



The Compton Spectrometer and Imager (COSI) project
(Formerly known as the Nuclear Compton Telescope (NCT) project)

A balloon-borne γ -ray spectrometer, polarimeter & imager

Prototype of a future compact Compton telescope space mission

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The MeV Universe: COSI major scientific goals

- Line emission

positron astrophysics:

the 511 keV line from the galactic center

nucleosynthesis gamma-ray lines:

^{26}Al (1809 keV), ^{56}Co (847, 1238 keV), ^{44}Ti (1157 keV)

Implications on *SN Ia*
and cosmology

- Continuum emission

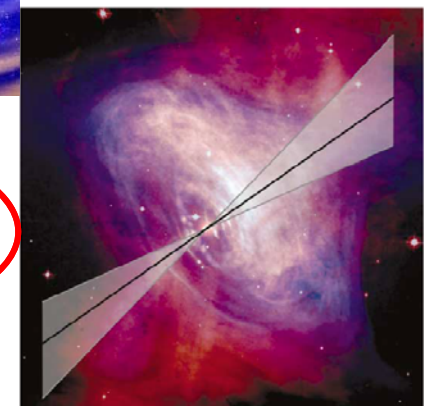
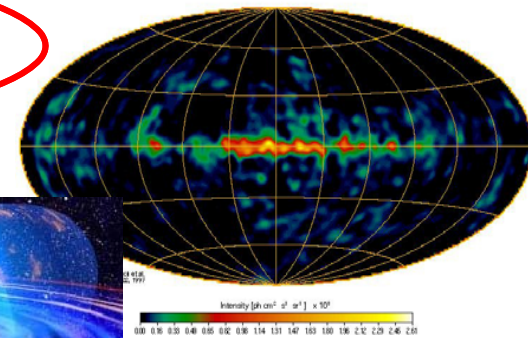
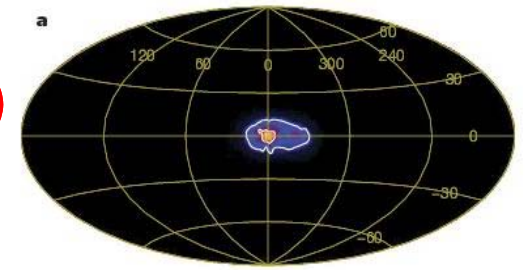
neutron stars, BH binaries, AGN

Gamma Ray Bursts (GRBs)

- Polarization measurements

pulsars and PWNe, GRBs

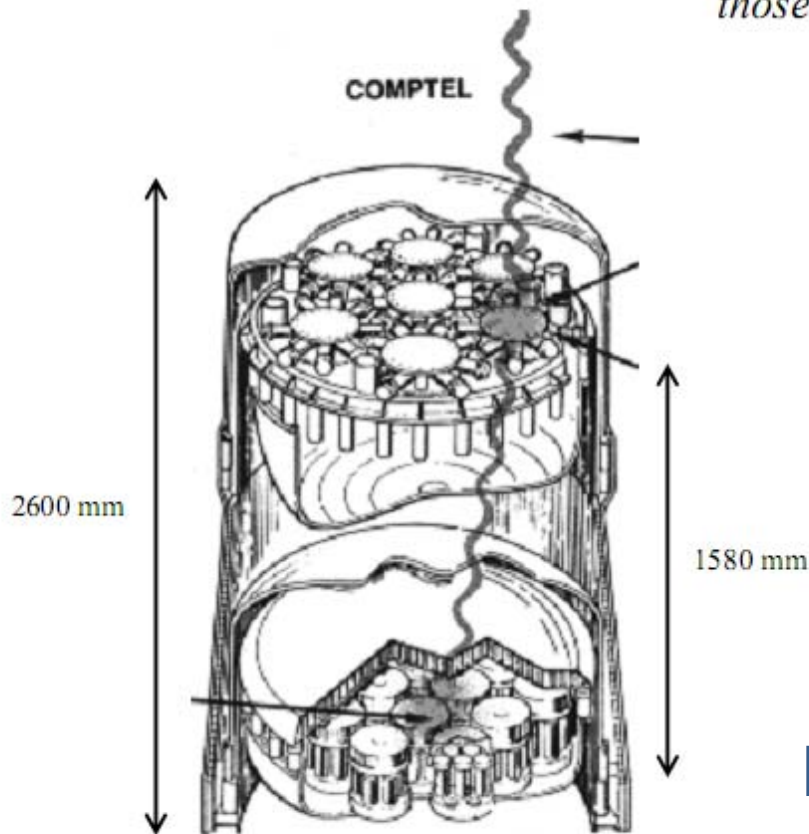
EM counterparts
to GW sources



Introduction – Compton Telescopes (Now/Then)

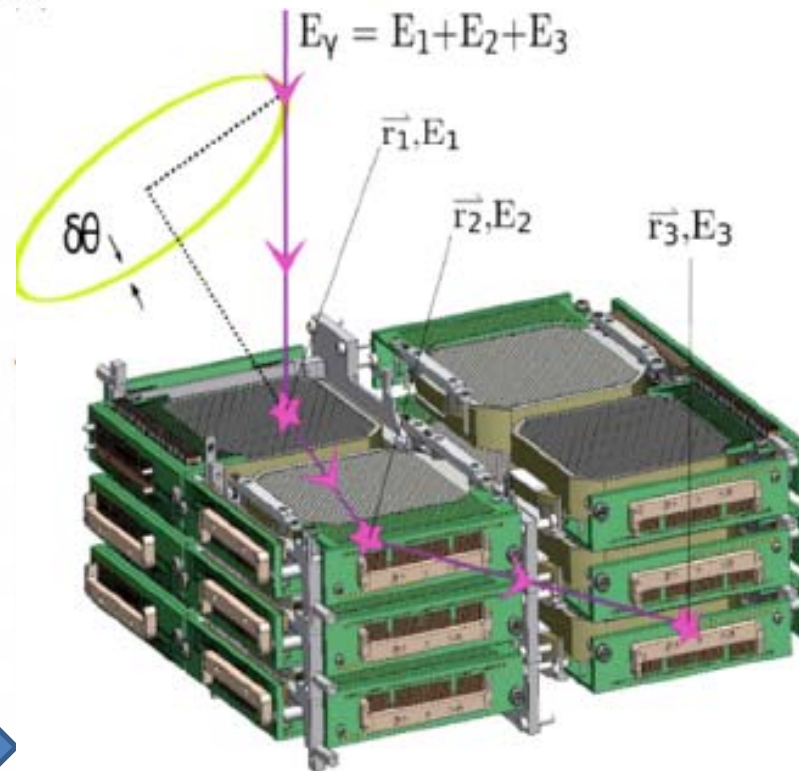


Over 3 decades of advances in γ -ray detector technologies beyond those on CGRO



- CGRO/COMPTEL
- $\sim 40,000 \text{ mm}^3$ resolution
 - $\Delta E/E \sim 10\%$
 - 0.1% efficiency

Improved performance with much smaller mass and volume



- $\sim 1 \text{ mm}^3$ resolution
- $\Delta E/E \sim 0.2\text{-}1\%$
- $\sim 10\%$ efficiency
- background rejection
- polarization

