How to Build an Entire Mission

The INTEGRAL Mission
from initial proposal to first scientific results

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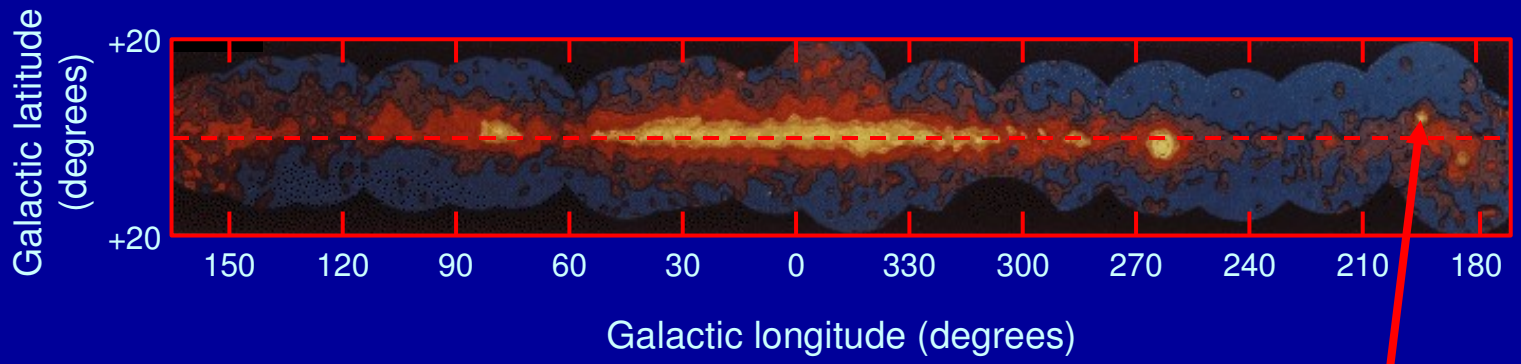
Observing the X- and Gamma-ray Sky

