China’s Lunar Exploration Space Astronomy Programs

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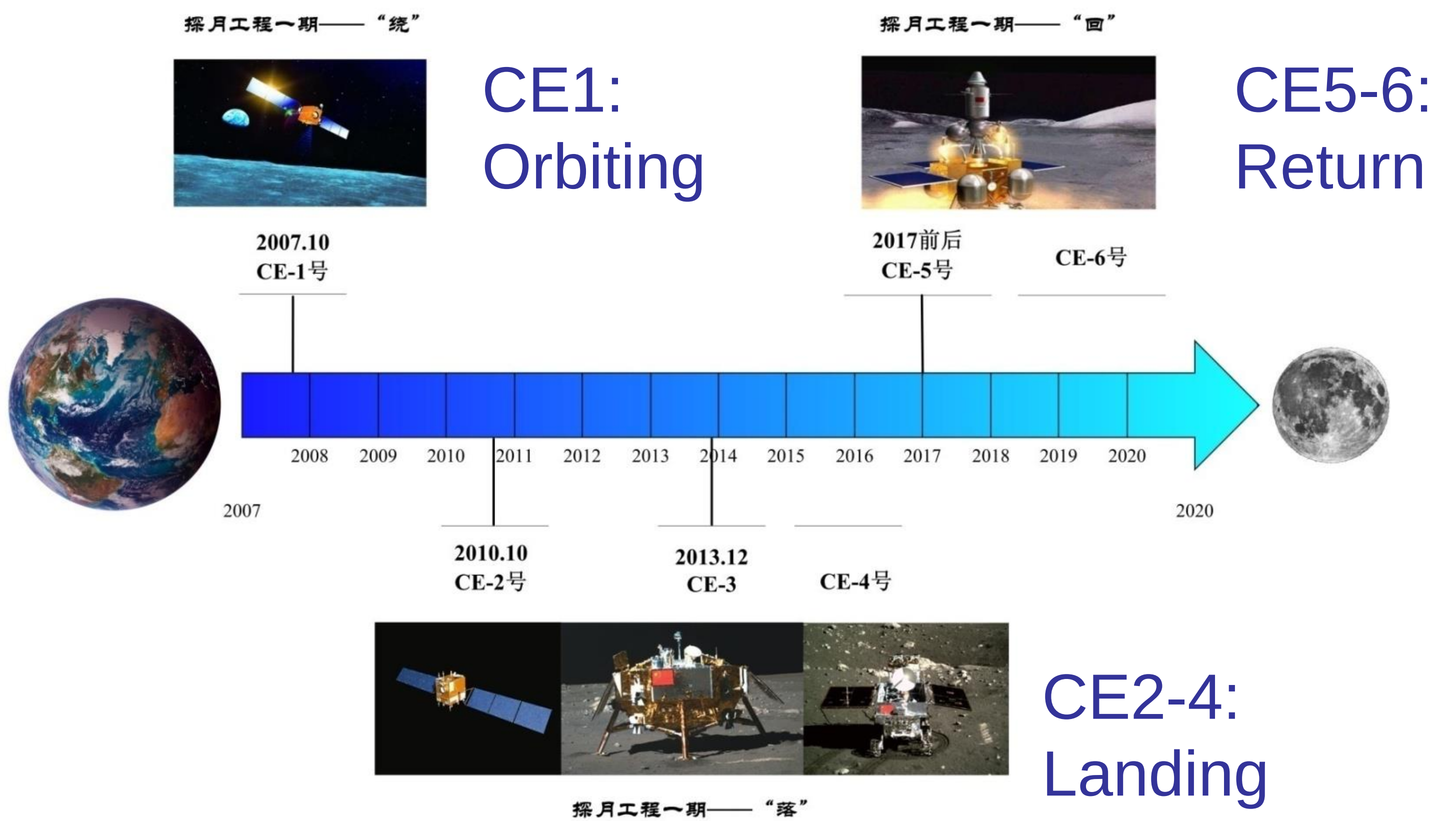
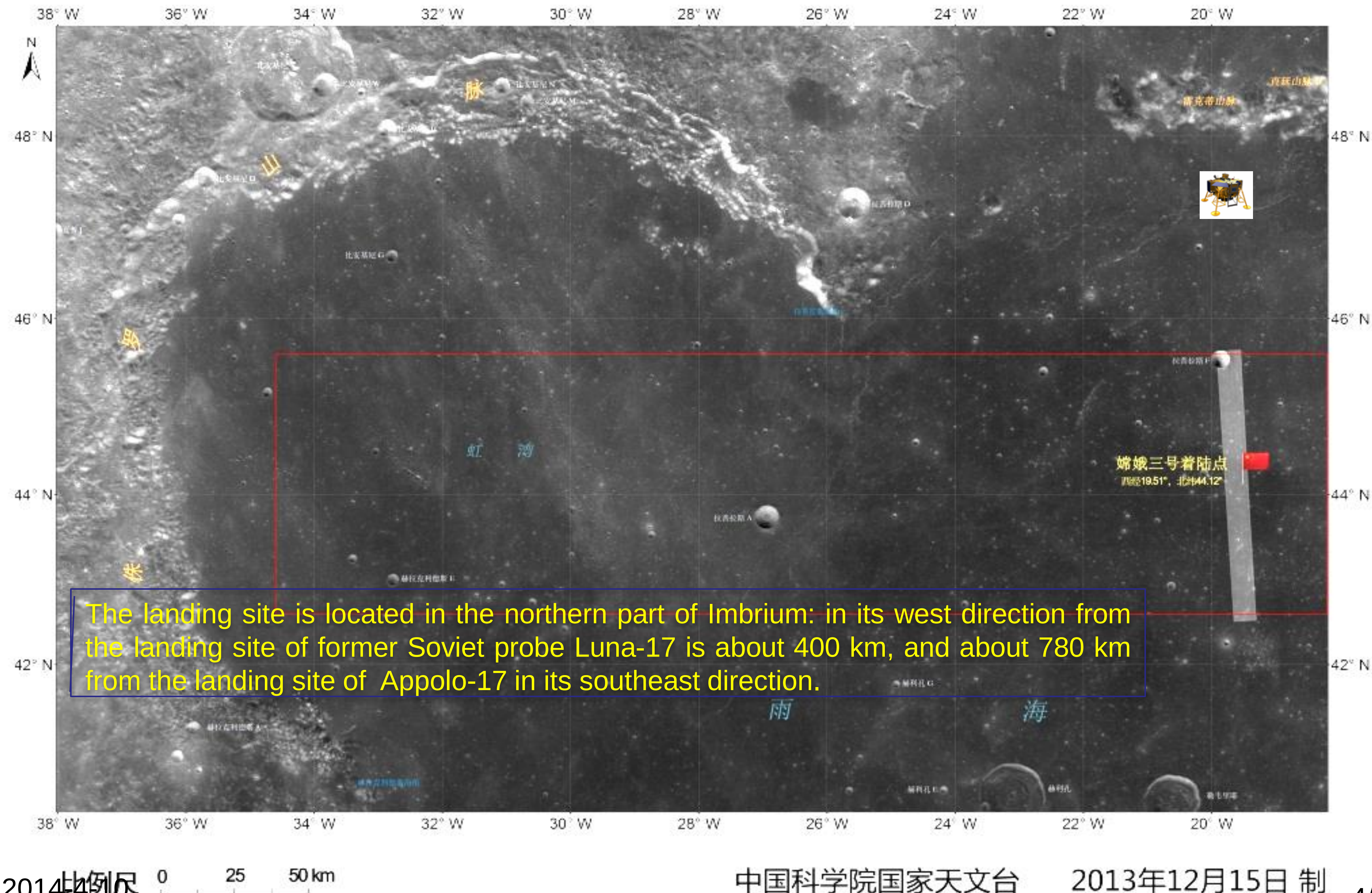
China Lunar Exploration Program

According to the announcement in 2002, from State Administration of Science, Technology and Industry for National Defense, PRC, China will carry out lunar exploration program (CLEP) including three phases before 2020:



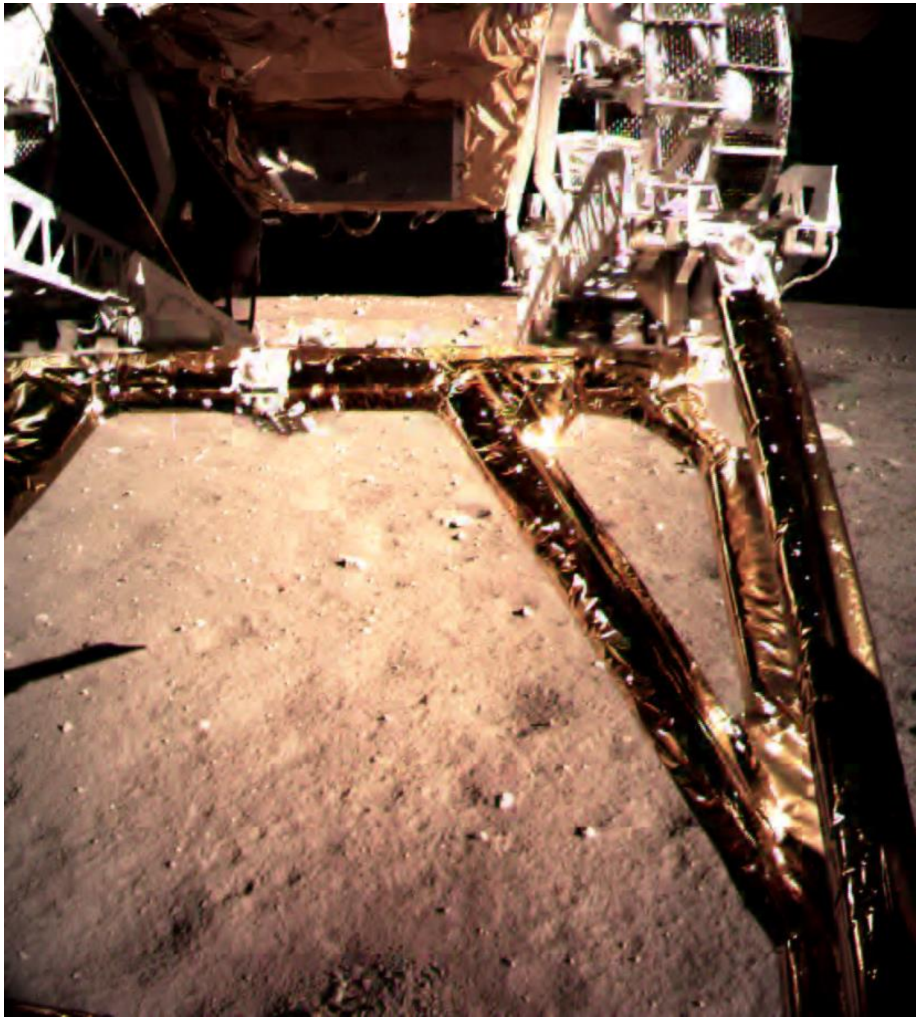
On December 2, 2013, CE-3 probe was launched from the Xichang Launch Center, southwest of China.

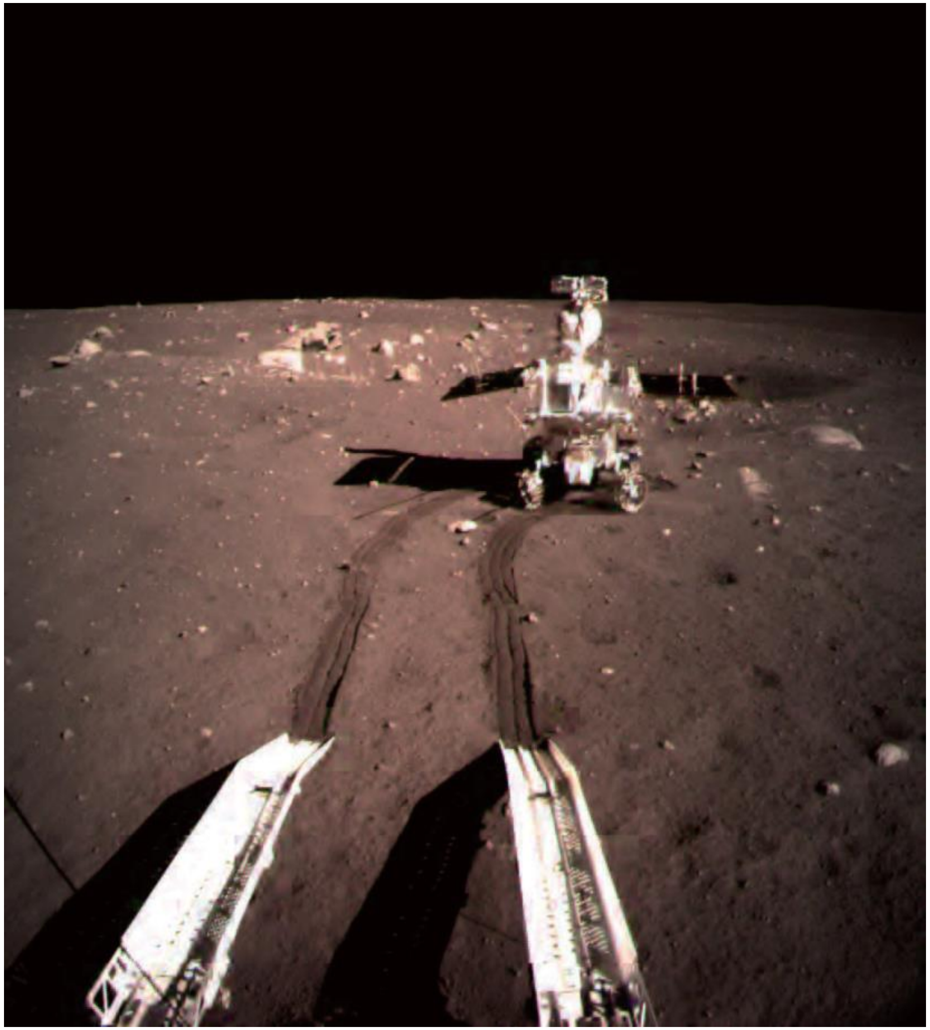
Landing site of CE-3: 44.12°N,19.51°W



The landing site is located in the northern part of Imbrium: in its west direction from the landing site of former Soviet probe Luna-17 is about 400 km, and about 780 km from the landing site of Appolo-17 in its southeast direction.

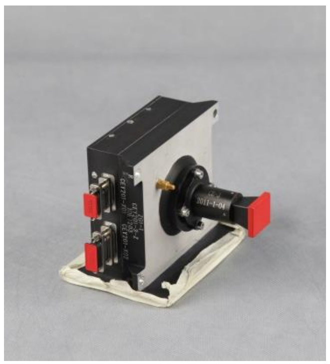
Separation between lander and rover





CE-3 mission: Lander

The CE-3 craft composed of a lander and a rover, and each of them carry four scientific payloads respectively.



Topography camera

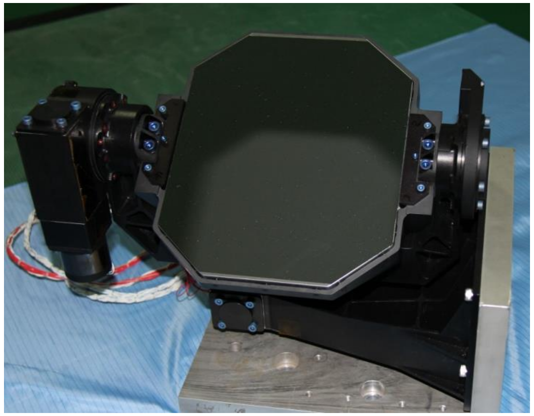
Landing camera

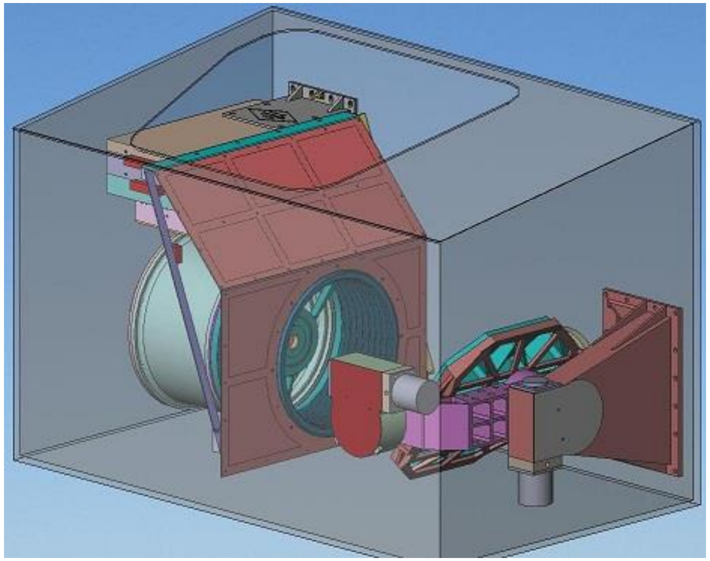
EUV camera

Lunar UV telescopes

Lunar Ultraviolet Telescope (LUT)

A telescope and a pointing reflector: the only working payload of CE-3 now.



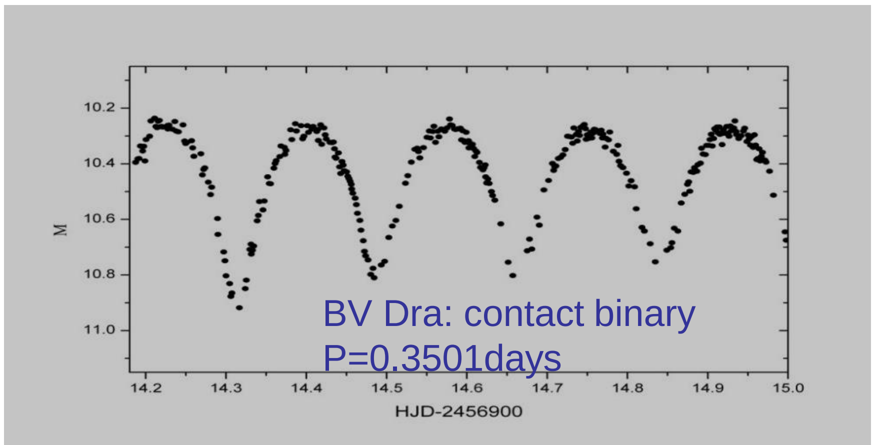


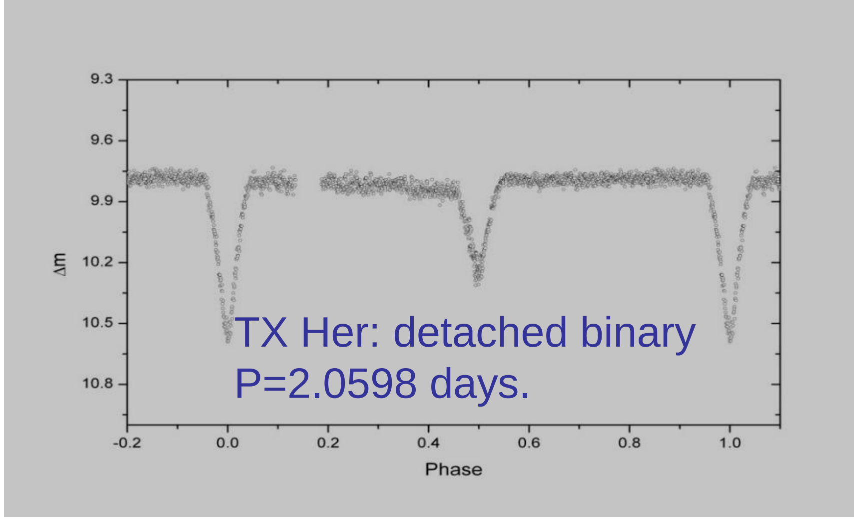
The Main Specifications of LUT

- Diameter: 150 mm
- Focal Length: 562.5 mm
- Wavelength: 245～340 nm
- Field of view: 1.36 × 1.36 Square Degrees
- CCD camera: e2v 47-20 UV enhanced (1024 ×1024 pixels)
- Limiting Mag.: 13.0 (Near UV)
- Download data: full frames/sub-windows
- Working time: lunar day time
- Life time: one year

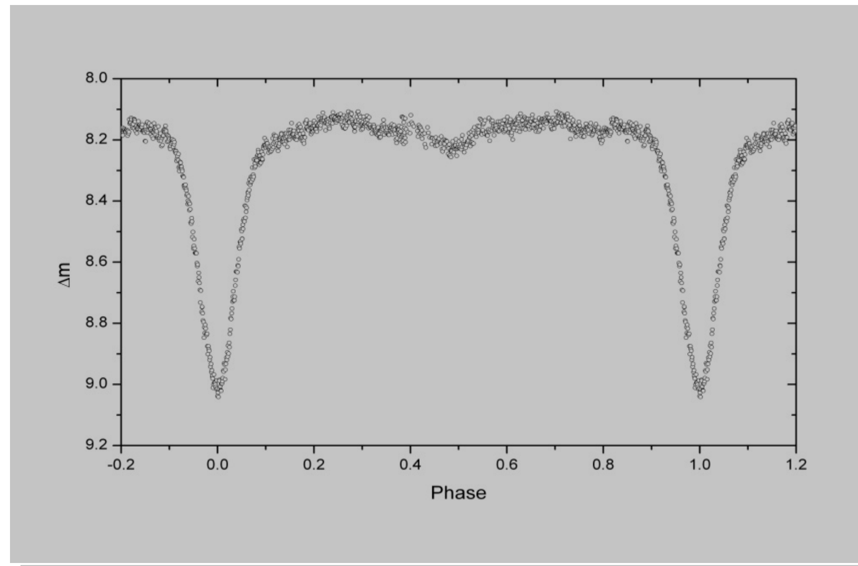
LUT results (1)

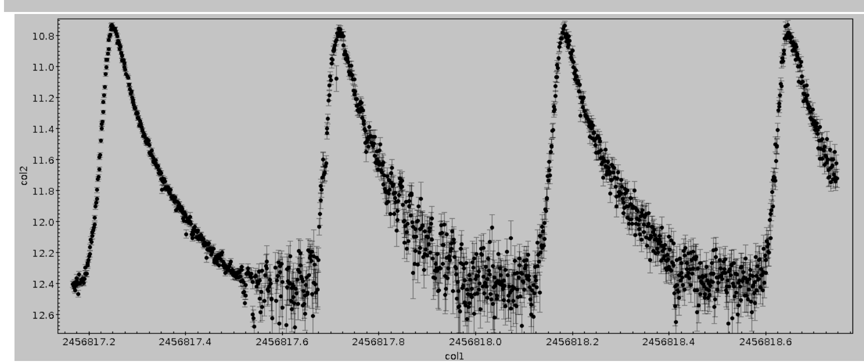
- Monitor of various variable stars hard to be done on ground
  - RR Lyrs: P~ 0.5-1 day
  - close binary stars





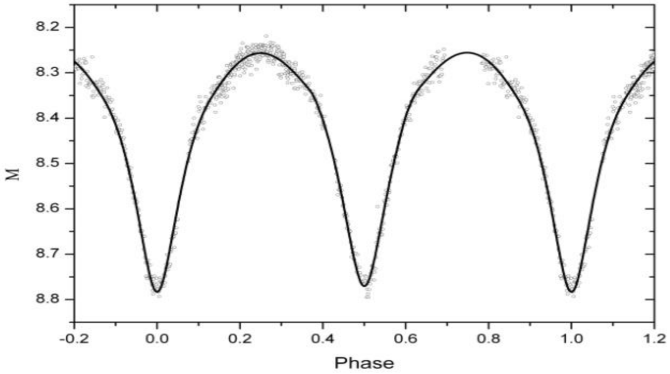
AI Dra: Algol-type eclipsing binary with P=1.1988 days.

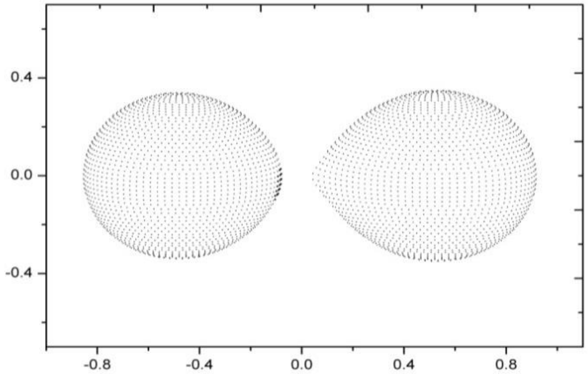




LUT results (1)

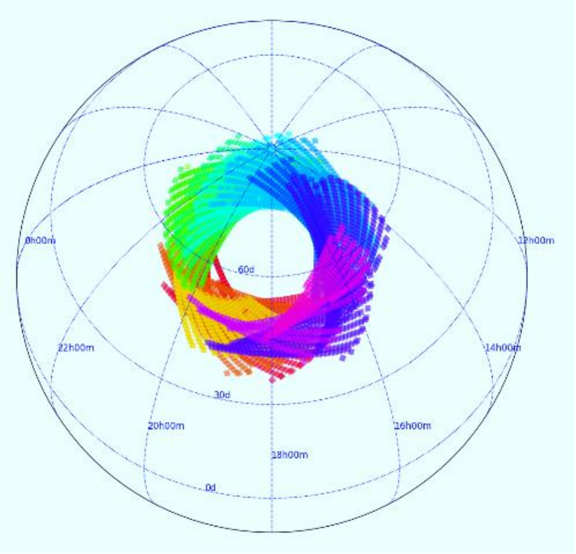
- GK Cep
  - Semi-detached binary star with P=0.936171 days.
  - Filling the critical Roche lobe and transferring mass to main component.
  - Presence of the third light, the cyclic change of the O-C diagram as well as the spectroscopic data reveal that there is a third body in the system.
- A rapidly mass-transferring binary star
  - In a triple system!
  - In critical evolution state (soon after equal mass)



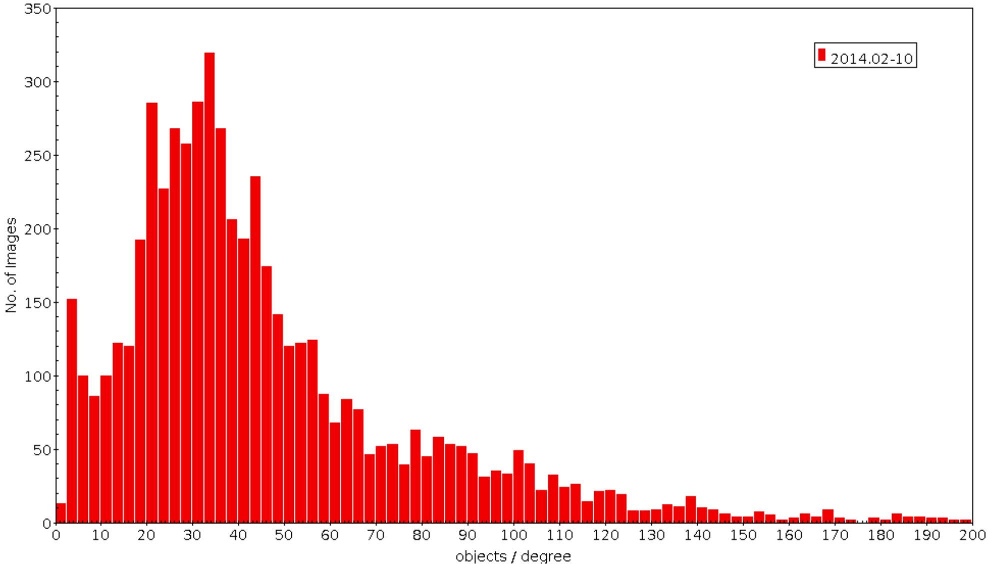


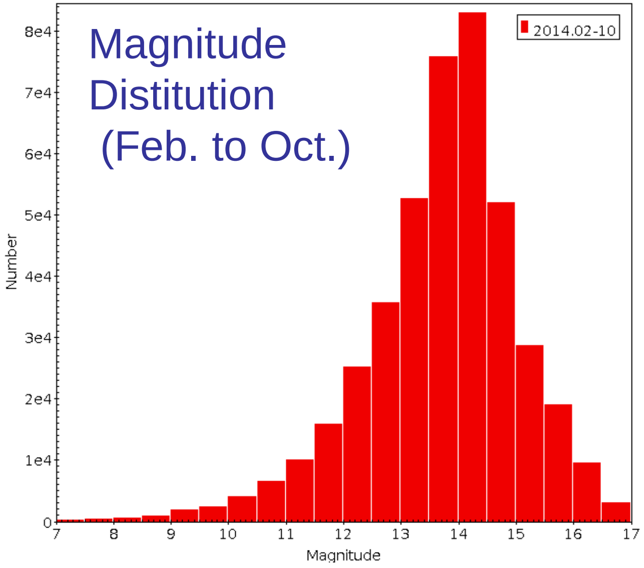
LUT results (2)

- Sky Survey in NUV
  - Finished available sky ~1700 deg^2 (up to Dec. 2014)
    - Total: ~ 88,000 objects (High S/N)



Stars per square degree (Feb. to Oct.)

