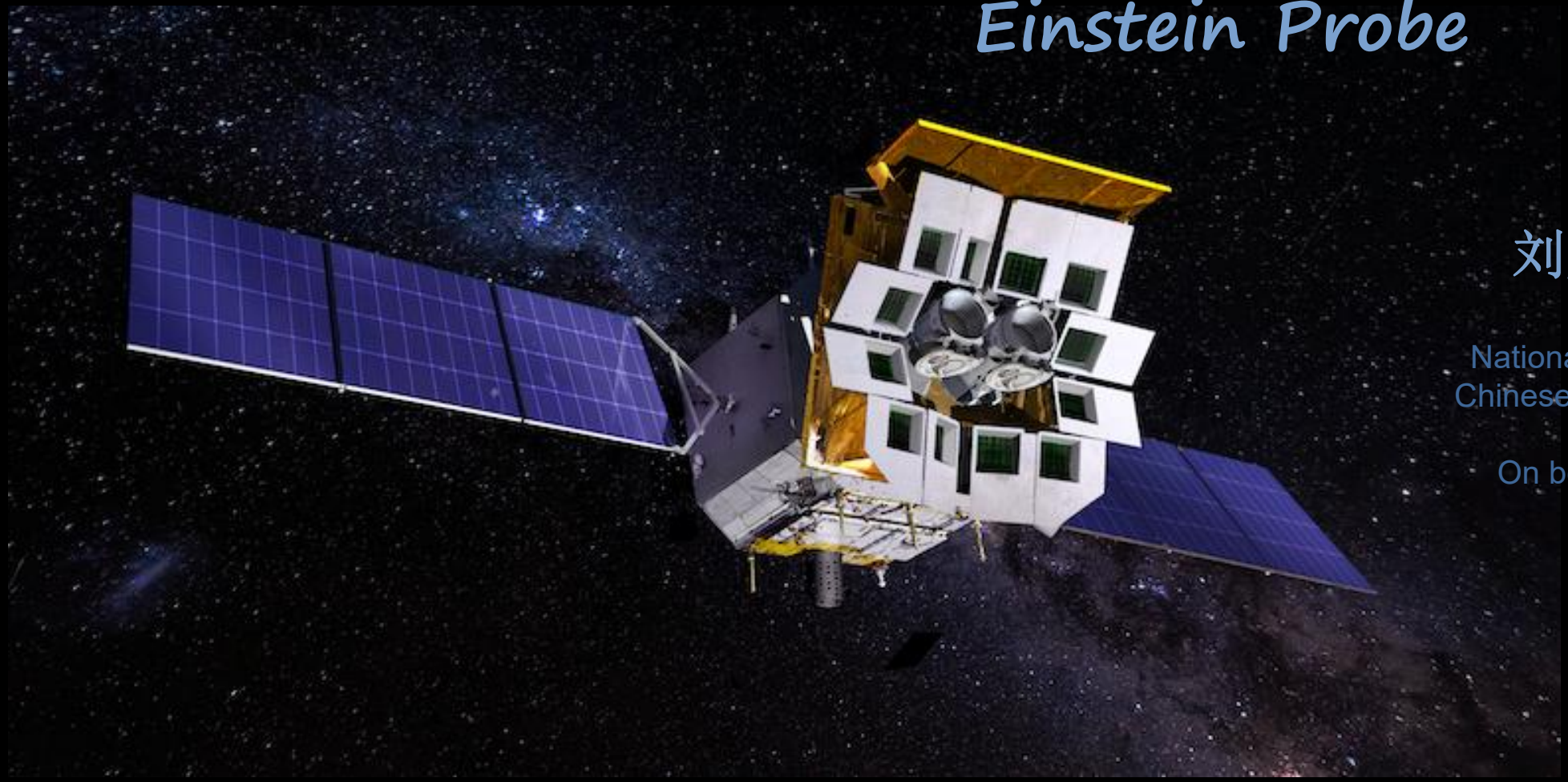
中国科学院
CHINESE ACADEMY OF SCIENCES

MPE

esa

Exploring the ever-changing X-ray Univ

Einstein Probe



刘元 **Yuan Liu**

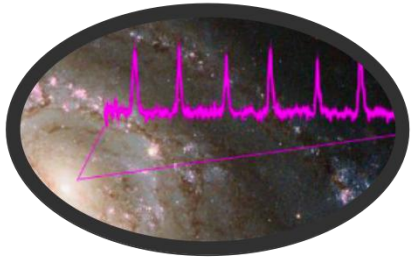
National Astro. Observatories
Chinese Academy of Sciences

On behalf of EP consortium

New high-energy transients & science questions

BH tidal disruption event

Demography of Black holes
How matter falls onto BH?
How jets form?



Quasi-periodic eruption

EMRI as GW sources?

Small numbers of known objects

Next generation X-ray monitors needed to see

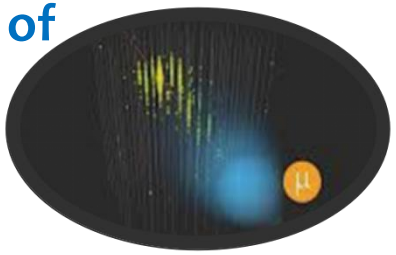
- **deeper/further**
- **High cadence**

High-redshift GRB

When first stars formed?
metal enrichment in early universe

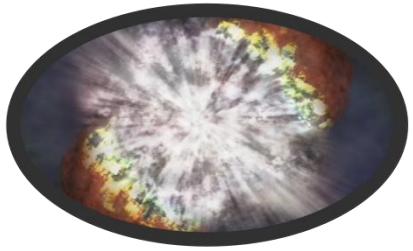
EM counterpart of neutrino events

How particles Accelerated?



Supernova shock breakout

Supernova physics & progenitors



EM counterpart of gravitational waves

What are EM counterparts?
How compact objects merge?

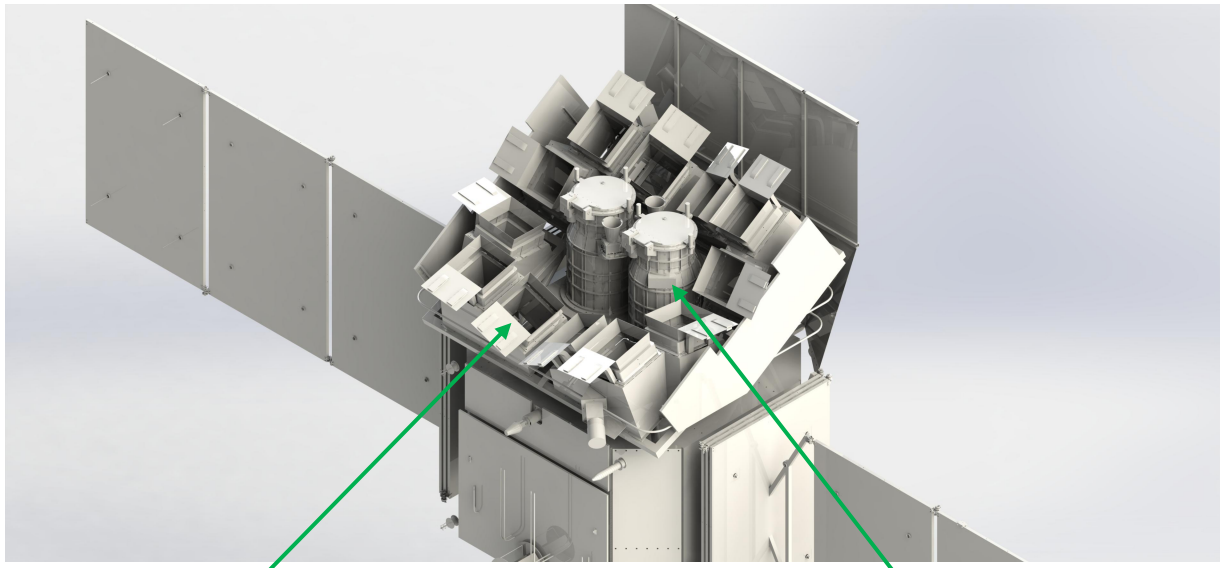
Einstein Probe (EP) mission of CAS

EP science goal

X-ray all-sky monitoring to discover & characterise high-energy transients, and to monitor variability of X-ray sources, at sensitivity > 1 order of magnitude better than current ones

- 2012: EP proposal
- Adoption: 2017-12
- CDR: 2022-03
- Current in phase D (Flight Model)
- Planned launch: by the end of 2023
- Lifetime: 3 years (goal 5 yr)
- International collaboration: ESA & MPE (+CNES)

Instruments & SC



Spacecraft

On-board data processing
Quick slew & autonomous follow-up

Wide-field X-ray Telescope

WXT (12 modules)

lobster-eye MPO
FoV: 3600 sq deg (1.1 sr)
band: 0.5 – 4 keV
spatial resolution: ~ 5’ (FWHM)
sensitivity: tens times better than current

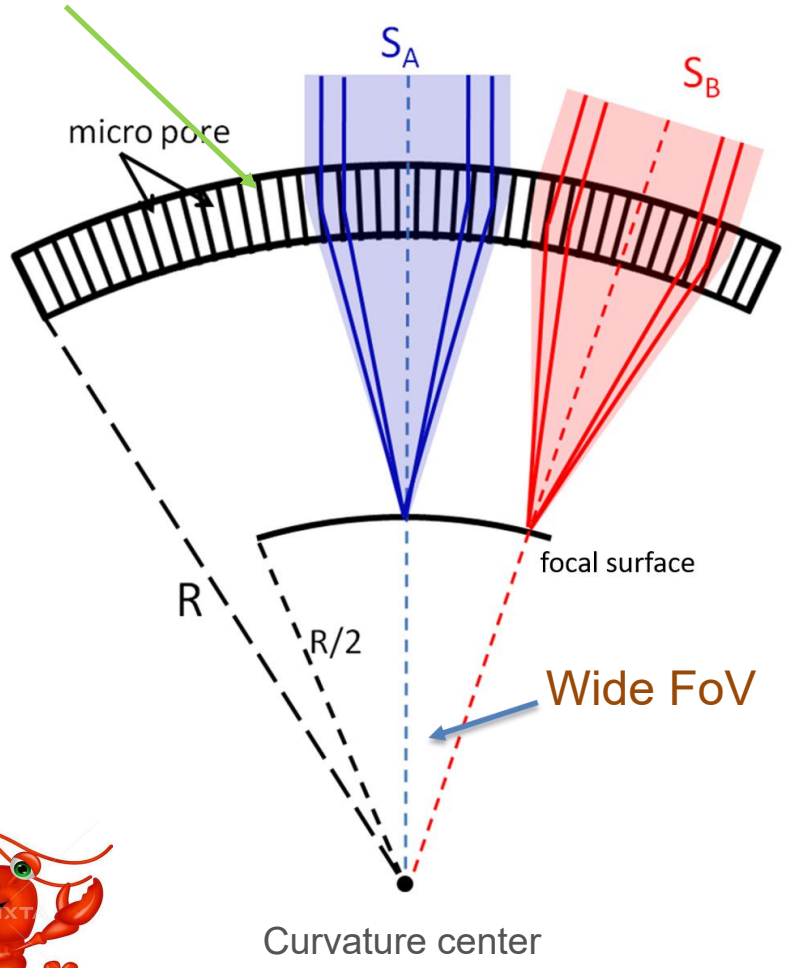
Follow-up X-ray Telescope

FXT (2 units)