4 April 2006

The roots of the mission

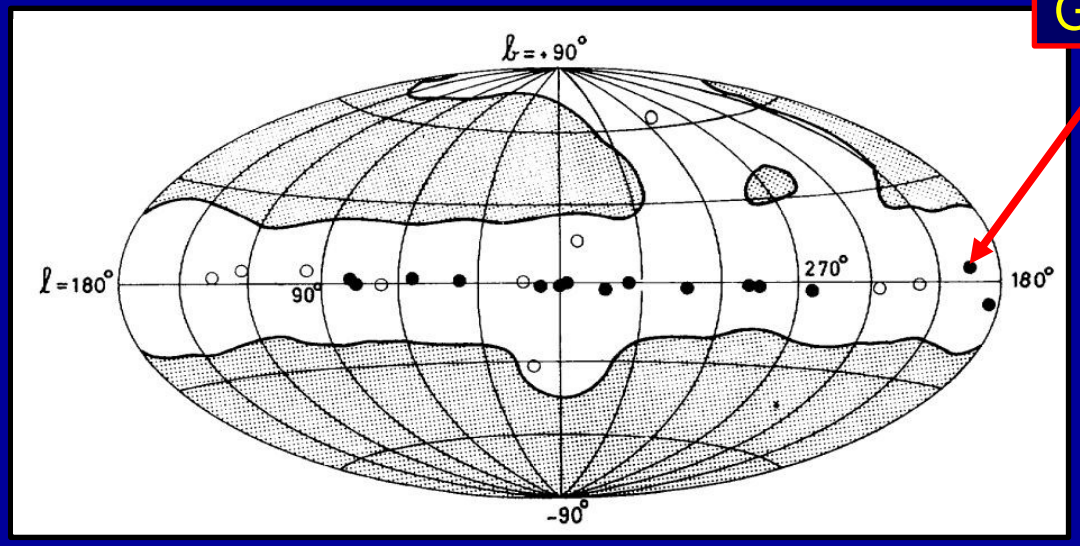
Gamma-ray source study

Gamma-ray source study in the COS-B era



Mayer-Hasselwander et al, A&A 107, 390, 1982

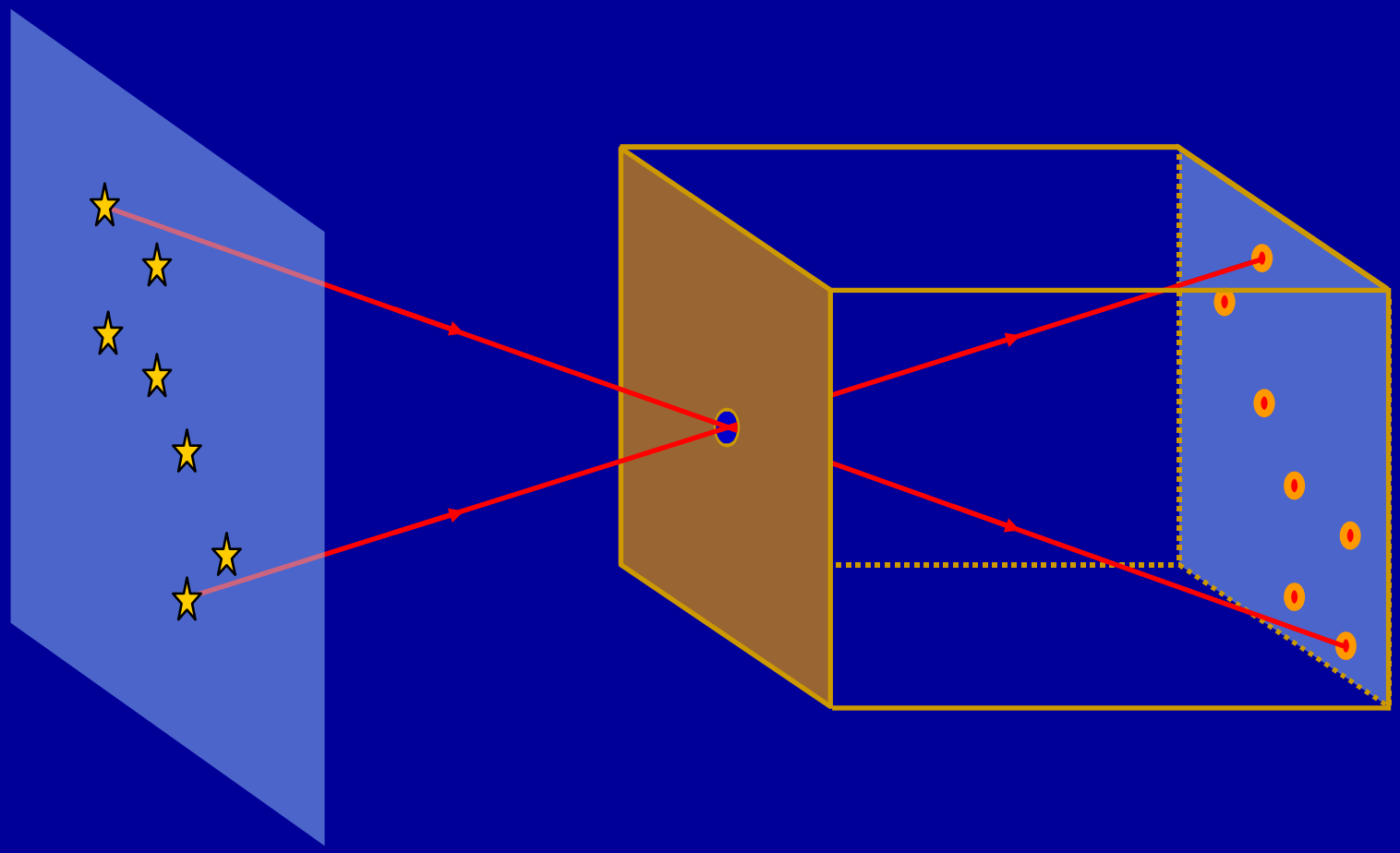
Geminga



Swanenburg et al, ApJ 243, 69, 1981

A first decisive innovation

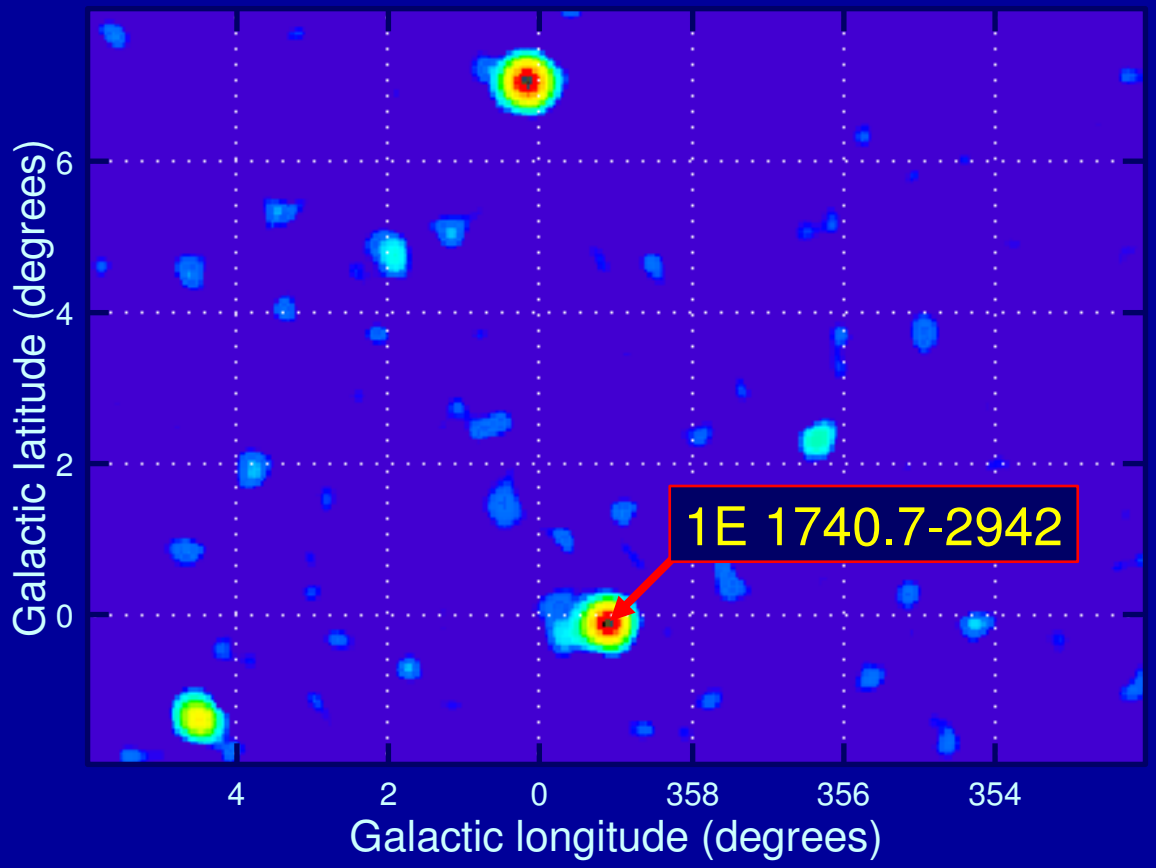
To use the coded-aperture technique for gamma-ray astronomy



First gamma-ray coded-mask telescope in space

The French telescope SIGMA aboard the Russian satellite GRANAT
Paul et al., Adv. & Sp. Res. 11, (8)289, 1991

Discovery of the first microquasar



Mirabel et al., Nat 358, 215, 1992

How to do even better ?

Solutions to do better…

Increase the angular resolution

Increase the spectral resolution

Solution: two instruments

Increase the sensitivity

Increase the spectral domain

Solution: two large instruments

Increase complexity

Increase costs

Solution: international cooperation

Framework: the European Space Agency

Project assumed name: INTEGRAL

INTEGRAL selection milestones

1989 *INTEGRAL is proposed in the framework of the announcement of opportunity for the M2 ESA medium size mission*

1990 *INTEGRAL ranks among the 8 missions selected for a preliminary feasibility study*

1991 *INTEGRAL ranks among the 4 missions selected for a full phase A study*

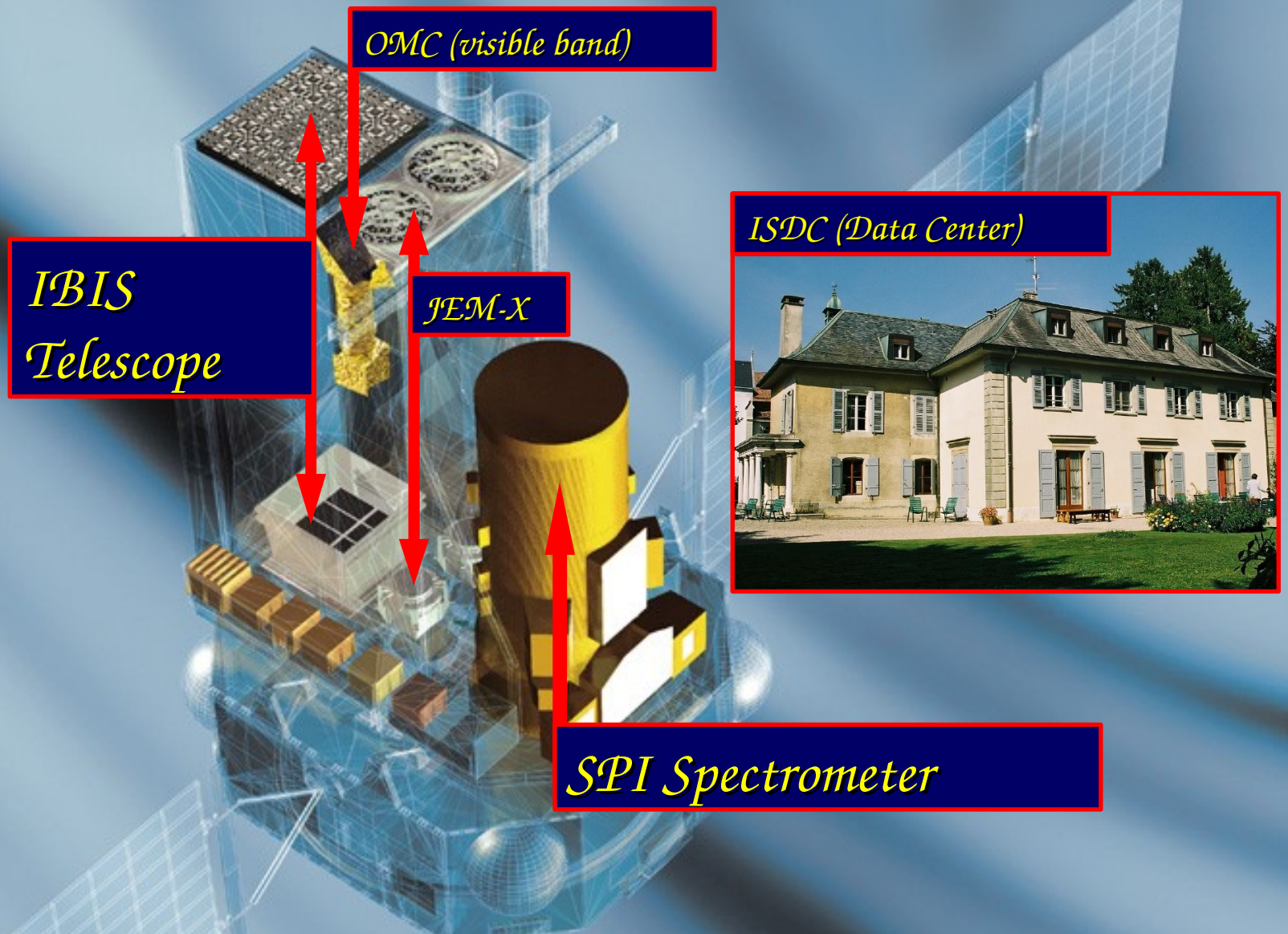
1993 *INTEGRAL is selected by the ESA Science Program Committee*

1994 *ESA announcement of opportunity for the INTEGRAL payload*
US and UK withdraw their contribution to the payload

1995 *INTEGRAL payload selection: France, Germany and Italy*
Compensate US and UK withdrawal

