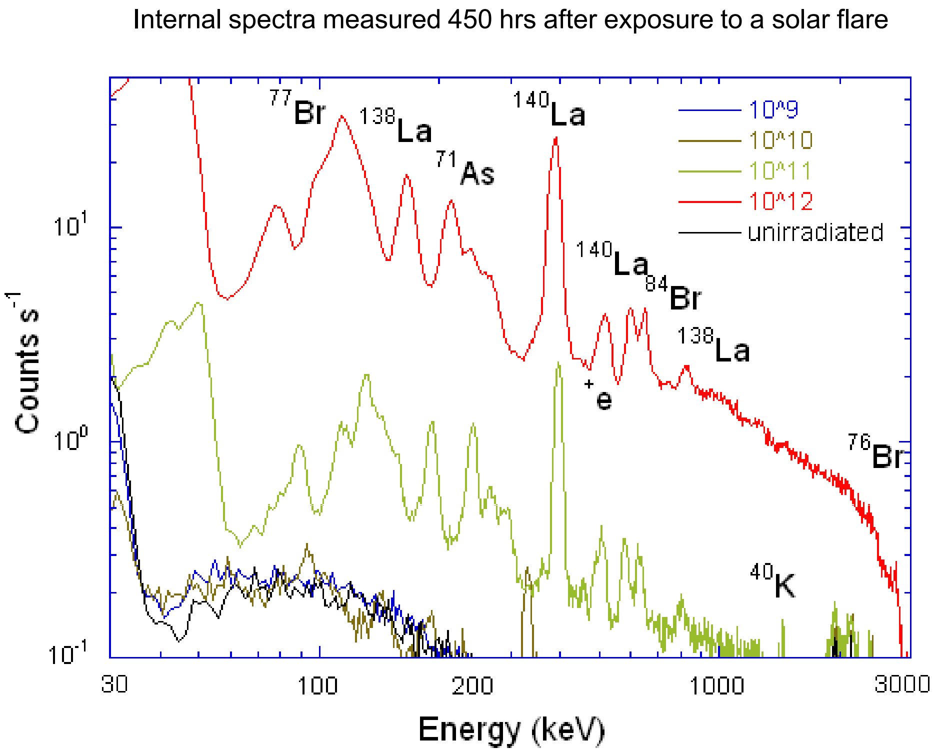
Det no.	Fluence protons cm^{-2}	60	662	1173	1332
		Energy (keV) FWHM resolution %			
J149	0	10.59	2.78	2.04	1.73
J150	0	12.01	3.28	2.58	2.42
J146	0	10.99	3.07	2.40	2.18
J148	0	10.62	2.95	2.23	2.06
J147	0	11.04	3.05	2.37	2.23

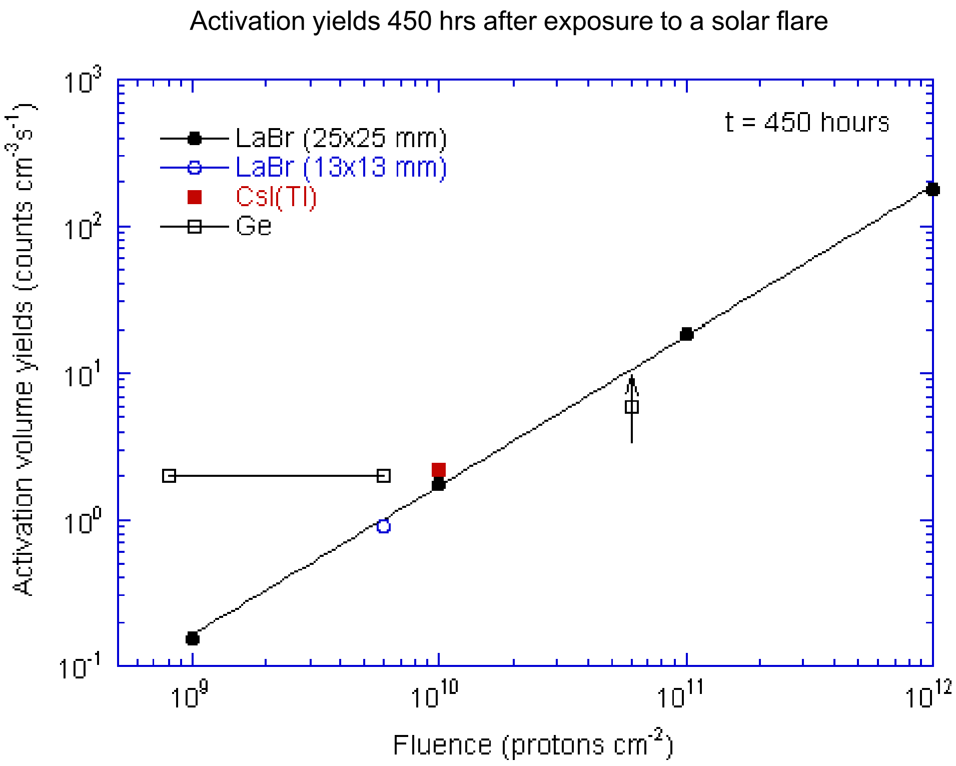
after irradiation

		60	661	1173	1332
J149	0	10.26	2.52	1.76	1.63
J150	10^9	12.10	2.80	2.16	1.97
J146	10^{10}	10.59	2.70	2.07	1.75
J148	10^{11}	11.51	2.75	1.85	1.79
J147	10^{12}	12.06	3.30	2.69	2.67

Issue 4. Activation

Measurements taken 450 hours after exposure





ISS long duration exposure tests

Four crystals (~1cm^3) delivered to Delft for characterization prior to delivery to IKI, then to the ISS

Four scintillators were delivered by ESA and Saint-Gobain for characterization of their properties.

$LaBr_3:Ce^{3+}$

$LaCl_3:Ce^{3+}$

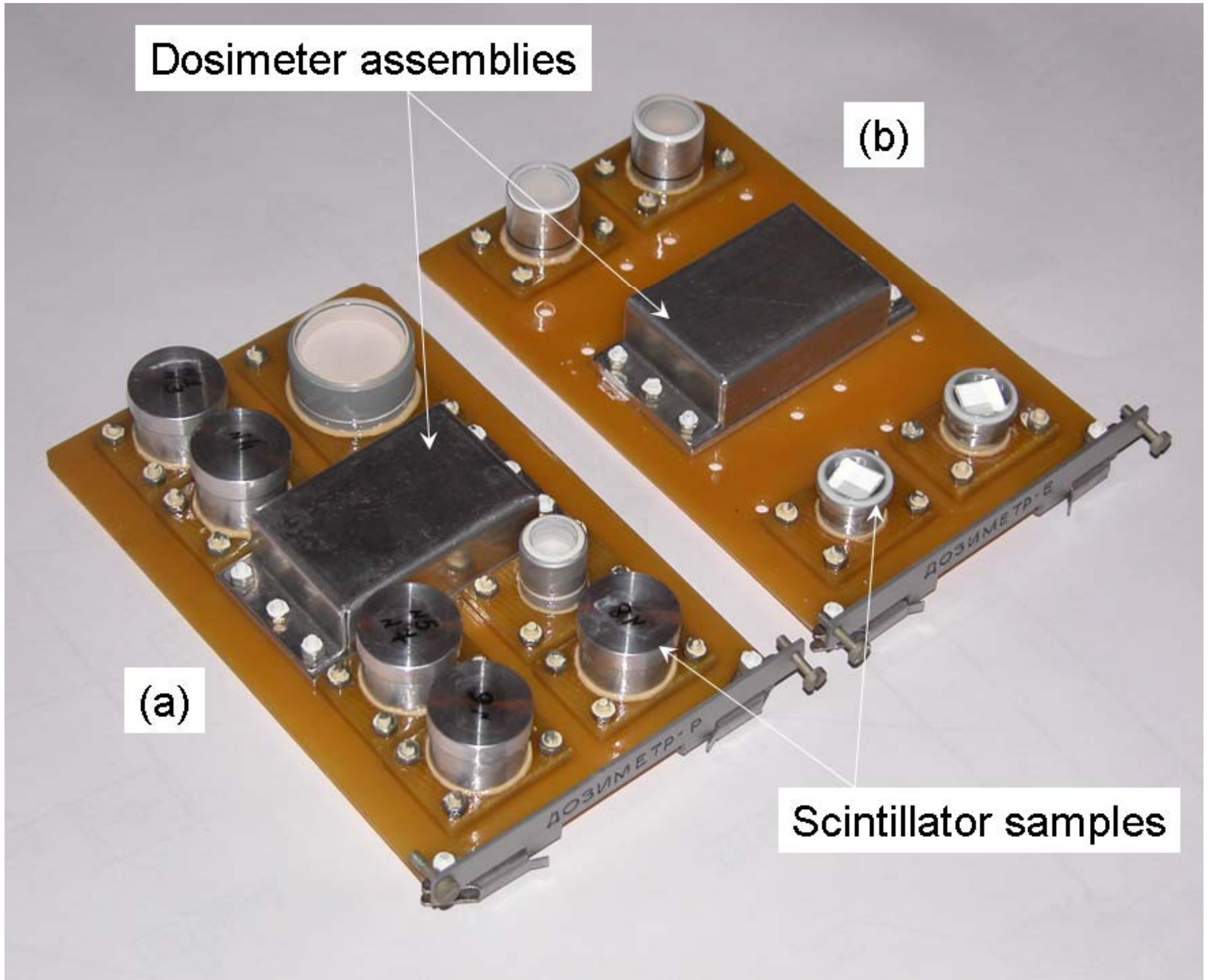
$(Lu,Y)SiO_5:Ce^{3+}$ (LYSO)

$LuAlO_3:Ce^{3+}$ (LuAP)

The following pre-flight measurements were made:

- recording of the X-ray excited emission spectrum
- recording of the X-ray excited afterglow
- recording of ^{137}Cs gamma ray pulse height spectra with 3 μs shaping time
- recording of ^{241}Am gamma ray pulse height spectra with 3 μs shaping time
- recording of the intrinsic activity

In-situ measurements on the ISS



Board 1 (right)
$(LuAl)O_3:Ce^{3+}$;
$LaBr_3:Ce^{3+}$;
$(LuY)SiO_5:Ce^{3+}$; $LaC1_3:Ce^{3+}$
(ESA/TUD Netherlands)

Board 2 (left)
$(Lu_{0.5}Y_{0.5})AlO_3:Ce^{3+}$;
$(Lu_{0.7}Y_{0.3})AlO_3:Ce^{3+}$;
$(Lu_2SiO_5):Ce^{3+}$;
$(Lu_2SiO_5):Ce^{3+}$;
$(YAlO_3):Ce^{3+}$;
$CsI:Tl^{+}$;
$NaI:Tl^{+}$;
(Russia, VIMS)

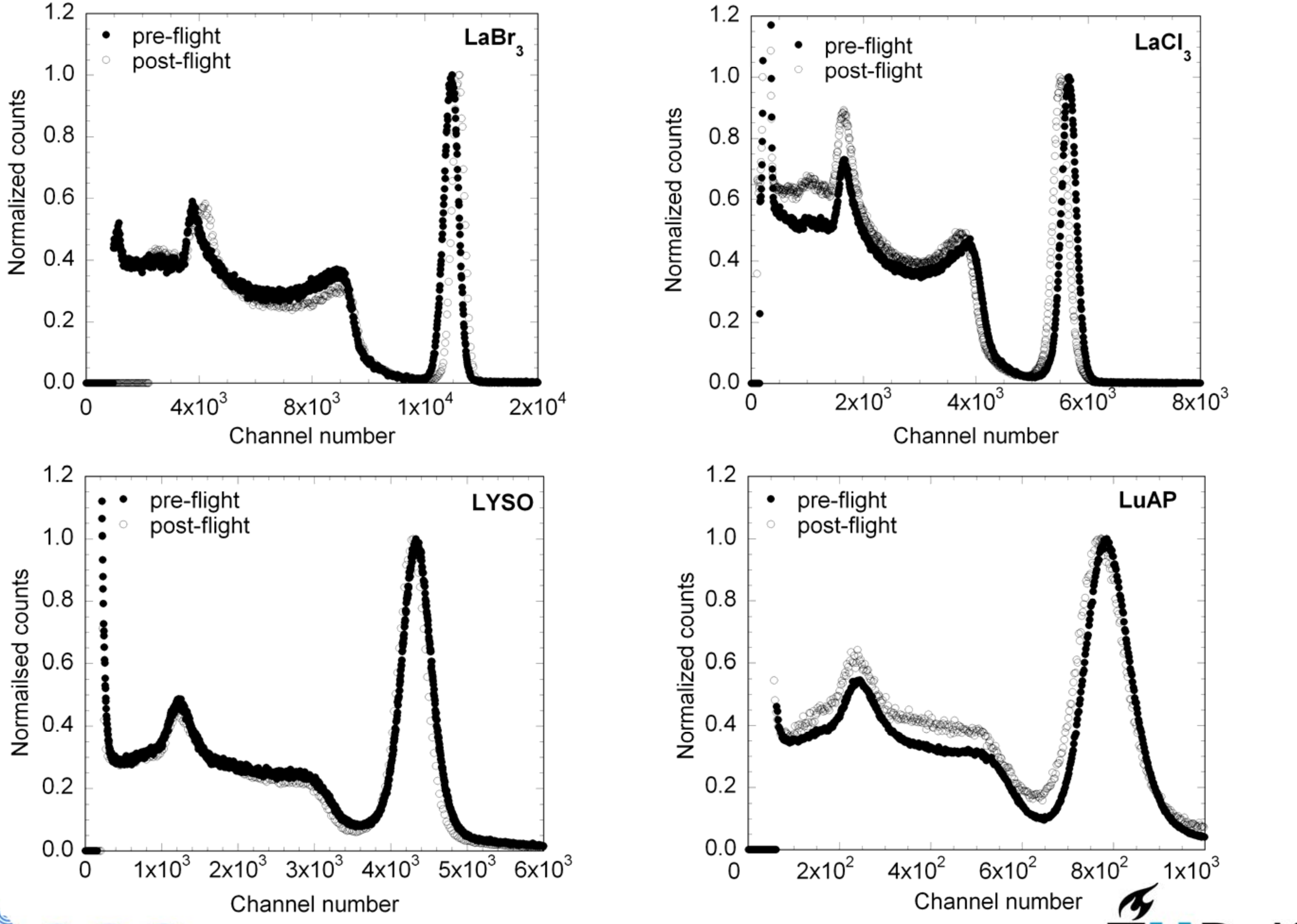
Solid state thermo-luminescent dosimeters DTG-4 (Russia, IMBP)
Plastic track detectors TASTRACK (Russia, IMBP + TASL, UK)

Courtesy A. Rogozhin

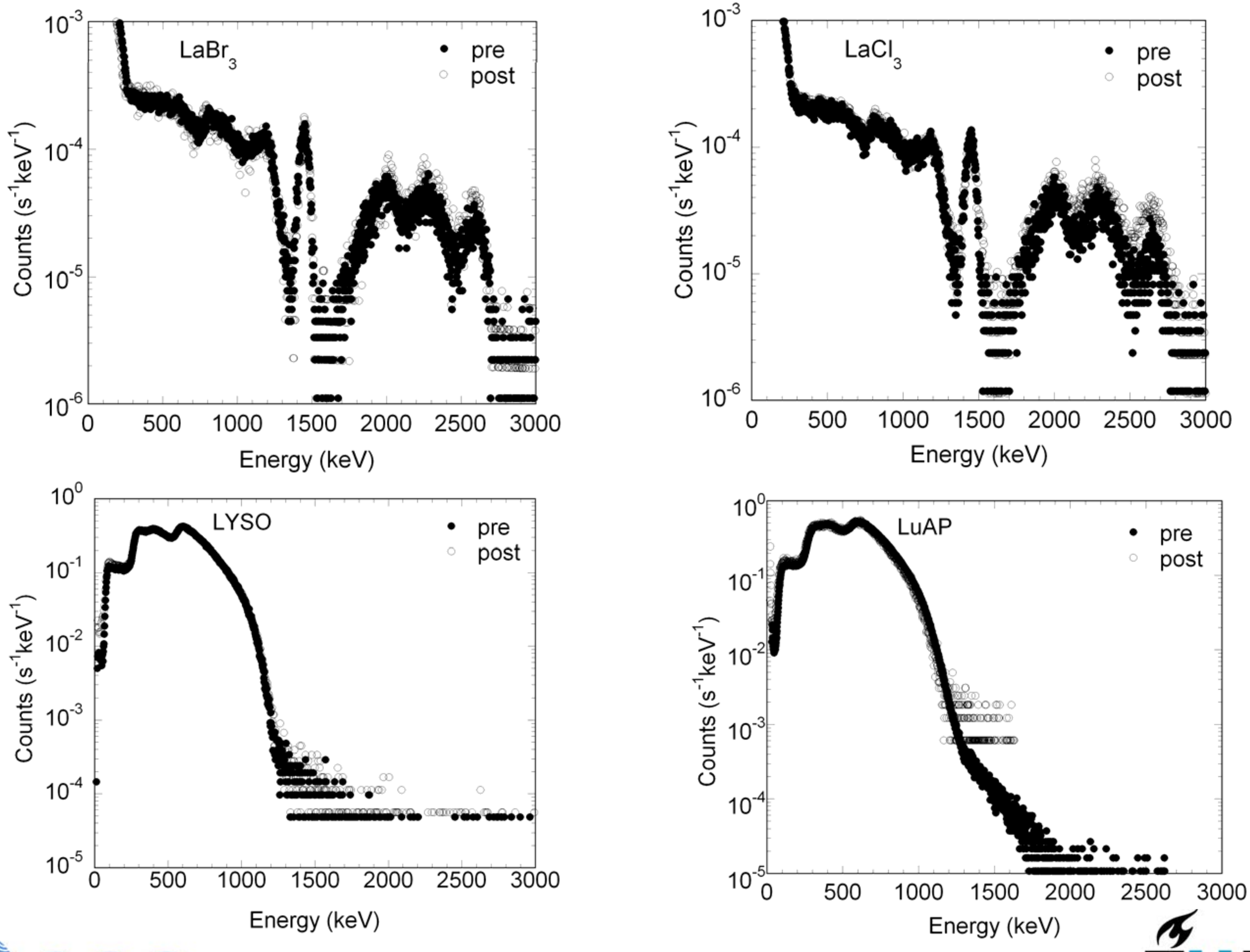
The internal block in position on the ISS

The external block in position on the ISS

Spectral response – pre and post flight



Internal activation – pre and post flight



Summary

Table 1. Measured photoelectron yields and intrinsic activities of all ESA samples. The pre-launch measurements took place in April, 2004 and the post flight in February, 2008. The quick-look characterization immediately after recovery showed essentially the same results. The activities were measured inside a lead castle.