Wolter-1 optics
FoV: ~1 deg
band: 0.3-10 keV
effective area: 300 cm^2 @1 keV (1 unit)
spatial resolution: 30” (HPD on-axis)

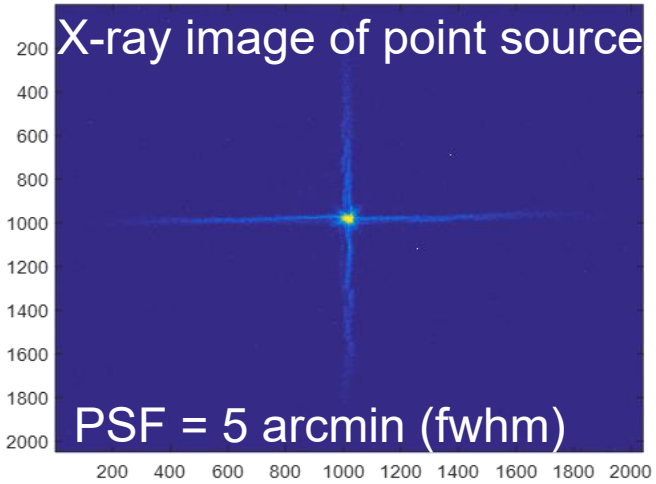
Lobster-eye micro-pore optics (MPO) for X-ray focusing

grazing incidence reflection



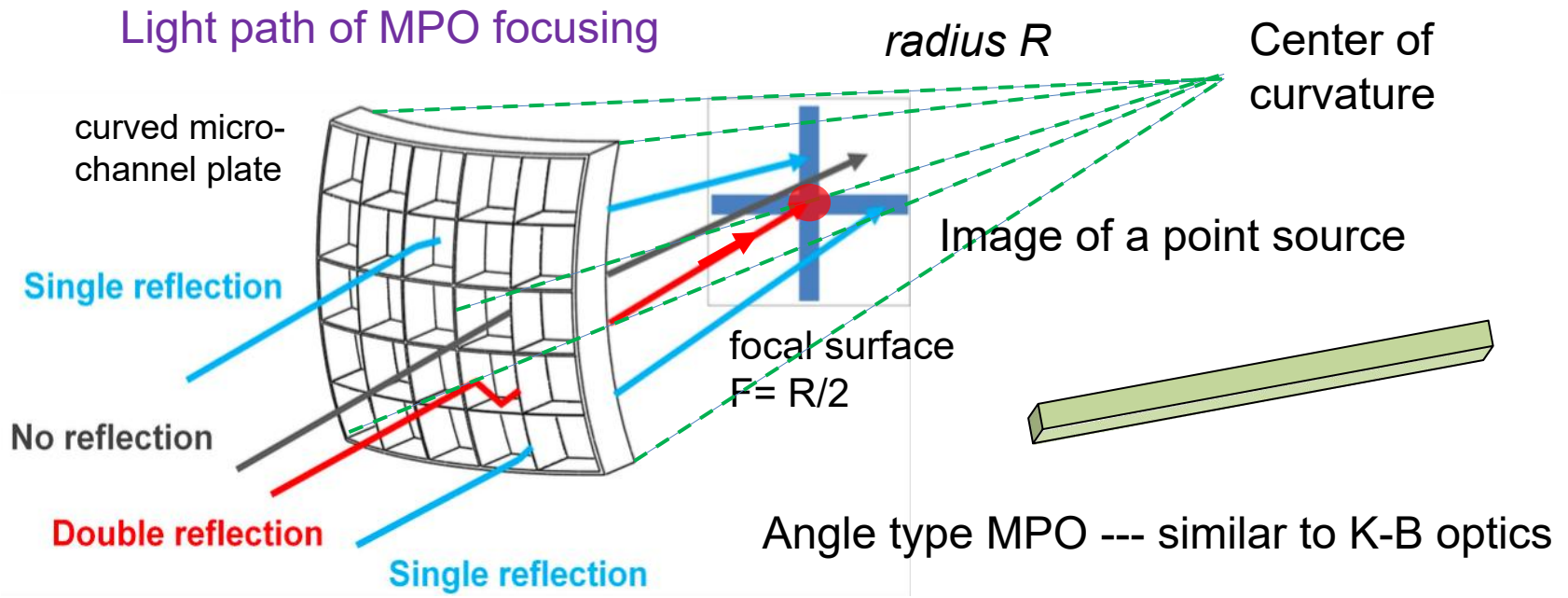
ideal optics for X-ray wide-field monitors

- wide field of view
- better angular resolution (5 arcmin)
- higher sensitivity
- optimised in soft X-ray

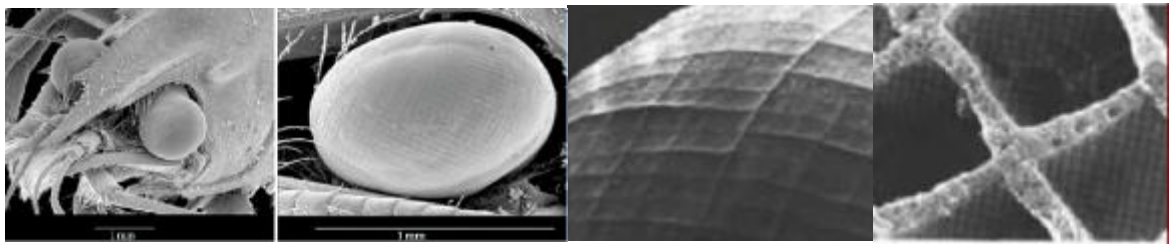


first proposed by R. Angel (1979); studied by a number of groups for many years e.g. Wilkins et al. (1989) ; Fraser et al. (1992); Kaaret (1992), also at NAOC since 2010

X-ray focusing optics: Micro-Pore Optics - Angel



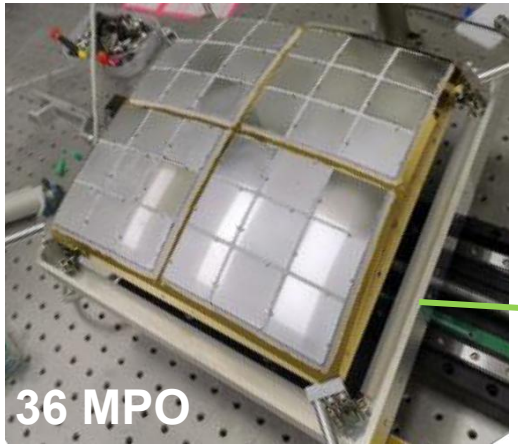
Lobster eye

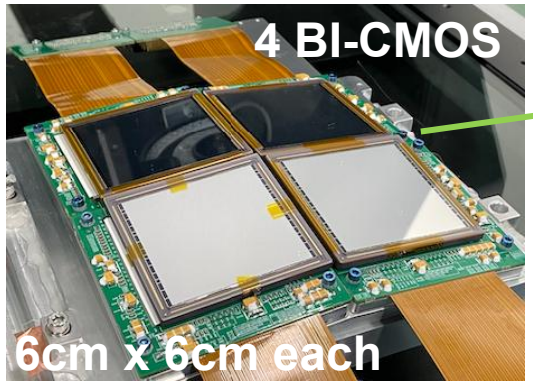


(also other crustaceans) SEM image (Gaten 1994)

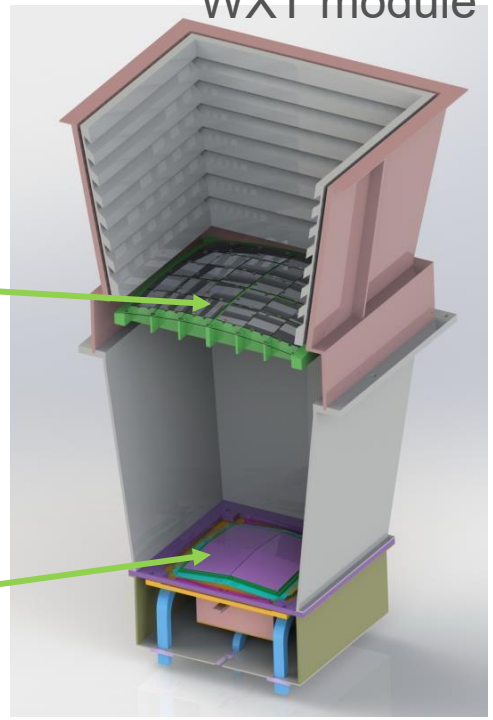
Lobsters see by light reflection (grazing incidence) rather than refraction !

Wide-field X-ray Telescope (WXT)