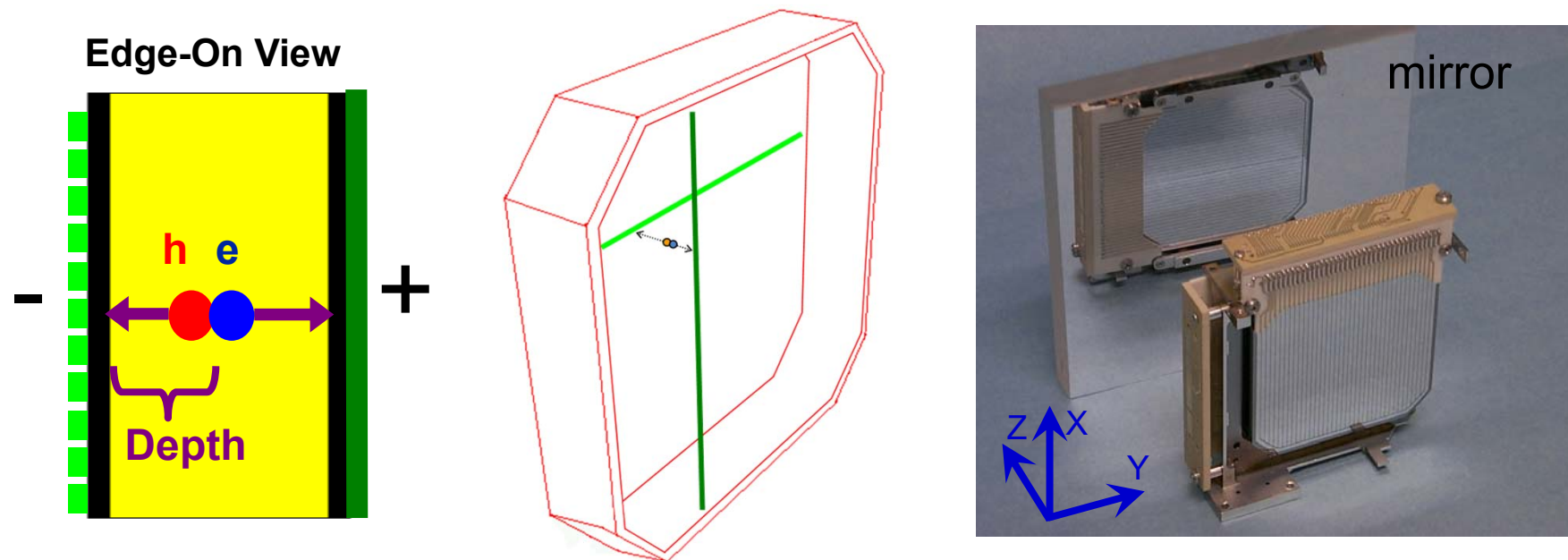
COSI scattering position measurement

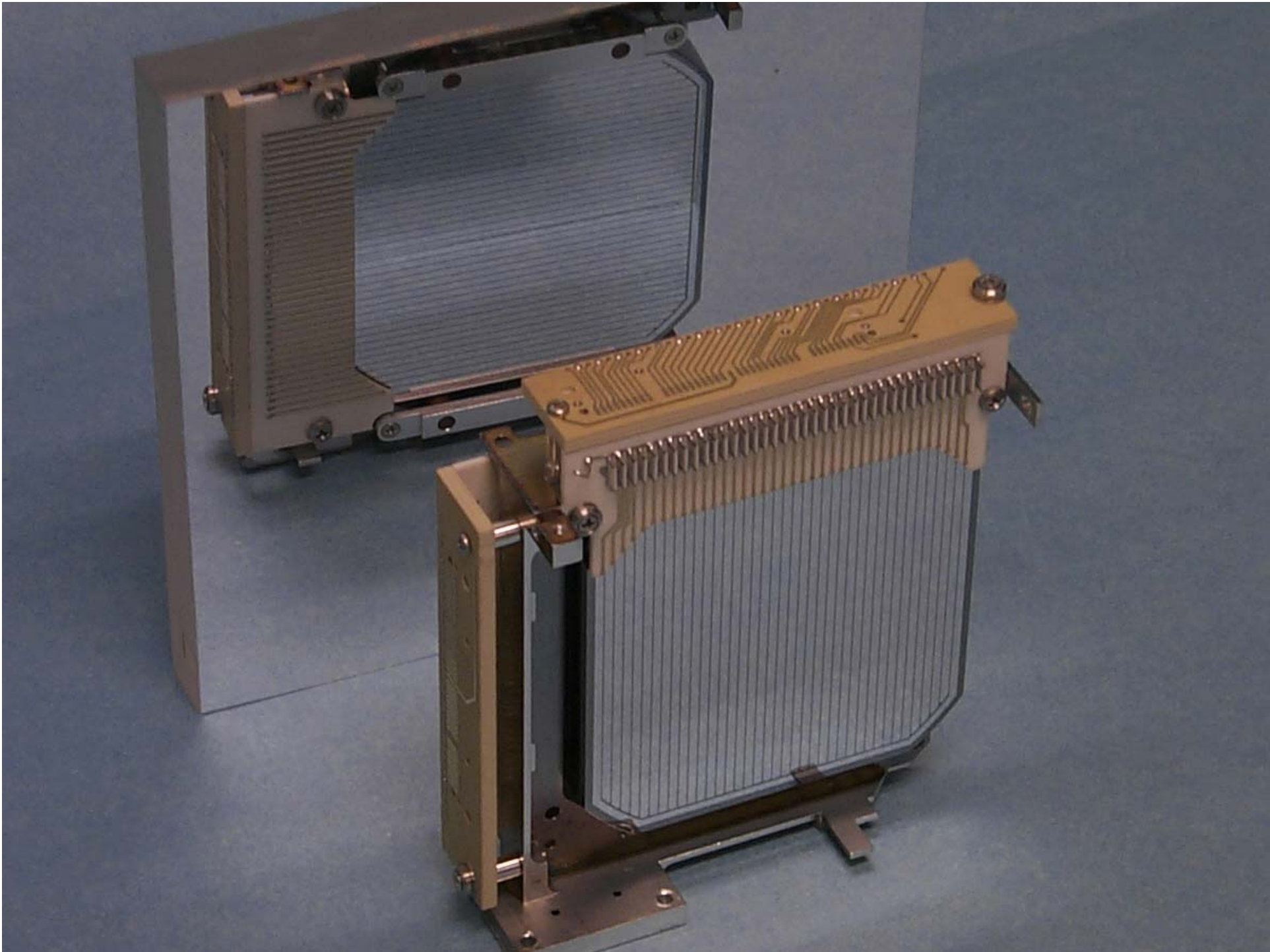
X and Y positions: determined by orthogonal strips

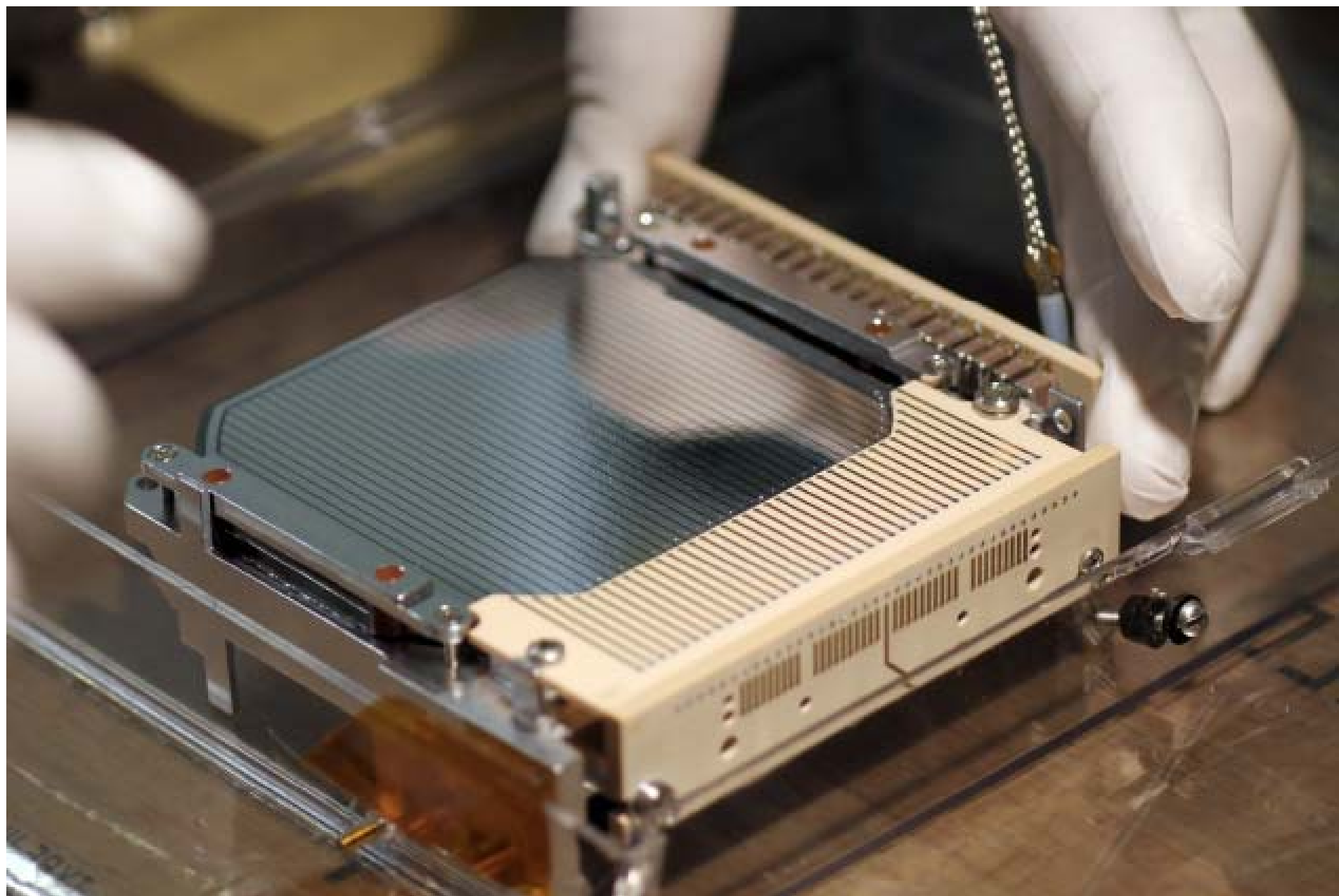
→ Strip pitch: 2 mm (0.25 mm gap)

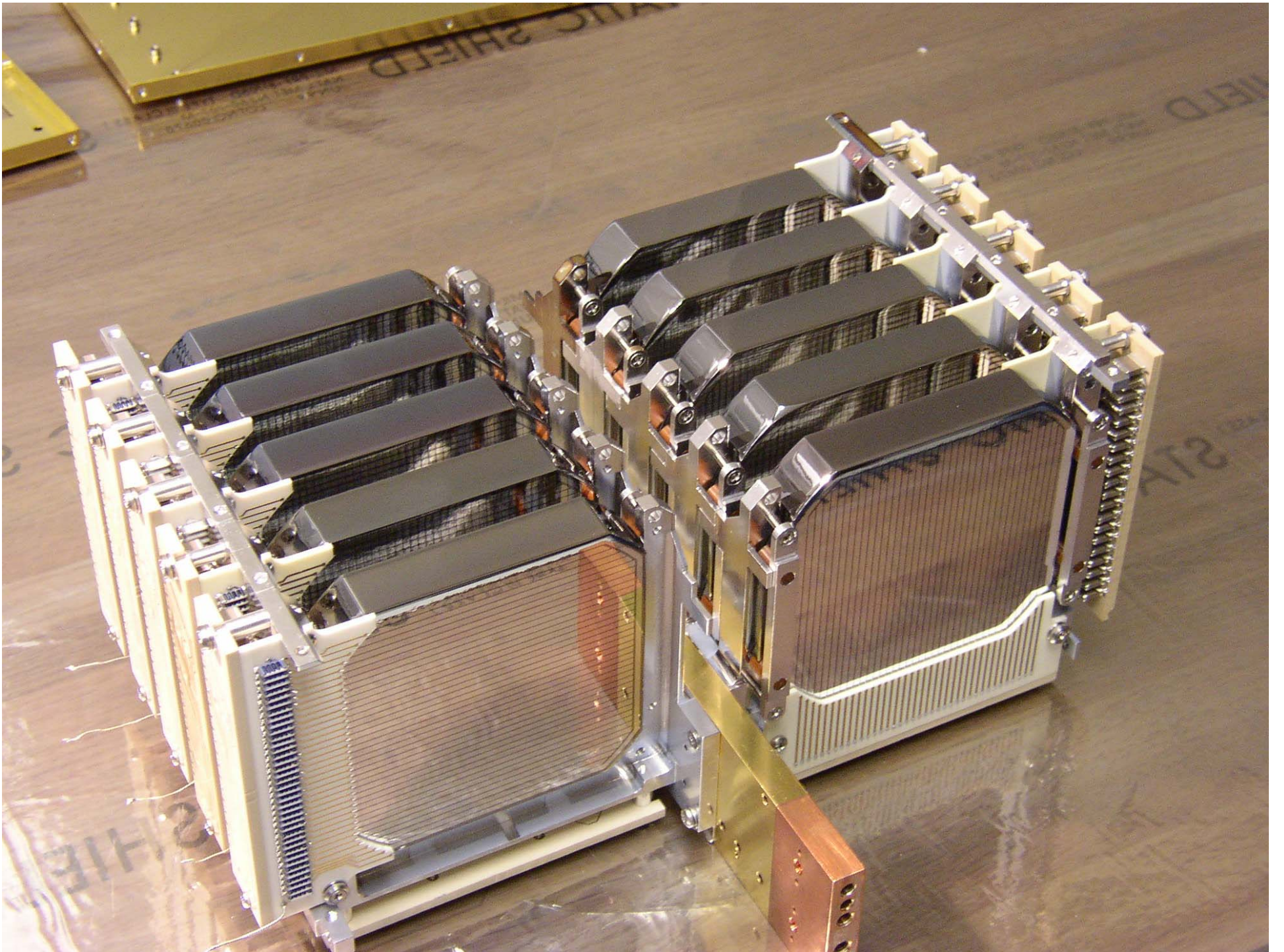
Z position: calculated by time difference between X & Y strips

→ Preliminary (depth) resolution: 0.2 mm









The COSI Collaboration



COSI-TW

NTHU **Chang, Hsiang-Kuang**
Chang, Yi-Chi
Chu, Che-Yan
Tseng, Chao-Hsiung
Yang, Chien-Ying

NCU Chang, Yuan-Hann

AS/Phys Lin, Chih-Hsun

NARL/NDL Shiao, Yu-Shao

Former members include
Chou, Yi (NCU),
Huang, Ming-Huei (NUU)

COSI-US

UCB **Boggs, Steven**
Chiu, Jeng-Lun
Kierans, Carolyn
Lowell, Alex
Sleator, Clio
Tomsick, John
Zoglauer, Andreas

