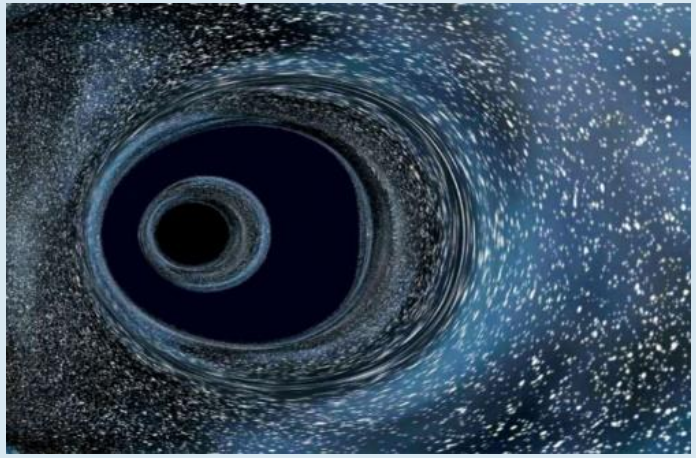
The operation of Einstein Probe in commissioning phase

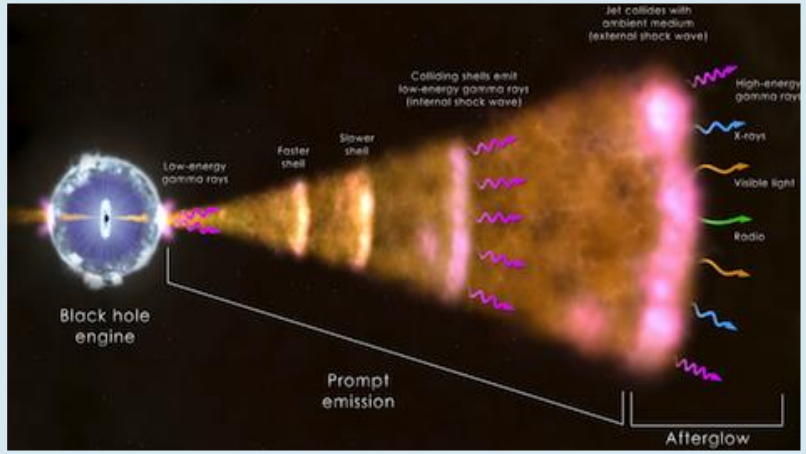
Image credit ESA/CAS

Einstein Probe Mission is a time-domain high-energy astrophysics mission funded by CAS in “Strategic Pilot Program” for Space Science.

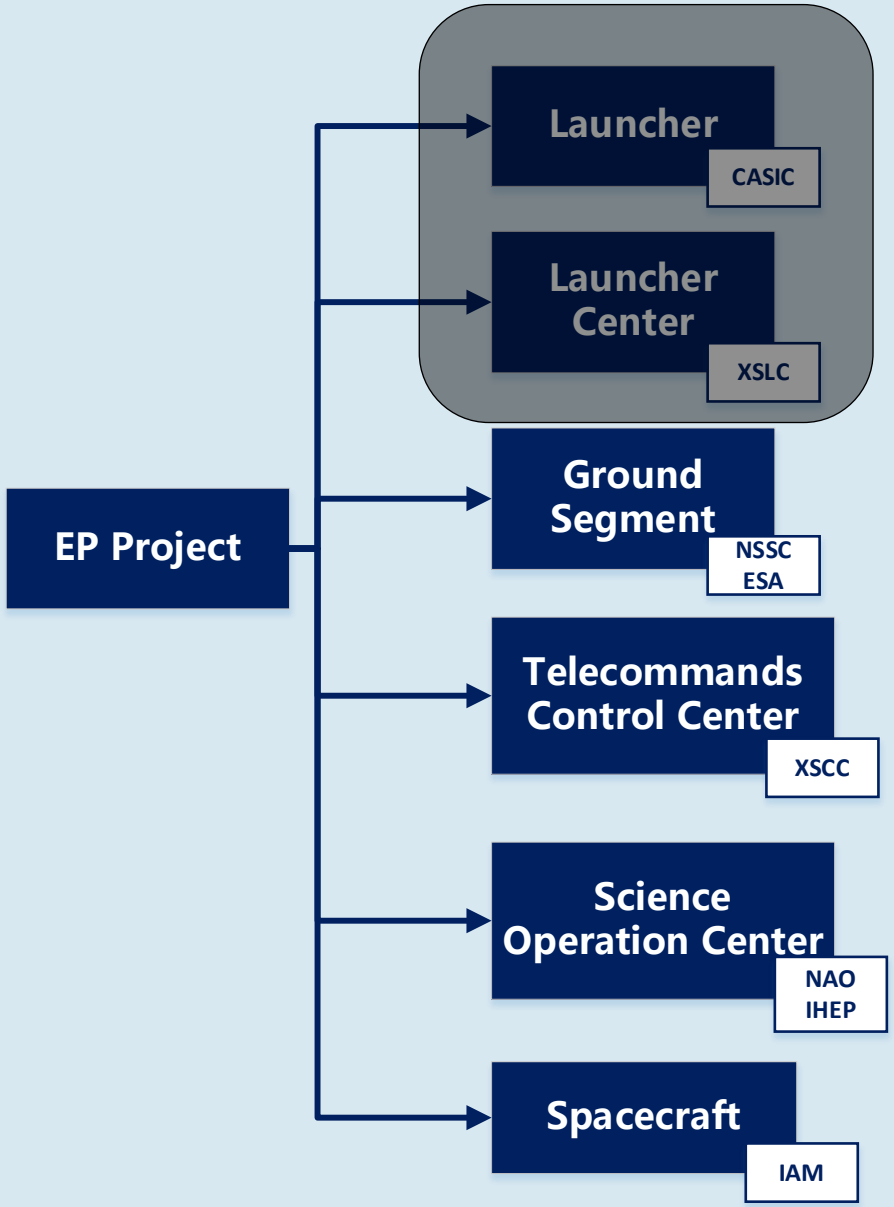
Primary science objectives are:

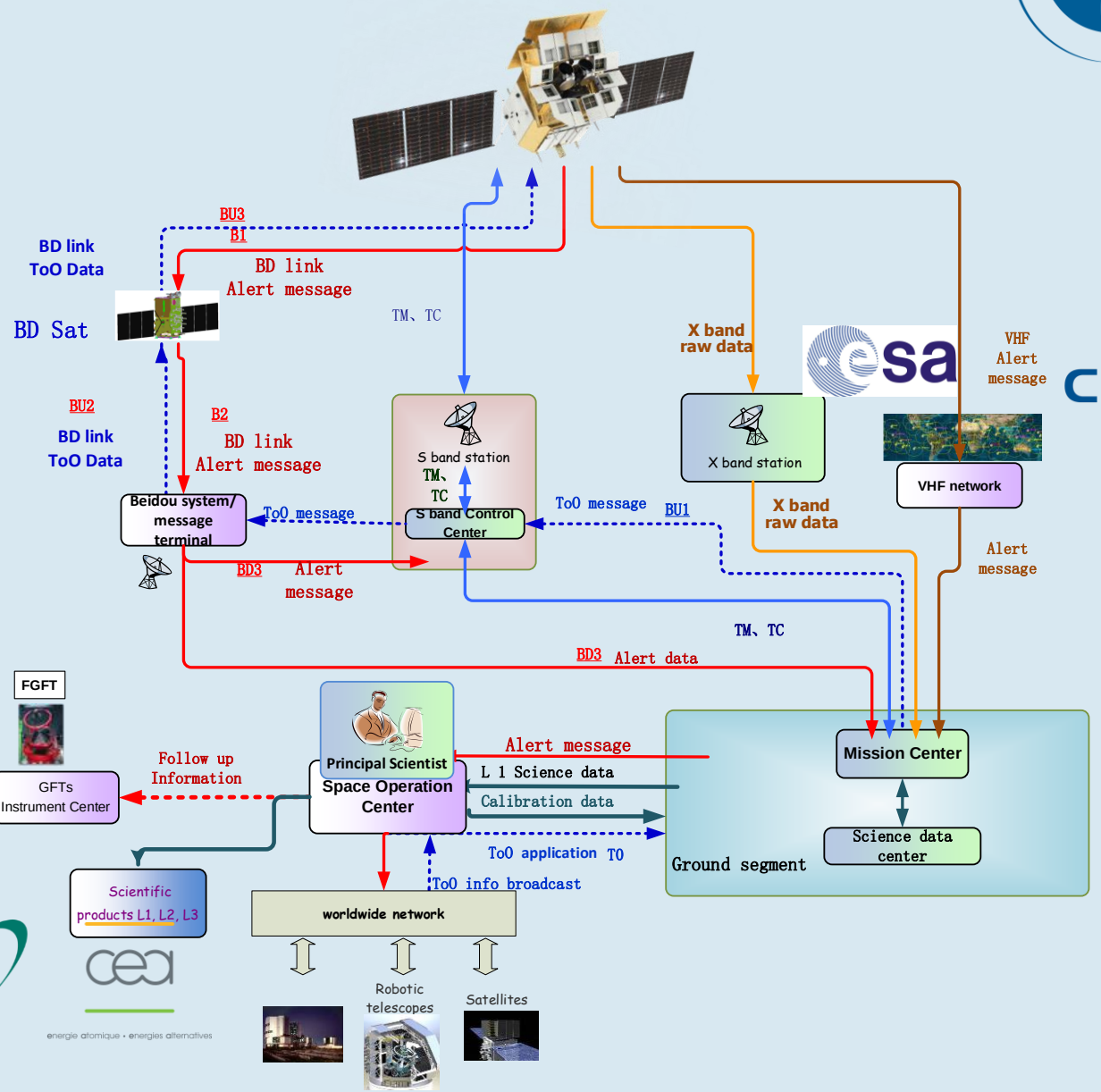
1. **Discover** and characterize cosmic X-ray transients and monitor the activity of known objects , to reveal their properties and gain insight into their nature and underlying physics.
2. **Discover** and characterize X-ray outbursts from normally quiescent black holes, for better understanding of the demography of black holes and their origin and evolution, as well as accretion physics.
3. **Search** for X-ray sources associated with gravitational-wave events and precisely locate them.



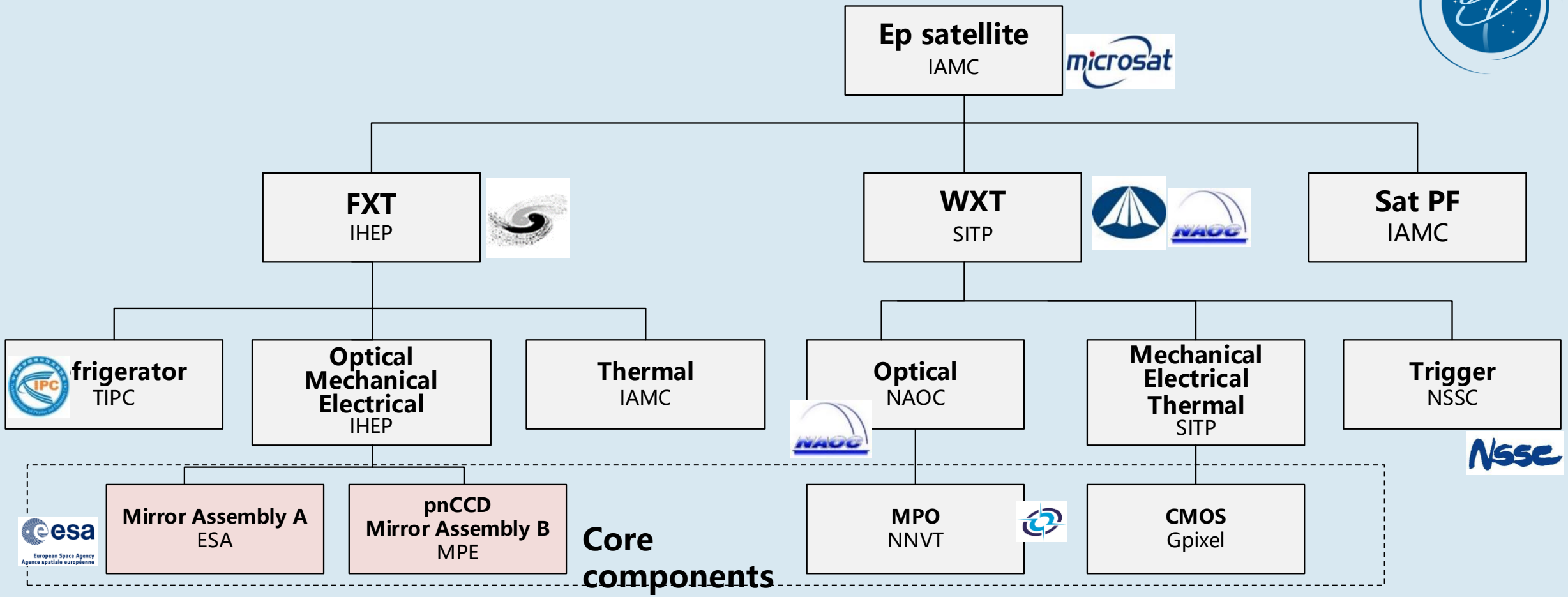


The Constitution of Engineering System





THE CONSTITUTION OF EP SATELLITE SYSTEM



- The composition includes 12 WXT modules , 2 FXT units, and 95 equipments and 48 software items
- WXT is developed by SITP, NAOC provides optical module, and Gpixel provids CMOS
- FXT is developed by IHEP, ESA provided Mirror A, MPE provided PnCCD and Mirror B (eRosita fs)

Milestone of mission

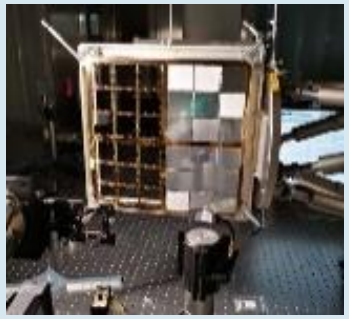
2013：mission proposed by National Astronomical Observation