WXT module

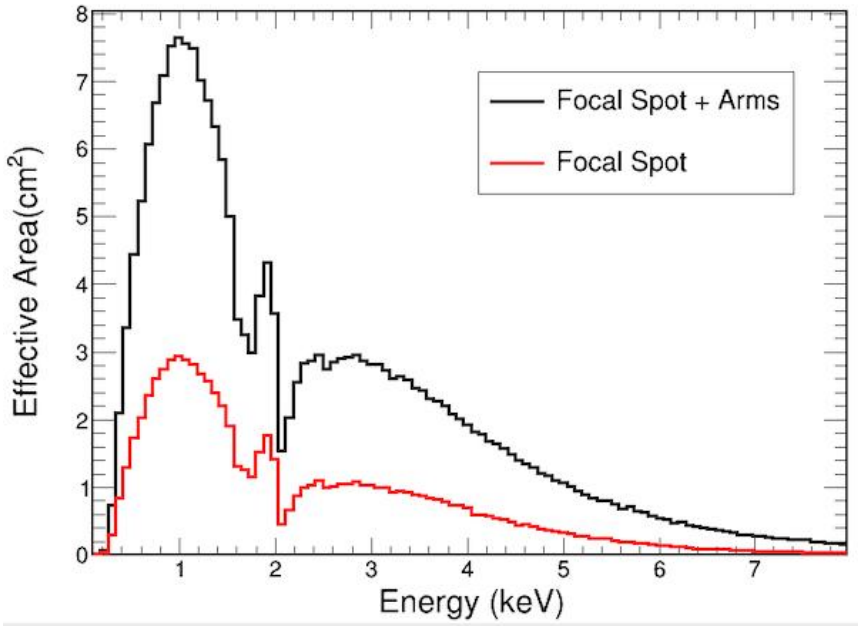


Focal length 375mm

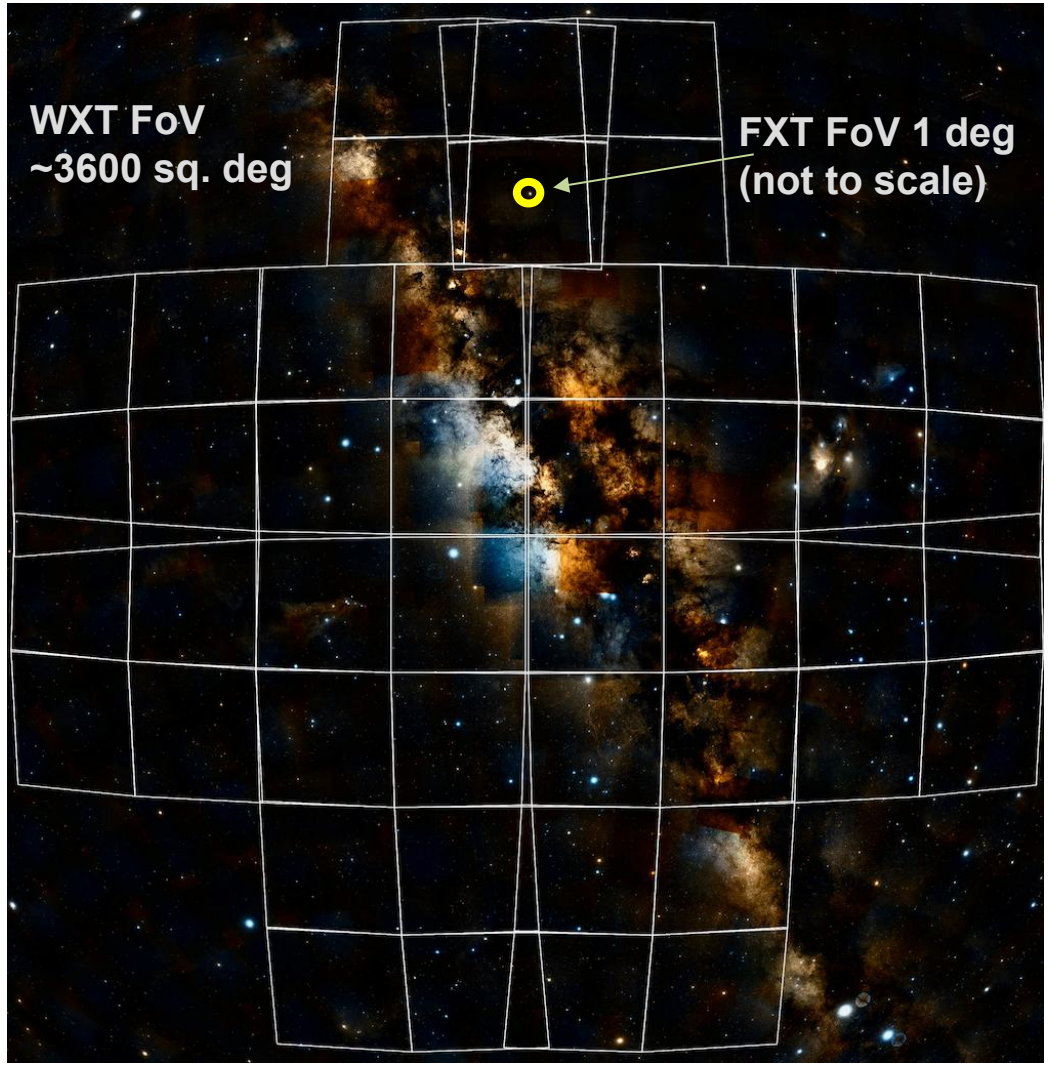
- development: CAS (SITP, NAO) + NNVT
- test/calibration: CAS & ESA
- WXT PI: X. Sun (SITP);
- Instr. Sci: Z. Ling (NAO); MA PI: C. Zhang (NAO)

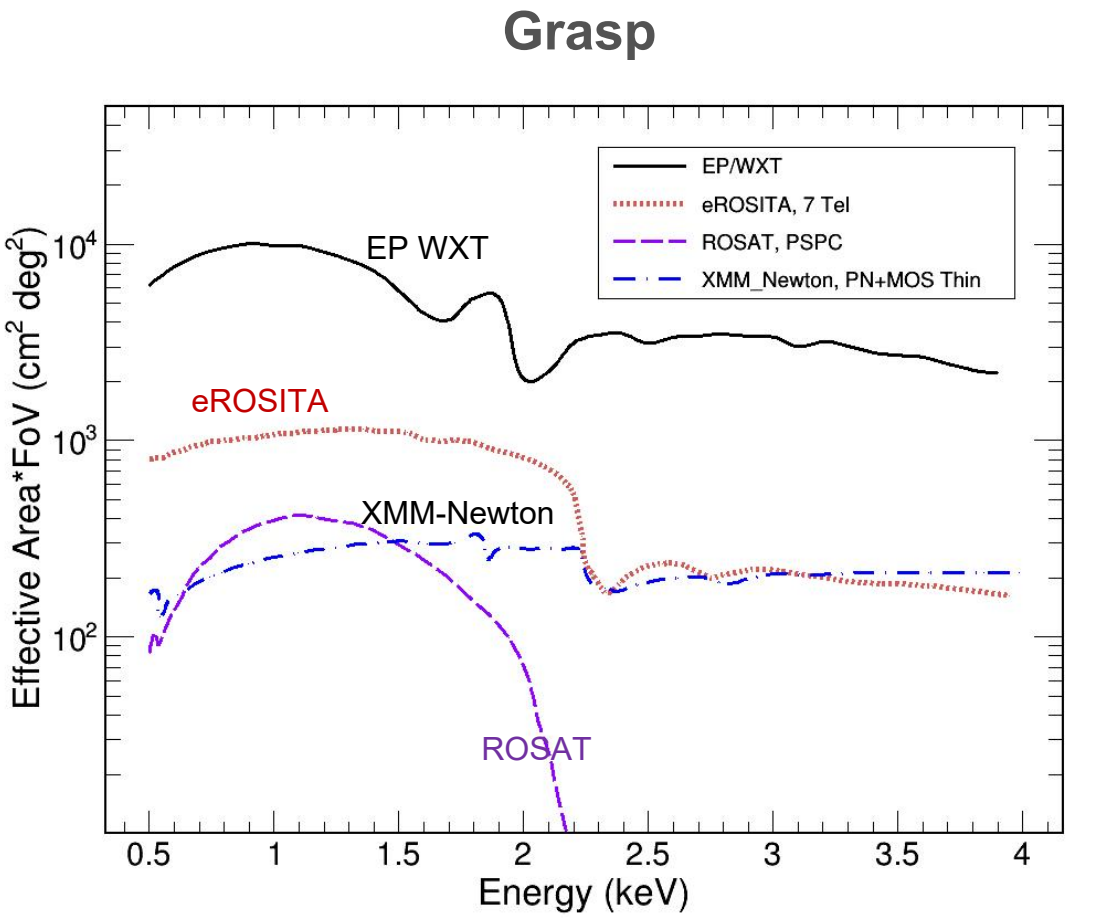
Technology challenges

- First large-FoV MPO telescope (432 plates)
- Large detector array (48 CMOS x 6 x 6 cm^2)
- Use of CMOS as X-ray detectors in space
- Soft X-ray band



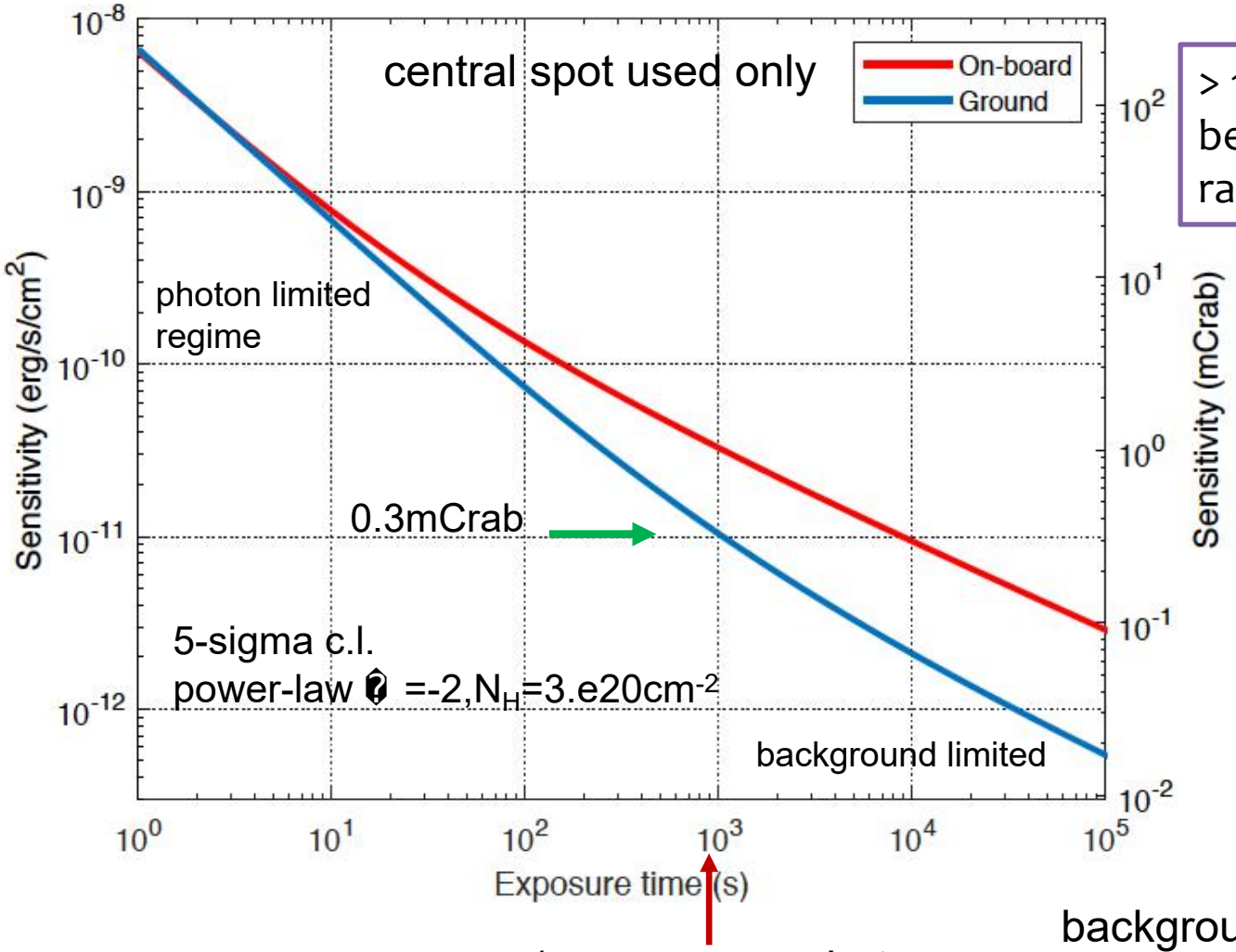
WXT FoV & Grasp





Zhao D. et al. 2017

Simulated EP WXT sensitivity



> 1 order of magnitude better than current X-ray ASM (MAXI, Swift)