1995 *National Agencies endorse participation to INTEGRAL*

Selected INTEGRAL payload



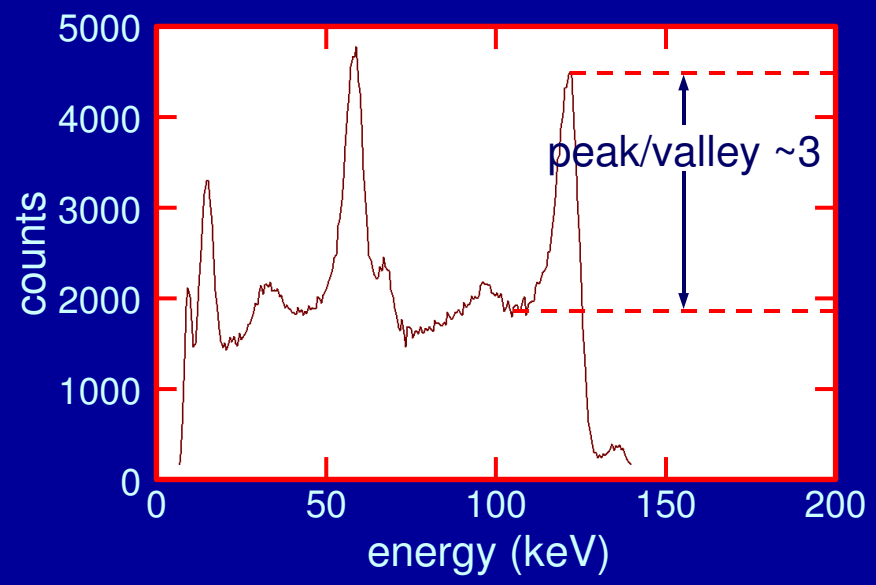
Development phases

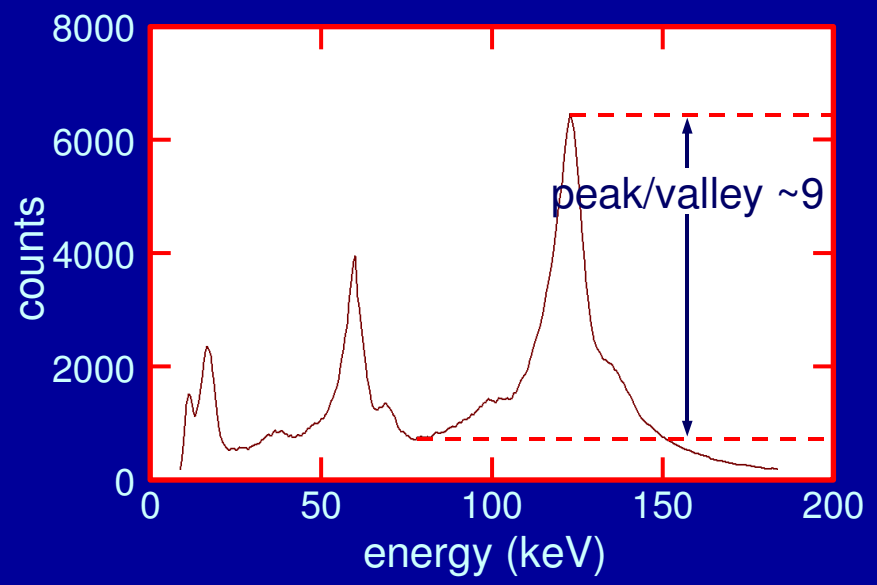
IBIS/ISGRI detector plane

A second decisive innovation

*To use cadmium telluride (*CdTe*), a material ideally suited to build a hard X-ray and low-energy gamma-ray detector plane*

- *High Z (*Cd: 48, Te: 52*) good for photoelectric effect*
- *High density (*~6*) good for compactness*
- *High resistivity (*10^9 cm*) at room temperature*





IBIS/ISGRI development milestones

1992 *First studies of a CdTe detector*

1993 *First studies of the production of a CdTe low-energy detector plane for INTEGRAL*

