Towards the X-ray and gamma-ray Nuclear Instrumentation for Astrophysics

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CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Outline

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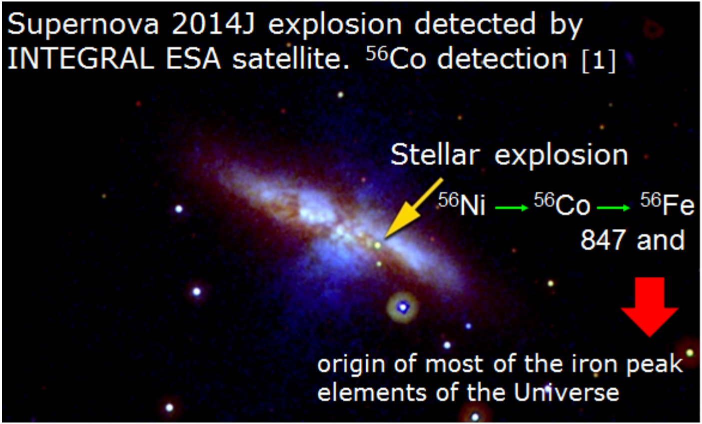
Motivation



Supernova 2014J explosion detected by INTEGRAL ESA satellite. ^{56}Co detection [1]

Stellar explosion

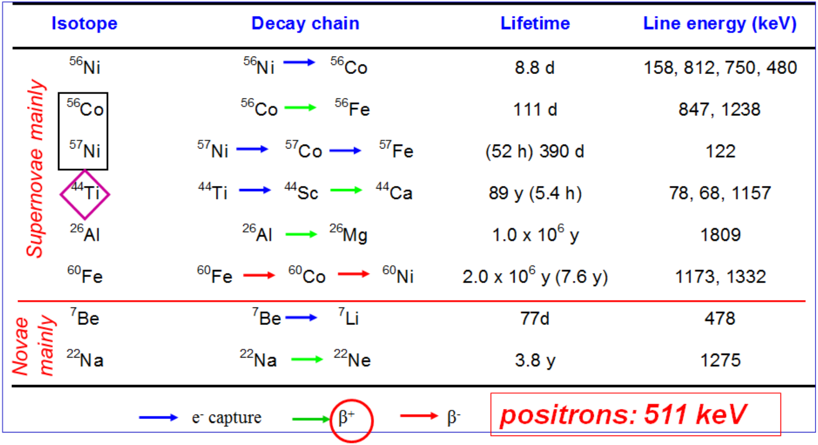
$^{56}\text{Ni} \rightarrow {}^{56}\text{Co} \rightarrow {}^{56}\text{Fe}$

847 and 1238keV

origin of most of the iron peak elements of the Universe

[1] J. Isern et. al., A&A 588, A67 (2016)

Radioactive isotopes relevant for γ-ray astronomy



	Isotope	**Decay chain**	**Lifetime**	**Line energy (keV)**
Supernovae mainly	^{56}Ni	^{56}Ni → ^{56}Co	8.8 d	158, 812, 750, 480
	^{56}Co	^{56}Co → ^{56}Fe	111 d	847, 1238
	^{57}Ni	^{57}Ni → ^{57}Co → ^{57}Fe	(52 h) 390 d	122
	^{44}Ti	^{44}Ti → ^{44}Sc → ^{44}Ca	89 y (5.4 h)	78, 68, 1157
	^{26}Al	^{26}Al → ^{26}Mg	1.0 x 10^6 y	1809
	^{60}Fe	^{60}Fe → ^{60}Co → ^{60}Ni	2.0 x 10^6 y (7.6 y)	1173, 1332
Novae mainly	^{7}Be	^{7}Be → ^{7}Li	77d	478
	^{22}Na	^{22}Na → ^{22}Ne	3.8 y	1275

→ e^- capture → β^+ → β^-

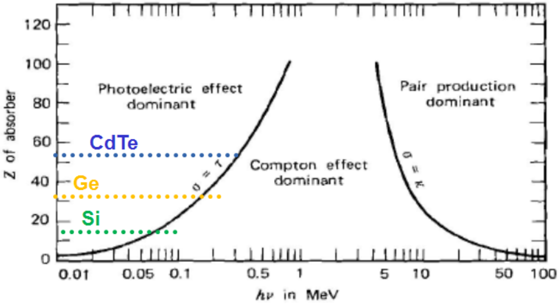
positrons: 511 keV

Outline

1. Motivation
2. Detection of hard X/γ-rays based on semiconductor detectors
3. Hard X/gamma-ray imaging detector concepts
4. Experimental set-up and spectral measurements