~ 1 survey snapshot

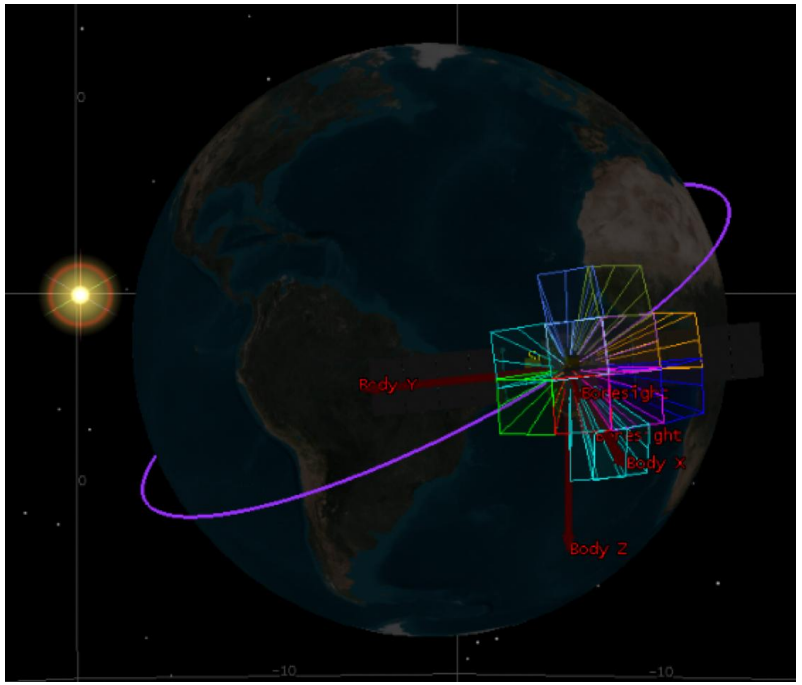
background 3.3 counts @ central spot

backgrounds : particles, diffuse background, with shielding

Zhao D. et al. 2017

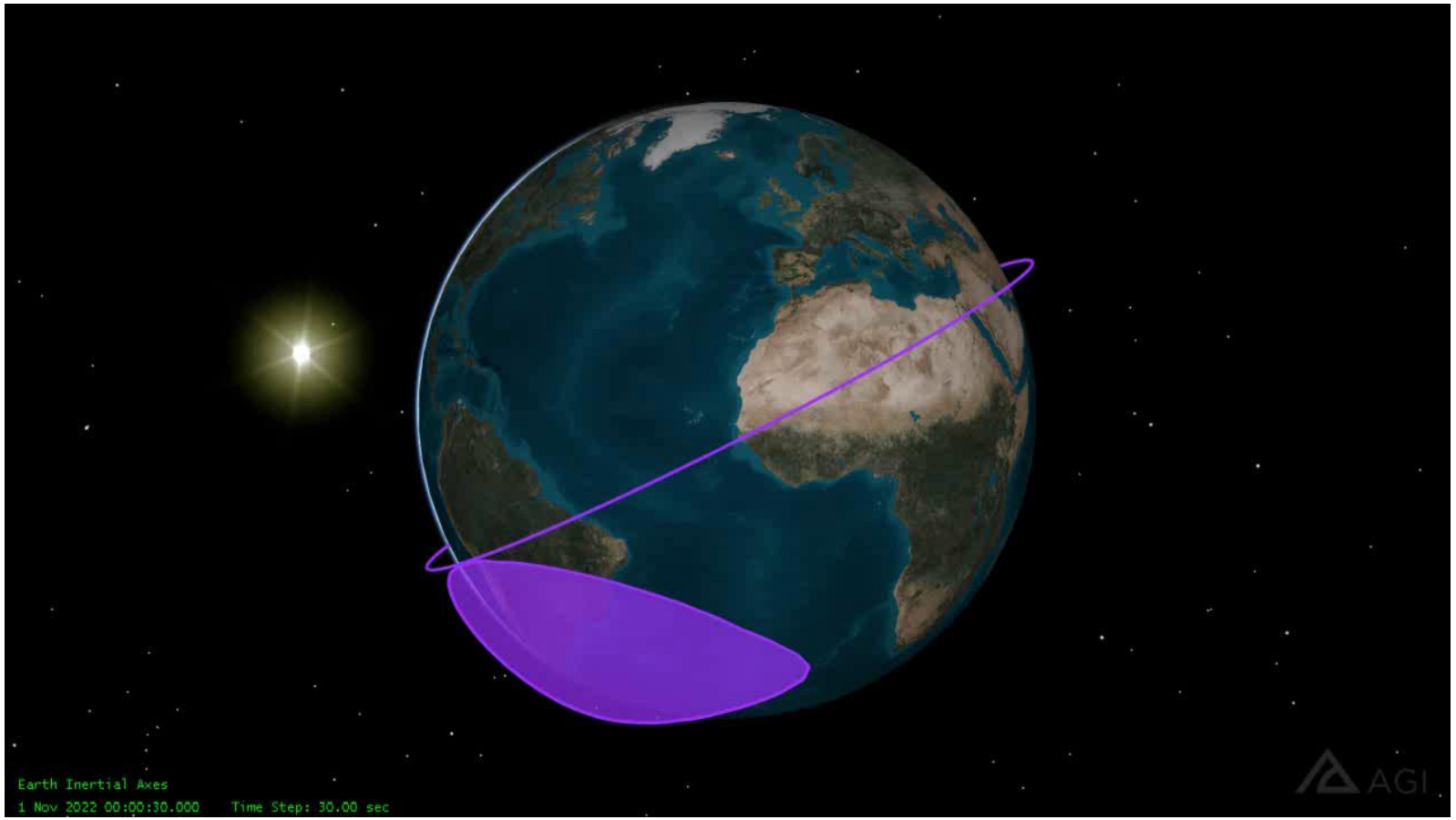
Mission profile

- Orbit: ~ 600 km (96min), incl. 29 deg
- Operation modes
  - Survey (WXT)
  - Autonomous X-ray follow-up (FXT)
  - Target of opportunity (FXT, WXT)
- Alert data rapid downlink
  - Beidou system (China)
  - VHF (CNES/France)
  - Transient alert information to be released immediately and publicly
- Target of opportunity command uplink
  - Normal (S-band): < 1 day
  - Time critical (Beidou): < 10 min

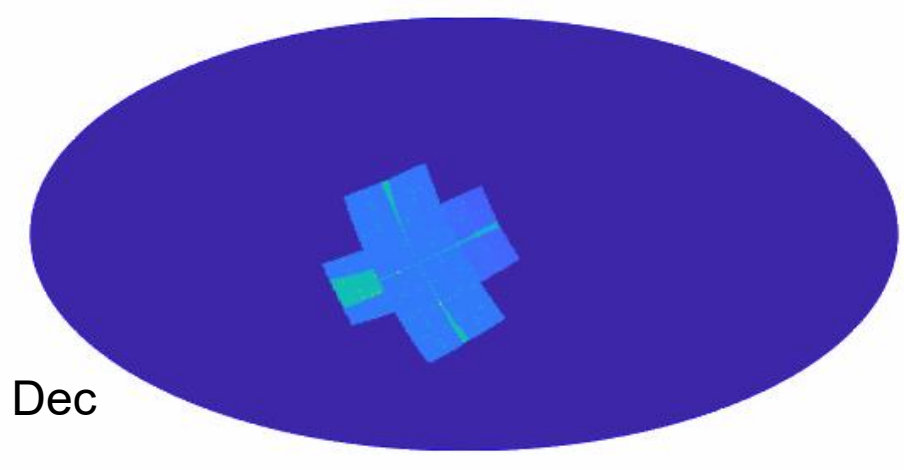


- EP Mission Centre @ NSSC/CAS
  ESA (GS telemetry support)
- EP Science Centre @ CAS
  NAOC+IHEP

EP all-sky survey mode

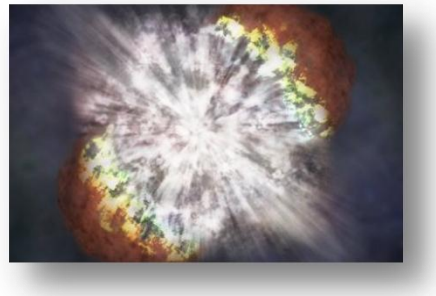


- anti-Sun pointings
- 3 snapshots per orbit, each ~20 min
- 3 orbits (~ 5 hr) cover half sky
- 1 day: ~ 45 snapshots



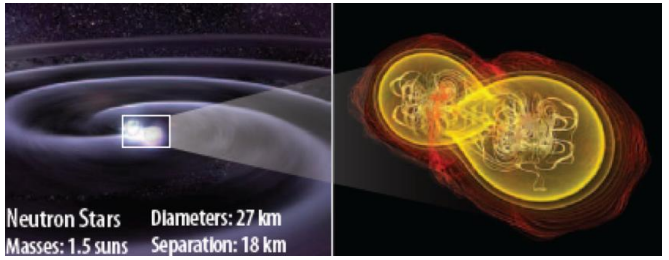
Main science objectives

Systematic survey of soft X-ray transients and variability of X-ray sources at an unprecedented combination of high sensitivity and cadence



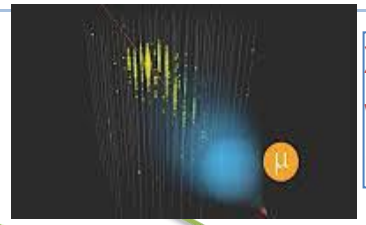
Discover otherwise quiescent black holes at almost all astrophysical mass scales and other compact objects by capturing their transient X-ray flares

Detect and localise the electromagnetic-wave sources of gravitational-wave events by synergy with gravitational-wave detectors

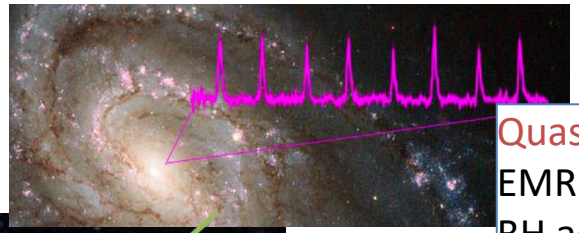


Various classes of high-E transients & variability

High redshift GRB
Early universe

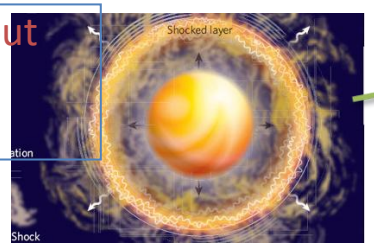


X-ray flares associated with neutrino events
particle acceleration



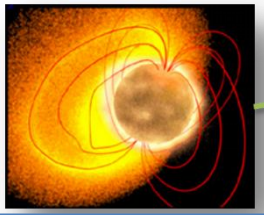
Quasi-periodic erruption
EMRI (GW source?)
BH accretion ?

SN shock breakout
SN physics
progenitors

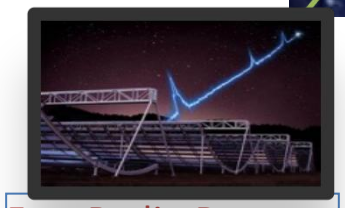


Active galactic nuclei
Extreme gravity, BH accretion/jets/growth

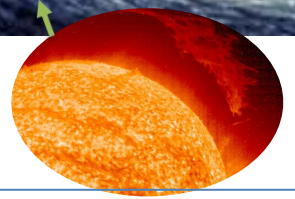
Intermediate-mass BH
BH physics/accretion



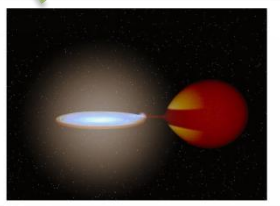
magnetar
extreme
magnetic Field



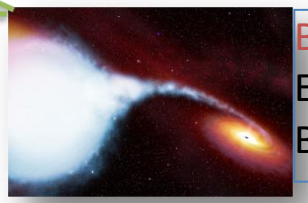
Fast Radio Burst
X-ray sources



Star X-ray flares
Magnetic fields
Corona activity

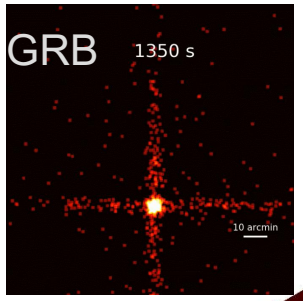


Thermal nuclear burst
Neutron stars physics



BH X-ray binary
Extreme gravity
BH physics/accretion

Simulated all-sky image & transients in 1-year



Estimated detection rates for selected classes

Type of transients	Detections per year
Tidal disruption event (TDE)	10s - 100
TDE with jet	several
Supernova shock breakout	10 – 10s
Long GRB	10s
High-z GRB (z > 6-8)	several
Short GRB	10
Low-luminosity GRB	10
Magnetar	a few
Stellar flares	a few 10^3
AGN monitored daily / weekly	tens / hundreds

 # transients per week

- EP: >10
- Swift: 2.5
- MAXI: 0.8

challenging to measure redshift !