LBNL Amman, Mark
Luke, Paul

France

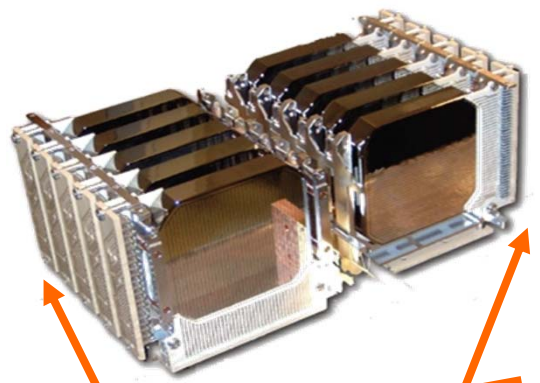
IRAP Jean, Pierre
von Ballmoos, Peter

COSI stratospheric balloon flights

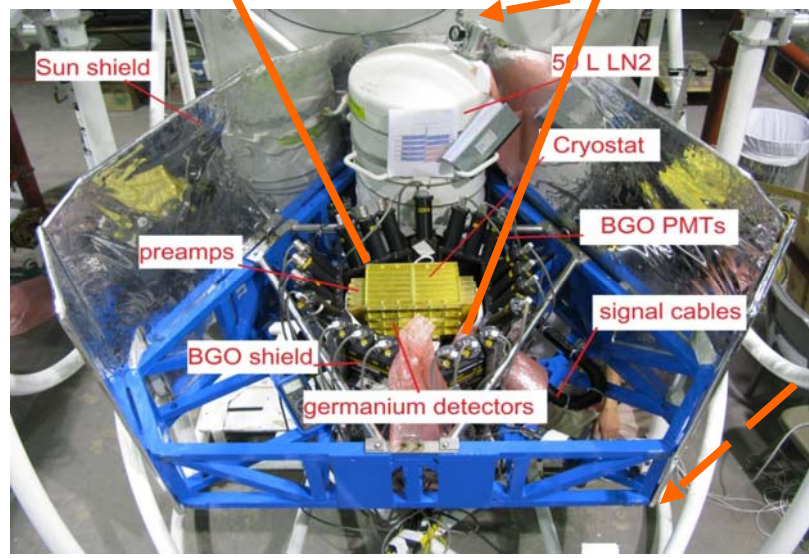
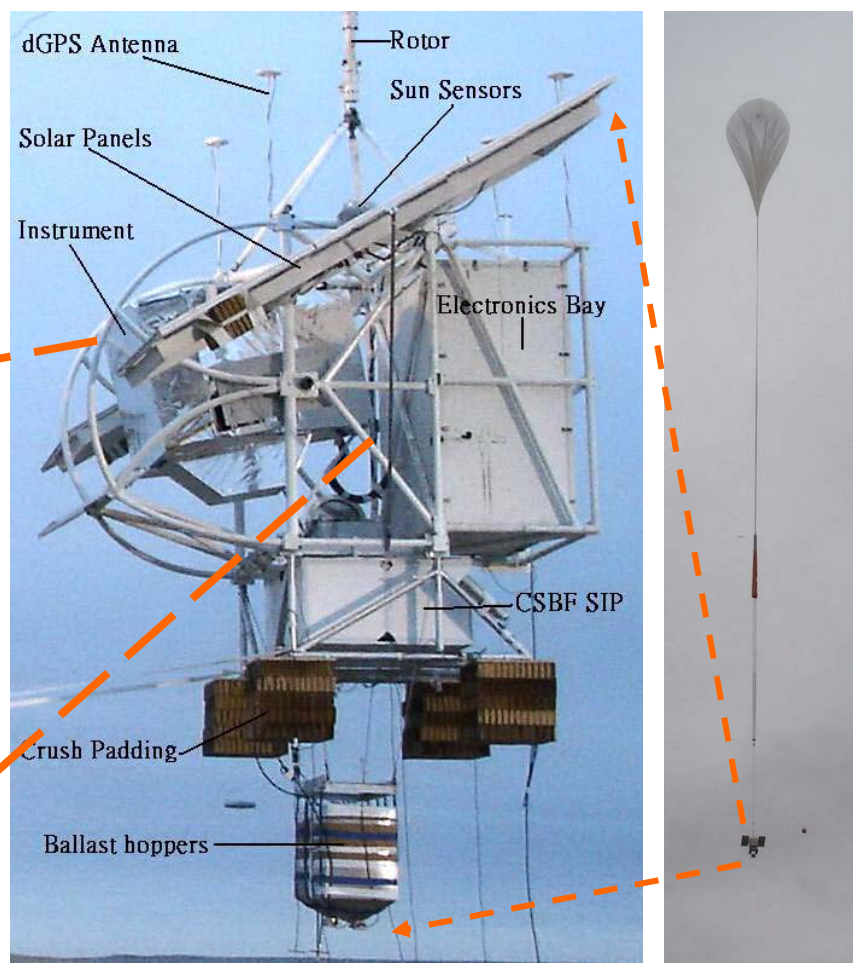
Launch date	Launch location	Primary target	Duration	# of GeDs
June 1, 2005	Ft. Sumner, NM, USA	background	8.5 hours	2
May 17, 2009	Ft. Sumner, NM, USA	Crab	38.5 hours	10
April 29, 2010	Alice Springs, Australia	Galactic center	crashed	10
Dec. 29, 2014	McMurdo, Antarctica	GRB	44 hours	12
May 17, 2016	Wanaka, New Zealand	Galactic center	47 days	12
Spring 2019	Wanaka, New Zealand	Galactic center	~ 100 days	12

NCT 2009 flight, NM, USA

Germanium Detector Array

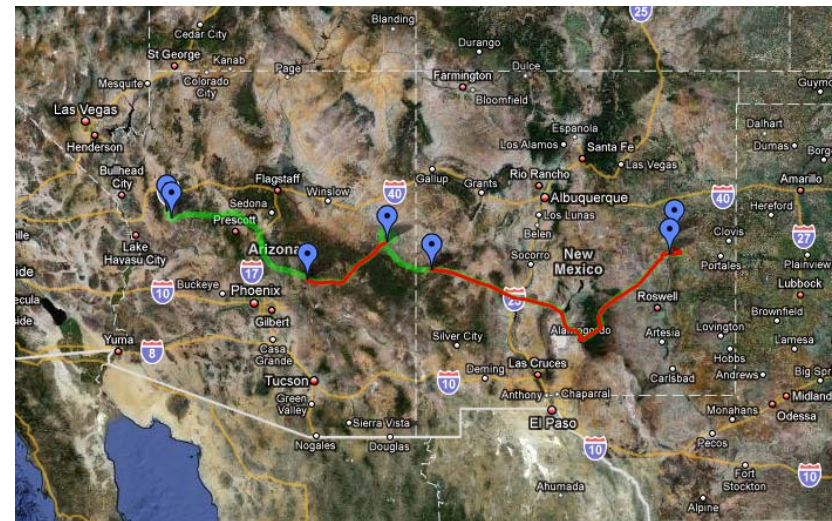
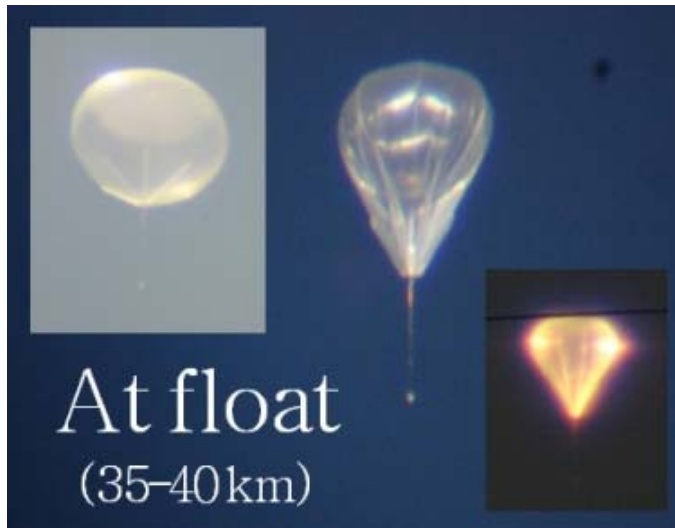


