CLAIRE's First Light

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Focusing nuclear gamma-rays
why?
how?
what for?

Does it work?
measuring the performance of a Laue lens
CLAIRE's balloon flight of June 14, 2001
CLAIRE TGD - confirming CLAIRE's first light

astronomy with radioactivities

28 May 2003, Kloster Seeon
Focusing Gamma-Rays - why?

- modulating aperture systems
- Compton telescopes
- crystal lens telescopes
  - geometric optics
  - quantum optics
  - wave optics
  - coherent scattering
  - incoherent scattering
  - absorption
  - geometric optics
Focusing Gamma-Rays - how?

\[ \lambda (511 \text{ keV}) = 2.42632 \times 10^{-2} \text{ Å} \]

Bragg condition

\[ 2d\sin \theta = n\lambda \]

\[ d[220] = 2.0004 \text{ Å} \]

\[ \arcsin(\lambda / 2d) = 0.347^\circ \]
Focusing Gamma-Rays - how?

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Laue-type Gamma-ray lens

\[ 2\theta = 0.695° \]

ex. radius [220] = 10.1 cm

=> focal length = 8.2 m

narrow band Laue lens: higher orders at larger radii (CLAIRE)
broad band Laue lens: most efficient order at all radii (MAX)
Focusing Gamma-Rays - what for?

Sensitive gamma-ray spectroscopy of

**Type Ia supernovae**
- probe initial conditions and dynamics of SN explosions,
- $^{56}\text{Ni}$ and $^{56}\text{Co}$ line of 5 to 10 SN1a per year

**Classical Novae**
- $^7\text{Be} \rightarrow ^7\text{Li}$ radioactivity
- early electron-positron annihilation

**Galactic microquasars**
- electron-positron annihilation signature,
- map the spatial extension of the emission along the jets

**Black-hole X-ray novae**
- observing the 460 - 511 keV band

Neutrons, stars, pulsars, X-ray Binaries, AGN
- solar flares, and gamma-ray afterglow from burst counterparts
MAX

a gamma-ray lens for nuclear astrophysics
- a broad bandpass "ring lens"

crystals - Cu (847 keV)
    Ge (511 keV)

dense packing of the crystals

only most efficient orders
    outer rings [111] Ge
    inner rings [111] Cu
- effective area

**Cu [111] crystals**
in 10 rings

- 825 keV
- 910 keV

**Ge [111] crystals**
in 14 rings

- 460 keV
- 522 keV

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**Cu [111] lens ring - diffracting area**

- Ge [111] plane
- 60° mosaicity
- 10 rings 87-96 cm
- individual crystals ~ 1 ccm
- weight: 57 kg

**Ge [111] lens ring - diffracting area**

- Ge [111] plane
- 30° mosaicity
- 14 rings 97-110 cm
- individual crystals ~ 1 ccm
- weight: 46 kg
two 100 keV broad energy bands diffracting simultaneously

MAX
inner radius 86 cm
outer radius 111 cm
focal length 133 m

MAX XL
inner radius 193 cm
outer radius 250 cm
focal length 300 m
The reflection efficiency of a Laue lens

\[ r_{th}(\theta) = 0.5 \left( 1 - e^{-2\alpha T} \right) \left( e^{-\mu T} \right) \] at \( E_{\text{Bragg}} \)

\( \mu \) Absorption coefficient \( (T \text{ crystal thickness}) \)
\( \alpha(\theta) \) diffraction coefficient : \( \alpha(\theta) \sim F^2 \lambda^3/V^2 \sin(\theta) \sim \theta^{5/3}/E^2 \)

efficiency decreases with increasing energy and order, and with decreasing structure factor.
Does it work? APS beam test of a Ge crystal

Synchrotron beam at Advanced Photon Source (divergence ≈ 3”)

diffraction efficiency : ratio of doubly diffracted / singly diffracted flux

A. Kohnle et al., NIM, 1998
Does it work? Laboratory measurements of CLAIRE measurements with a $^{57}$Co source at 14 m only yield an efficiency of 3.2%.
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Does it work ... for an astrophysical source?