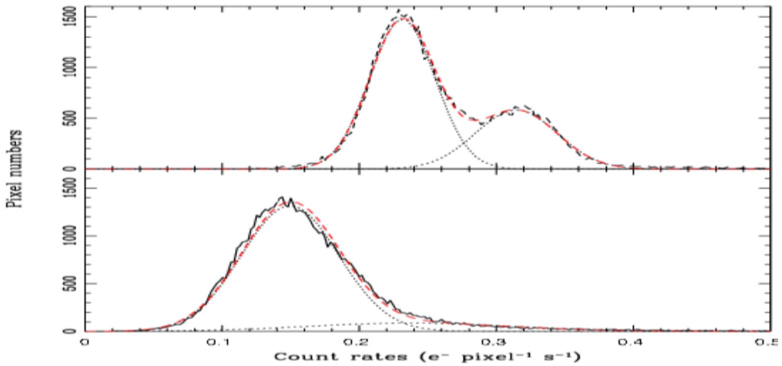


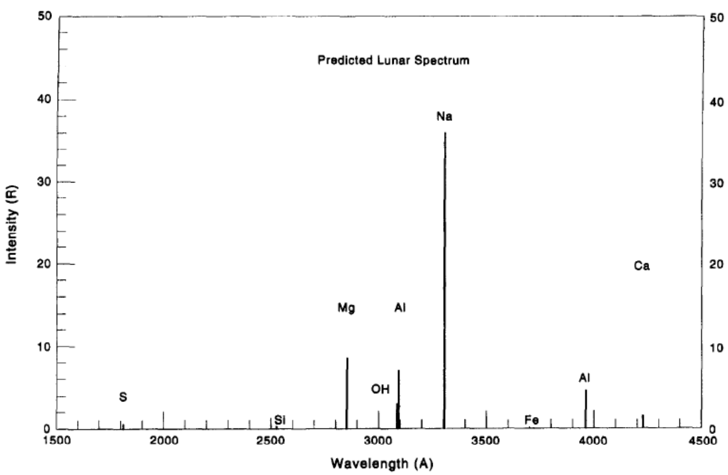


LUT results (3)

- OH(0-0)($A^2\Sigma^+$-$X^2\Pi$) 3087Å band emission
- Image background statistics
- The lowest upper limit on OH concentration (Wang+ 2015，P&SS)

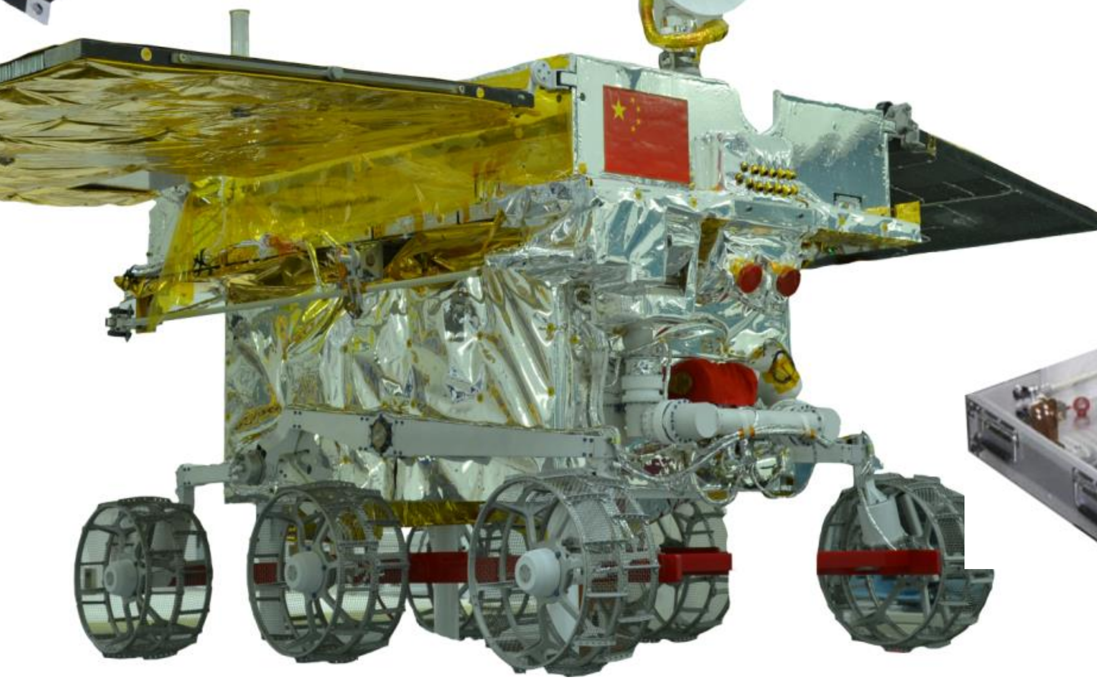
Method	Surface concentration（cm^{-3})
HST spectroscopy	$<10^6(5\sigma)$
Apollo12/14/15 CCGEs	$<10^7$
Chandrayaan/CHACE	$<2\times10^9$
LUT background emission	$<4\times10^4$



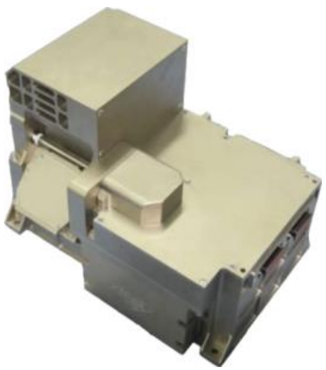


CE-3 mission: Rover (failed on 2014-01-16)

Panoramic camera



Active Particle-induced X-ray Spectrometer (APXS)



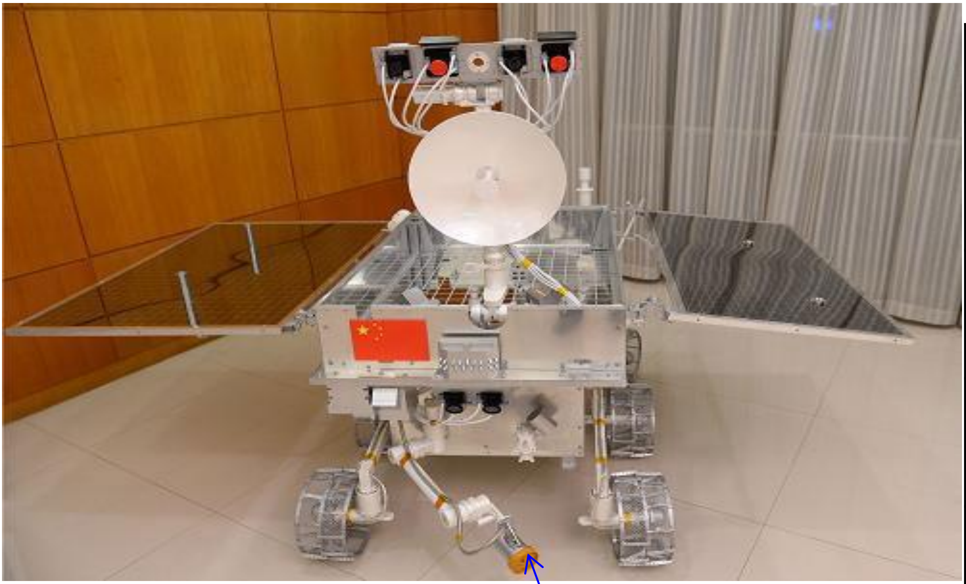
VIS-NIR Imaging Spectrometers

Rover named by “YuTu”, meaning a jade rabbit from Chinese ancient fairy tale

Lunar Penetrating Radar

APXS

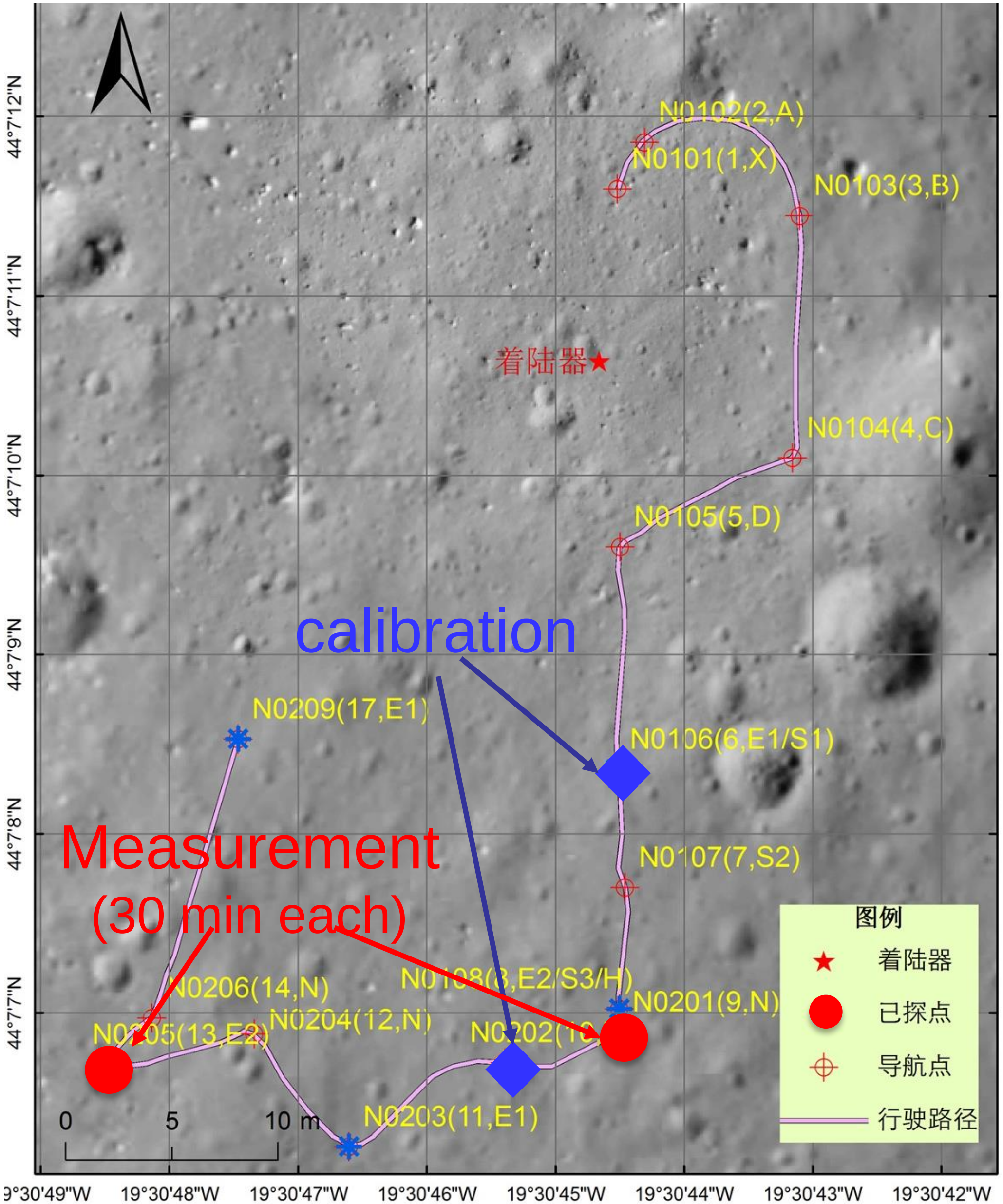
Its scientific objective is to investigate the elemental compositions *in situ*. Combined with the data from VIS-NIR Imaging Spectrometer, Panoramic Camera and Lunar Penetrating Radar, it will provide crucial data for lunar geochemistry and geology evolution studies.



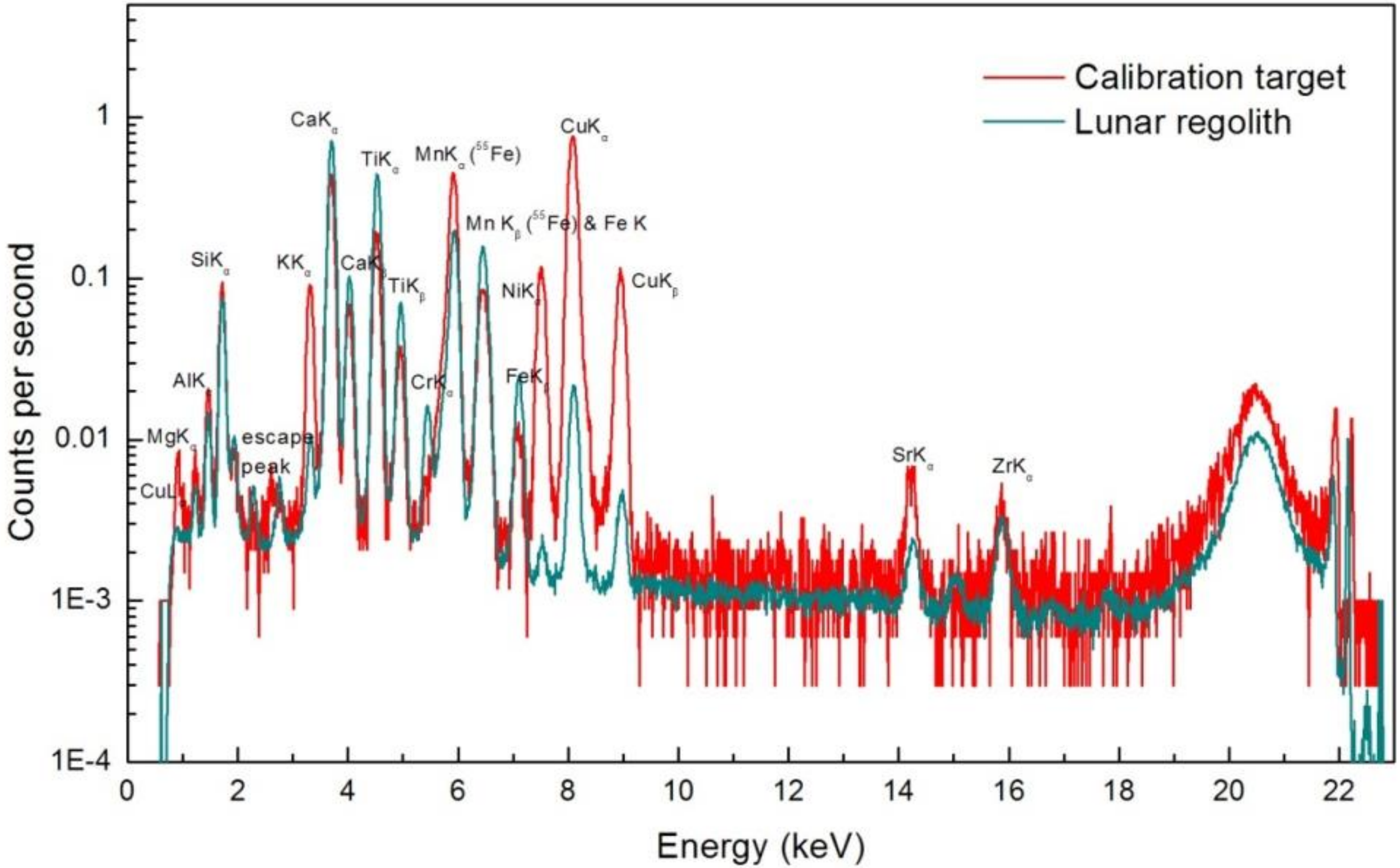
sensor head of APXS

Items	Main parameters
energy resolution	80~150eV@5.9keV（FWHM）
energy range	0.5-20keV
excitation source	^{55}Fe and ^{109}Cd
working distance	10~30mm

AXPS operations

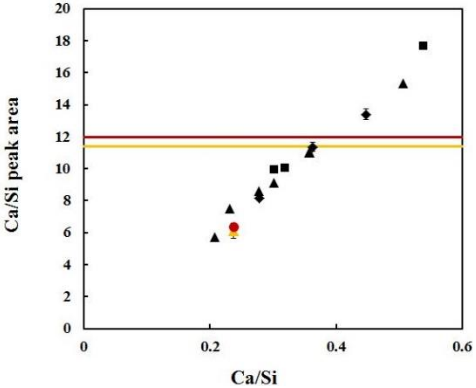


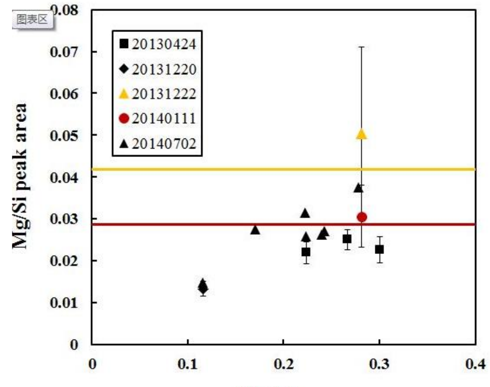
AXPS spectrum

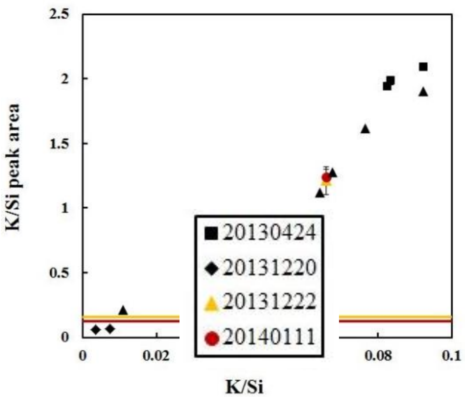


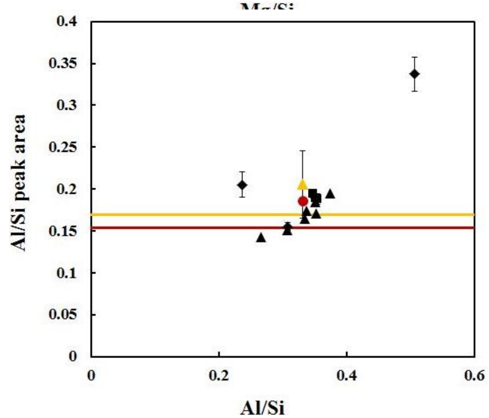
Regolith	MgO	Al2O3	SiO2	K2O	CaO	TiO2	FeO	Total
PIXS-E-006.2A	6.33	10.31	41.59	0.18	11.76	5.33	20.28	95.79
Calibration Target	10.1	13.47	46.20	1.71	7.15	2.05	9.99	90.69

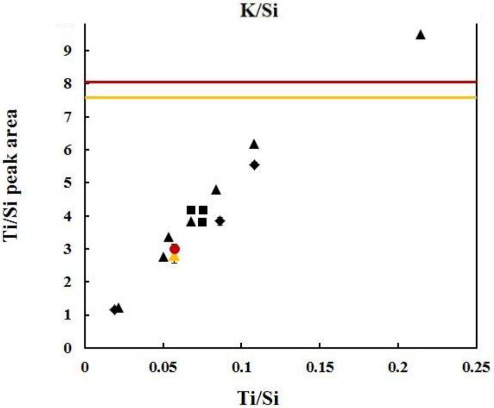
AXPS results

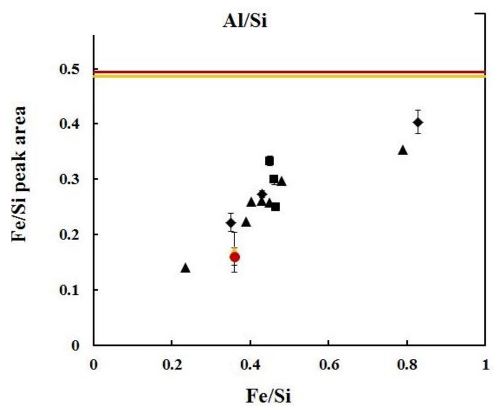




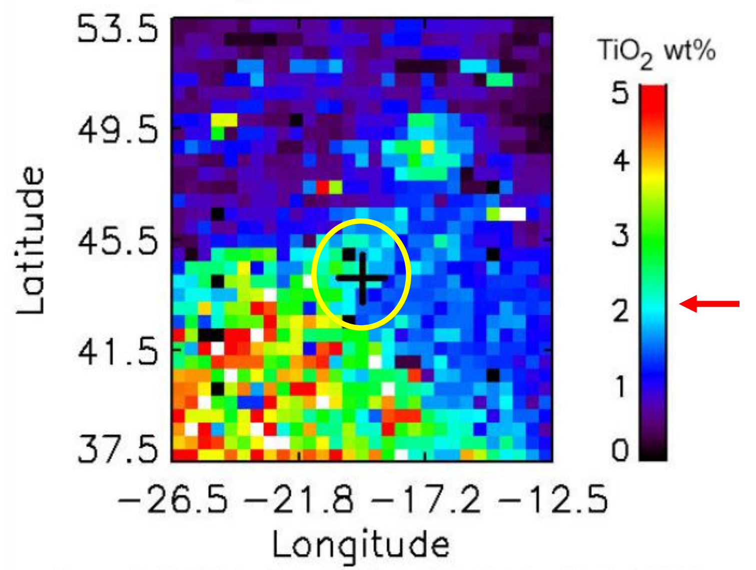








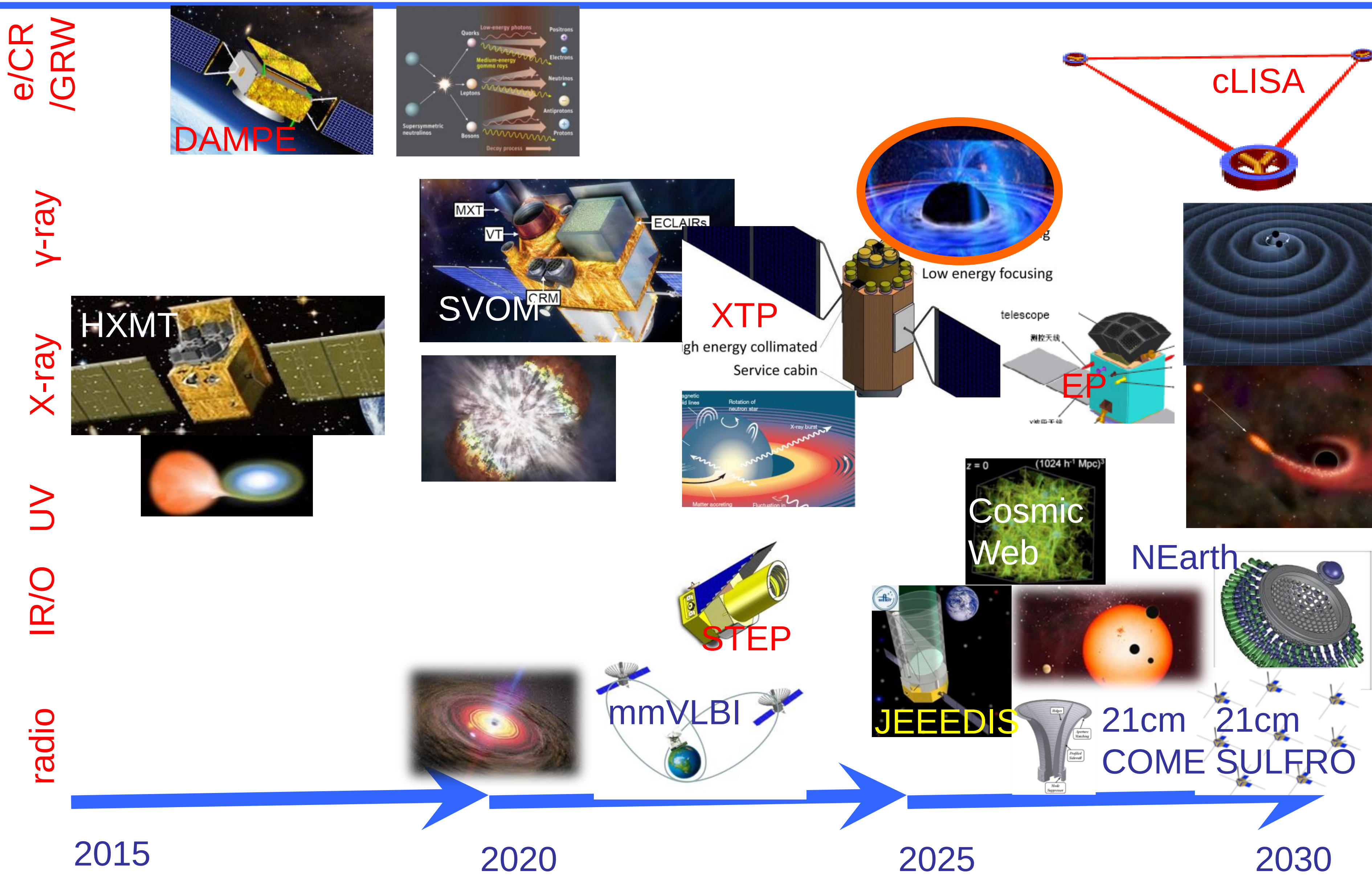
TiO_2 Concentration of the Lunar Surface at the Chang'e-3 Landing Site



(Prepared by Sarah Crites, Univ. of Hawaii, for PSRD. Data from Gillis *et al.*, 2003.)

Experimental results show that peak areas of **Ca, K, Ti have good** correlation with their content, but not for the **Mg, Fe, Al: CaO 11.8 wt%, K_2O 0.18 wt%, TiO_2 5.6 wt% (**standardization by Si).

China's Space Astronomy Satellites

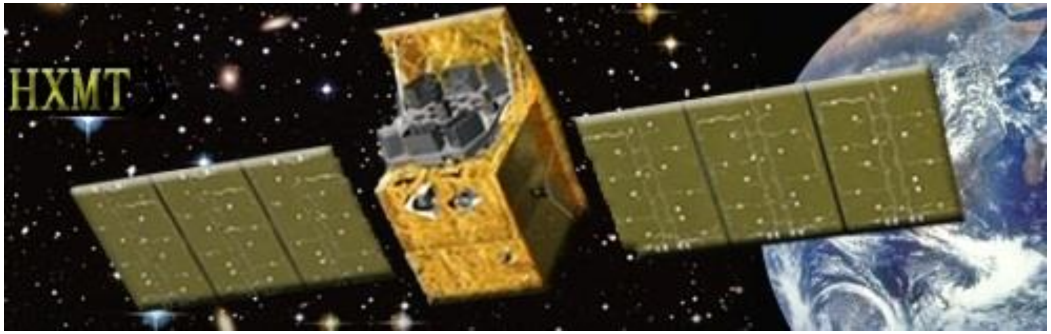


Hard X-ray Modulation Telescope (HXMT)

- Main scientific objectives (1-250 keV energy band)
  - ✓Scan monitoring of the Galactic plane → transients watch dog: need ground follow-up observations.
  - ✓Pointed observations → Black hole and neutron star x-ray binaries: need coordinated ground observations

Satellite Facts:

- ✓ Mass: ~2800 kg
- ✓ Orbit: 550 km, 43°
- ✓ Lifetime: 4 yrs



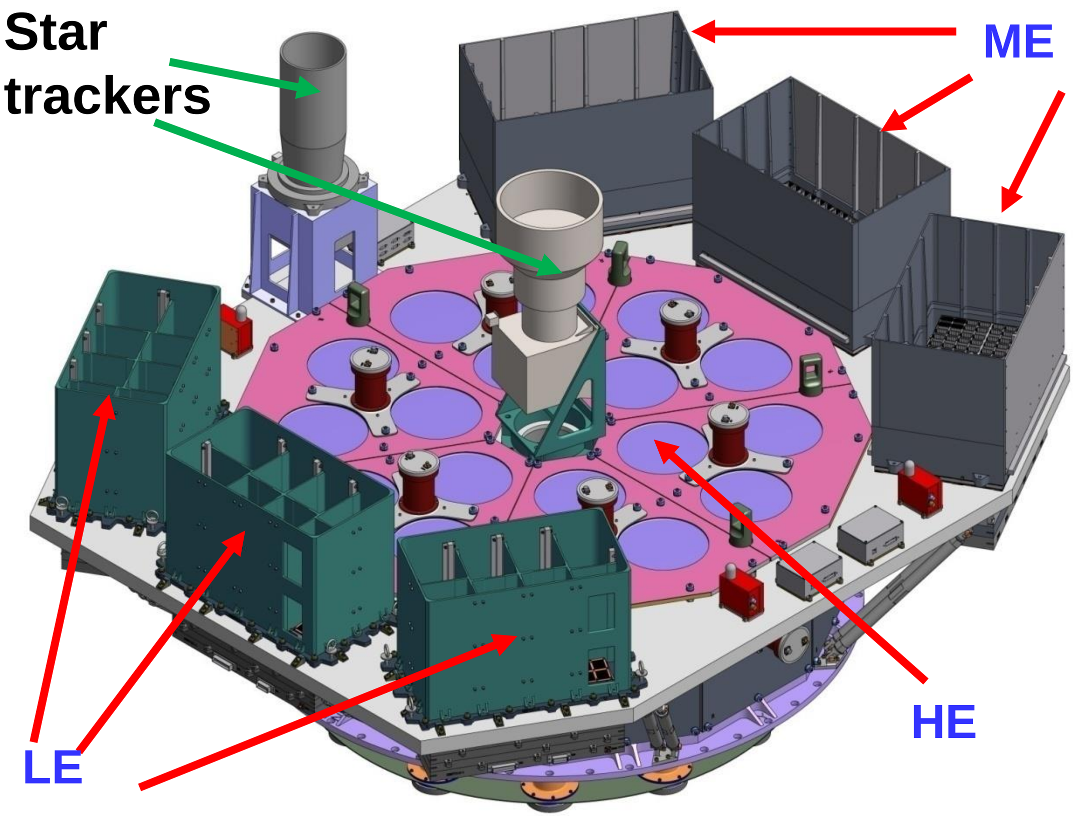
Officially approved in March 2011

Entered Phase-B (Engineering model phase) in 12/2011

Now finishing the construction of the qualification models

Planned launch time: 2016

HXMT Payloads



High Energg (HE):

NaI/CsI, 20-250 keV, 5000 cm^2

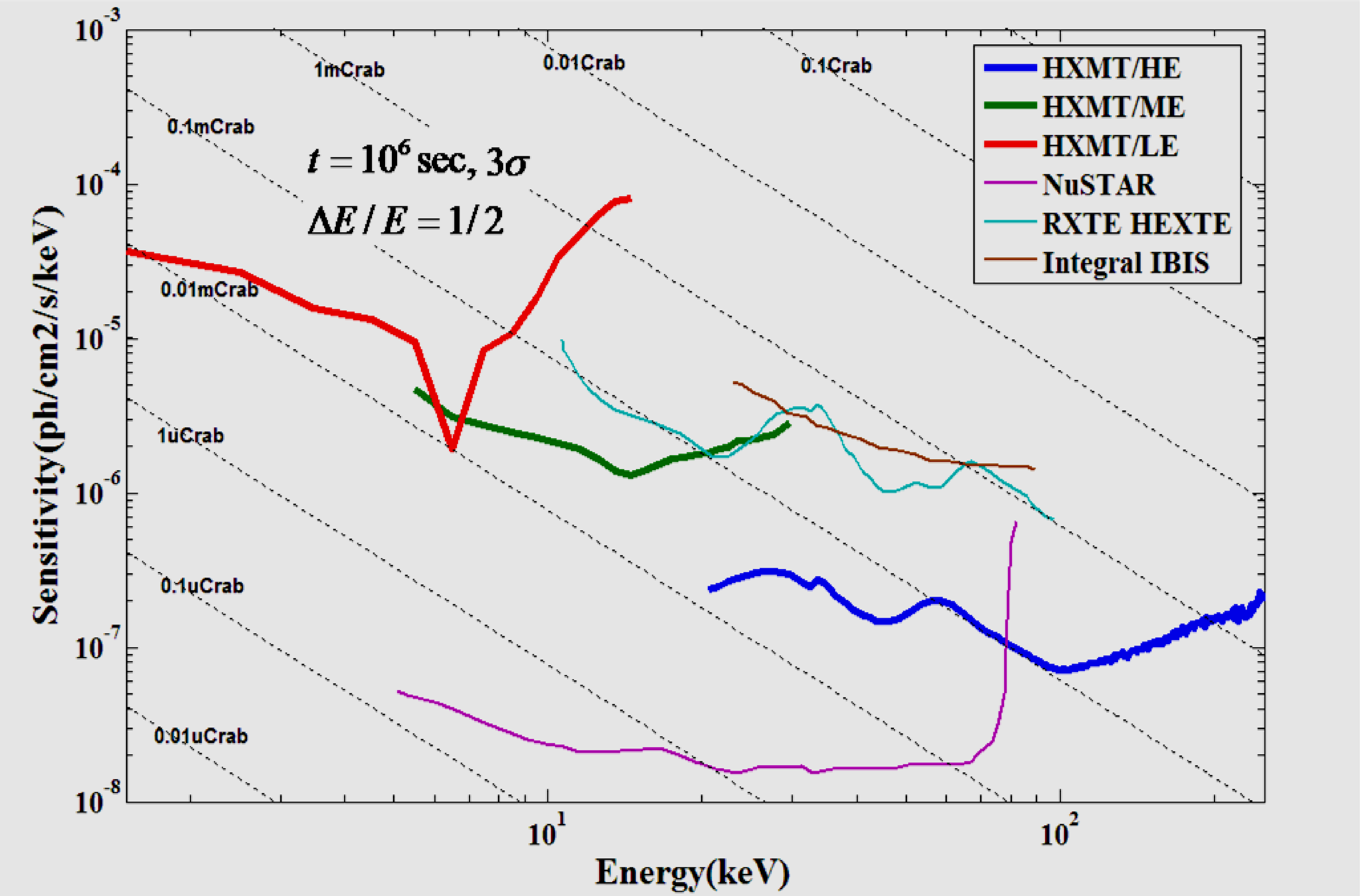
Medium (ME):