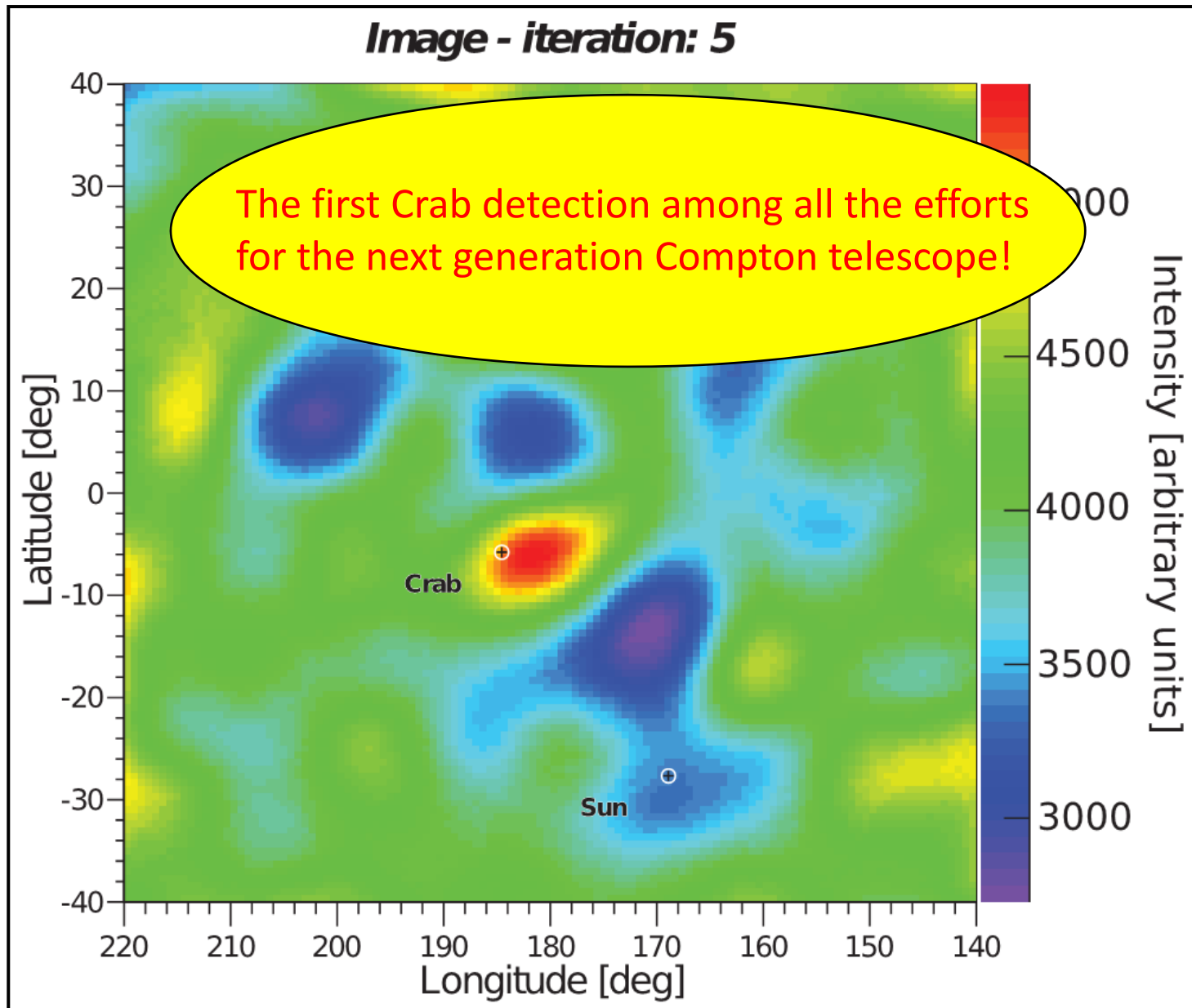
Instrument Gondola



Instrument Cradle

NCT flight on May 17, 2009

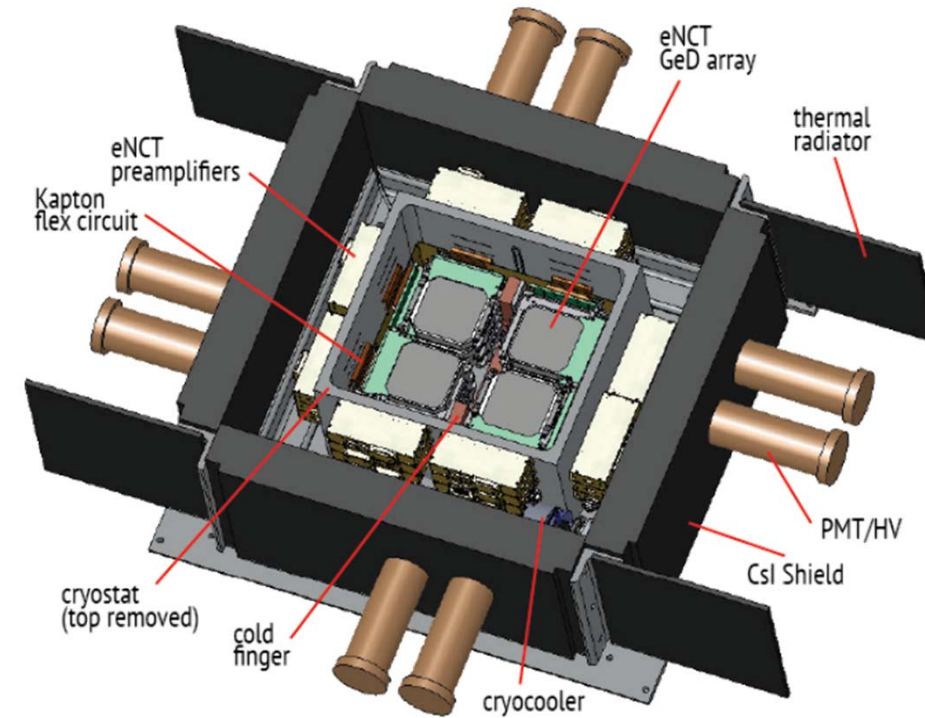
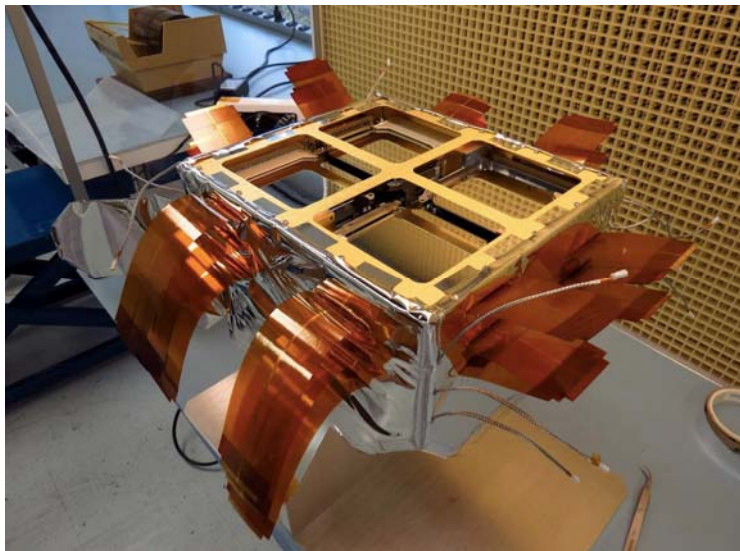
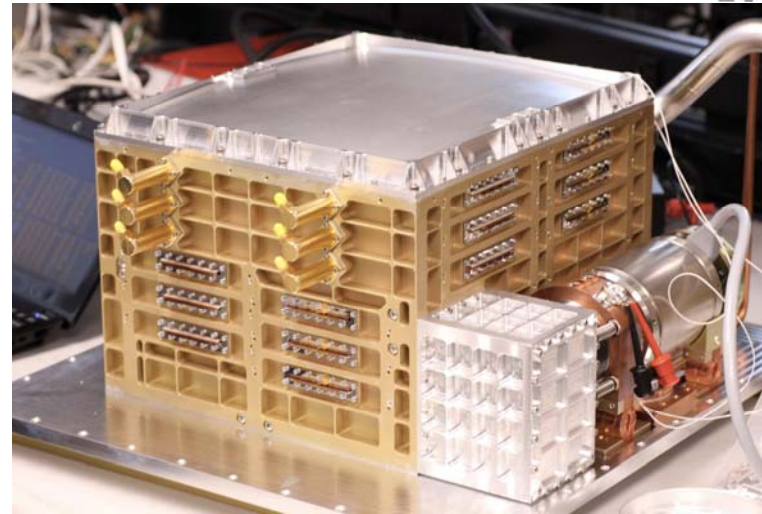


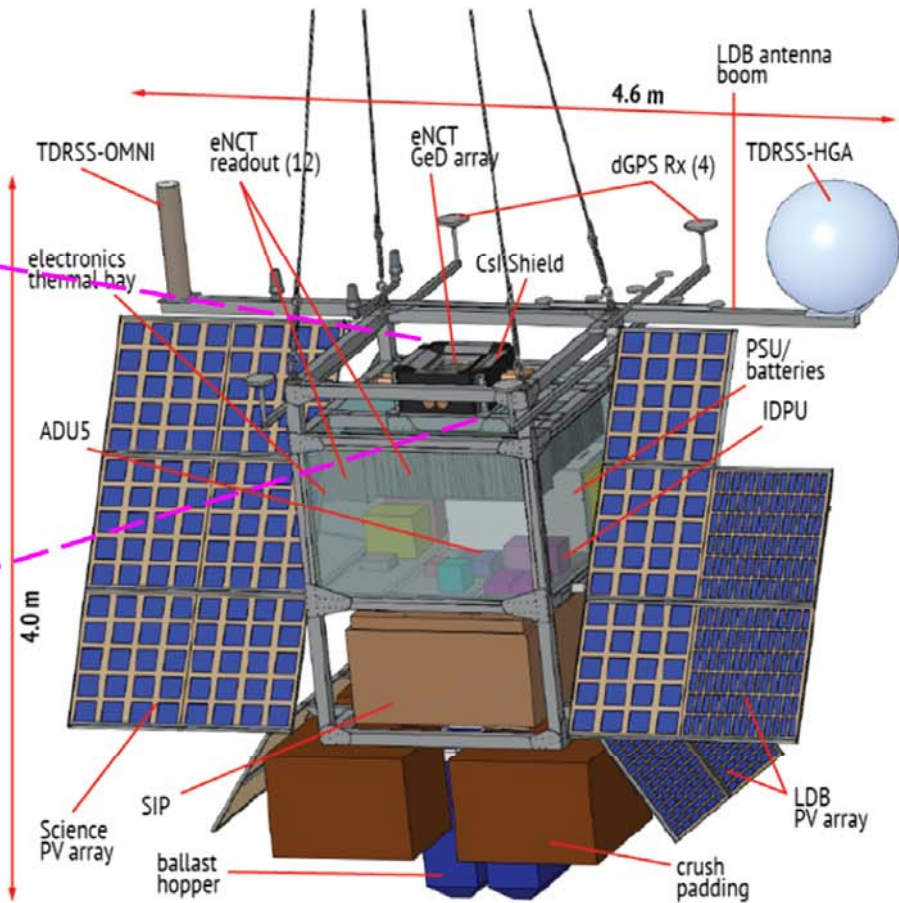
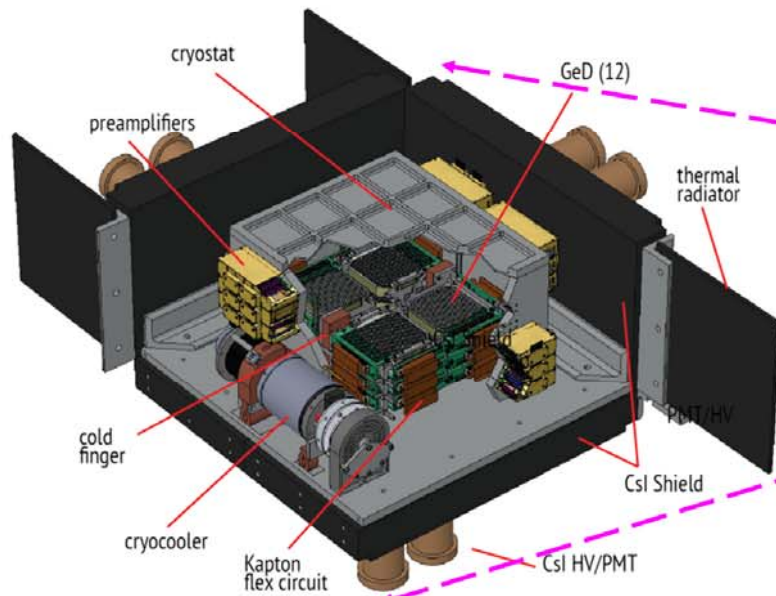


NCT image of the Crab Nebula from the 2009 flight

(Bandstra et al. 2011, ApJ 738: 8)

