Gamma Ray Astronomy Instrumentation

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NASA-GSFC

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11th COSPAR Capacity Building Workshop
Bangalore

Outline

Ballooning

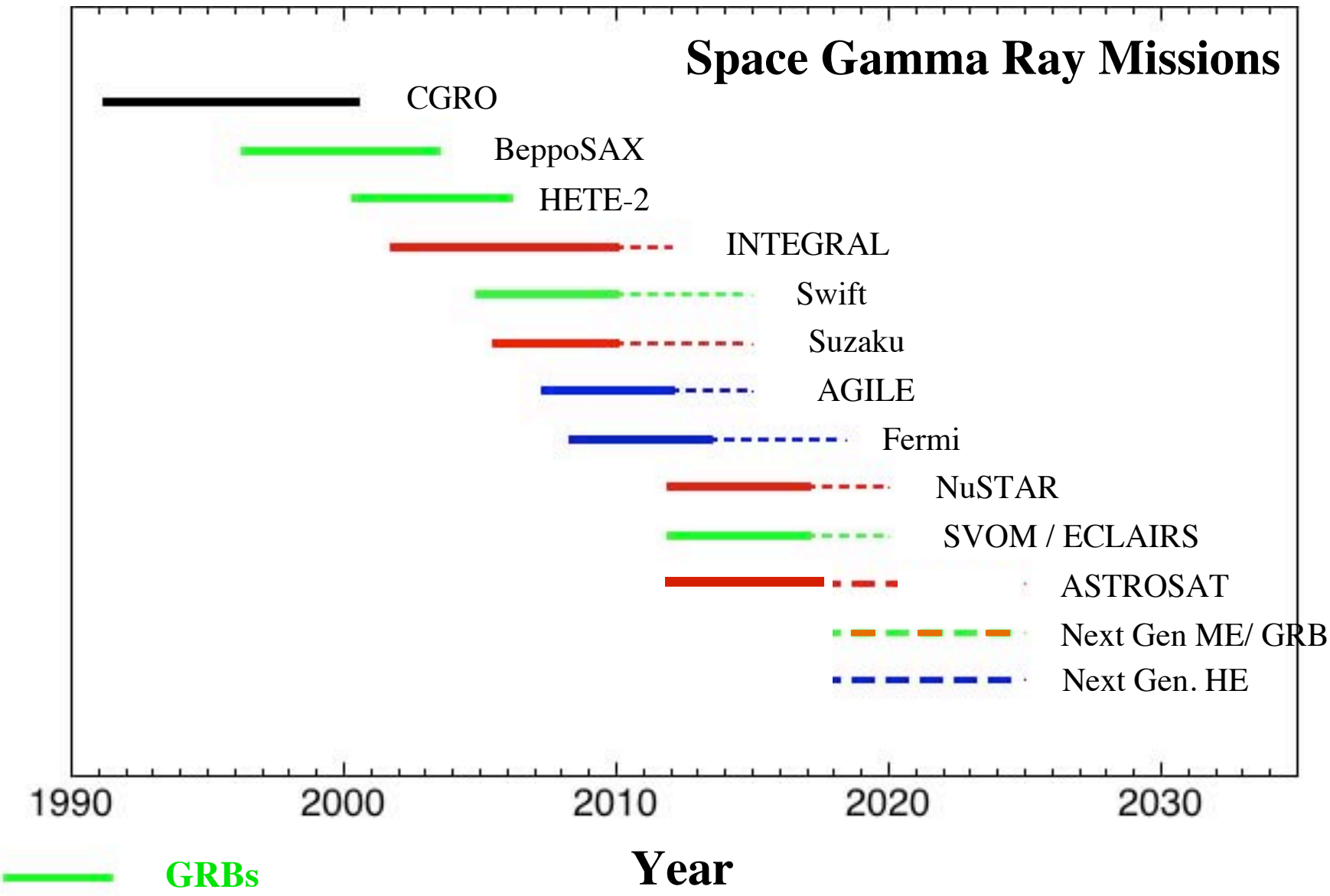
Detector materials

100 keV / coded aperture instrumentation

MeV / Compton scattering instrumentation

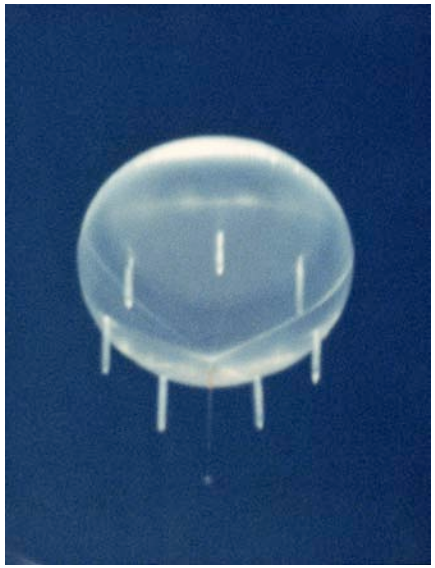
GeV / pair production instrumentation

Future
- GeV
- Focusing hard X-rays
- Polarization



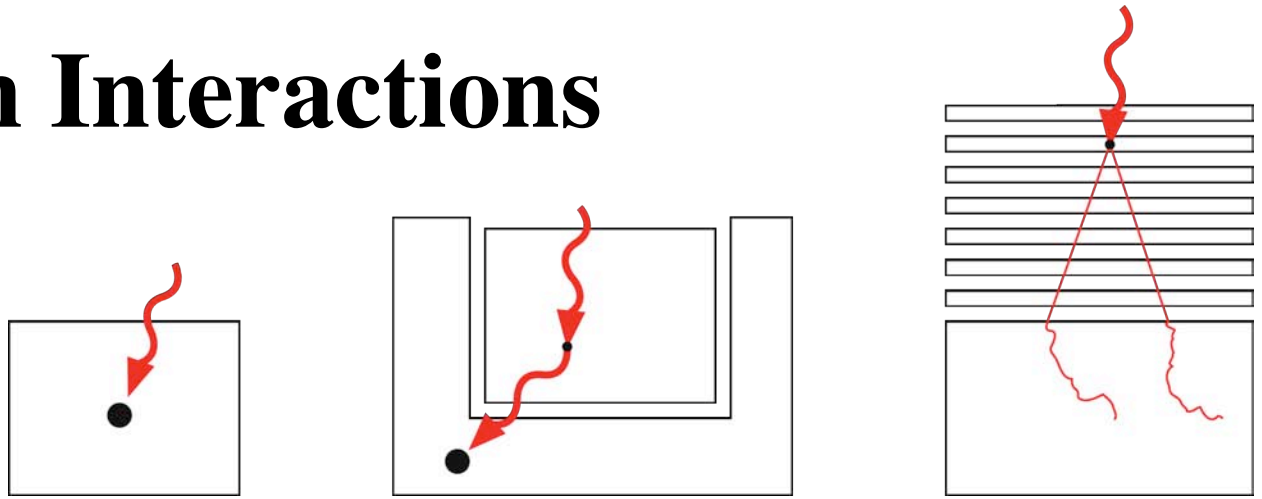
also RHESSI, ASTRO-H, Spectrum X

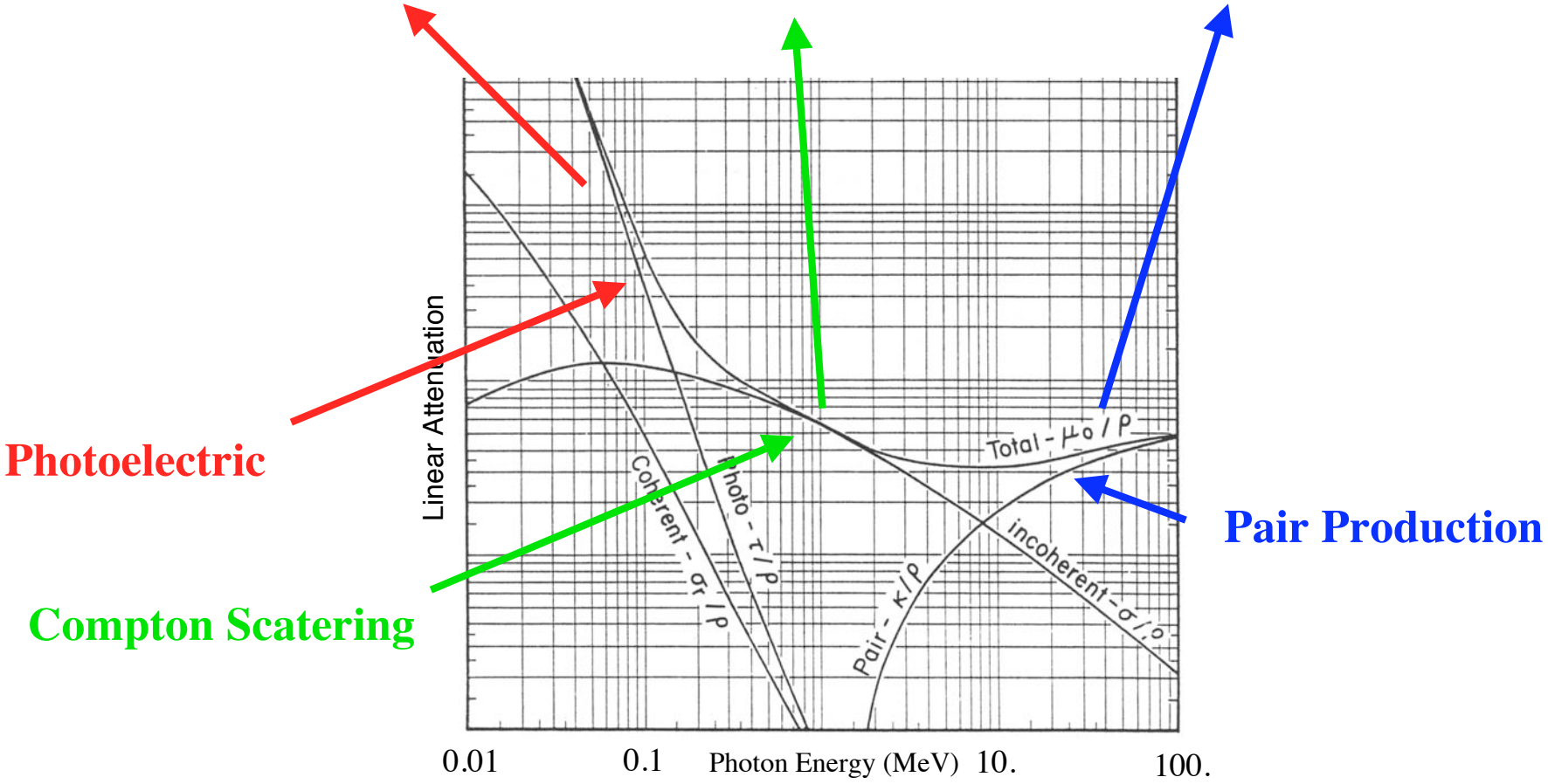

1969 Palestine Texas
1/2 meter balloon payload
GSFC - Fichtel group




GRIS

Photon Interactions





Scintillation Detectors

Material	Density [g/cm^3]	Light [10^3 ph/MeV]	ΔE/E [@ 662 keV]	Decay [ns]	Sizes	Applications
NaI	3.7	39	7%	230	Large	Spectroscopy
CsI	4.5	39	8%	630	Large	Spectroscopy
BGO	7.1	9	>10%	300	Large	Shielding
GSO	6.7	9	6%	66	Small	Spectroscopy
$LaBr_3$	5.3	63	<3%	25	Small	Spectroscopy

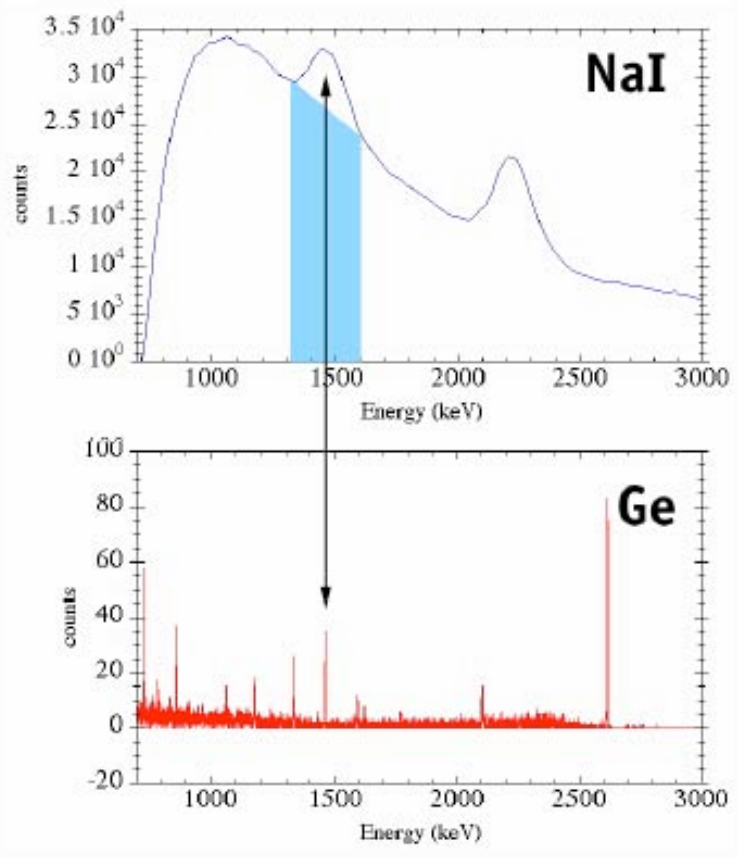
photoelectric, Compton telescopes, calorimeters, shielding

Semiconductor Detectors

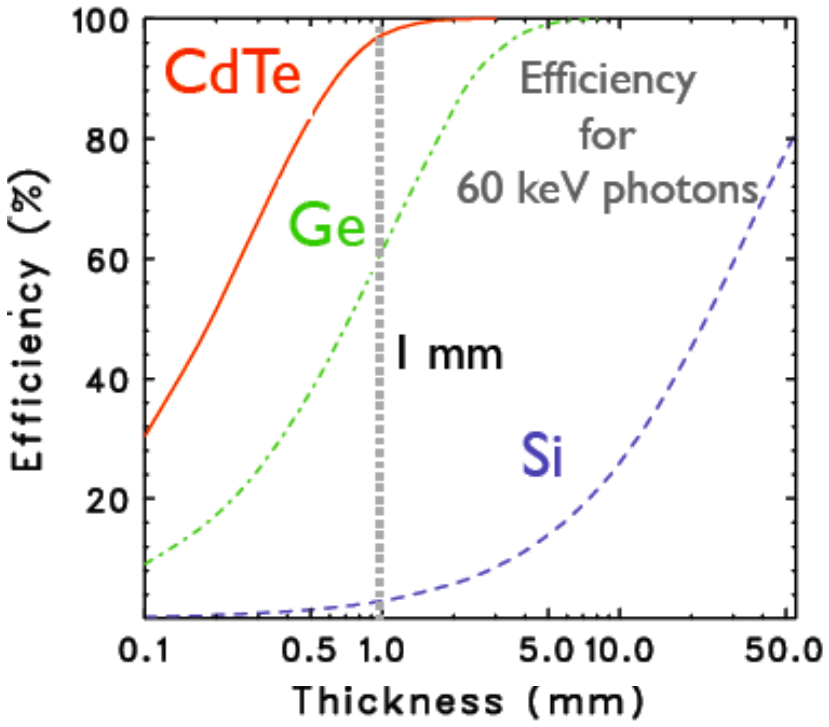
Material	Density [g/cm^3]	Z	E_{gap} [eV]	T_{op}	Applications
Si	2.3	14	1.1	<0˚ C	X-ray/Hard X-ray Imaging
Ge	5.3	32	0.67	100 K	Gamma-ray spectroscopy
CdZnTe	5.8	~50	1.4	~10˚ C	Hard X-ray Imaging

Si - photoelectric & pair telecsopes
Ge - photoelectric & Compton telescopes
CdZnTe - photoelectric