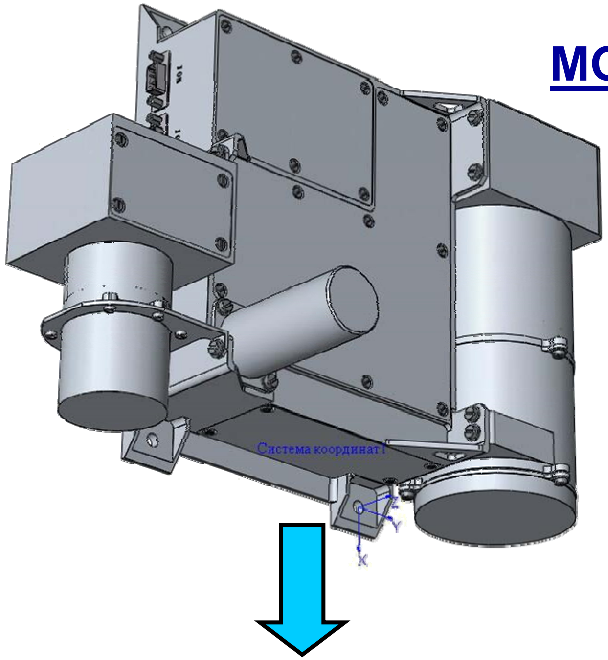
Sample	**Photoelectron yields**				**Intrinsic Activity**	
	Pre-launch		Post Flight		Pre-launch	Post Flight
	Yield (phe/MeV)	ΔE (%)	Yield (phe/MeV)	ΔE (%)	Rate (Bq cm^{-3})	Rate (Bq cm^{-3})
$LaBr_3:Ce^{3+}$	13900	4.9	12850	3.9	0.50	0.52
$LaCl_3:Ce^{3+}$	6300	5.2	5617	5.7	0.52	0.61
$(Lu,Y)SiO_5:Ce^{3+}$(LYSO)	4340	9.9	4283	9.7	227	230
$LuAlO_3:Ce^{3+}$ (LuAP)	790	13.1	772	14.4	285	286

Table 2. The pre and post launch intrinsic activities measured at various times before and after launch. The integral rates were assessed over the energy range 50 keV to 3000 keV.

Sample	Intrinsic activity 50 keV-3000 keV (Bq)			
	Pre launch Delft	Post landing VIMS +1 day	ESTEC +10 days	Delft +100 days
$LaBr_3$	1.05	1.25	1.05	1.03
$LaCl_3$	0.85	1.19	1.03	0.98
LuAP	279	311	313	286
LYSO	227	289	231	230

Bottom line – no change

MGNS: main characteristics



Goal: Gamma and neutron mapping of Mercury surface

Science objectives:

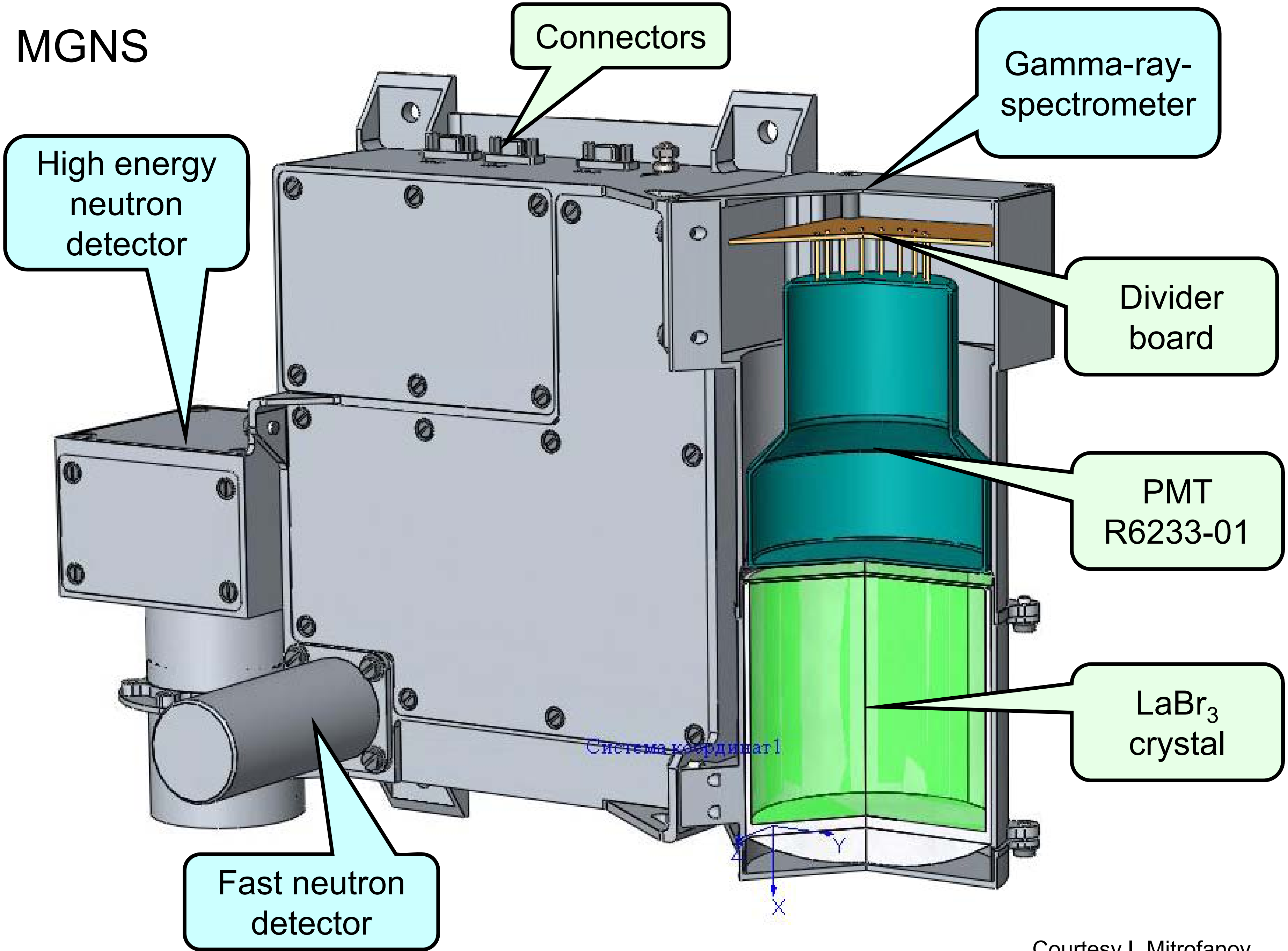
- The mapping of water content in Mercury subsurface
- The mapping of Mercury soil composition

Parameters:

PARAMETER	VALUE
Mass	5.2 kg
Power	5 W
Volume	-
Surface Resolution	400 km
Minimal time resolution	2-4 sec
Energy range, neutrons	Multi energy bands covering 10^{-3} eV – 15 кeV
Energy range, gamma	300 keV – 10 MeV
Energy resolution, gamma	3% at 660 keV
Detectors	3He – proportional counters, stilben crystal, $LaBr_3$ crystal
Temperature range	(-20C, 40C)
Position	ESA: BepiColombo
Altitude	400 km – 1500 km

Courtesy I. Mitrofanov

MGNS

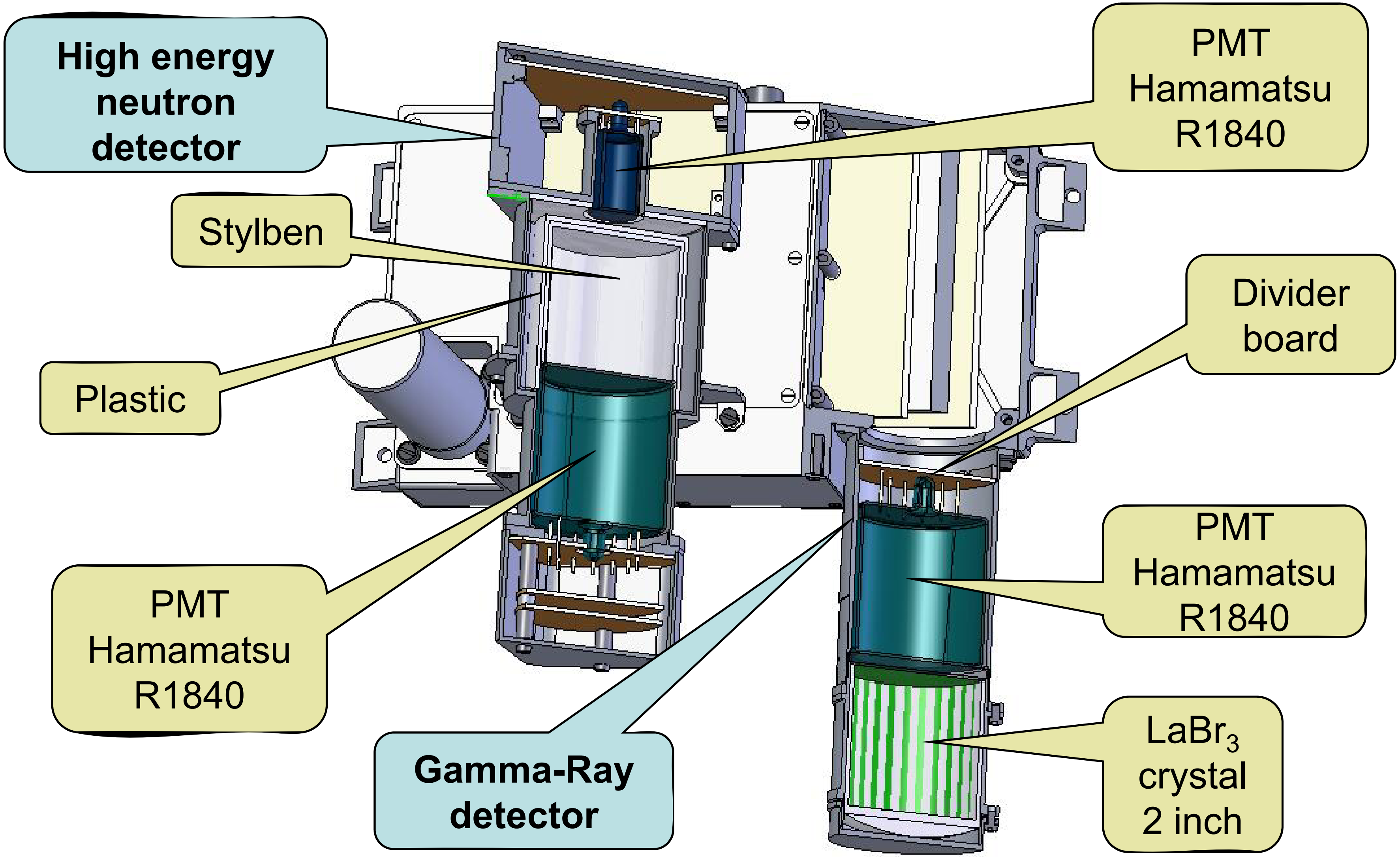


Courtesy I. Mitrofanov

The immediate future - Phobos Grunt

Courtesy I. Mitrofanov

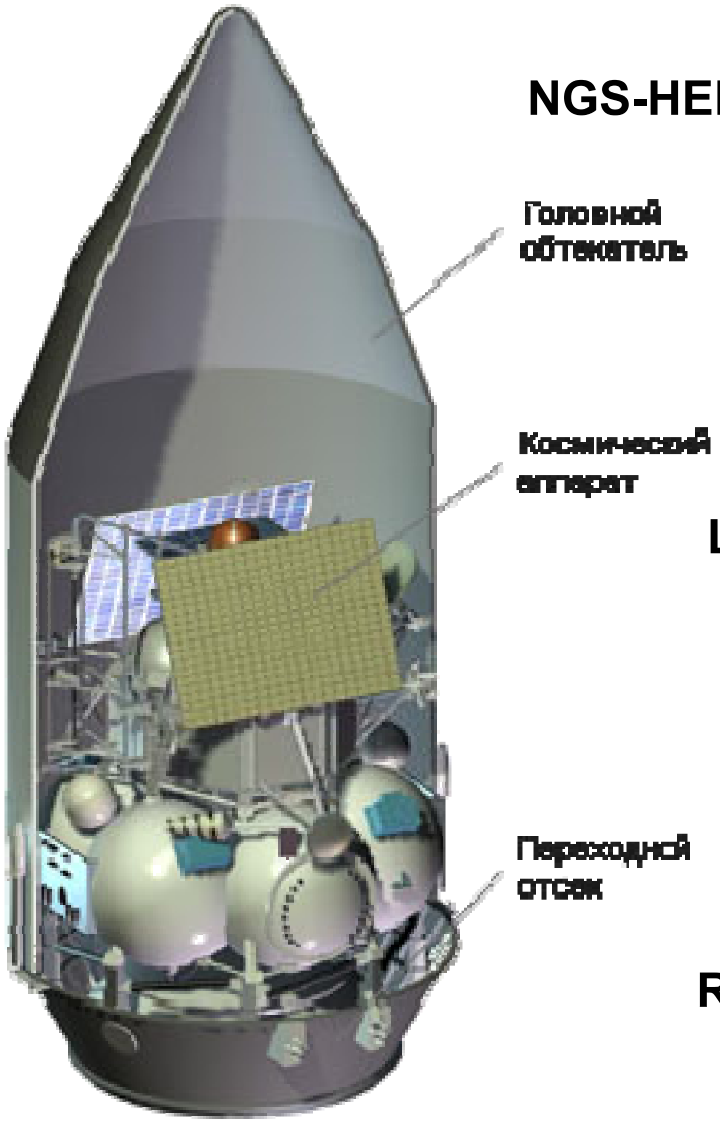
NGS-HEND2 mechanical design: high energy neutron detector and gamma-ray spectrometer