1995 *Selection of the IBIS telescope with a CdTe detector plane*

1997 *Mechanical and thermal model of the ISGRI detector plane*

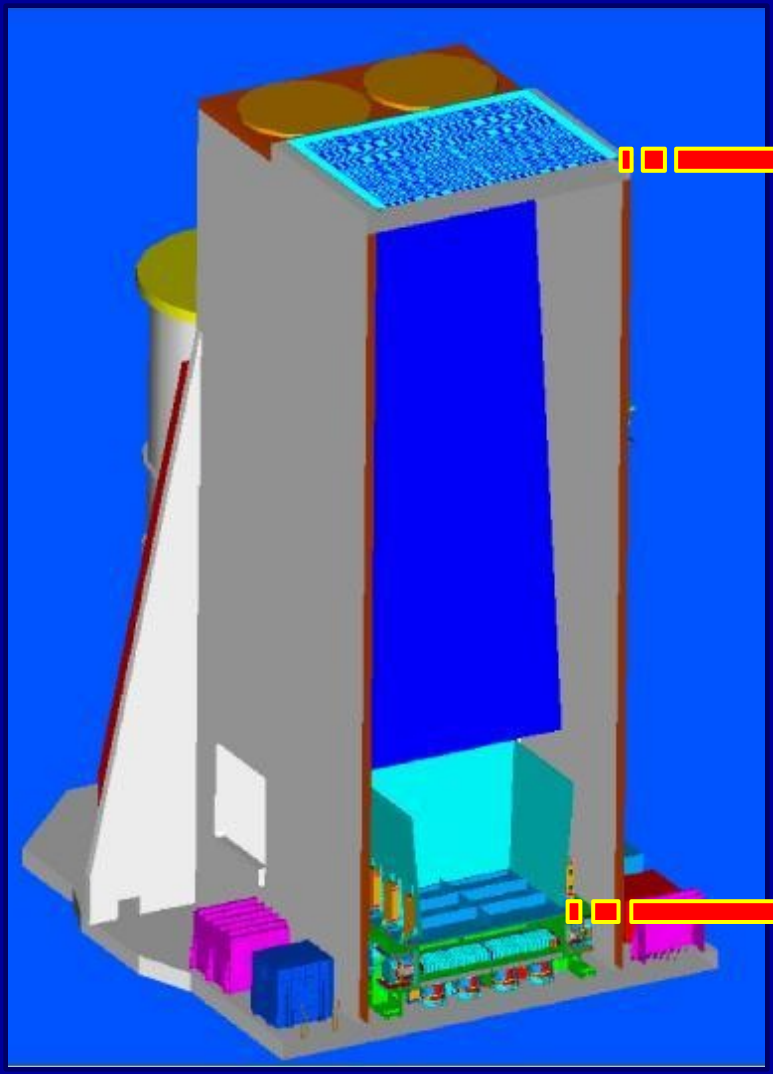
1998 *Electrical model*

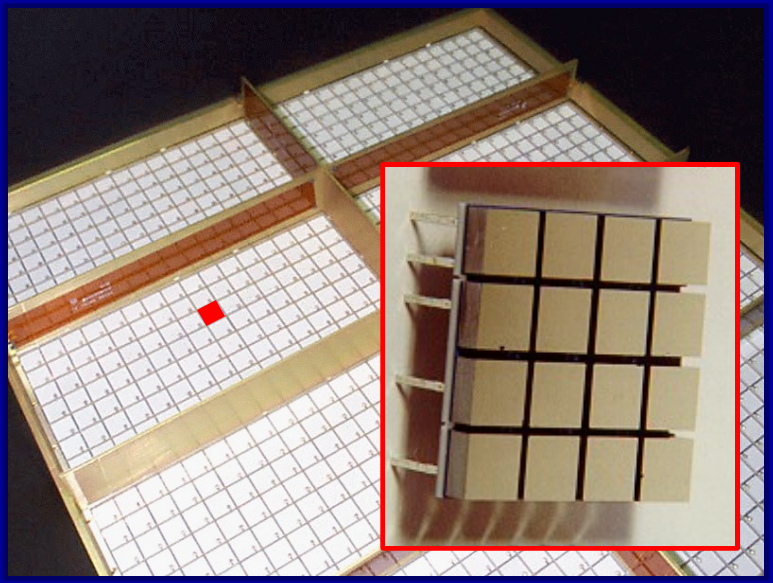
1999 *Qualification model*

2001 *Flight model*

2001 *ISGRI integration within the IBIS telescope*

IBIS: an imager also able to make spectra

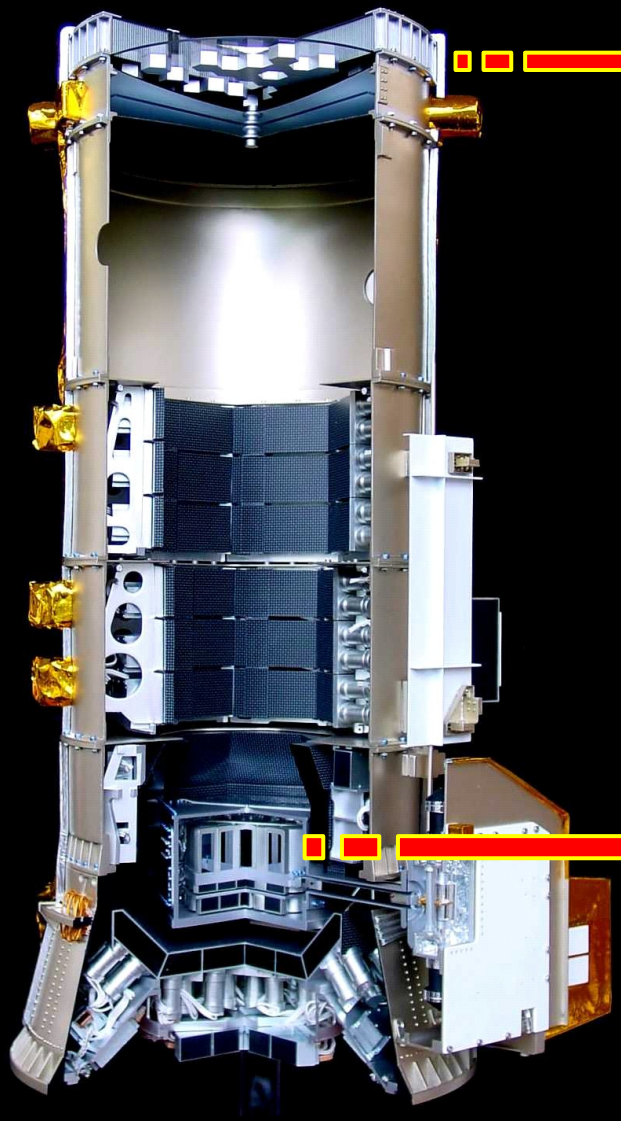


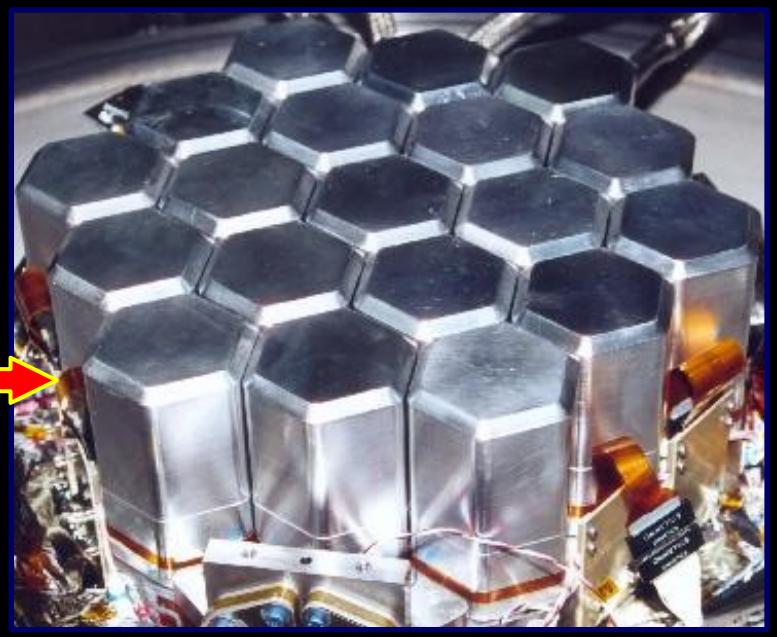


Ground calibrations

The spectrometer SPI

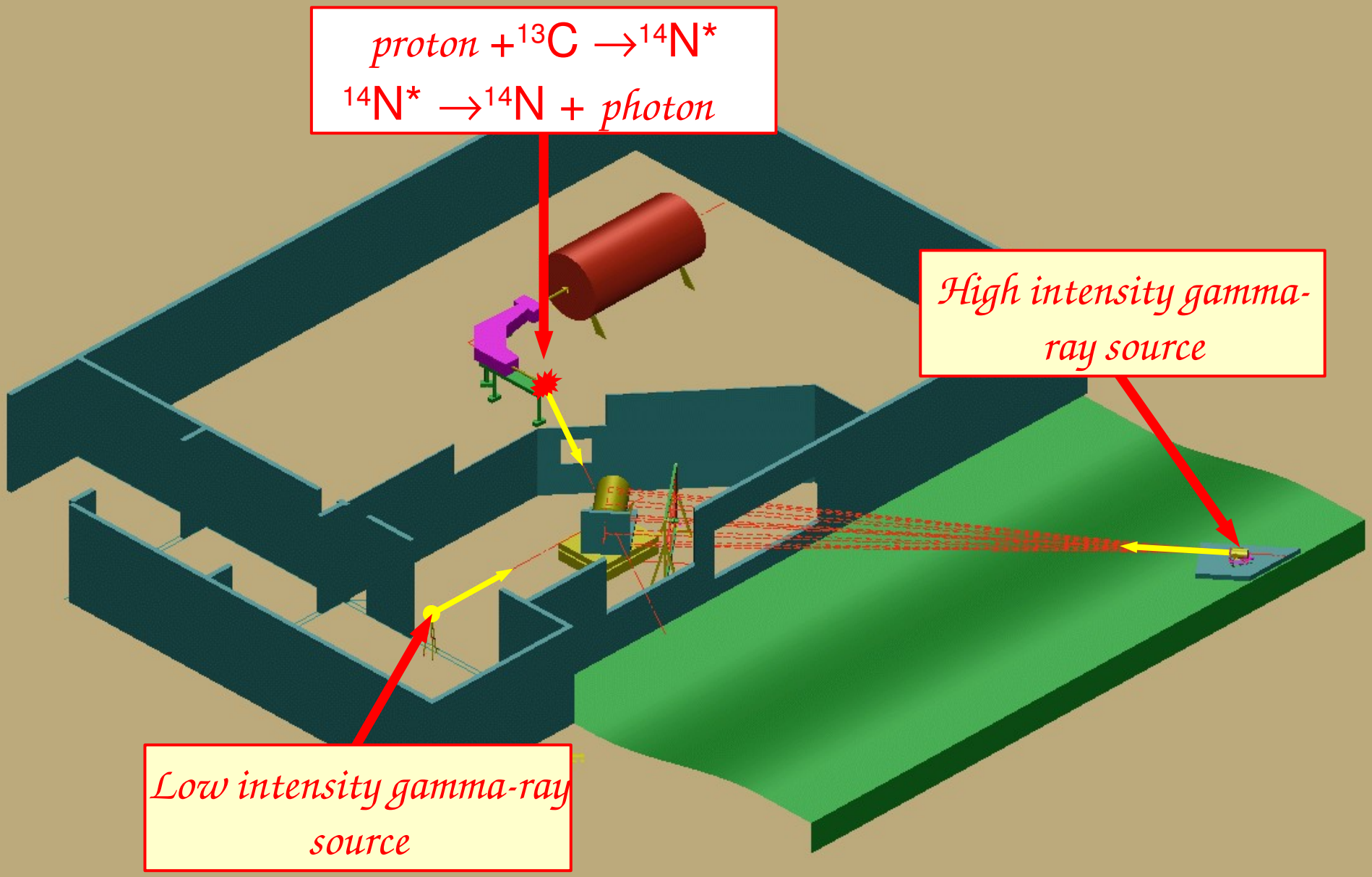
SPI: a spectrometer also able to make images





March/April 2001

Bruyères-le-Châtel (France) SPI calibration


proton + $^{13}C \rightarrow {}^{14}N^*$
$^{14}N^* \rightarrow {}^{14}N$ + *photon*
High intensity gamma-ray source
Low intensity gamma-ray source