Semiconductor Detectors

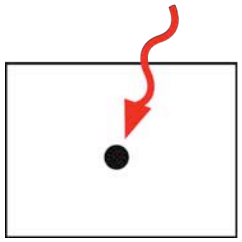


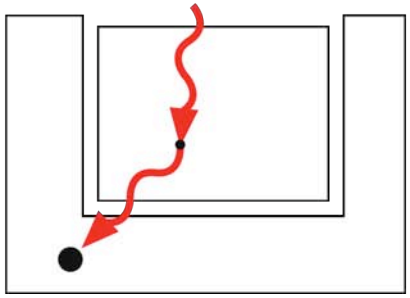
Knoedlseder

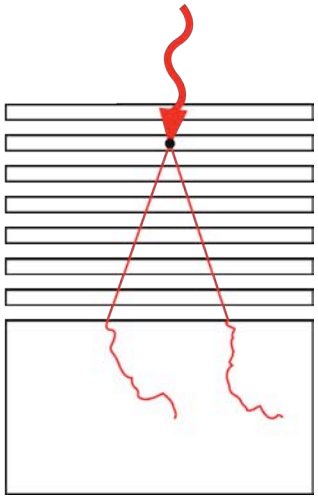


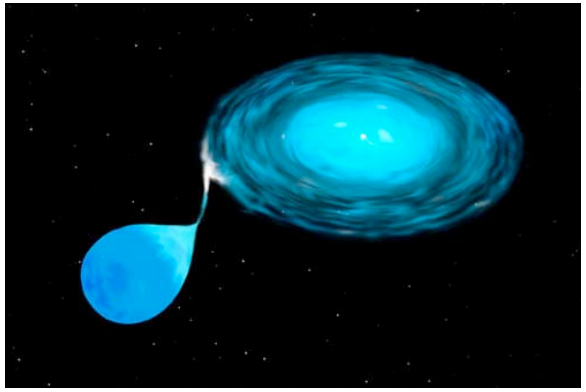
Takahashi

Science by Technique

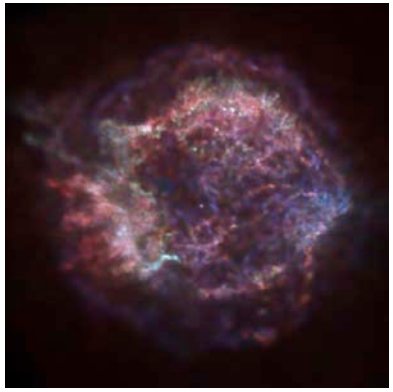




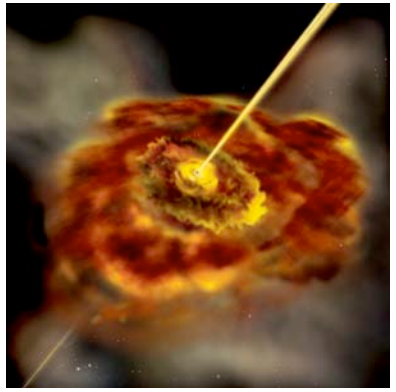




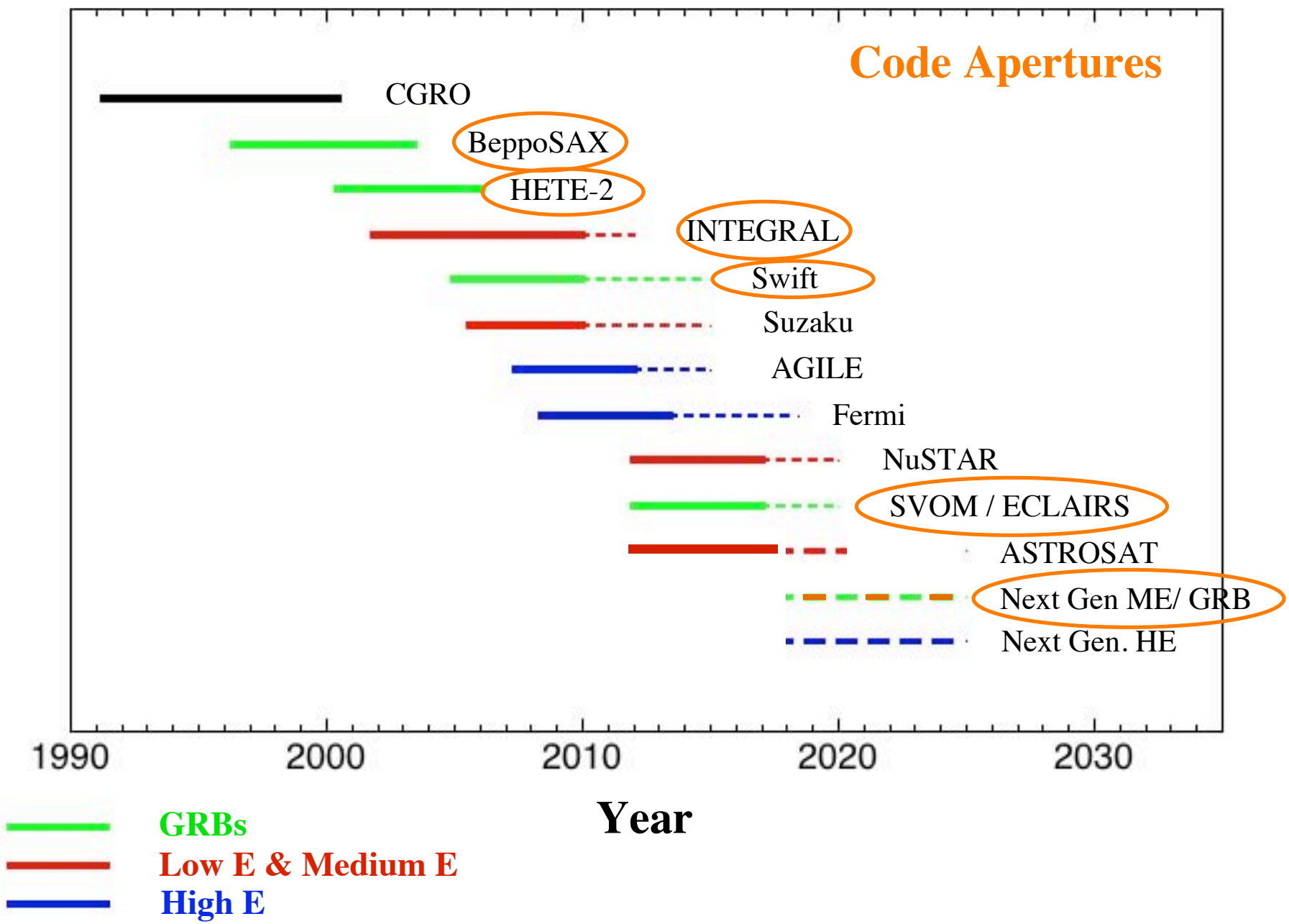
Galactic Neutron Stars



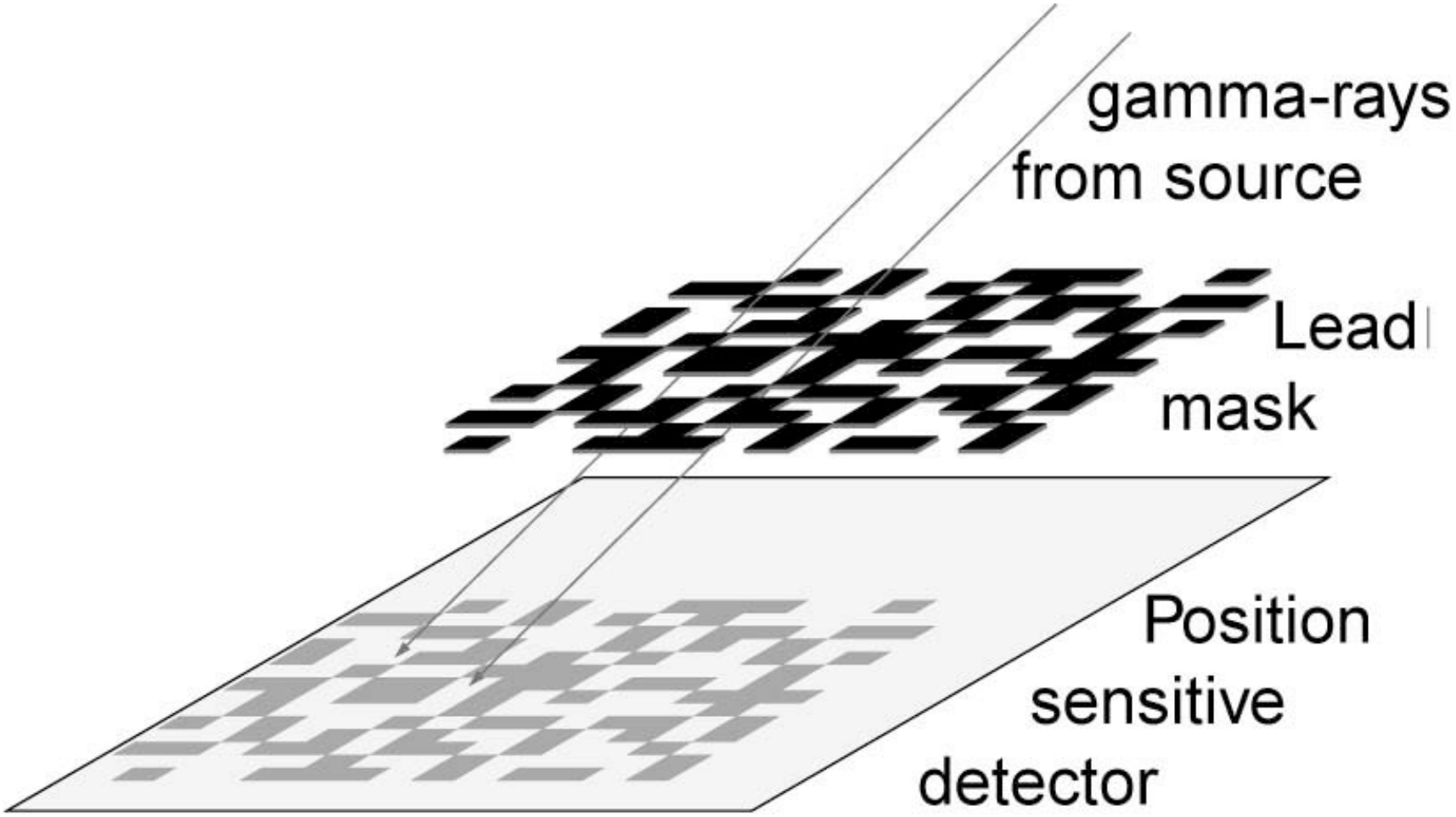
Supernova



Active Galaxy Jets


Code Apertures
CGRO
BeppoSAX
HETE-2
INTEGRAL
Swift
Suzaku
AGILE
Fermi
NuSTAR
SVOM / ECLAIRS
ASTROSAT
Next Gen ME/ GRB
Next Gen. HE
1990
2000
2010
2020
2030
Year
GRBs
Low E & Medium E
High E

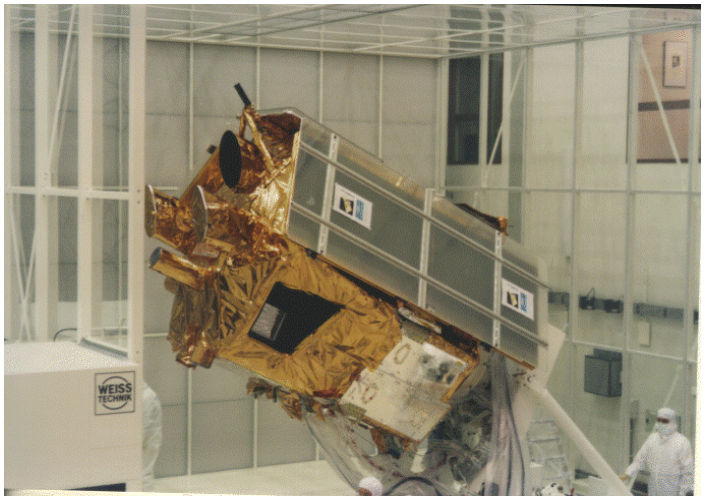
Coded Aperture Imaging



advantage - large FoV disadvantage - high background

Coded Aperture Missions

BeppoSAX (1996 - 2002)



Swift (2004 - now)

EXIST (future)

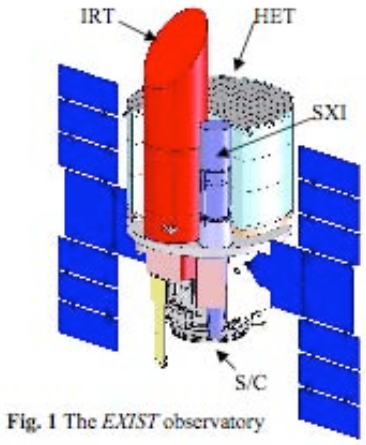


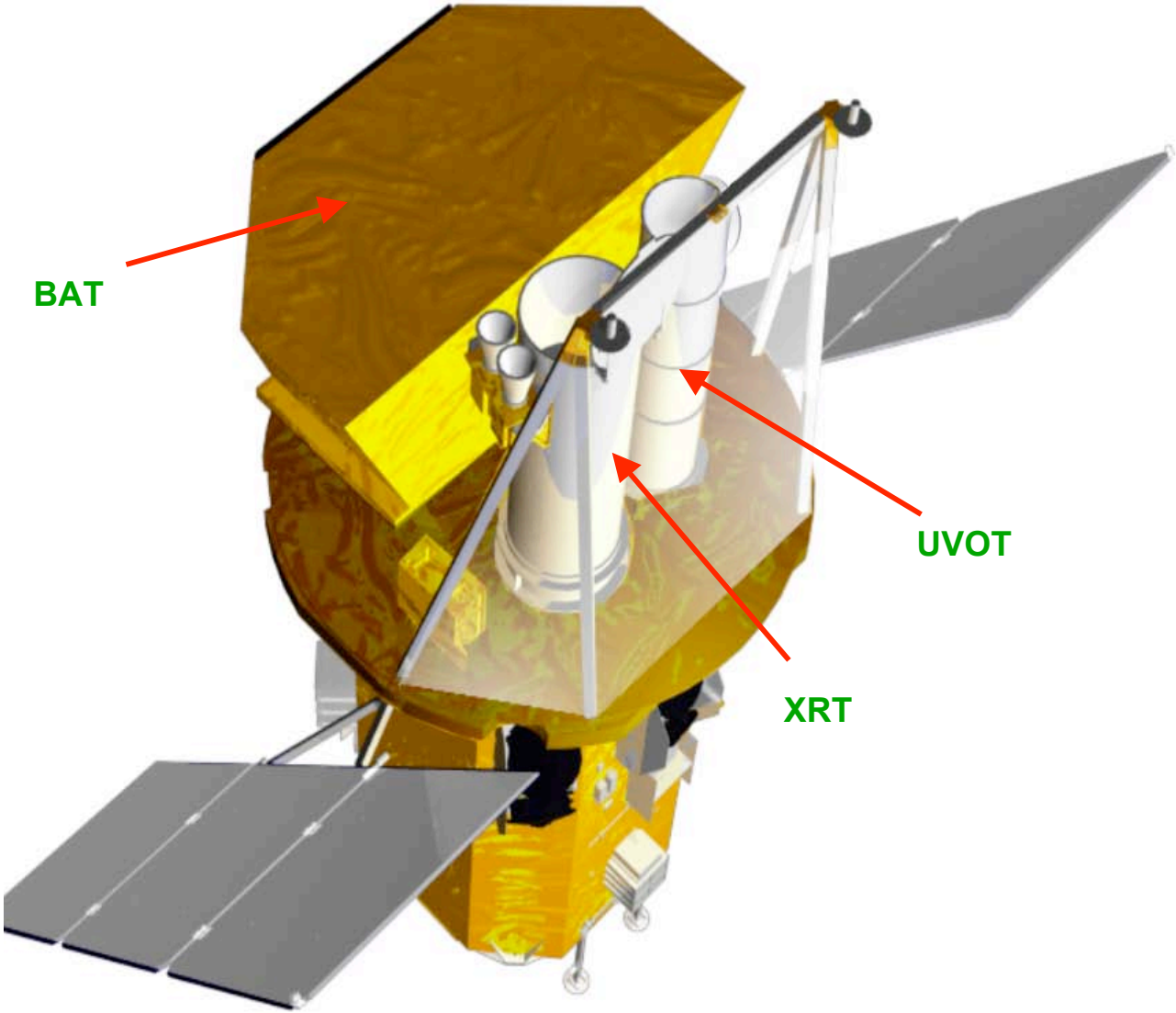
Fig. 1 The *EXIST* observatory

JANUS (future)