Si-PIN,5-30 keV, 952 cm^2

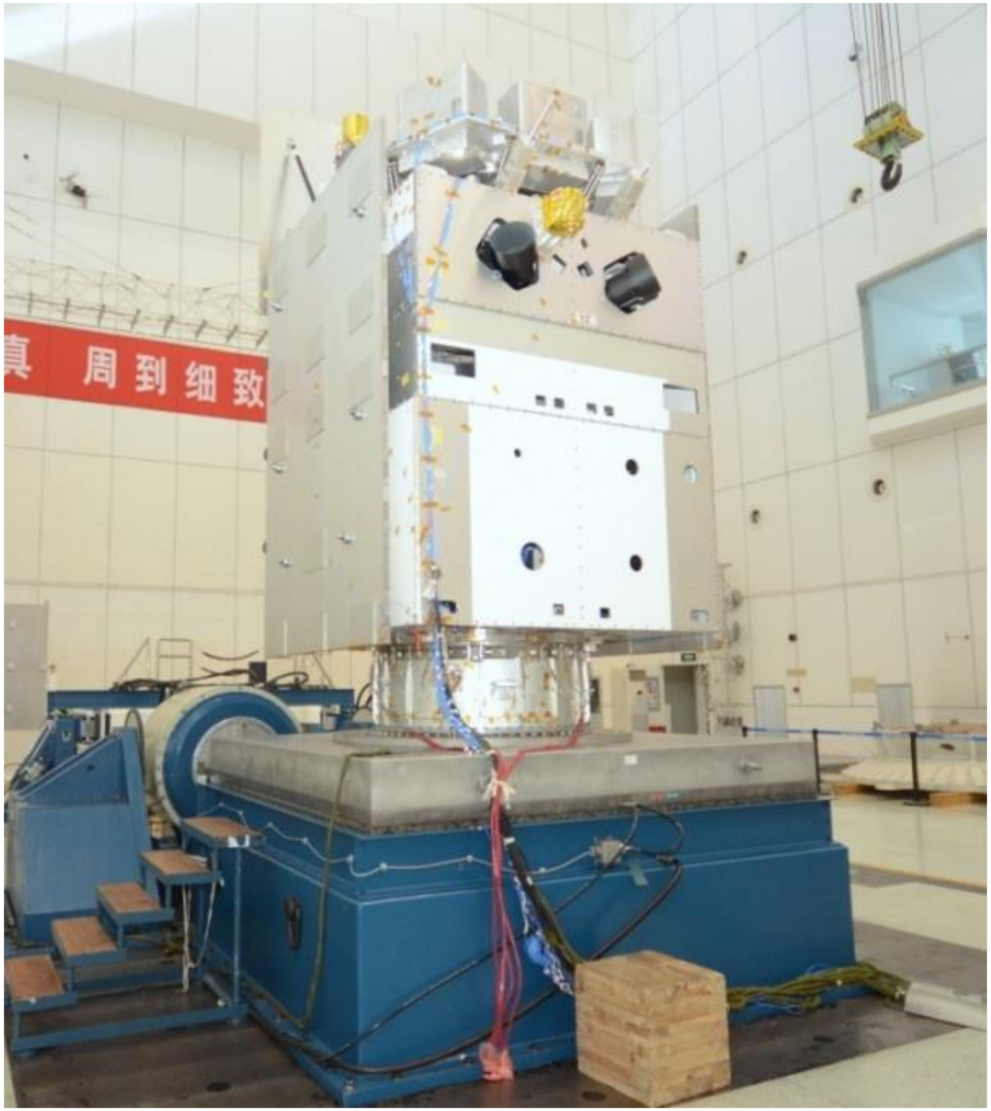
Low Energy (LE):

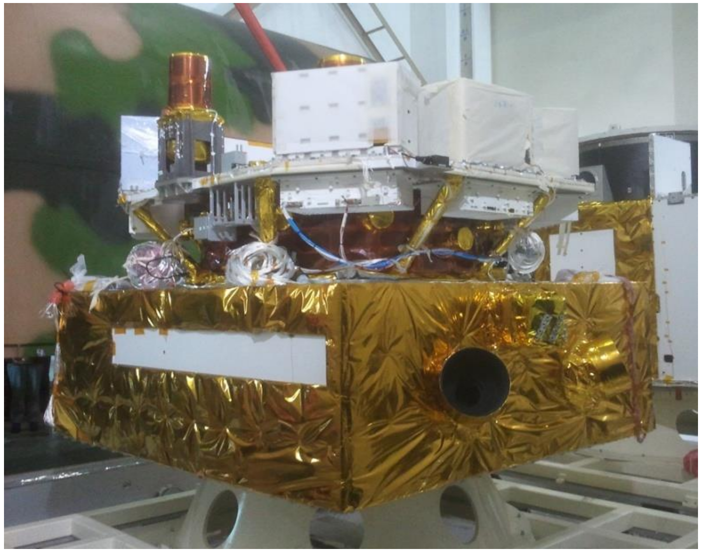
SCD,1-15 keV, 384 cm^2

HXMT Sensitivity

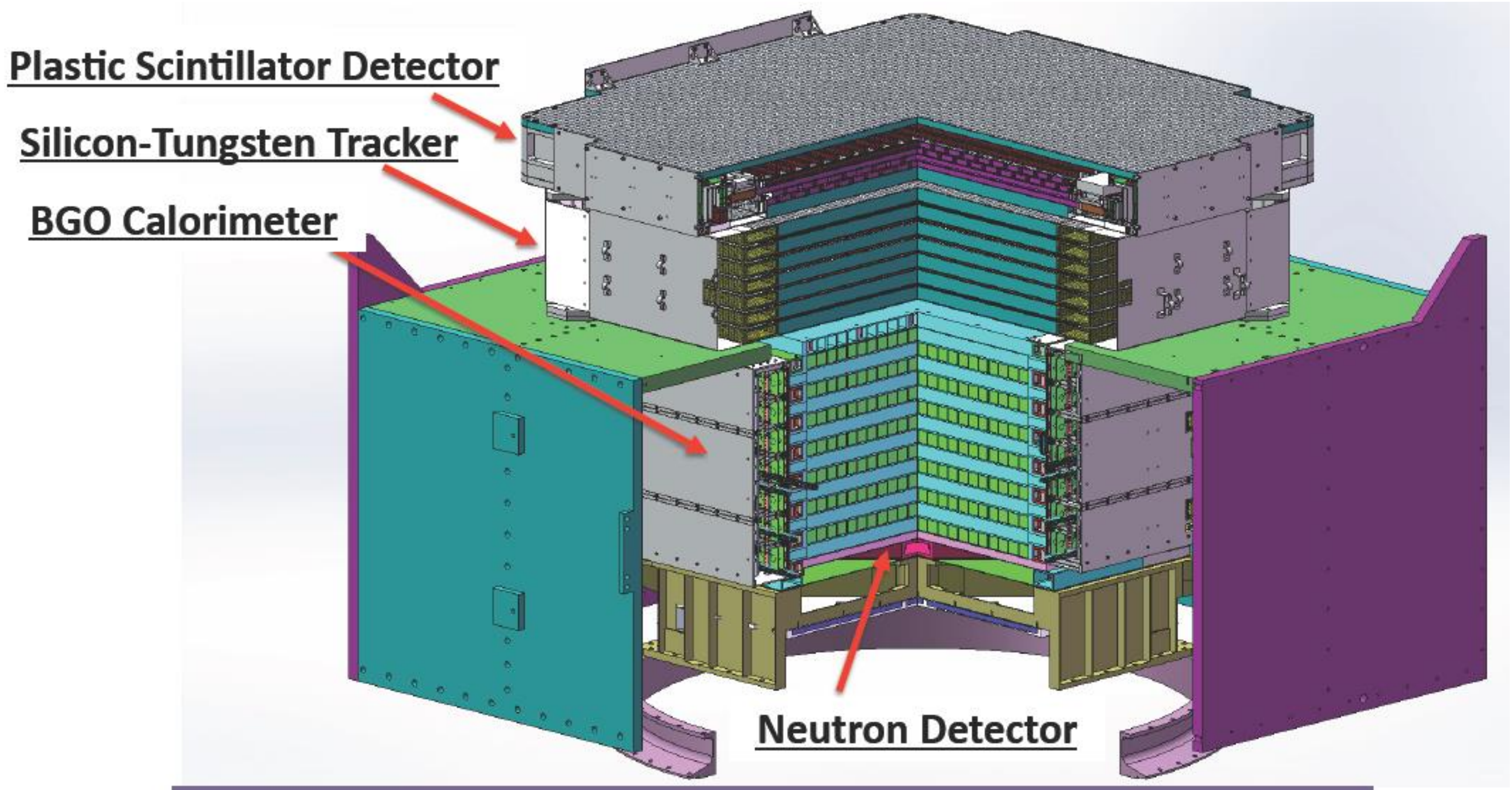


Current status of HXMT



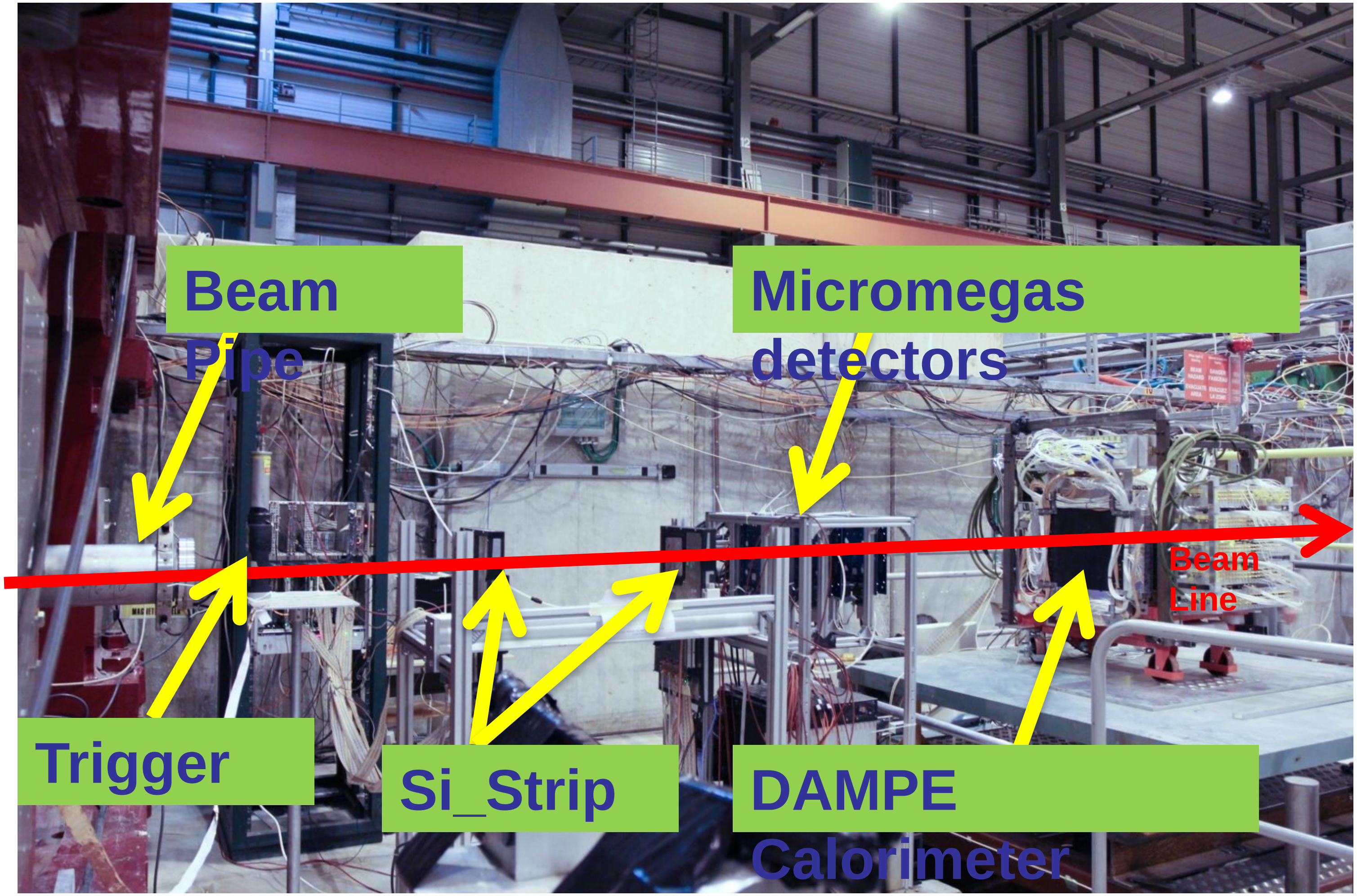


DAMPE: launch in ~2015



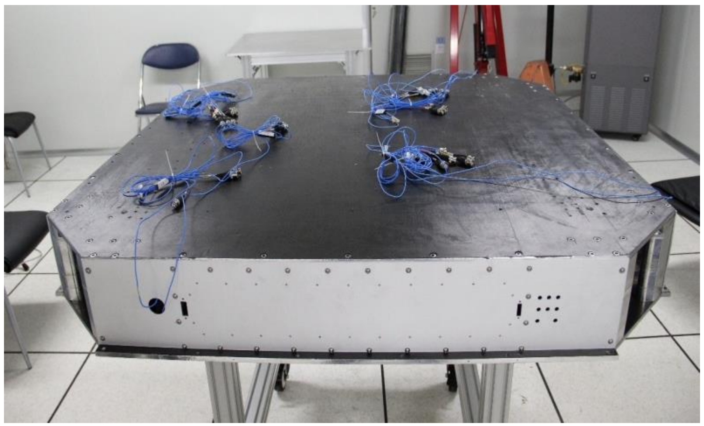
W converter + thick calorimeter (total 33 X_0) + precise tracking + charge measurement ➡ high energy γ-ray, electron and CR telescope

DAMPE beam test at CERN



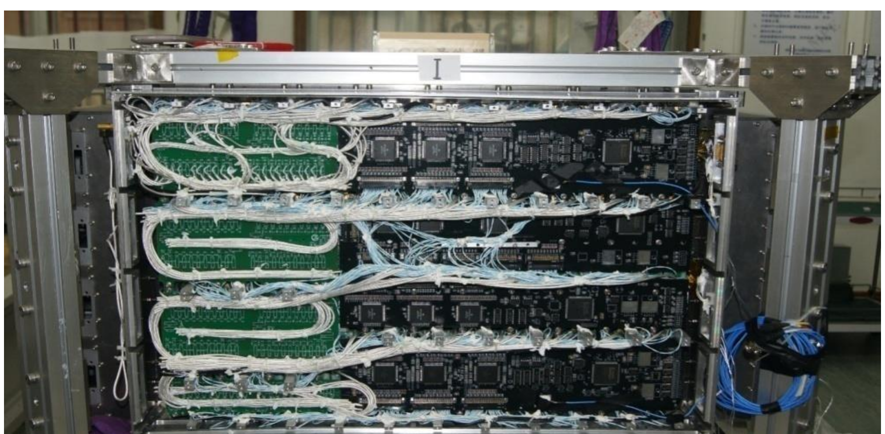
Vibration Test

Plastic Hodoscope

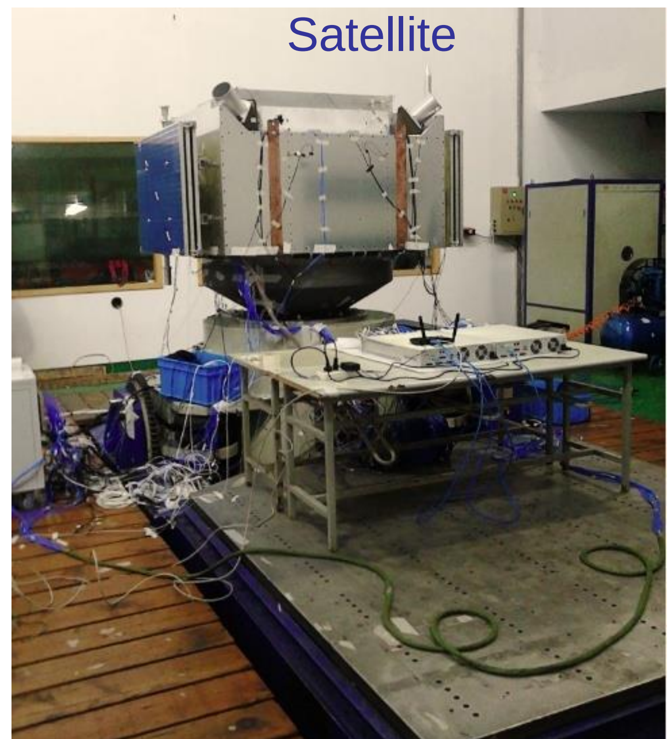


Neutron Detector

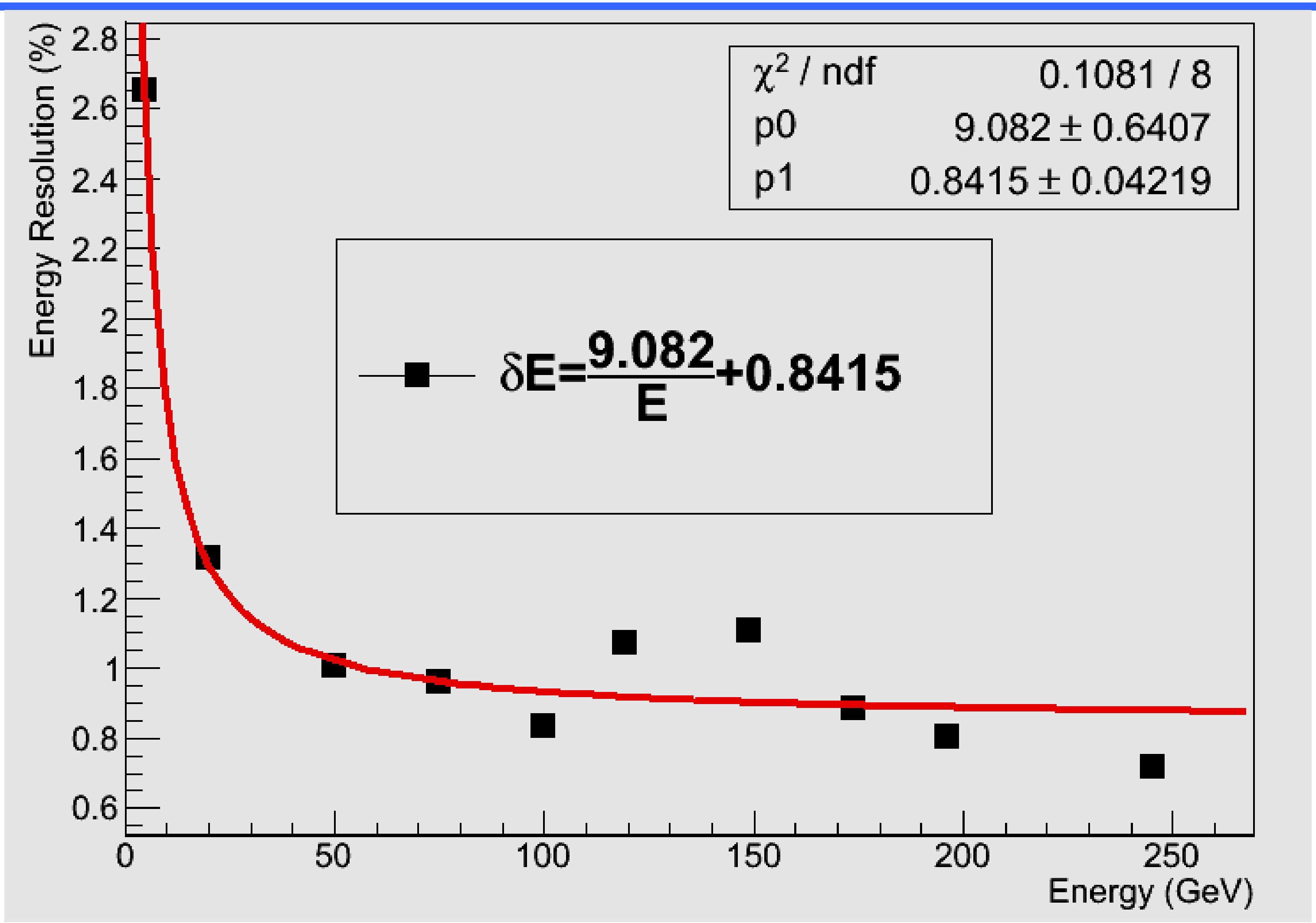
BGO Cal.