Note: subject to large uncertainties…

EP consortium

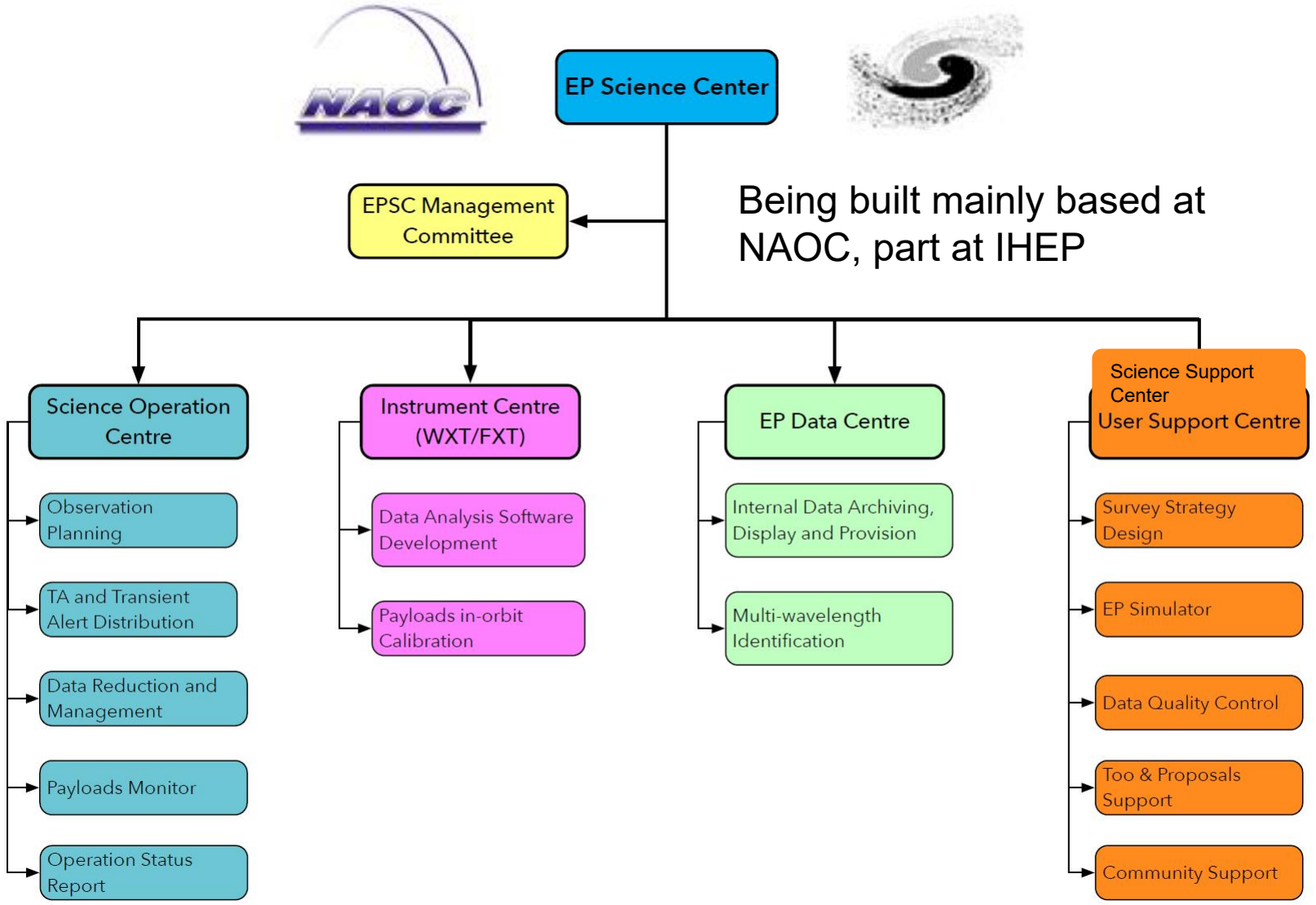
- **Chinese Academy of Sciences**
  - Managed by CAS's National Space Science Centre (NSSC)
  - Institutes: NAOC, IHEP, SITP, MicroSAT, NSSC, others

- **European Space Agency** (Mission of Opportunity)
  - Hardware contribution (mainly FXT Mirror module)
  - Ground station support
  - Science management support

- **Max-Planck-Inst. for extraterrestrial Physics, Germany**
  - Hardware contribution (FXT pn-CCD modules, eROSITA MA FS)

- **CNES, France** (Agreement to be signed)
  - VHF network & support (contribution to EP Science Centre)