2013-2015：Phase A study, including key technology tackling and system technology assessment

2017.12 ： Mission adoption, Project Officially Approved

2017.12

Mission kick off



2019.12

- Phase B closed
- Phase C kick-off

2021.12

- Phase c closed
- Phase d kick-off

2023.06

- FM sat test

2023.11

- FAR

2024.1.9

Launch

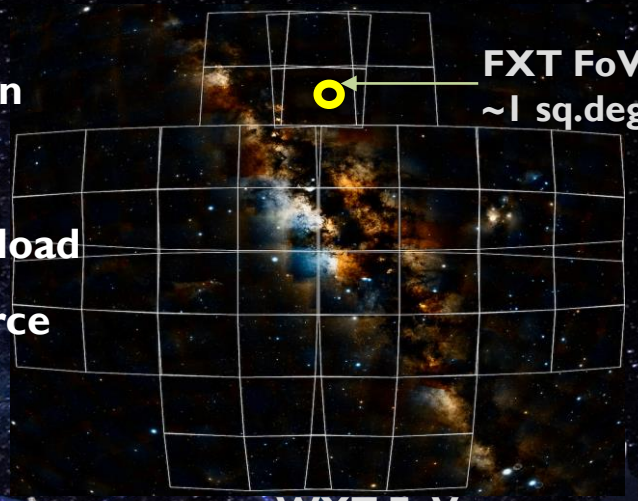
4 features of EP

① Large FoV soft X-ray observation

② High maneuvering capability

③ Fast Alert distribution & ToO upload

④ Precise positioning of X-ray source



WXT（12 modules）
FOV≥3850 sq deg (1.1 sr)
0.5~4keV

FXT （2 units）
FOV~1 deg
0.3~10keV

Circular Orbit:
(eccentricity~0)
Altitude:600km
Inclination： 29 degree

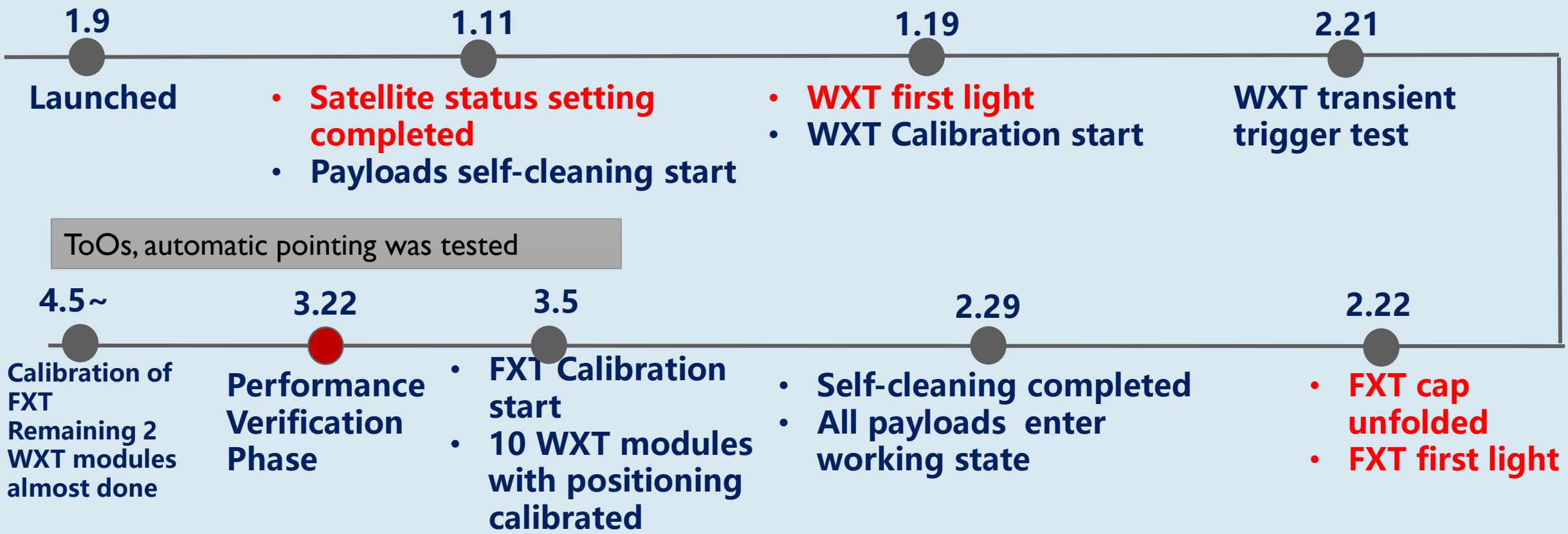
Maneuver ability： 60° /4min
AKE for FXT： ≤10” @1σ
Attitude Stability： 1”/s

Φ2992mm×3418mm ~1450kg

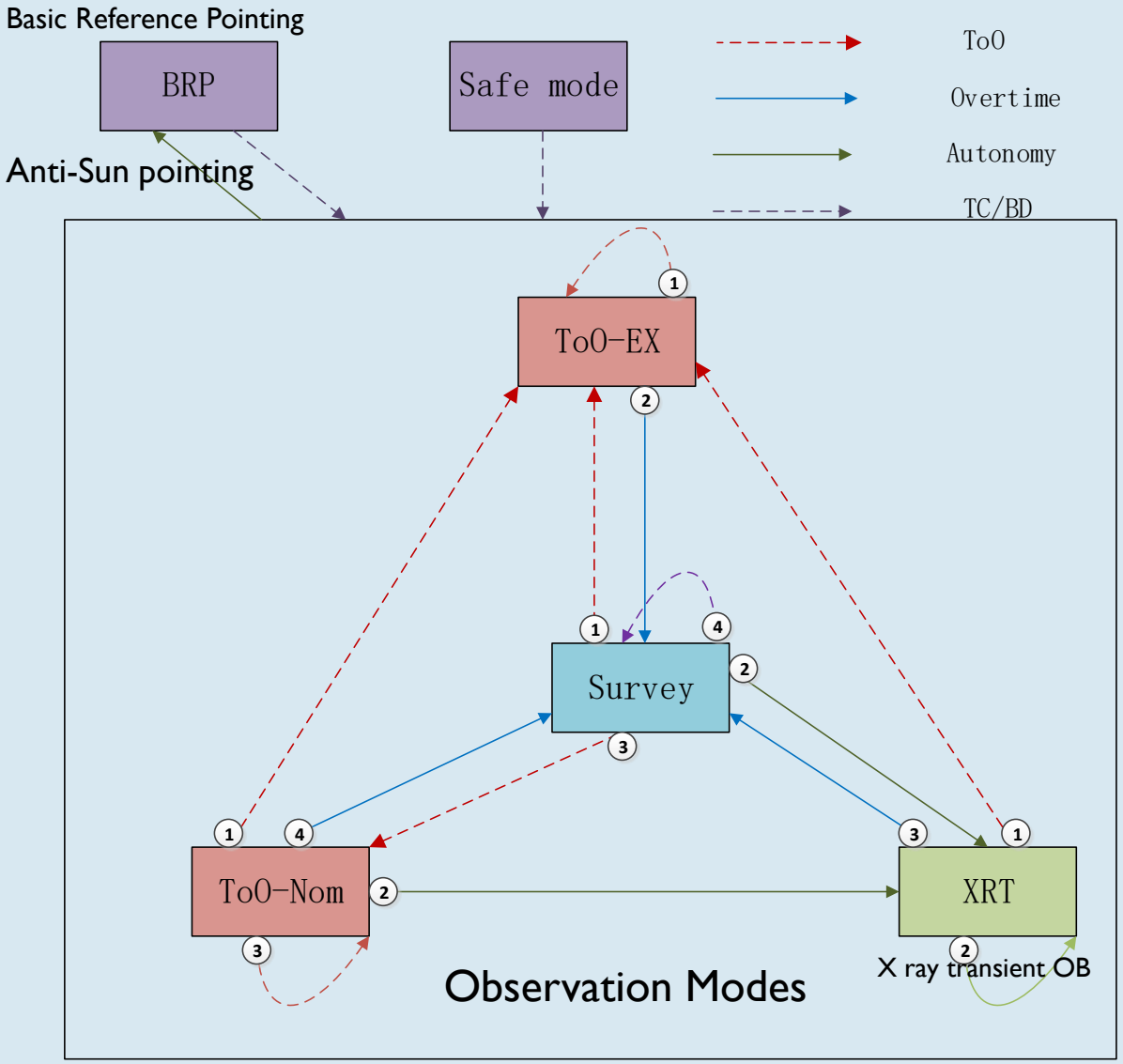
Satellite test in-orbit process

☐ Most of in-orbit verification has been completed, and FXT calibration is on-going

- Verified performance of satellite, Completed payload
- Verified board to ground interface and workflow



Satellite operation mode in orbit verification

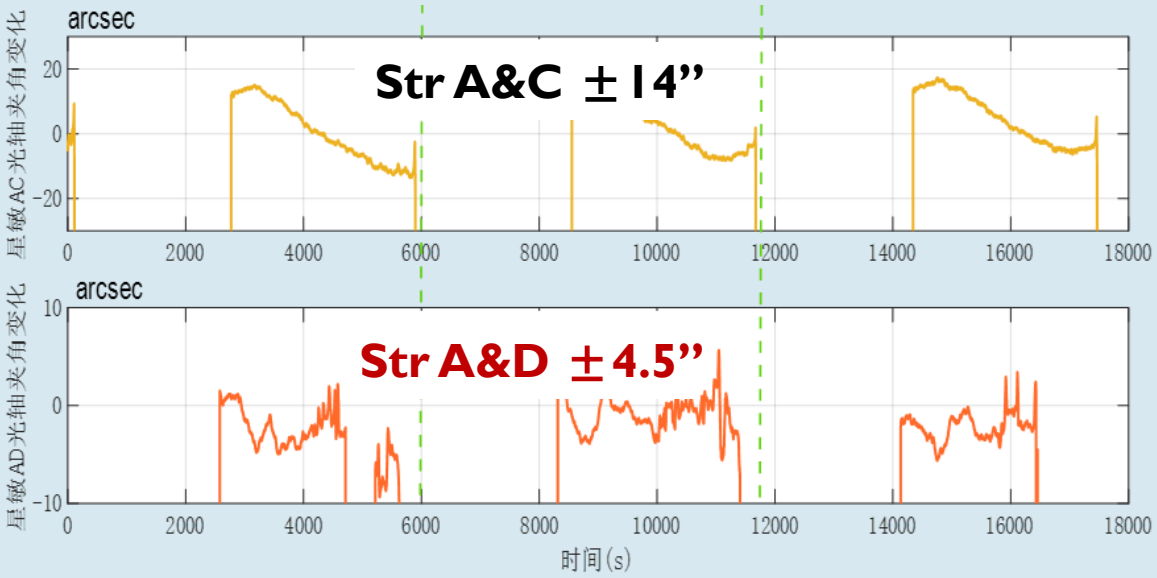


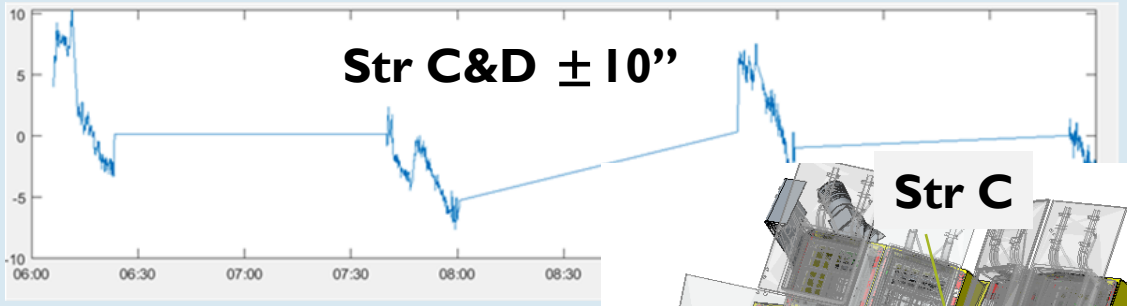
EP observations on board management

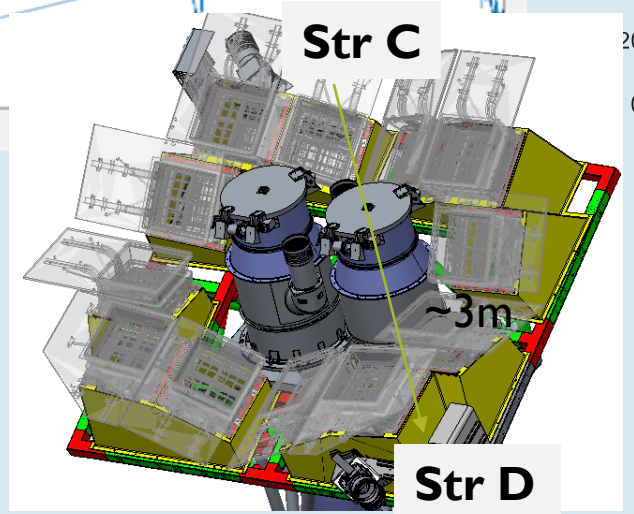
- ✓ Full Sky Survey: about 3 pointings per orbit and each about 20 min.
- ✓ ToO-Nom
- ✓ ToO-EX（Exceptional Target of opportunity）
- ✓ ToO-MM（Multi-Message）
- ✓ Payload configuration
- ✓ General slew point management form
- ✓ Earth eclipse management form