Satellite

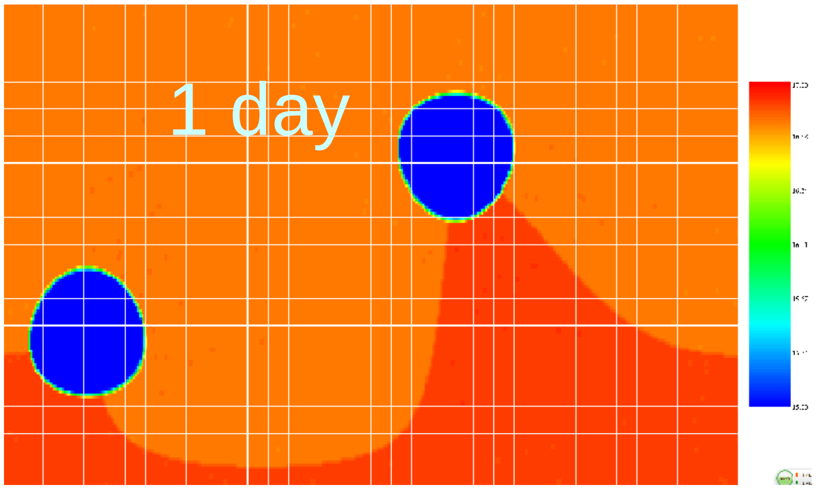


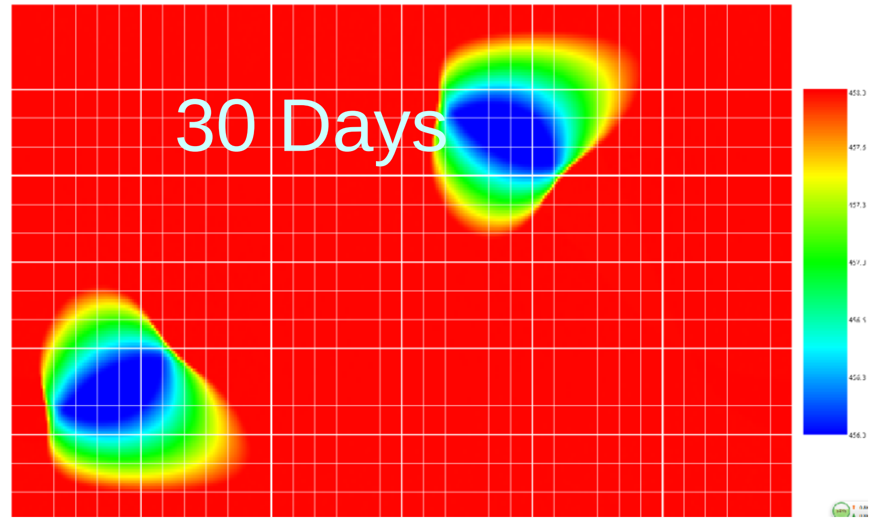
Energy Resolution

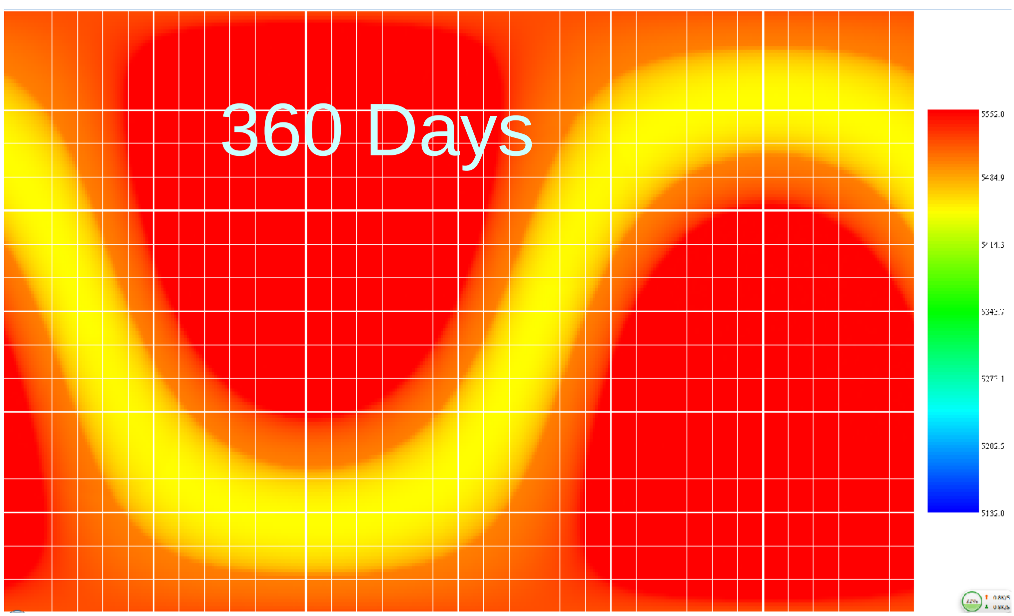


Energy Resolution can reach 0.79%@ 250 GeV

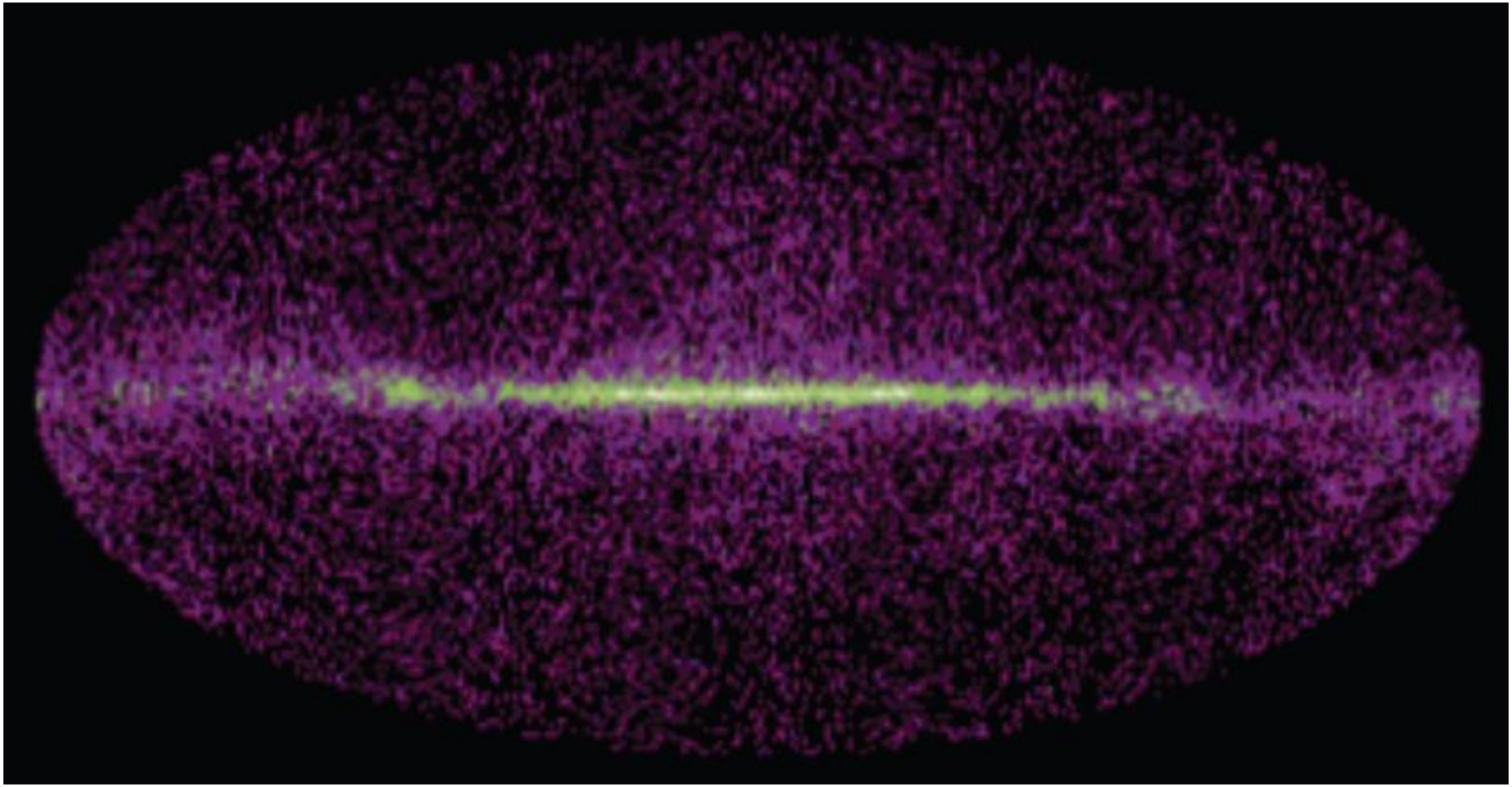
Exposure time



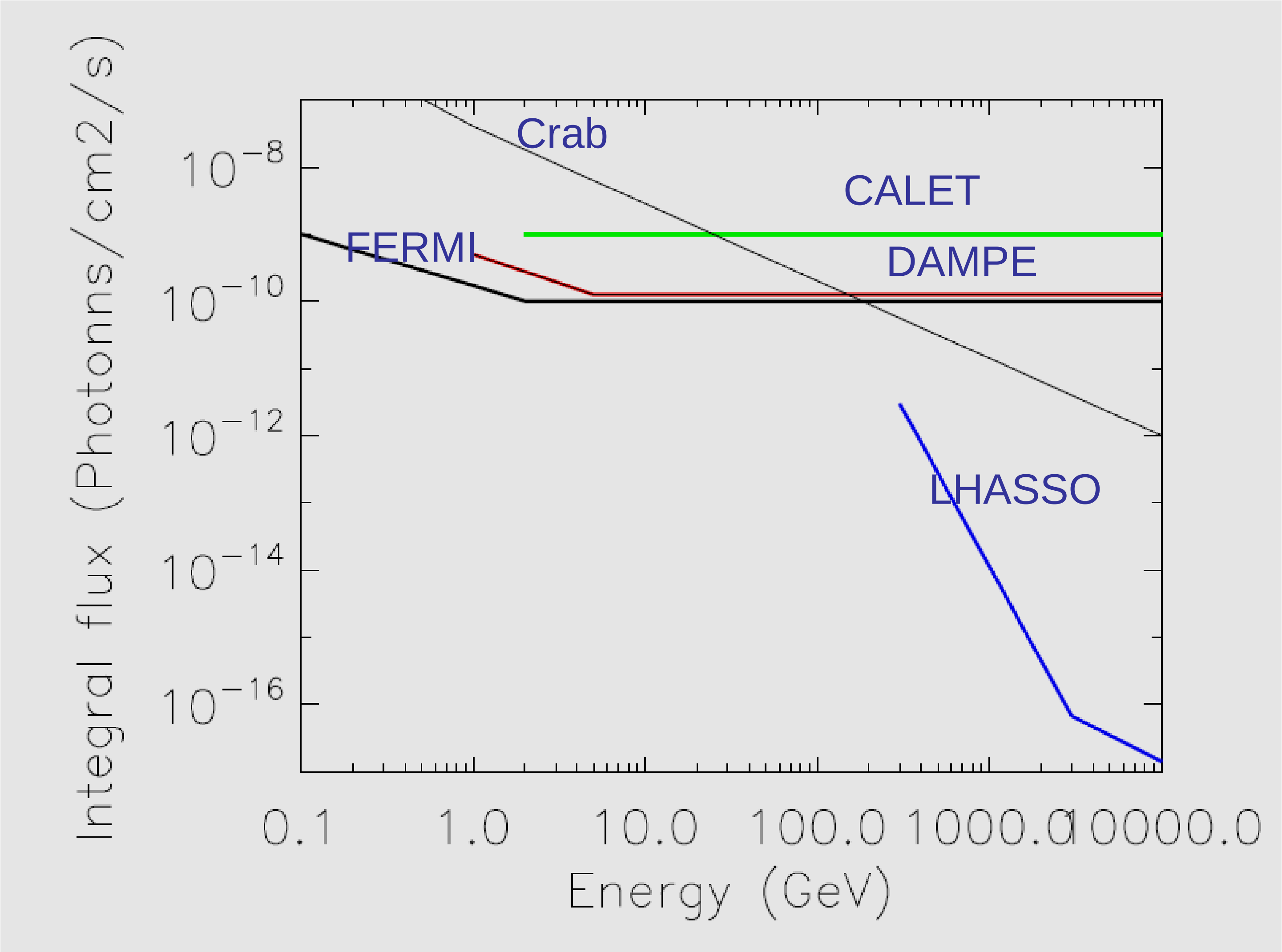




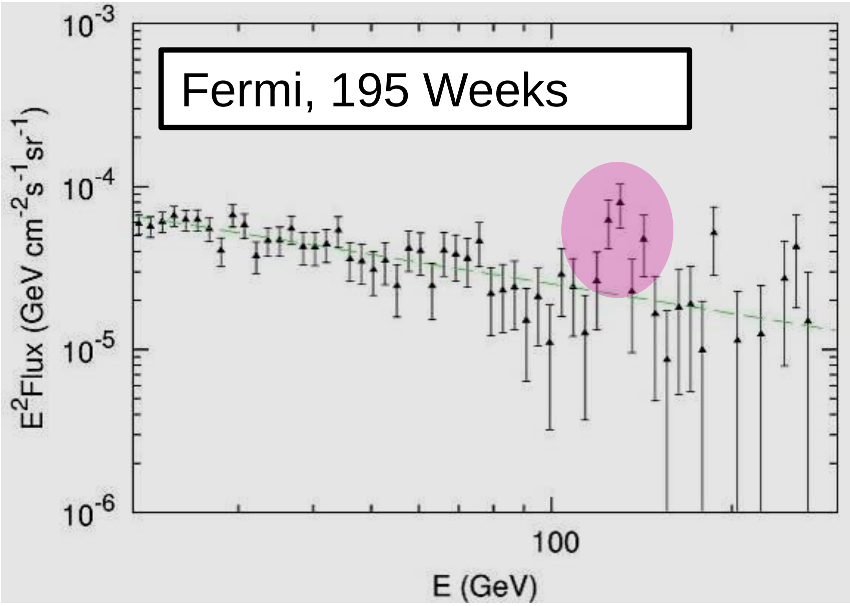
Gamma-ray mapping by 30 days

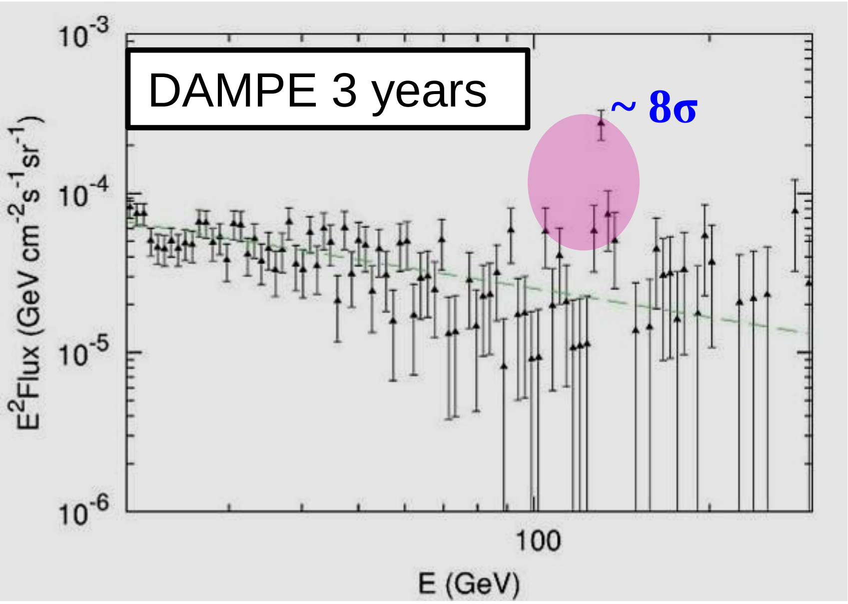


Gamma-ray Sensitivity



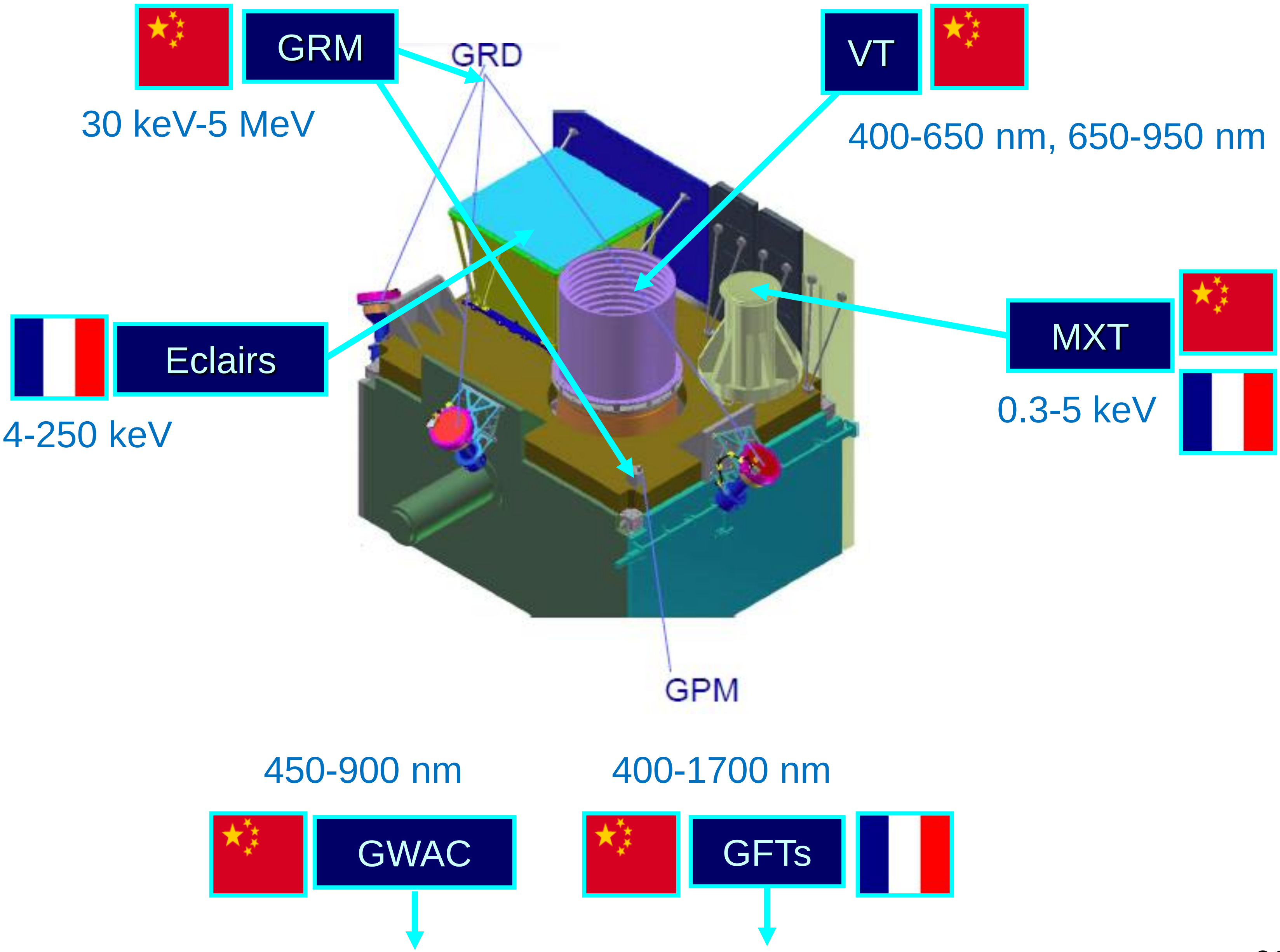
DAMPE for gamma-ray line observations





DAMPE will confirm or deny the “suspicious” dark matter annihilation line of Fermi with high significance

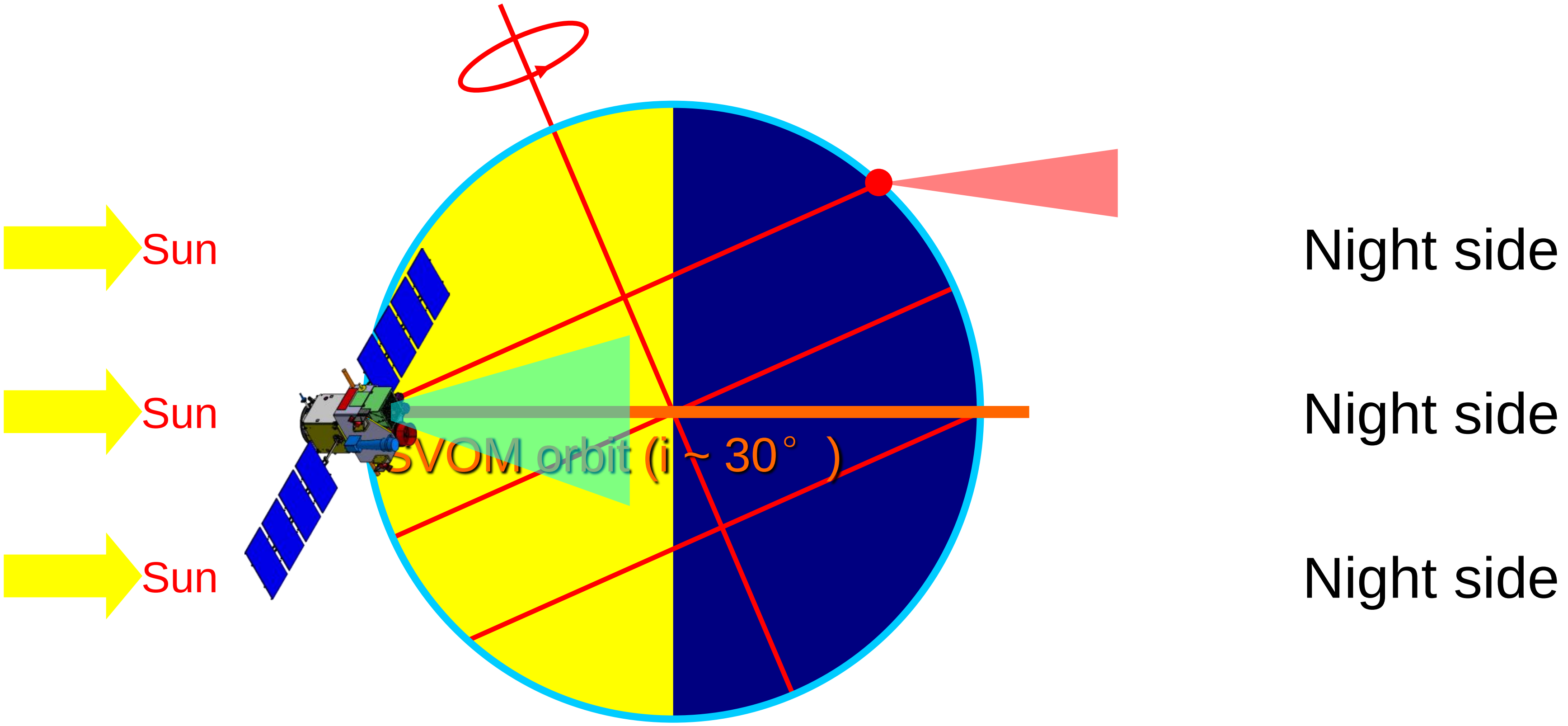
SVOM: ~2021 launch



Space instrument performances

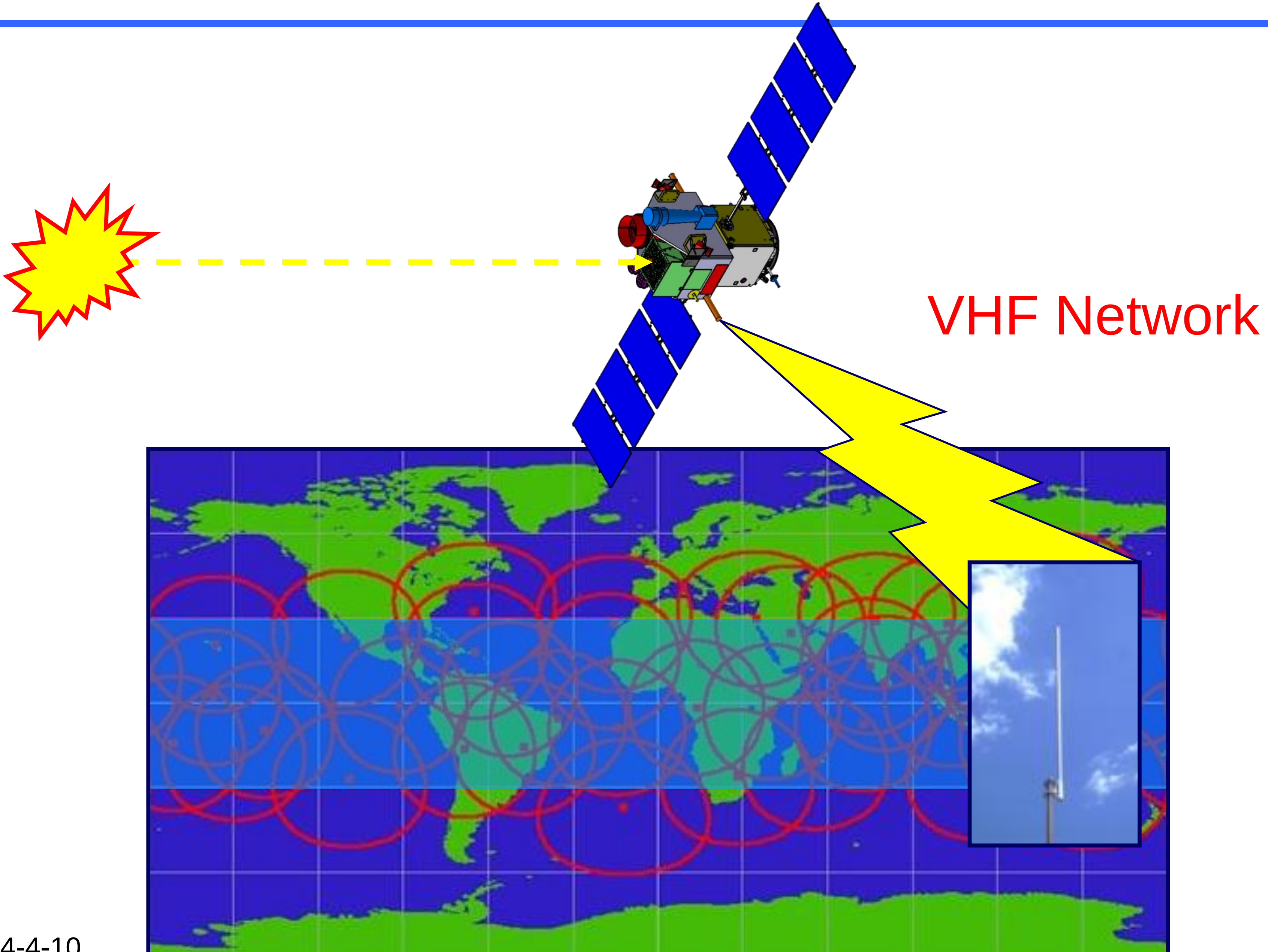
	Spectral band	Field of View	Allocation Accuracy	GRBs/yr (Dect. Rate)
GRM	30 keV-5 MeV	2 sr	2-5 deg	~80
ECLAIRs	4-250 keV	2 sr	10 arcmin	~70
MXT	0.3-5 keV	65× 65 arcmin	30 arcsec	~90%
VT	400-650 nm 650-950 nm	26 × 26 arcsec	1 arcsec	~80%

Pointing strategy: anti-solar



About 75% of the GRBs detected by SVOM to be well above the horizon of large ground based telescopes all located at tropical latitudes

Prompt dissemination of GRB parameters



GRB observation strategy

Space

GRB trigger provided by ECLAIRs at time T_0

T_0 + 5 min

VT (V & R band photometry)
MXT (Soft X-ray photometry)

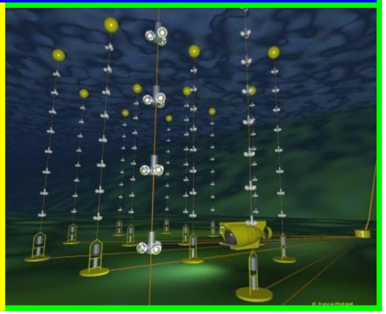
T_0 +1 min

Ground

GWAC
GFTs (g, r, i, J, H)

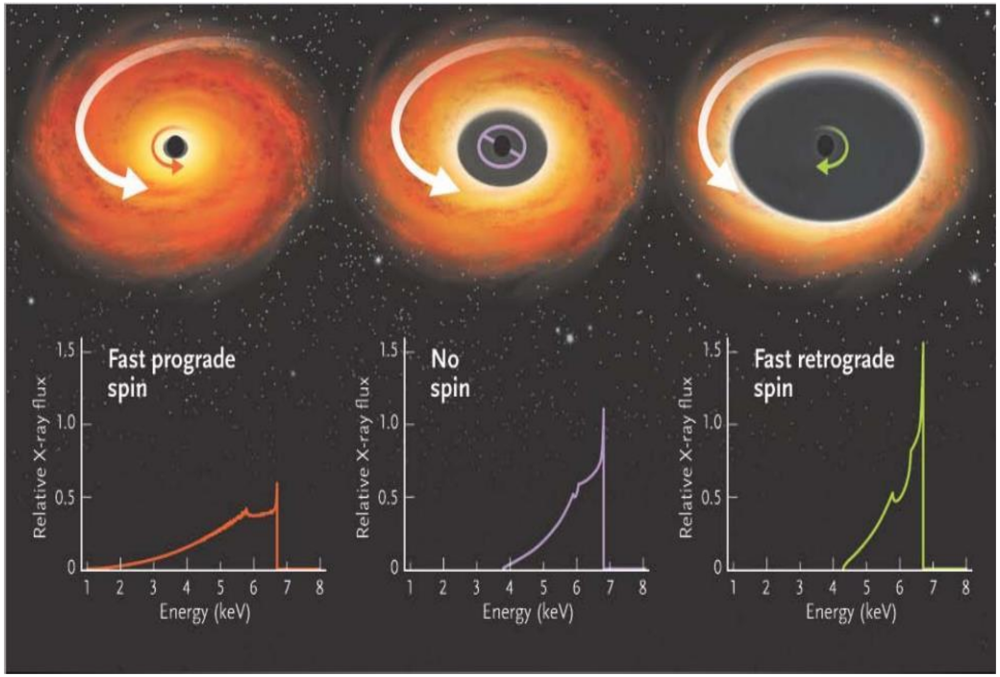
1-2 m robotic telescopes

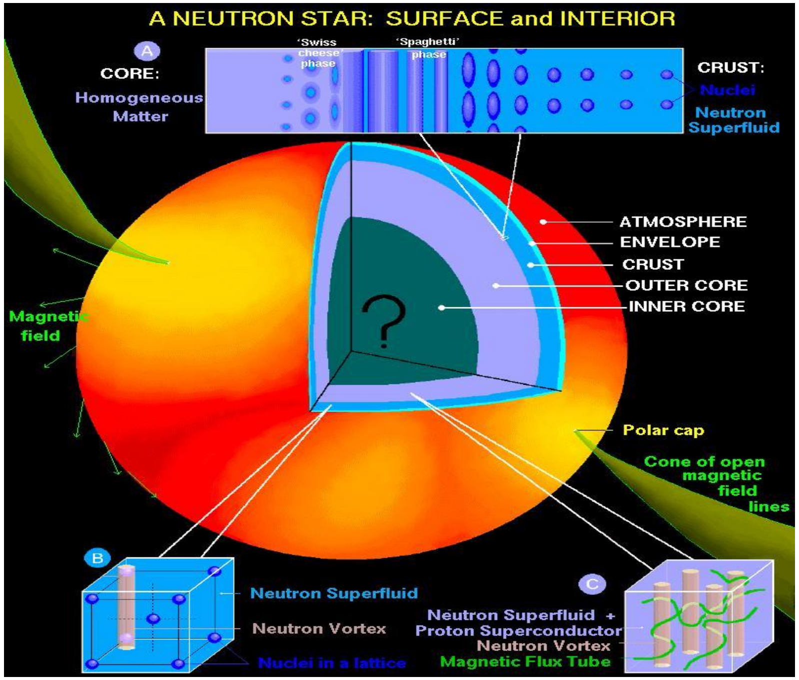
Multi messenger follow-up



X-ray Timing and Polarization（XTP）

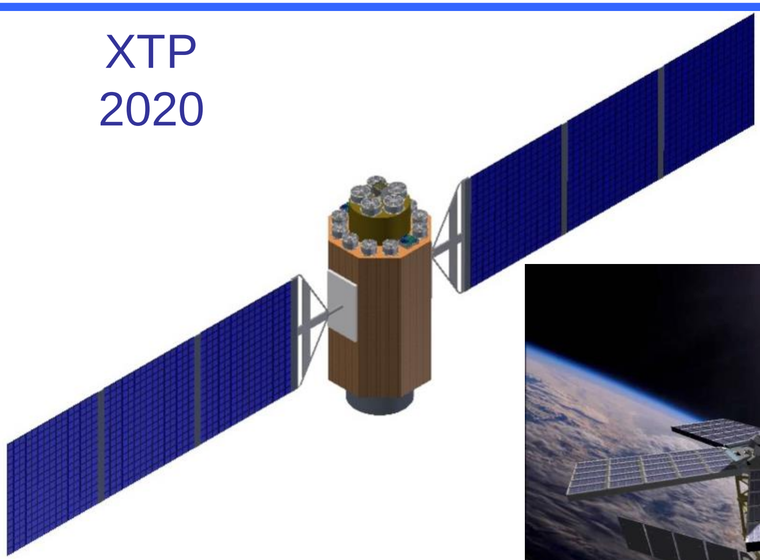
- Physical laws under extreme conditions → neutron stars & black holes
- 1-singularity (BH); 2-stars (NS and Magnetar); 3-extremes (gravity, density, magnetism)





The Three Musketeers of Future X-ray Astronomy?

XTP
2020



$1^{S}2^{S}3^{E}$

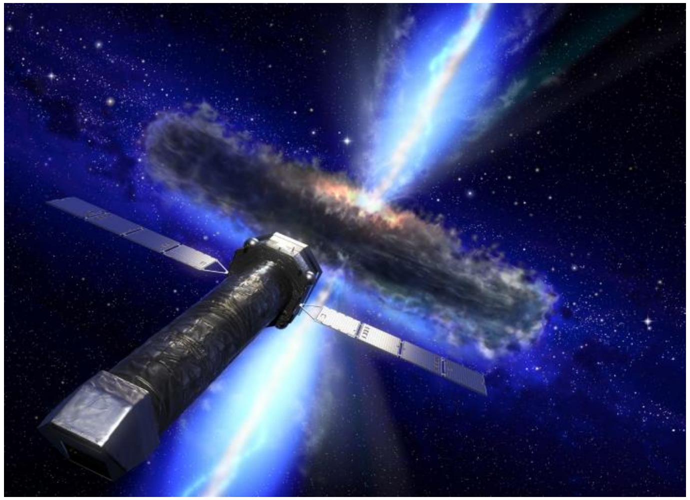
From Galactic compact objects to active galactic nuclei

LOFT
2025?

Gravity: BH X-ray binaries

NS EoS: neutron stars

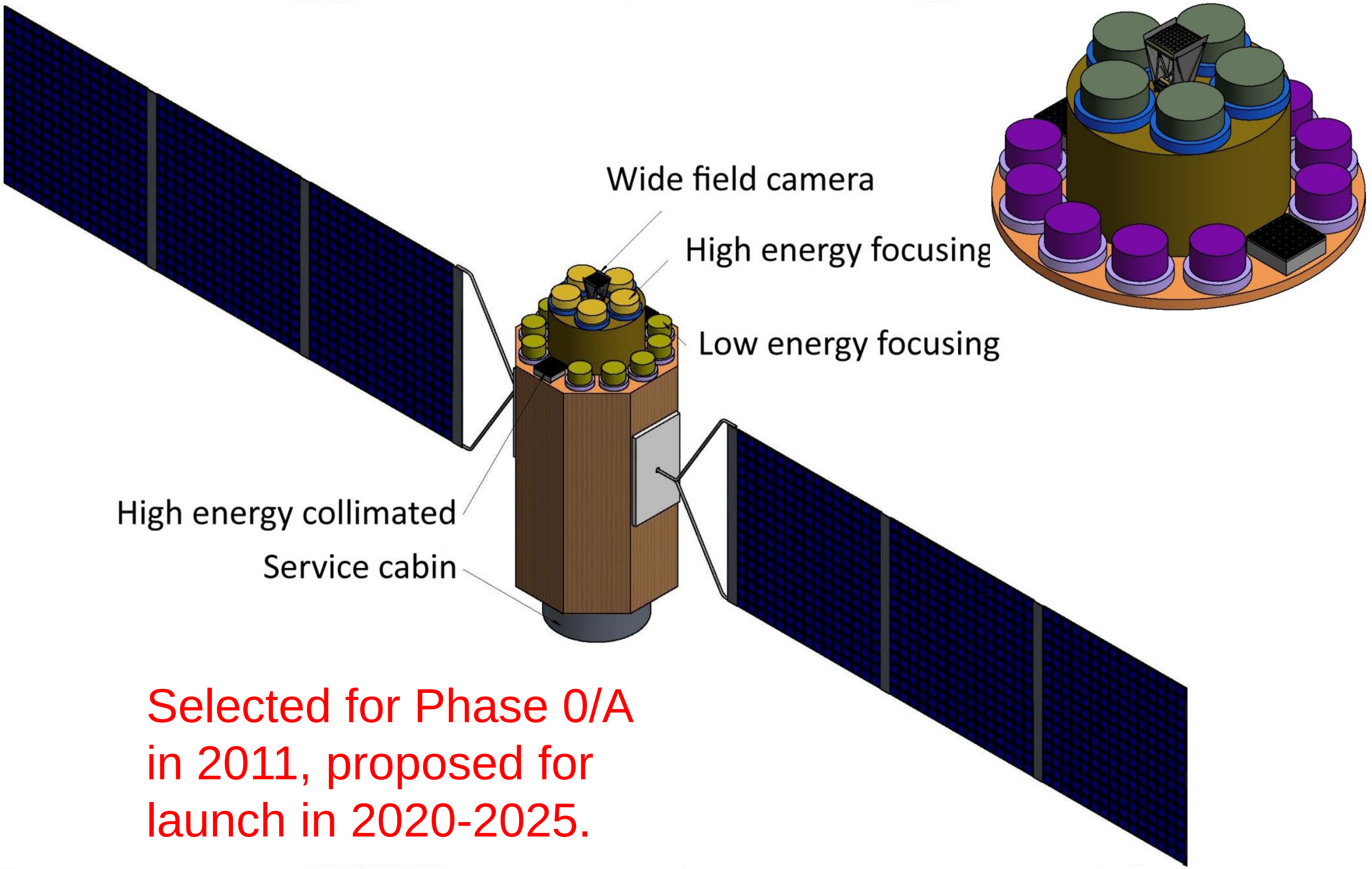
Athena
2028



Cosmology: missing baryons

Gravity: active galactic nuclei

XTP satellite



Selected for Phase 0/A in 2011, proposed for launch in 2020-2025.