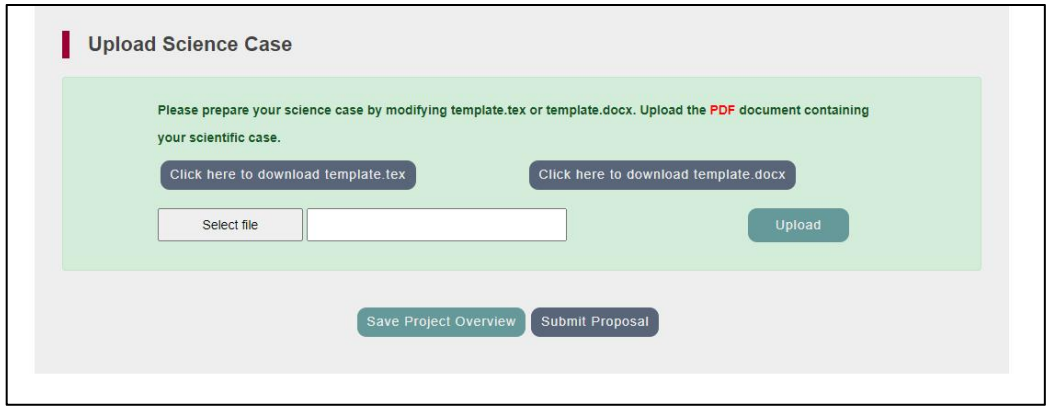
EP Science Center



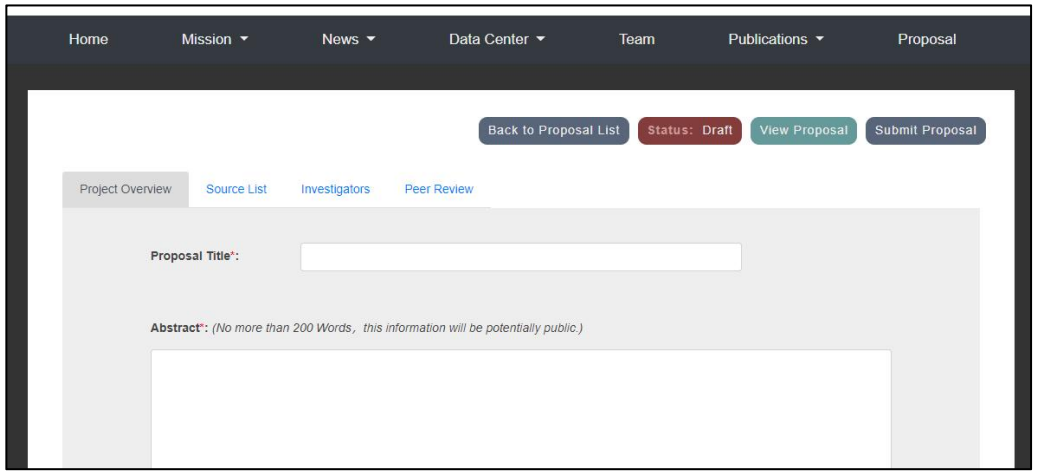
Proposal Tools

- Proposal submission and review

Proposal Management



Science Use Case Submission

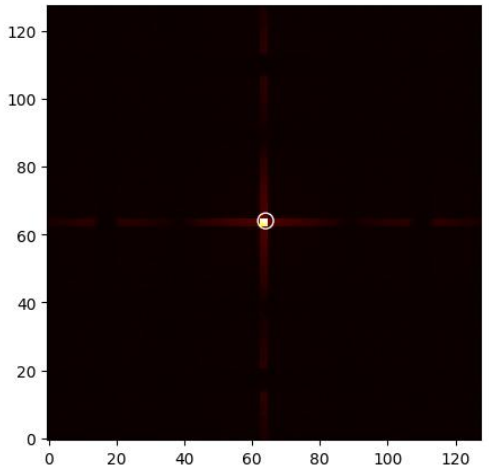


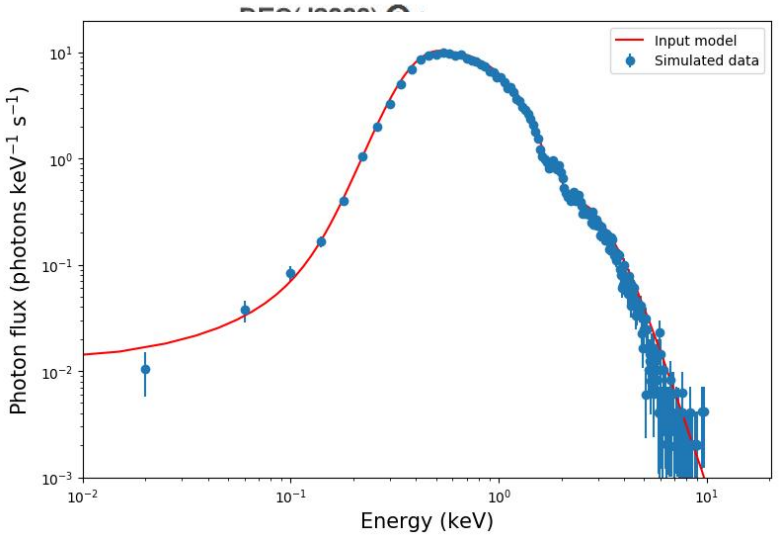
Proposal Content Filling

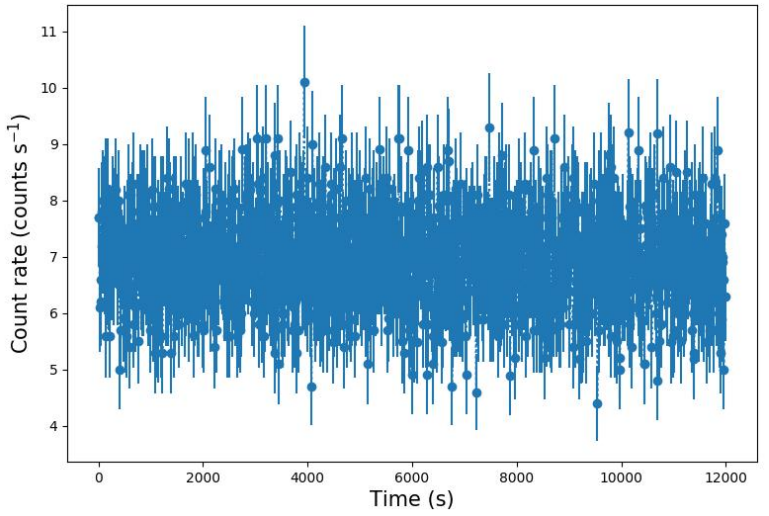
Proposal Review Management

WXT online simulator

- Simple and quick

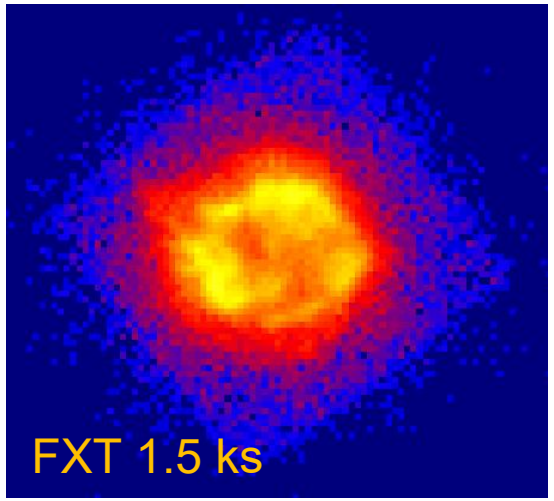


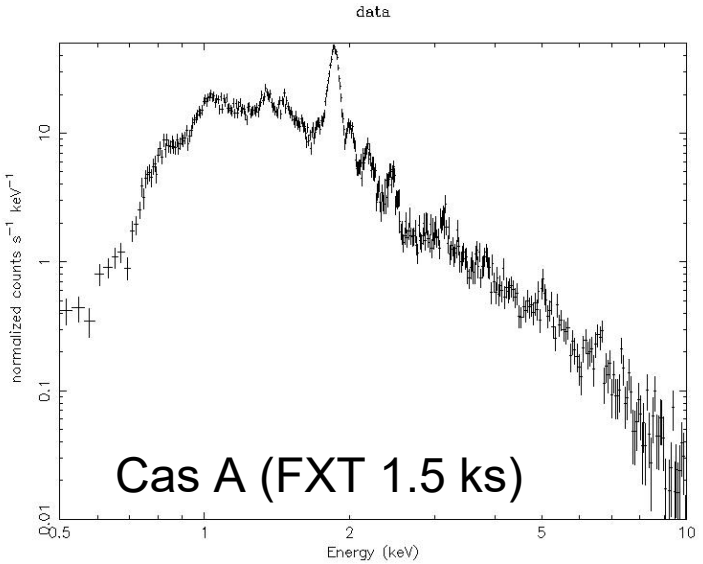


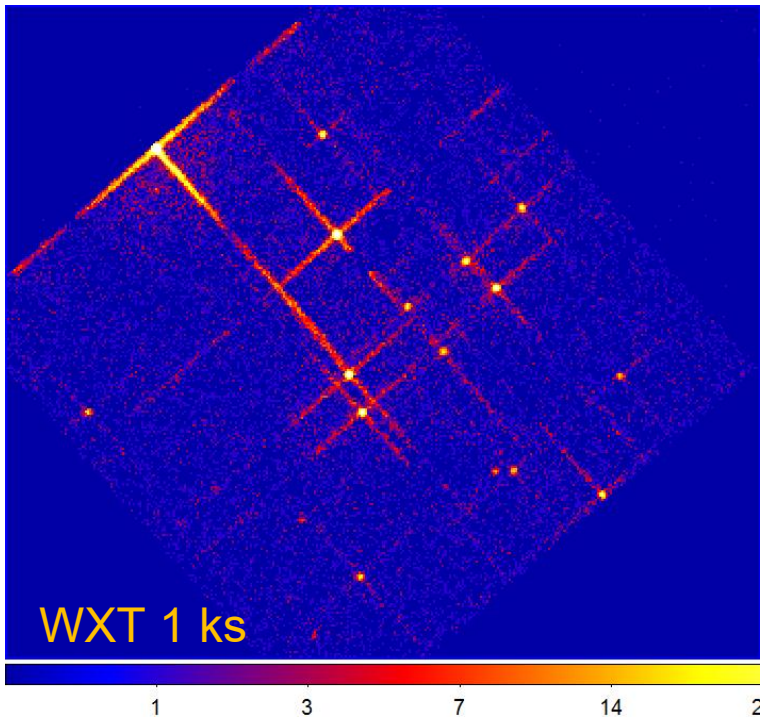


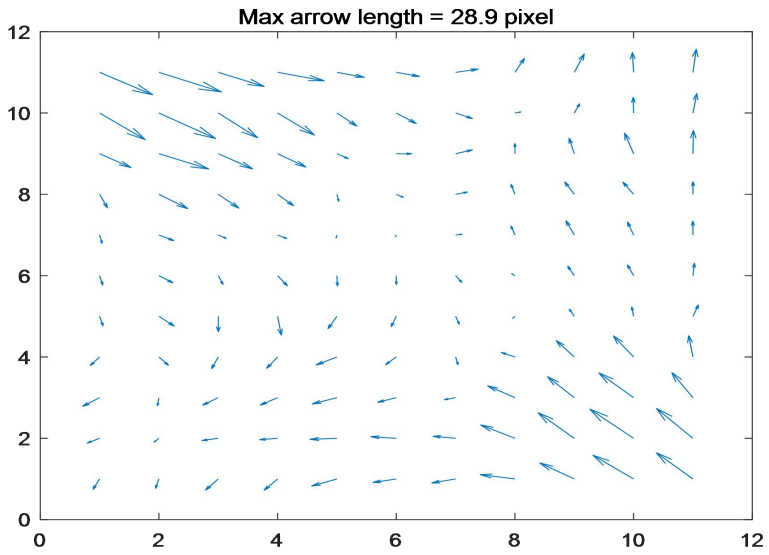
Data reduction software

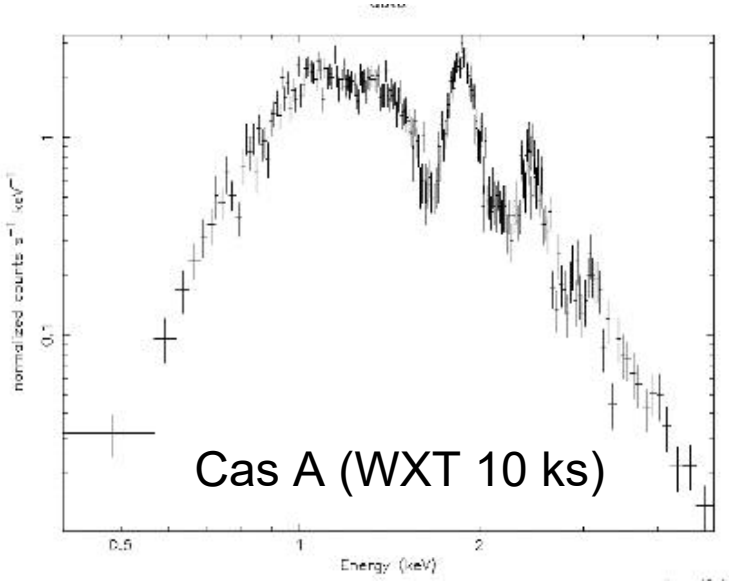
- Define data products
- Build CALDB
- Develop and test software
- HEASARC framework