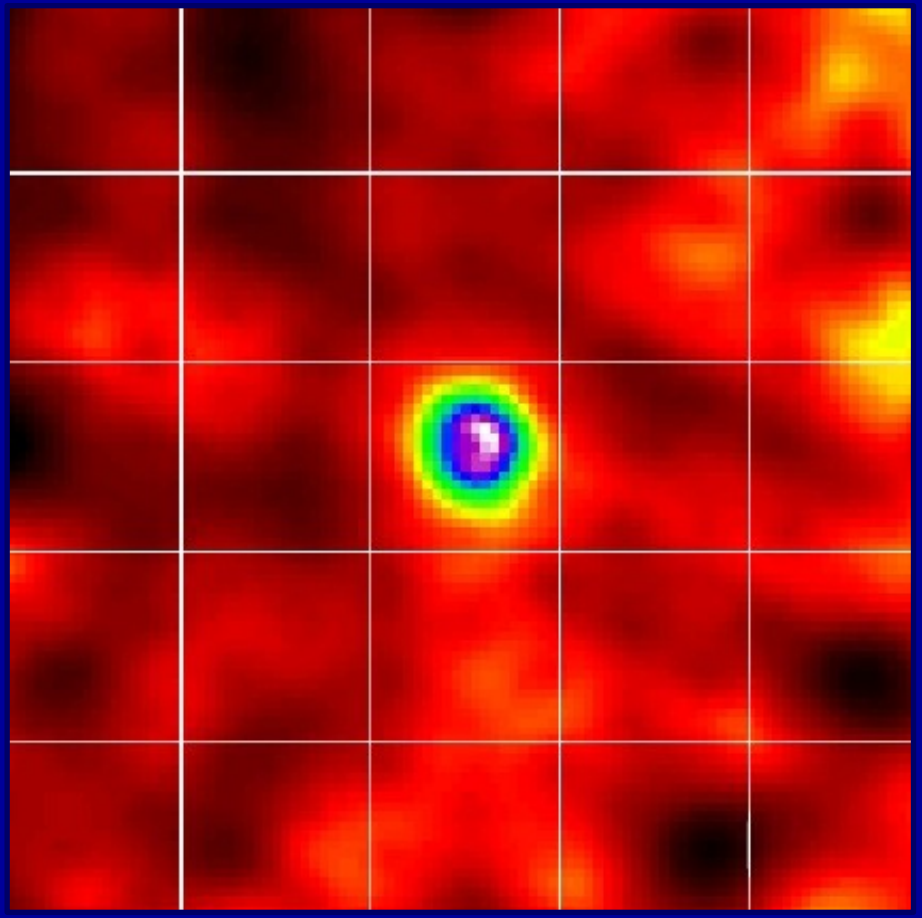
16 April 2001

Saclay (France) making of the ^{24}Na *source (half-life* 15 h*)*

18 April 2001

Opening of the ^{24}Na *source*

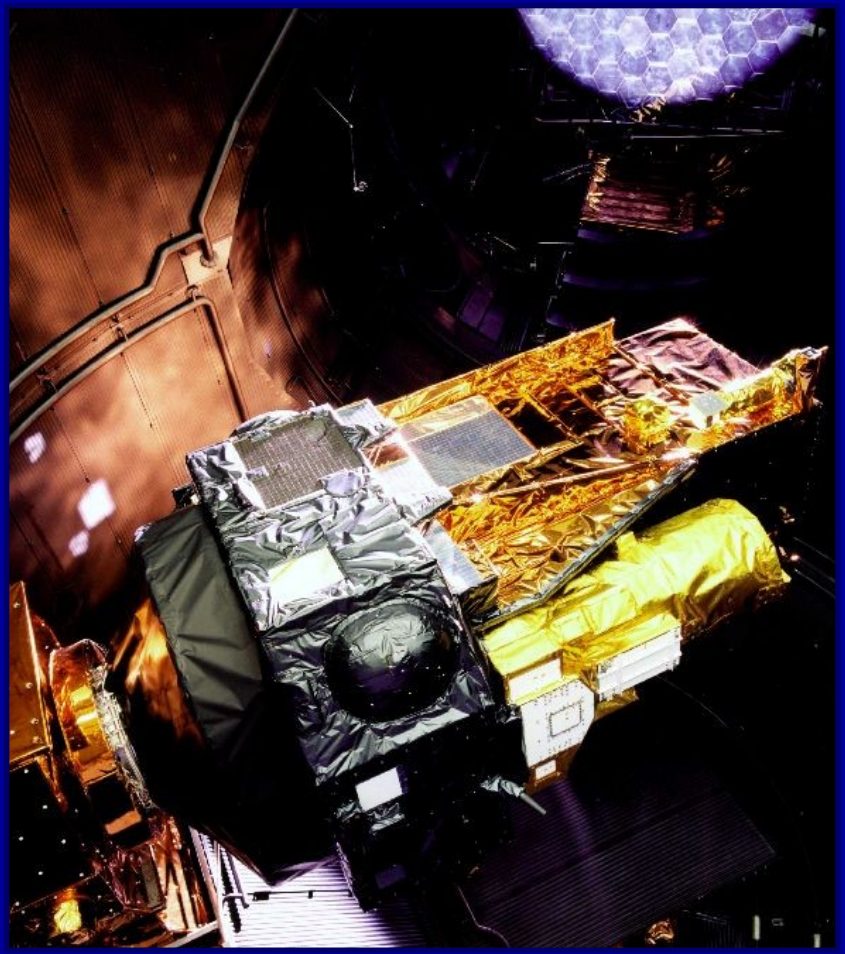
19 April 2001



SPI image of the ^{24}Na *source*

Final phases

February 2002

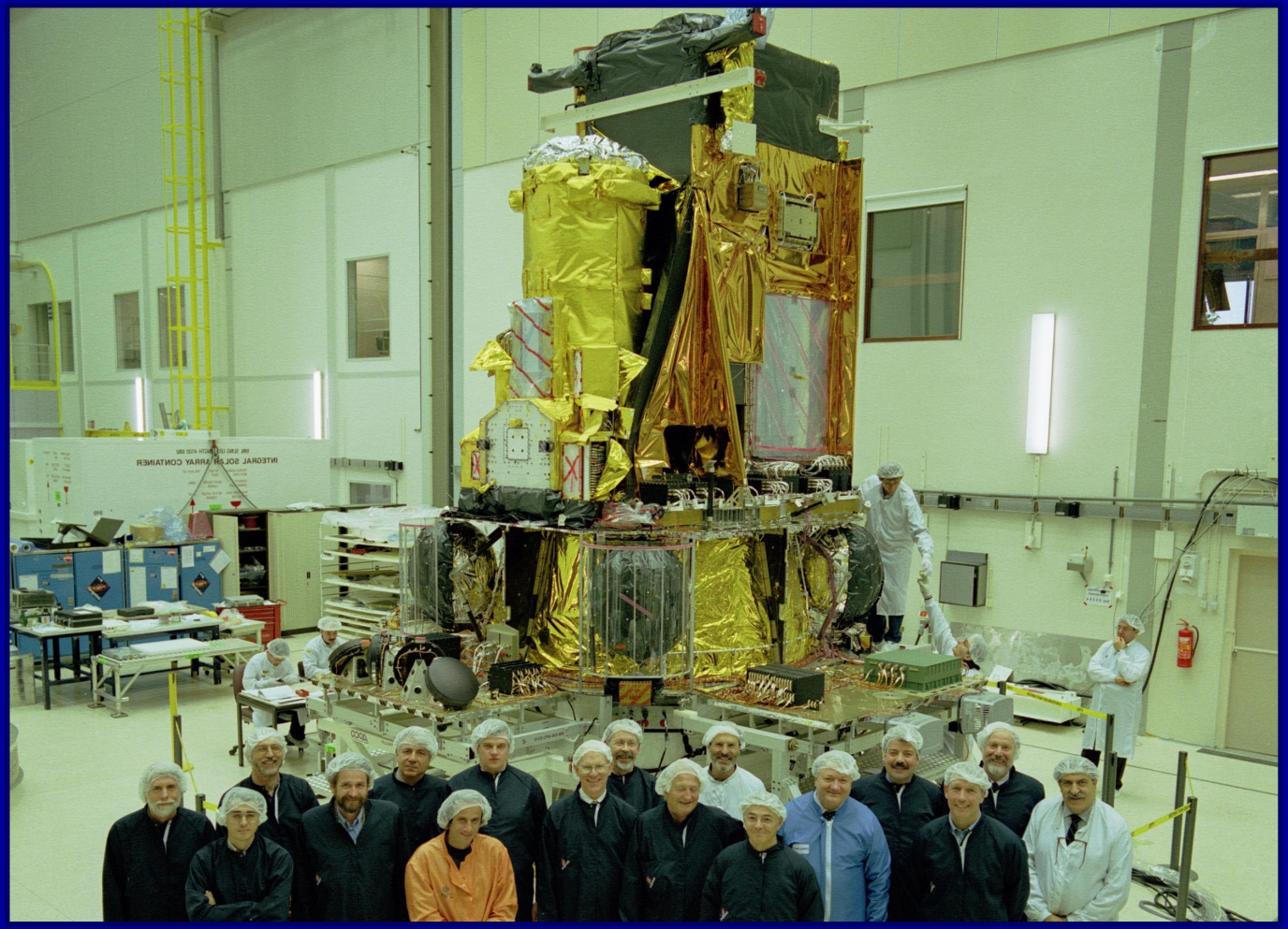


Thermal vacuum test

Vibration test

ESTEC Noordwijk (The Netherlands)