Satellite fitting in launcher

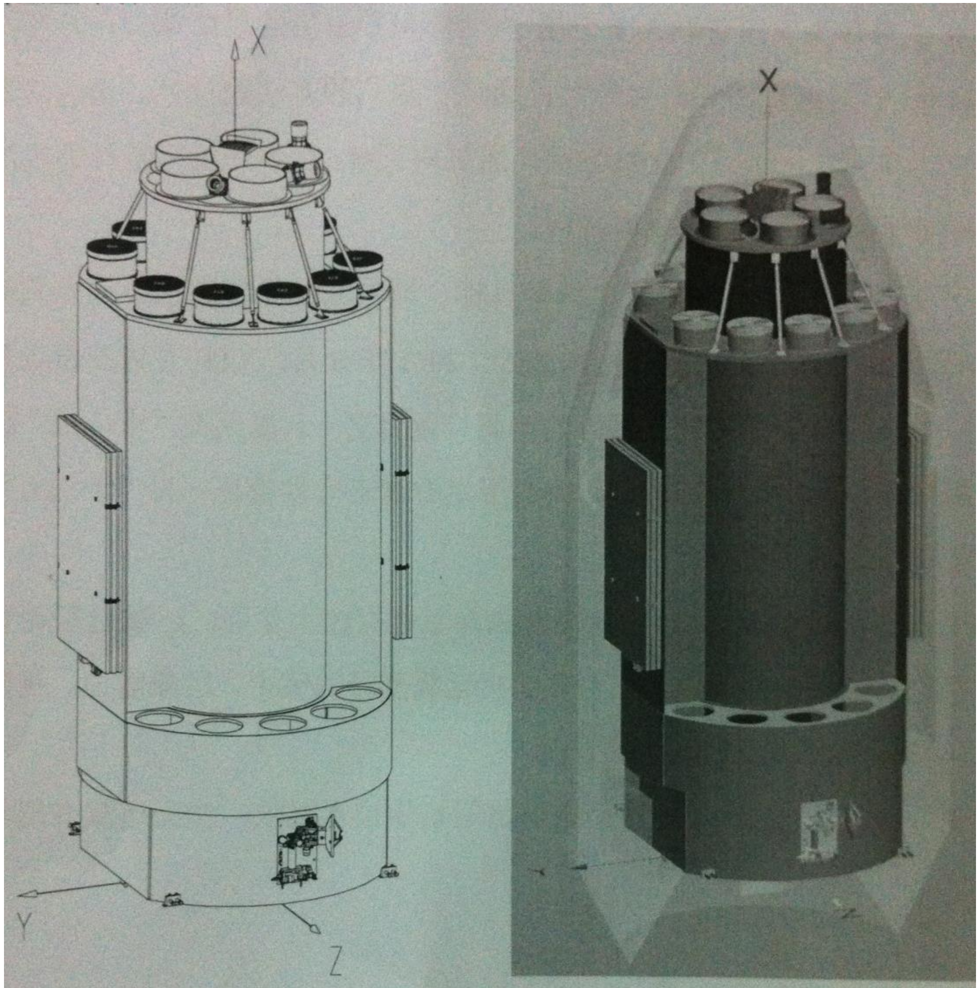
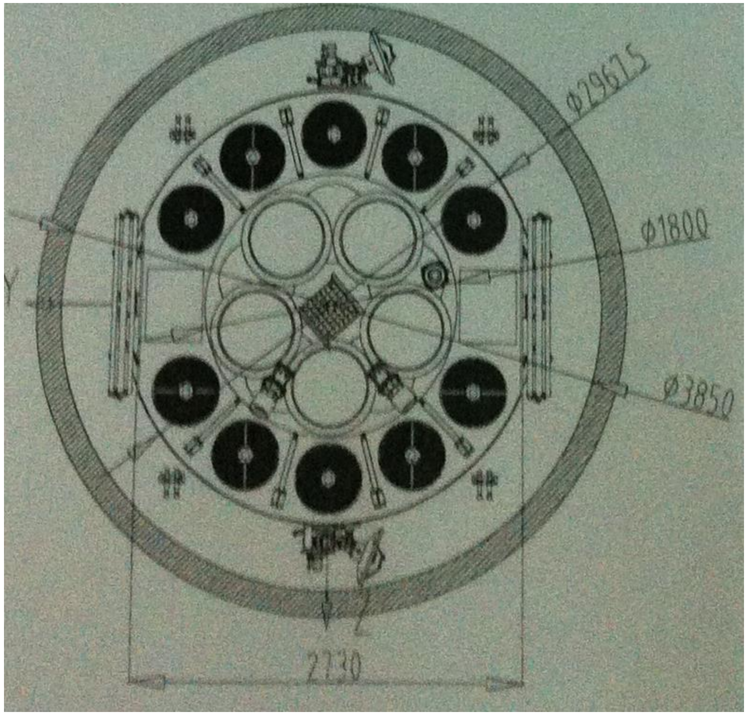
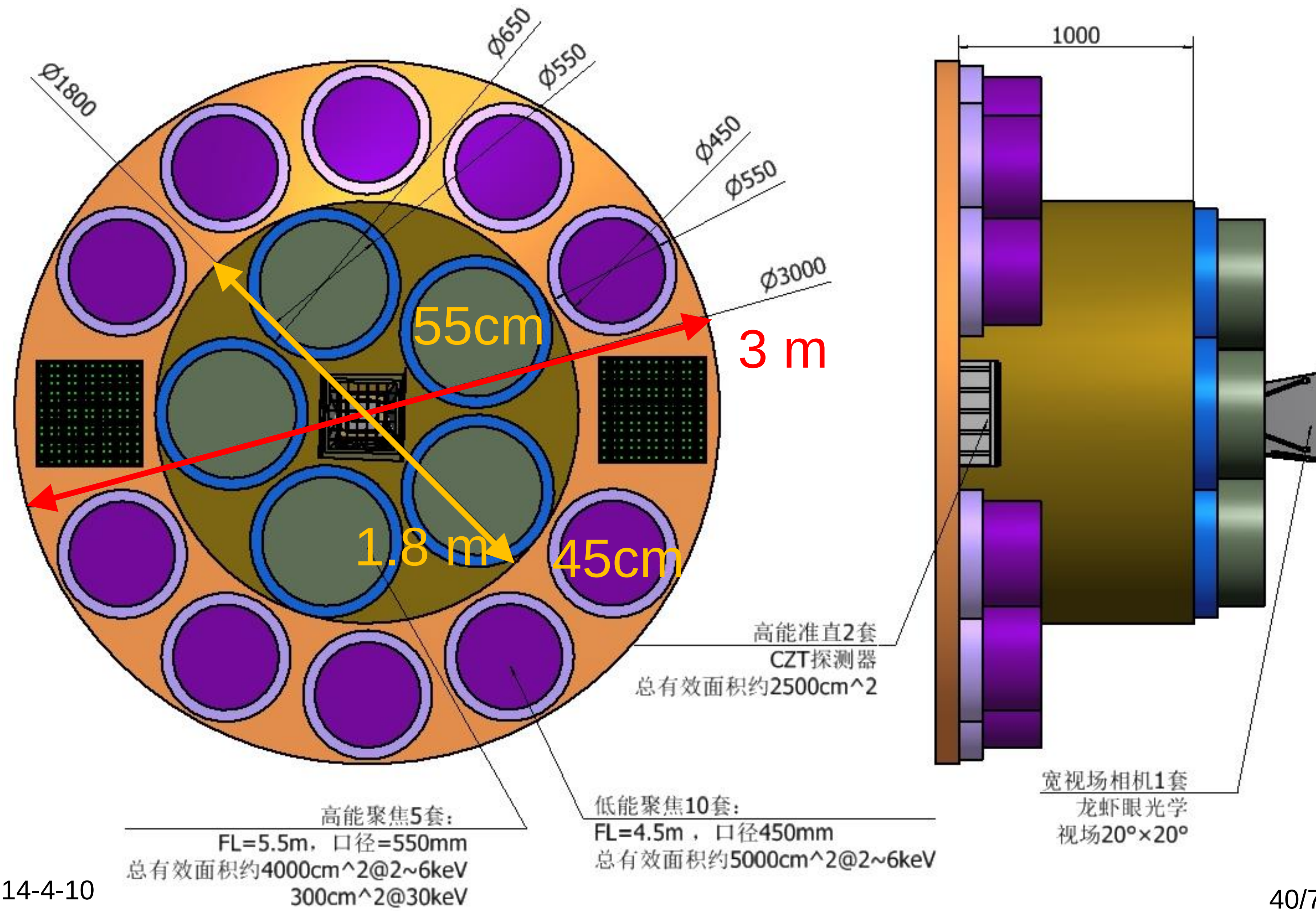


图 1 卫星本体坐标系定义

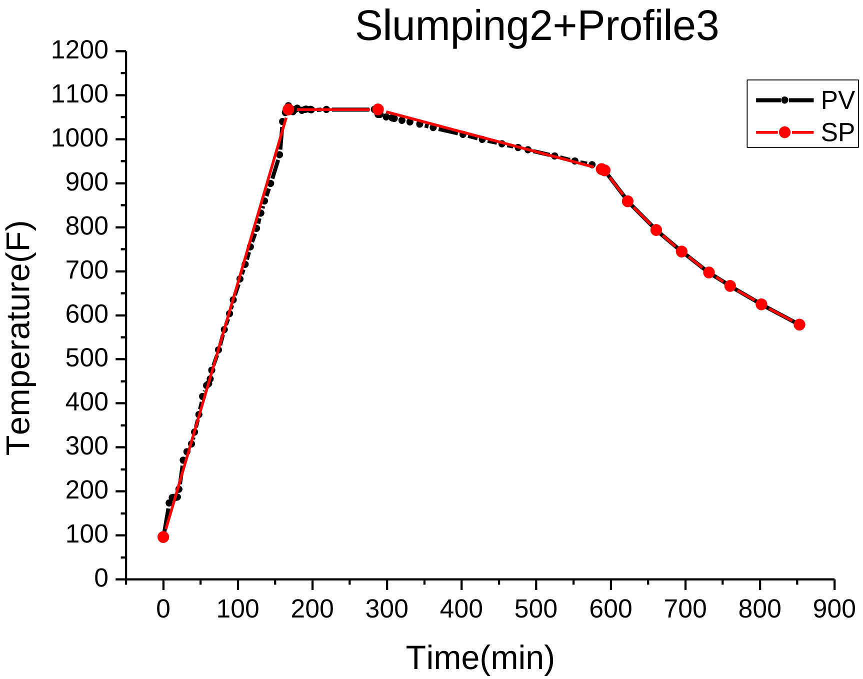


XTP payload layout



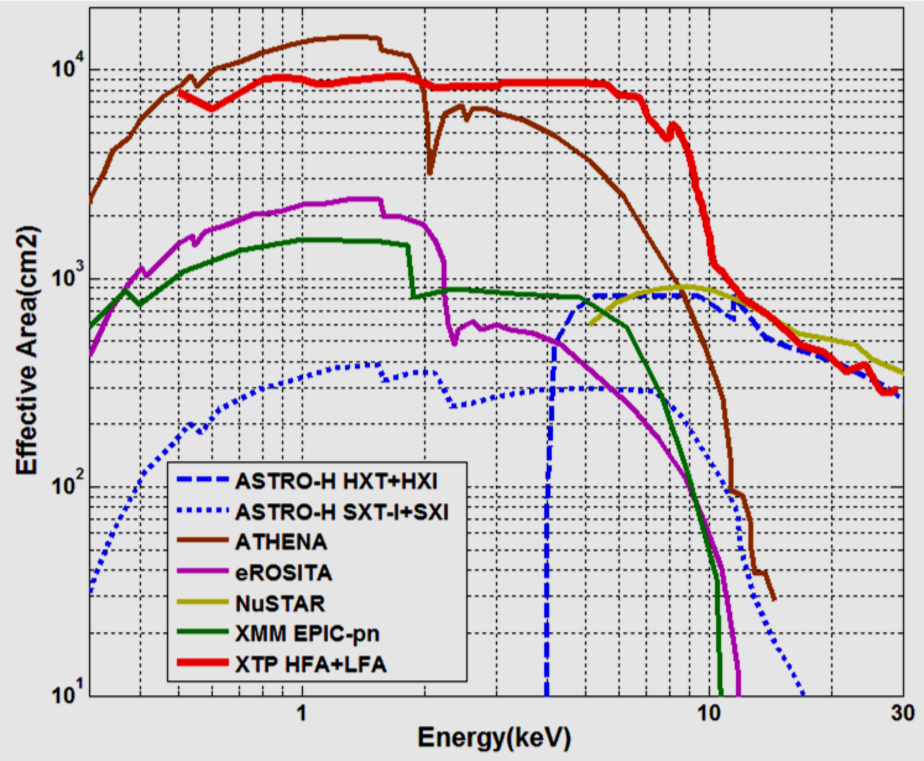
Slumped glass mirror

L&L Furnace

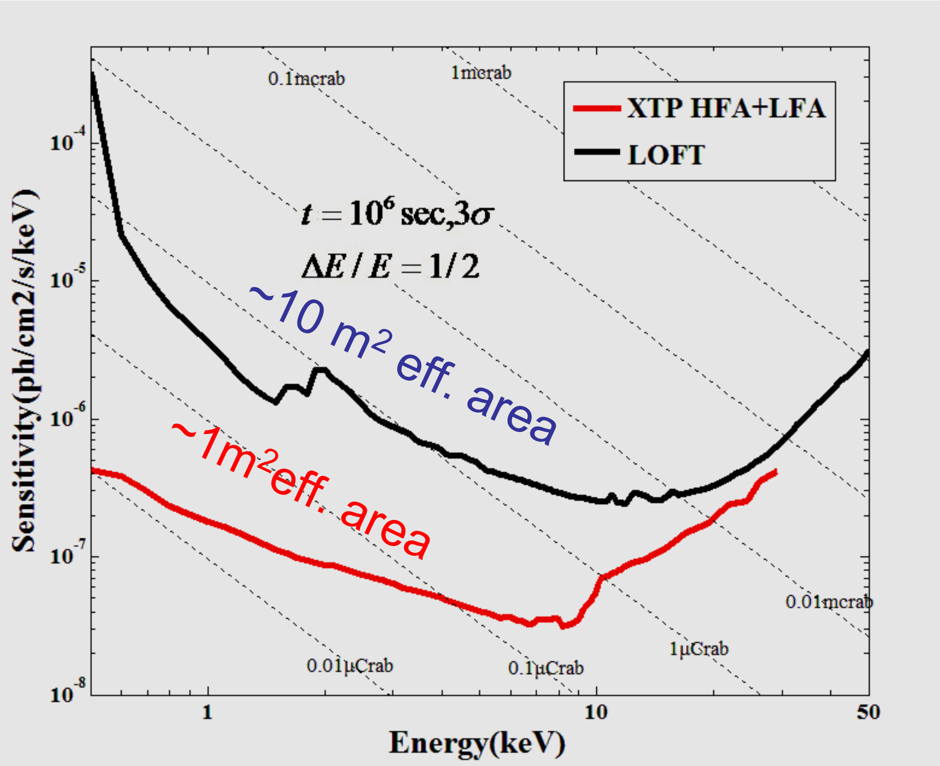


Temperature curve

Advantages of XTP



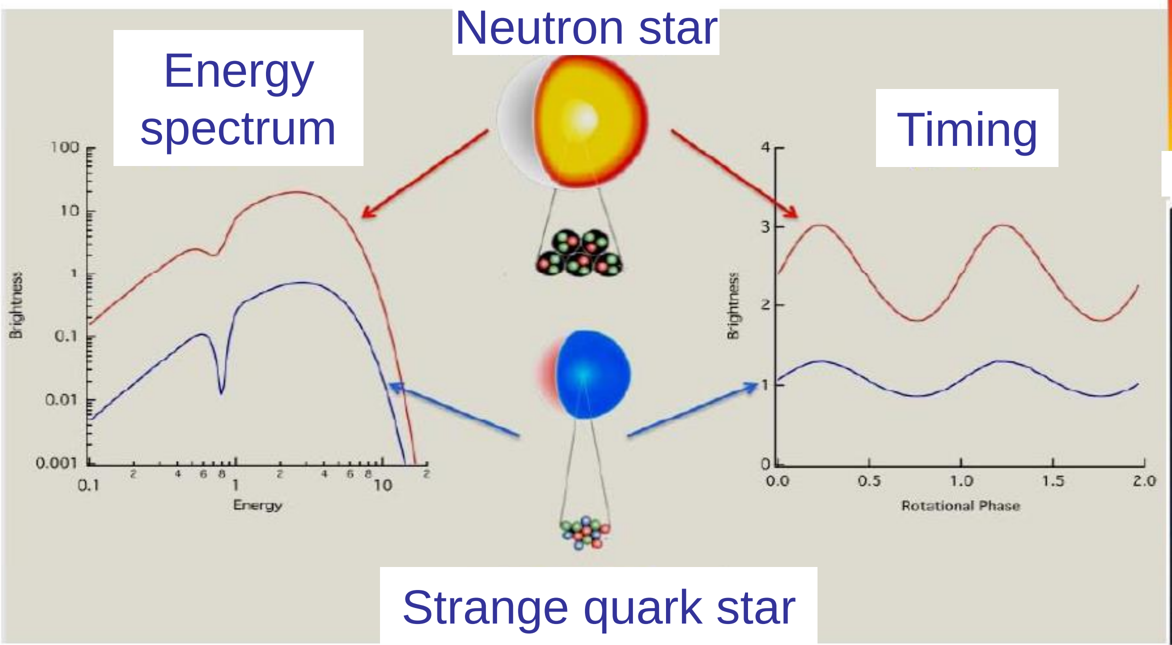
Comparison of effective areas between XTP and other focusing telescopes: wins at 2-10 keV!



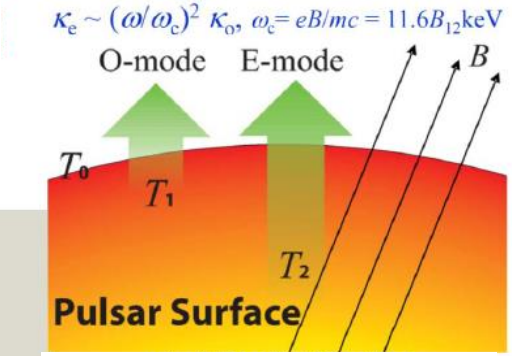
Comparison of sensitivity between XTP and the largest collimated telescope LOFT: wins at <30 keV!

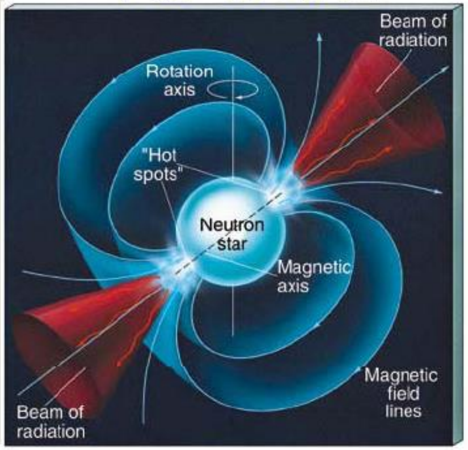
The power of multi-parameter probe

Deciding factors: (1) A neutron star has atmosphere, but a quark star does not; (2) B(magnetar) ~ $10^{14\text{-}15}$ G >> B(neutron star) ~ $10^{8\text{-}12}$ G.



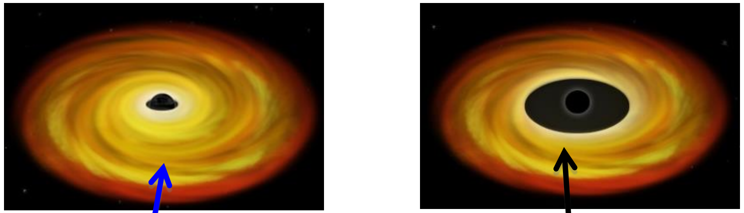
Low energy X-ray pol.

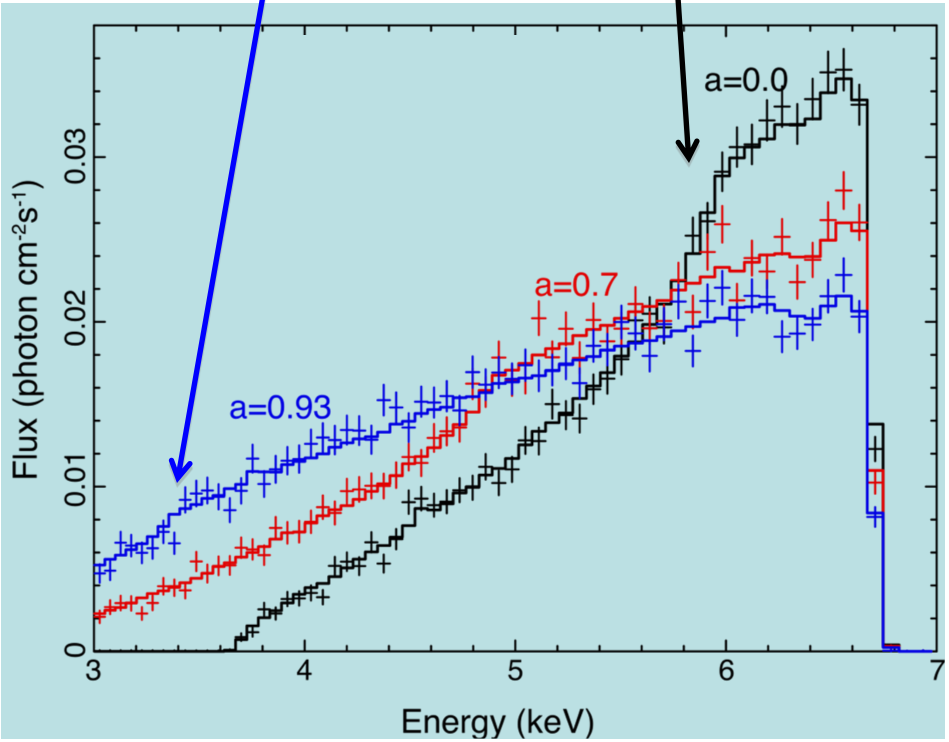




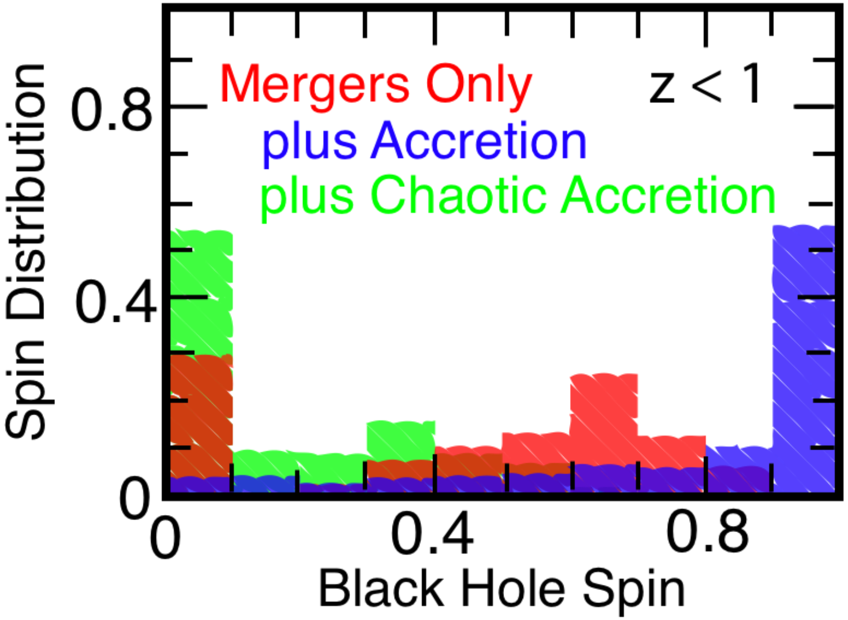
Medium energy X-ray pol.

General Relativity and Black Hole Spin





Berti & Volonteri (2008)



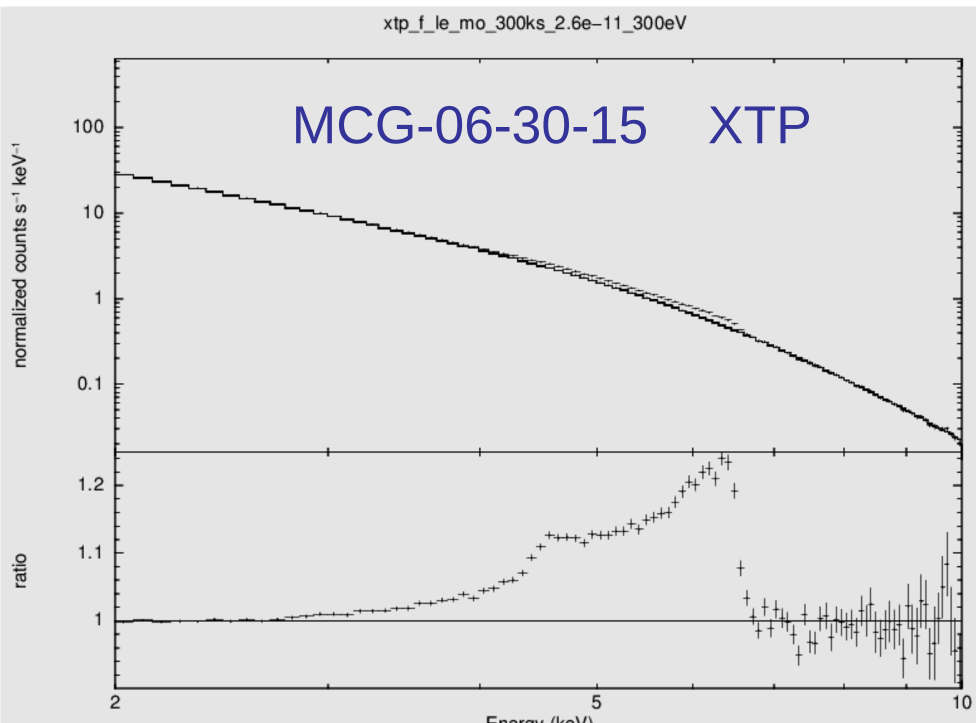
Simulated Observation of Broad Fe Line

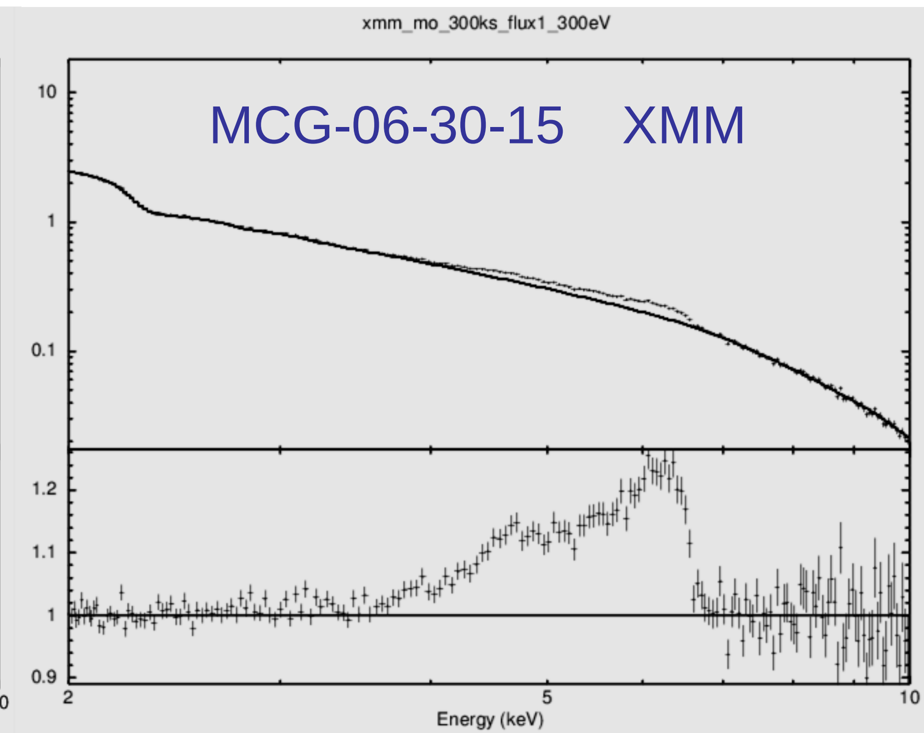
XTP Aeff ~ 1 m^2 @1keV focusing telescope

a=0.81 deviation ~ 0.15

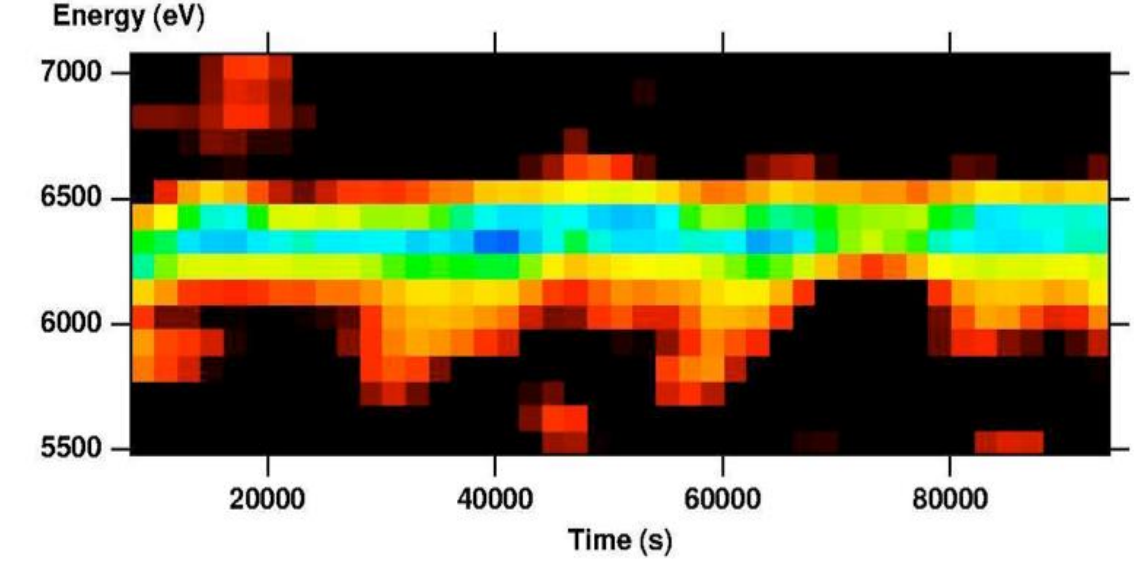
$N_H = 4.1 \times 10^{-22}$ $\Gamma = 2.0$ $\mathrm{Spin}(a) = 0.970$

$\mathrm{Flux}: 2.6 \times 10^{-11} \mathrm{erg\ s^{-1} cm^{-2}}$ $\mathrm{Exposure}: 300\mathrm{ks}$ $\mathrm{Fe\ K}\alpha\ EW: 300\mathrm{eV}$