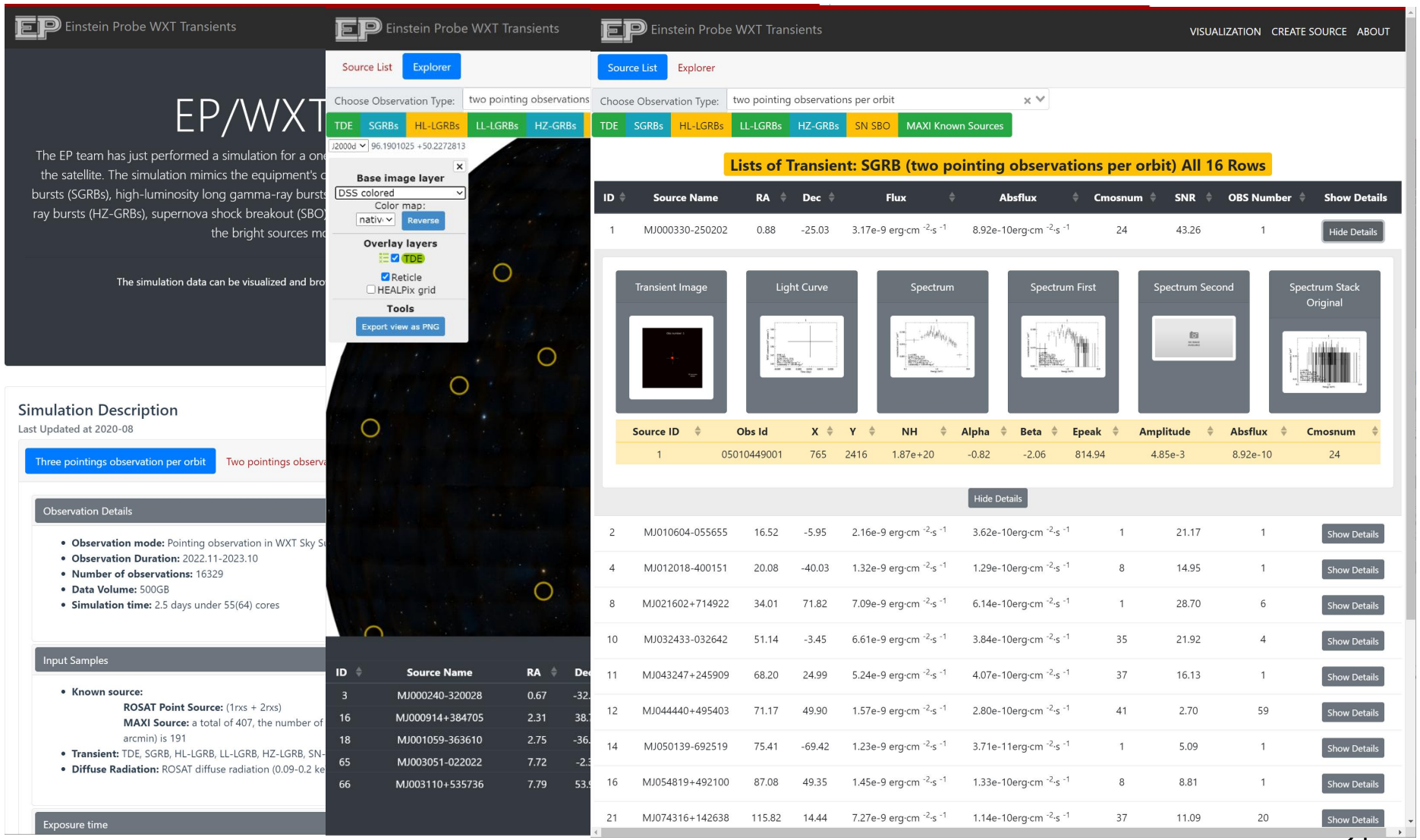








Transient database

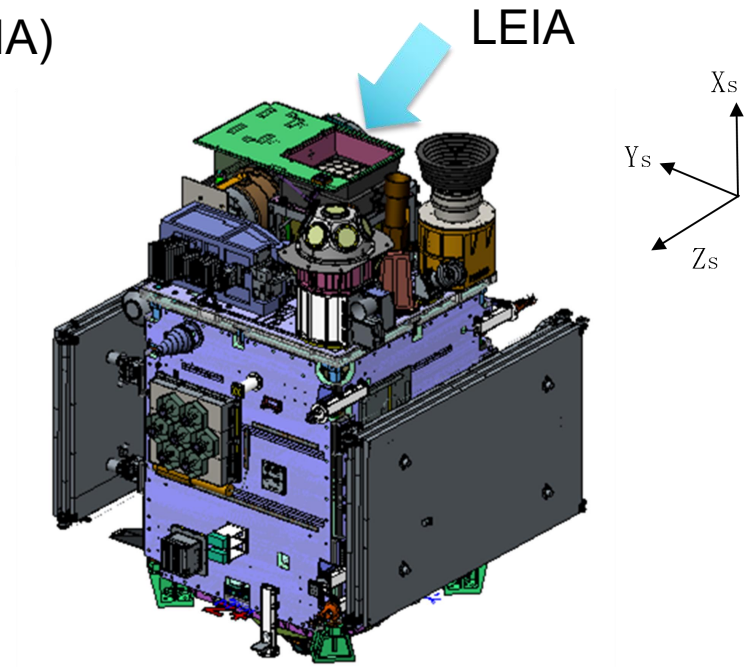


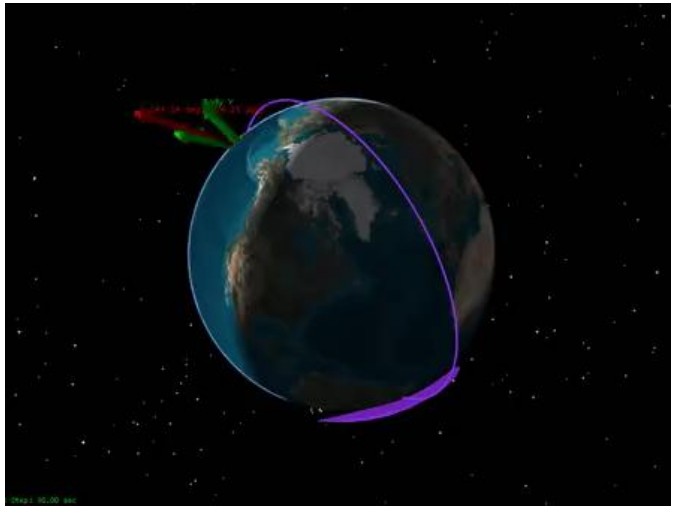
Data policy

- Alert information of transients will be released immediately
  - Source position, flux, time, etc.
- Data will be made public after proprietary periods
  - Survey and follow-up observations: one year
  - ToOs: 6 months
- EP science team: a single joint team of all partners
  - CAS-ESA-MPE: 80% - 10% -10%
  - Joint exploitation of EP data with projects led by the parties in above proportion
  - Science management committee composed of members from all three parties

WXT pathfinder

Lobster Eye Imager for Astronomy (LEIA)