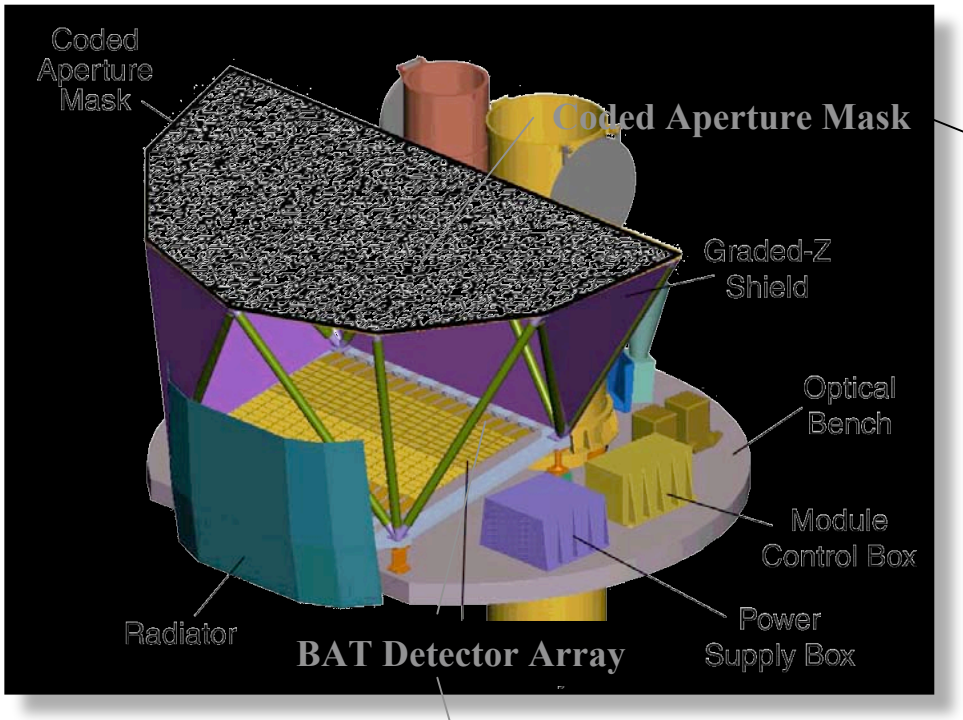
SVOM (2012 -)

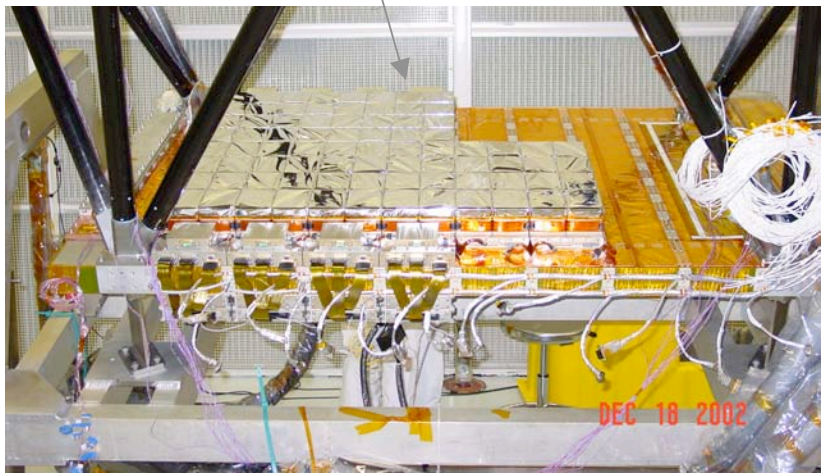
also INTEGRAL, ASTROSAT

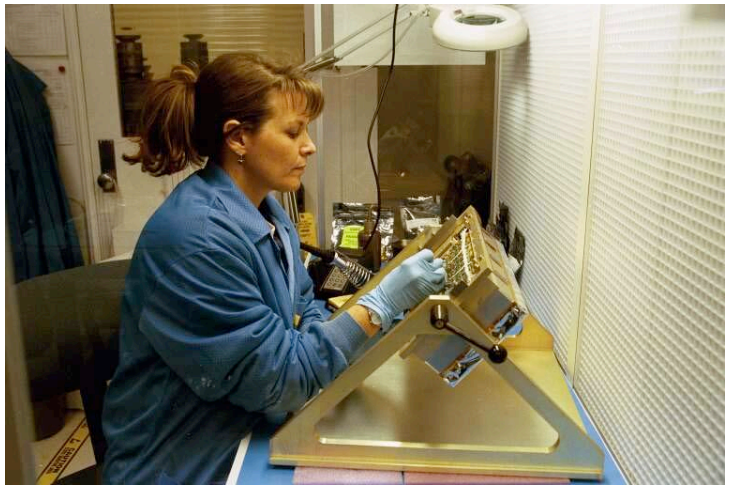
Swift Observatory



Swift Burst Alert Telescope (BAT)







BAT Detectors

13 - 350 keV

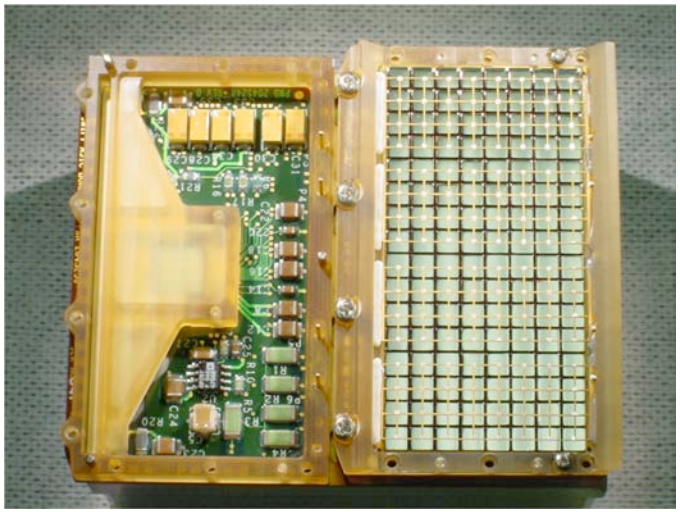
32,000 CdZnTe detectors

4 mm x 4 mm x 2 mm thick

eV Products

5200 cm^2 detector area

~100˚ field of view to maximize GRB detection



BAT Wrapped Up for
Thermal Vac Testing

Image Tests

Radioactive source moved on x-y stage

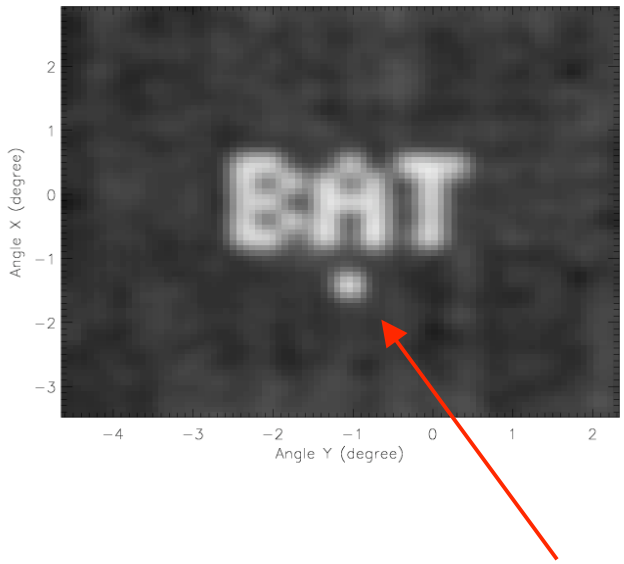
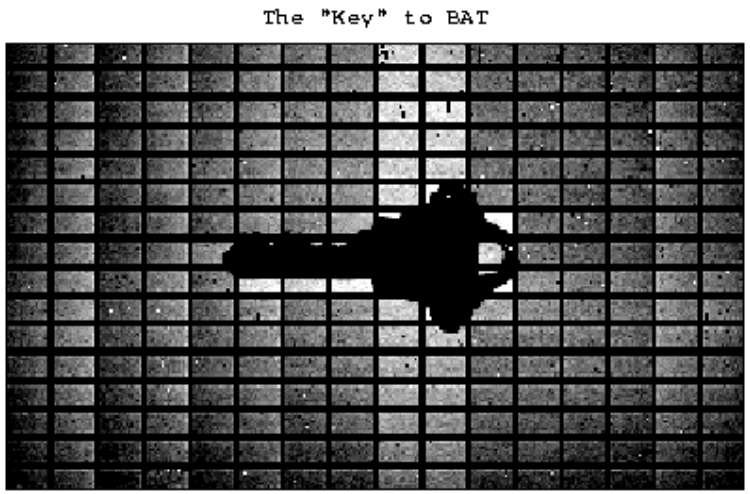


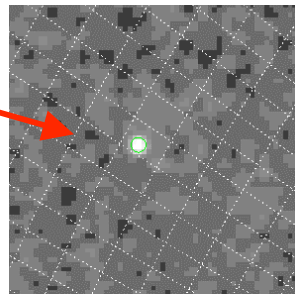
Image of "normal" house key on BAT detector array