26 March 2002



INTEGRAL ready for flight

24 August 2002

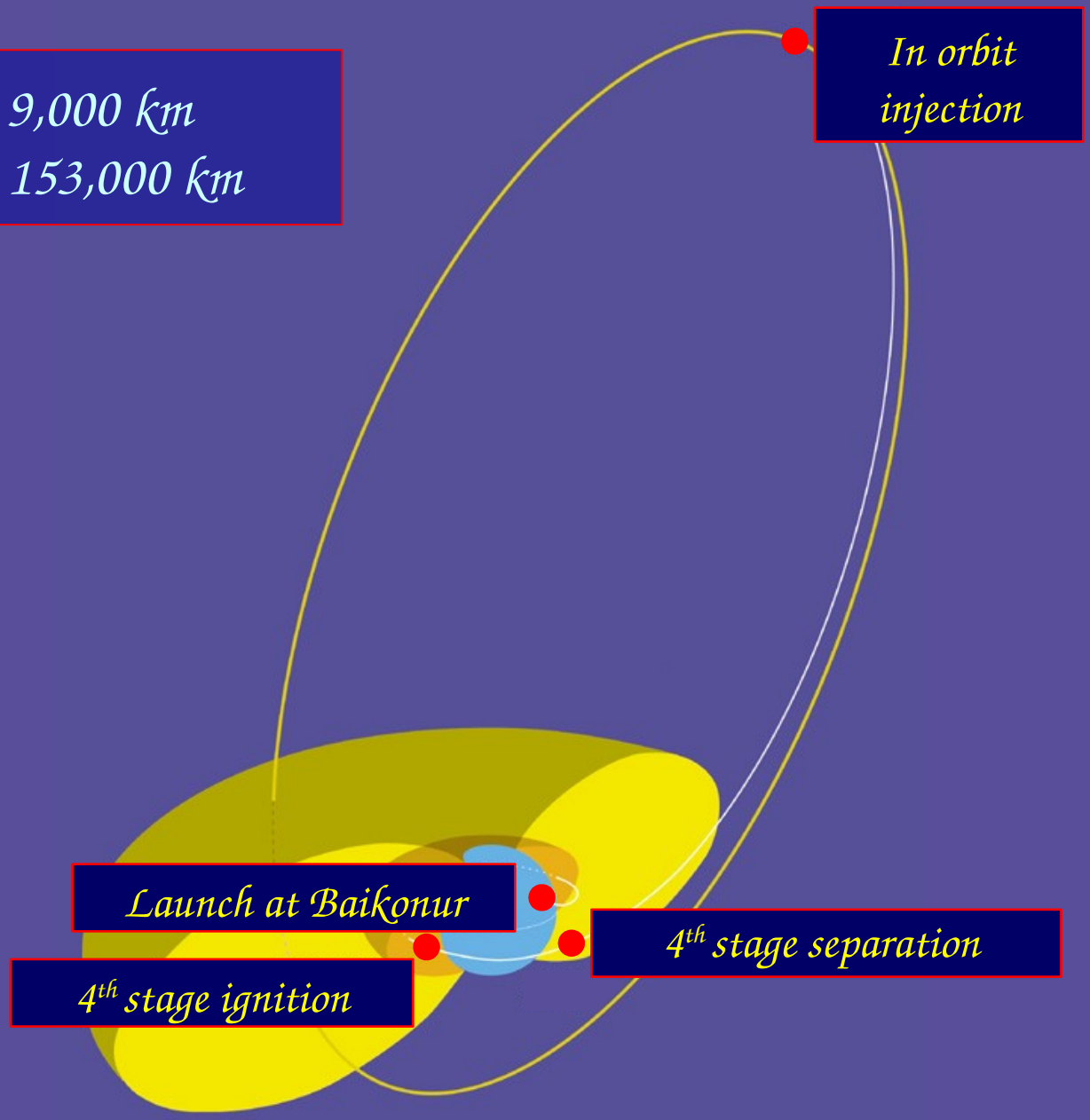
Arrival of INTEGRAL in Baikonur (Kazakhstan)

2 October 2002

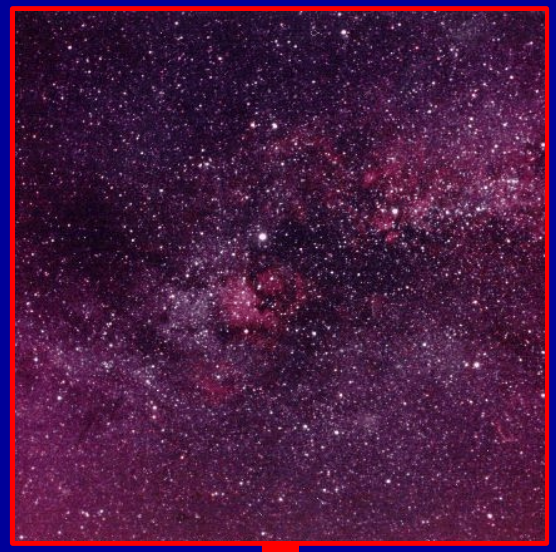
INTEGRAL mounted on the 4th stage

17 October 2002

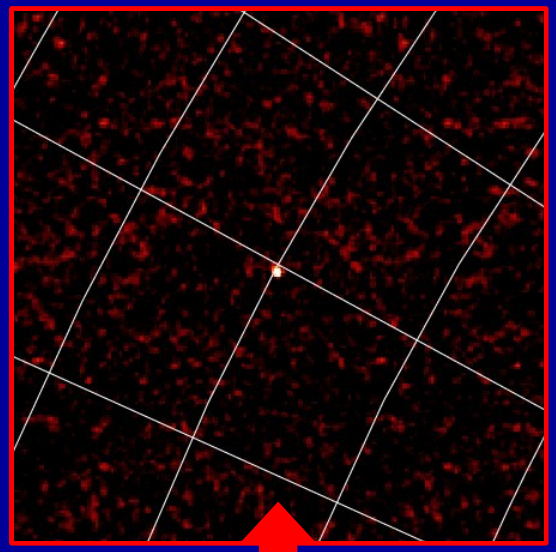
Launch of the PROTON rocket


Perigee: 9,000 km
Apogee: 153,000 km
In orbit injection
Launch at Baikonur
4th stage separation
4th stage ignition