Note：①②③④mean mode switching priority

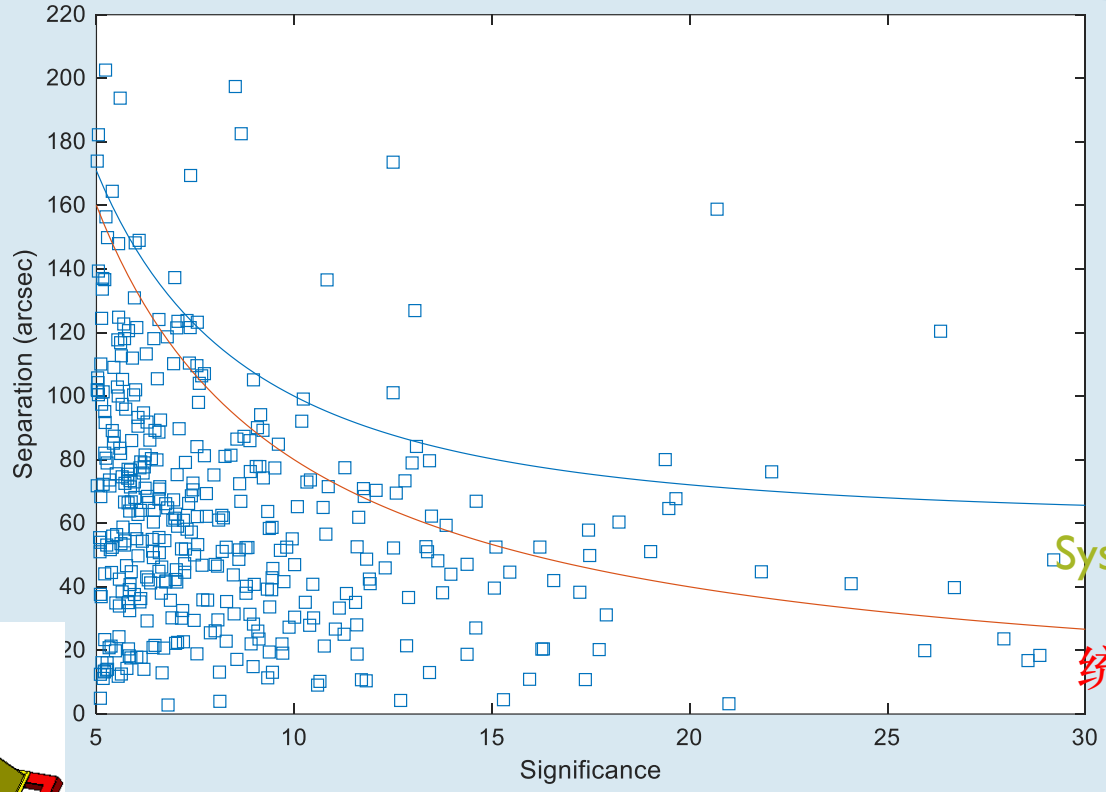
Thermo-elastic & WXT positioning accuracy







WXT X ray source positioning accuracy (J2000)

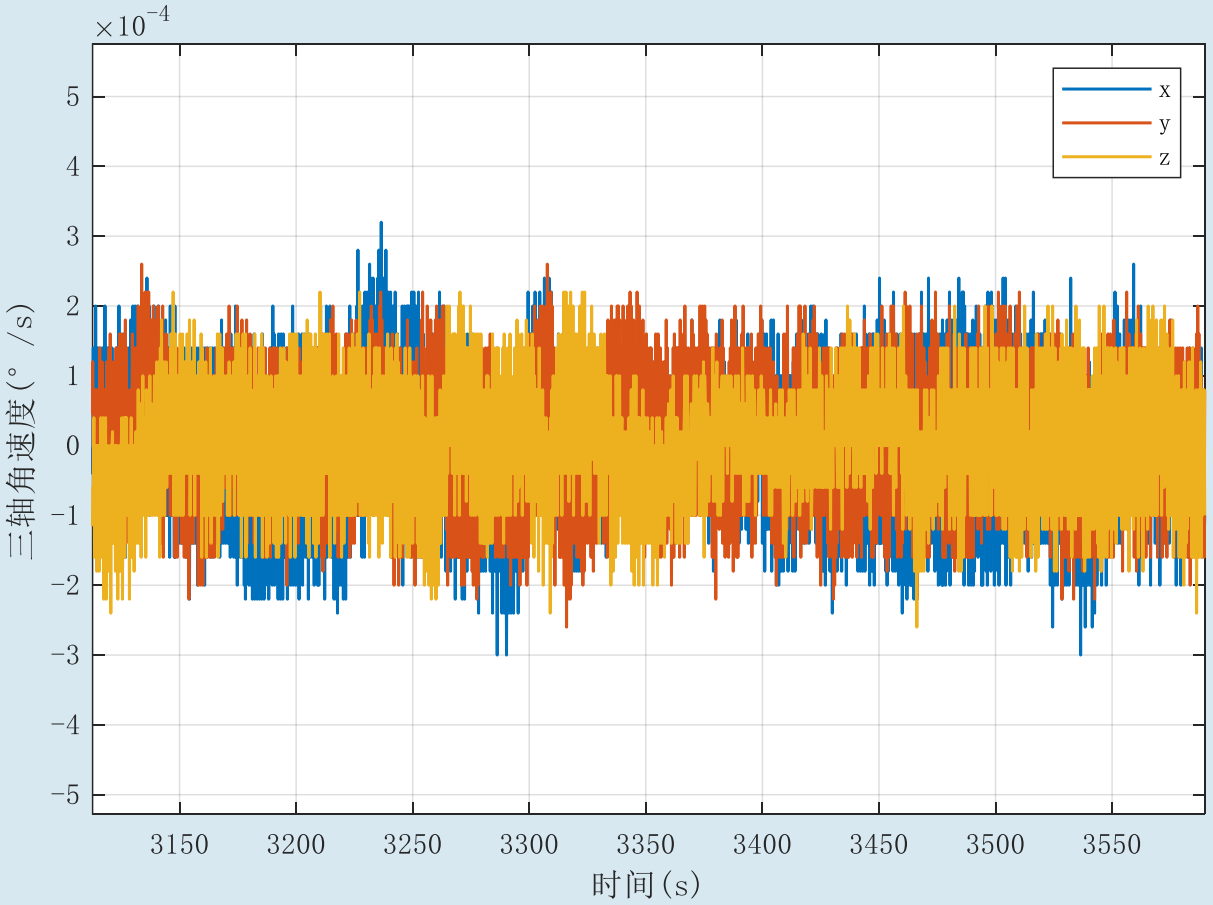


60 “
System leve

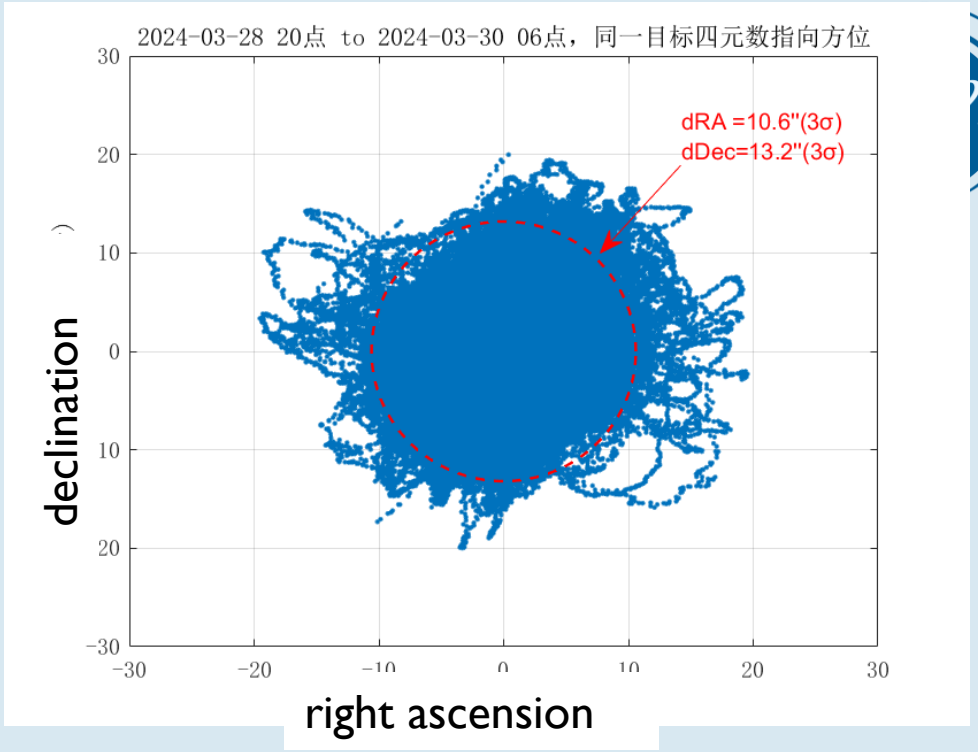
统计误差

Performance of AOCS

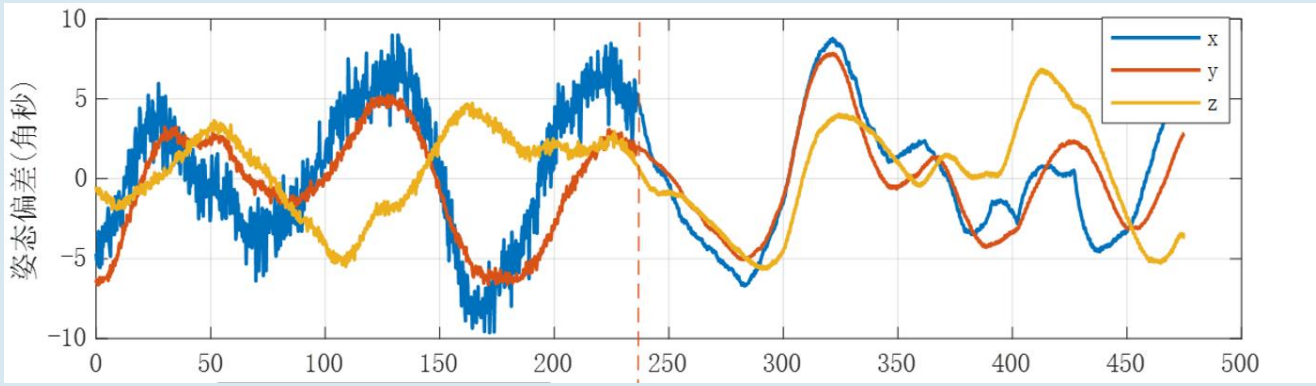
- **Pointing Stability ~1 “/s(~0.0003 °/s)**
- **APE**(absolute pointing error)**≤ 10”**



Pointing Stability ~1 “/s(~0.0003 °/s)



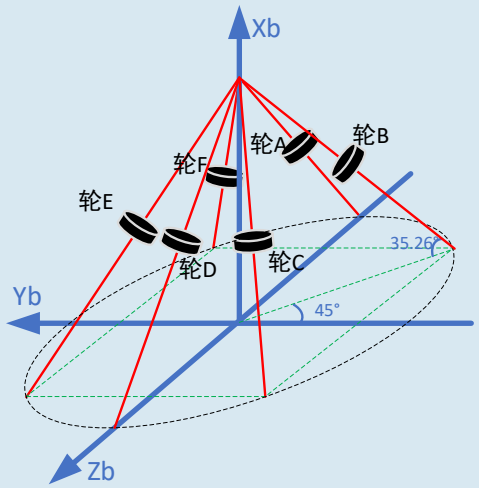
Pointing Stability within [10.6 13.2] “/34hours

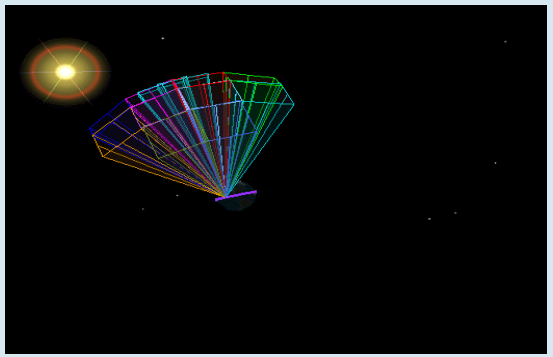


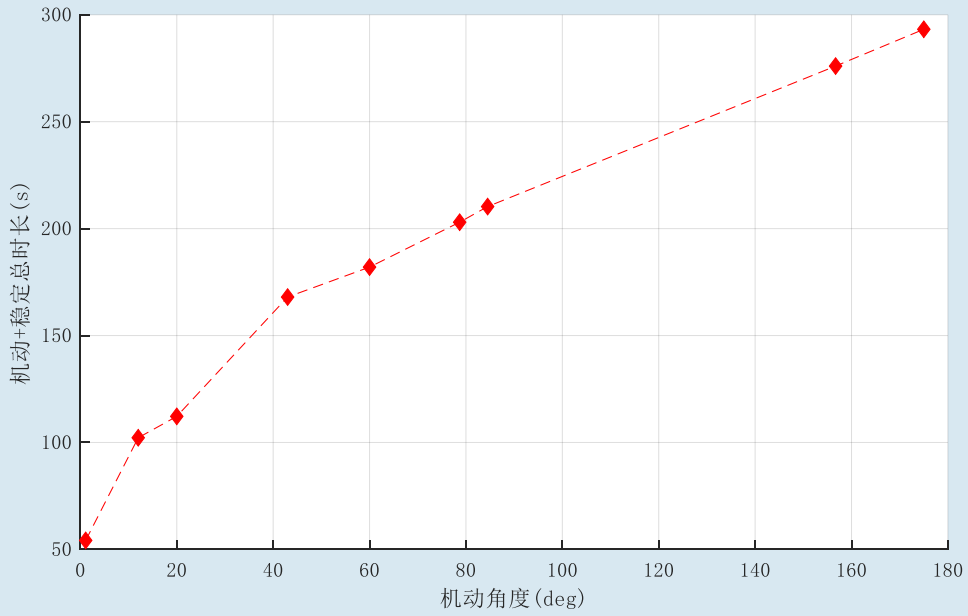
APE ≤10”