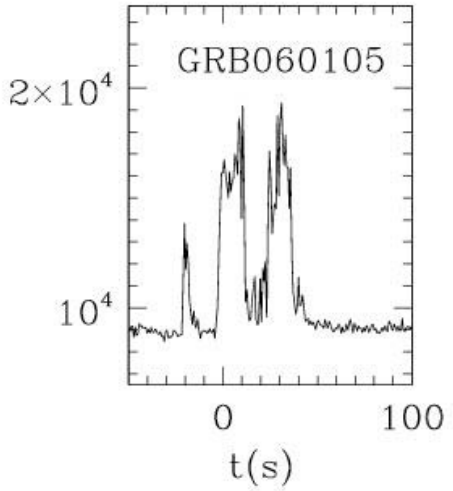
20 arcmin PSF

BAT Performance

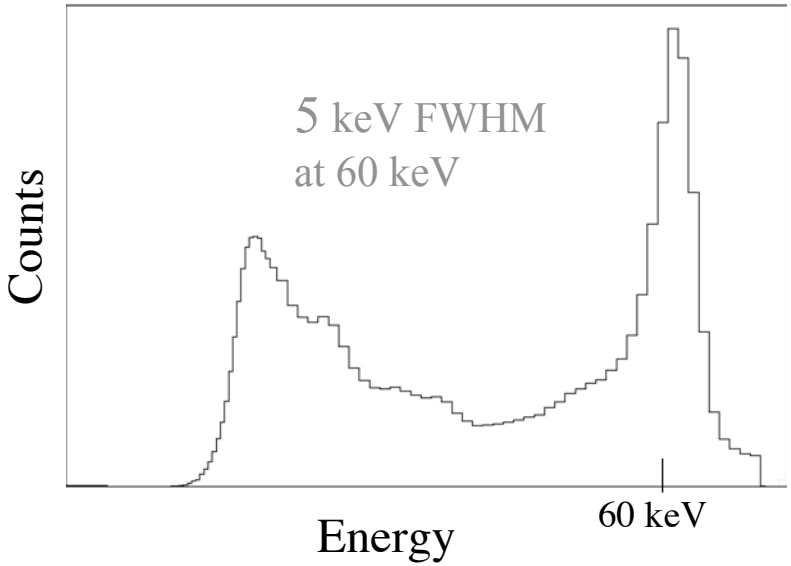
GRB 050525A



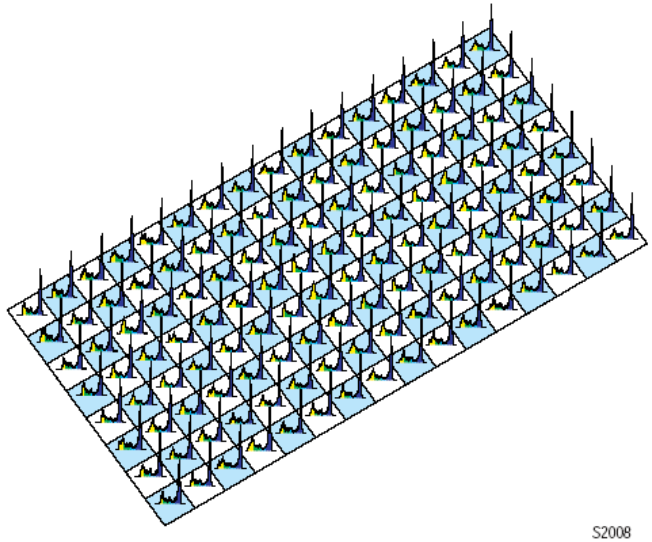
GRB Lightcurves

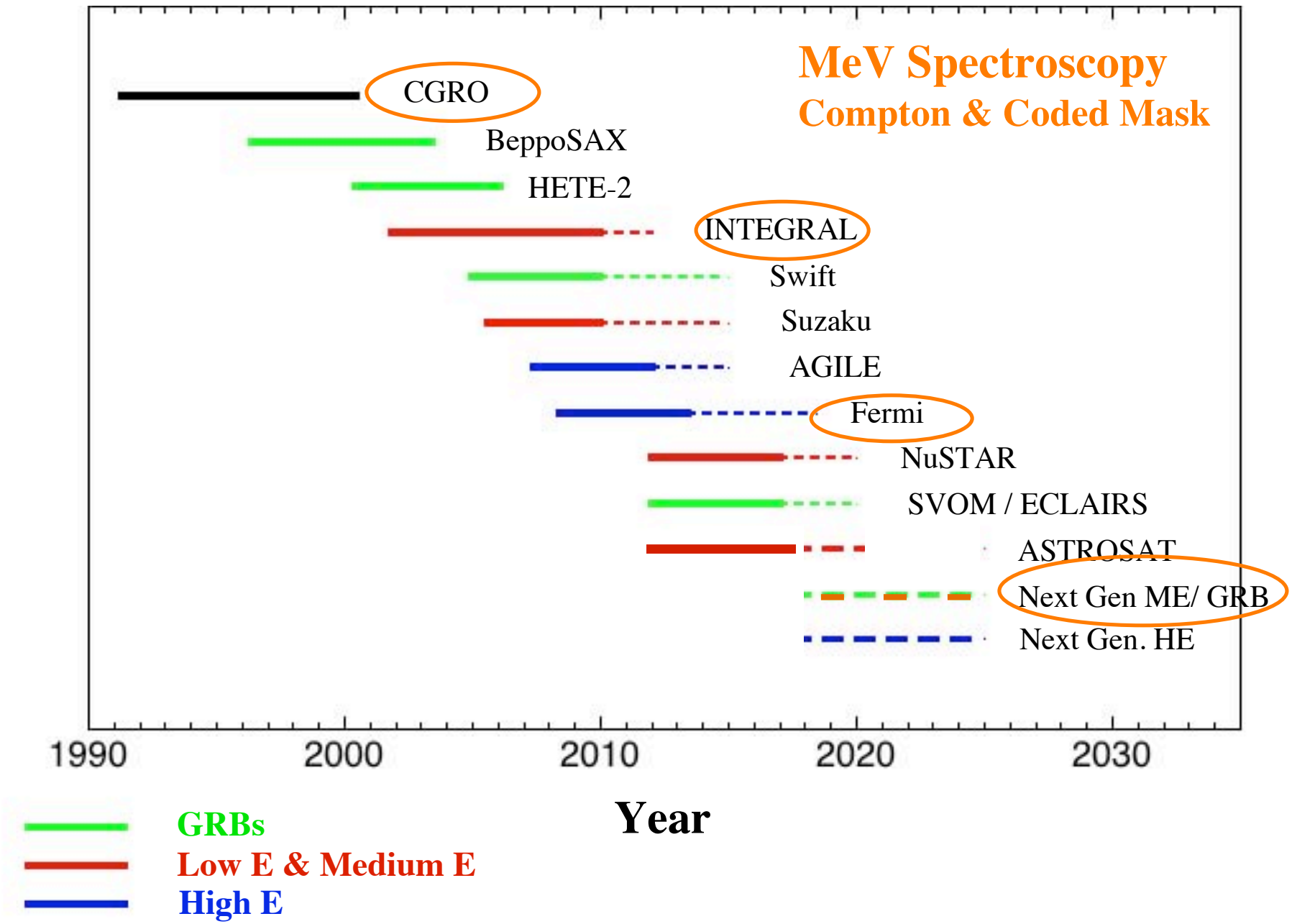


On-orbit Am^{241} Summed Spectrum

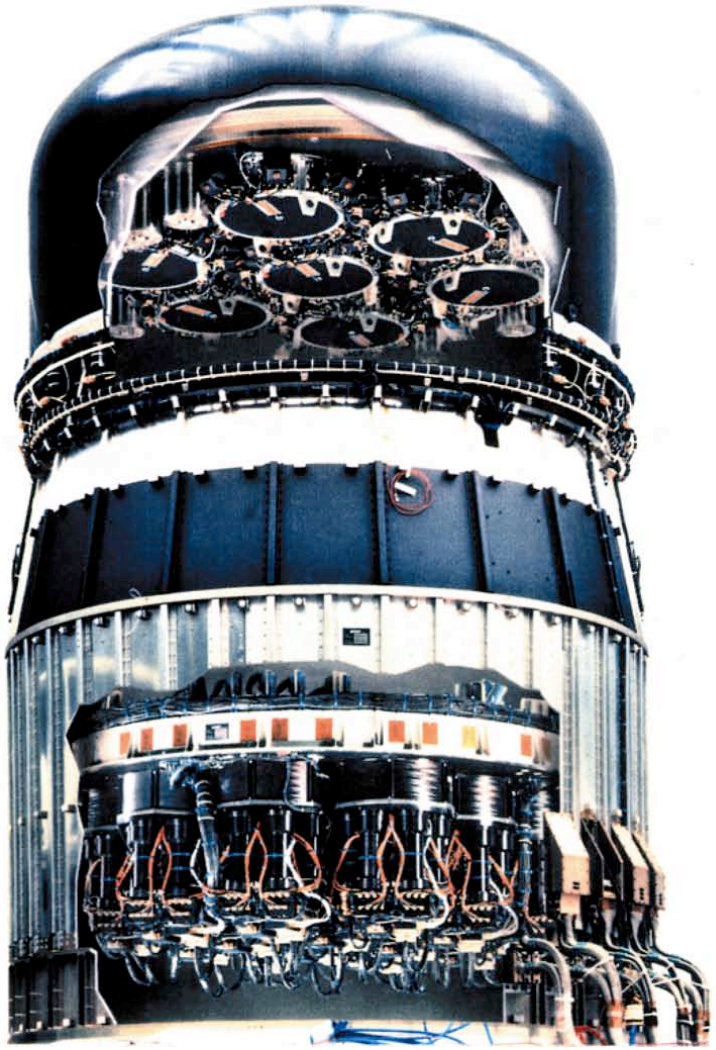


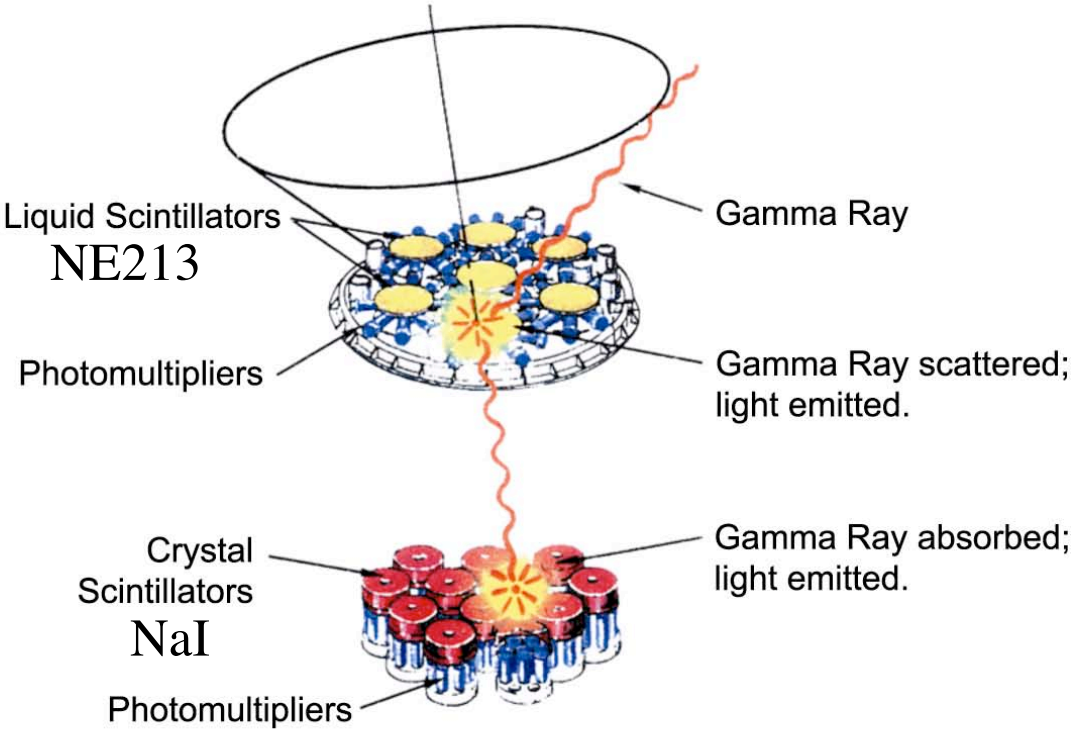
Individual BAT Spectra - 1 Module



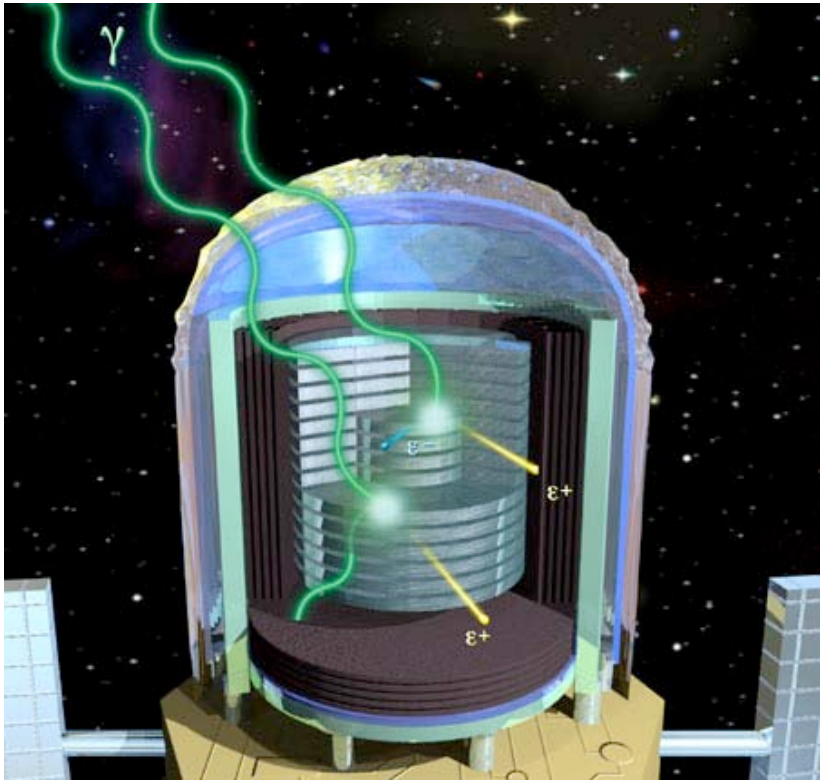

MeV Spectroscopy
Compton & Coded Mask
CGRO
BeppoSAX
HETE-2
INTEGRAL
Swift
Suzaku
AGILE
Fermi
NuSTAR
SVOM / ECLAIRS
ASTROSAT
Next Gen ME/ GRB
Next Gen. HE
1990
2000
2010
2020
2030
Year
GRBs
Low E & Medium E
High E

CGRO COMPTEL Instrument





Future Advanced Compton Telescope



Dense-packed Ge and CdZnTe Strip Detectors

Mission concept phase

Technology development

Medium energy range
0.2 - 10 MeV

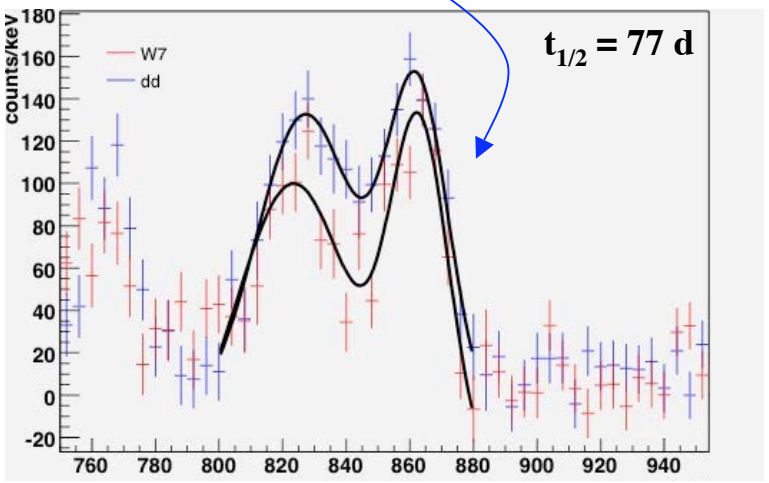
Nuclear γ-ray lines

Pulsars

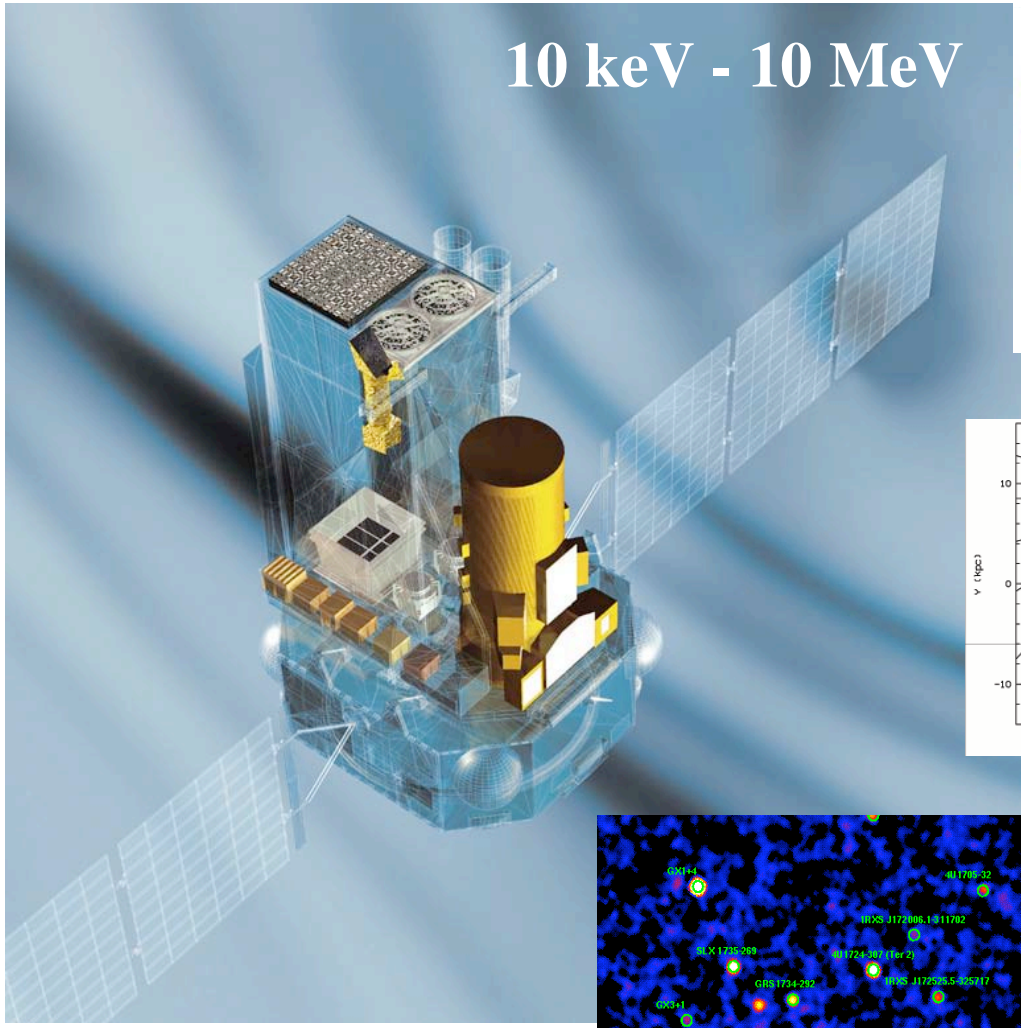
Blazars

SN Ia @ 10 Mpc

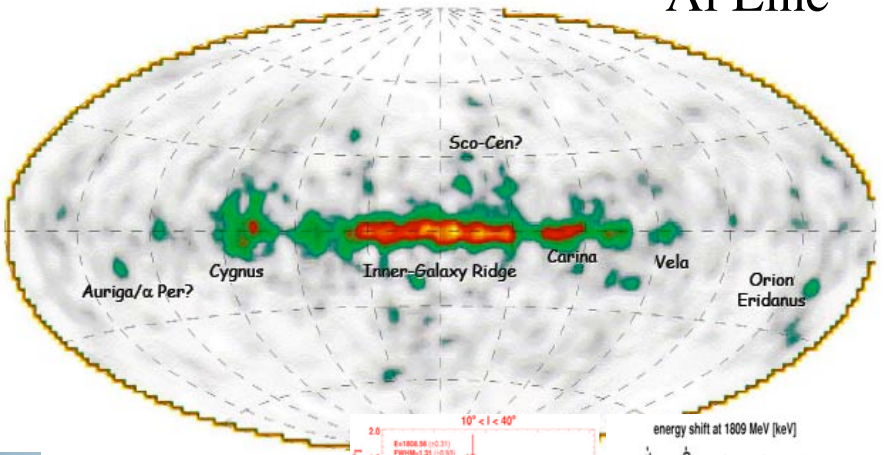
$^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$