In orbit calibration



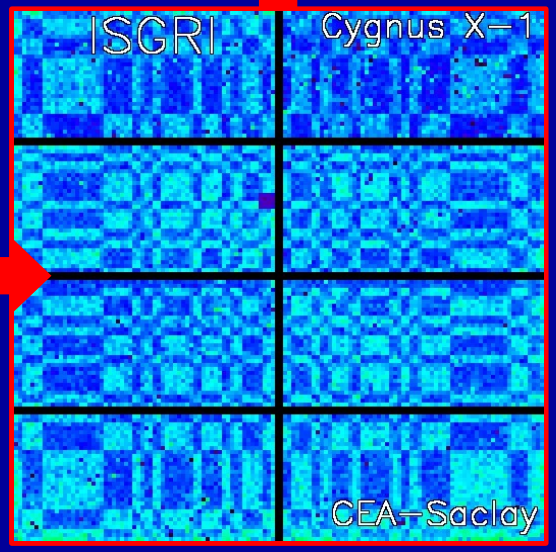
November 2002



Observation

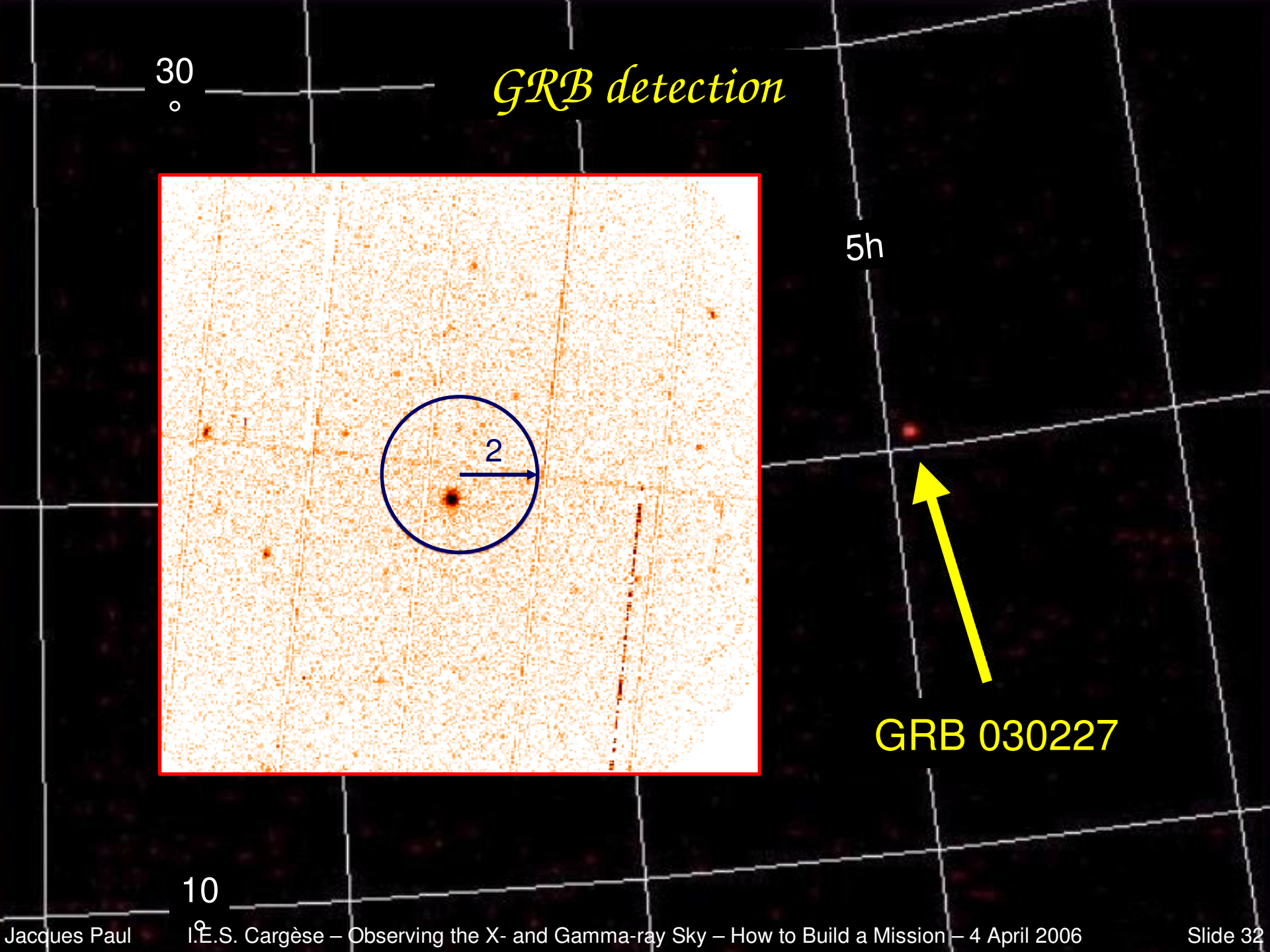
Decoding

Transmission

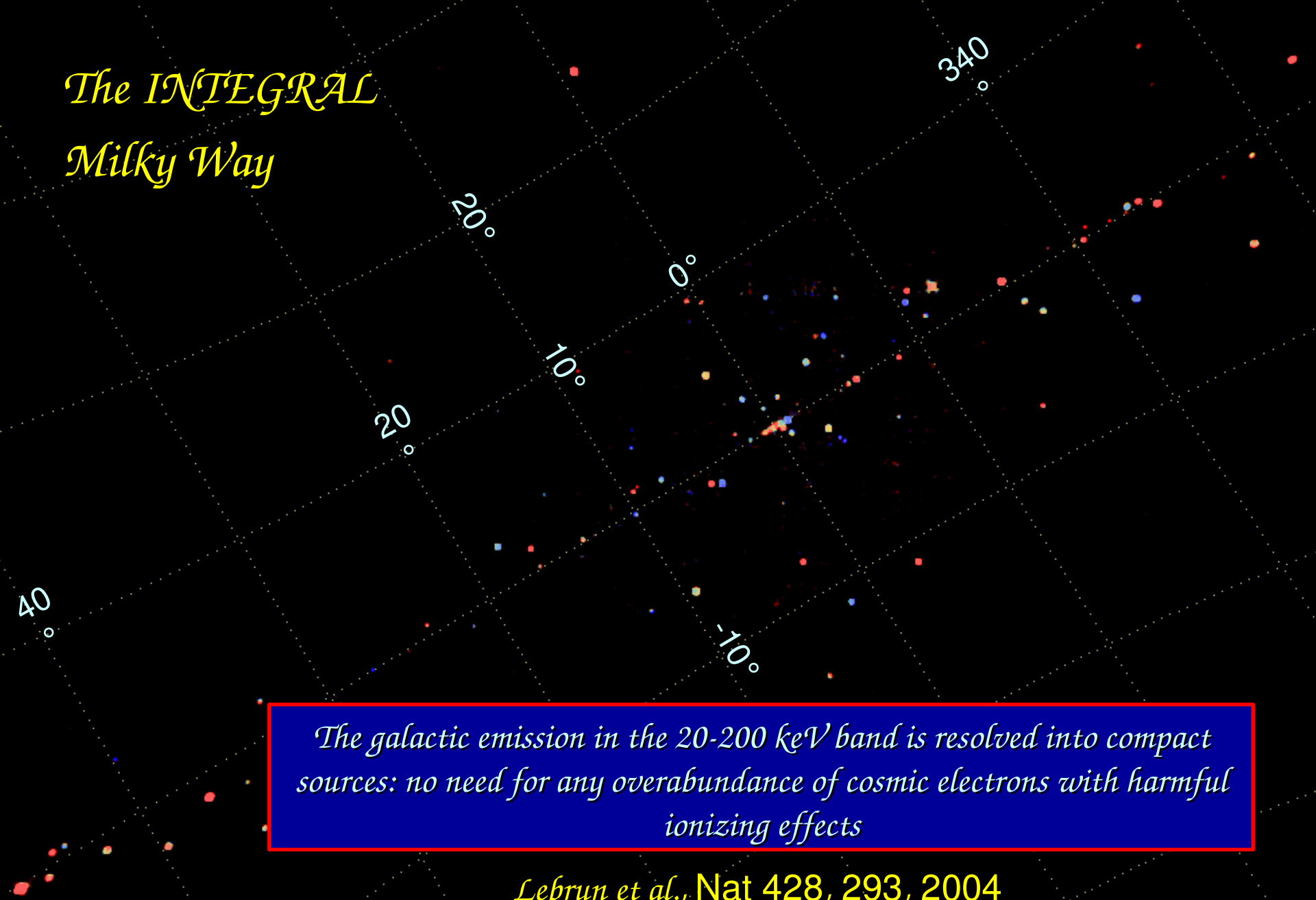


First scientific results

GRB detection



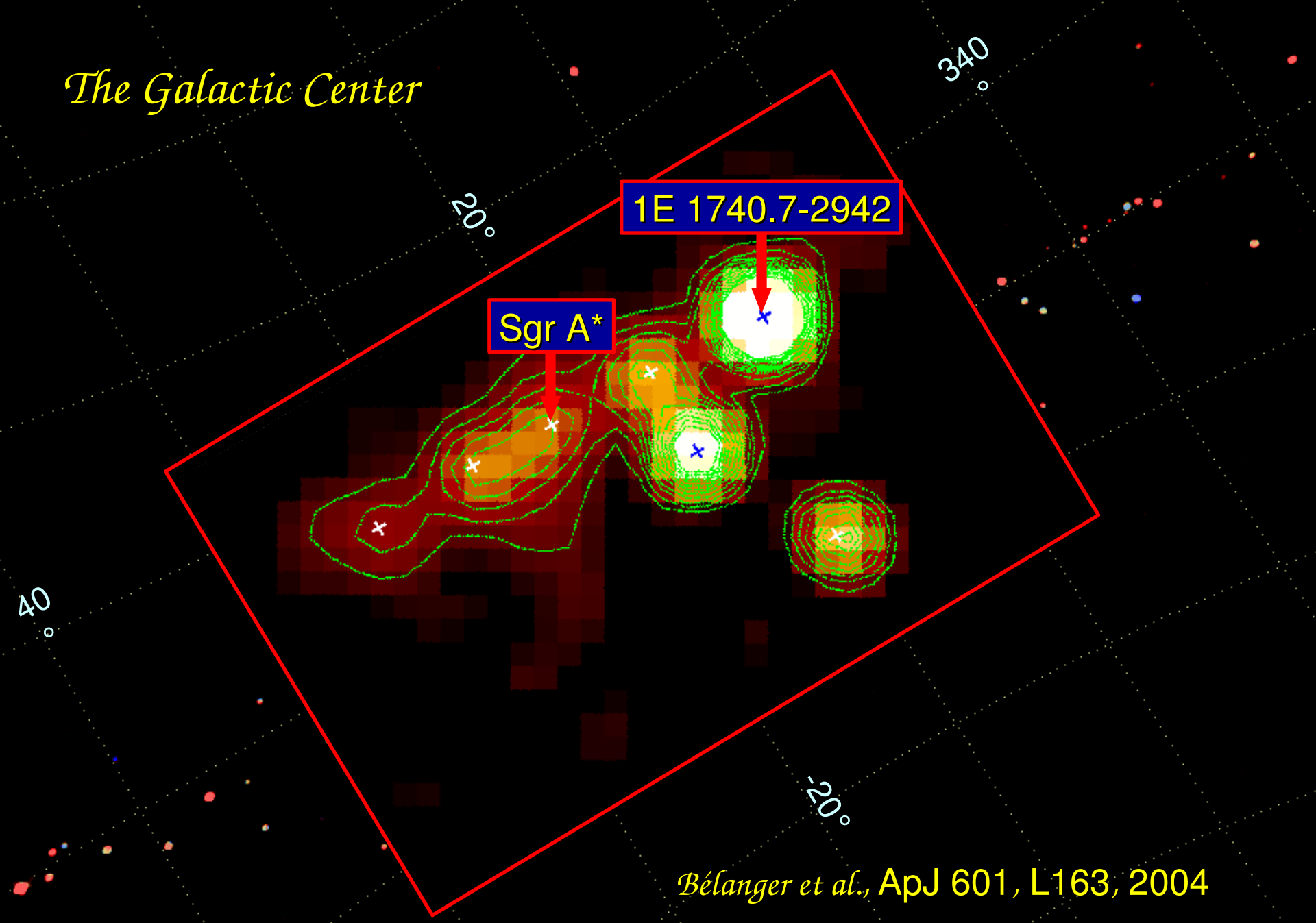
The INTEGRAL Milky Way



The galactic emission in the 20-200 keV band is resolved into compact sources: no need for any overabundance of cosmic electrons with harmful ionizing effects