The COSI 2014 flight



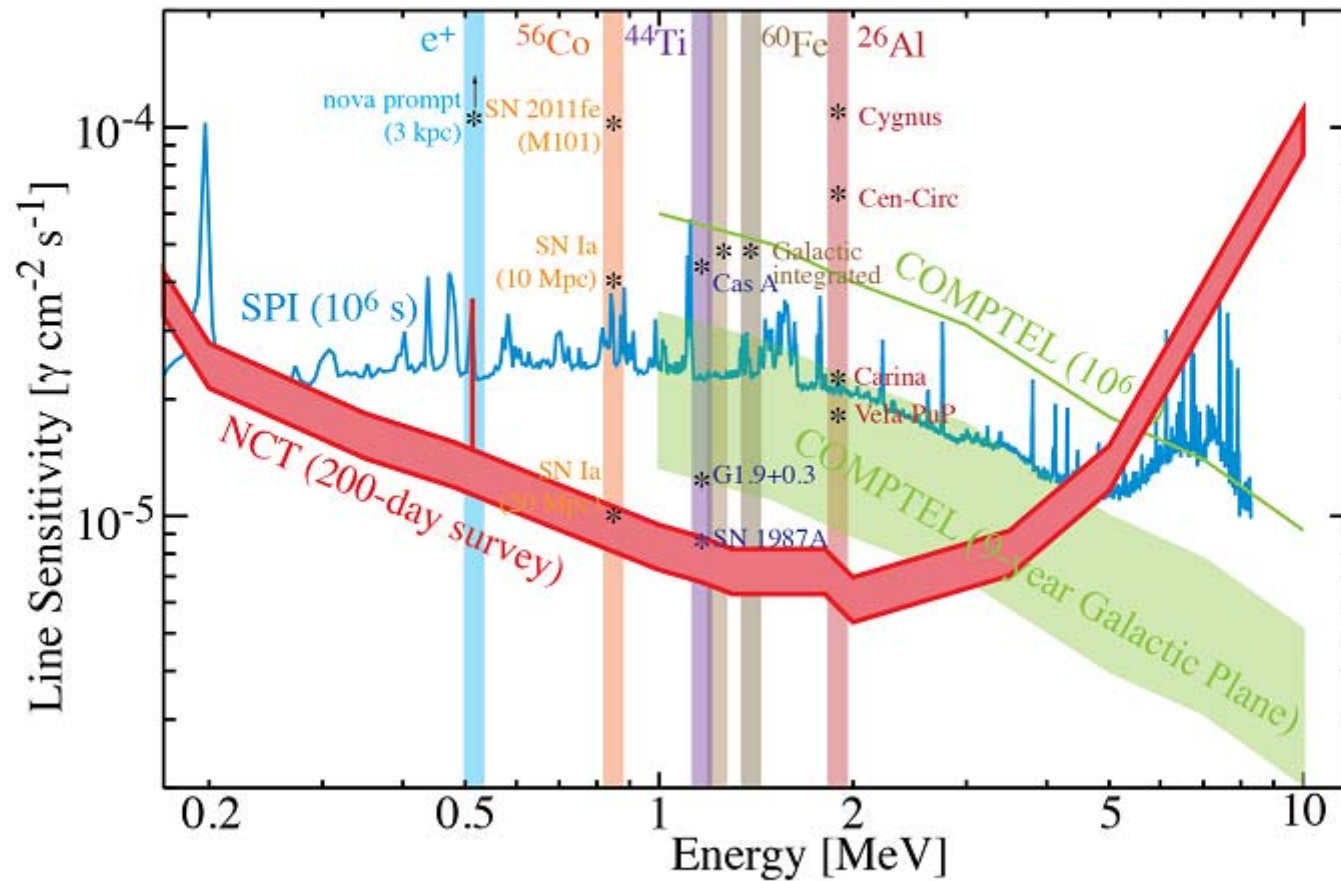


- < New detector geometry >
- ✓ 2×2×3 detector array
 - ✓ LN2 replaced by cryocooler
 - ✓ Whole new gondola
 - ✓ BGO shields → Csi shields
 - ✓ No pointing system

Configuration of the NCT'14 instrument

Nuclear Line Science

in the Galactic Center region



The 2016 & 2018 New Zealand Campaigns

Flight type: Super-pressure
ULDB

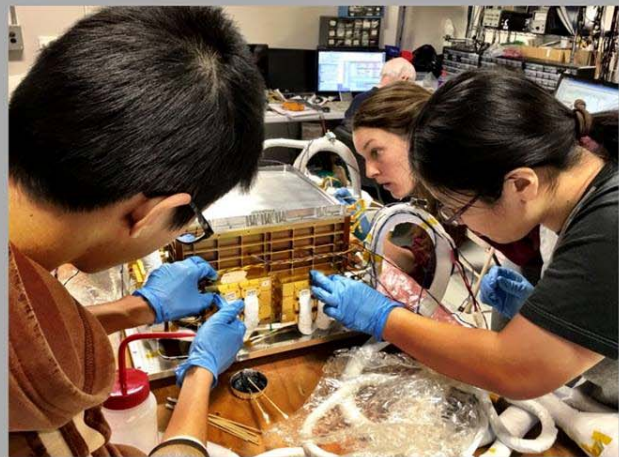
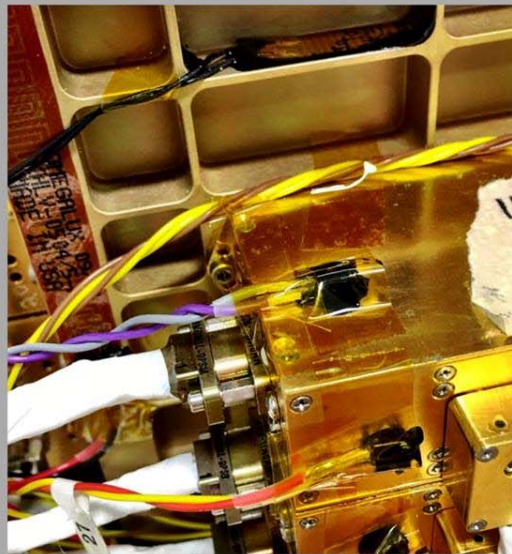
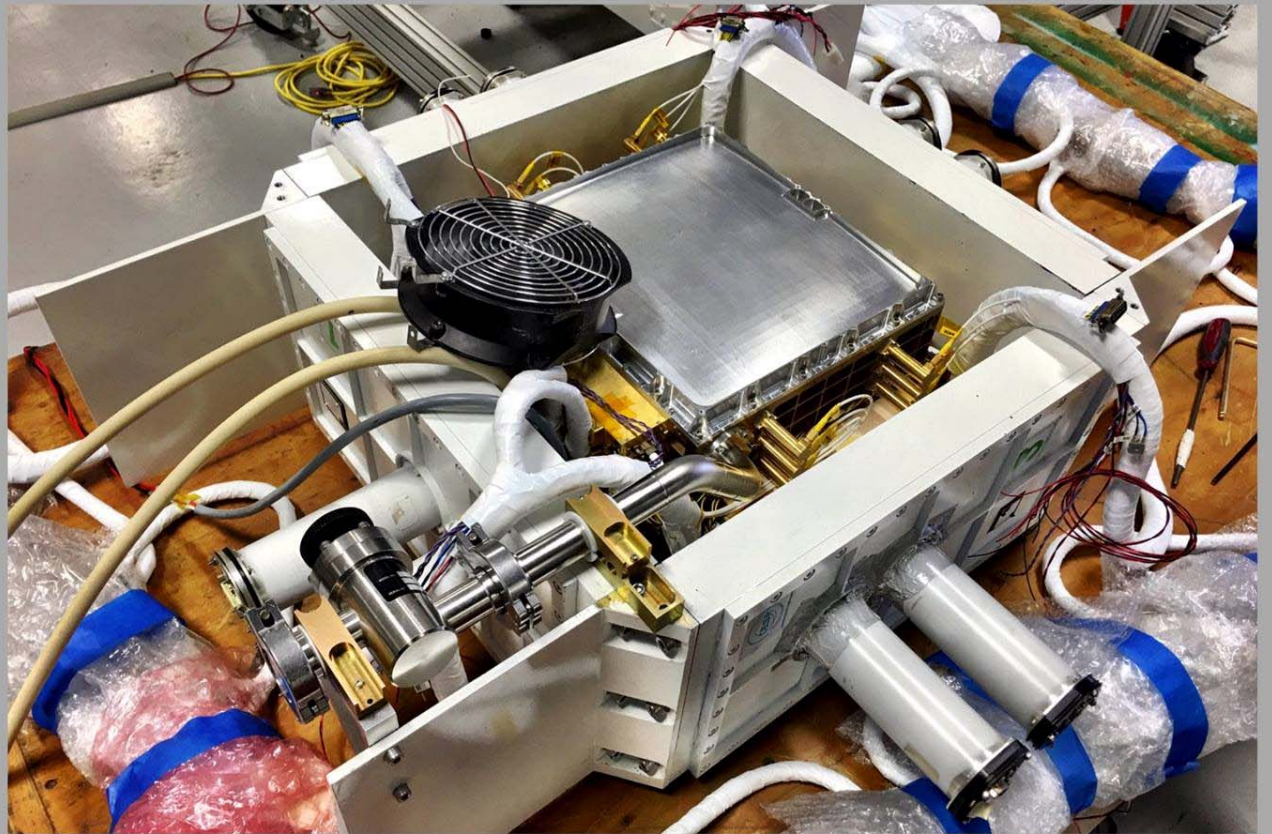
Anticipated launch dates:
June 2016 & 18

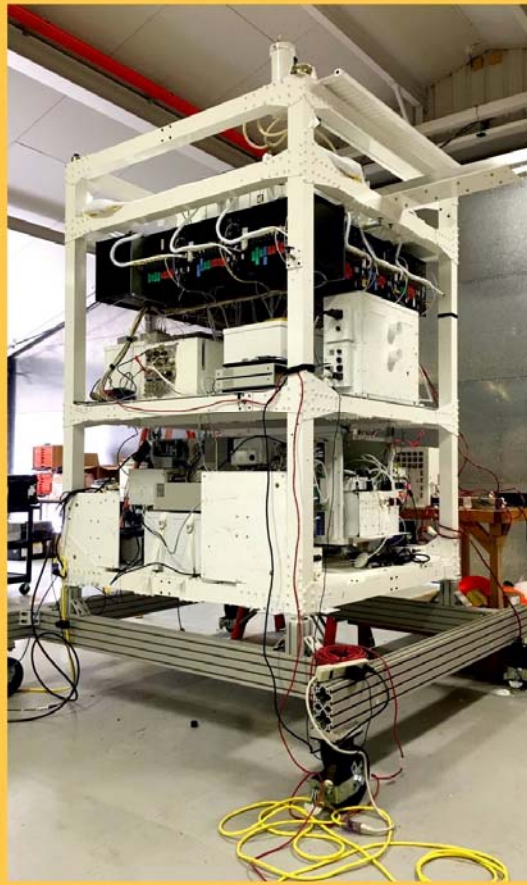
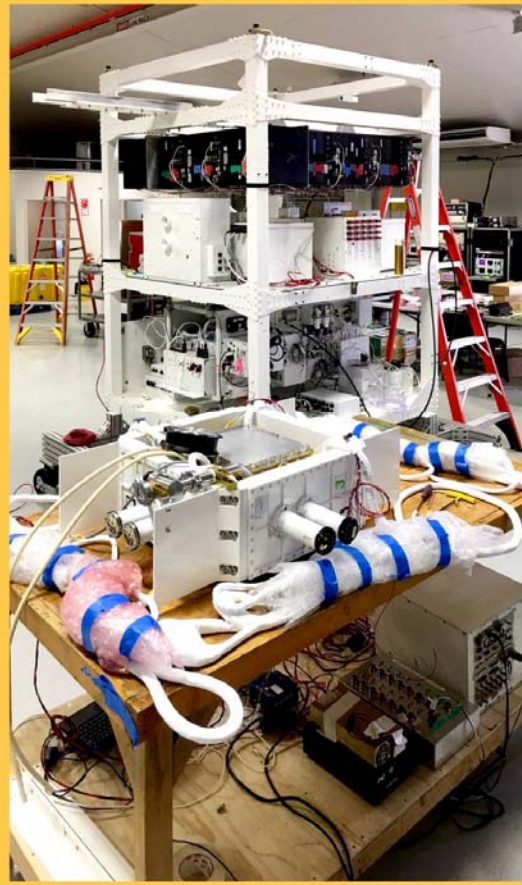
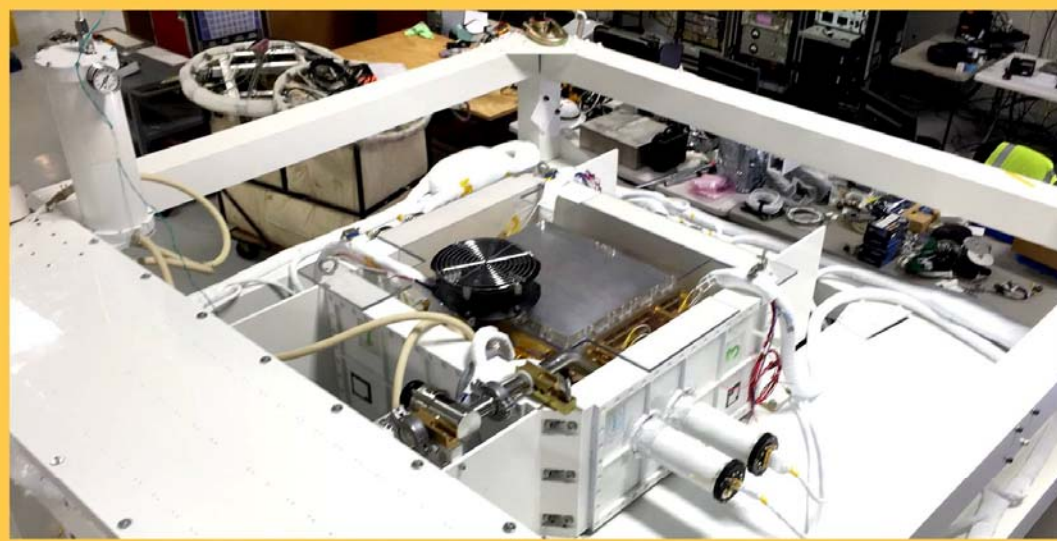
Duration: Up to 100 days –
multiple times around the
world