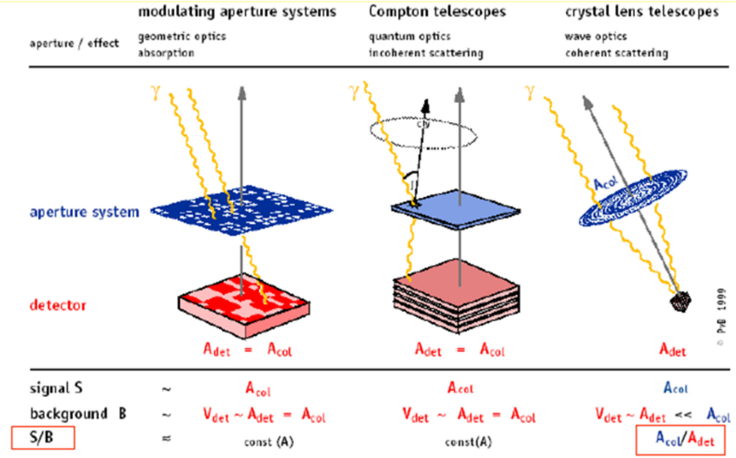
How can hard-X / γ-rays be detected?

- γ-ray absorption mechanism: photoelectric absorption; Compton scattering; pair ($e^{-} - e^{+}$) creation



Region of interest (~ 100keV to 2MeV) is dominated by the Compton effect

Imaging of hard X/γ-rays in the keV to MeV range



	modulating aperture systems	Compton telescopes	crystal lens telescopes
aperture / effect	geometric optics absorption	quantum optics incoherent scattering	wave optics coherent scattering

signal S	~	A_{col}	A_{col}	A_{col}
background B	~	$V_{det} \sim A_{det} = A_{col}$	$V_{det} \sim A_{det} = A_{col}$	$V_{det} \sim A_{det} << A_{col}$
S/B	≈	const (A)	const(A)	A_{col}/A_{det}

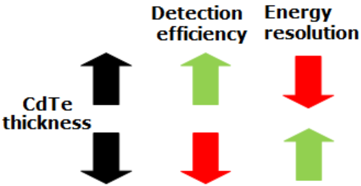
Hard X/γ-rays imaging instruments

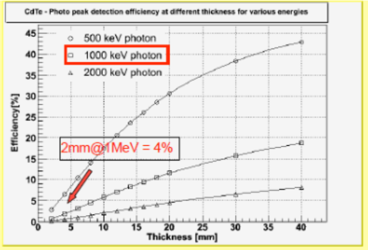
Modulation aperture system	Compton telescope	Crystal lens telescope
INTEGRAL/SPI and IBIS (2002-) Swift/BAT (2004-) **e-XTP/WFM** (LOFT heritage)	CGRO/COMPTEL (1991-2000) ASTRO-H/SGD (2016) COSI balloon-borne (2016) **e-ASTROGAM** (ESA call for M5)	Claire balloon flight (2001) MAX proposal GRI proposal DUAL proposal

Outline

Challenge

Reaching E $\sim$ 1MeV with high detection efficiency, keeping a good spatial and energetic resolution.

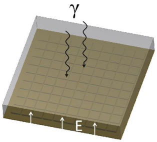


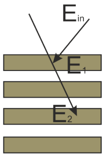


Optimal trade-off between the efficiency and the energy resolution $\Rightarrow$ GEANT4 Monte-Carlo simulation

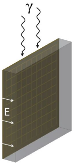
Proposal concepts

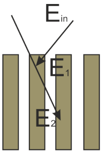
- Stack of CdTe pixel/strip detectors as in SGD in Astro-H





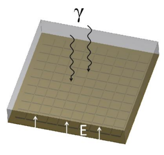
- Stack in the PTF (Planar Transfer Field) detector configuration

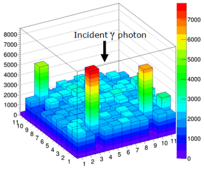




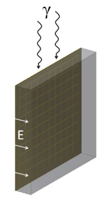
Proposal concepts

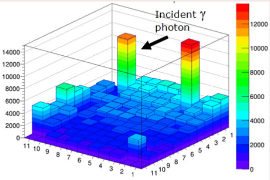
Planar Parallel Field (PPF) configuration





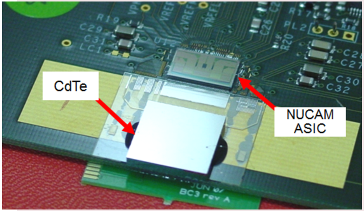
Planar Transverse Field (PTF) configuration





Hard X/γ-ray imaging detector implementation(1)

CdTe pixel module with NUCAM read-out chip



CdTe detector characteristics:

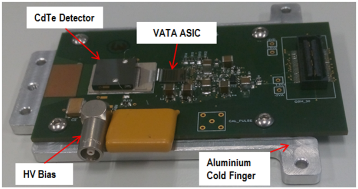
- 11 x 11 pixels, electron collection
- 12.15 x 12.15 x 2 mm^3
- Pt-Ohmic/CdTe/Pt

NUCAM ASIC performances:

- 128 channel low noise
- On-chip ADC with 12 bits
- output data: channel n^o, peak amplitude and collection time

Hard X/γ-ray imaging detector implementation(2)