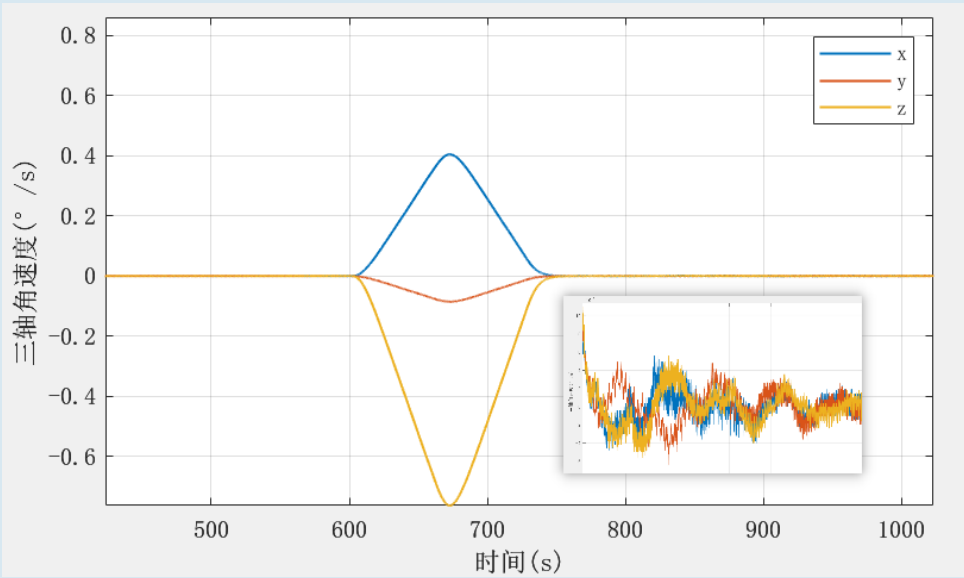
Satellite maneuverability performance in orbit

Maneuver angle/degree	43.0	60.0	78.7	84.5	156.7	175.0
Stable time/second	168.0	182.0	203.0	210.3	276.0	293.2







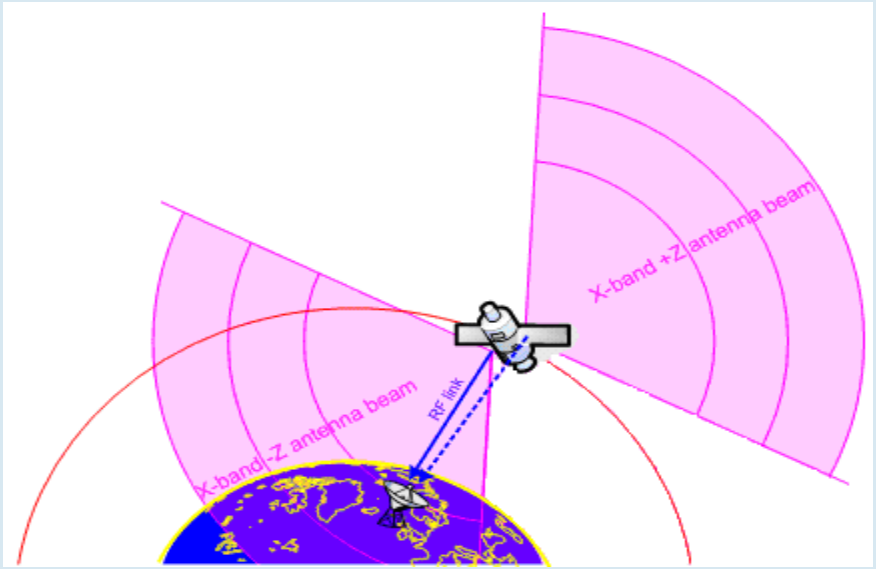


angular velocity during maneuvering

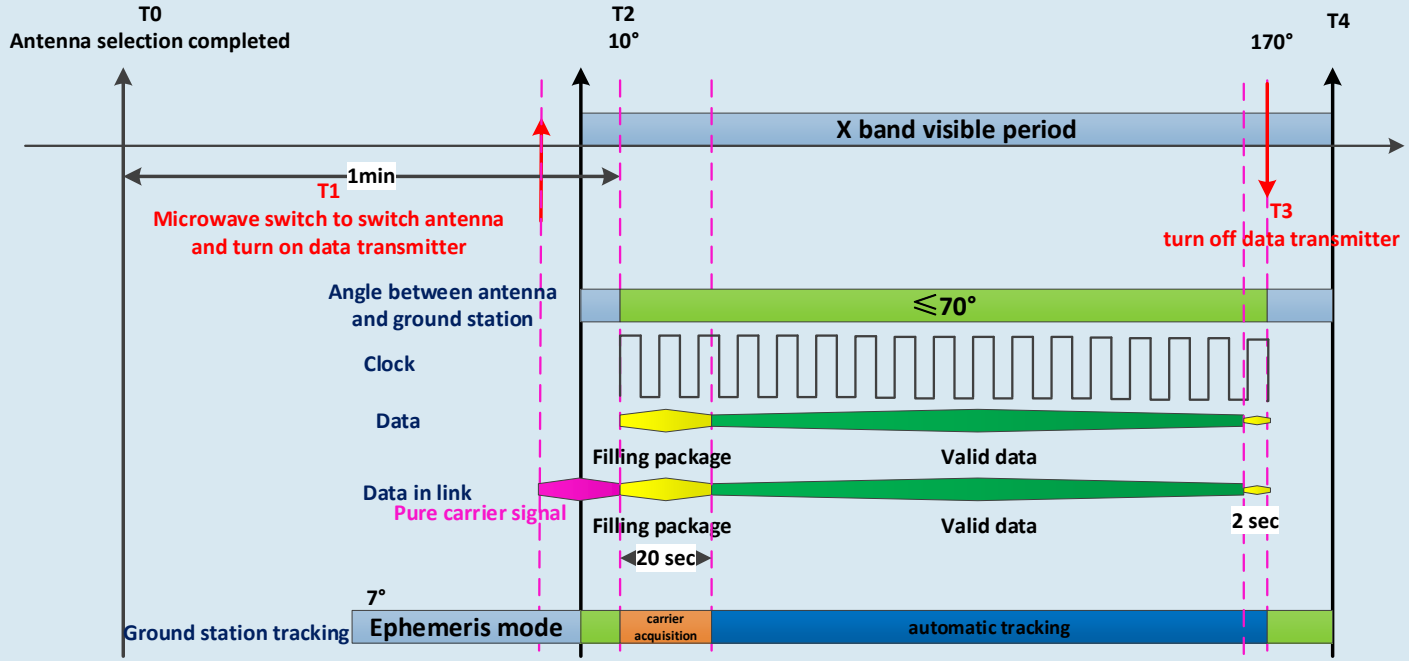
Satellite maneuverability of 60 °/182s, better than requirement

Status of X band data transmission

- X band Board to ground link meets the requirements of the link budget ,Ground station demodulation threshold E_b/N_0~18dB with error rate ~10^{-10}
- The antenna selection management function is correct
- On March 21, 2024, the ESA station joined the normal operation phase



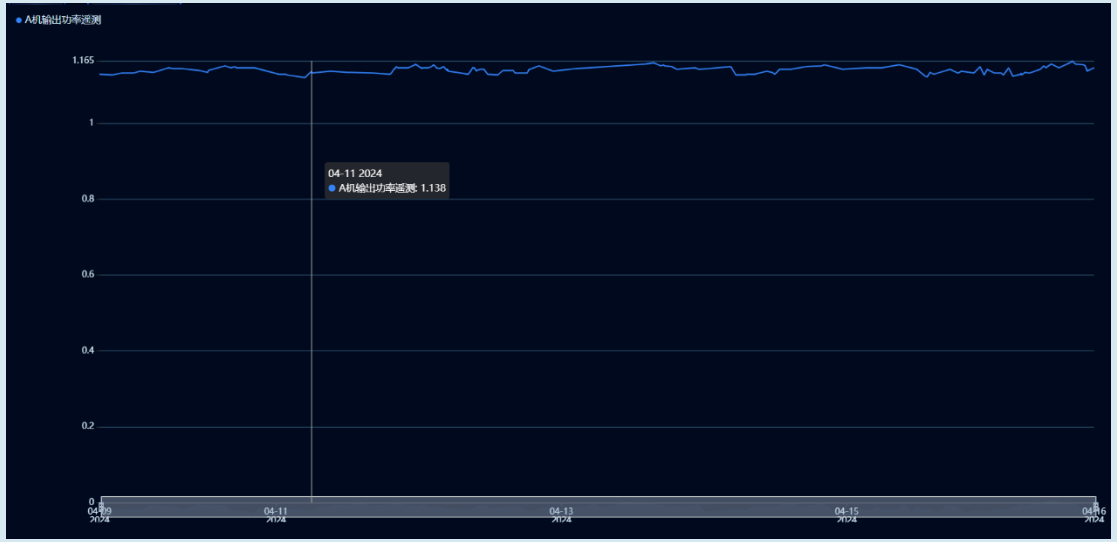
Sketch of data transmission entry



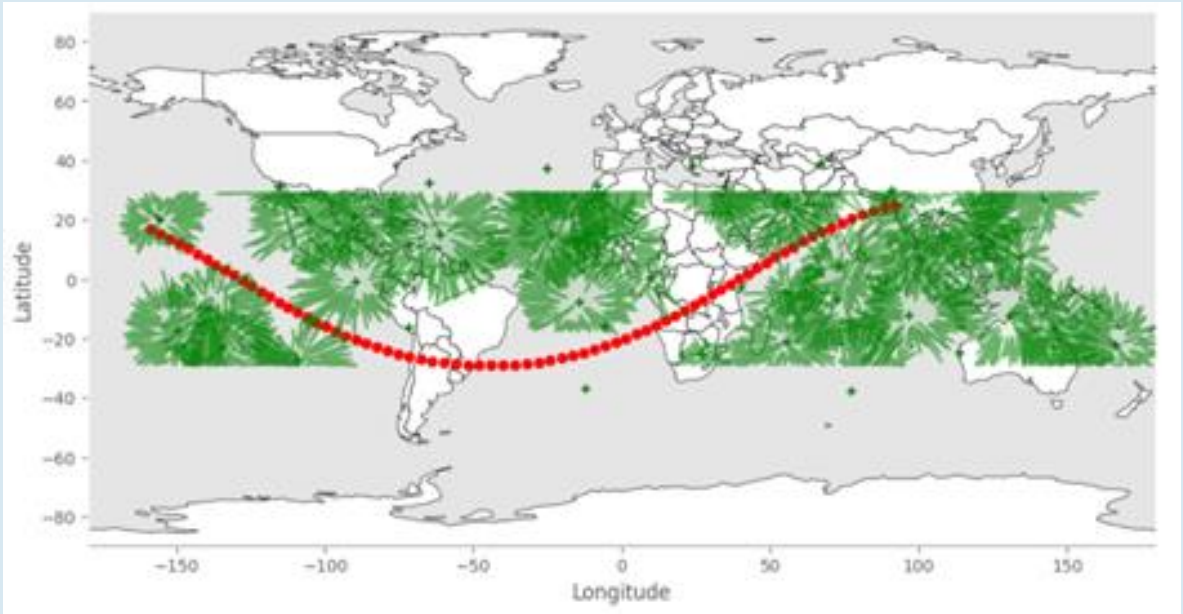
antenna selection process

Status of VHF

- The VHF transmitter , demonstrating normal and stable functionality
- In February， WXT photon list was lost once，and it was repeated 3 times with 5 minute intervals as default. EP changed the interval to 10 mins，photon list never lost again



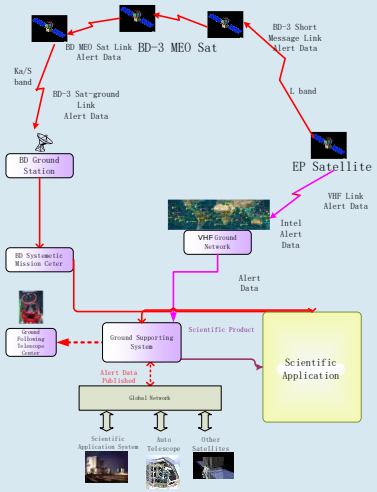
Stable output power of transmitter



Receiving reliability due to gap

Status of Beidou RDSS

- Global Alert and ToO message quick transmission achieved
- End to End delay，ToO message upload，average delay ~60s，best within 43s；Alert message down link，average delay ~15s，best within 10s
- Over ~200 downlink messages/day，~10 uplink messages/day，fully capable for emergency telecommand & telemetry redundance



Ground network

Beidou RDSS message frame format					
XX	XX	XX	Pack num	Pack ID	DATA
1bit	3bit	6bit	7bit	7bit	≤536bit

Telecommand frame format				
SYNC COD	HEAD	XXX	DATA	CRC

L band constellation network Ka\S band

EP satellite → MEO (out bond) → MEO (domestic) → Beidou master station → ground/science system

Alert

L band constellation network L band

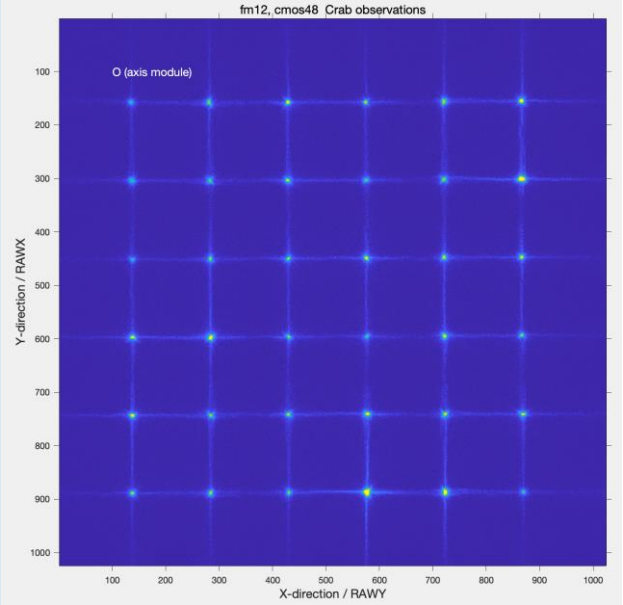
Beidou master station → MEO (domestic) → MEO (outbond) → EP