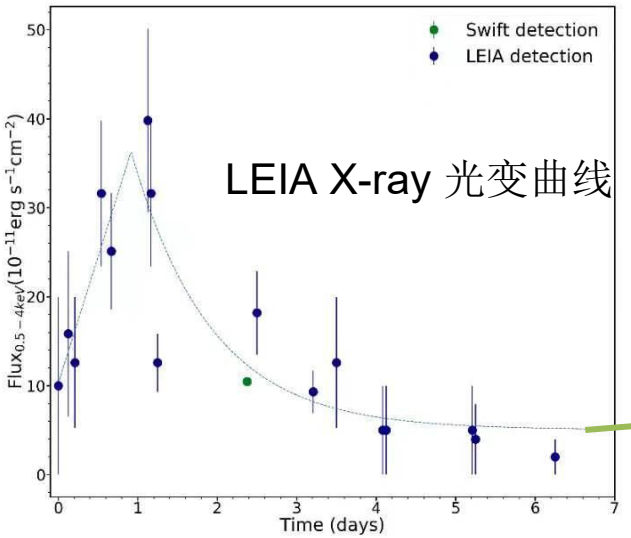


Successfully launched 2022 July 27, @Jiuquan

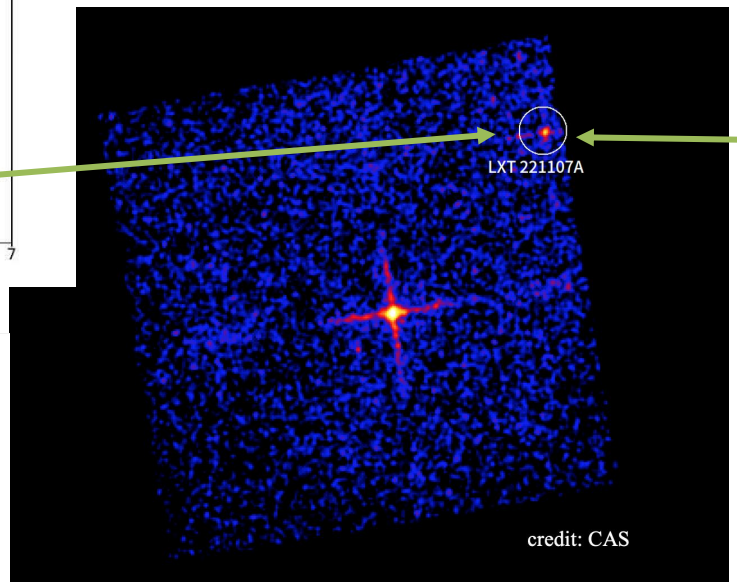
- 中科院力学所力箭 1 号

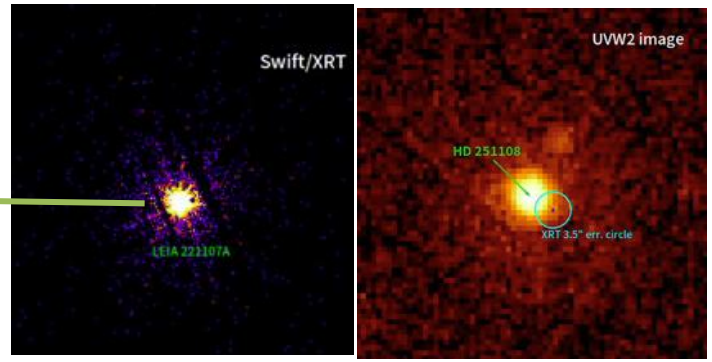
LEIA first results: stellar flares

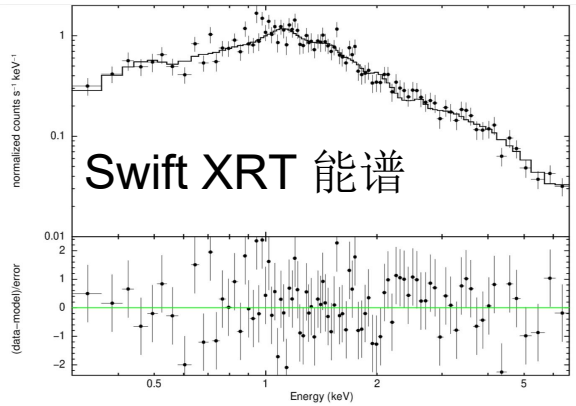
- LXT 221107A 超级恒星耀发

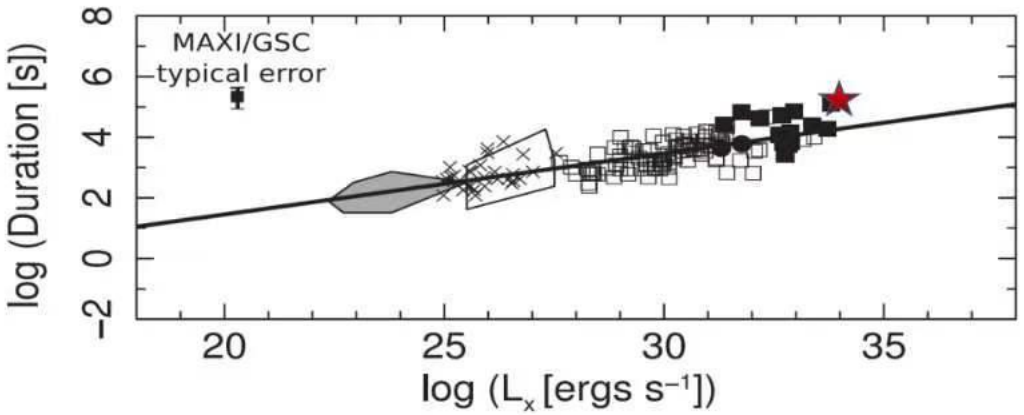


LXT221107A 恒星X-ray超级耀发



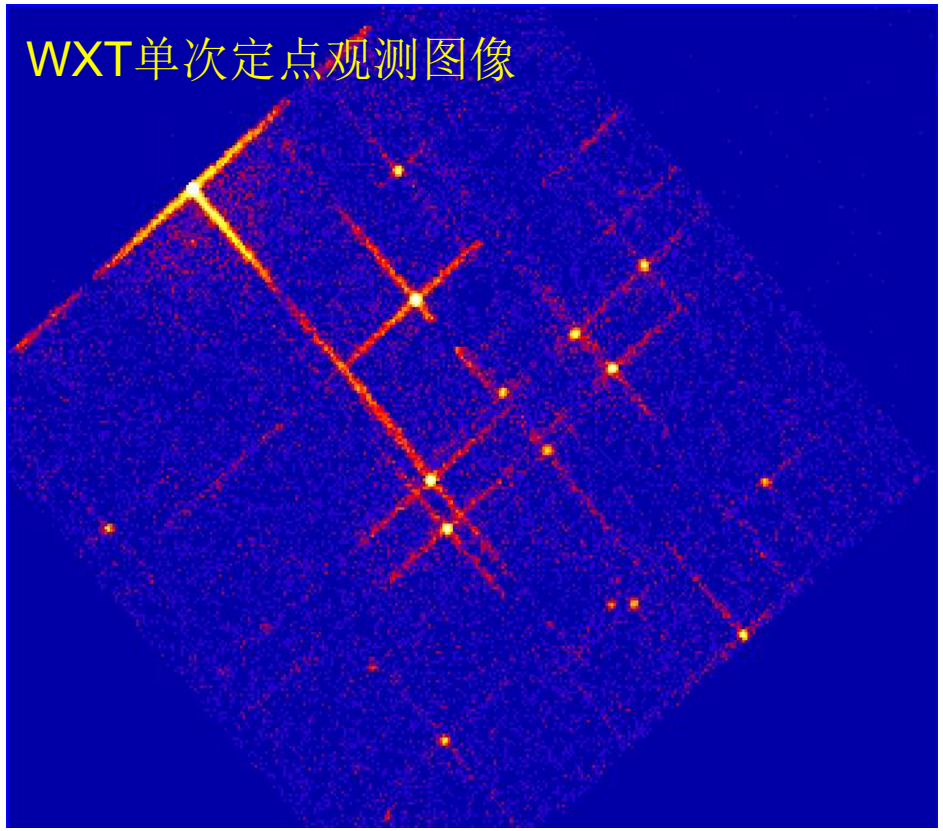


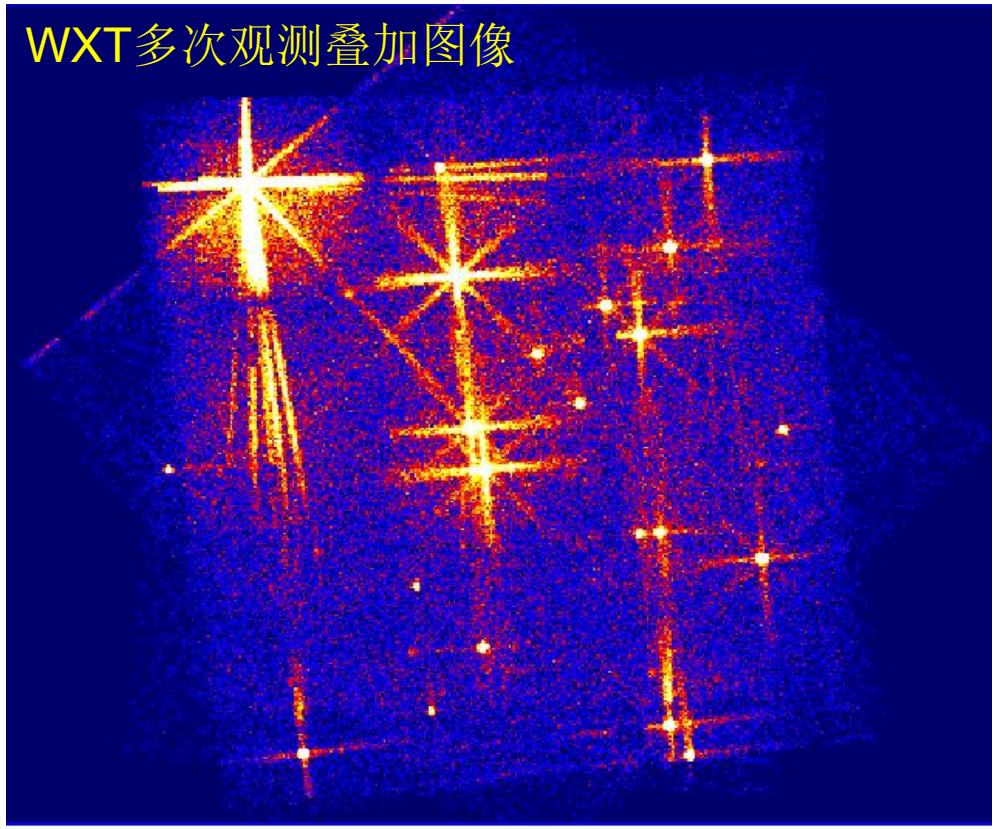




源探测

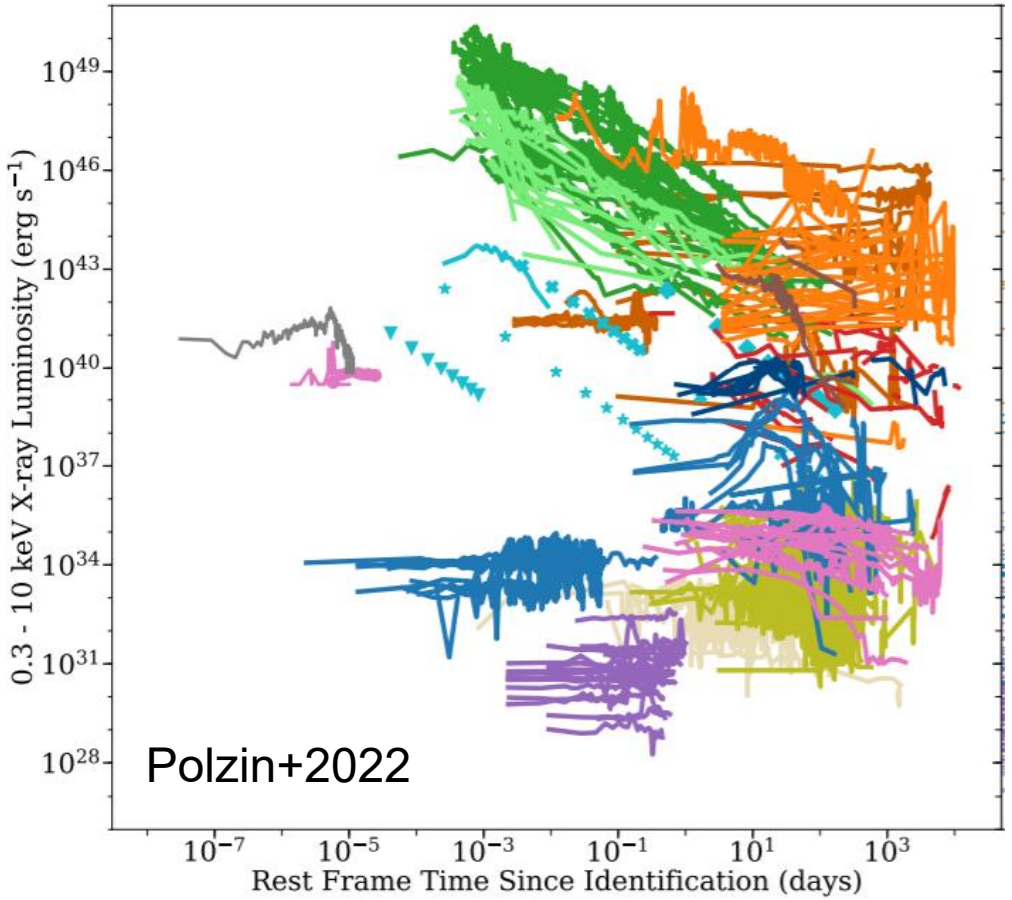
- 含有十字臂结构图像的源探测方法
- 多次叠加图像的源探测方法
- 依据光子列表的源探测方法



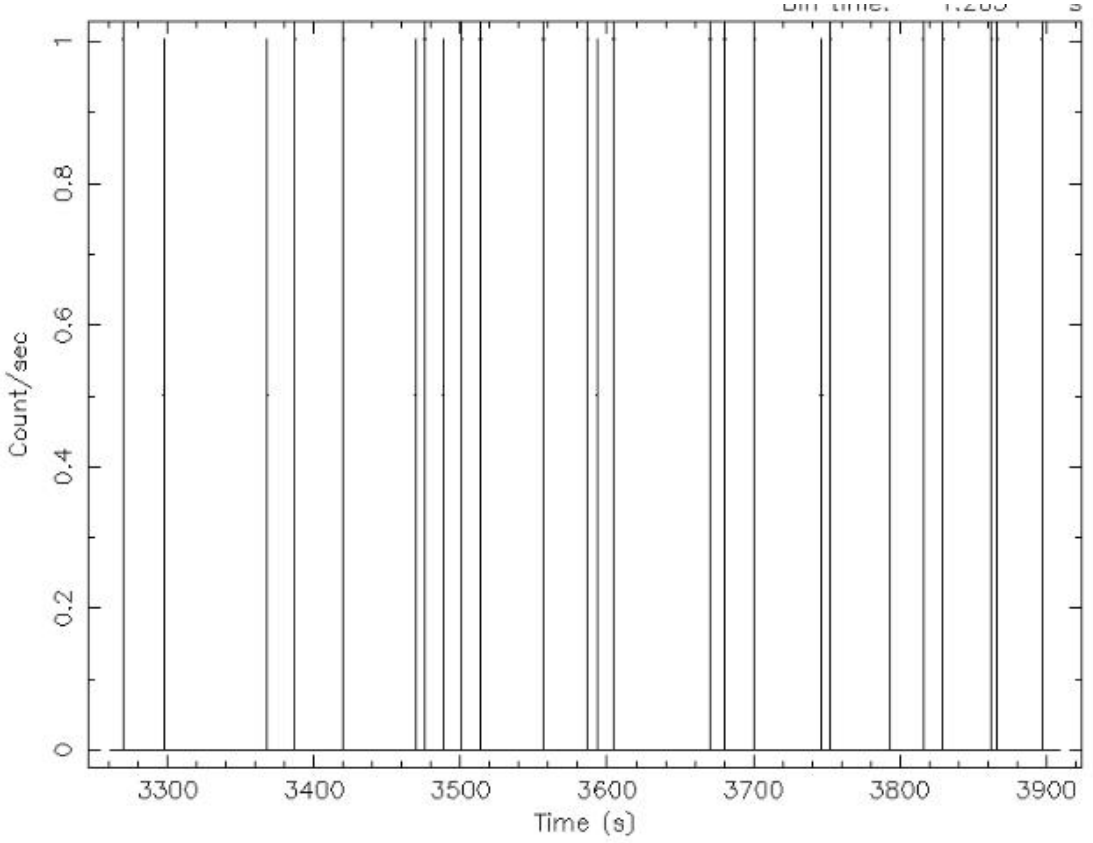


源分类

- X射线暂现源的类别众多，在探测到之后如何根据WXT的数据以及其他多波段设备的数据对源进行快速、准确的分类？
- 如何有效地确定已知类别的源的同时发现未知的新型暂现天体？



WXT光变曲线示例



EP项目招聘岗位

EP科学中心项目支持科学家

职责：

（1）参与EP科学中心的日常运行工作，包括担任值班科学家或观测助手、开发和维护相关软件、处理各类运行数据、观测任务、用户信息等工作。

（2）基于EP和EP探路者LEIA载荷的数据，结合其他地面和空间望远镜的协同/后随观测，开展相关的X射线天文和高能天体物理的观测和理论研究。

（3）负责人交办的其他工作

要求：

具有良好的科学素养和研究能力，具有物理学或天文学博士学位。从事高能天体物理方向研究（具有X射线天文研究经历优先）。

EP网站和服务器运维工程师

职责：

（1）负责EP网站的日常维护和需求开发及网站Bug处理；

（2）根据需求完成EP网站信息的更新以及信息资源的整合；

（3）配合完成EP相关软件的升级、更新和维护等工作；

（4）负责计算机网络、服务器安全运行和数据备份，网络对外接口和系统安全管理等工作；

（5）负责人交办的其他工作

要求：

本科（含）以上学历，具有实际软件工程开发经验；具有物理或天文相关方向研究经历优先；精通C/C++程序开发； 熟悉常用脚本语言和Linux系统的使用；熟悉软件工程管理。

Summary

- X-ray sky is rich in various classes of transients and variables
- Future of monitoring dynamic X-ray sky is promising, enabled by Lobster-eye MPO technology
- Einstein Probe will discover/characterise a large number of faint X-ray transients, and monitor source variability
- Challenges to source detection and classification

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