Main science goals:

- Nuclear line science in
Galactic Center region
- Gamma-ray burst
polarization













Launch attempt # 3, April 27, 2016



Launch attempt # 3, April 27, 2016

COSI Launch

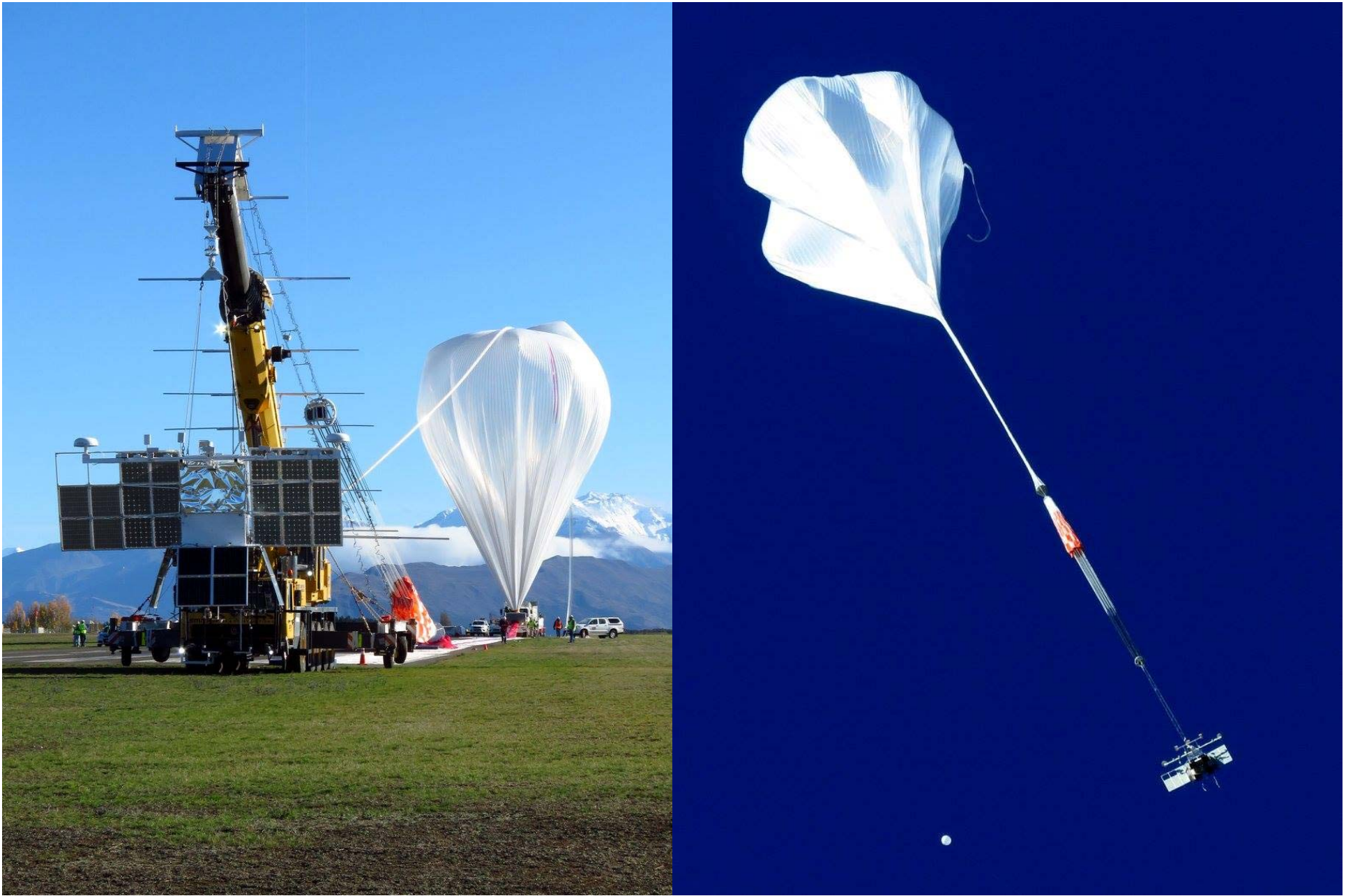


Balloon Inflation



COSI and Balloon Layout



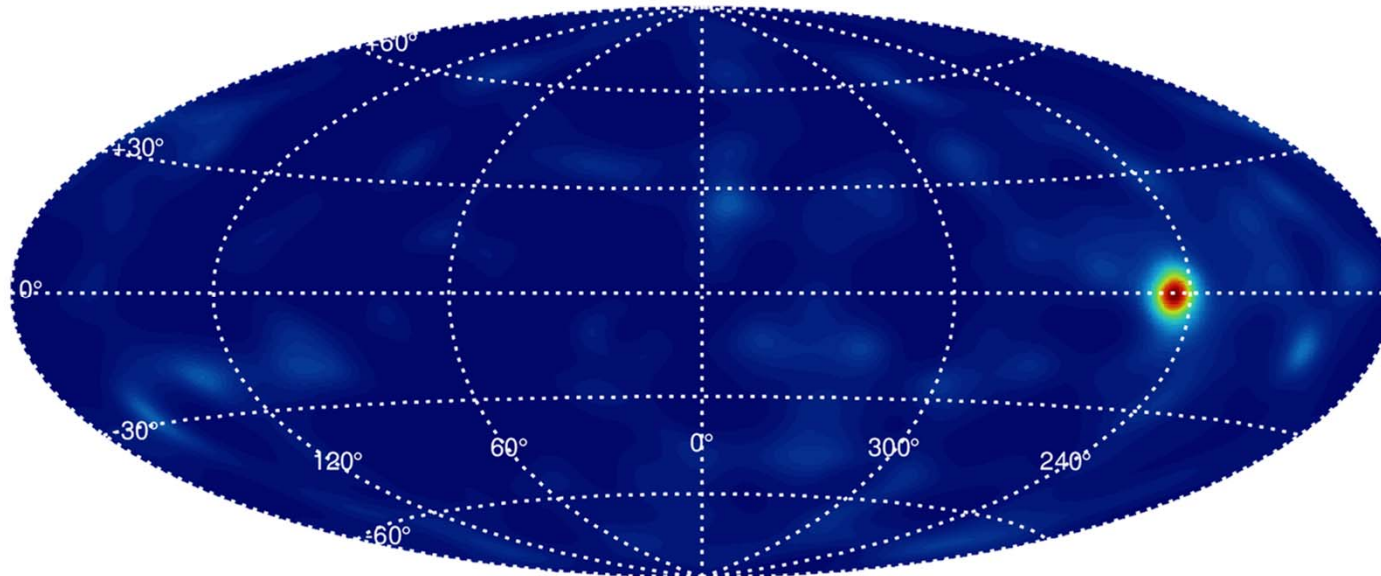
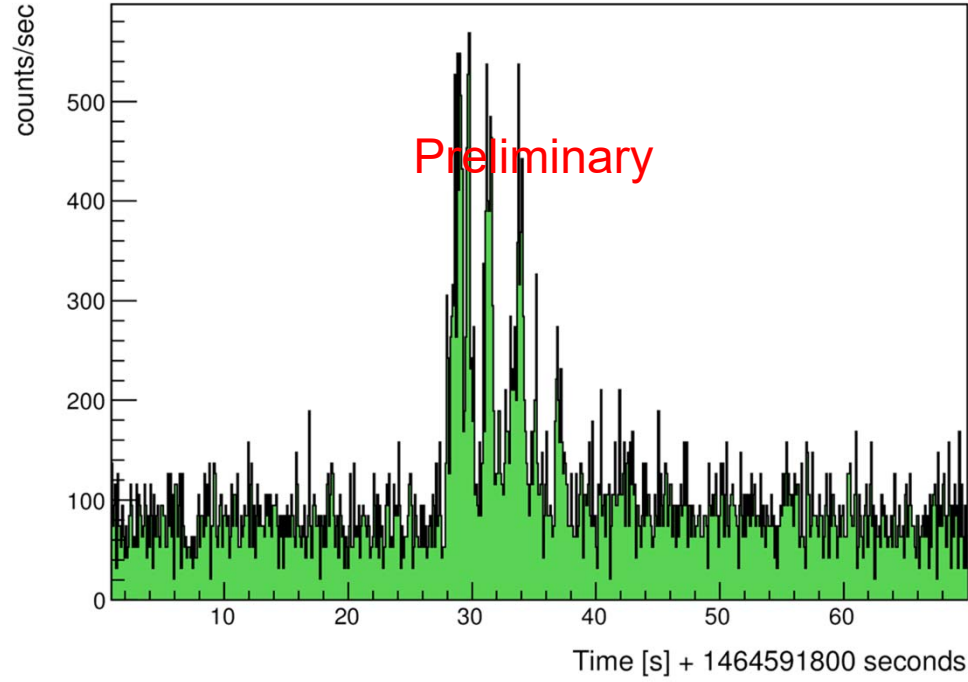