Courtesy I. Mitrofanov

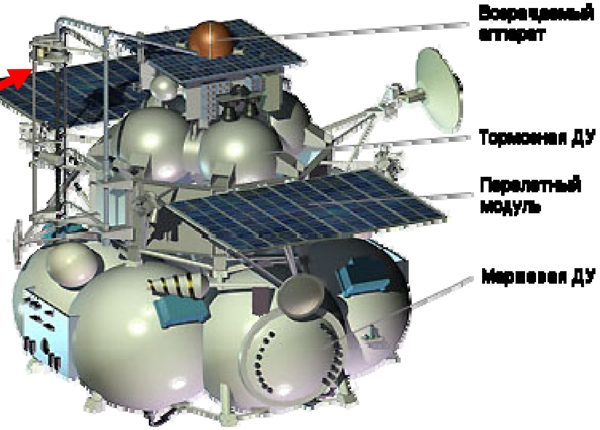
Phobos Grunt

КА “Фобос-Грунт"

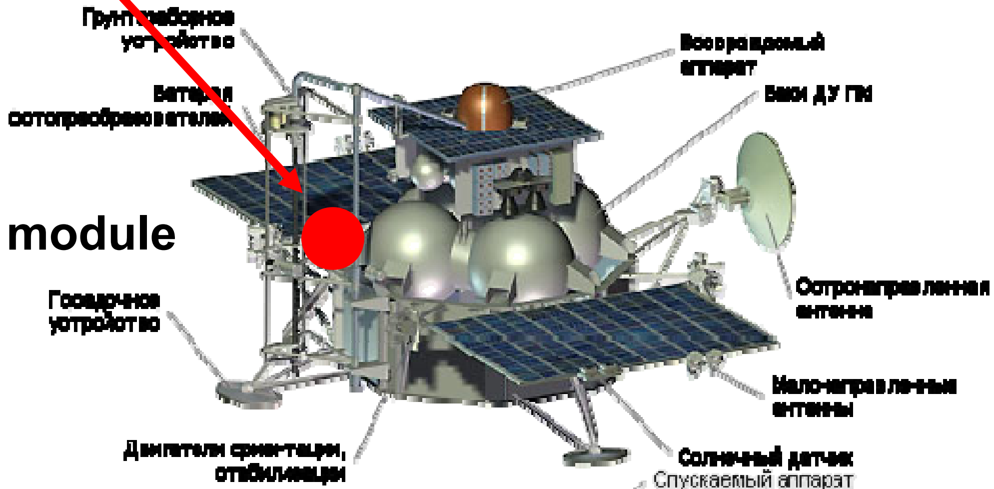


NGS-HEND2

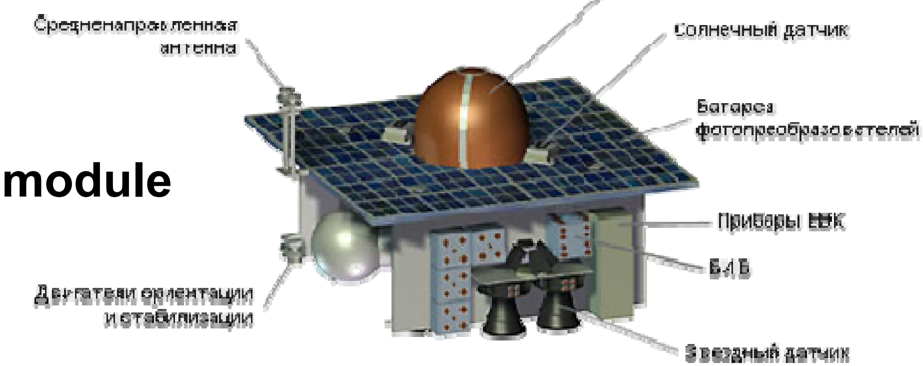
Cruise module



Landing module



Returned module



Courtesy I. Mitrofanov

CdZnTe growth program

In support of future X-and Gamma-ray astronomy missions

Problem

CZT is increasingly used in space applications

Essentially single non-European vendor

End user licence required

Market dominated by Medical and Homeland security applications

CdZnTe use in Space

Current Missions

INTEGRAL - In terms of current missions, 16,384 crystals of CdTe were used to form the focal plane of the ISGRI instrument. The vendor was Acrorad (Japan).

Solar X-ray Spectrometer (SOXS) employed CZT in its high energy focal plane. The vendor was eV products

SWIFT - The Burst Alert Telescope (BAT) onboard Swift utilizes 32,768 crystals of CdZnTe. The vendor was eV Products.

Future Missions

Chandrayaan-1 is an Indian lunar mission with ESA support due for launch in 2008. A proposed X-ray instrument initially baselined 1000 CdZnTe crystals. The procurement cost from eV Products was USD 200,000. The cost of 1000 CdTe crystals from Acrorad of Japan was USD 33,000 (2 month delivery).

EXIST - X-ray mission that will use a large detection plane composed of 320 elements of CdZnTe. The detection plane is currently under development. The vendor is eV products

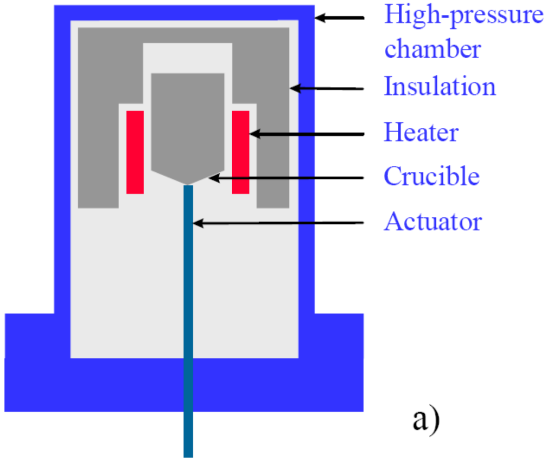
MIRAX - Galactic Bulge Transient Monitor mission will use 27 cross-strip CZT detectors. The vendor is eV products.

Simbol-X - High energy detector consists of 37 CZT modules.

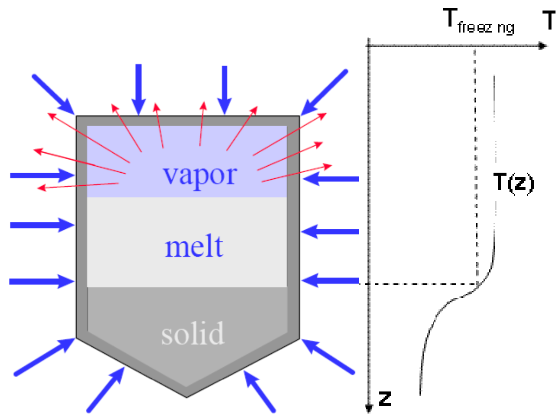
Constellation X - Over 1500 cm^2 of CdZnTe is currently base-lined. The vendor will be eV products

XEUS – Combined CCD/CZT modules proposed.

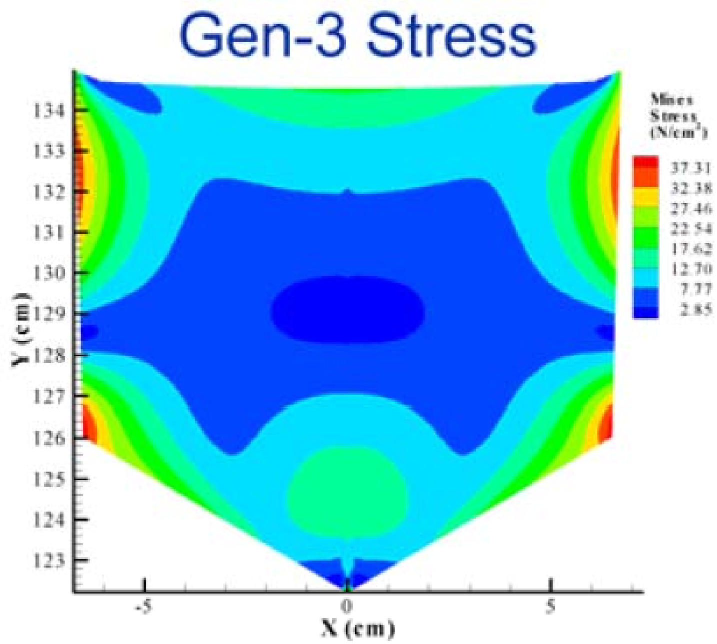
CdZnTe growth High Pressure Bridgman



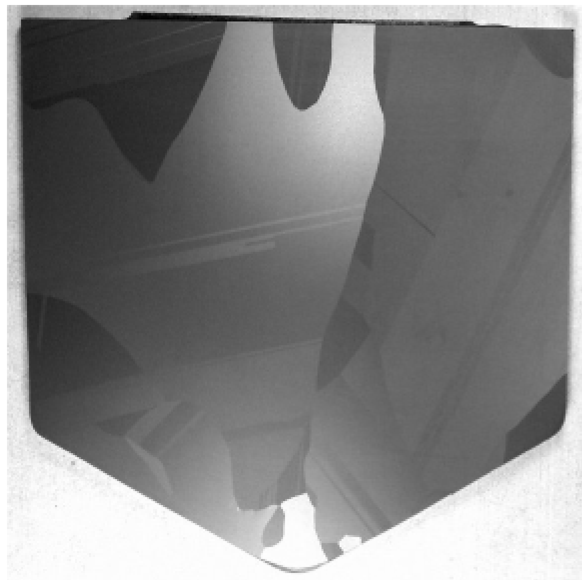
a)



b)



Current xtal size limited to 15x15x7.5 mm^3

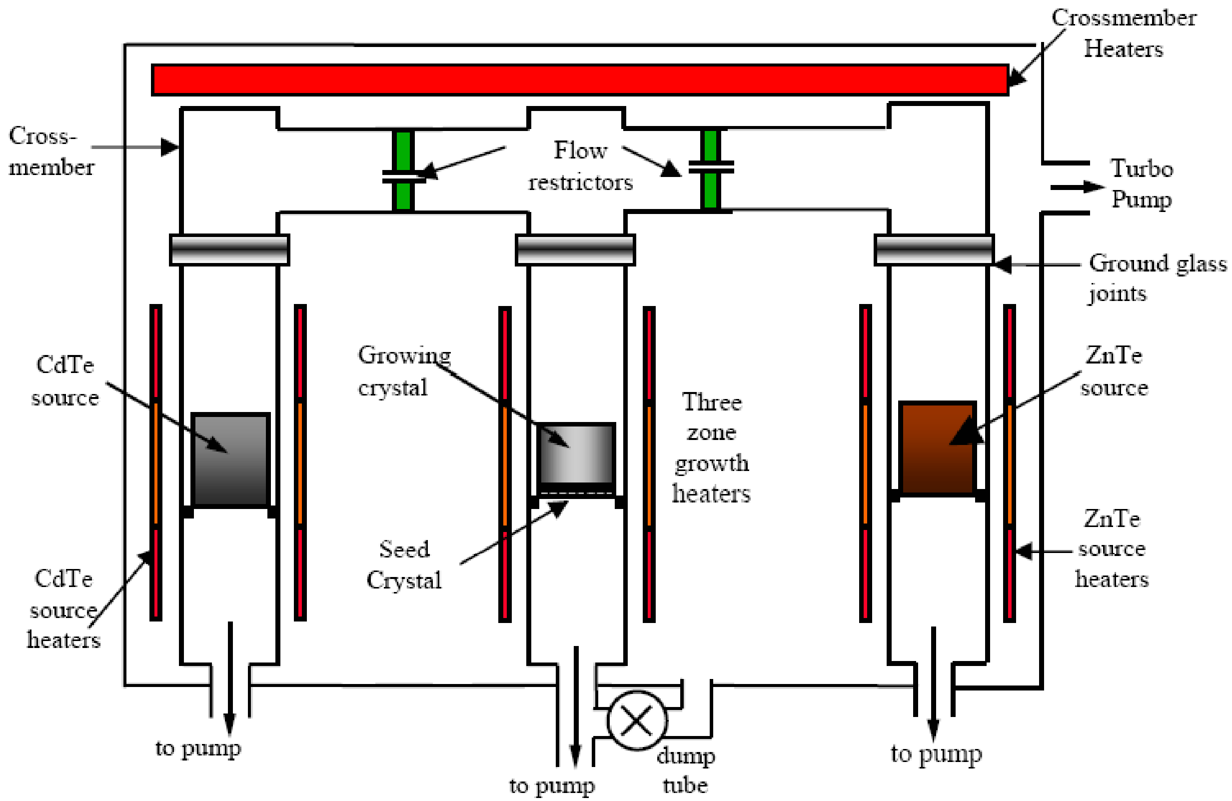


Multi-Tube Physical Vapour Transport Method

Durham Scientific Crystals, Patents - Europe (covering Germany, France, UK and Italy) : EP1019568 United States of America : US 6,375,739, Japan : PCT/GB98/02224

Advantages over HPB

- Low pressure
- In-situ compounding
- Lower thermal stresses
- Higher purity
- Improved stoichiometry
- Larger single crystals
- No self poisoning
- Reusable quartzware
- Low cost