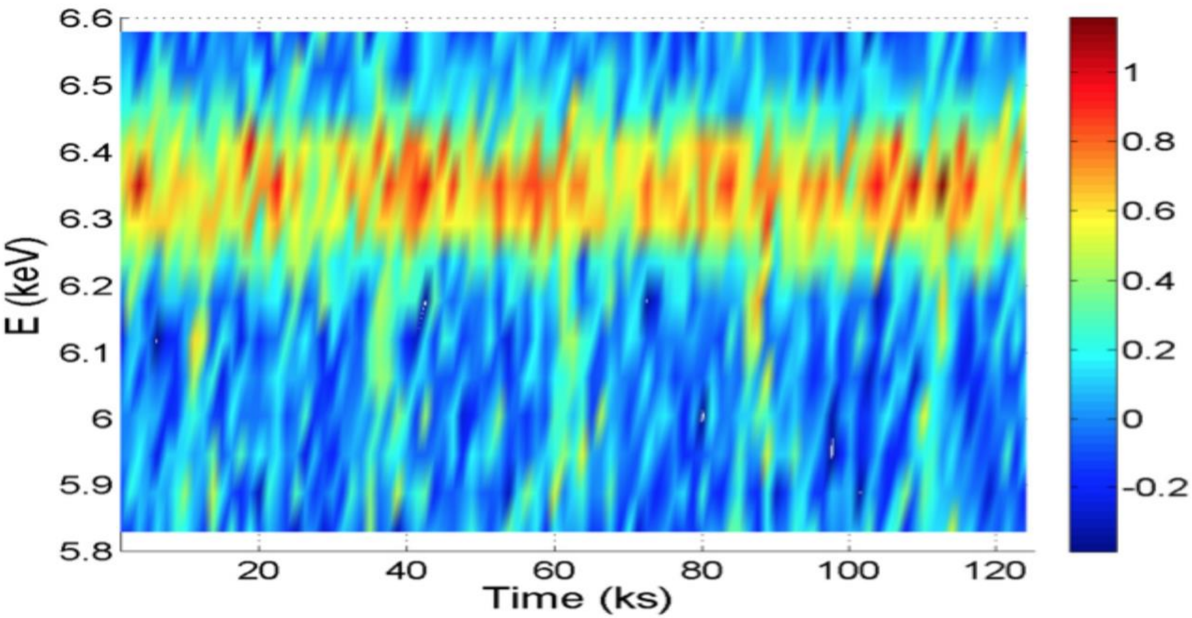


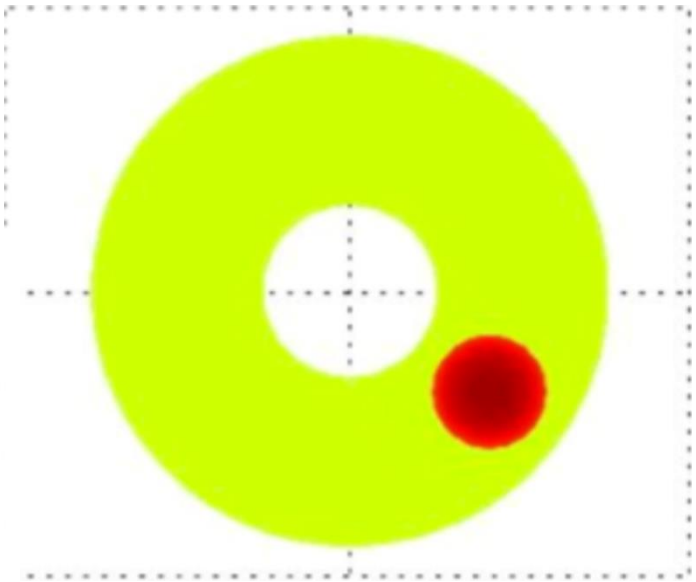


Seeing matter orbiting around a BH



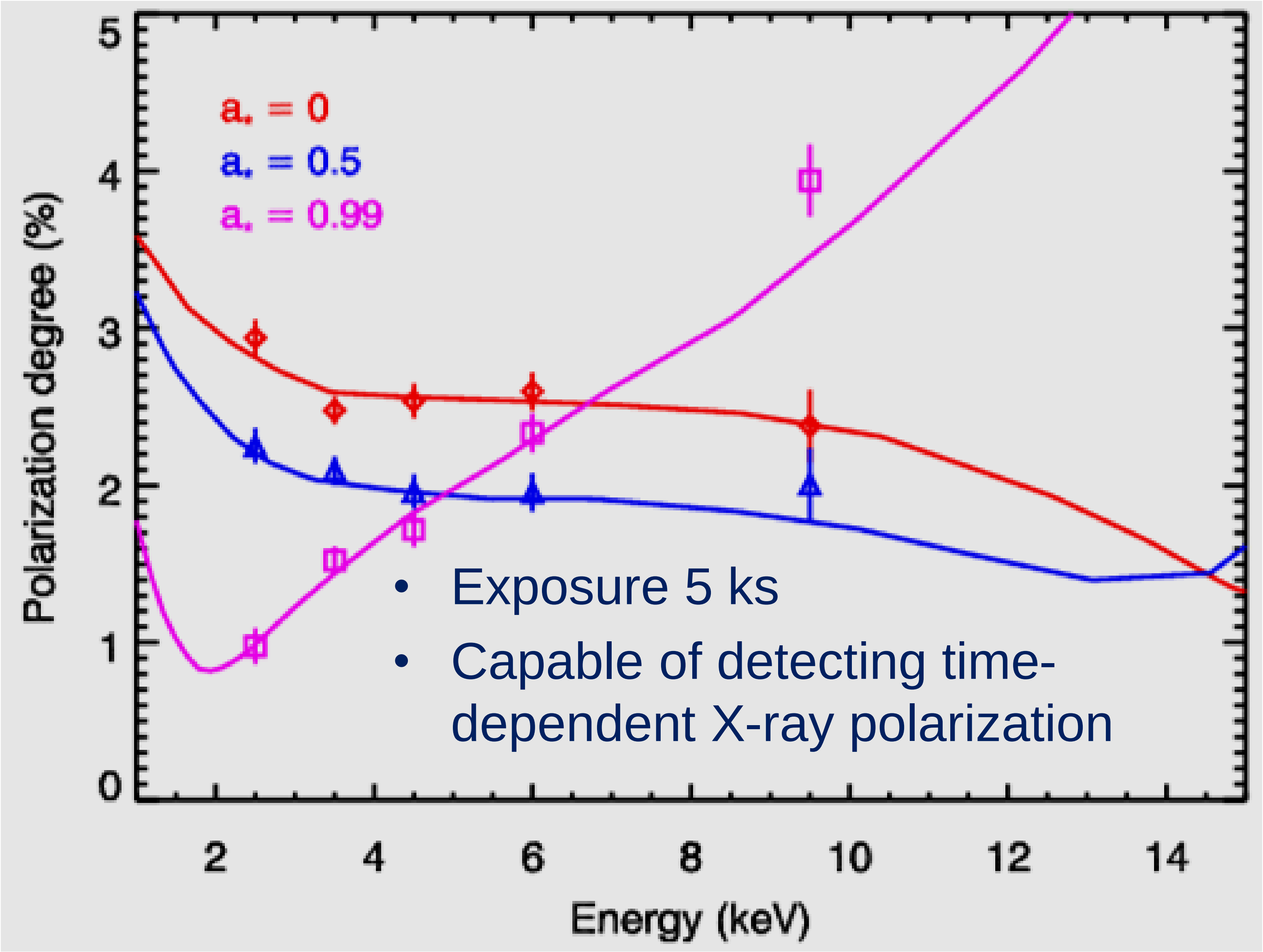
XMM-Newton:
NGC3516
(Iwasawa et al. 2004）





XTP simulation

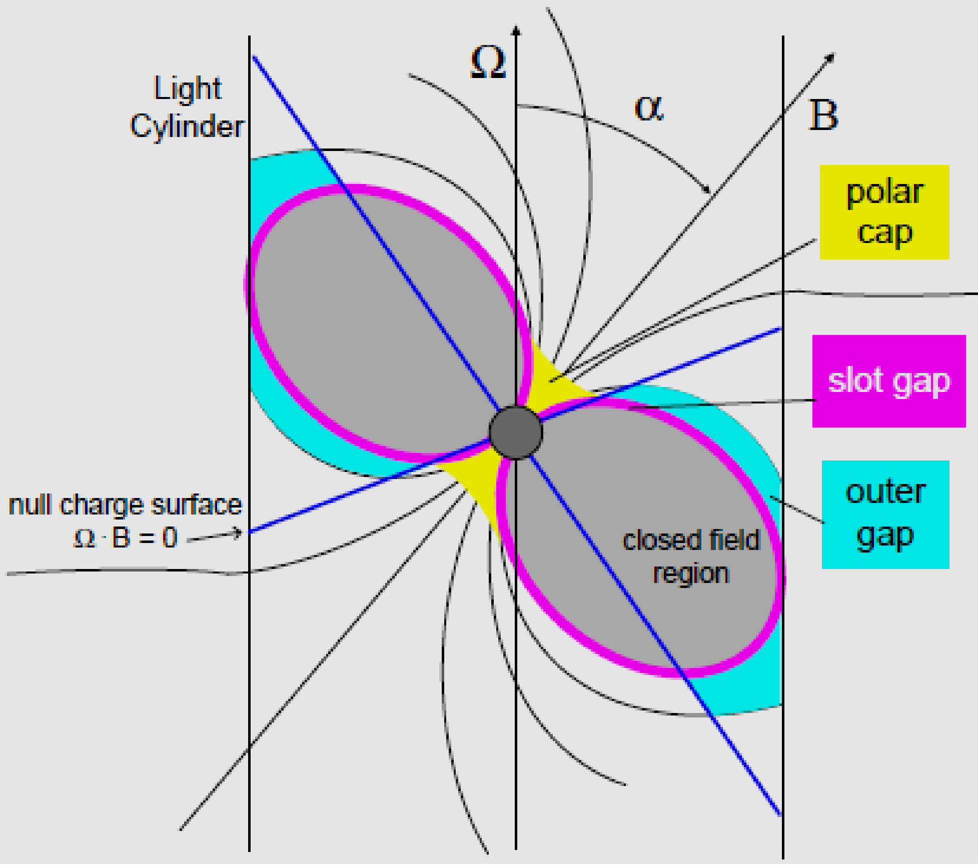
XTP Polarimetry: GRS 1915+105



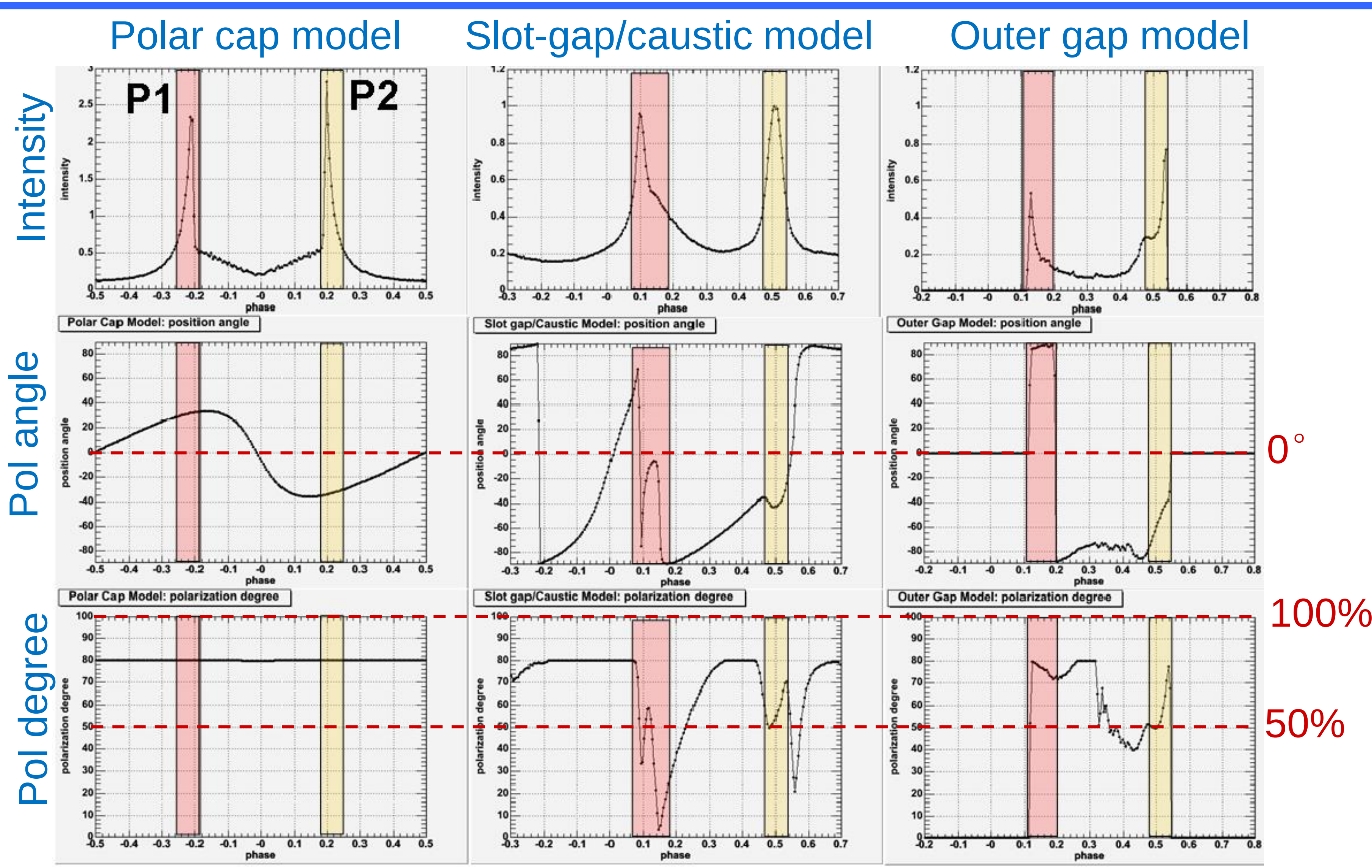
- Exposure 5 ks
- Capable of detecting time-dependent X-ray polarization

Rotation-powered pulsars

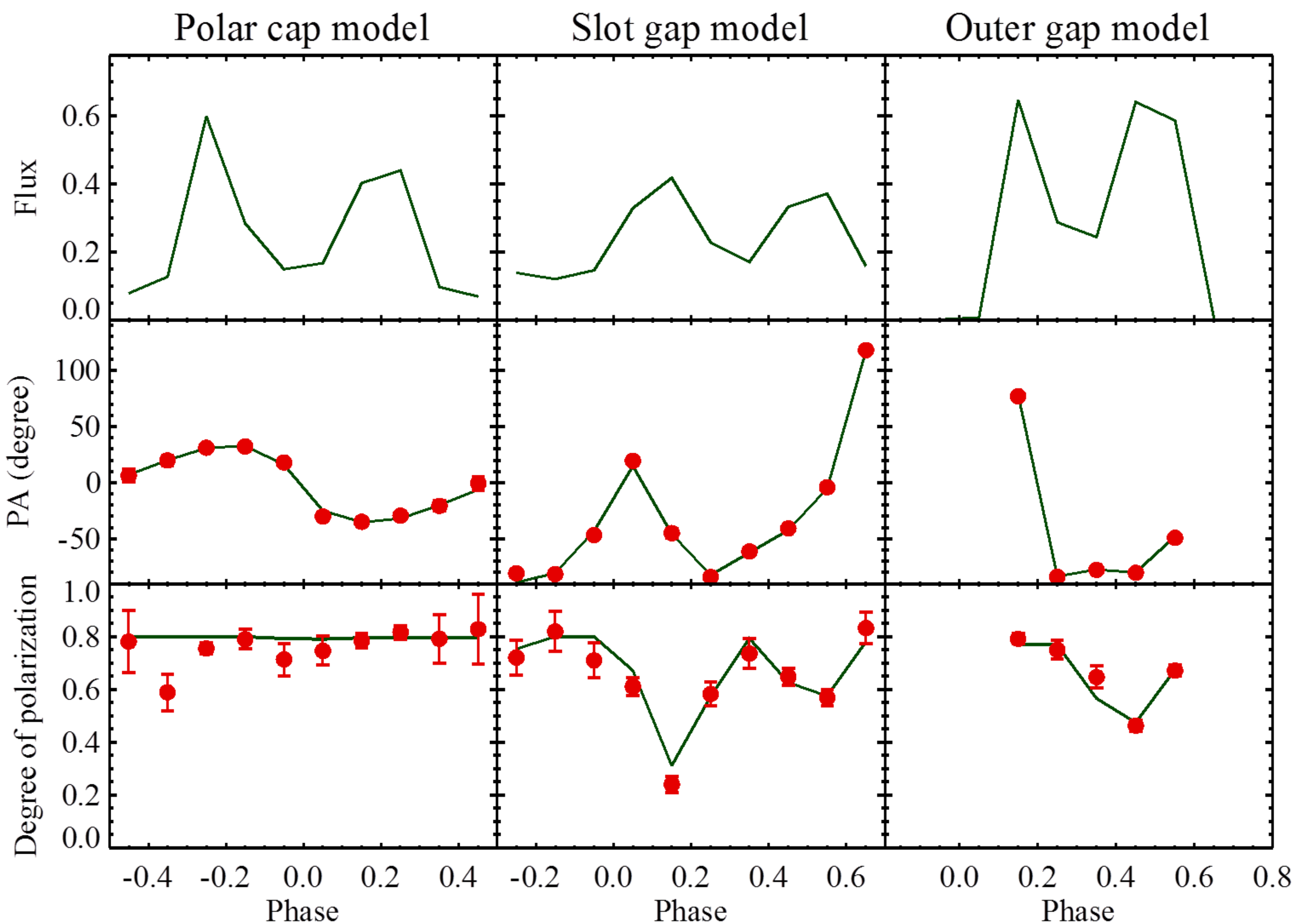
- Three competing models
  - Polar cap (Daugherty & Harding 1996)
  - Slot gap (Muslimov & Harding 2004)
  - Outer gap (Romani 1996; Takana 2007)



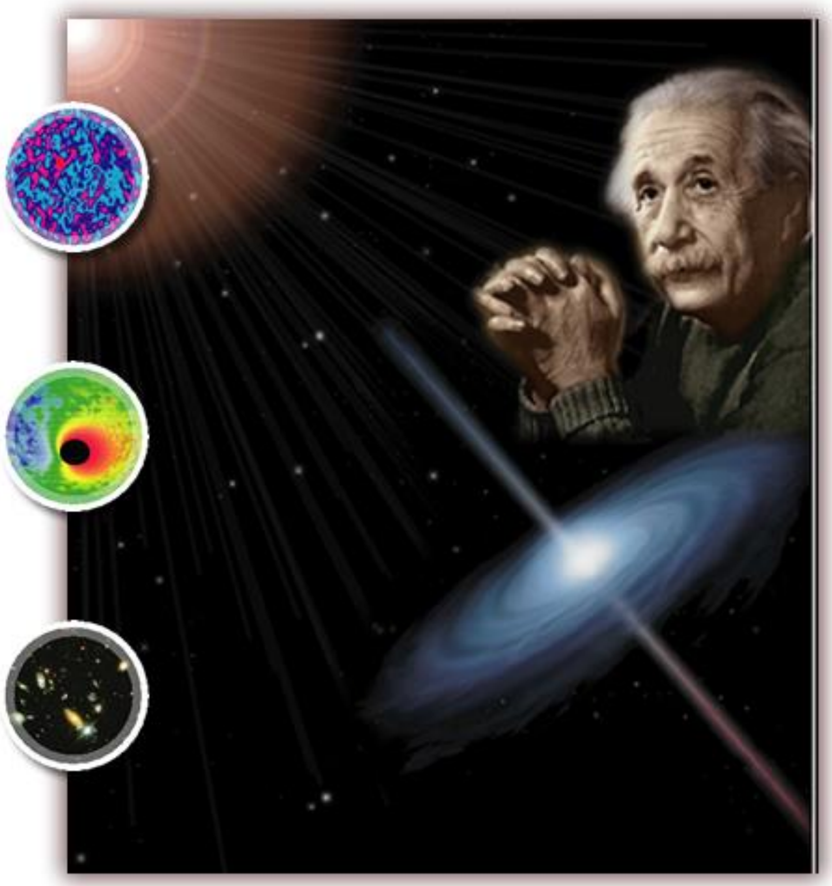
Polarization is sensitive to pulsar model



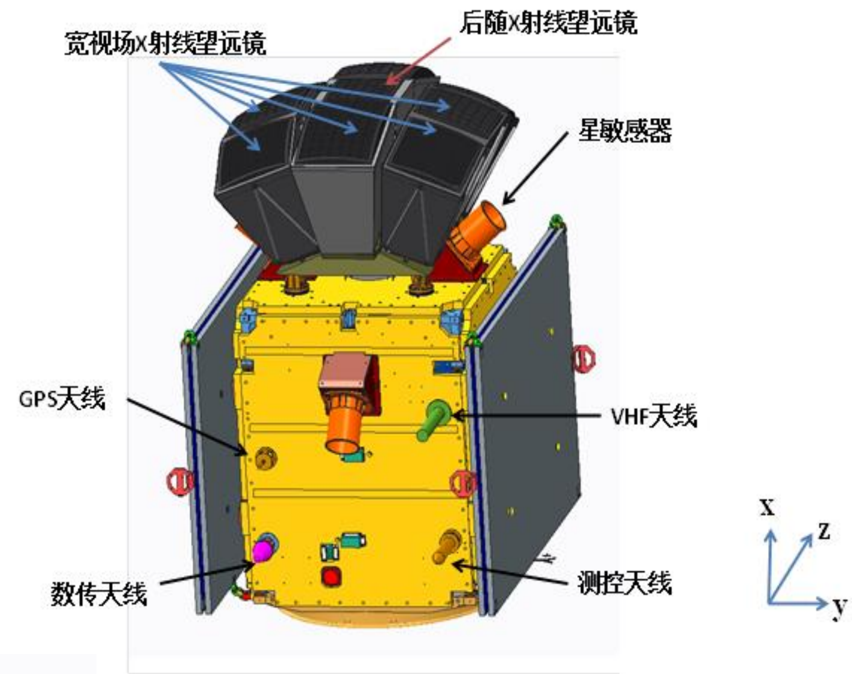
XTP discriminates pulsar models: 0.01 Crab

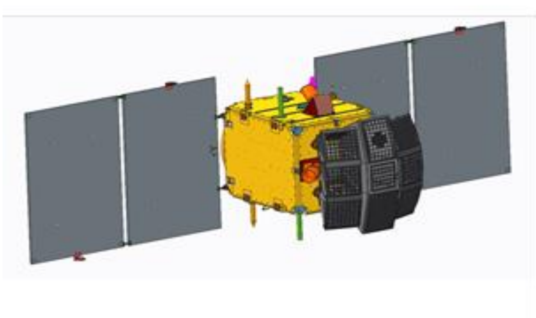


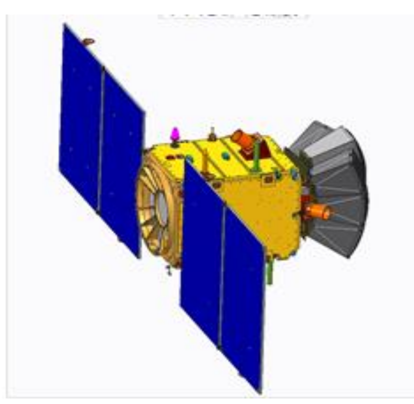
Einstein Probe (EP)



Lobster-eye optics

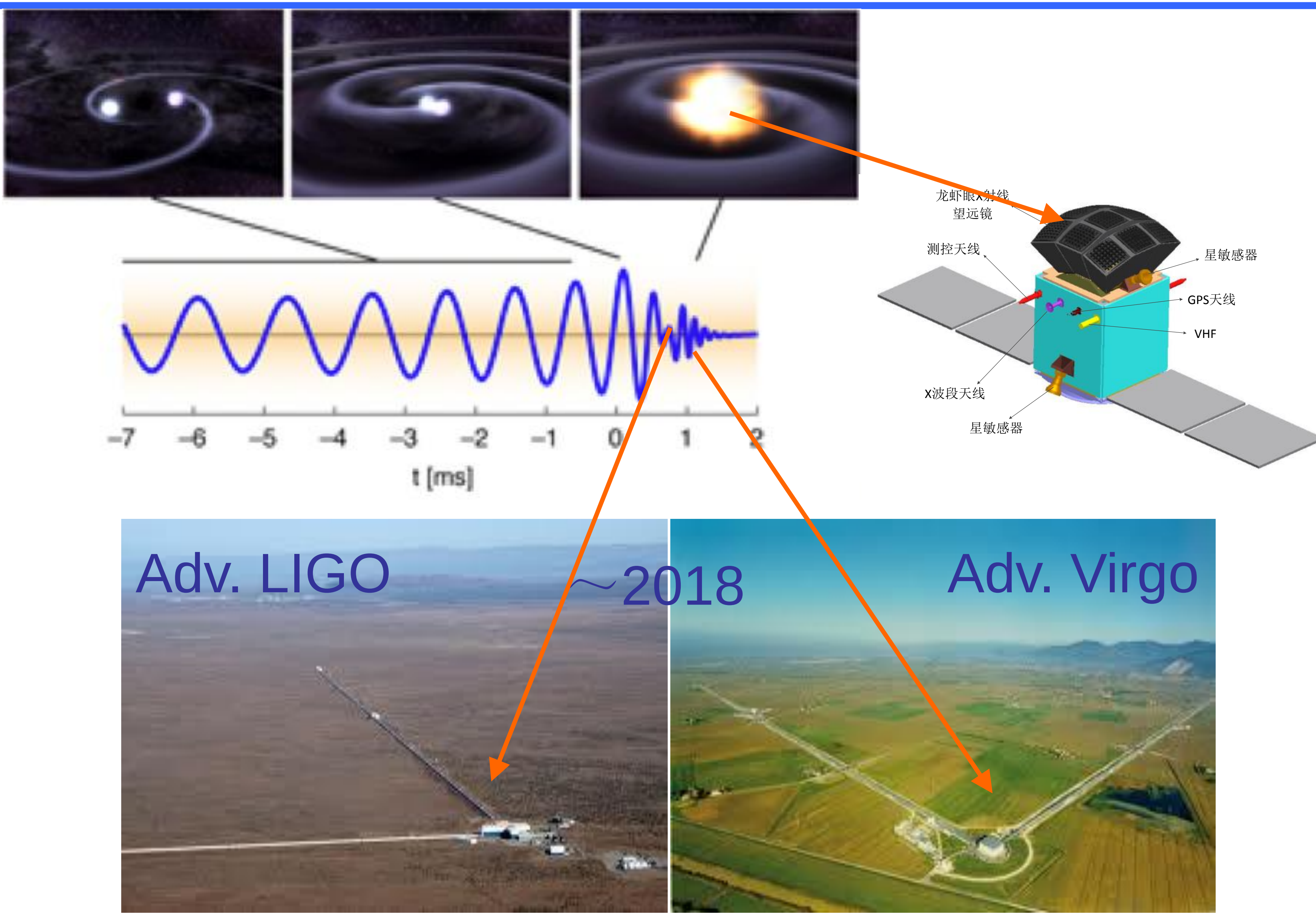




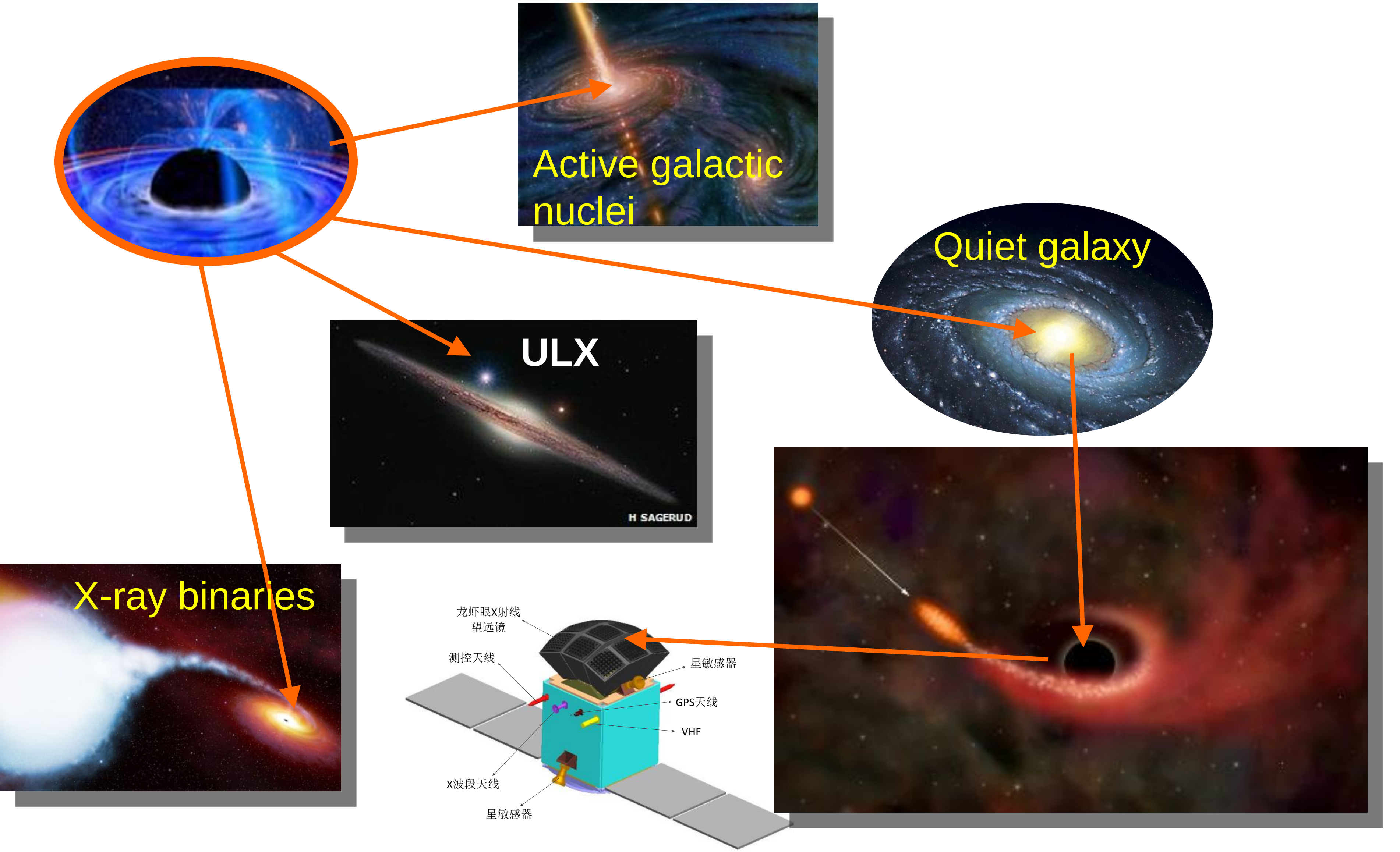


Selected for Phase 0/A in 2013, proposed for launch in 2020-2025.