COSI launch at Wanaka, New Zealand, May 17, 2016

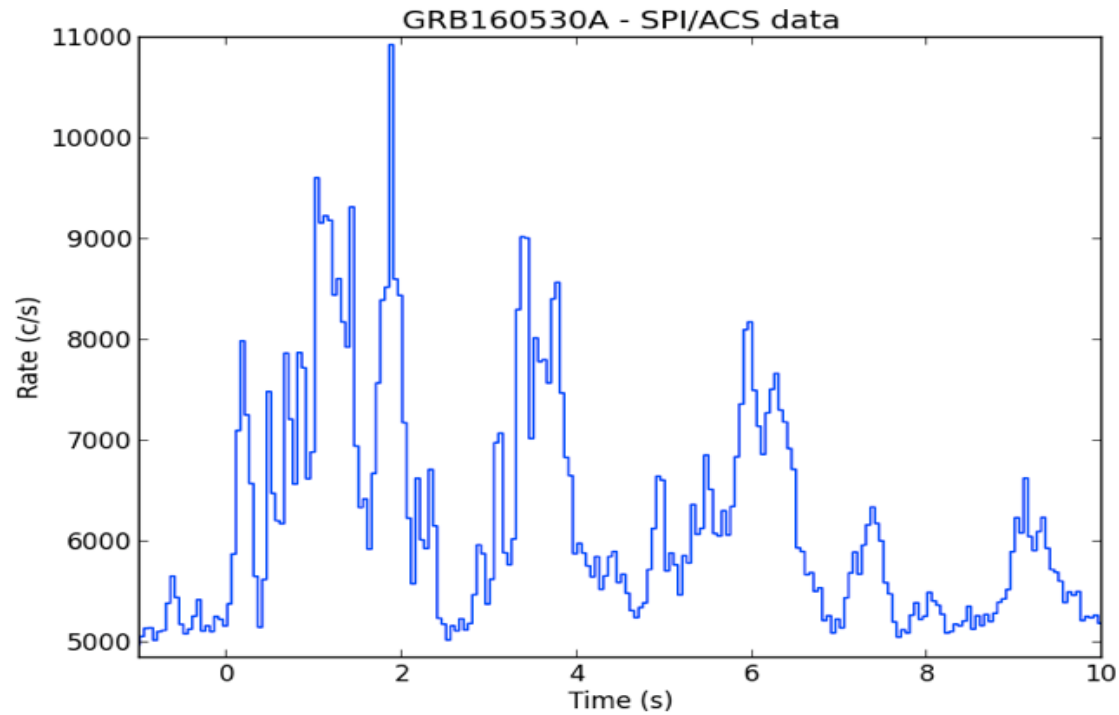
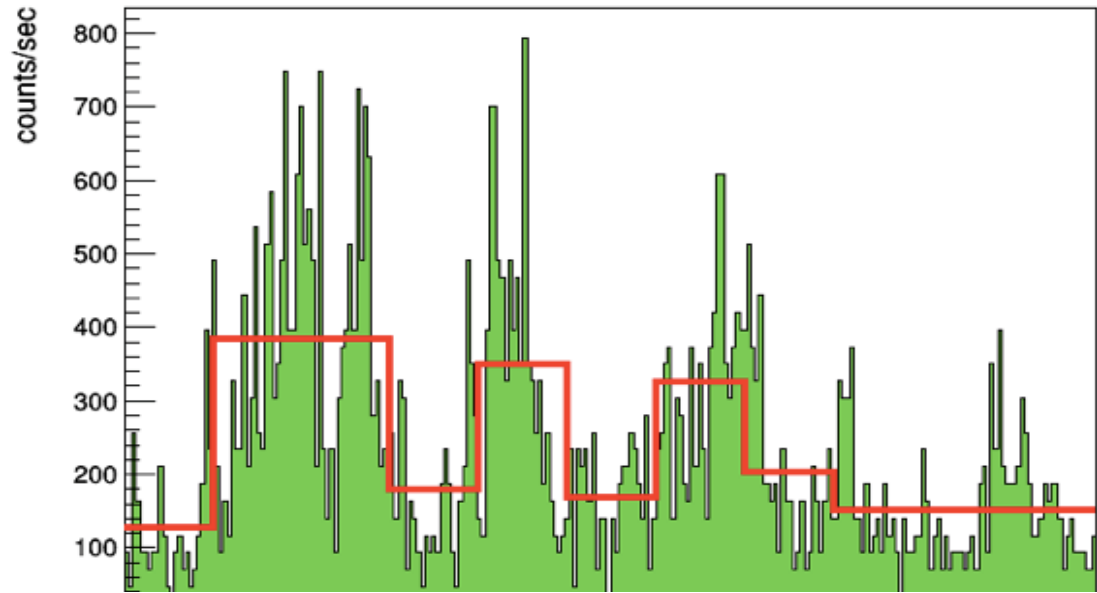


COSI at float, 33.5 km above the surface

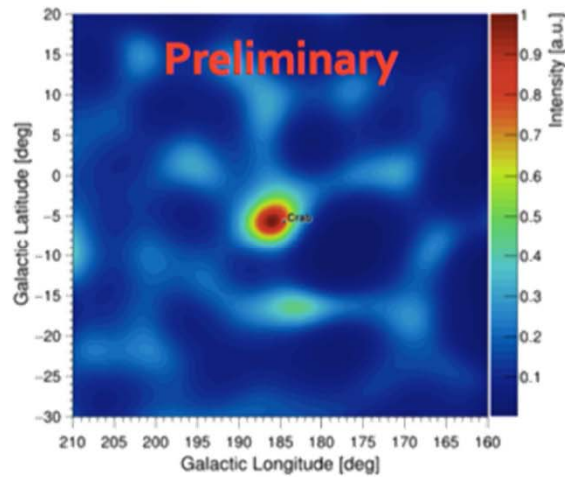
GRB160530A



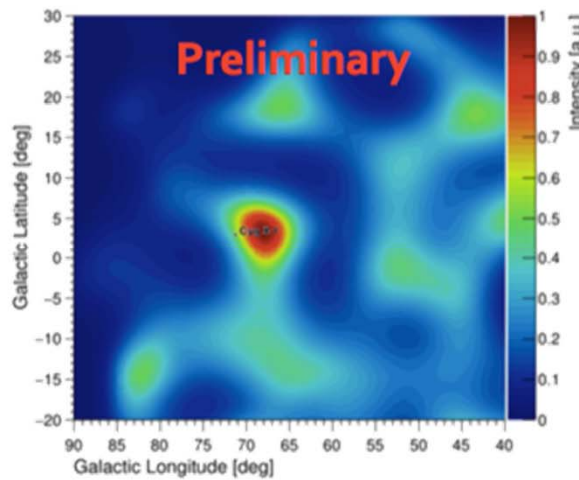
GRB160530A - COSI discovery data



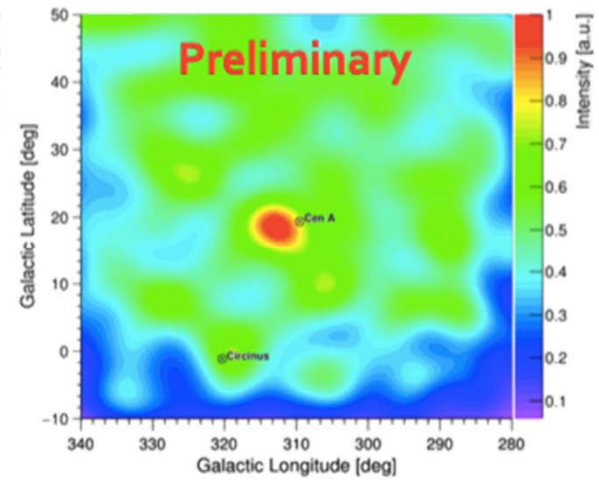
Crab
(pulsar wind nebula)



Cyg X-1
(Galactic black hole)



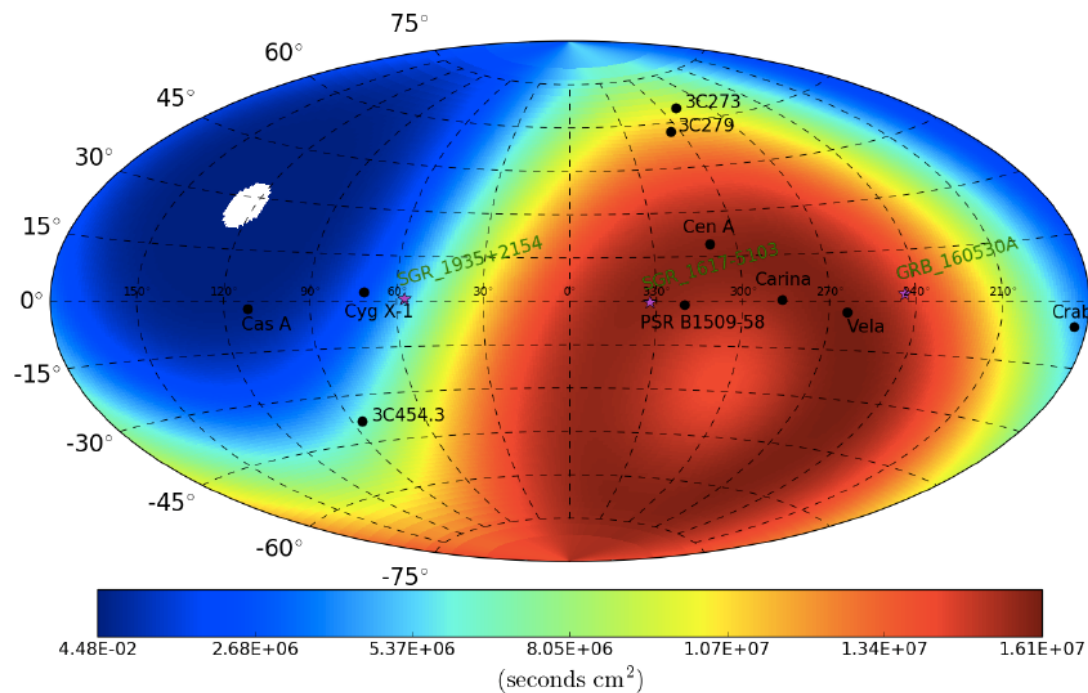
Cen A
(closest AGN)



Best 2 days of data

~3 days within field-of-view

8 days of data



The COSI 2016 flight exposure map using a simulated effective area at 356 keV.

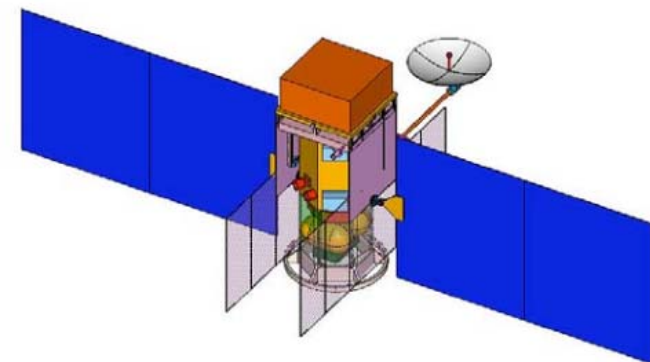
COSI 2016 flight path (May 17 – July 2)