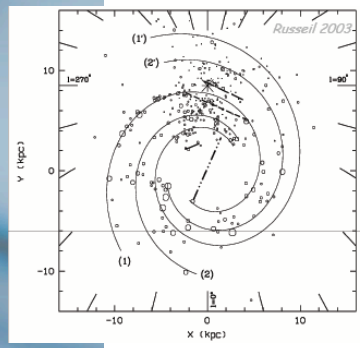


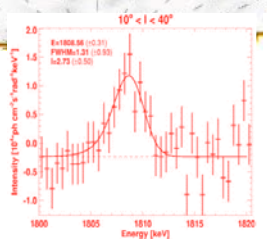
INTEGRAL

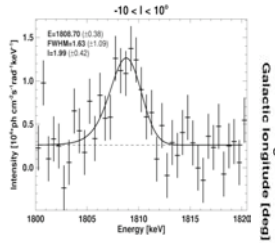


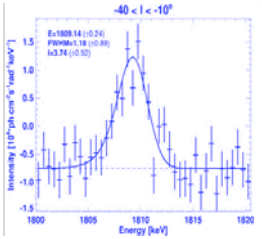
^{26}Al Line

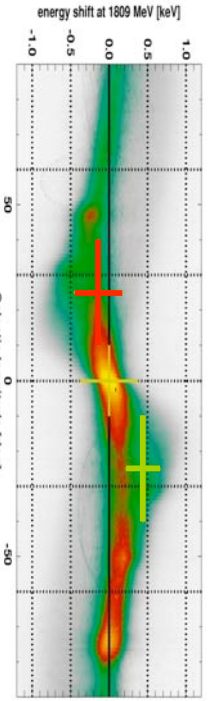


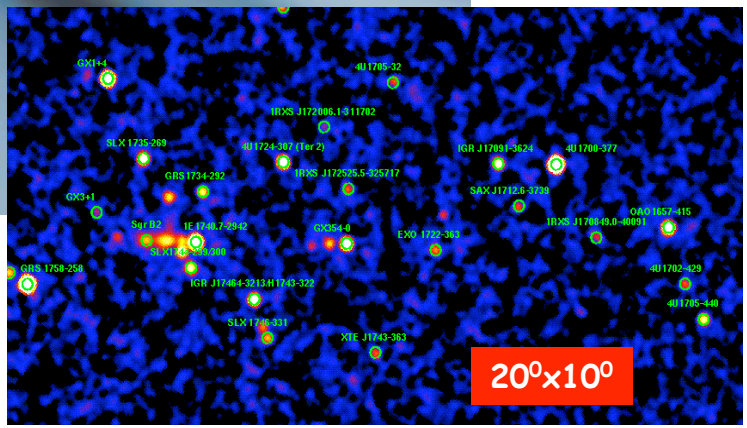








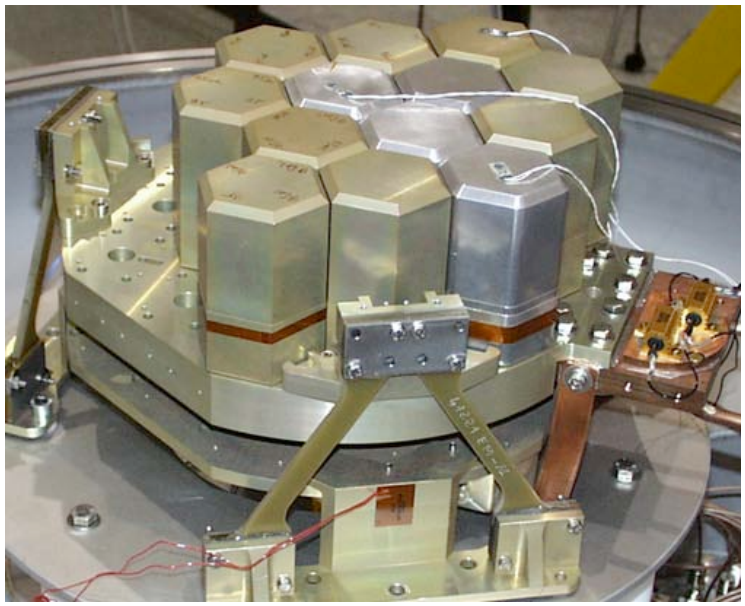




Hard X-ray Map

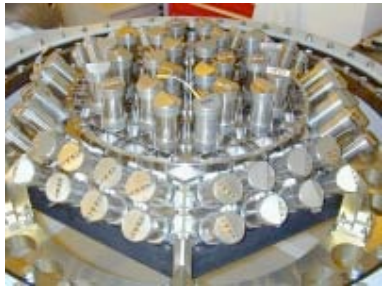
INTEGRAL SPI Instrument

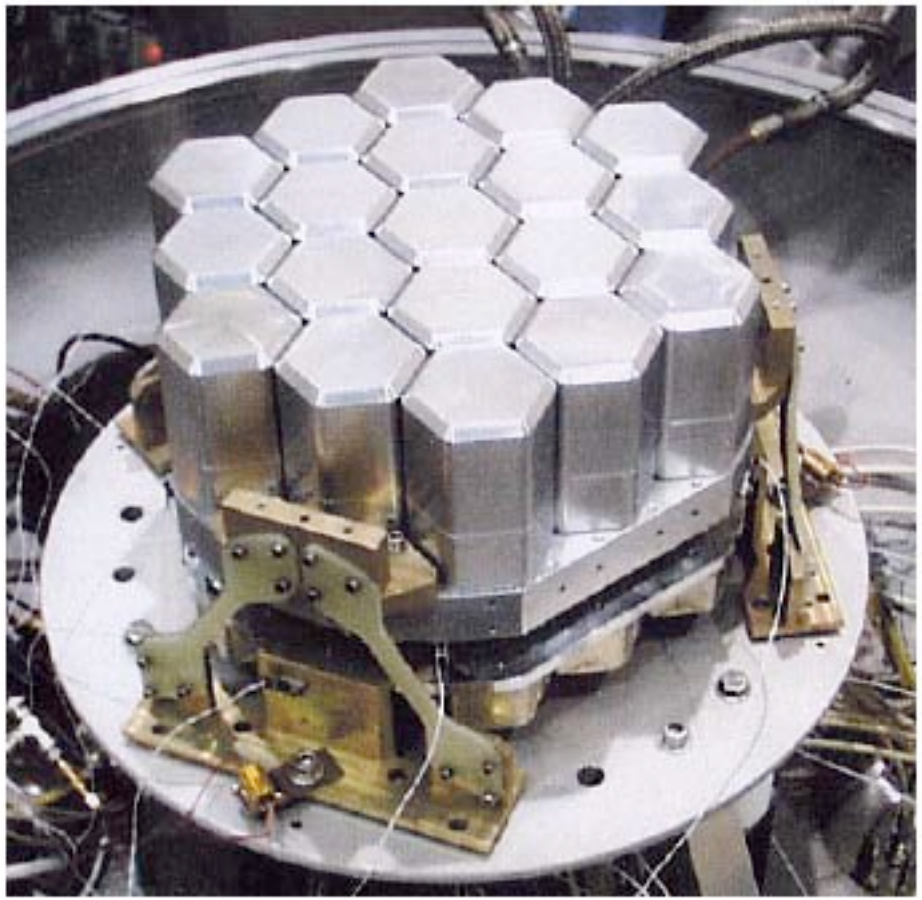
Tungsten mask

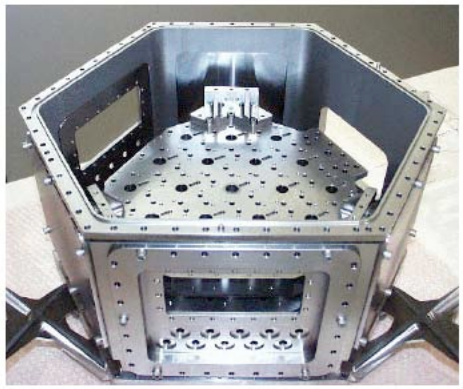


Ge detectors

400 kg
BGO shield







SPI Ge Array

19 Ge detectors

n-type HP coaxials

6 cm x 7 cm hexagonal

500 cm^2 detector area

3500 cm^3 volume (19 kg)

Hoboken Ge

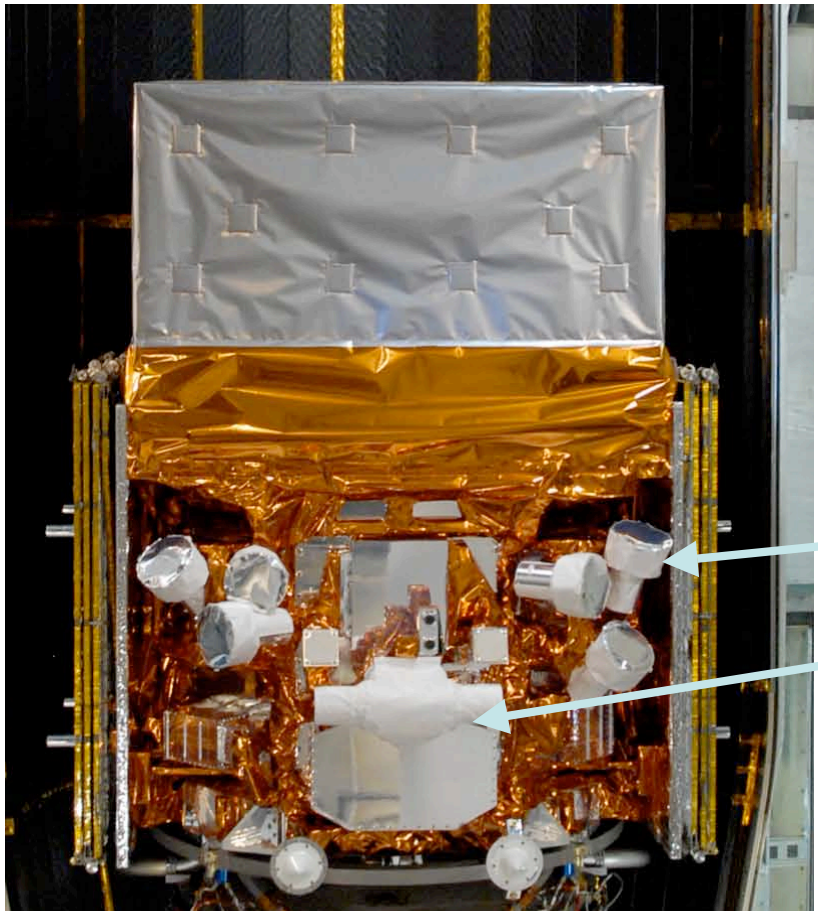
4000 V bias

2 keV @ 1 MeV resolution

85 K Stirling cyle cooler

Be cryostat (210 K)

Fermi GBM Instrument

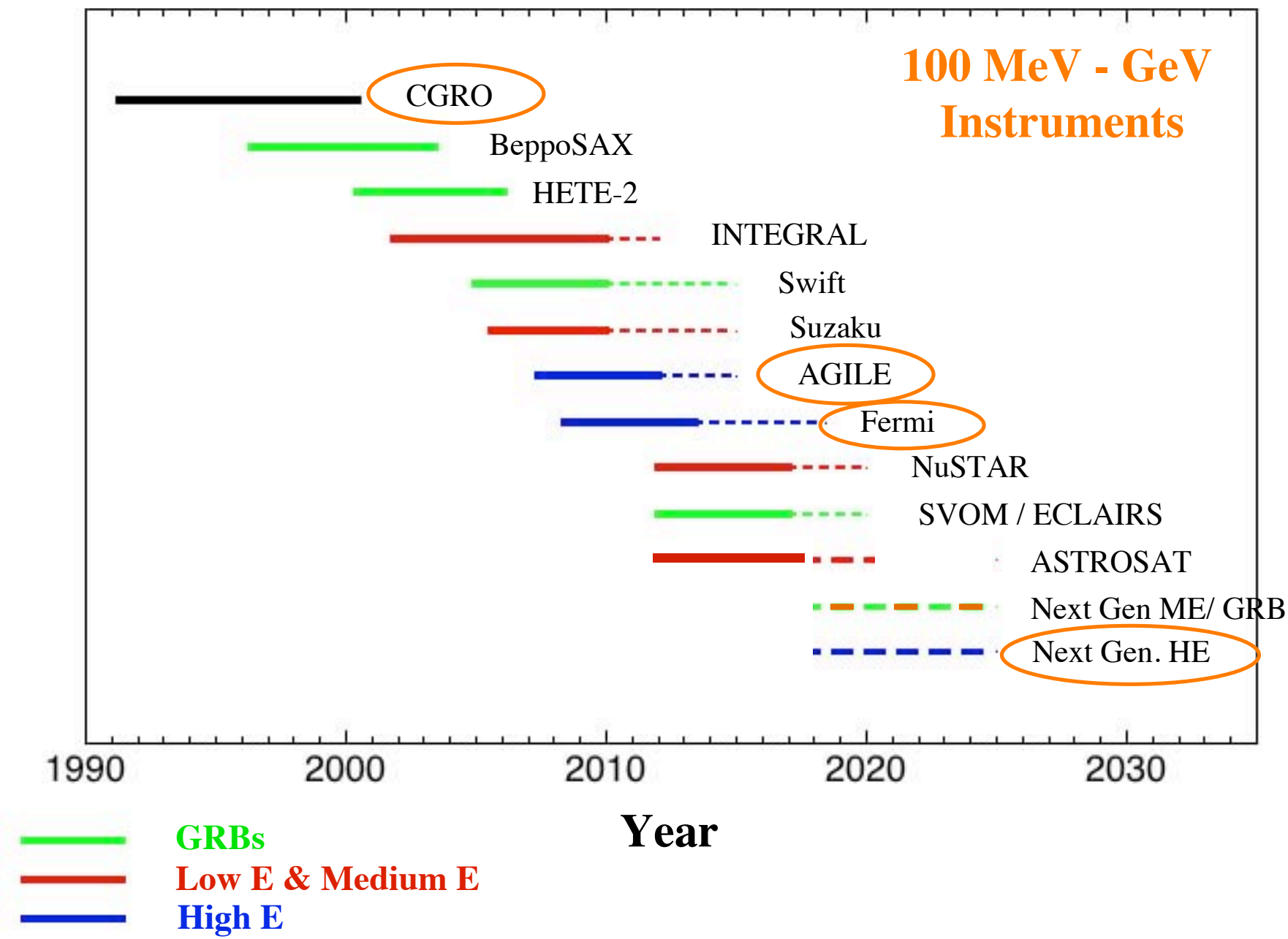


Gamma-ray Burst Monitor (GBM)

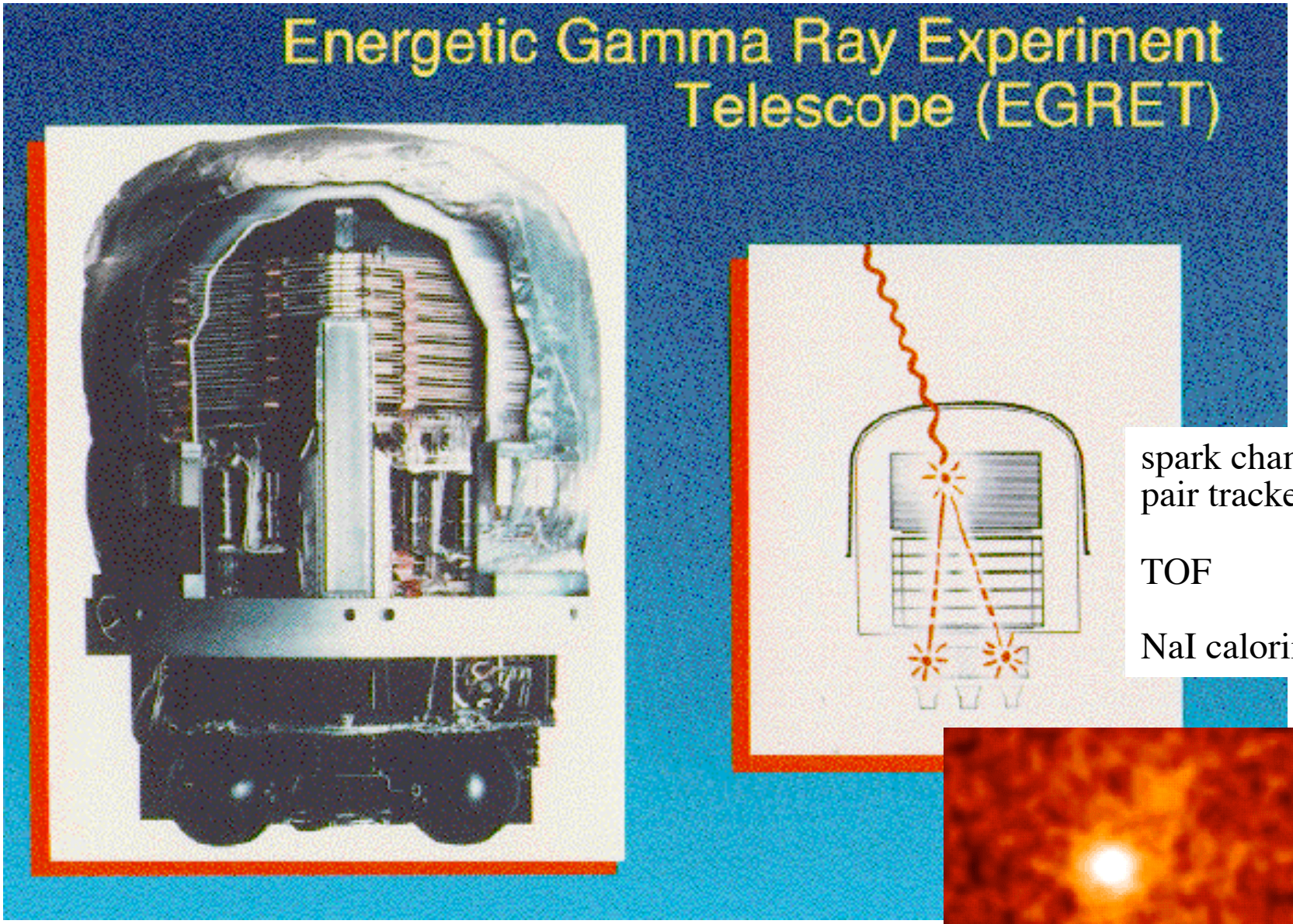
- 8 keV - 40 MeV
- views entire unocculted sky