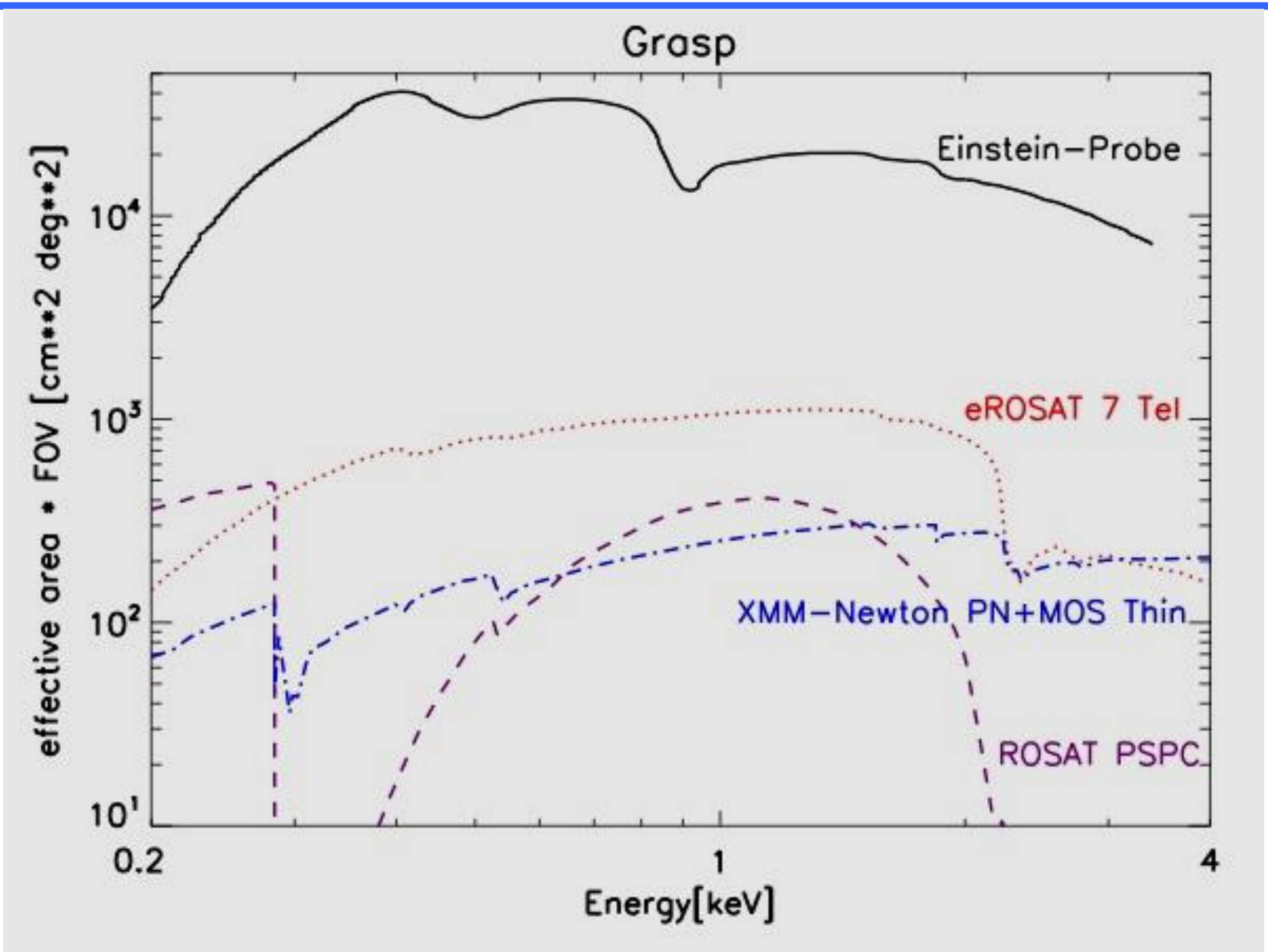
EM counterparts of GW explosions



Black holes of all scales in the universe



Capability of Einstein Probe



China's Space Station Program

2020

Phase -II

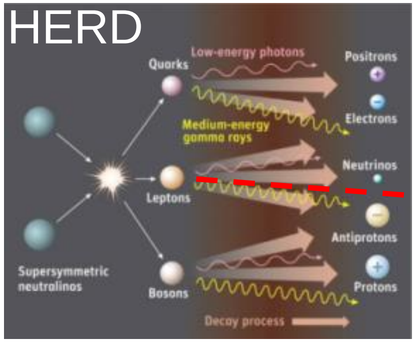
2016

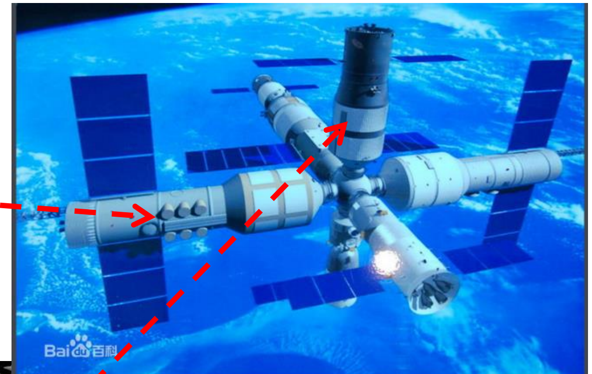
Phase -II

2011

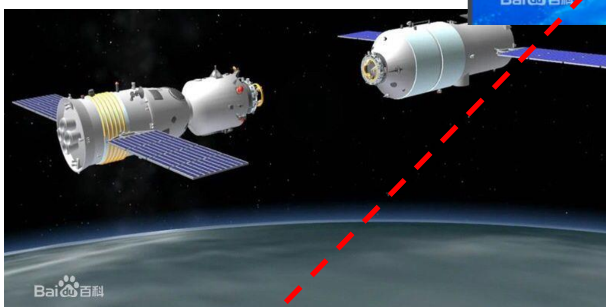
Phase -I

2003

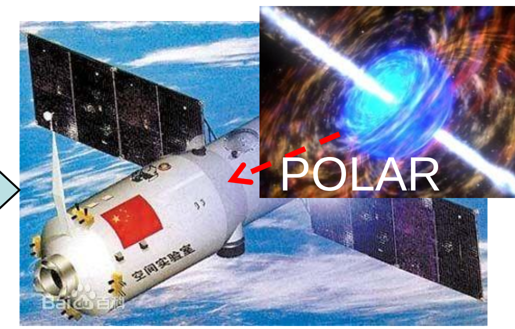


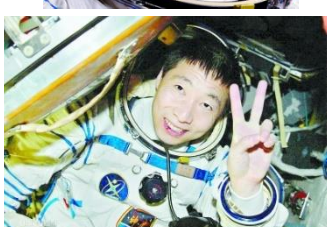


Space Station
3 large modules
+ 2 m telescope
~10-year lifetime



Space lab: no living cabin

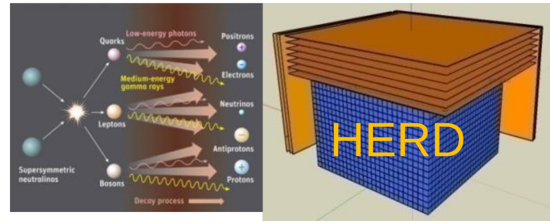




10 astronauts in 5 flights → space walk

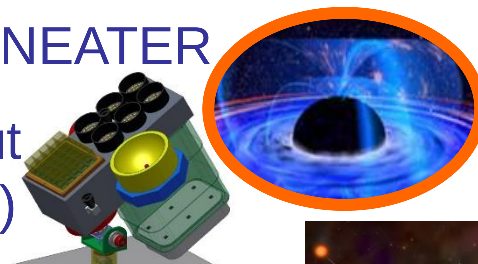
China's Space Station Astronomy Program

e/CR



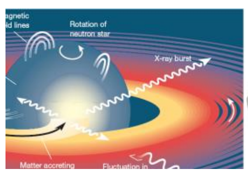
γ-ray

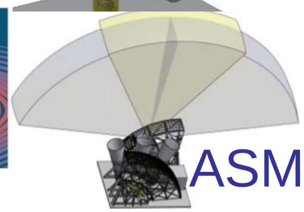
NEATER



(a mini XTP but
with low-E pol.)

X-ray





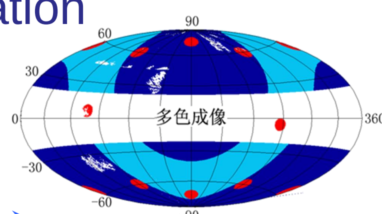
ASM

(EP in scanning
mode without XFT)

?

IR/O

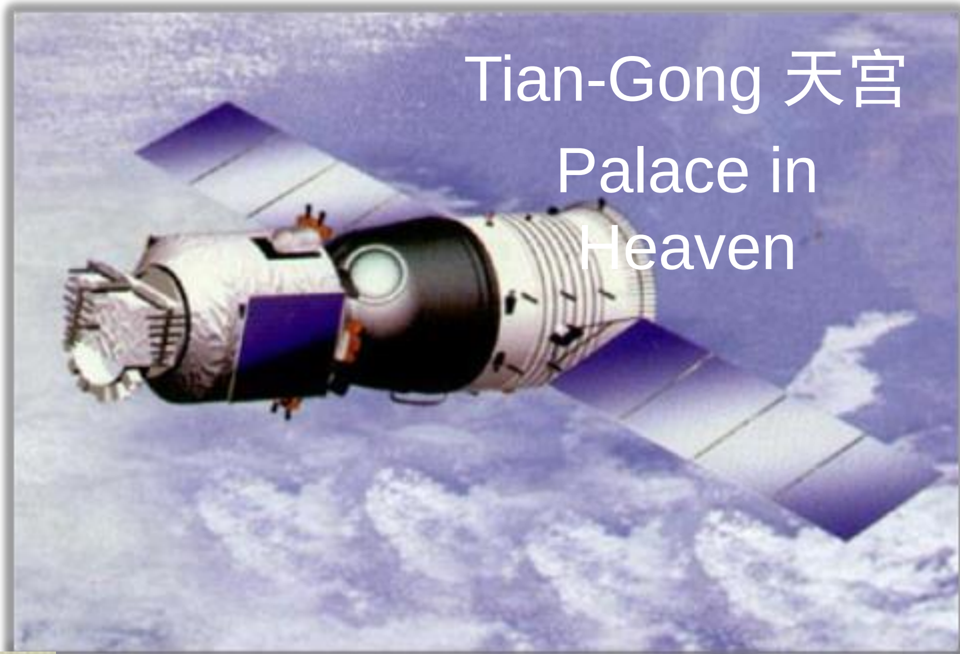
Chinese Space Station
Optical Survey
Dark Energy

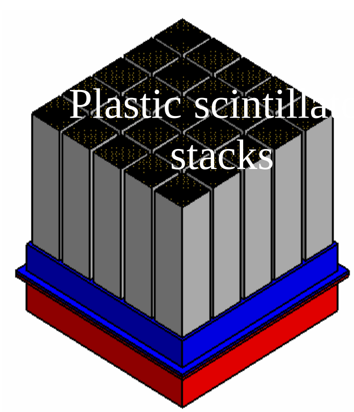


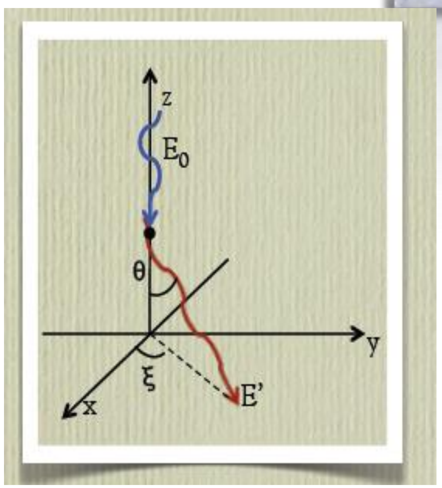
2015 → 2020 → 2025 → 2030

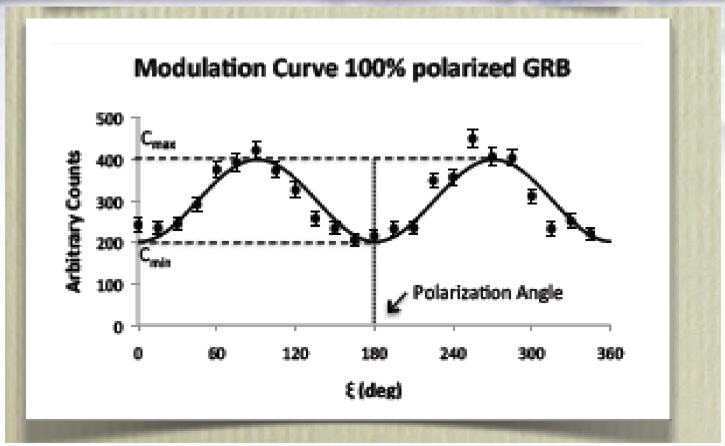
Gamma-ray burst polarization : POLAR

- China- Switzerland collaboration
  - Energy range: 50-350 keV; FOV of POLAR: ~½ sky
- Onboard China's spacelab TG-2: launch time 2016
- Main science: GRB jet & central engine; tests of quantum gravity theories

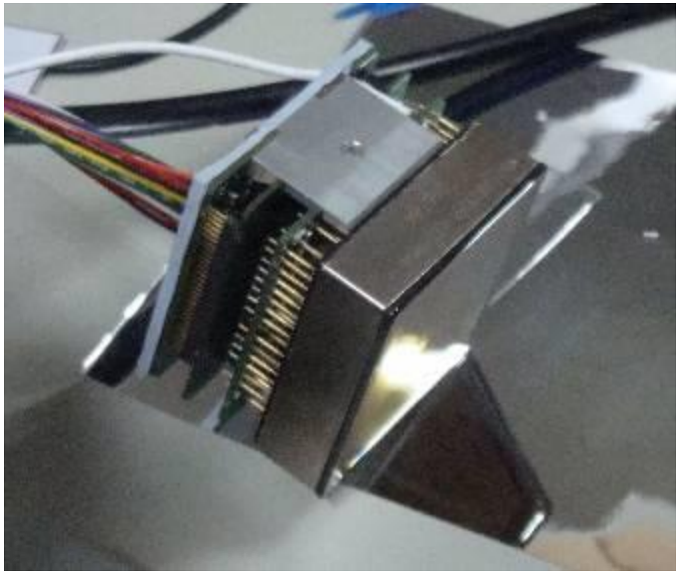


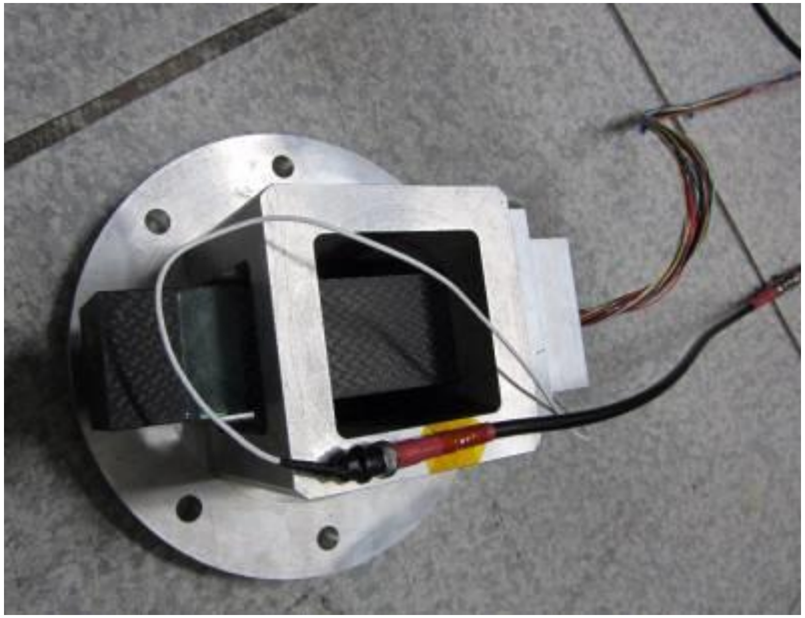




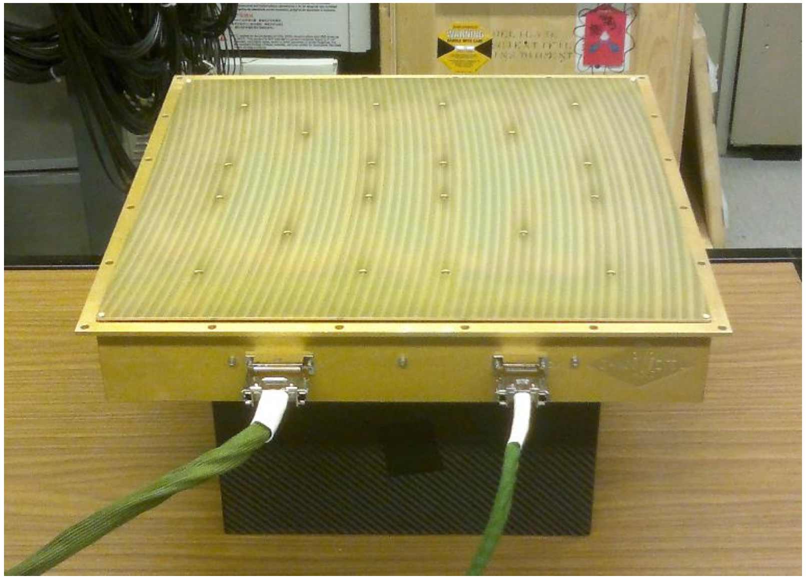


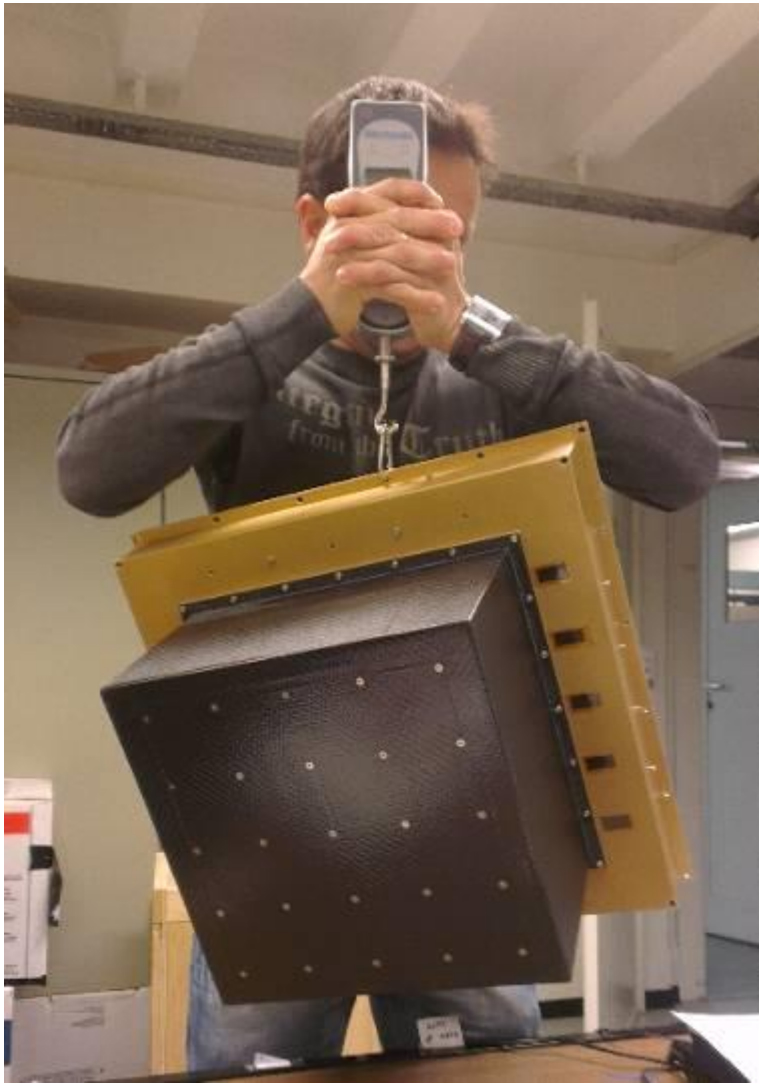
POLAR Hardware Pieces



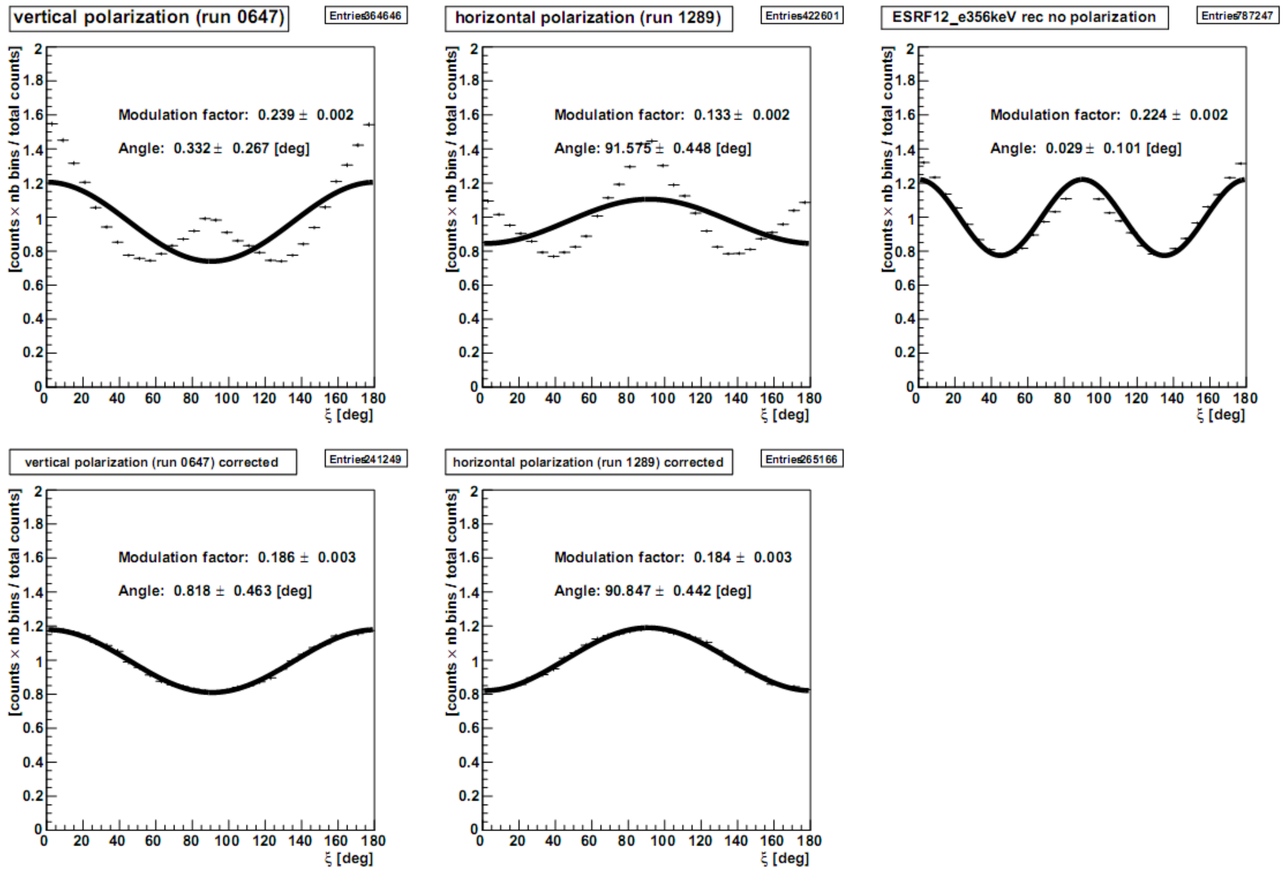


POLAR Qualification Modules





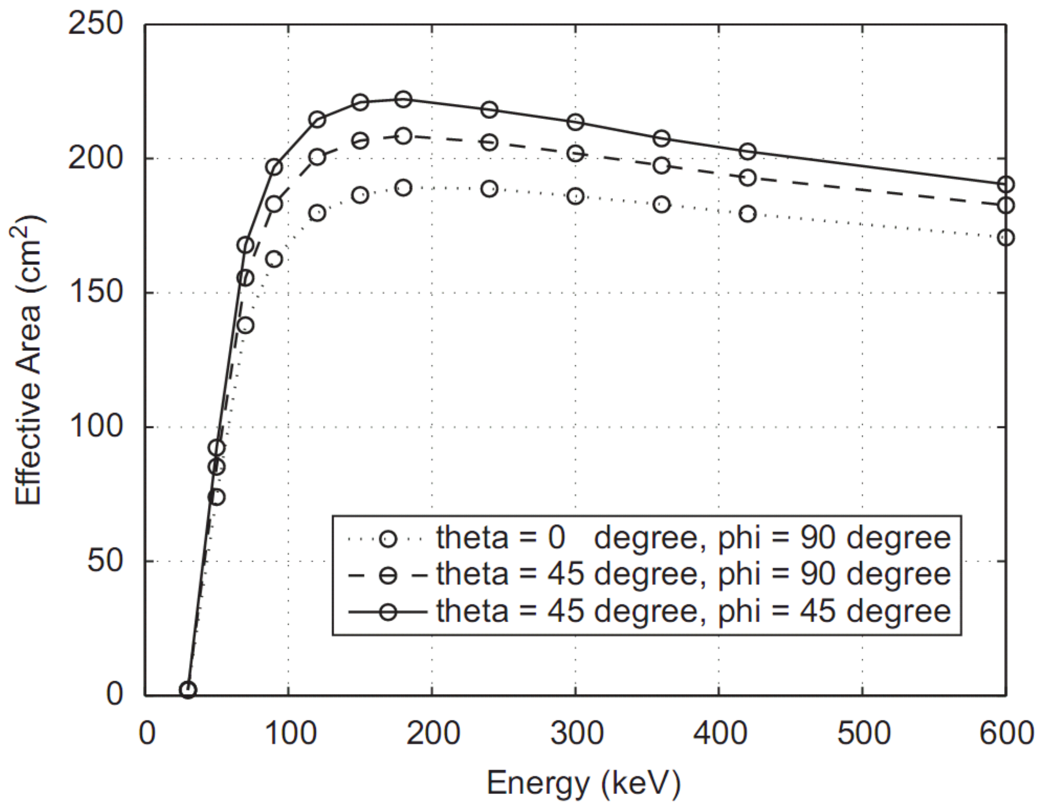
POLAR ESRF Calibration

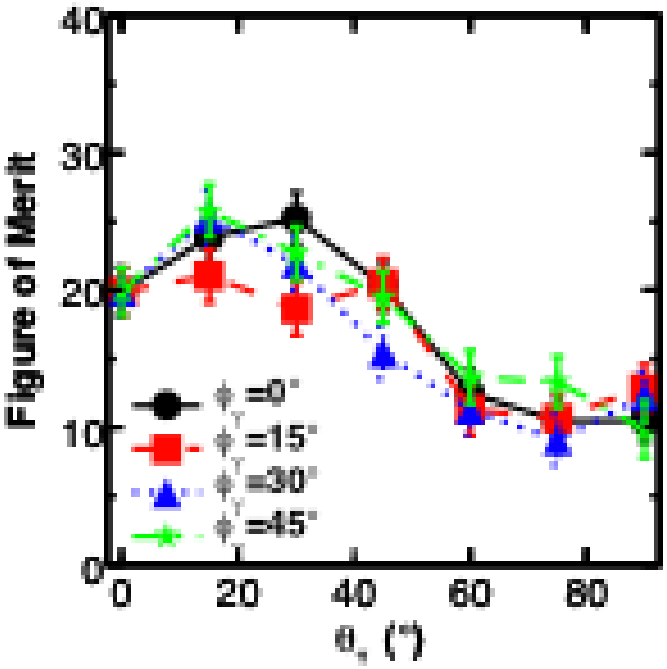


Results agree with Monte-Carlo simulations

Effective Area of POLAR

- Monte Carlo based study
- A_{eff} is dependent on E and incoming photon angle
- Figure of merit: A_{eff} x μ_{100}

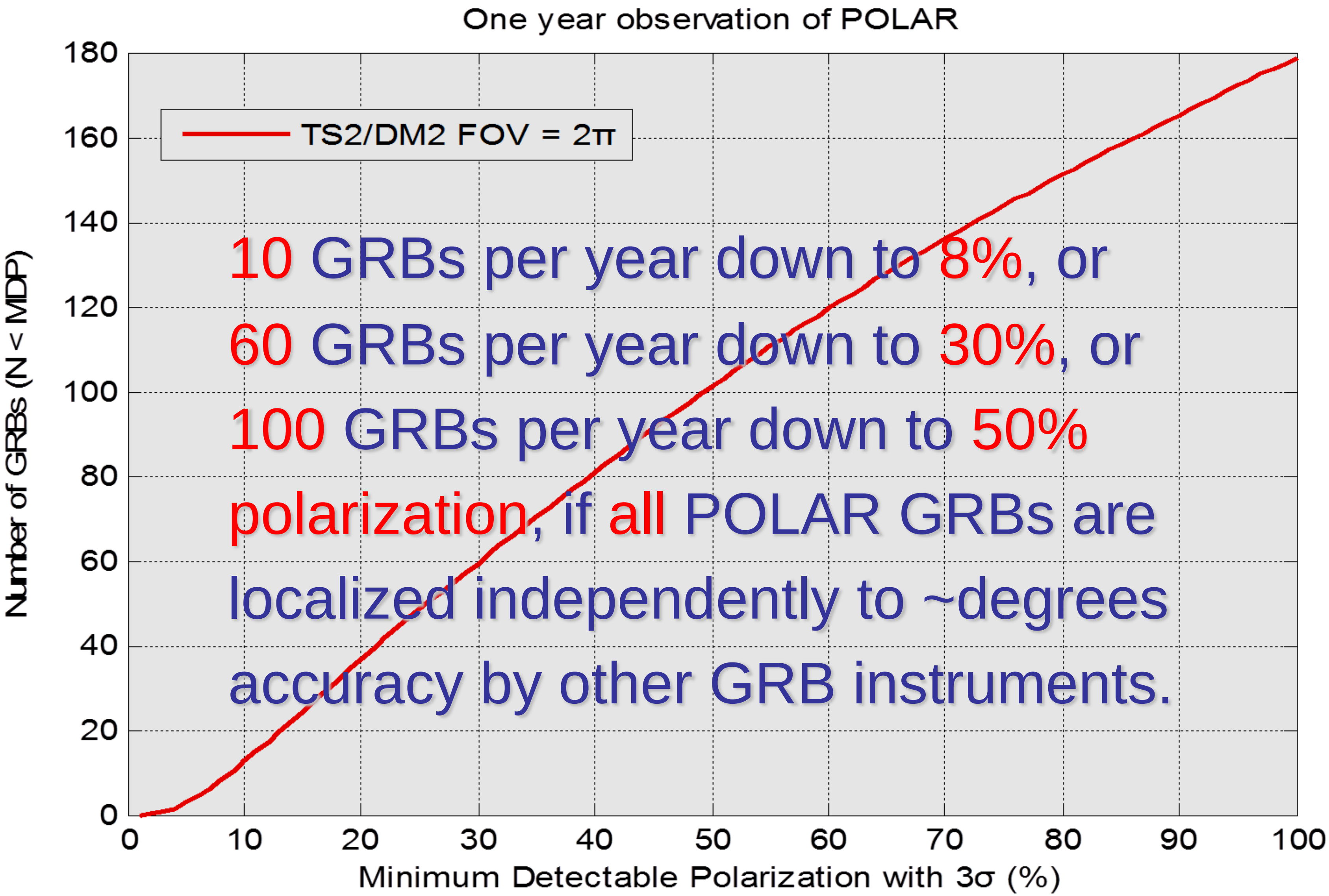




S. Xiong, N. Produit, B. Wu, Expected performance of a hard X-ray polarimeter (POLAR) by Monte Carlo simulation, Nucl. Instr. and Meth. A 606 (2009) 552

E. Suarez Garcia, Ph.D. Thesis, Univ. de Genève, 2010

POLAR capability



10 GRBs per year down to 8%, or 60 GRBs per year down to 30%, or 100 GRBs per year down to 50% polarization, if all POLAR GRBs are localized independently to ~degrees accuracy by other GRB instruments.


background
Gamma-ray
HERD
electron
proton
He
Dark matter particle

HERD: High Energy cosmic-Radiation Detector

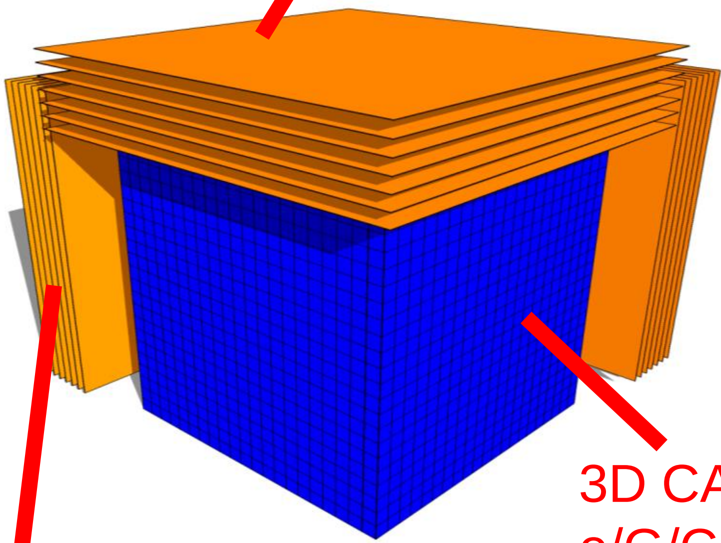
Science goals	Mission requirements
Dark matter search	R1: Better statistical measurements of e/γ between 100 GeV to 10 TeV
Origin of Galactic Cosmic rays	R2: Better spectral and composition measurements of CRs between 300 GeV to PeV* with a large geometrical factor

Secondary science: monitoring of GRBs, microquasars, Blazars and other transients.