proooving the principle of a Laue lens on a balloon gondola

<table>
<thead>
<tr>
<th>constraints</th>
<th>design consequences</th>
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<tr>
<td>balloon: focal length &lt; 3m</td>
<td>max. area requires higher orders</td>
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<tr>
<td></td>
<td>=&gt; narrow band Laue lens</td>
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<td></td>
<td>=&gt; diffracted energy &lt; 200 keV</td>
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<tr>
<td>astrophysics: ∃ (line) source</td>
<td>Crab nebula ($\Delta E \approx 1.5$ keV at 170 keV)</td>
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<tr>
<td>&quot;Gap flight&quot;: June</td>
<td>use the sun as guidestar</td>
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<tr>
<td>pointing: min. field rotation</td>
<td>launch window - 14/15 June</td>
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Launch : 8h15 UT, from the CNES balloon base Gap-Tallard (French Alps)
Balloon : Zodiac Z600 (600,000 m³)
floating altitude : > 41 km (3.8 g/cm² residual atmosphere), during 5h 30’
Landing : 17 h UT, Bergerac, Acquitaine (~Bordeaux region)
CLAIRE 2001: Laue lens and fine pointing system

- 576 Ge crystals
- $A_{\text{geo}} = 511 \text{ cm}^2$
- $E_{\text{diff}} = 170 \text{ keV}$, $\Delta E \approx 1.5 \text{ keV}$
- FOV $\approx 45$ arcsec
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Optical axis
- invar. pixel of rotating CCD
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optical axis
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fine pointing
- Geneva actuators 1
- precision sun sensor 2
- wide field CCD camera 3
- inclinometers 4
- mechanical & laser gyros 5

=> stability \( \approx 3 \text{ arcsec} \)
CLAIRE 2001: Ge detector matrix and ACS

detector
- 3x3 matrix
- high purity Ge
- 1.5*1.5*4cm

cooling
- pressurized N dewar

ACS system
- CsI shield
- BGO collimator
CLAIRE 2001: flight spectra
CLAIRE 2001: simulated Monte-Carlo flight

Crab nebula (Pelling et al. 1987)

spectrum: $1.3 \times 10^{-4}$ [ph cm$^{-2}$ s$^{-1}$ keV$^{-1}$] @170 keV
angular size 20"

calculus of astronomical position (flight data)
Atmosphere (absorption US std atm. 1976)
altitude, zenith angle (TM)

≈ 70% trans.

Lens
lens/gondola pointing from flight data (TM)
tuning data of all crystals
diffraction (Darwin)

≈ [111]

ε diff (pic)

≈ 30%

detector and electronics

position of focal spot (TM)
calculus of the focal spot position
detection efficiency (2D, Monte Carlo)
anticoincidence (anti-Compton)

~25 Crab photons "detected"

$E_{\text{peak}} = 169.6$ keV

FWHM = 7.9 keV
CLAIRE 2001: primary (detector) and fine (Crab) pointing

primary pointing  lens  fine pointing

Ge matrix
offset

oscillations

optical axis

Crab
offset
oscillations
CLAIRE 2001: Crab fine pointing

Crab position within CLAIRE’s "field of view"

~ 3h40 exposure (pointing < 90 ”)

Problem: offset due to non-parallelism of sun-filters...
CLAIRE 2001: Crab fine pointing

Crab position within CLAIRE's "field of view"

Offset correction applied

~ 1h30 exposure (pointing < 90")
search for Crab signal on the focal plane by offsetting detector position ... (fishing expedition)
CLAIRE 2001: primary pointing

primary pointing  lens

oscillations

constraining the possible detector offsets after reassembling CLAIRE in 2003
CLAIRE 2001: detection of the Crab

detection of 30 photons
(3.7 $\sigma$ signal w/o number of trials)

139 keV BG line

198 keV BG line
is the lens performing as expected for sources at infinity?

source at 14.2 m
E = 122 keV

"tuning beamline" at CESR Toulouse
is the lens performing as expected for sources at infinity?

![Graph showing energy distribution with sources at 14.2 m (E = 122 keV) and 170 keV.]
CLAIRE TGD : Ordis, Catalunia, 19-23 May 2003
CLAIRE TGD: looking at a source at quasi-infinite distance

- Source at 14.2 m, E = 122 keV
- Source at 205 m, E = 165 keV
- Source at 170 keV
CLAIRE TGD: looking at a source at quasi-infinite distance

- Source at 14.2 m, $E = 122$ keV
- Source at 205 m, $E = 165$ keV
- Source at 170 keV

4.1 keV
gamma-ray astronomy is beginning to see

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