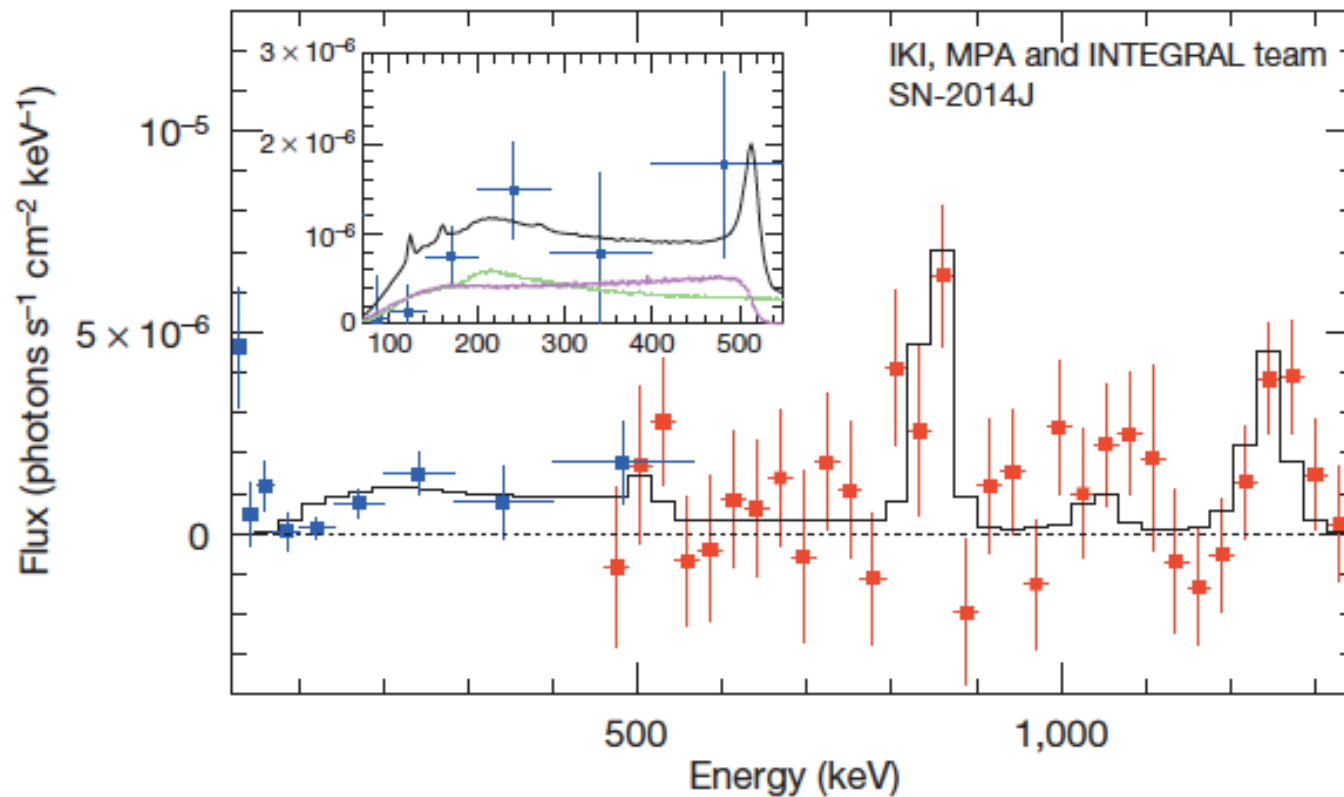


Data are being analyzed to study GRB160530A, Galactic 511-keV emission, and some other sources like BHXR, AGN, AXP/SGR and pulsars.

Now we are also preparing for the 2019 flight and working on new electronics systems.

Working for a future
COSI-based space mission ...





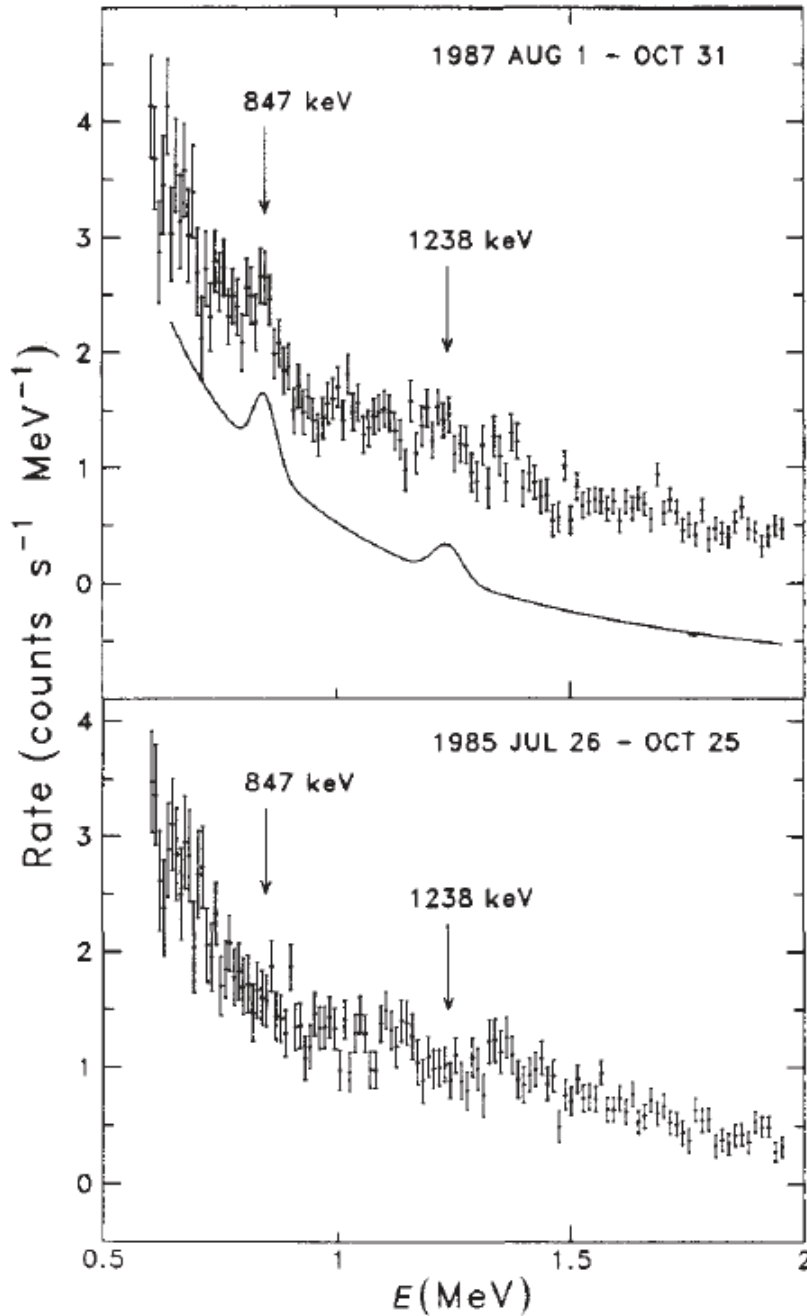
The *first* detection of nucleosynthesis lines from a *type Ia* supernova!

(M82: 3.5 Mpc away)

(M101: 6.4 Mpc away)

Figure 1 | Gamma-ray lines from Co decay at 847 and 1,238 keV in the spectrum of SN 2014J. The spectrum was obtained by INTEGRAL between days 50 and 100 after the outburst. Red and blue points show SPI and ISGRI/IBIS data, respectively. The flux below 60 keV is dominated by the emission of M82. The black curve shows a fiducial model of the supernova spectrum for day 75 after the explosion. Inset, lower-energy part of the spectrum (black). The expected contributions of three-photon positronium annihilation (magenta) and Compton down-scattered emission from 847 and 1,238 keV lines (green) are also shown. All error bars, 1 s.d.

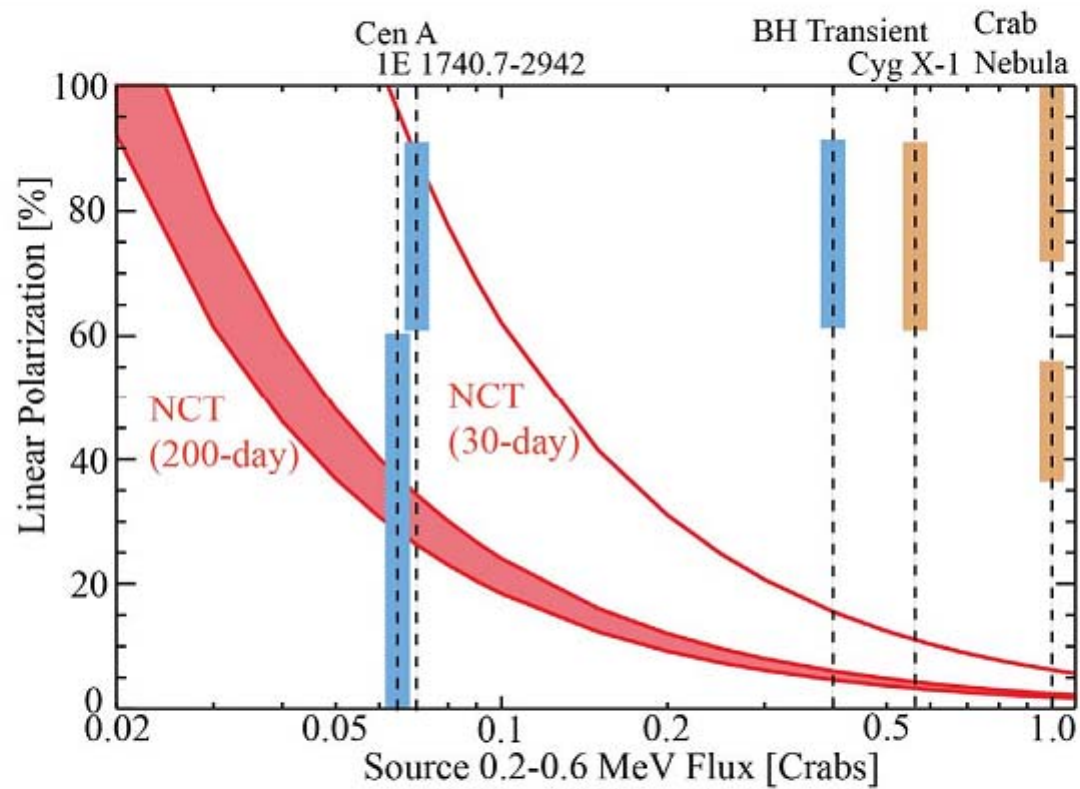
(Churazov et al. 2014, Nature 512, 406)



The *first* detection of nucleosynthesis lines from a *type II* supernova!

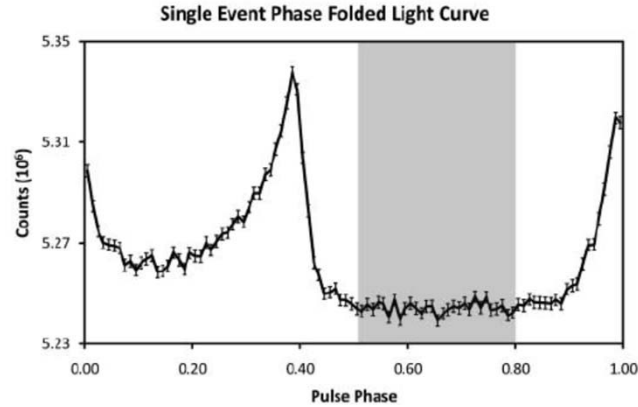
The ⁵⁶Co lines as detected from SN 1987A by SMM/GRS.
(Matz et al. 1988, Nature 331, 416)

Polarization Performance



Orange: Measured polarization (from Cyg X-1 and Crab)
Blue: Estimated polarization

Fig. 1. The light curve of the Crab emission as seen by SPI nonscattered events. The 0.1- to 1-MeV gamma-ray events used for the polarization analysis were selected from within the phase interval from 0.5 to 0.8 of the pulsar period (shaded area).



Where does the Crab MeV emission come from?

From SPI measurement :

Polarization degree
 $46\% \pm 10\%$

Polarization angle
 $123^\circ \pm 11^\circ$

(A. J. Dean et al. 2008, Science 321, 1183)

(M. Forot et al. 2008, ApJ 688, L29, for IBIS measurement)

Fig. 2. The gamma-ray polarization vector superimposed on a composite image of the Crab from Chandra (x-ray/blue) and the Hubble Space Telescope (optical/red). The vector is drawn so as to pass through the position of the pulsar. The limits on the direction of the vector are indicated by the shading. The direction of the polarization vector shows a remarkable alignment with the inner jet structure. [Image credits: NASA/CXC/ASU/ J. Hester et al., *Astrophys. J.* **577**, L49 (2002) (x-ray image) and NASA/HST/ASU/ J. Hester et al., *Astrophys. J.* **577**, L49 (2002) (optical image)]