Schematic of new MTPVT system for the growth of CZT

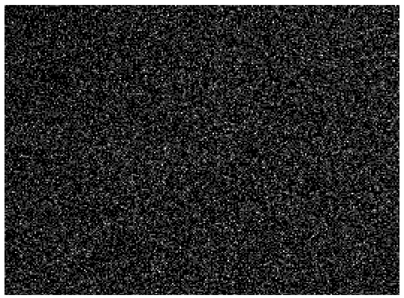
ITI Phase I – Bench top simulator

Function: To provide the necessary temperature profile for crystal growth

Quartzware

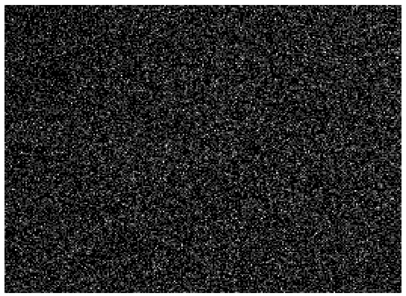
Furnace
Enclosure

Cadmium



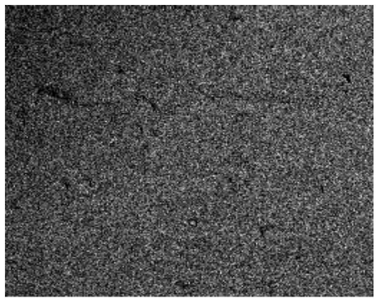
2 mm

Tellurium



2 mm

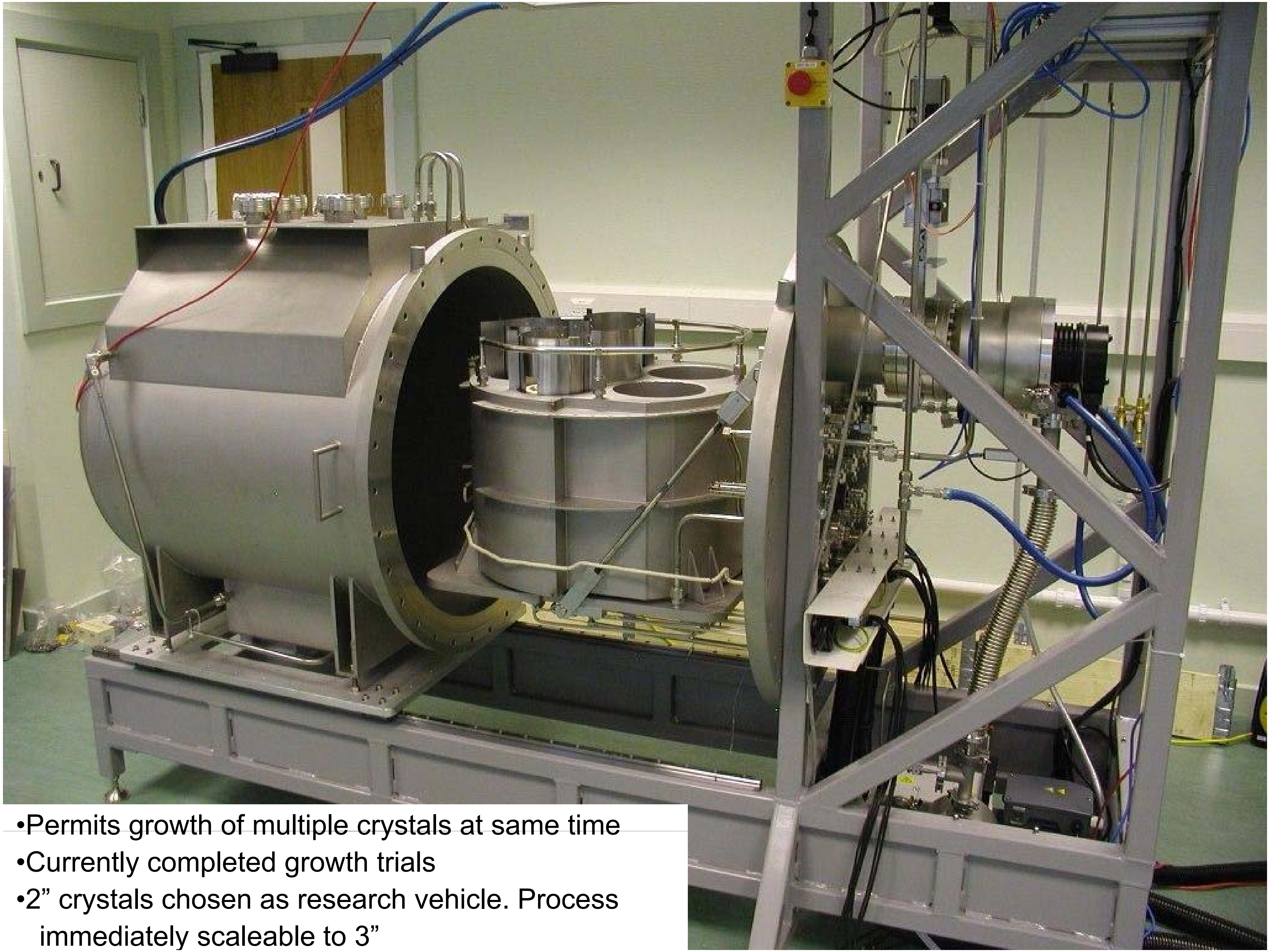
Zinc



2 mm

EDAX


Phase II - industrialization

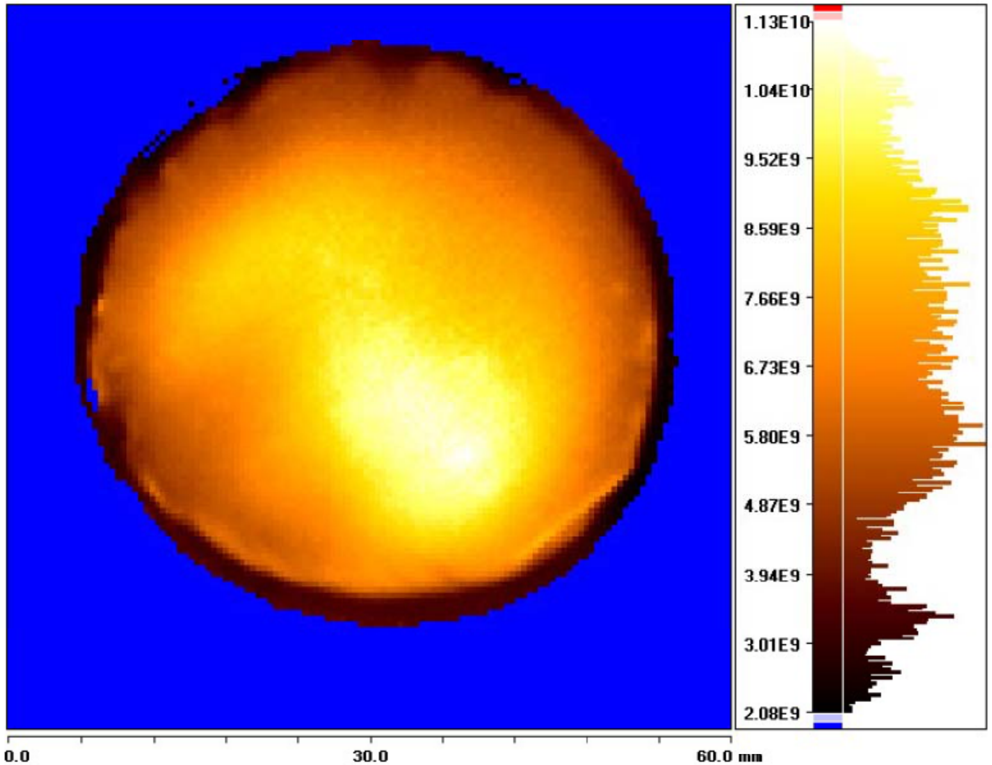


- Permits growth of multiple crystals at same time
- Currently completed growth trials
- 2” crystals chosen as research vehicle. Process immediately scaleable to 3”

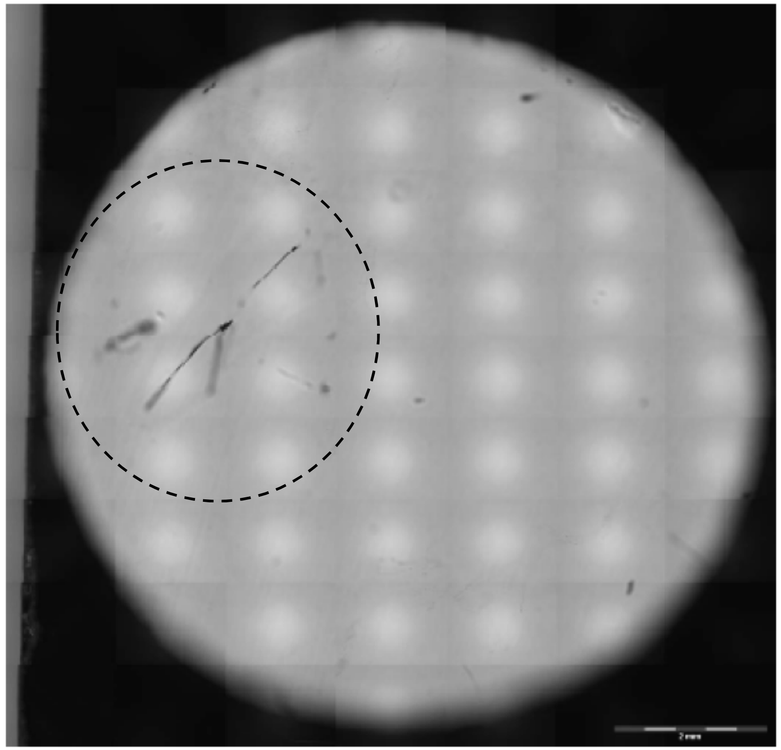
M4_019, 50 mm diameter CZT boule grown in new MTPVT system

Resistivity and IR maps

Mean ρ=6.8 x$10^9\Omega$cm

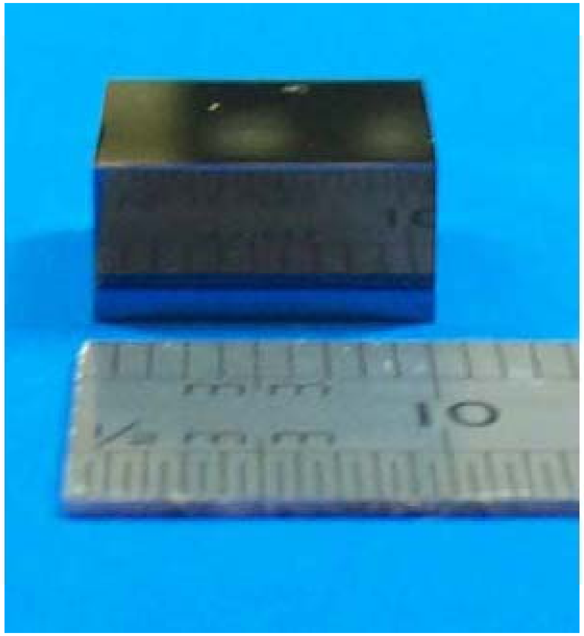


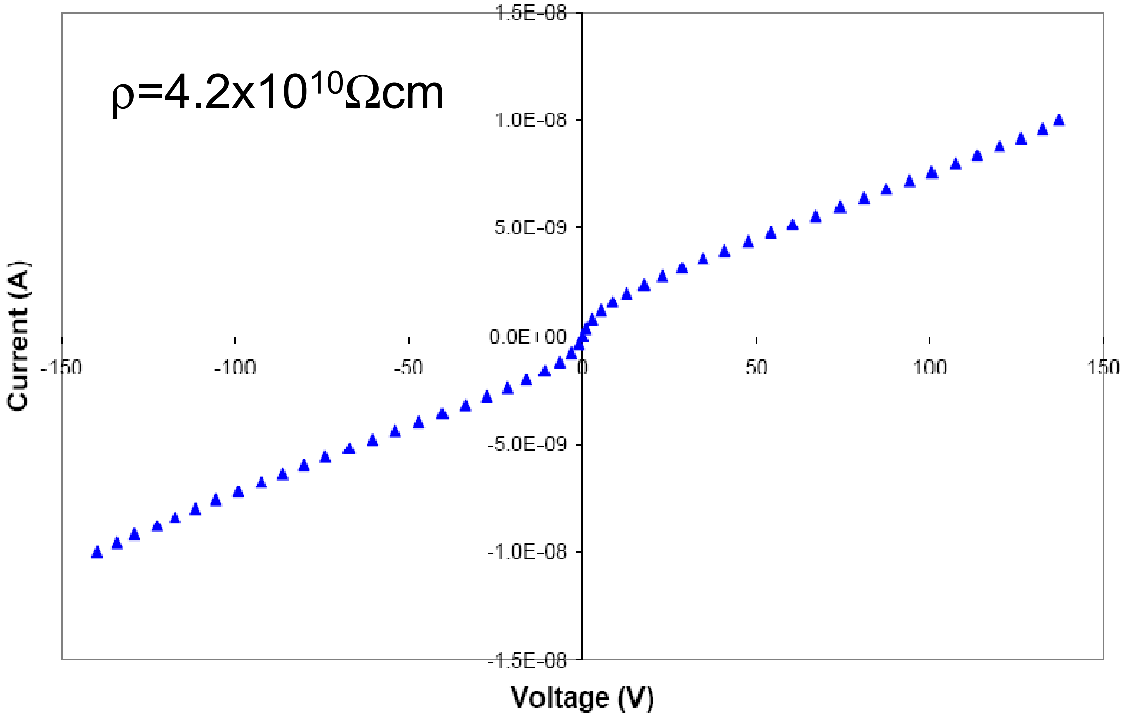
Resistivity map of M4_019



Infra-red microscopy map of M4_019_4

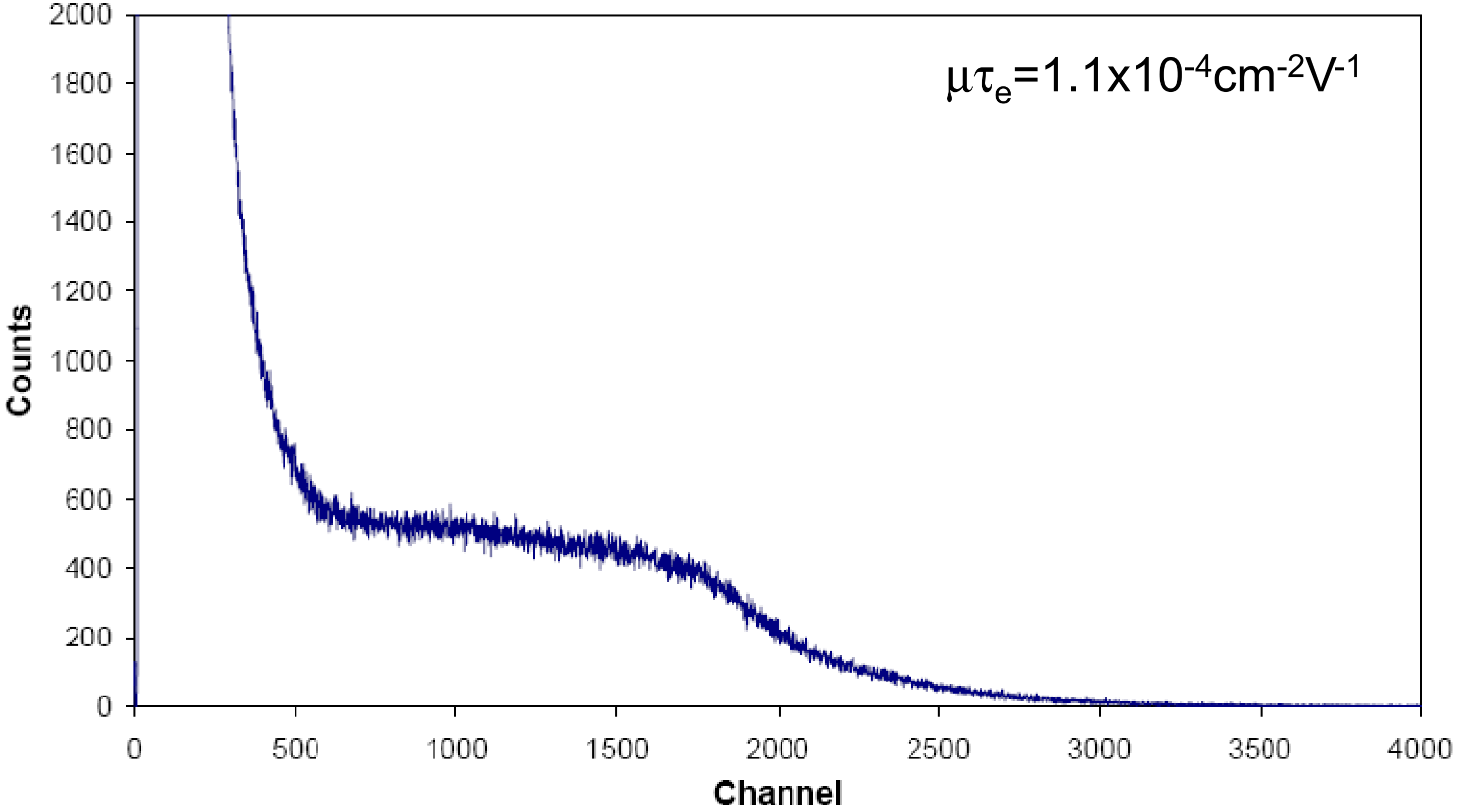
I/V characteristics





Two contact current-voltage measurements for die M4_019_4

Spectral performance ^{57}Co



^{57}Co spectrum at 400V for samples M4_19_4, size 10 x 10 mm

GDMS analysis of impurities in CdTe source materials and grown crystals

Element	Source 1 Conc [ppm wt]	Source 2 Conc [ppm wt]	Crystal 1 Conc [ppm wt]	Crystal 2 Conc [ppm wt
Na	< 0.05	< 0.05	< 0.05	< 0.05
Mg	< 0.005	< 0.005	< 0.005	< 0.005
Al	0.10	< 0.005	< 0.005	< 0.005
Si	0.45	0.02	0.04	0.05
S	0.05	0.07	0.36	0.04
Cl	2.0	0.04	0.08	0.03
K	< 0.05	< 0.05	< 0.05	< 0.05
Ca	0.14	< 0.05	< 0.05	< 0.05
Ti	0.008	< 0.005	< 0.005	< 0.005
V	< 0.005	< 0.005	< 0.005	< 0.005
Mn	< 0.01	< 0.01	< 0.01	< 0.01
Fe	0.03	< 0.005	0.03	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005
Ni	0.04	< 0.005	< 0.005	< 0.005
Cu	3.1	< 0.01	0.43	< 0.01
Zn	< 0.01	< 0.01	Matrix	Matrix
As	< 0.1	< 0.1	0.79	< 0.1
Se	< 0.1	< 0.1	0.47	< 0.1
Br	< 0.05	< 0.05	< 0.05	< 0.05
Ag	0.44	< 0.05	< 0.05	< 0.05
Cd	Matrix	Matrix	Matrix	Matrix
In	Binder	Binder	Binder	Binder
Sn	< 0.05	< 0.05	< 0.05	< 0.05
Sb	< 0.05	< 0.05	< 0.05	< 0.05
Te	Matrix	Matrix	Matrix	Matrix
I	450	< 0.5	14	< 0.5

Before (6N source)

Sample reference	Size (mm)	Resistivity from IV measurement (Ωcm)	μτ (cm^2/V)
M4_19_1	10x10x2	5.4x10^{10}	1.2x10^{-4}
M4_19_2	10x10x2	4.17x10^{10}	1.1x10^{-4}
M4_19_3	10x10x2	4.69x10^{10}	1.2x10^{-4}
M4_19_4	10x10x2	5.4x10^{10}	1.1x10^{-4}
M4_19_4_3	5x5x2	5.4x10^{10}	1.1x10^{-4}
M4_19_4_4	5x5x2	5.4x10^{10}	1.1x10^{-4}