12 NaI detectors - 8 keV to 1 MeV

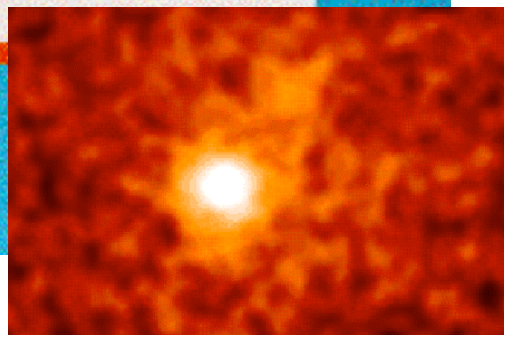
2 BGO detectors - 150 keV to 40 MeV


100 MeV - GeV
Instruments
CGRO
BeppoSAX
HETE-2
INTEGRAL
Swift
Suzaku
AGILE
Fermi
NuSTAR
SVOM / ECLAIRS
ASTROSAT
Next Gen ME/ GRB
Next Gen. HE
1990
2000
2010
2020
2030
Year
GRBs
Low E & Medium E
High E

CGRO EGRET Instrument



3C279 Image



LAT Instrument

16 identical towers
tracker, calorimeter, ACD

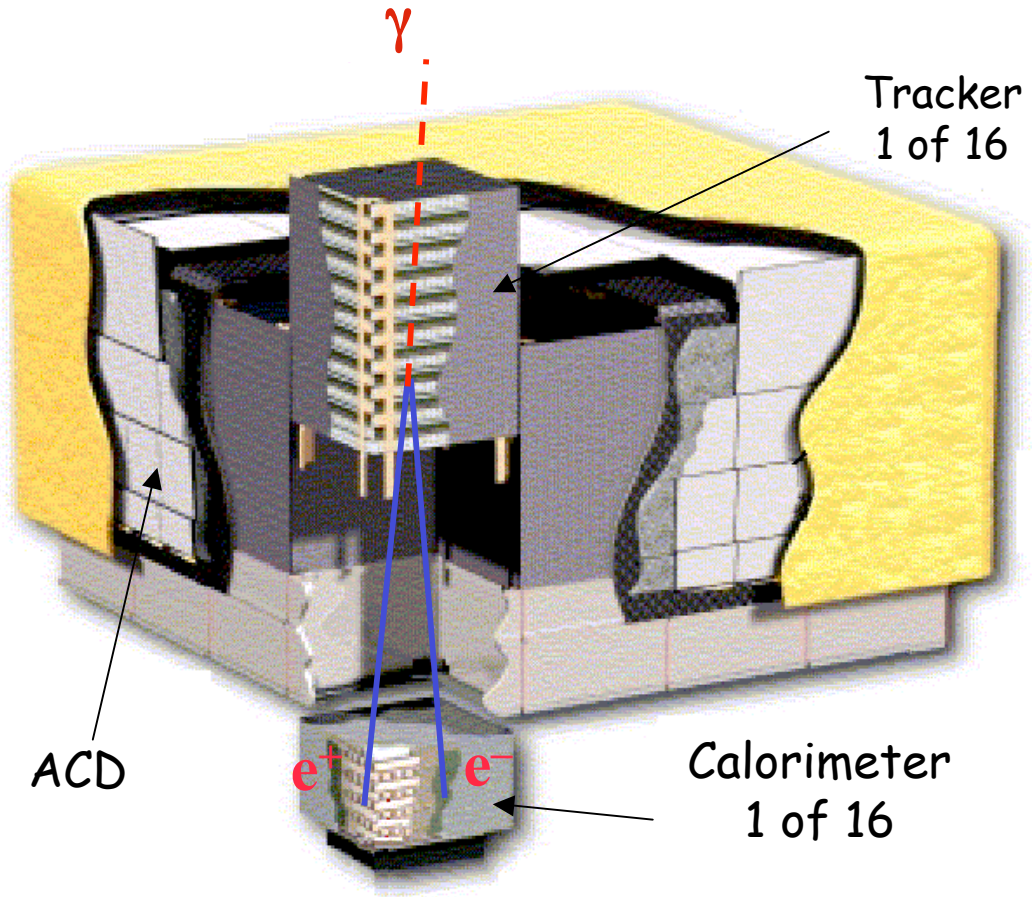
Field of view: 2 sr (4x EGRET)

Range: 20 MeV - 300 GeV

Area: ~8,000 cm^2 (6x EGRET)

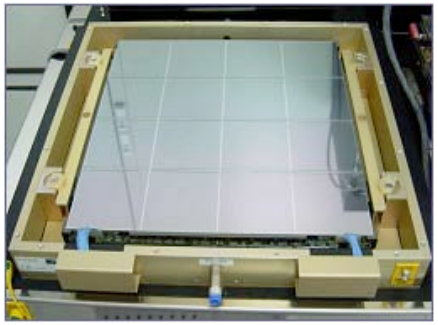
Sensitivity:
< 6 x 10^{-9} photon cm^{-2} s^{-1}
(25x better than EGRET)

No expendable gas



AGILE mission in Italy is 1 tower with thin calorimeter

LAT Tracker



Si strip detectors

6 cm x 6 cm

201 micron pitch, 1-D

24 layers of 25 detectors

68 m^2 of Si

1.5x10^6 readout channels

Hamamatsu

Assembled in Italy & US
Integrated at SLAC
Environmental testing at NRL

GeV-TeV Ground-based Instruments

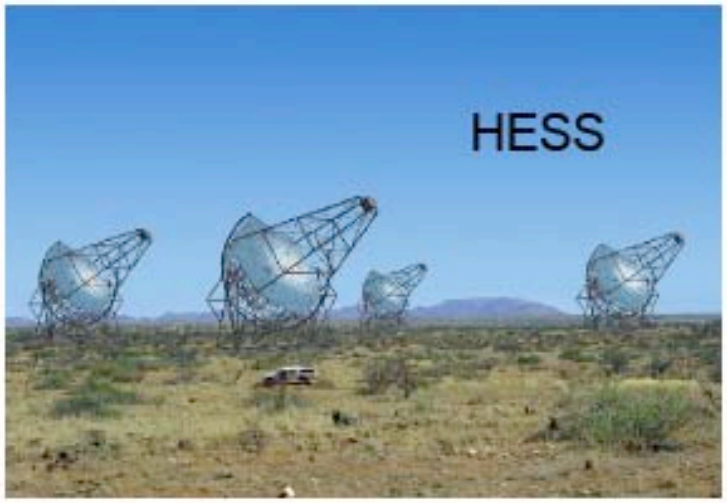
also Tibet, ARGO

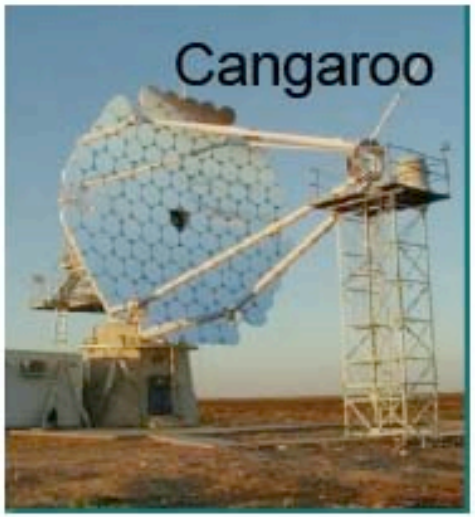
Cherenkov Telescopes

← Water

Air →

↓ ↓ ↓

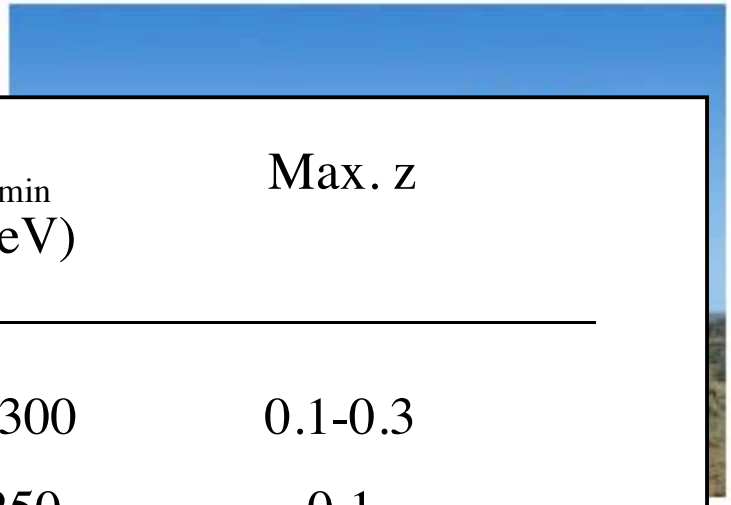




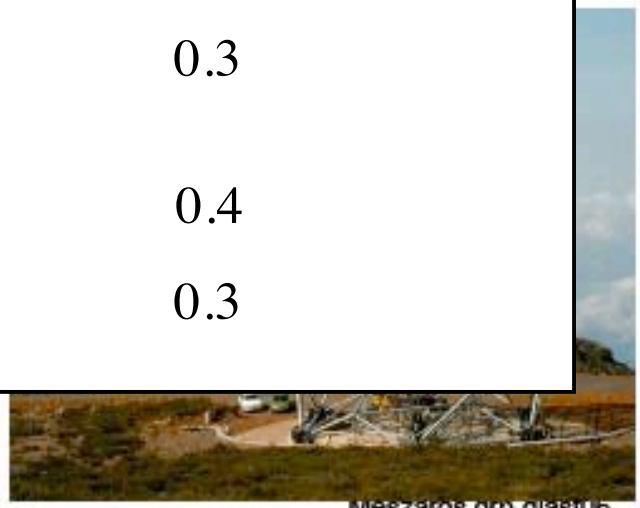
VERITAS

GeV-TeV Ground-based Instruments

also Tibet, ARGO

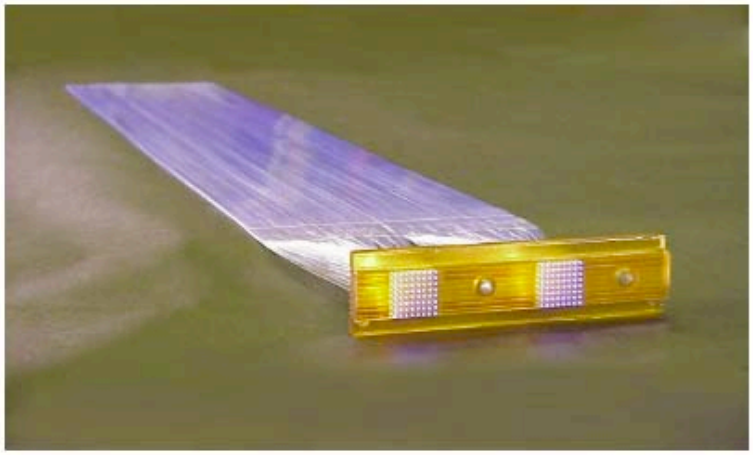


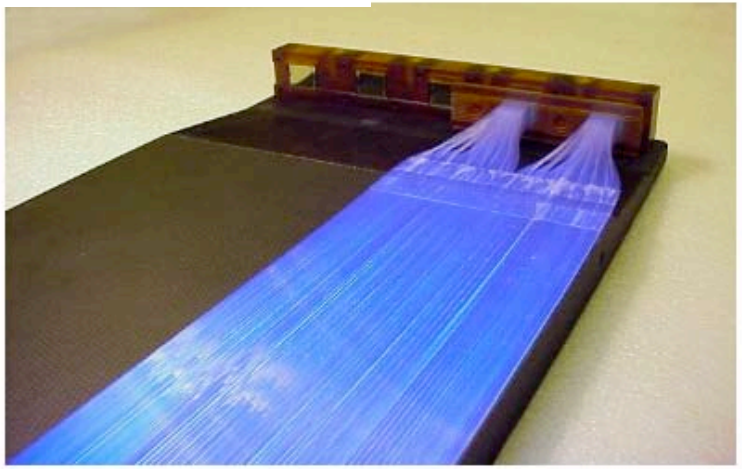
Instrument	FOV (°)	E_{min} (GeV)	Max. z
MILAGRO	~90	100-300	0.1-0.3
CANGAROO III	4	~250	0.1
H.E.S.S. (H.E.S.S. II	5	~100 ~50)	0.3
MAGIC	3.5	60	0.4
VERITAS	4.5	~100	0.3