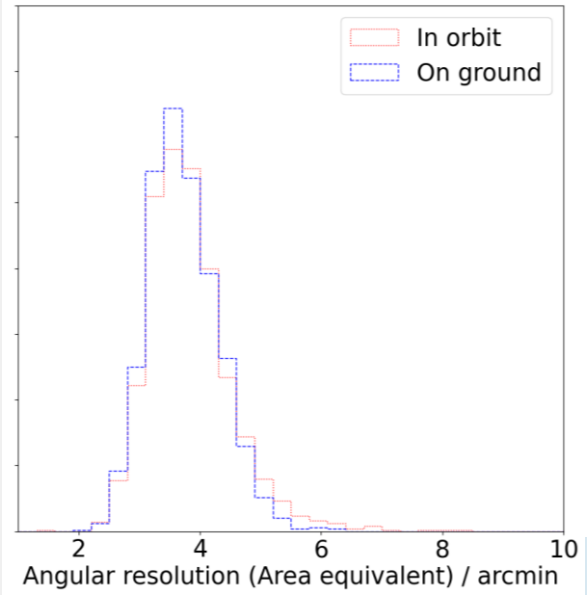
ToO

WXT performance in orbit

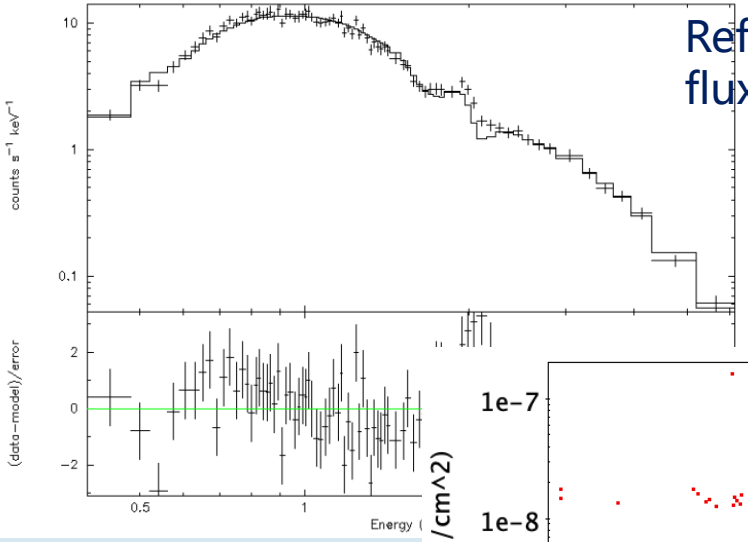
◻ WXT core performances in orbit are basically consistent with ground tests

Angular resolution ≤ 5′ @1keV

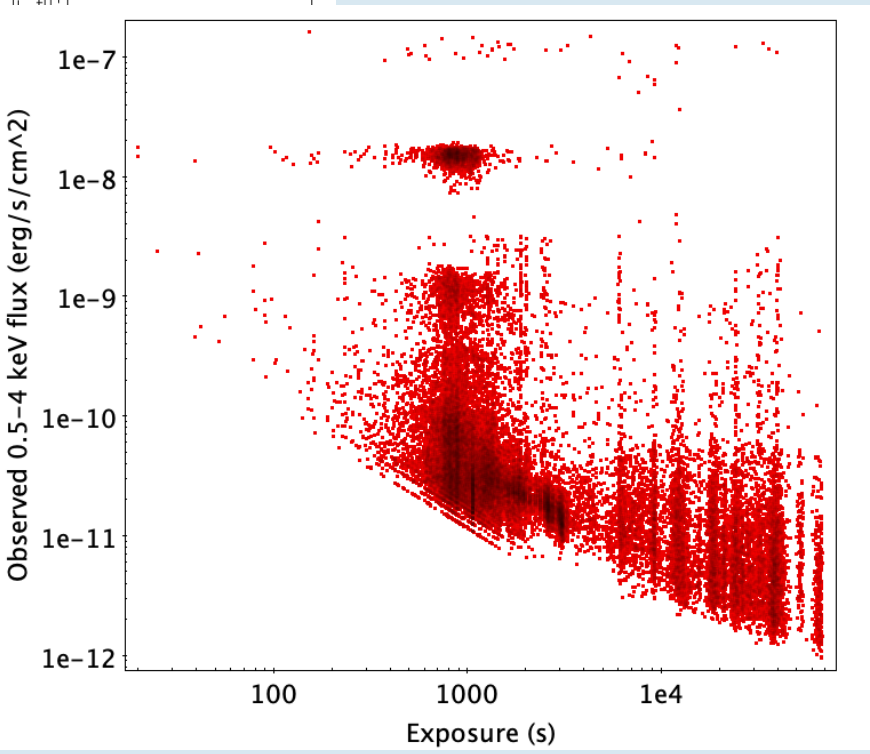




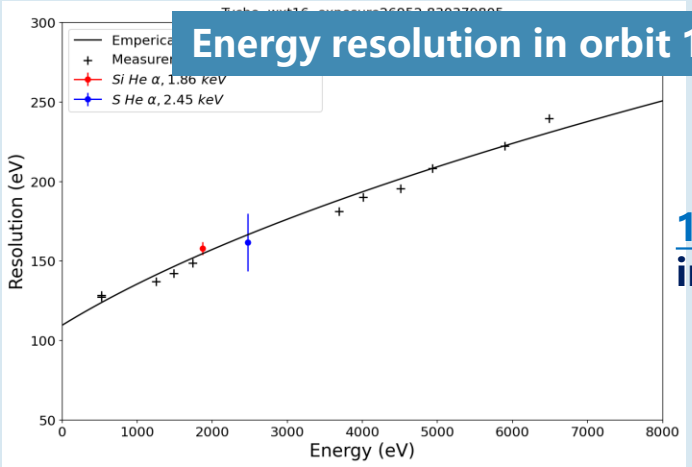
The effective area in orbit ~3 cm²@1keV



Refer **Crab** counts and flux calculate EA in orbit



Energy resolution in orbit 121.9eV@1.25keV

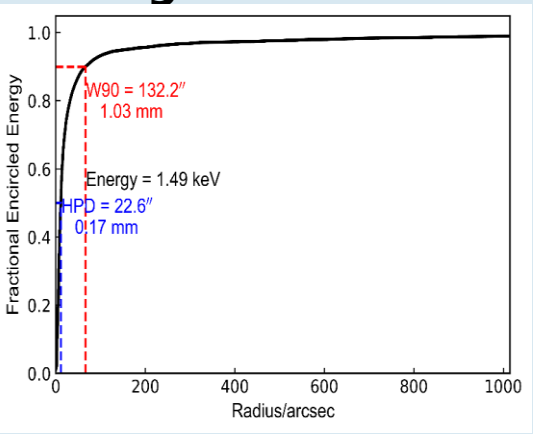


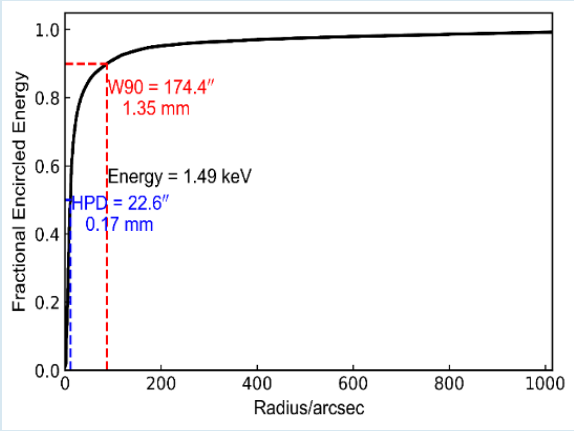
121.9eV@1.25KeV in orbit

FXT performance in orbit

☐ FXT core performances in orbit are basically consistent with ground tests

On ground test





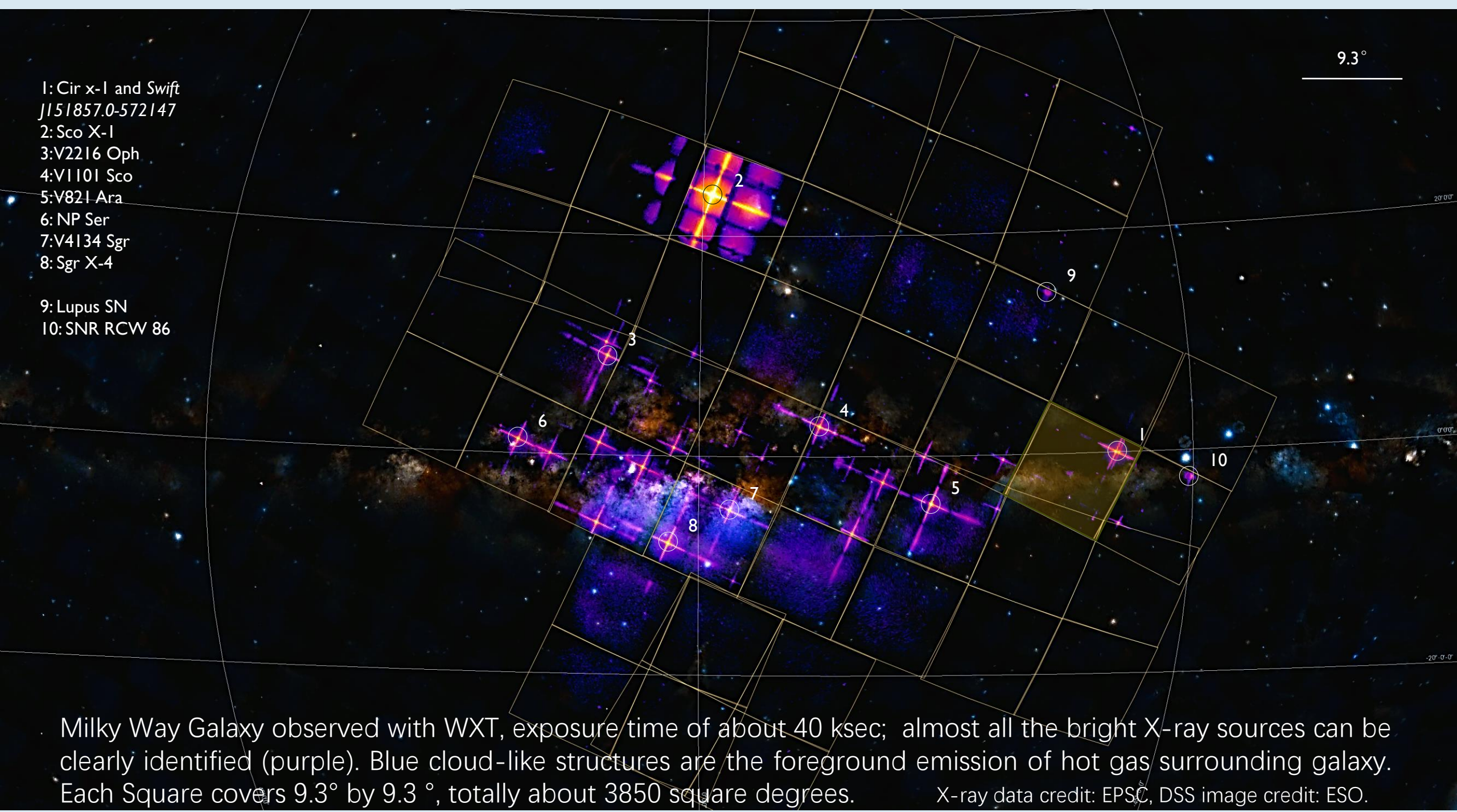
Angular resolution
A：22.6”，on axis;B：22.6”，on axis

EA (cm^2)		
Energy (keV)	**FXTA no filter**	**FXTB thin filter**
C-K: 0.28	137.57	63.24
O-K: 0.53	269.29	181.12
Cu-L: 0.93	332.96	295.15
Mg-K: 1.25	**330.87**	**337.52**
Al-K: 1.49	332.75	354.81
Ag-L: 2.98	88.39	88.65
Ti-K: 4.51	77.4	80.22
Fe-K: 6.4	36.21	41.3
Cu-K: 8.04	20.27	22.5