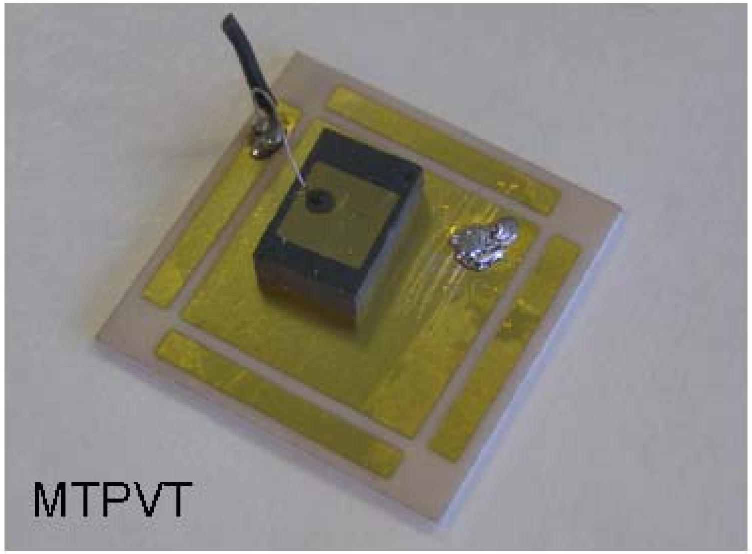
After (7N source)

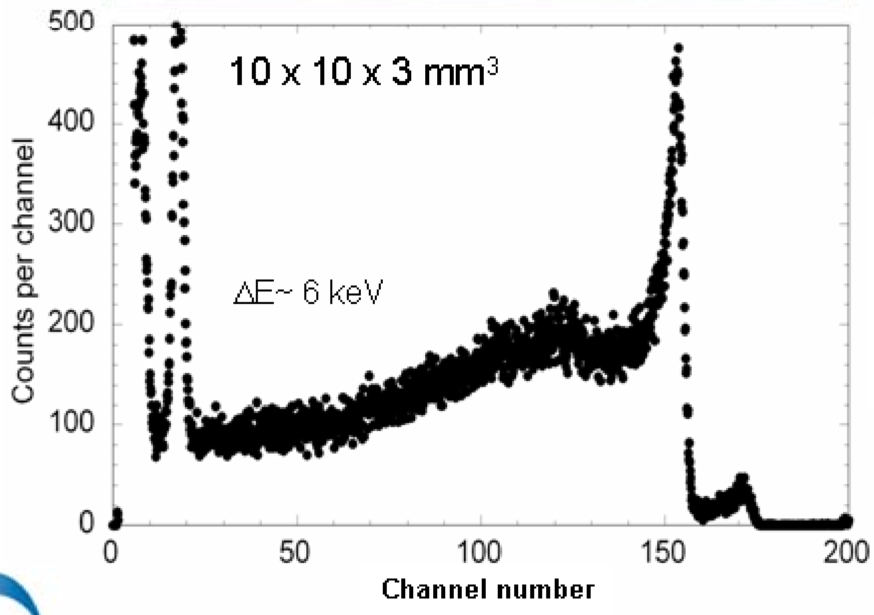
Properties of die from CZT boule M4_019

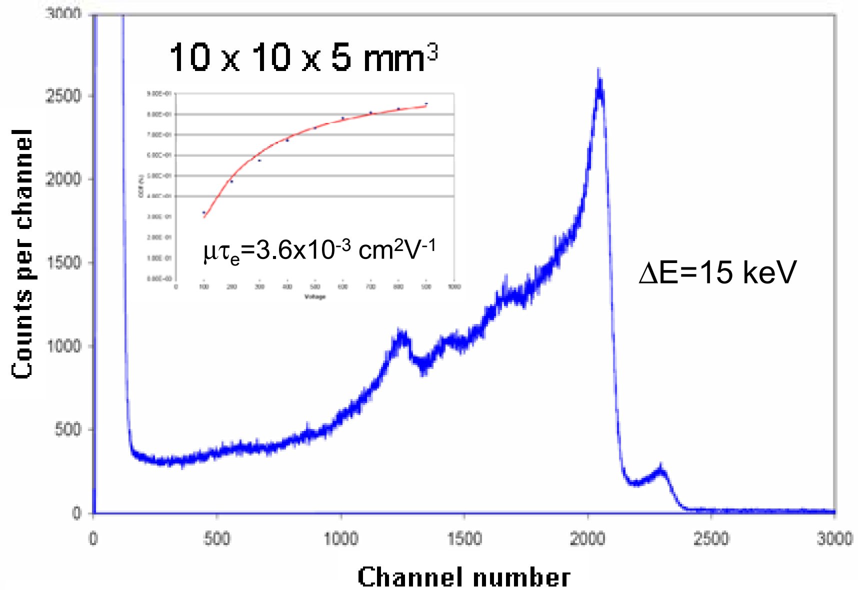
Sample reference	Size (mm)	Resistivity from IV measurement (Ωcm)	μτ (cm^2/V)
M4_023_1	5x5x5	1.5x10^{10}	2x10^{-3}
M4_023_3	10x10x5	1.4x10^{10}	1.1x10^{-3}
M4_023_4	5x5x5	1.310^{10}	1.93x10^{-3}
M4_023_6	10x10x5	2.1x10^{10}	3.6x10^{-3}

Properties of die from CZT boule M4_023

Comparison of ^{57}Co spectral performance








ELIZABETH II D G REG F D 2005

MINIATURIZATION

Conventional detector development

Miniature, minimally resourced Ge spectrometer

Goal

To produce a high resolution spectrometer package suitable for flight on ESA spacecraft, satisfying the following requirements

1. No cryogens

1. Base temperature < 90K

1. Accommodation (<5 L)

1. Power consumption <15W

1. Mass < 8 kg

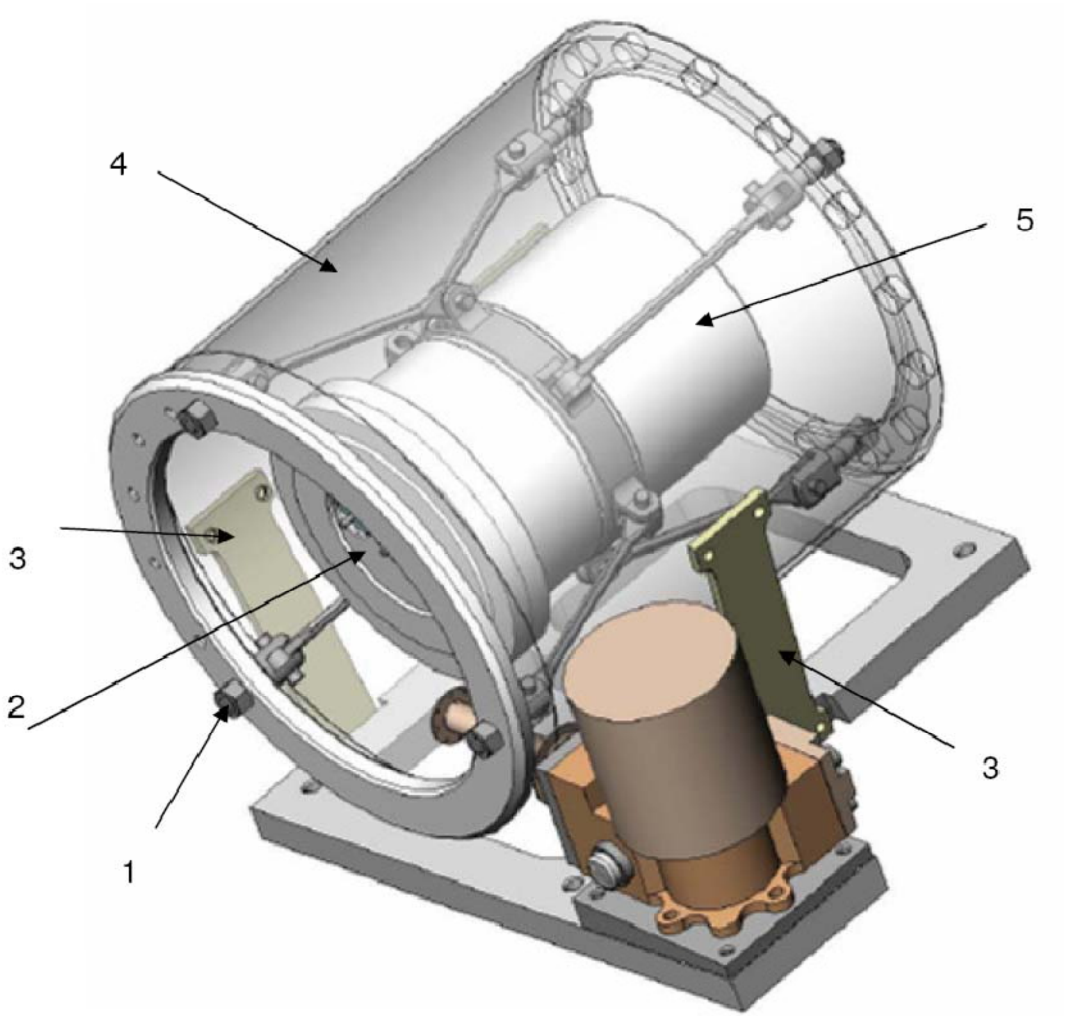
1. Energy resolution < 3 keV FWHM @ 1332 keV

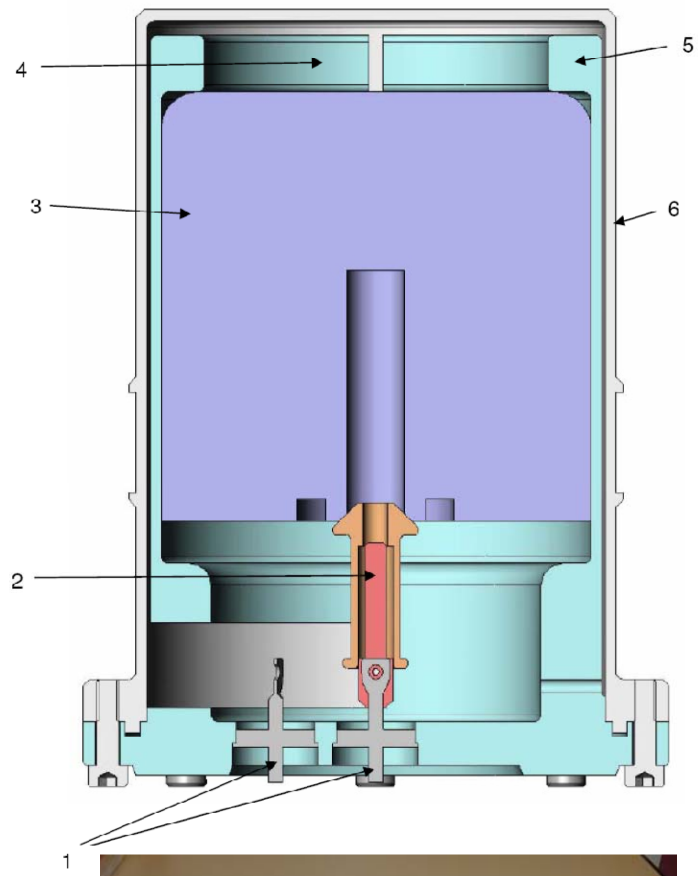
1. Crystal size > 150 cm^3 (>120% relative to NaI)