Future Technologies

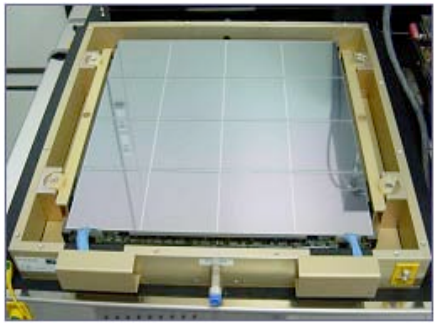
Scintillating Fibers





Binns, Buckley & Wash U. group

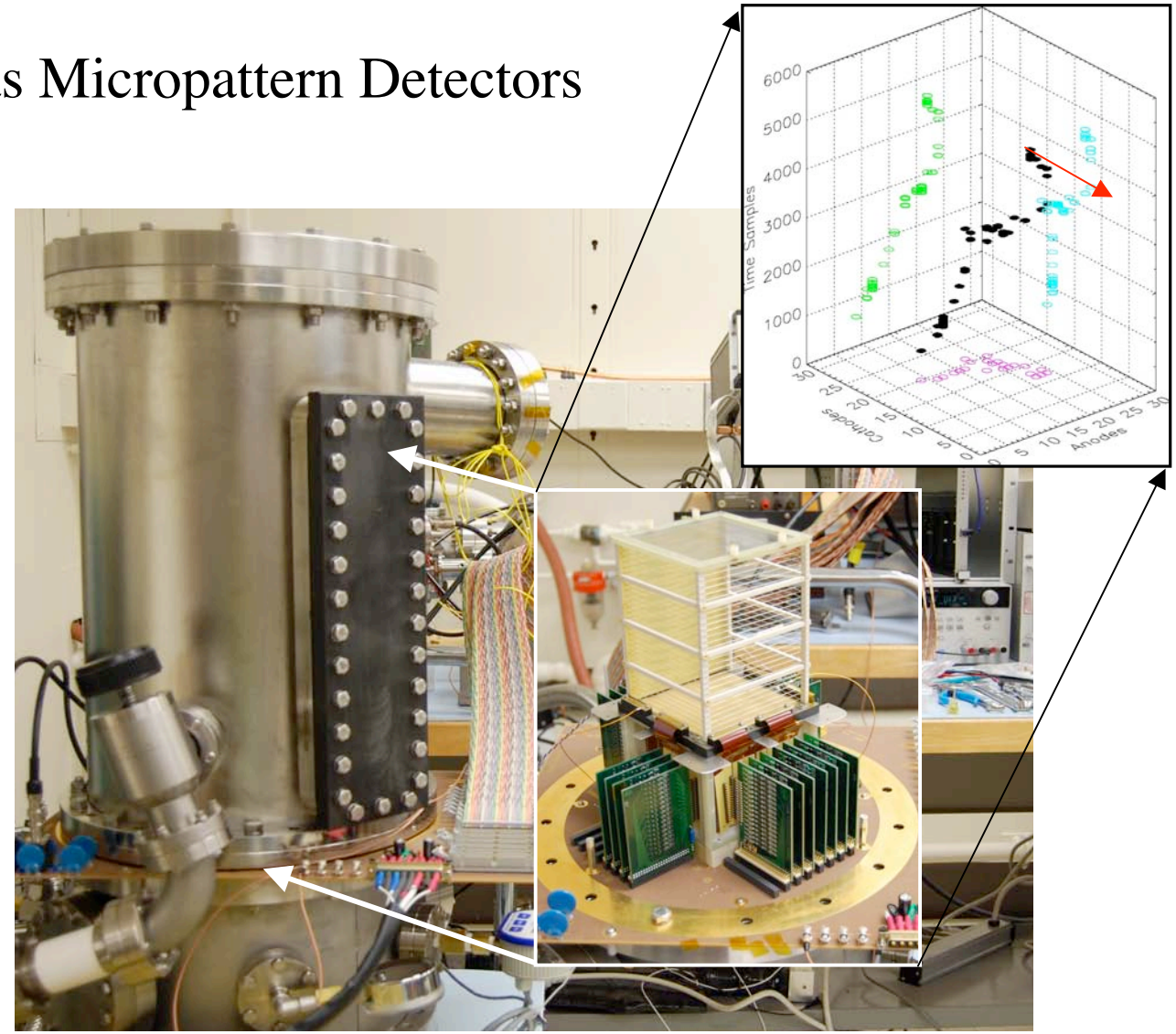
Si Strip Detectors



LAT tracker team
Japan, Italy, US

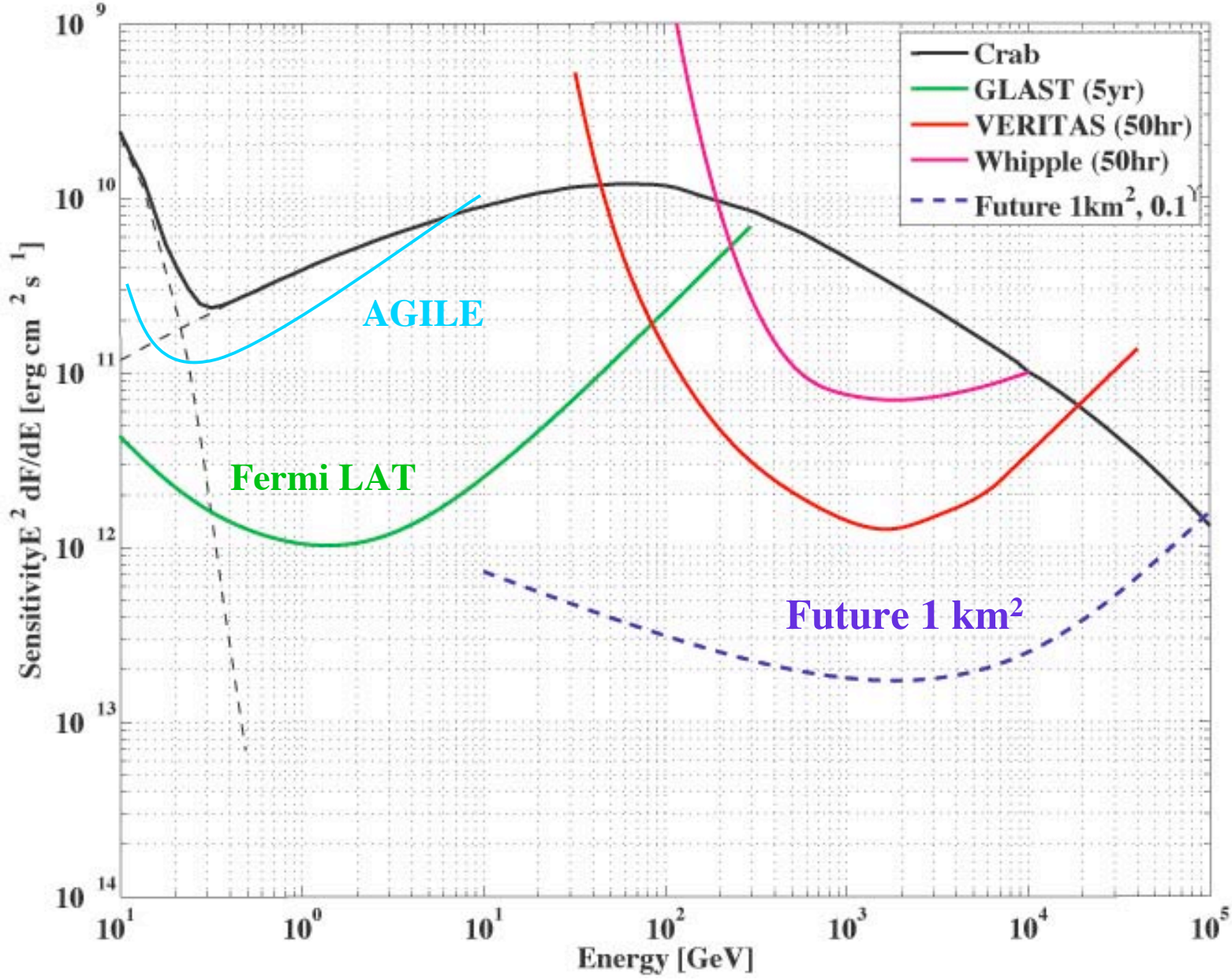
Future Technologies cont.

3-D Gas Micropattern Detectors



Hunter & GSFC group

Sensitivity



AGIS
CTA

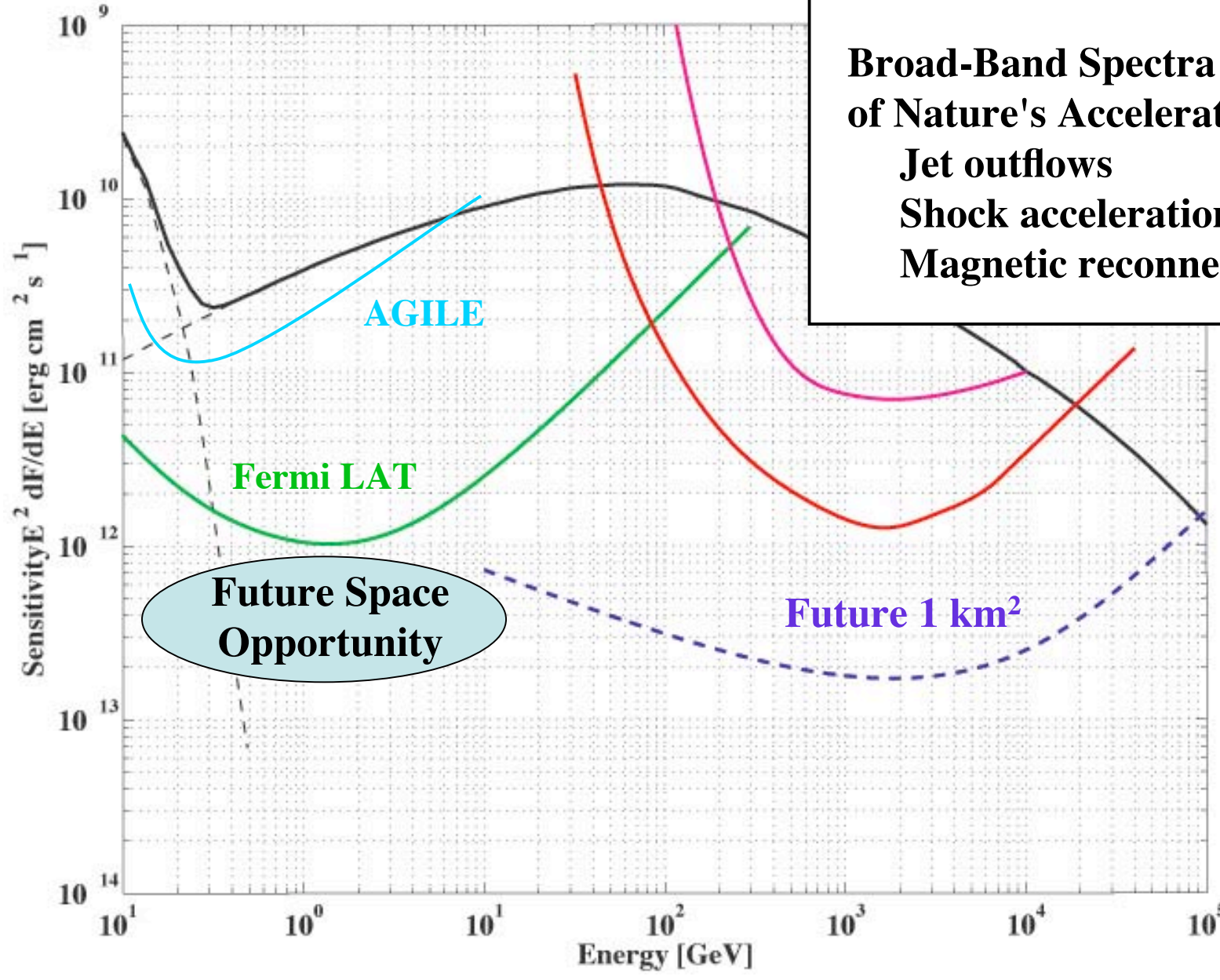
Fegan

Sensitivity

Future Science

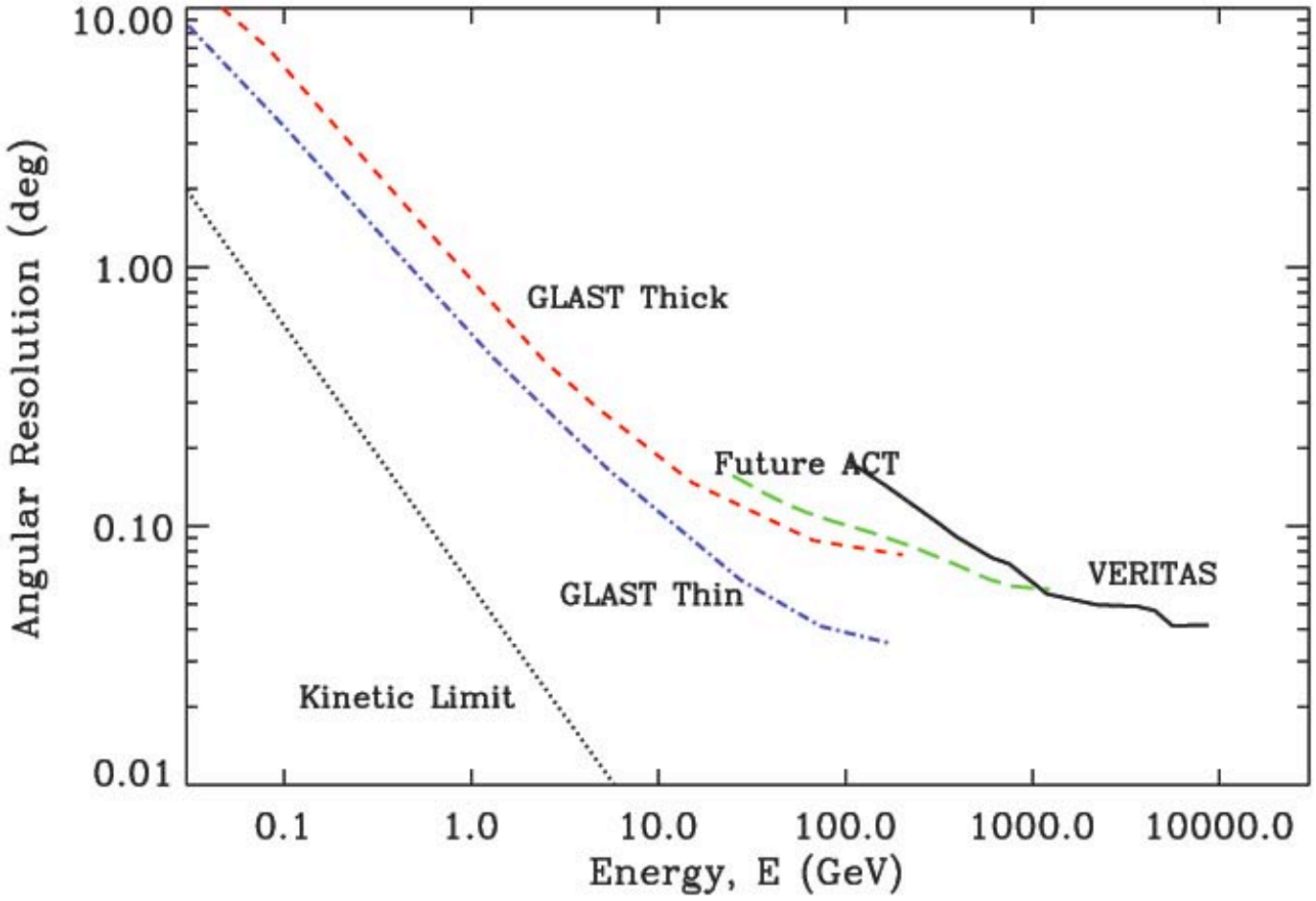
Broad-Band Spectra Studies of Nature's Accelerators