In orbit

Angular resolution
A：23.7”，on axis
B：20.1”，on axis

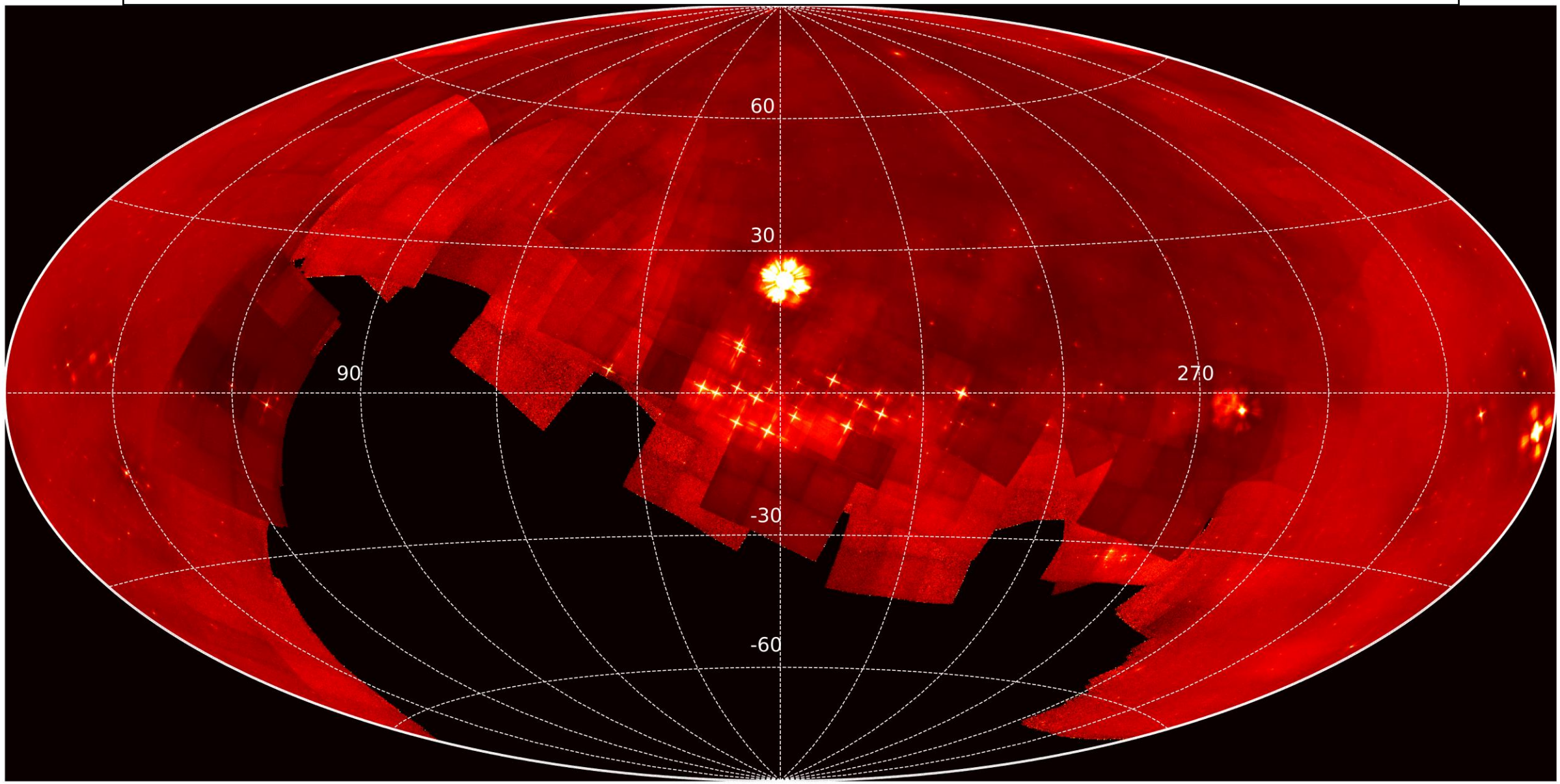
Effective area
A：~286cm^2@1.25 keV，on axis，medium filter
B：~320cm^2@1.25 keV，on axis，medium filter



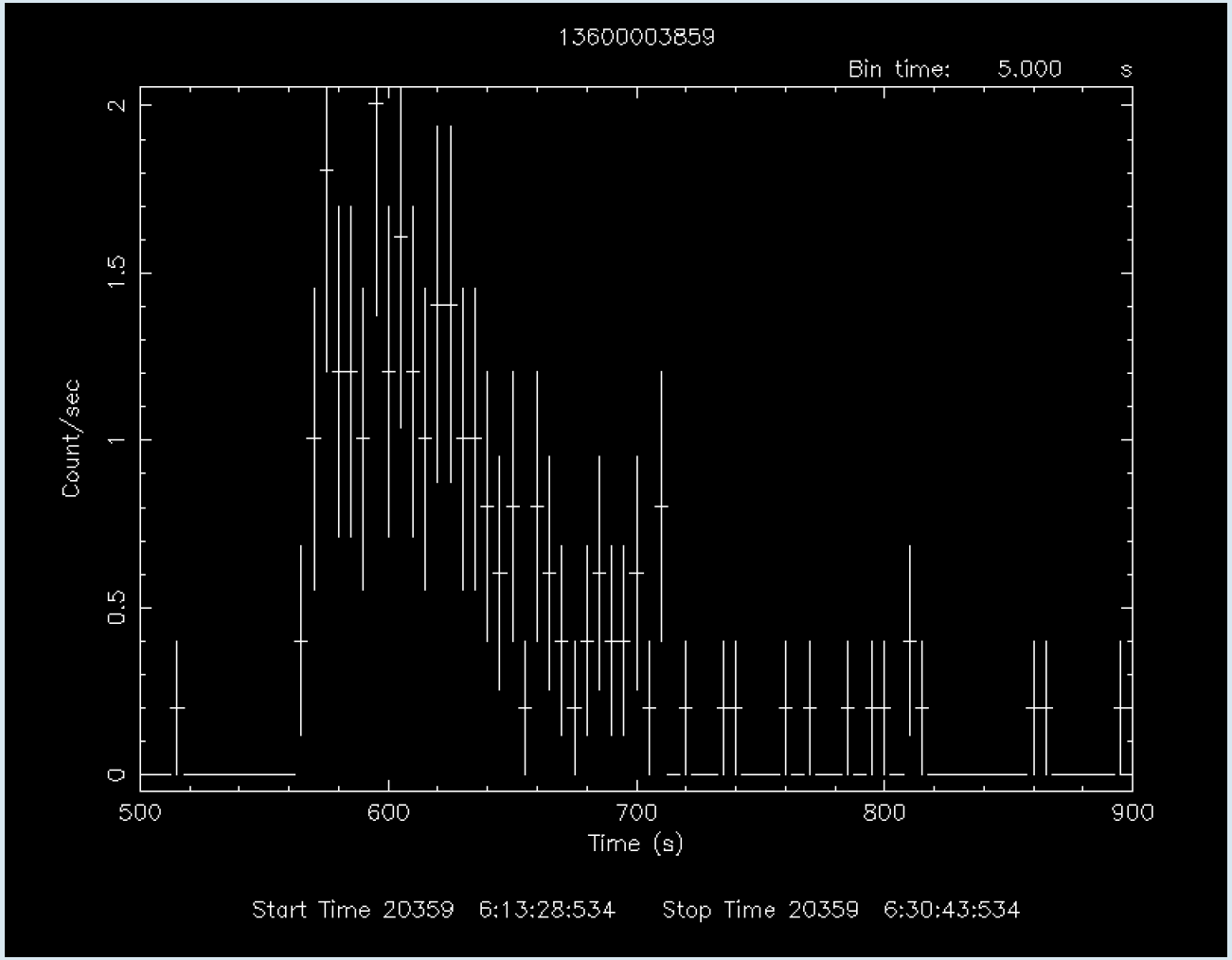
Milky Way Galaxy observed with WXT, exposure time of about 40 ksec; almost all the bright X-ray sources can be clearly identified (purple). Blue cloud-like structures are the foreground emission of hot gas surrounding galaxy. Each Square covers 9.3° by 9.3 °, totally about 3850 square degrees.

X-ray data credit: EPSC, DSS image credit: ESO.

Soft X-ray sky in the eye of lobster (EP-WXT)

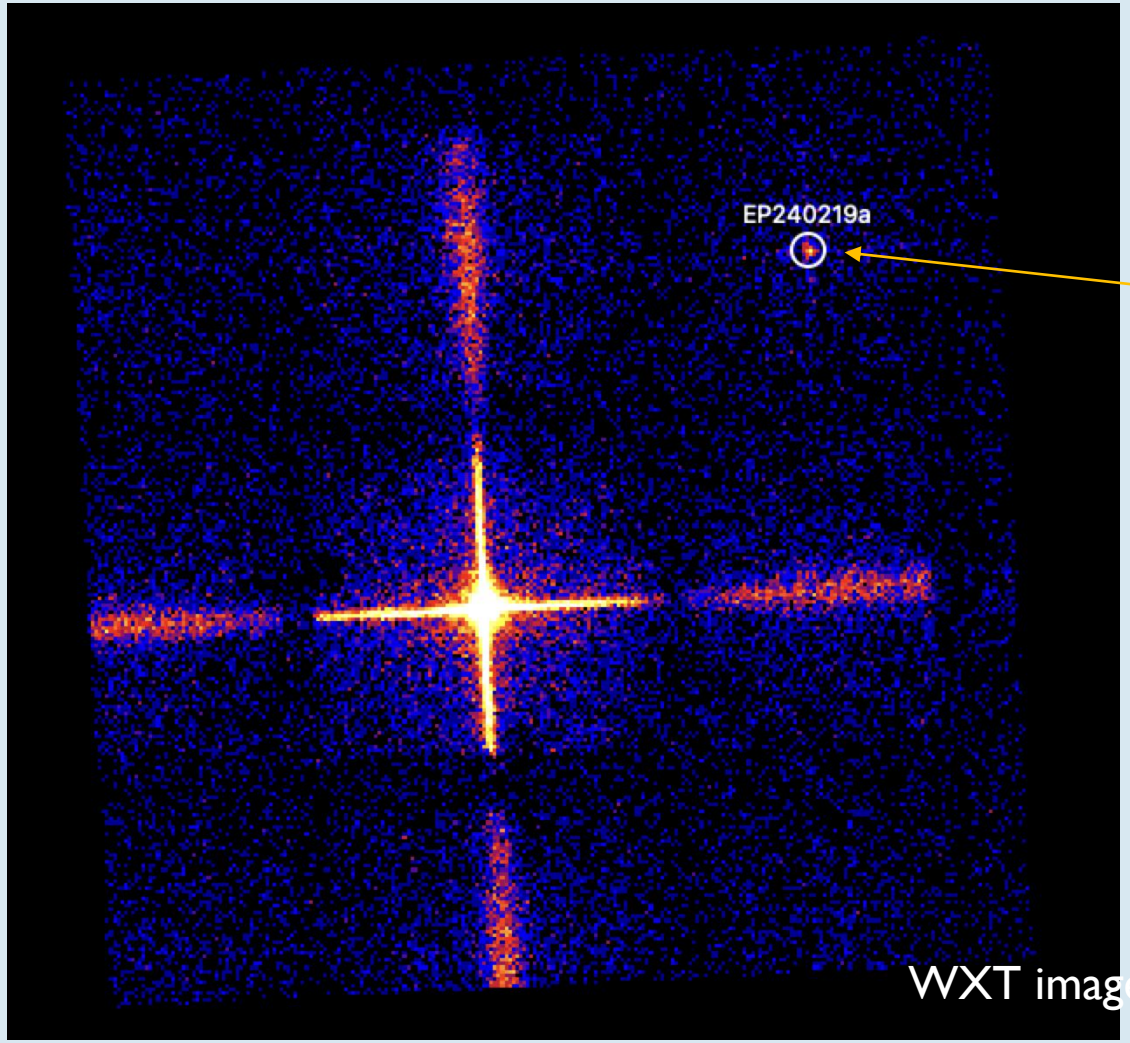


Very first X-ray transient EP240219a

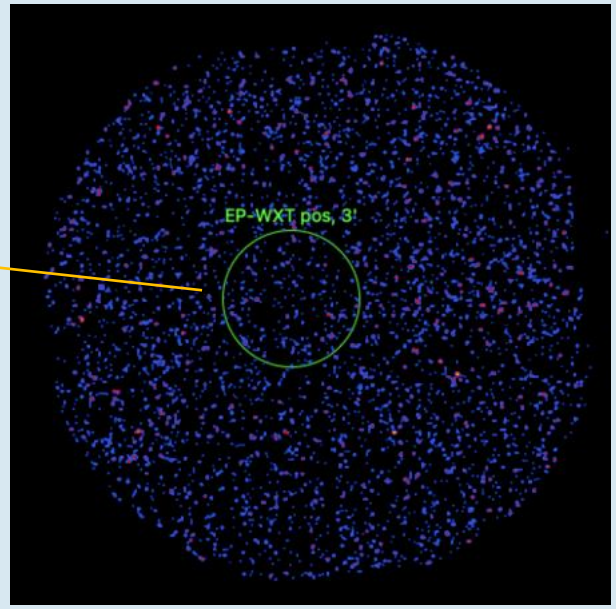


- Duration < 200s
- Peak flux : 5e-9 erg/cm2/s (1/5 Crab nebula)
- Gamma-ray burst counterpart detected by Feimi/GBM: (Zhang ATel #16473)
- Undetected by Swift/XRT 39 hours later
- Atel sent from EPSC: 1st EP alert!
- No optical counterpart found (starting T0+3days)
  - Timely response important!