2. Anneal capability (at least 100^{o}C)

1. 5-10 year lifetime

Miniature, resource-efficient Ge spectrometer development

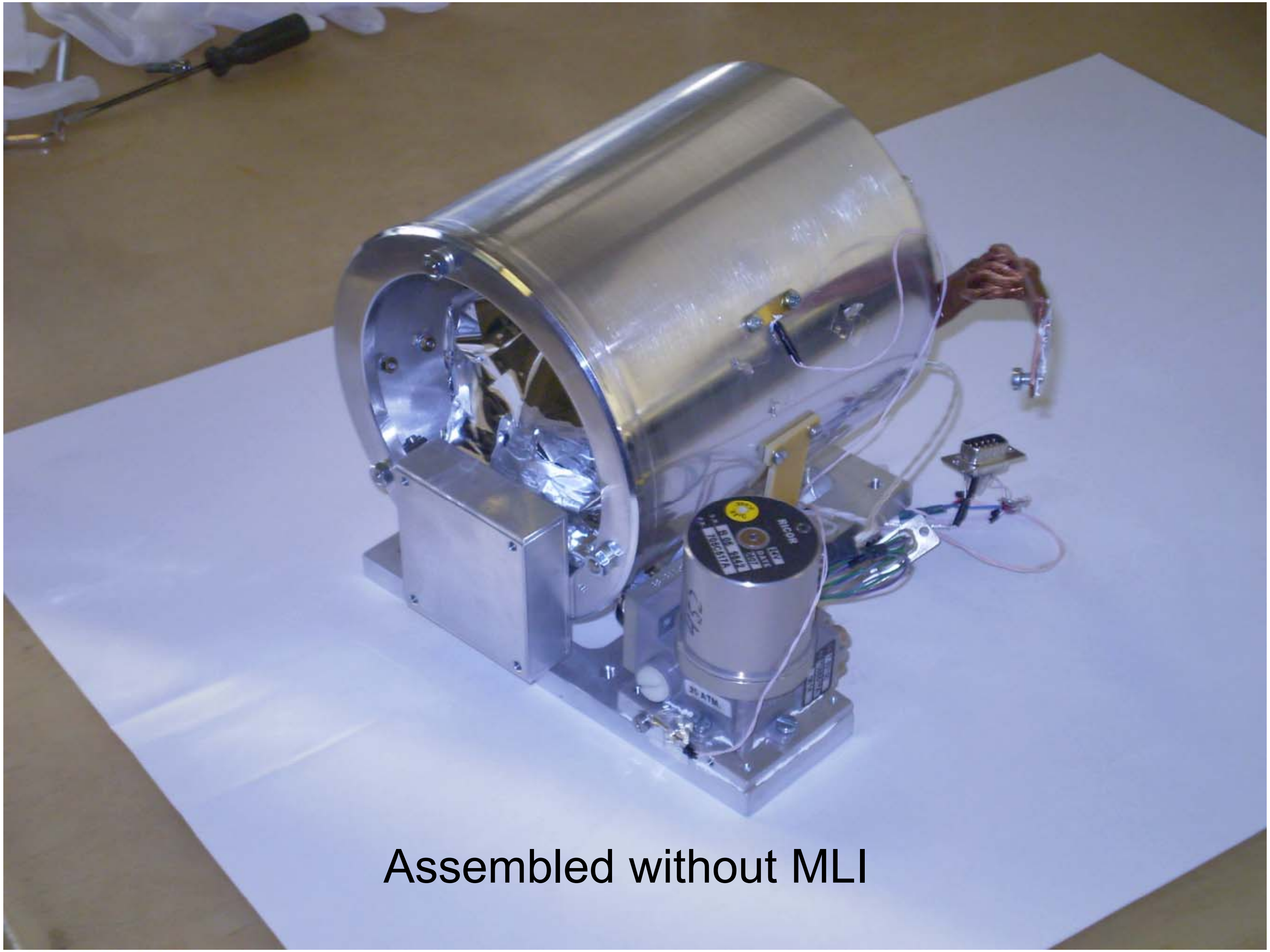


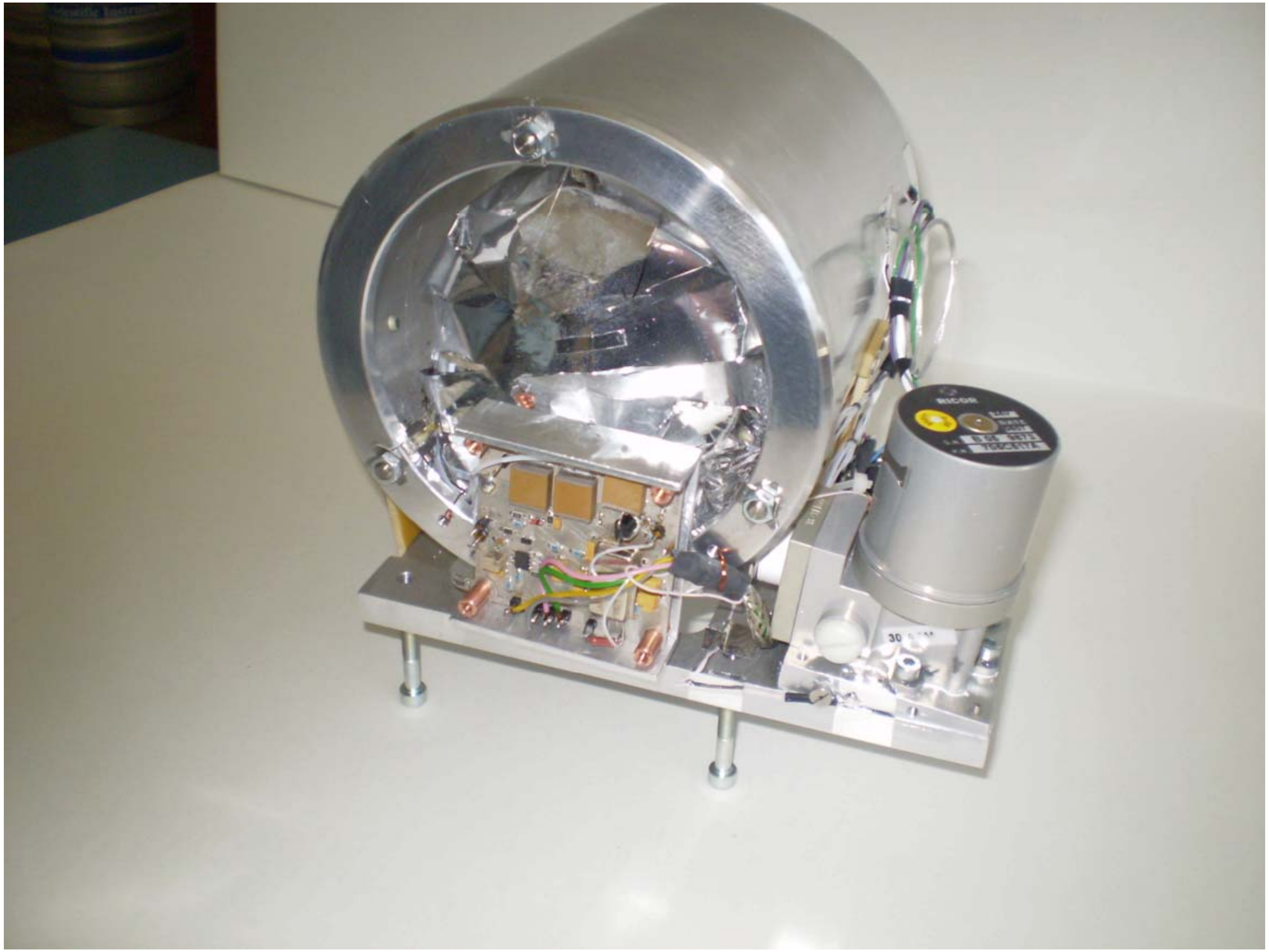


1. Caving bush for Preamplifier securing
2. Hermetic electro inputs
3. Detection Unit holder
4. Detection Unit housing (taken off by convention)
5. Gas-filling capsule with HPGe detector

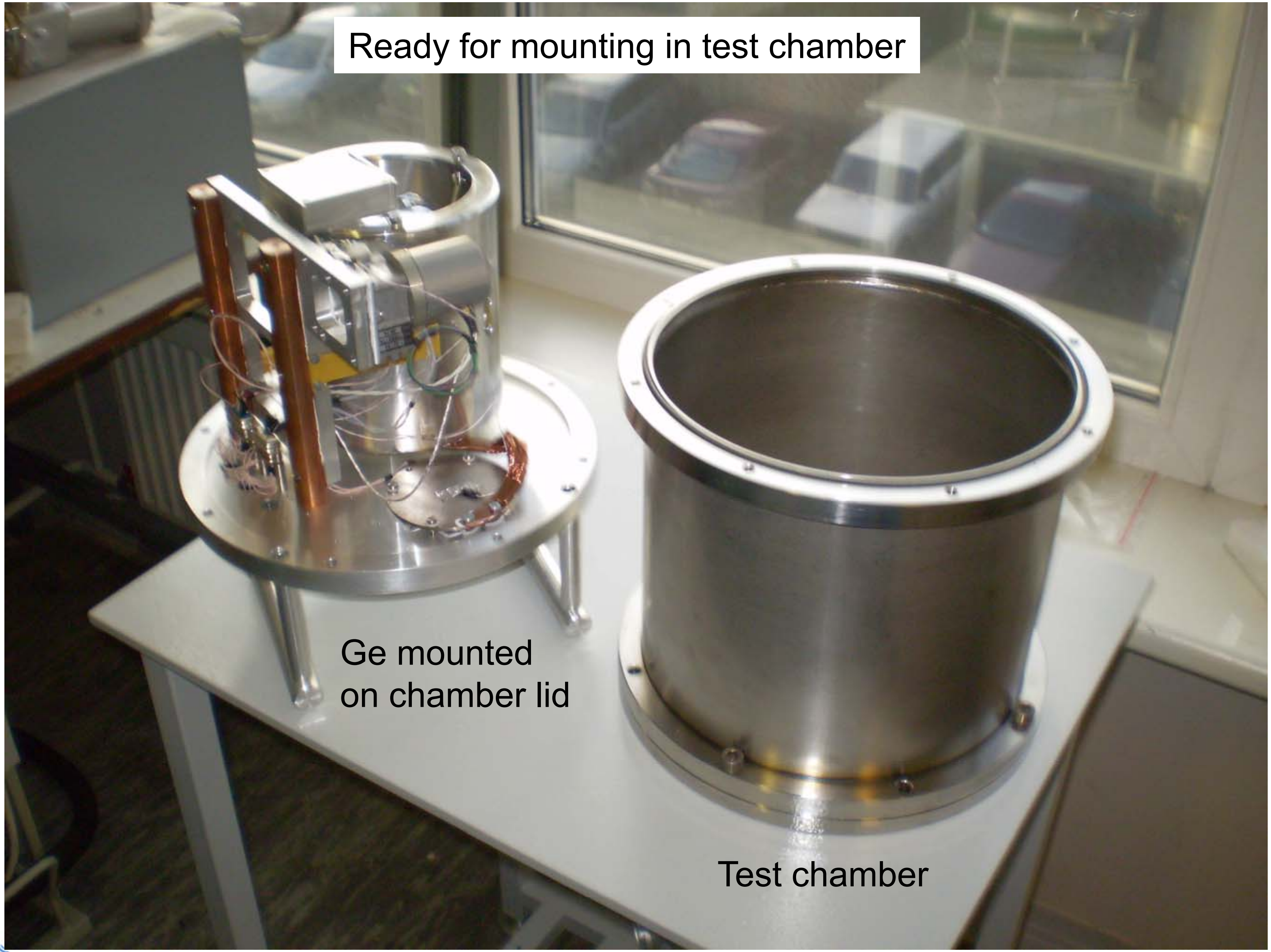
The cryostat, thermal isolators, and mechanical cooler

HPGe Detector cryostat with RICOR Sterling-cycle K508 cooler


Assembled without MLI

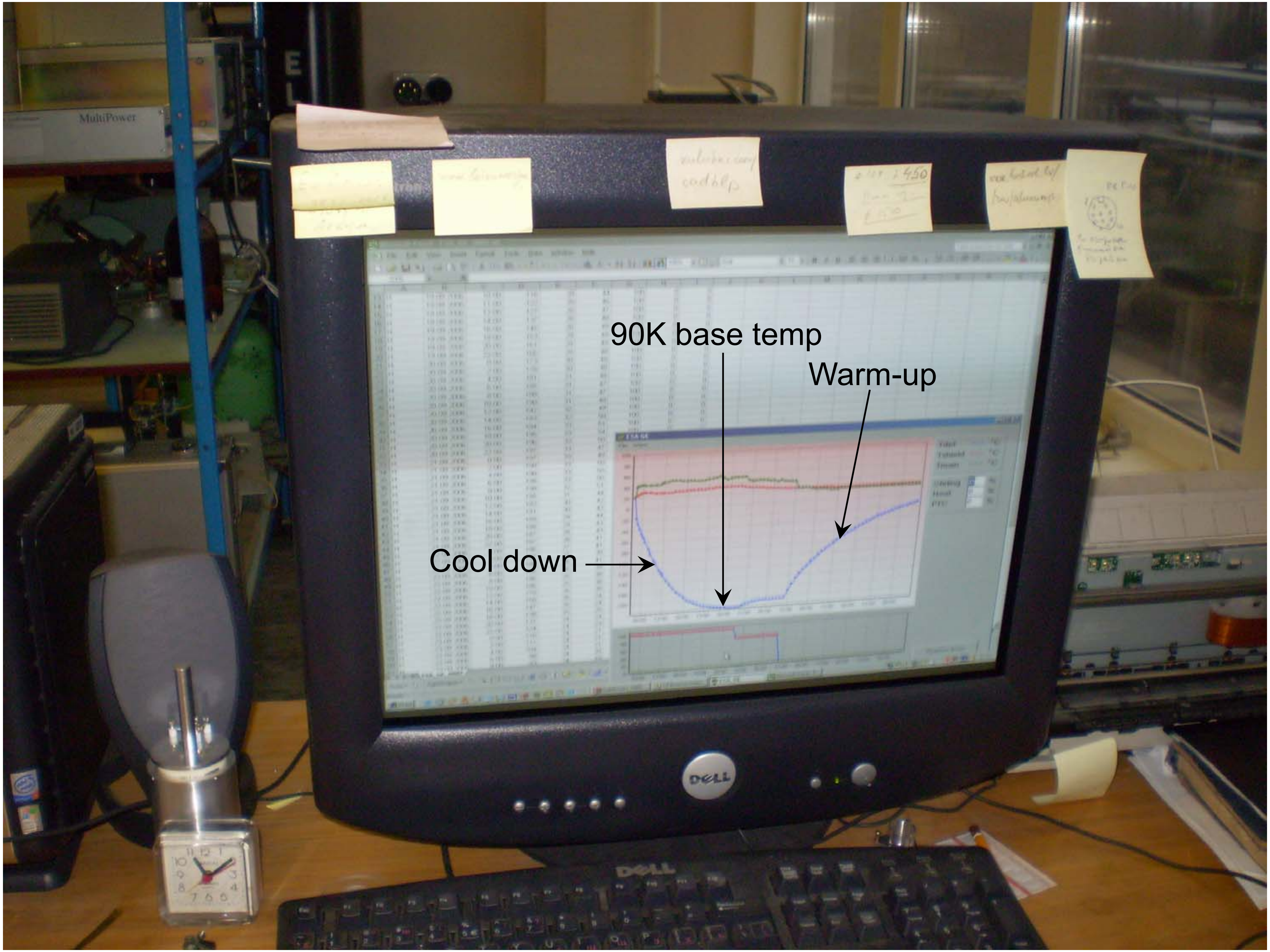


HPGe Detector in thermal shield with RICOR K508 cooler


Ready for mounting in test chamber
Ge mounted
on chamber lid
Test chamber


Cool-down
- 164

Bingo !



90K base temp
Warm-up
Cool down
MultiPower
DELL

Nominal cool-down operation detector and cold finger temperate profiles

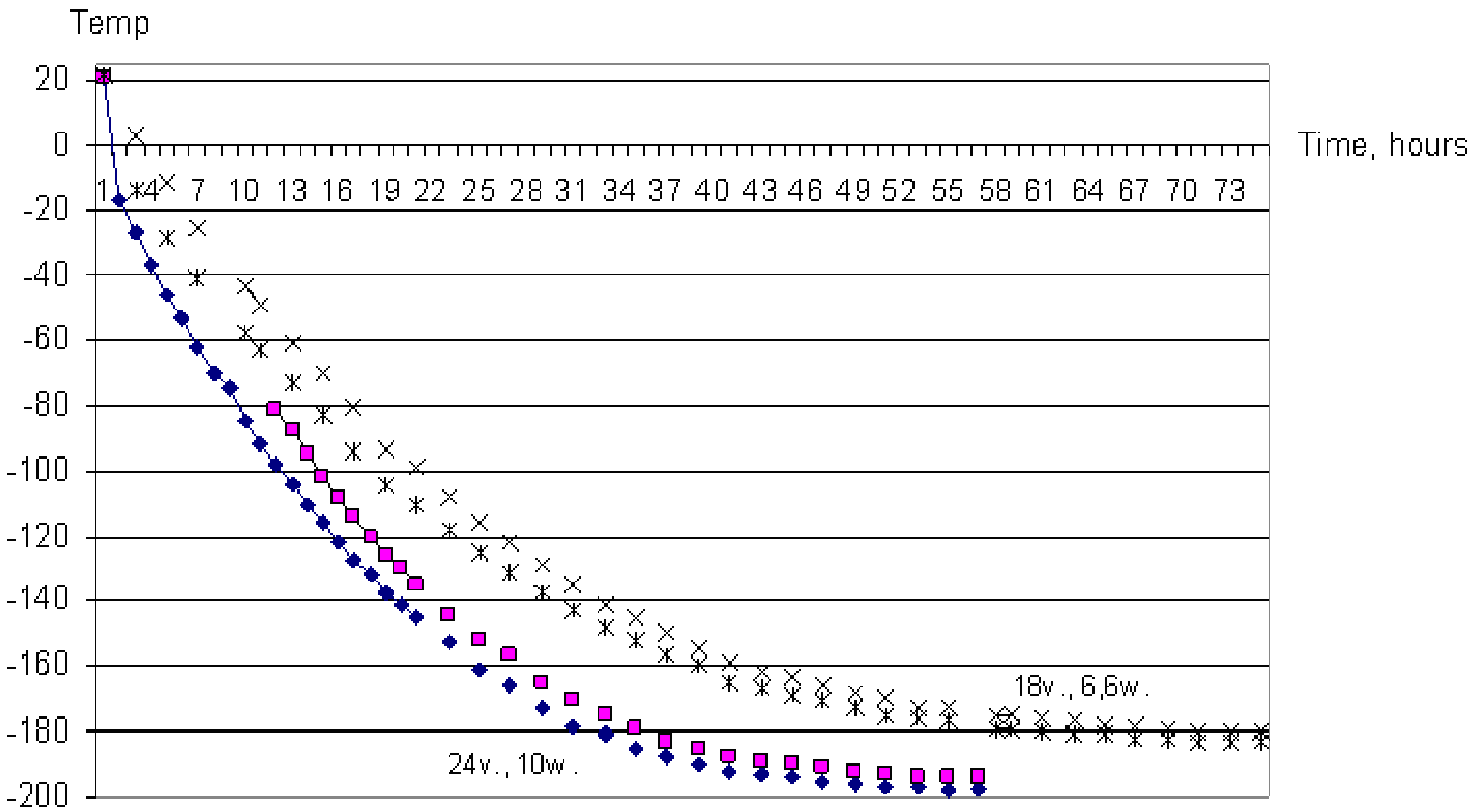
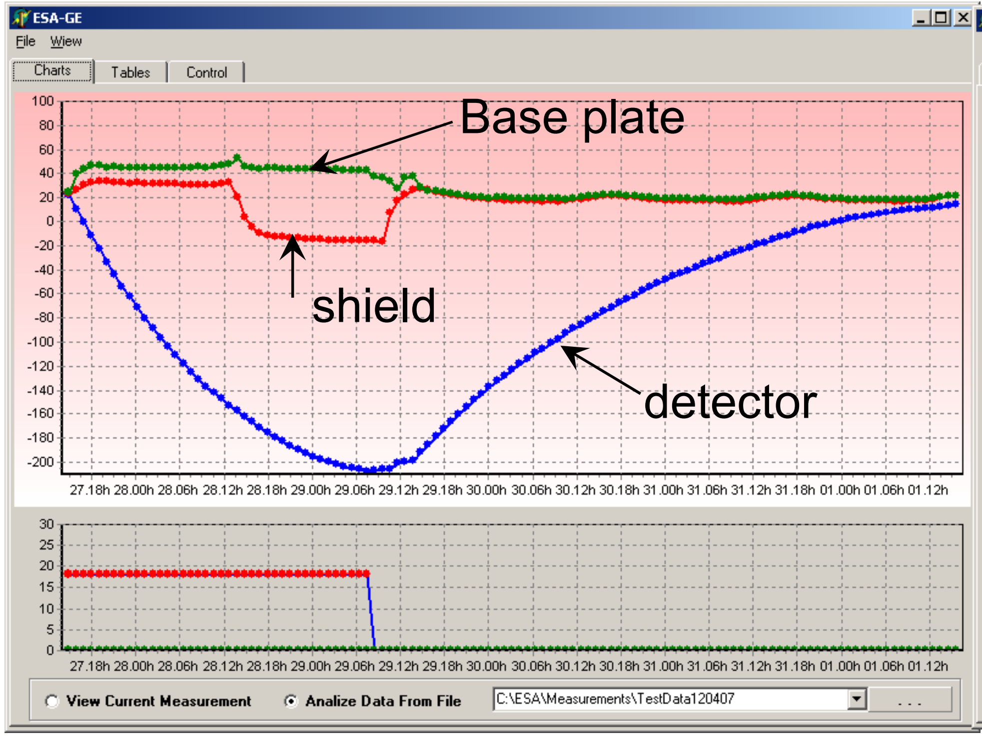
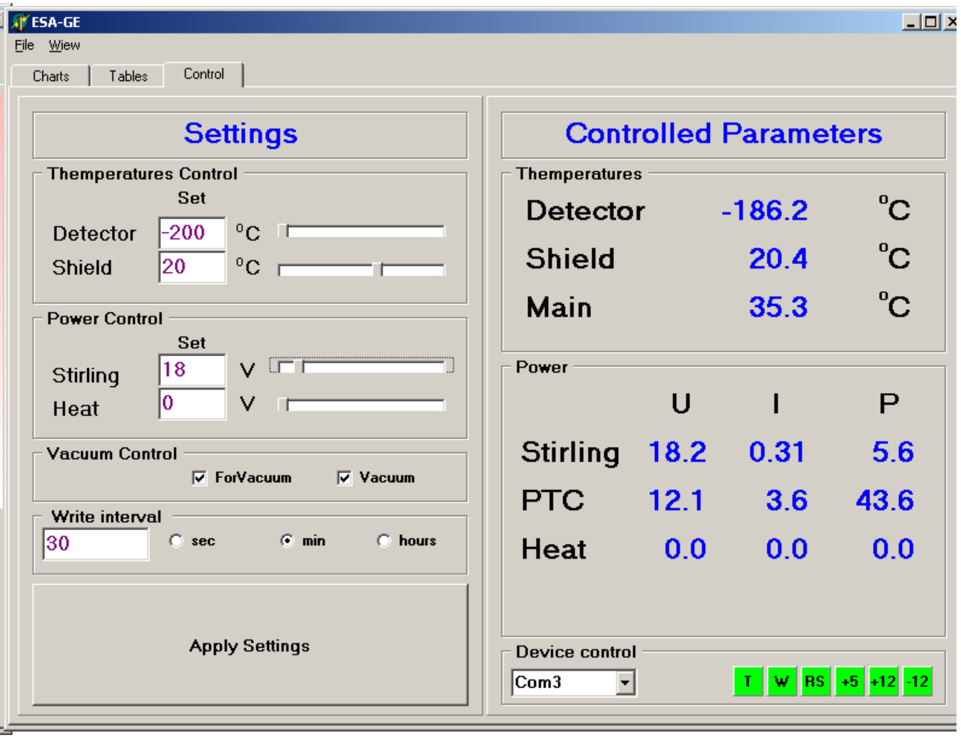