HERD Design：3D Calo & 5-Side Sensitive

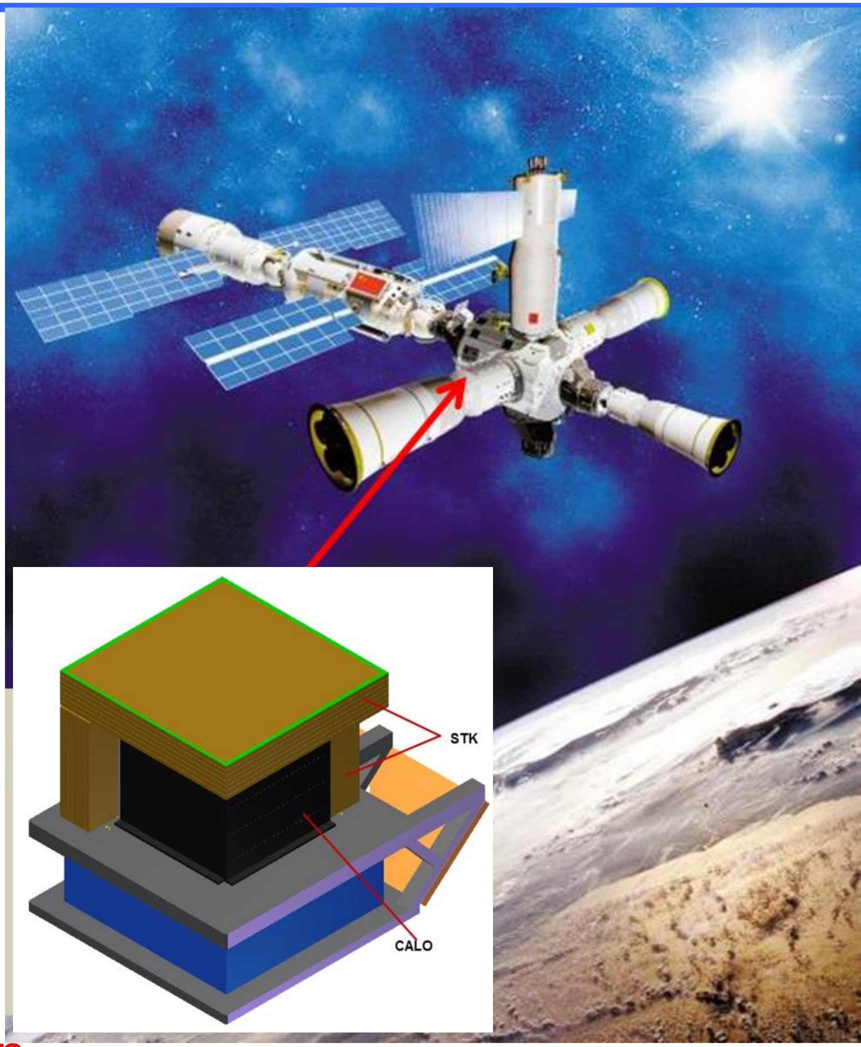
n10X acceptance than most others, but weight 2.3 T ~1/3 AMS

STK(W+SSD)
Charge
gamma-ray direction
CR back scatter



STK(W+SSD)

3D CALO
e/G/CR energy
e/p discrimination



Characteristics of all components

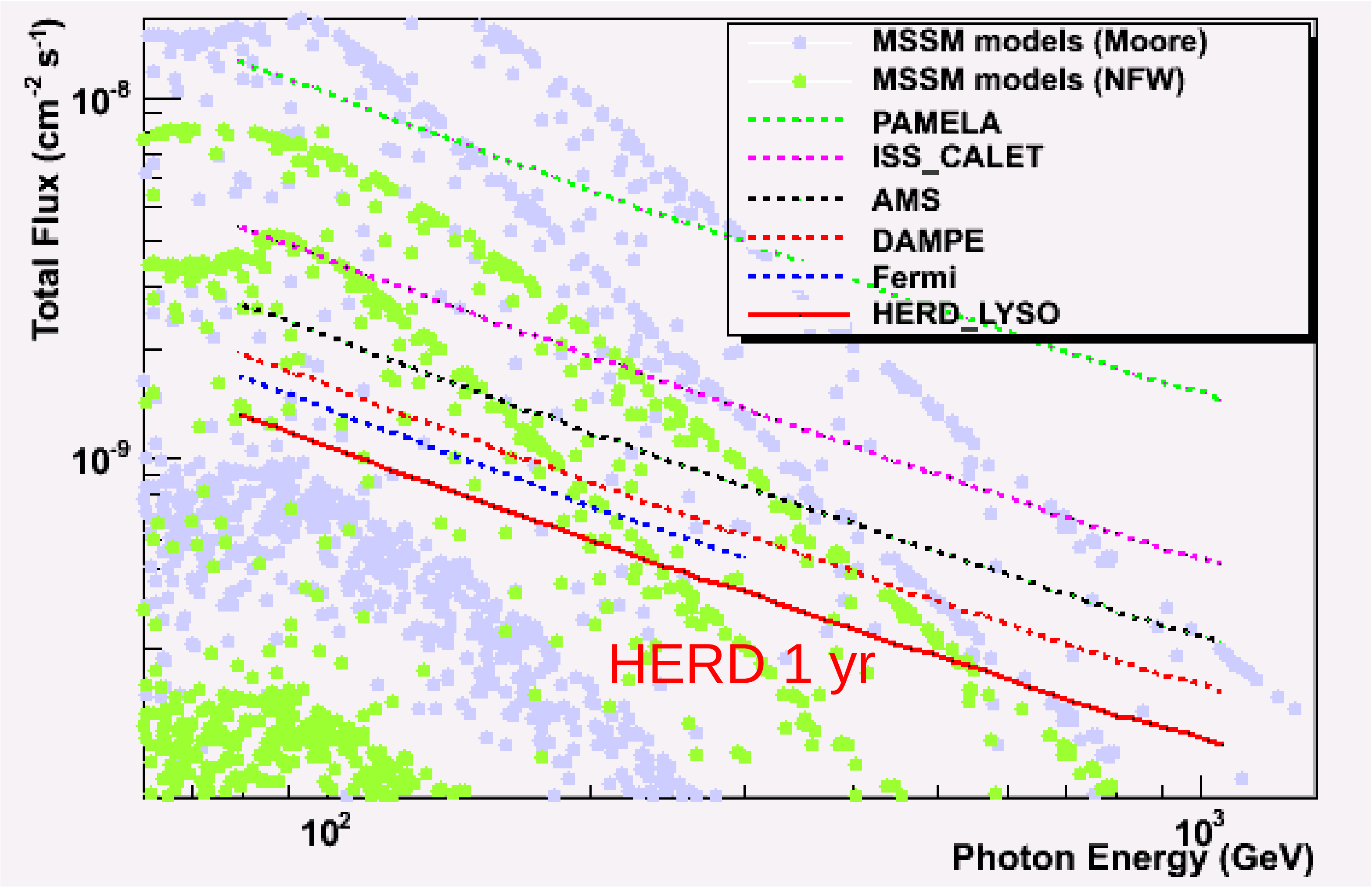
	type	size	X0,λ	unit	main functions
5-side STK	W+Si strips	70 cm × 70 cm	2 X0	7 x-y (W foils)	Charge Early shower Tracks
3-D CALO	~10K LYSO cubes	63 cm × 63 cm × 63 cm	55 X0 3 λ	3 cm × 3 cm × 3 cm	e/γ energy nucleon energy e/p separation

Total detector weight: ~2300 kg

Expected performance of HERD

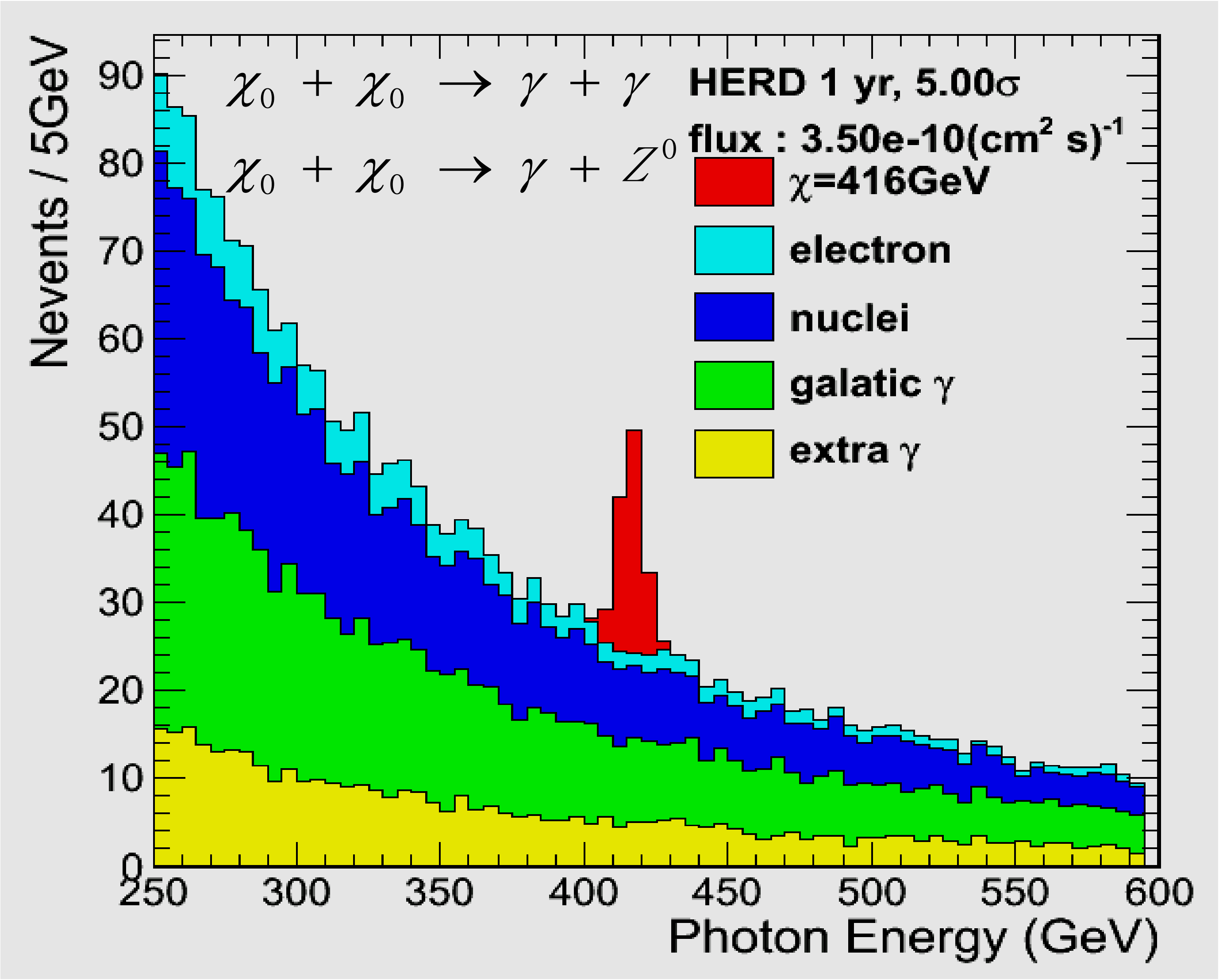
γ/e energy range (CALO)	tens of GeV-10TeV
nucleon energy range (CALO)	up to PeV
γ/e angular resol. (top Si-strips)	0.1^{o}
nucleon charge resol. (all Si-strips)	0.1-0.15 c.u
γ/e energy resolution (CALO)	<1%@200GeV
proton energy resolution (CALO)	20%
e/p separation power (CALO)	$<10^{-5}$
electron eff. geometrical factor (CALO)	3.7 m^2sr@600 GeV
proton eff. geometrical factor (CALO)	2.6 m^2sr@400 TeV

HERD sensitivity to gamma-ray line

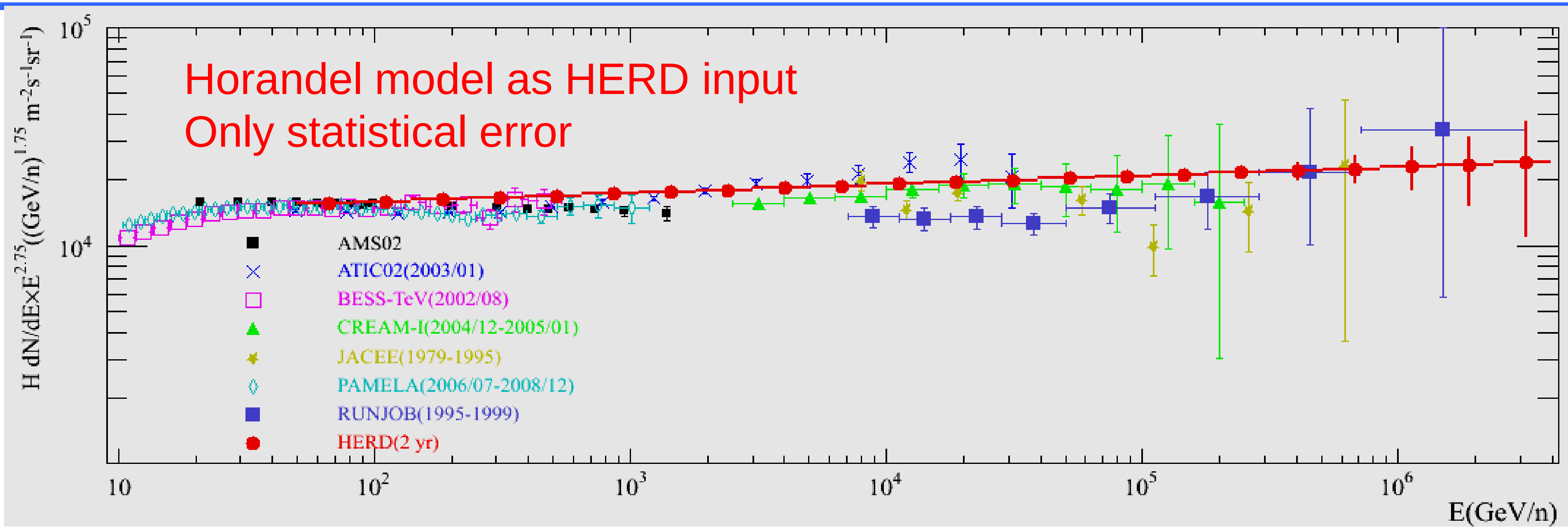


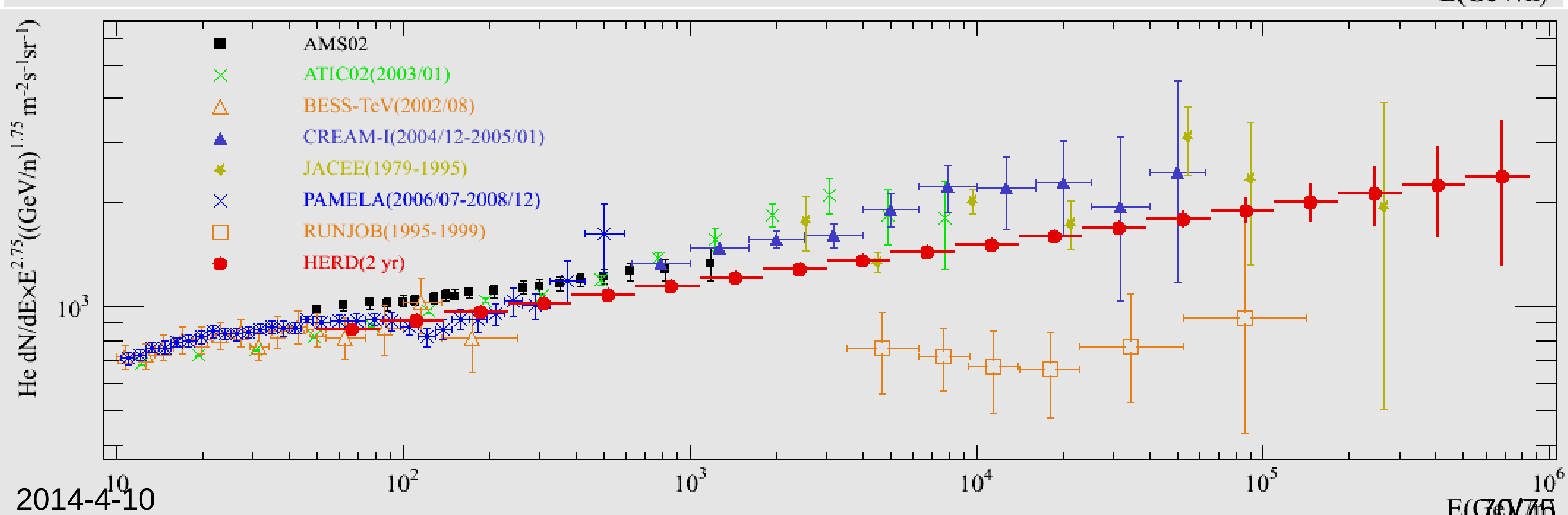
PAMELA: 2006-2016 CALET: 2015-2020; AMS: 2011-2021; DAMPE: 2015-2020; Fermi: 2008-2018; HERD: 2020-2021

DM annihilation line of HERD

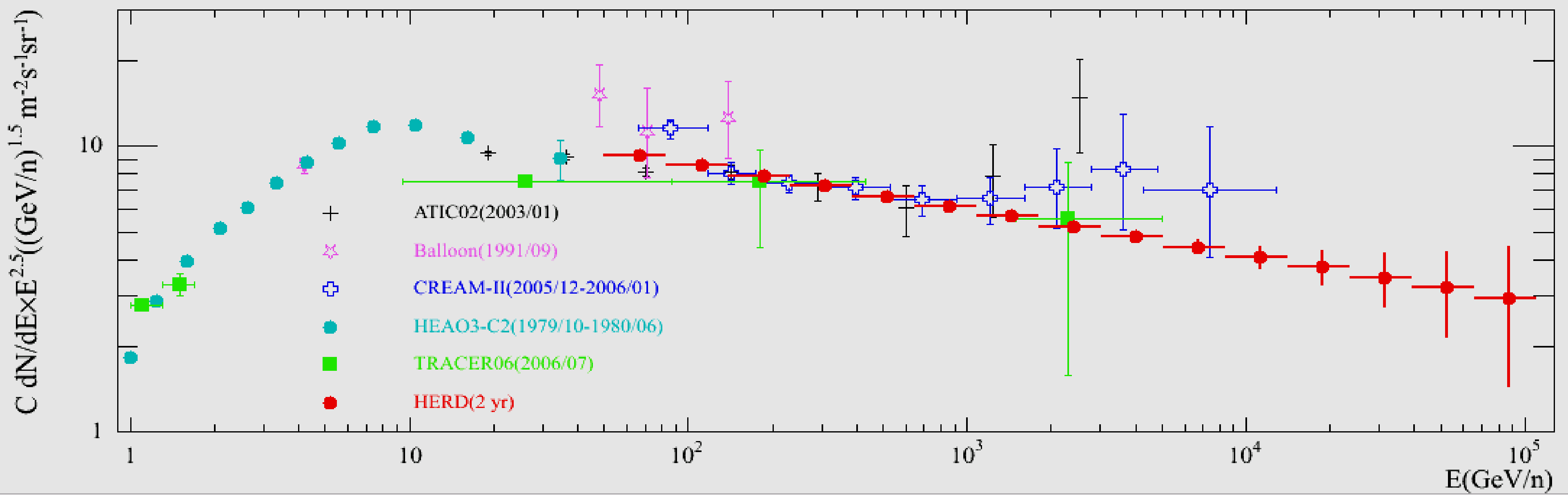


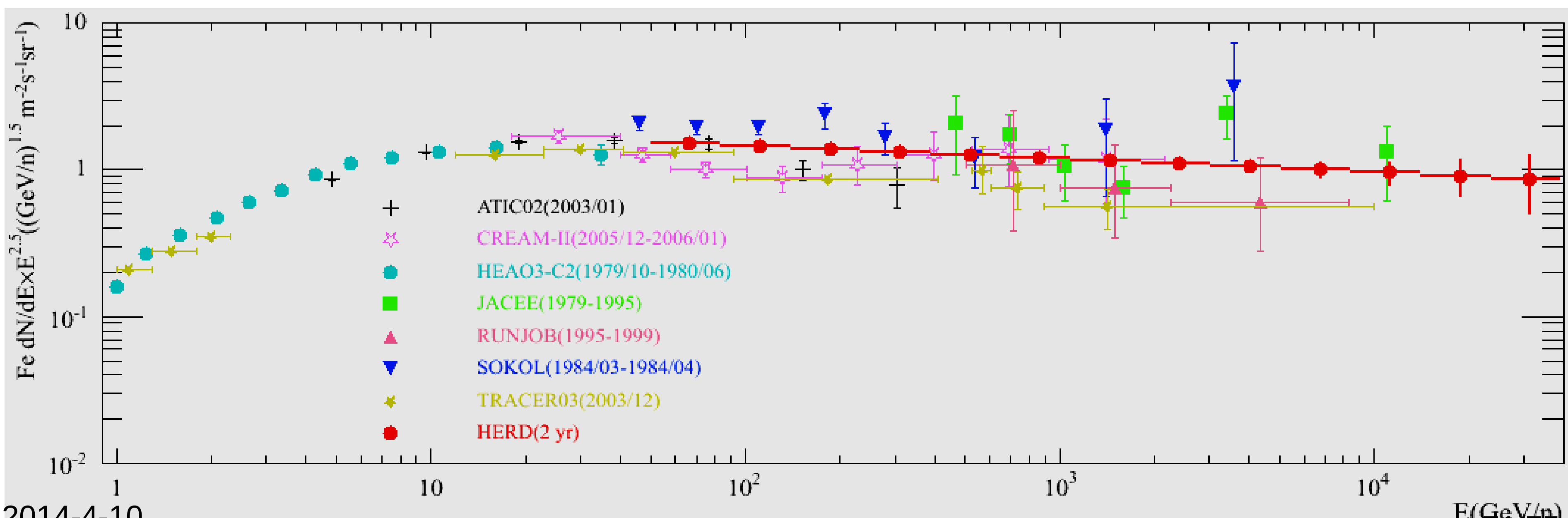
Expected HERD Proton and He Spectra





Expected HERD Spectra of C and Fe

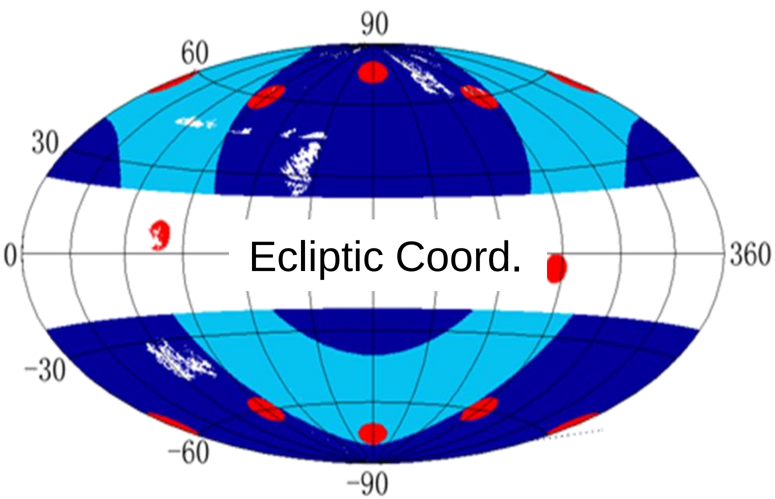




Chinese Space Station Optical Survey

- 25000□° imaging survey: 250-1050nm, ≥6 filters, g, r, & i ≥ AB25 mag (5σ, point source)
- 800□° deep imaging survey: g, r, & i ≥ AB26.5 mag
- 10000□° medium & high galactic latitude slitless spectroscopy survey: g, r, & i continuum ≥ AB21 mag

2022?



Survey Science

Cosmology: dark energy, dark matter, gravity, large-scale structure, neutrinos, primordial non-Gaussianity…

AGNs: high-z AGNs, clustering, dual AGNs, variability, UV excess, host galaxies…

Galaxies: formation & evolution, mergers, high-zs, dwarfs, LSBs, near field, halos properties…

Milky Way: structure, satellites, dust, extinction…

Stellar science: formation, dwarfs, metal poor…

Solar system (high inclination): TNO、NEA…

Astrometry: reference frame, star clusters…

…

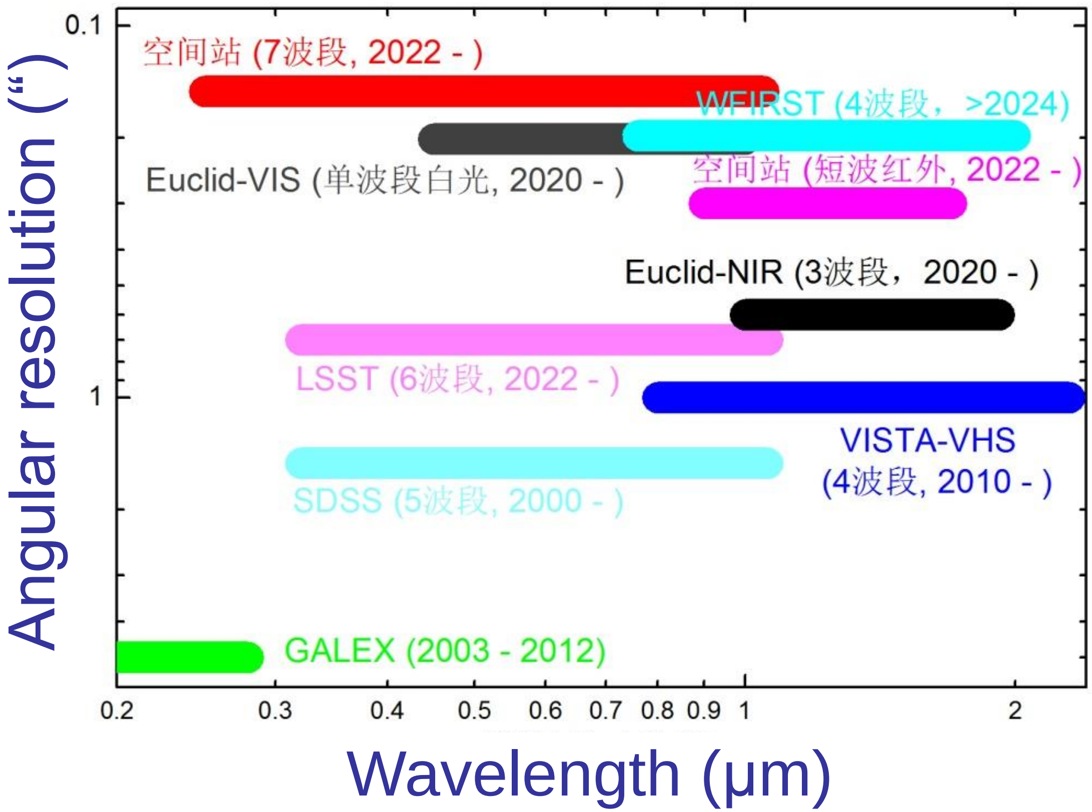
Comparison with Other Surveys

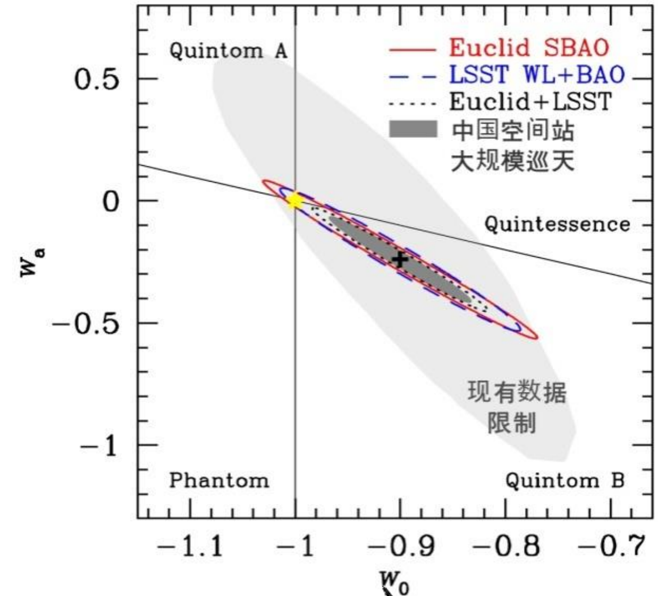
Project	Site	Launch/Op	FoV	R_{EE80}	Num pixels	Area	Wavelength	Num Filter	Spec
			deg^2	″	10^9	deg^2	nm		
Space Station	LEO	2022	1.1 0.002	0.15 0.25	2.5 0.002	25000 -	250—1050 900—1700	7 2	yes yes
Euclid	L2	2020	0.56 0.55	>0.2 0.6	0.6 0.07	15000	550—920 1000—2000	1 3	no yes
WFIRST	GEO	≥2024	0.28	>0.2	0.3	2400	927—2000	4	yes
LSST	Chile	2022	9.6	>0.7	3.2	20000	320—1050	6	no

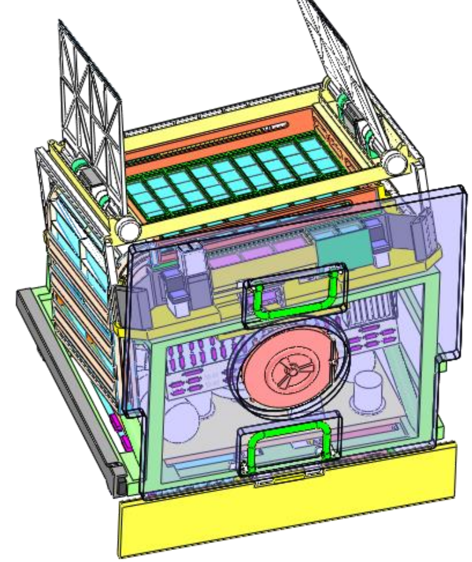
5σ point source limiting AB mag of Space Station Survey

	Exp	NUV	u	g	r	i	z	Y
Imaging	2×150s	25.5	25.5	26.1	25.9	25.7	25.5	24.7
Deep Imaging	7×200s	26.5	26.5	27.1	26.8	26.7	26.5	25.7
Slitless Spec	2×200s	20.3	21.0	21.3	21.4	21.4	21.5	21.0

Comparison with Other Surveys







The Chinese space station optical survey is very competitive among its peers, and its capability, especially high-resolution near-UV imaging and slitless spectroscopy in the optical, is unique and highly complementary to other surveys.

Summary

- Lunar Exploration: CE-3
  - Lunar UV Telescope (LUT) and Active Particle-Excitation X-ray Spectrometer (APXS)
- Astronomy satellite
  - Approved: DArk Matter Particle Exploration (DAMPE, 2015), Hard X-ray Modulation Telescope (HXMT, 2016), Space Variable Object Monitor (SVOM, 2021)
  - Phase 0/A: X-ray Timing and Polarization (XTP), Einstein Probe (EP), Search for Terrestrial Earth Program (STEP), sub-mm VLBI
- Manned Space Flight Program
  - Approved: Gamma-ray burst polarization (POLAR, 2016), Space Station Optical Survey (2022?)
  - Phase 0/A: Neutron-star Astrophysics & Technology Exploration Research (NEATER, 2021?), X-ray All Sky Monitor (ASM, 2021?)