Very first X-ray transient EP240219a



WXT image

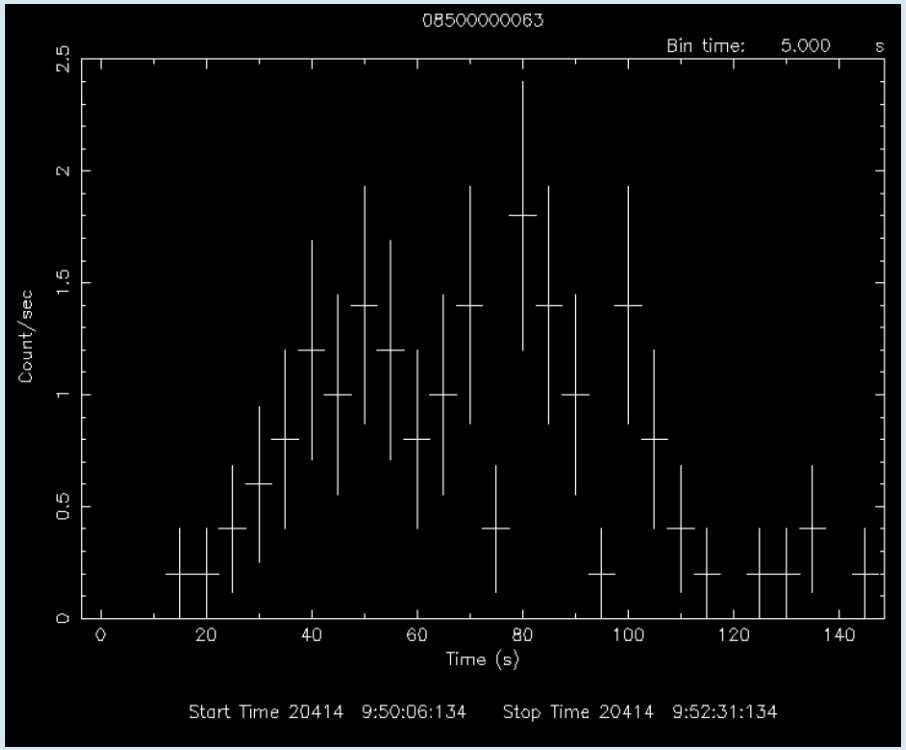


Undetected by NASA's Swift/XRT

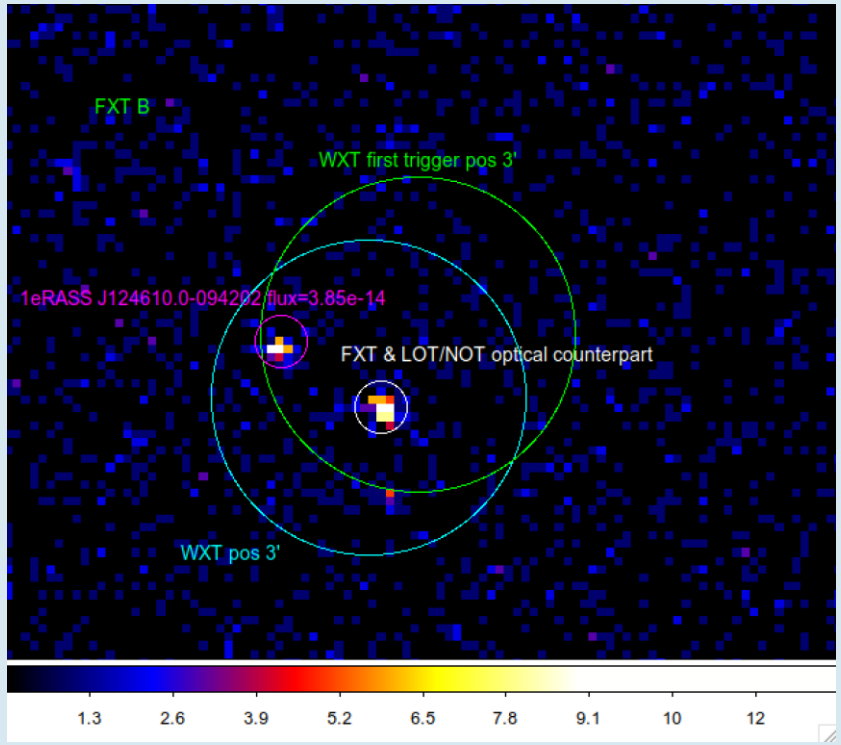
39 hours later

Fast X-ray transients: EP240414a

WXT on-board triggering

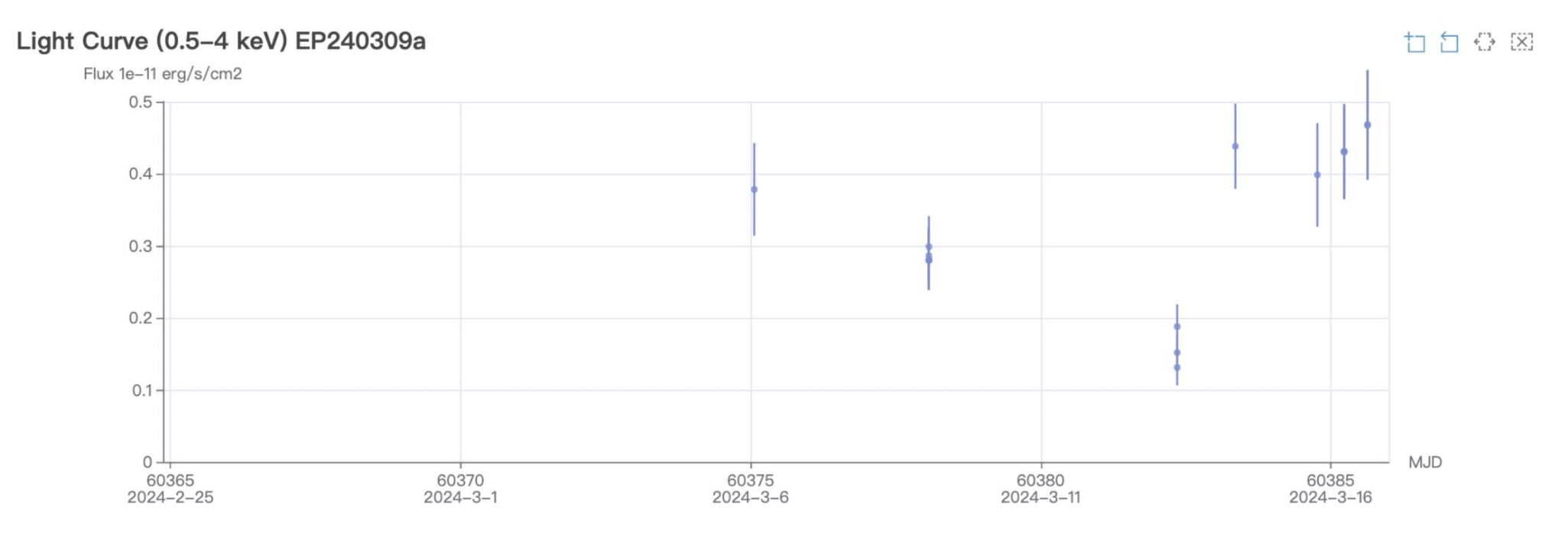


FXT observation (expo: 7.2 ks) ~2 hr later



- AT2024gsa, first detected by LOT ~3.13 hours later, r-band = 21.52 mag (AB).
- host galaxy, SDSS J124601.99-094309.3, redshift z = 0.41
- source offset of ~25 kpc in projection (Jonker et al. GCN 36110).

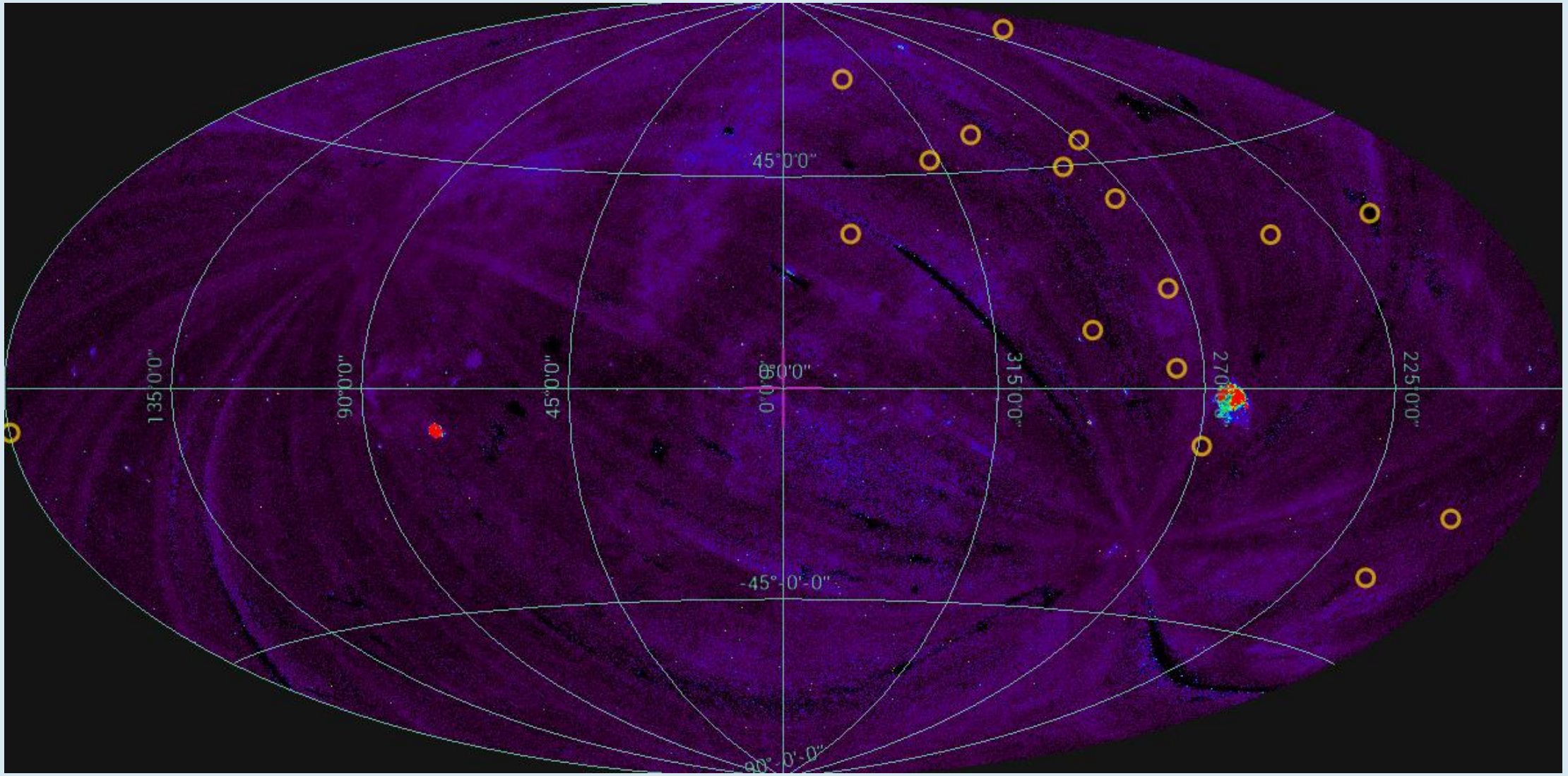
EP240309a: long-timescale X-ray transient



- FXT follow-up
- A bright UV source with a highly variable optical counterpart
- SALT spectrum, (ATel #16554), MeerKAT observation (ATel #16572)

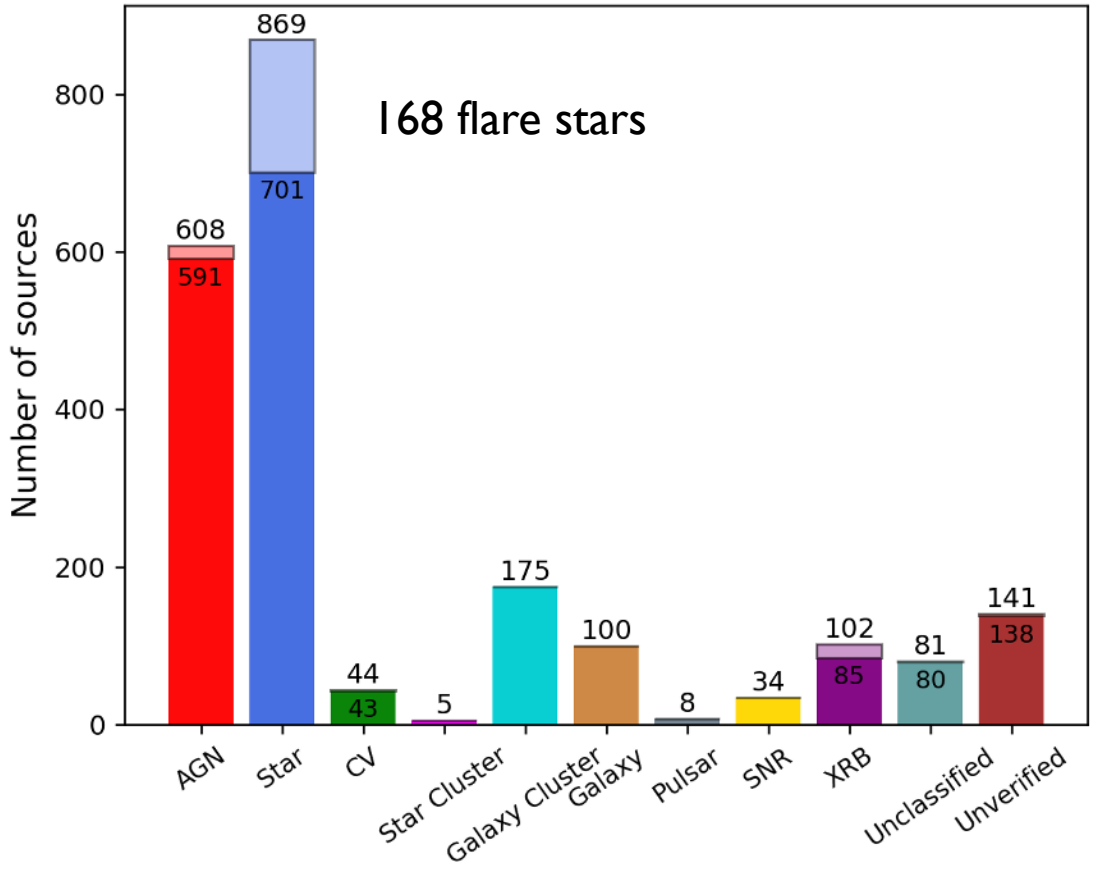
a magnetic cataclysmic variable containing a white dwarf (Potter et al.)