Fig 1. Diagram of temperature change on the detector`s holder and cold finger K508.

Thermal cycling

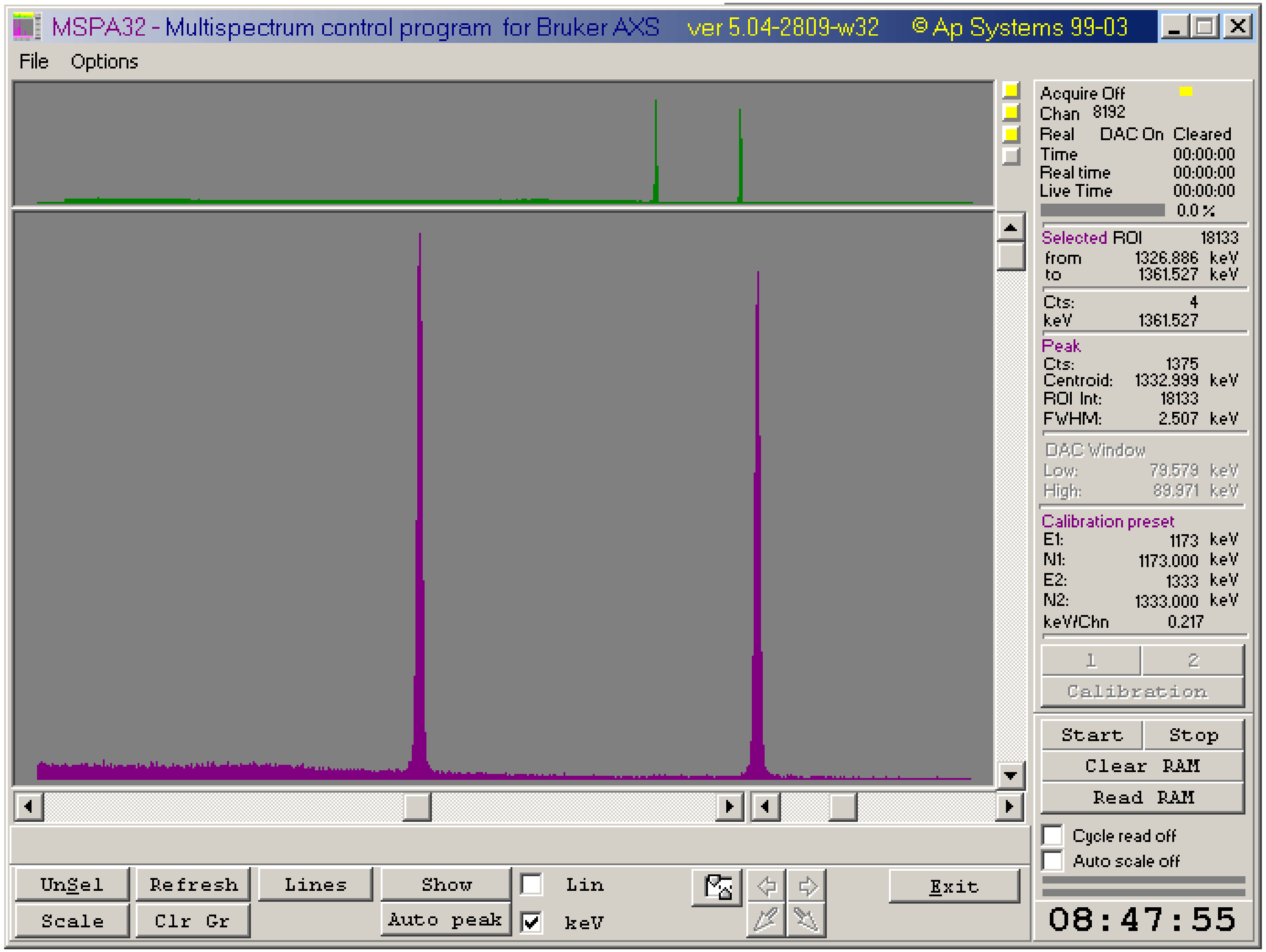




Problems

1. N_2 drying
2. High pressure of N_2 (up to 3.5 atm.) in detector capsule
3. Purity of N_2 gas (6N sources not good enough, solution - distill directly from atmosphere)
4. Static electricity
5. Mechanical vibration 10-20 kHz from Ricor K508
6. Electromagnetic noise from K508 internal generator and converter

Spectral performance



^{60}Co spectrum, ΔE = 2.5 keV @ 1.33 MeV

Miniature Ge spectrometer performance summary

• Xtal reaches operational temperature after 52 hours and a base temperature of 90K in 72 hours.

• Long term thermal cycling over 12 months gives perfectly reproducible results.

• Cooling power is 11 W. The maintenance temperature is 6.6 W. Rapid warm-up power (24 hours) is 4W.

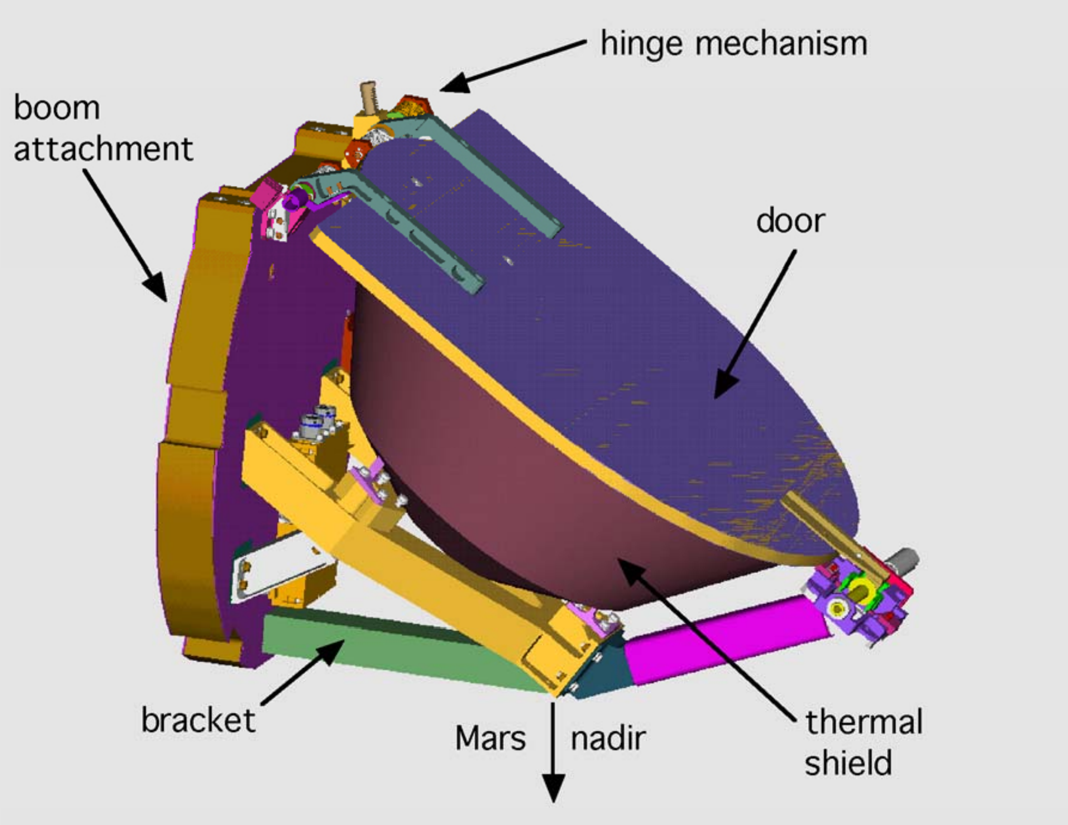
• The total mass for the entire system excluding the DPU but including the preamp is 3.5 kg.

• Next step - radiation "resistant" Ge
resource reduction

Comparison of the Messenger GRS & ESA GRS

Performance	Messenger	ESA GRS
HPGe crystal dimensions	50 mm dia x 50 mm	60 mm dia x 60 mm
Cryo cooler	K508	K508
Weight	9200 g	3870 g
Power	6.6 W (24 W peak)	6.6 W (10.5 W peak)
Detector temperature, K at temperature of the shield	88.4 K -25^{o}C (passive radiator)	87.6 K -17^{o}C
Energy resolution on 1332 keV	3.5 keV	2.5 keV
Power of annealing heater, W	2.0 W	4.2 W
Annealing temperature ^{o}C	85 ^{o}C	100 ^{o}C
Cooling time, hours	37.5 hrs	64 hrs (P=8.4 W)
Detector warm up time to 0^{o}C		72 hrs
Warm up time with heater		10 hrs

Mars Odyssey GRS



Ge xtal	6.7 cm x 6.7 cm
Mass	30.5 kg
Power	32.0 W
Dimensions	46.8 x 53.4 x 60. 4 cm^3

Functional block diagram of the electronics

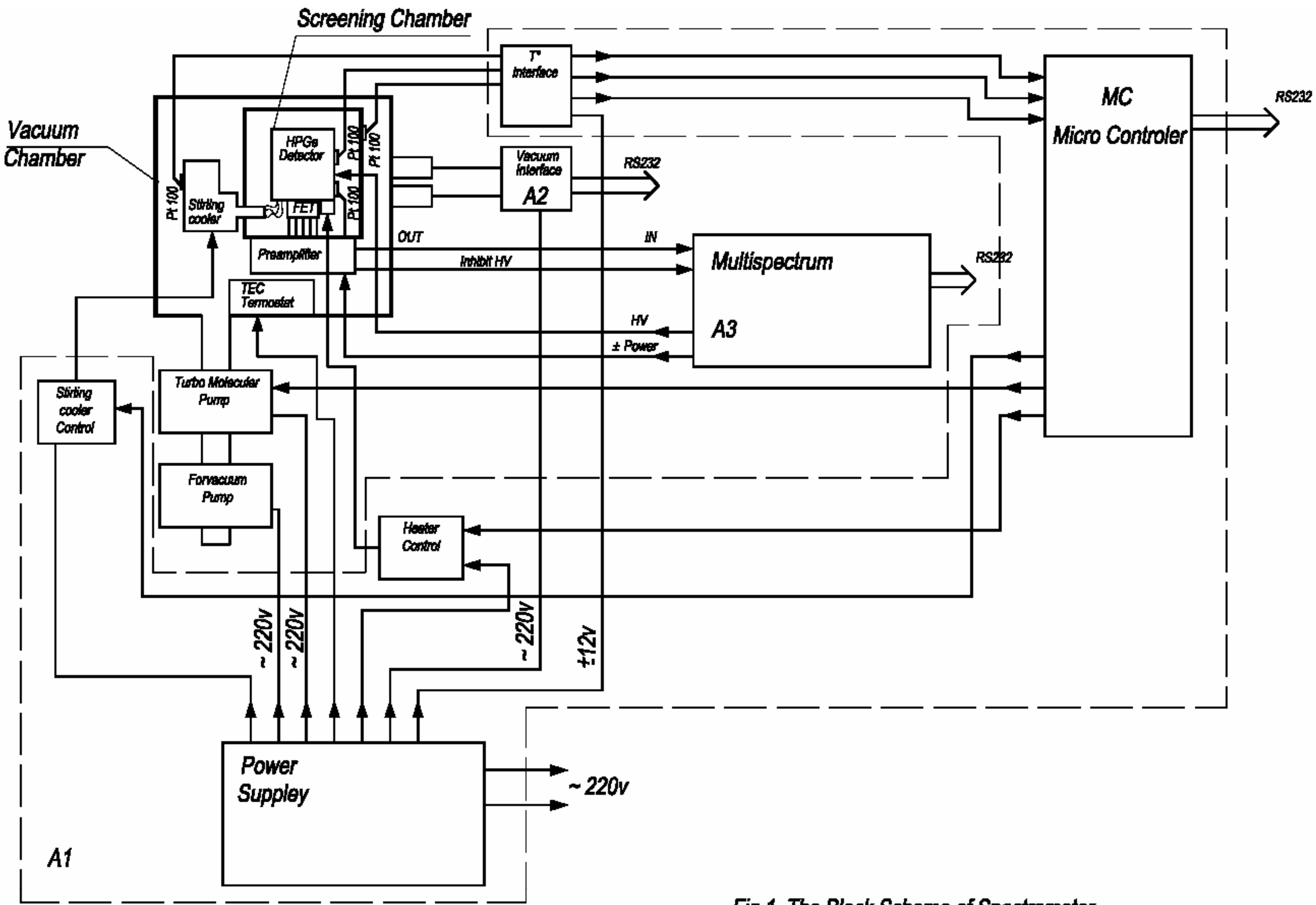
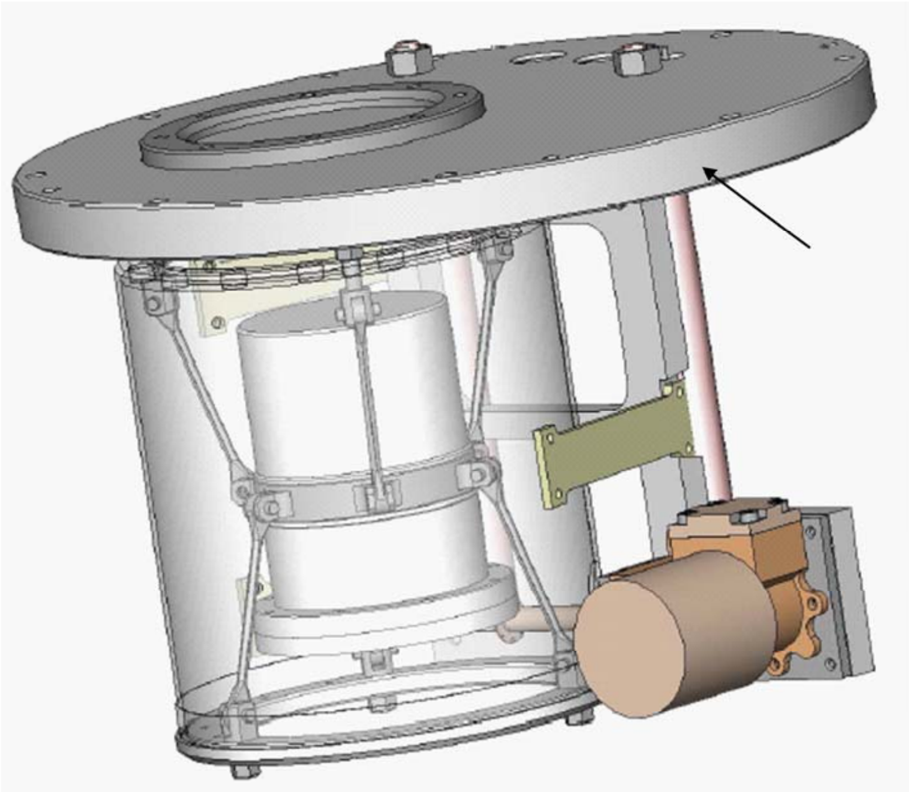
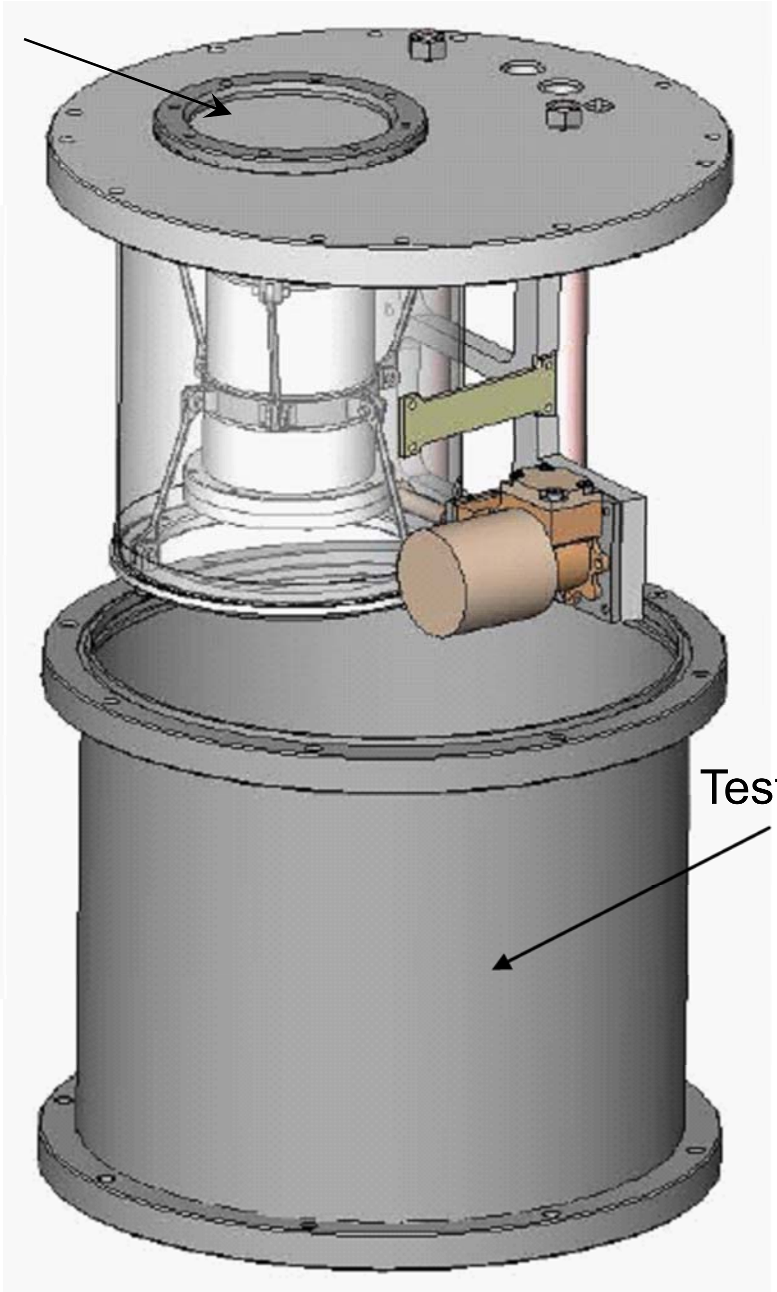