CdTe pixel module with VATA read-out chip



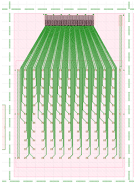
CdTe detector characteristics:

- 11 x 11 pixels, electron collection
- 12.15 x 12.15 x 2 mm^3
- Al-Schottky/CdTe/Pt

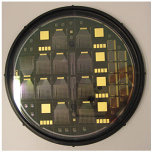
VATA ASIC performances:

- 128 channel low noise
- trigger capability
- serial, sparse read-out mode

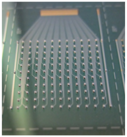
CdTe detector hybridisation



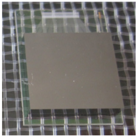
Pitch adapter design for a 11 x 11 pixel detector



4 inch Sapphire wafer with pitch adapters fabricated at IMB (CNM-CSIC) clean room

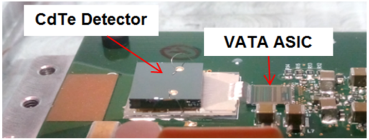


Solder bumps deposited on the pitch adapter by IFAE



Detector attachment at low temperature by IFAE and IMB

Wire-bonding of the ASIC control pads

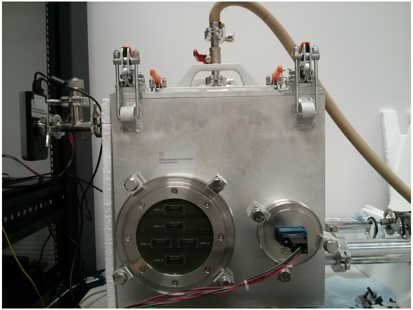


Wire-bonding of the ASIC inputs pads and detector HV bias

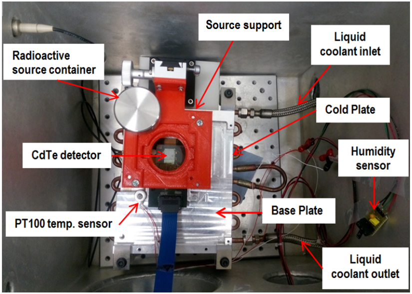
Outline

ICE's Radiation Laboratory

Experimental set-up

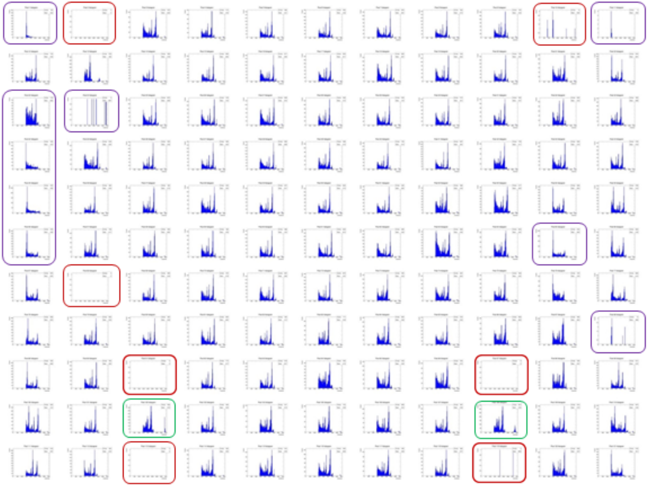


vacuum chamber ⇒ controlled atmosphere

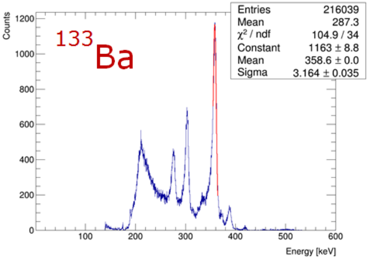


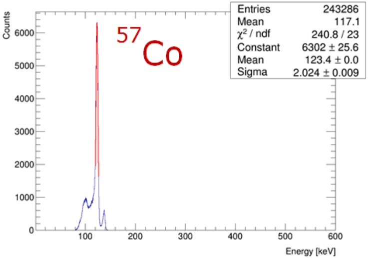
inside of vacuum chamber

Detector response @^{133}Ba, -500V, -10^{o}C



Sum spectrum @-500V, -10^{o}C, cathode illumination





Energy resolution

- 7.4keV FWHM @ 356keV ($\Delta E/E$=2.1%)
- 4.7keV FWHM @ 122keV ($\Delta E/E$=3.8%)

Summary

- New instruments with high sensitivity, high detection efficiency and high energy resolution are needed to understand nuclear explosions in the MeV domain.
- Detectors based on semiconductors material like CdTe, Si and Ge with various configurations (pixels, strips) can fulfill the demanding requirements to study in detail high energetic phenomenas.
- Advanced Compton telescopes are promising instruments which may lead future gamma-ray space missions.
- ICE's radiation lab is working. The available equipment allows characterising radiation solid state detectors (i.e. Cd(Zn)Te or Si) in a controllable environment.

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THANK YOU FOR YOUR ATTENTION!