- Jet outflows
- Shock acceleration
- Magnetic reconnection



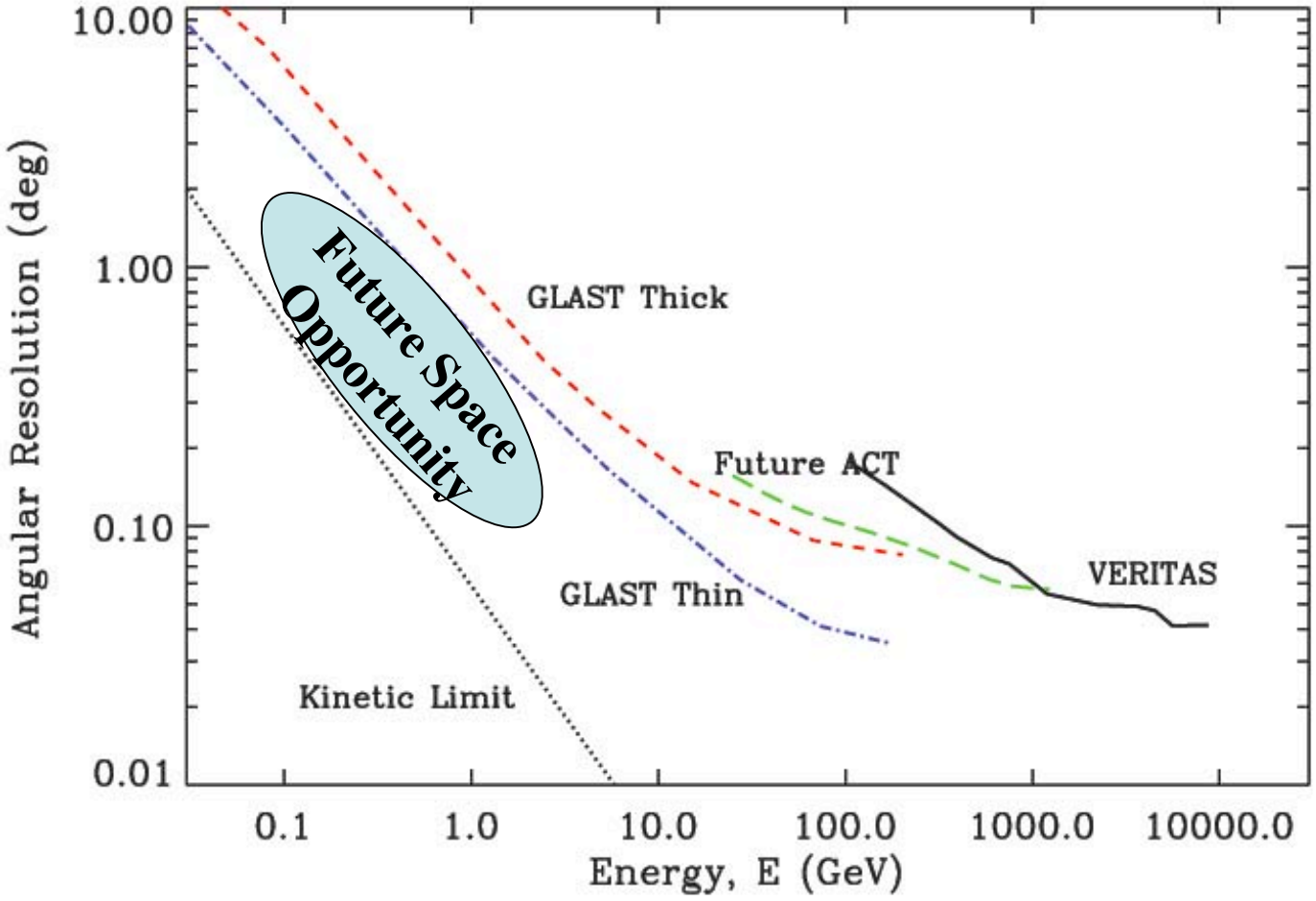
Fegan

Instrument Angular Resolutions

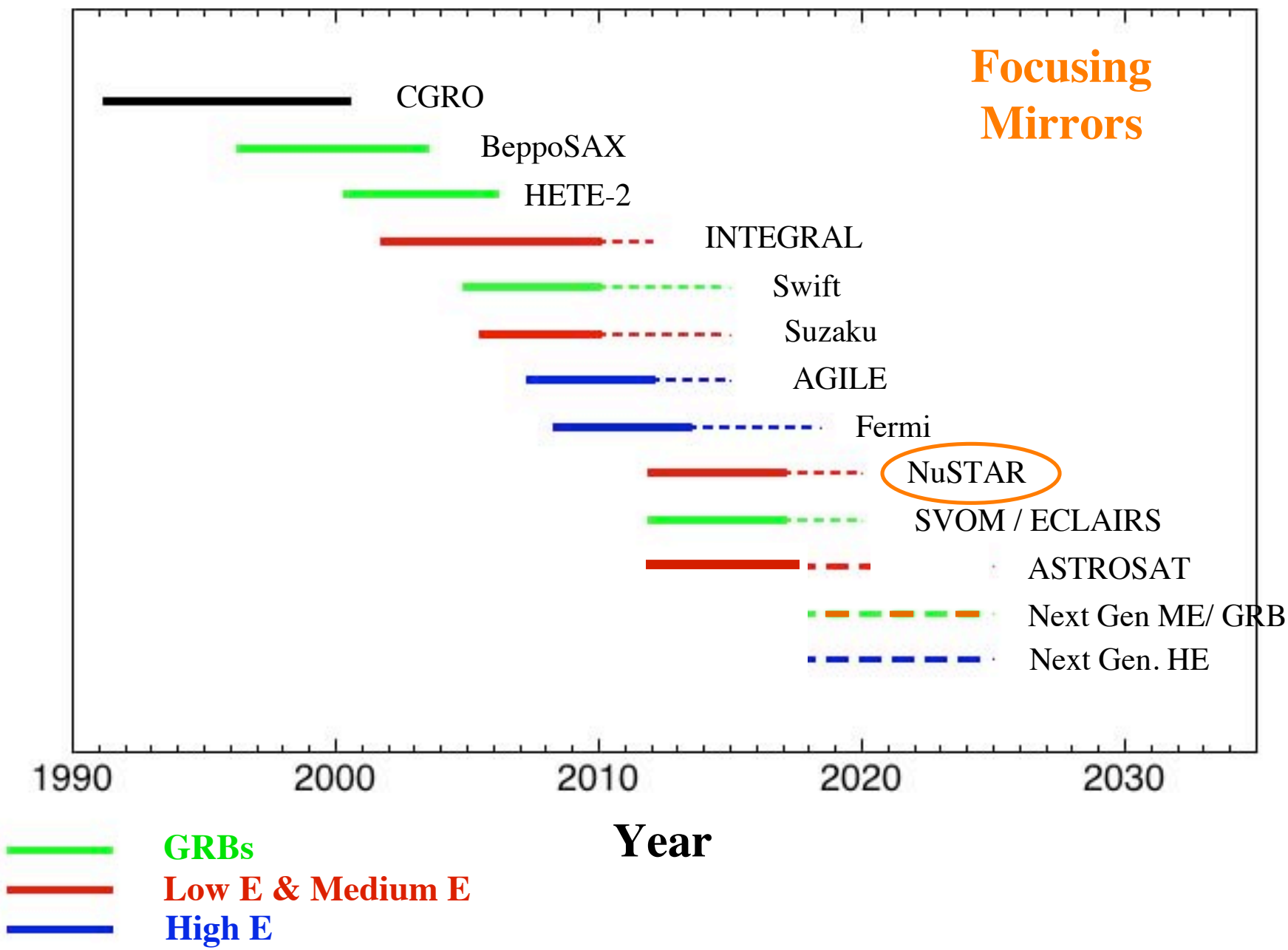


Buckley

Instrument Angular Resolutions



Buckley


Focusing Mirrors
CGRO
BeppoSAX
HETE-2
INTEGRAL
Swift
Suzaku
AGILE
Fermi
NuSTAR
SVOM / ECLAIRS
ASTROSAT
Next Gen ME/ GRB
Next Gen. HE
1990
2000
2010
2020
2030
Year
GRBs
Low E & Medium E
High E

InFOCμS

Focusing optics balloon telescope

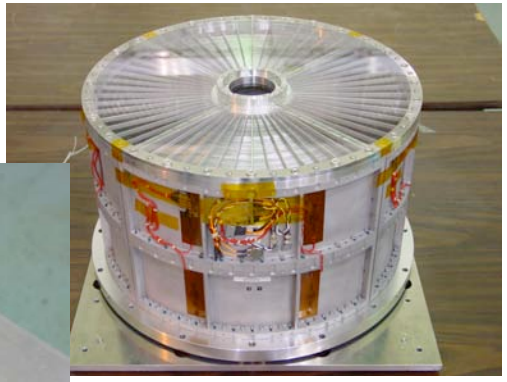
Hard X-rays (20-60 keV)

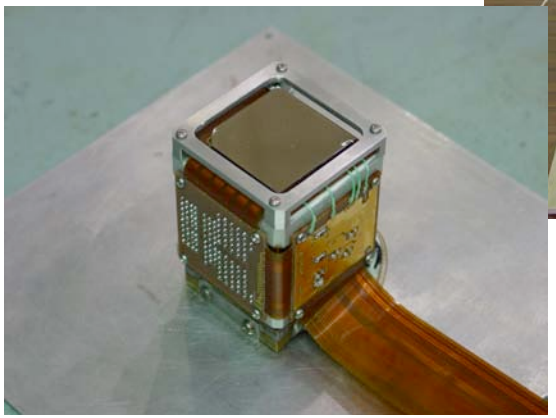
<100 μCrab sensitivity

Pathfinder for NuSTAR, ASTRO-H & IXO

Flown in 2001 & 2004

mirror





CdZnTe detector

Bragg reflection from multilayers

Pt/C sputtering

Multilayer thickness ~0.5 micron

shells per module = 130

#layers 15-150, need ~4 ŧ roughness

NuSTAR

Launch ~2012

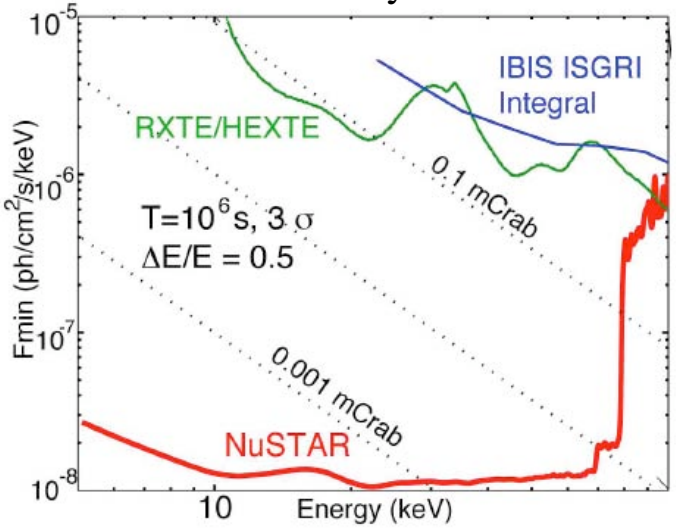
Hard X-ray focusing mission

~100 better sensitivity than coded-masks

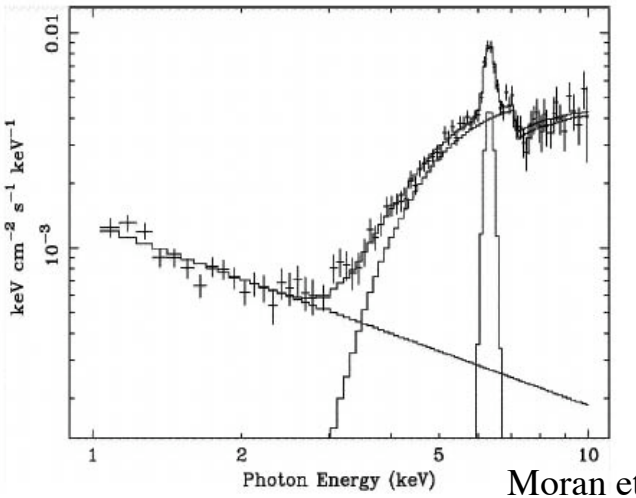
AGN survey

SNR imaging

Sensitivity



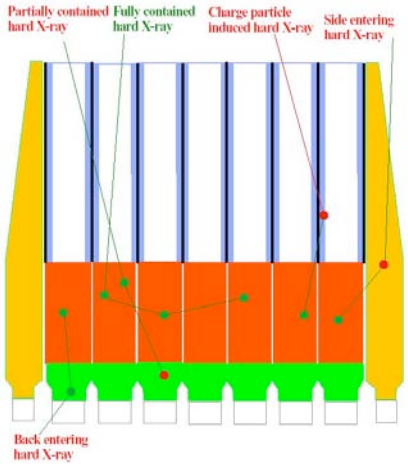
Absorbed Sy 2 Spectrum

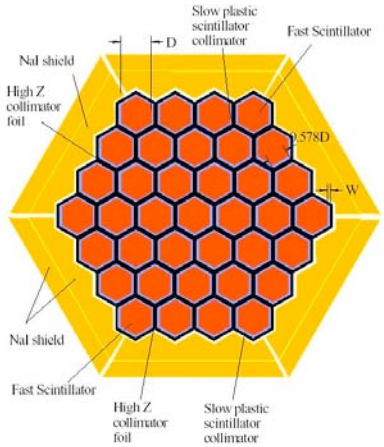


Moran et al. 2001

Future Polarization Mission

PoGO

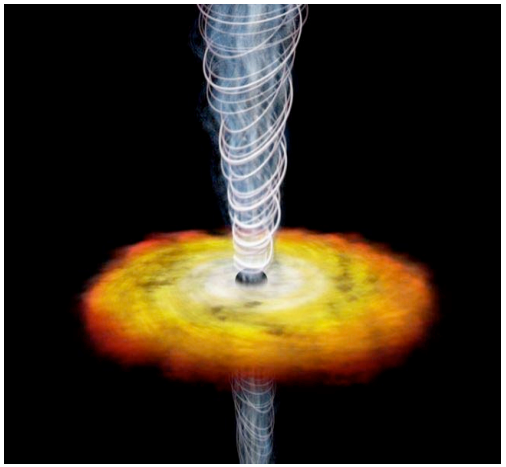




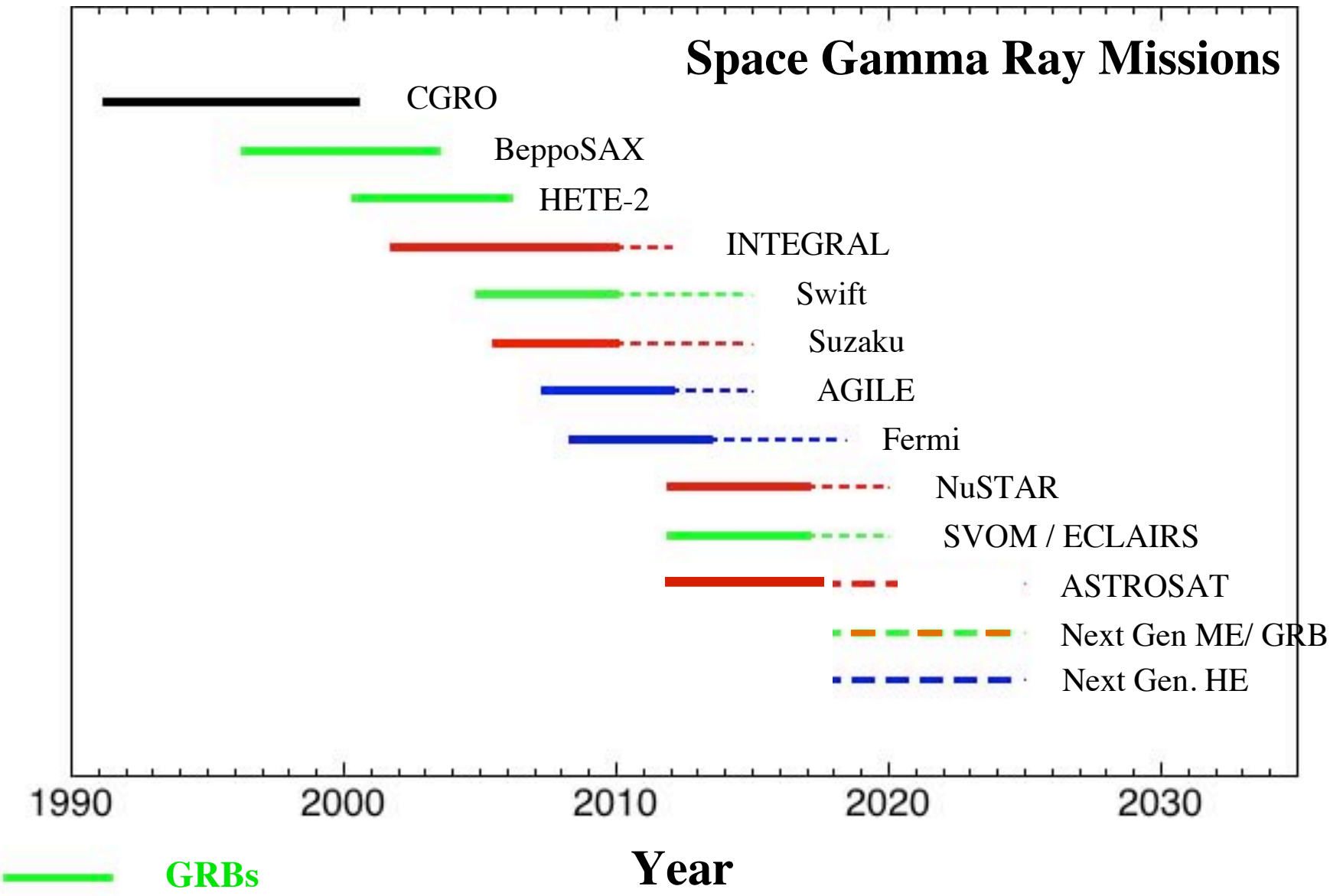
Technology development phase

Compton scattering is polarization dependent

Jet outflows & SNRs



Crab Nebula - Chandra



also RHESSI, ASTRO-H, Spectrum X