Fig.1. The Block Scheme of Spectrometer Based of HP(Ge) Detector.

HPGe spectrometer integration into test chamber

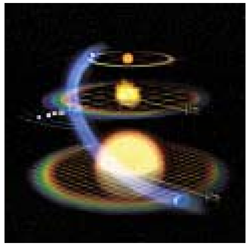




Cosmic Vision slides


Cosmic Vision:
Future Space Science for Europe

Cosmic vision – based on 4 fundamental themes



What are the conditions for life and planetary formation?

This theme looks at the emergence of life not only in our Solar System but also in 'exoplanets' orbiting other stars. This requires the study of how and where stars form, how planets emerge from this process, and the appearance of signs of life (bio-markers) in other stellar systems as well as our own.

How does the Solar System work?

This will be a global attempt to understand the Solar System as a whole, from the Sun to the limits of its sphere of influence, as well as the formation mechanisms of gaseous giants and their moons, and the role of small bodies and asteroids in the process of planetary formation.

What are the fundamental laws of the Universe?

A century after Einstein's theory of relativity was proposed, physics remains a vast field for investigation. The laws of physics as currently formulated do not apply at extreme conditions, and are not at all understood for the first fractions of seconds after the Big Bang. Some implications, like the behaviour of matter at extremely high temperatures and energies or the existence of gravity waves, still have to be explored.

How did the Universe begin and what is it made of?

The origin and early evolution of the Universe is still largely unknown. Less than 5% of the mass of the Universe has been identified, the rest being composed of mysterious 'dark matter' (23%) and 'dark energy' - one of the most surprising recent discoveries.

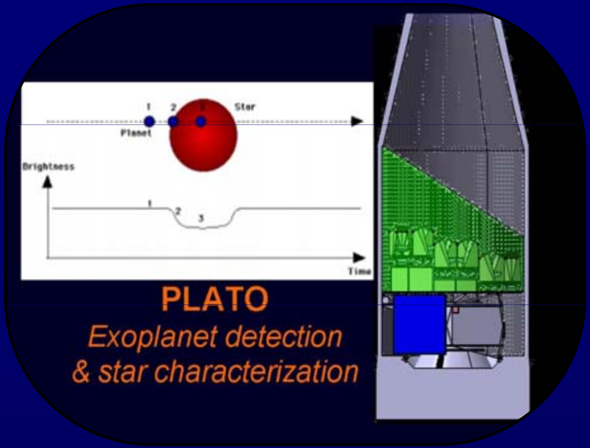
- Very successful response to Call for Ideas issued Summer 2007

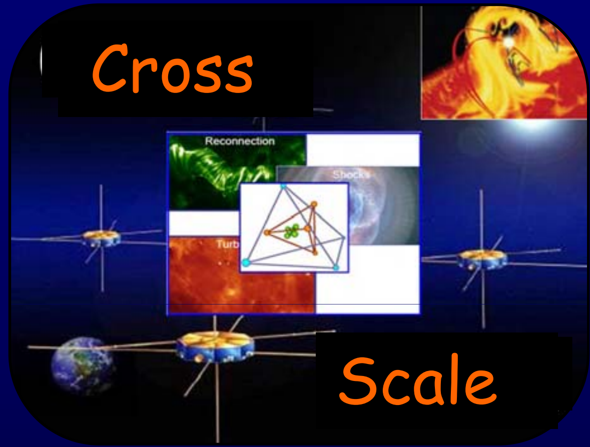
- Exciting array of missions under study – sorted into M class and L-class missions
  - *Dark Energy, Blackholes + Cosmology, Earth-like Exoplanet Search, Asteroid Sample Return, NextGen Infrared Observatory, Sun-Earth interactions, Jupiter or Saturn system exploration*

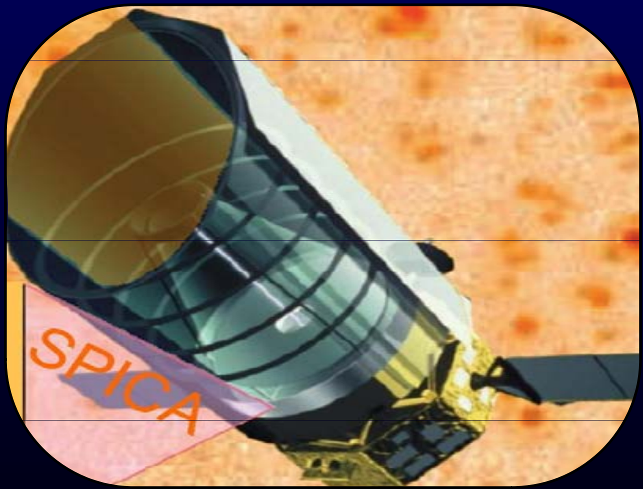
- International Cooperation
  - *Negotiations opened with NASA, JAXA, RSA, ISRO, CNSA*
  - *« Orchestrating world space science »*

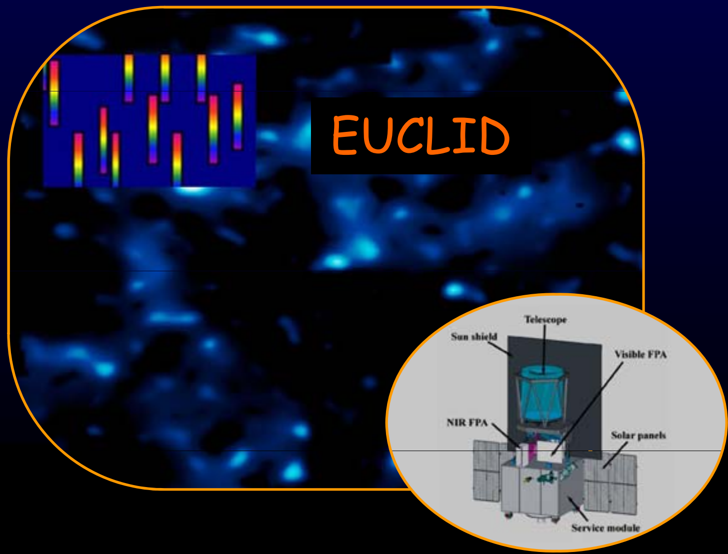
- Concerns
  - *How achievable are the targets set by scientists?*
  - *Technology readiness ?*

M class missions

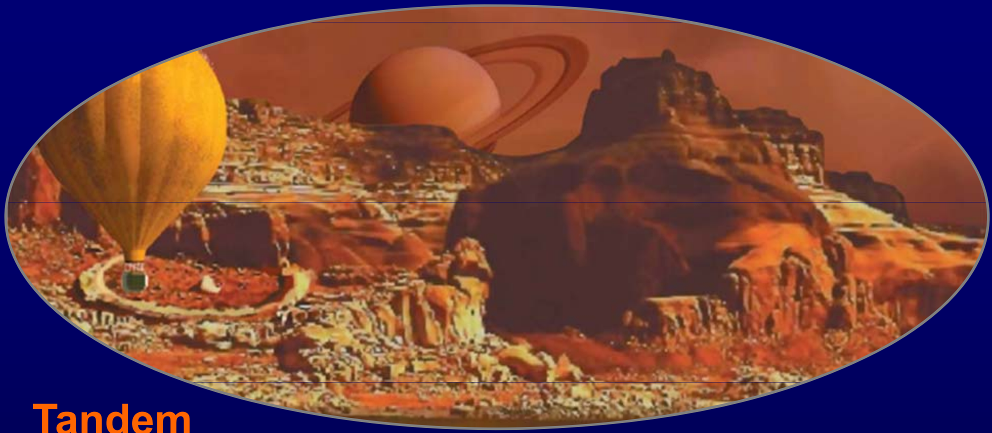




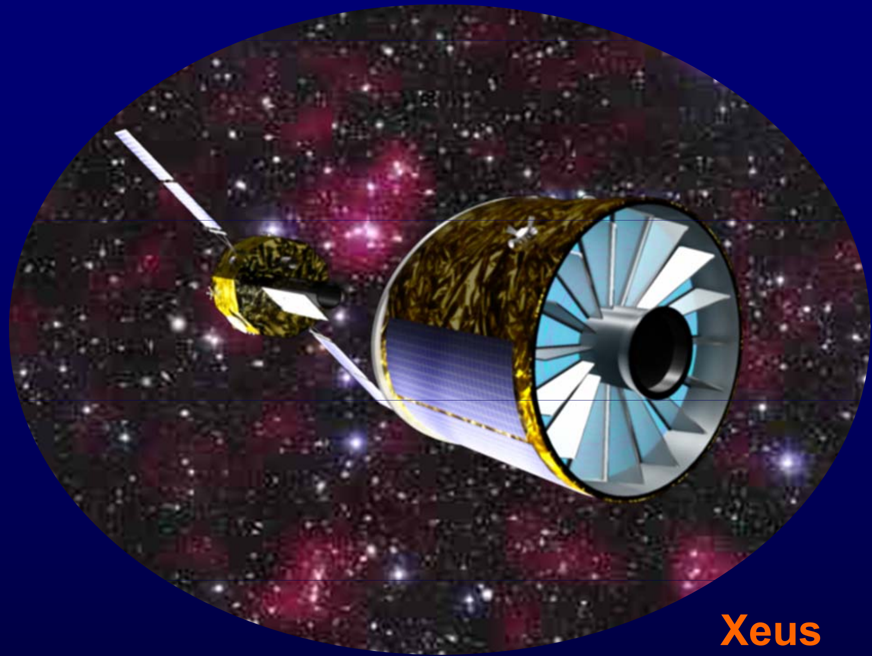




L class missions

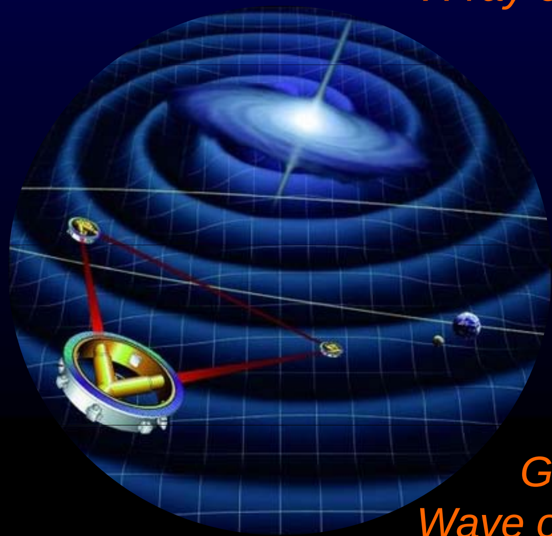


Tandem
mission to Saturn/Titan



Xeus
X-ray observatory

Laplace
mission to the Jupiter system



LISA
Gravitational Wave observatory

esa SCIENCE

Selected cosmic Vision Missions

Euclid - To map the geometry of the dark Universe

PLATO - Discover and characterise a large number of close-by exoplanetary systems, with a precision in the determination of mass and radius of 1%

SPICA - Understanding how galaxies, stars and planets form and evolve as well as the interaction between the astrophysical processes that have led to the formation of our own Solar System

TandEM/TSSM - To understand the atmosphere, surface and interior; determine chemistry; and derive constraints on orgin and evolution of Titan and of the Saturnian system as whole, with an emphasis on Enceladus.

LAPLACE/EJSM - What have been the conditions for the formation of the Jupiter system? How does Jupiter work? Is Europa habitable?

Marco Polo - Return to Earth multiple unaltered samples from a NEO

Cross-Scale - Quantifying the coupling in plasmas between different physical scales in order to address fundamental questions such as: how shocks accelerate and heat particles; how reconnection converts magnetic energy and how turbulence transports energy from source to dissipation.

LISA - The primary scientific goal of the Laser Interferometer Space Antenna (LISA) mission is to detect and observe gravitational waves from astronomical sources such as massive black holes (MBHs) and galactic binaries in a frequency range of 10^{-4} to 10^{-1} Hz. LISA consists of three spacecraft that act as an interferometer with an arm length of 5 million kilometres.

XEUS – Detect the earliest massive black holes and study their growth and evolution. Study the first gravitationally-bound dark matter dominated systems. Observe matter under extreme conditions.