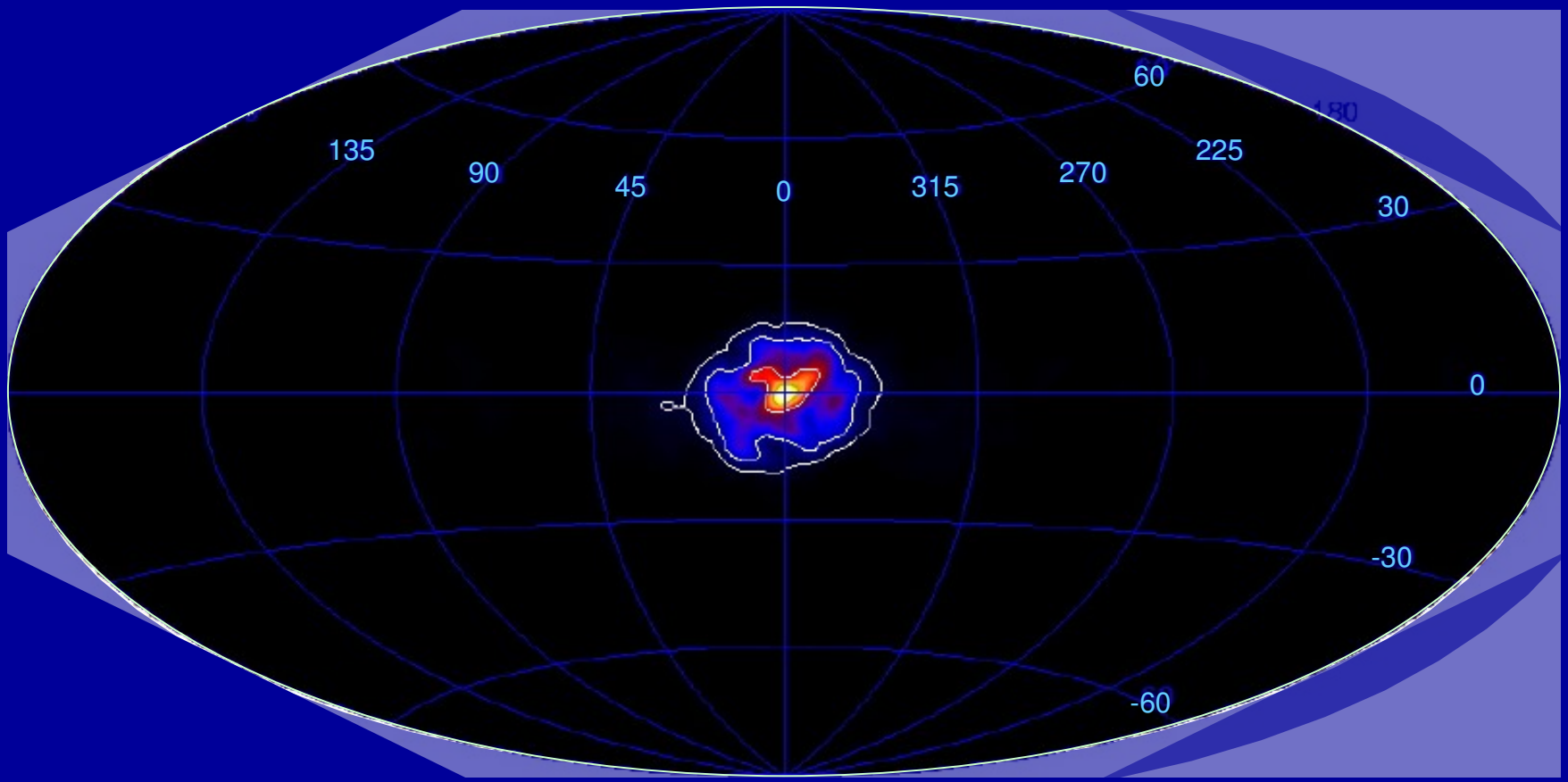
Lebrun et al., Nat 428, 293, 2004

The Galactic Center



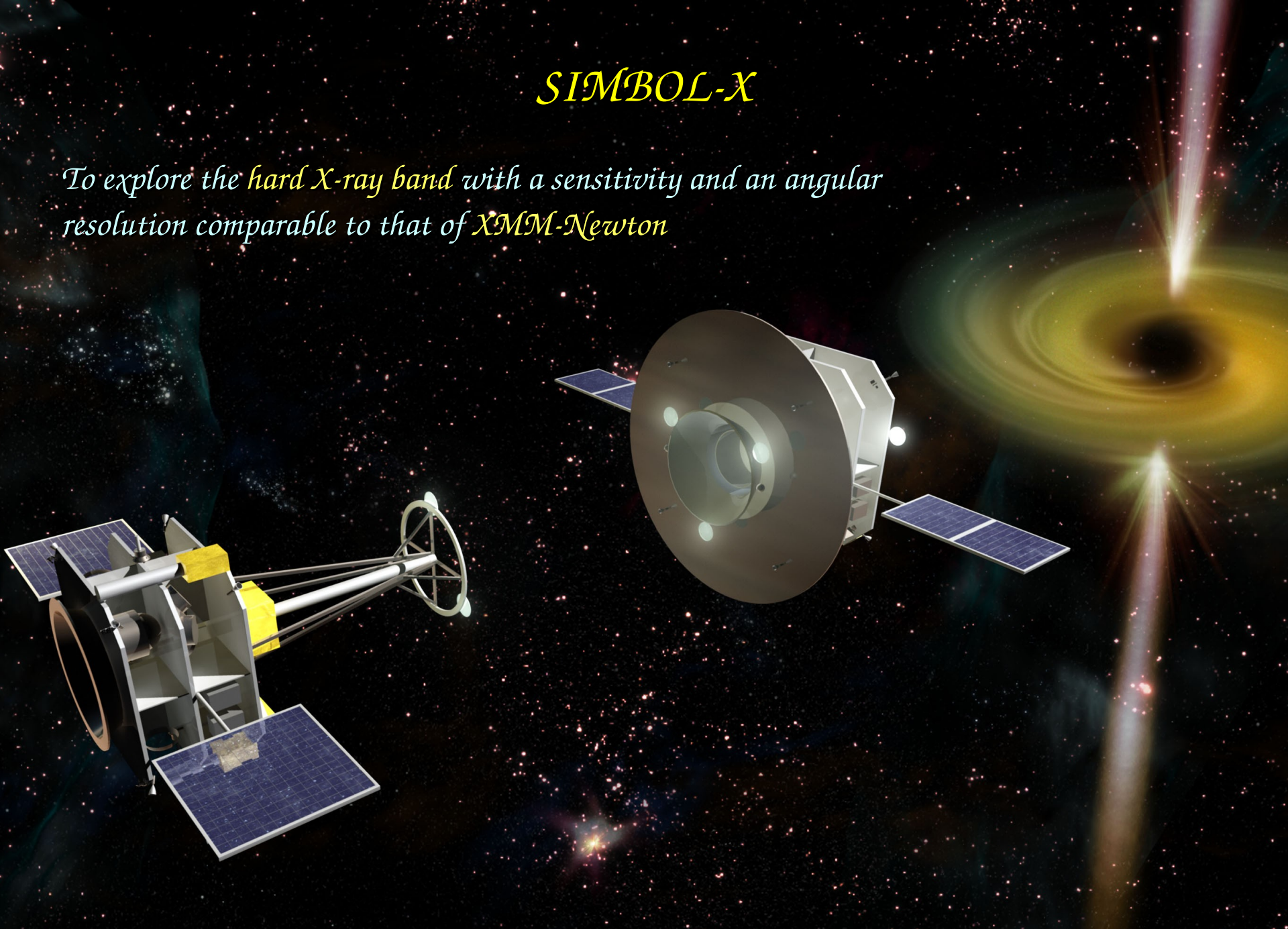
Bélanger et al., ApJ 601, L163, 2004

Galactic 511 keV emission



Knödlseder et al., A&A, in press (Astro-ph/0506026)

There is a life after
INTEGRAL

SIMBOL-X

To explore the hard X-ray band with a sensitivity and an angular resolution comparable to that of XMM-Newton