POSITIONS OF EP TRANSIENTS ON THE SKY

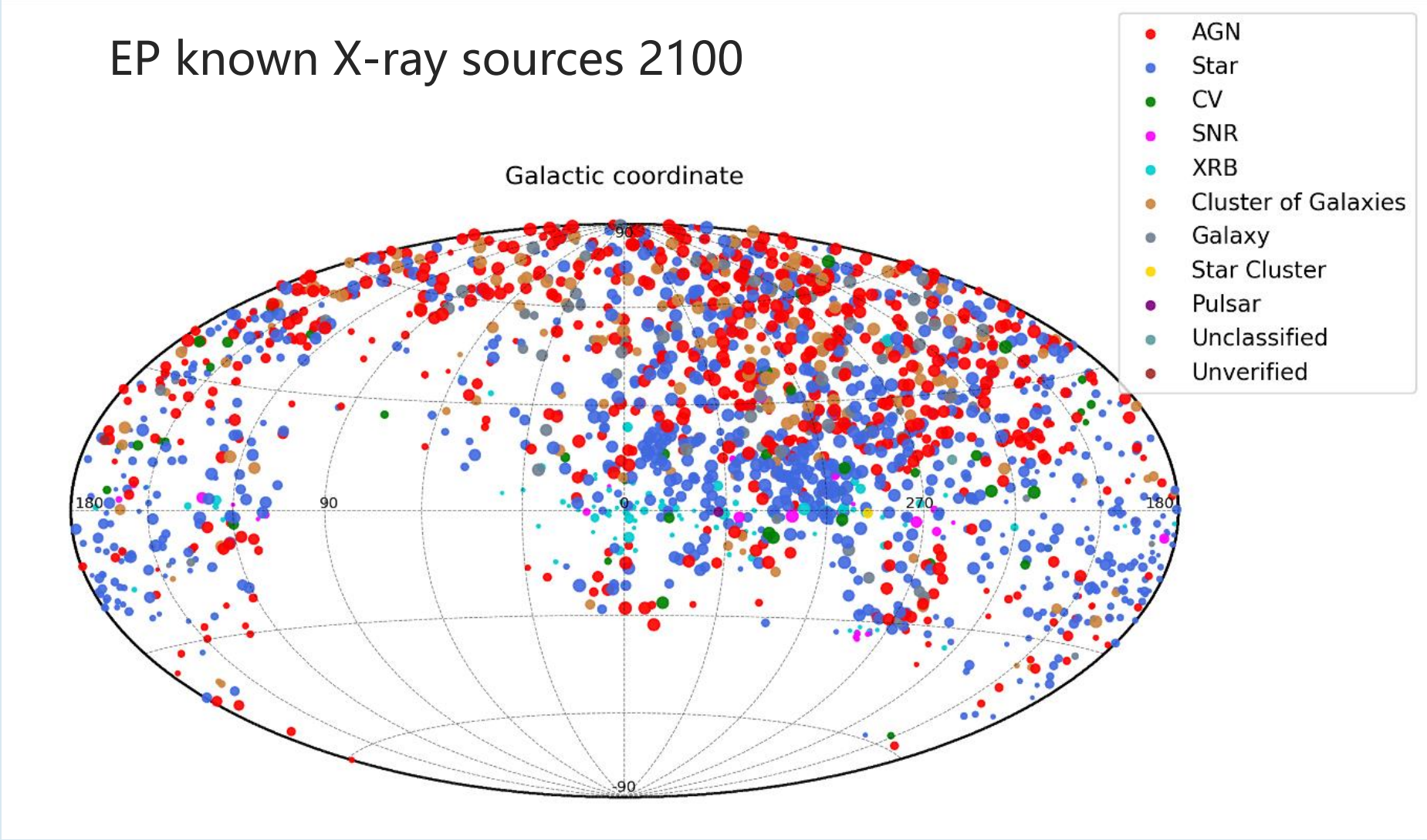


KNOWN X-RAY SOURCES DETECTED WITH EP-WXT

Number: 2100



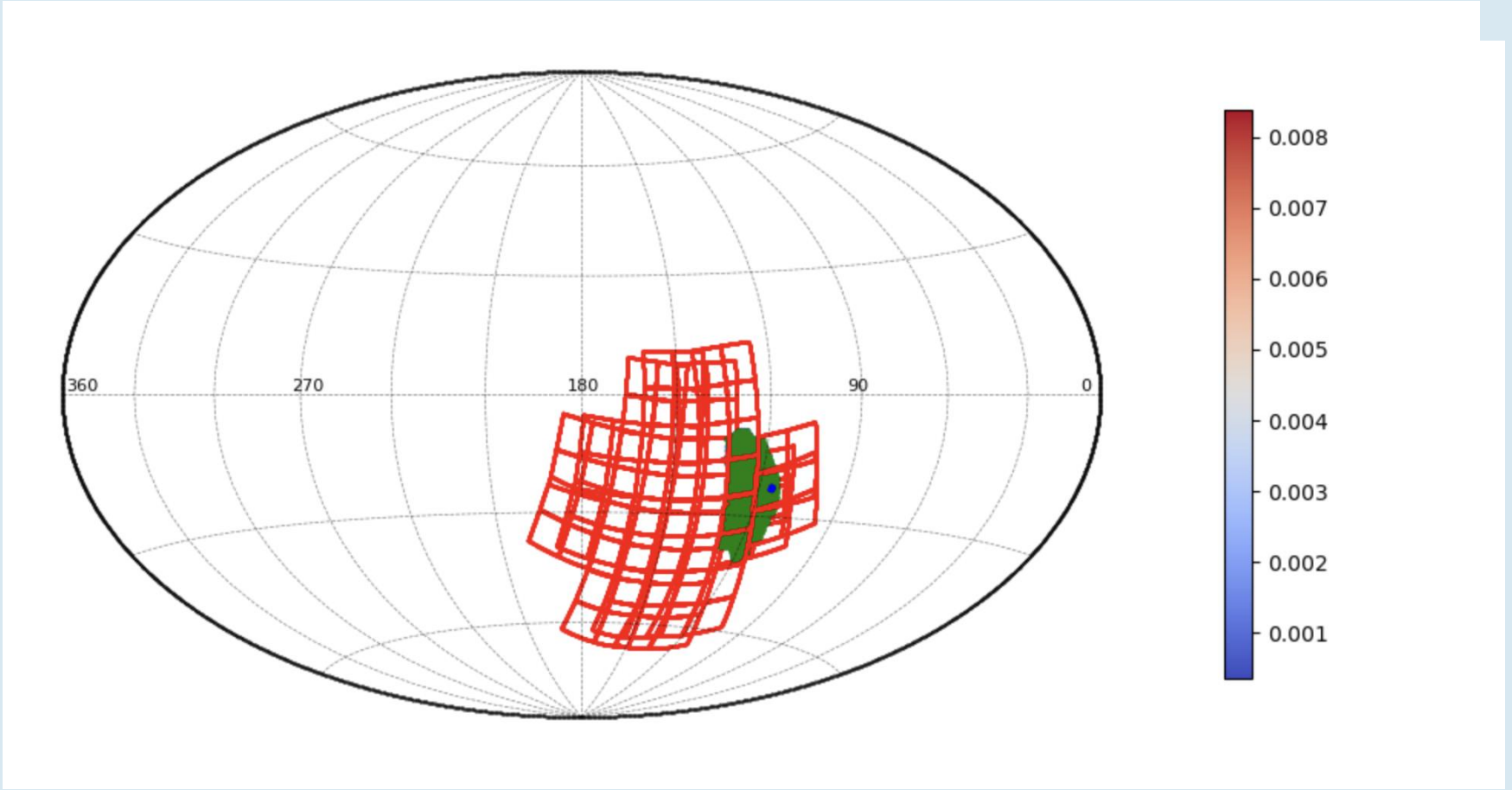
Known X-ray sources detected with EP-WXT



LIGO gravitational wave event S240422ed

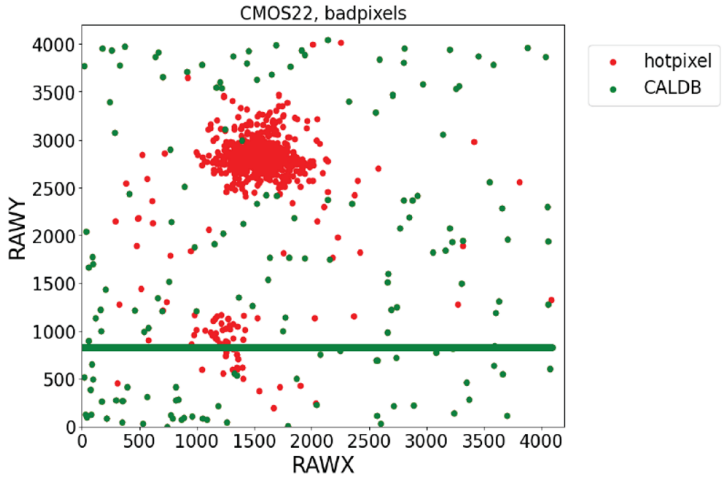
- BH+NS, distance 214 +/- 64 Mpc

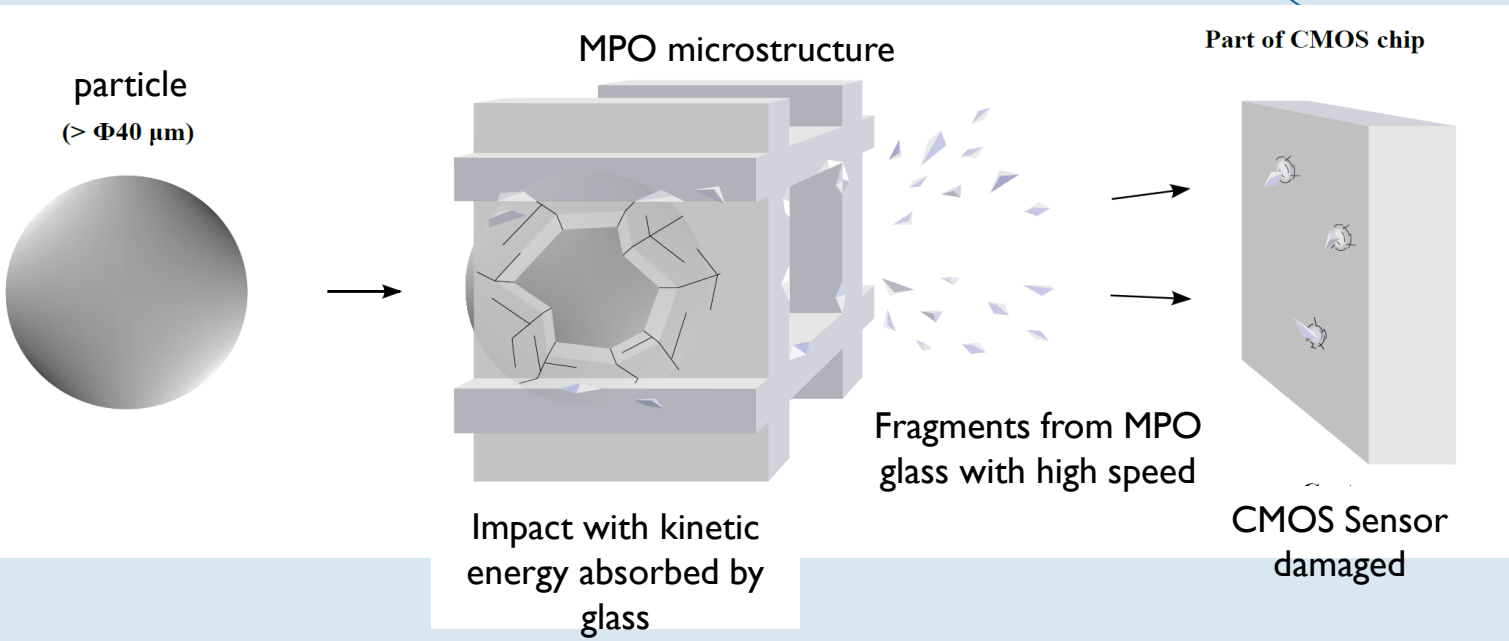
EP observation started 3 hours after the LIGO alert

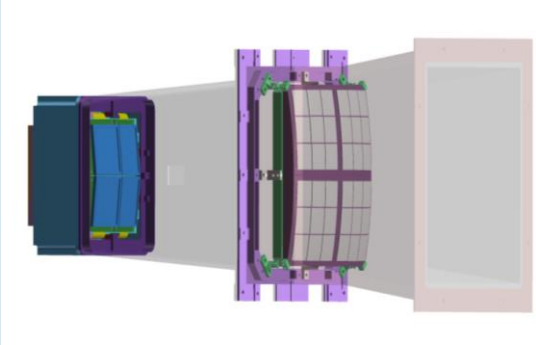


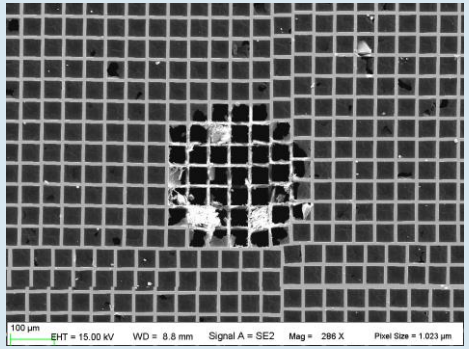
THE MAJOR THREATEN TO WXT: MICROMETEOROID

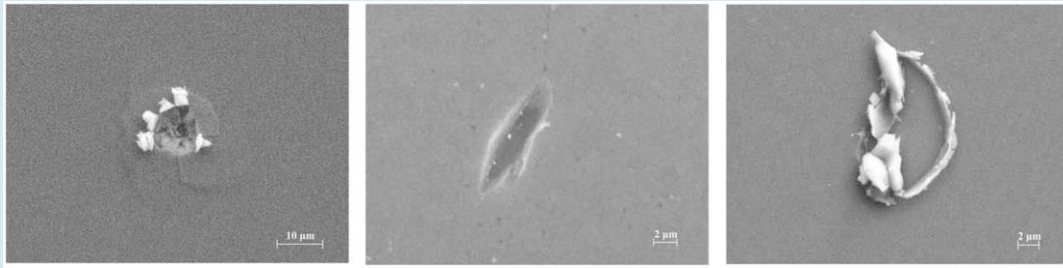
7.1.22 CMOS 22











- Several impacts been identified with observable damage on CMOS sensors
- Almost once per month per CMOS sensor

SUMMARY

- Exciting: EP has detected dozens of transient sources so far.
- Diverse times: GRB (high-z, and new subtypes?), flares from stars, white dwarf, neutron star, black hole
- The delay of transient alert to the STP/community is being improved.
- EP science team has already started actively working on the data
- The future looks great!
- However, lots of work to be done for the success of commissioning …