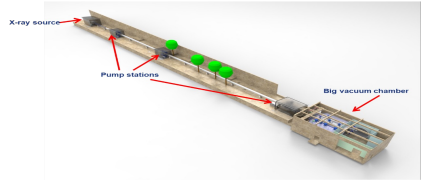
百米标定装置单能 X射线源研究及标定应用

侯懂杰
中国科学院高能物理研究所



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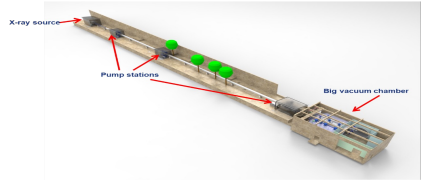
③ 空间X射线望远镜标定

④ 总结与展望



一、研究背景及国内外进展

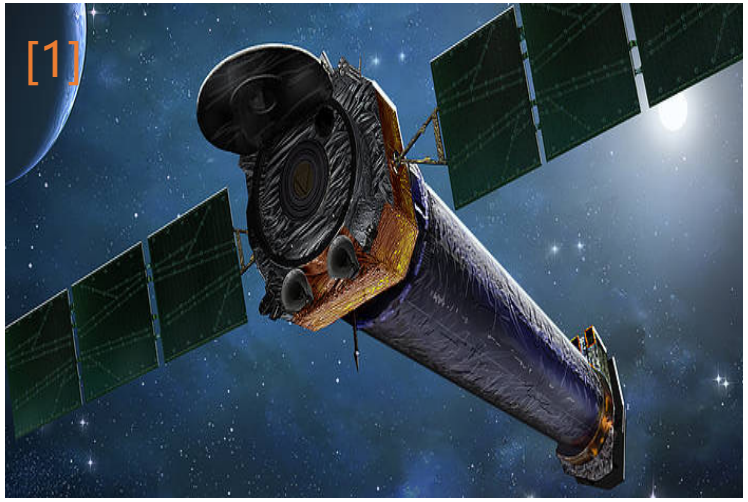
1.1 国内外X射线望远镜

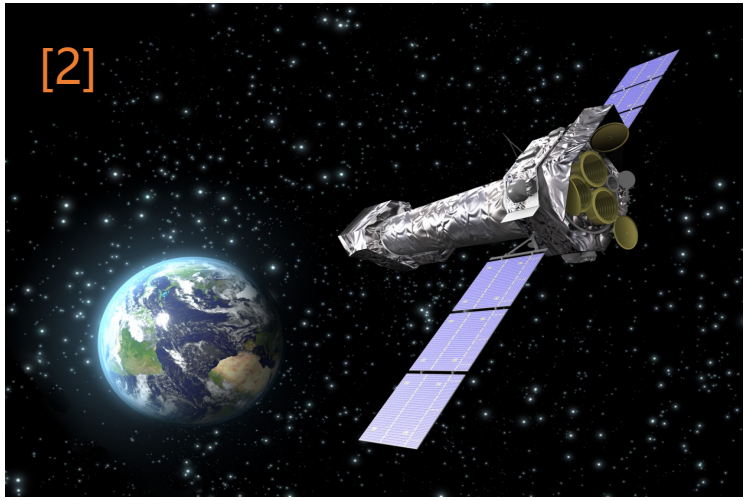
[1] Chandra, 1999, NASA

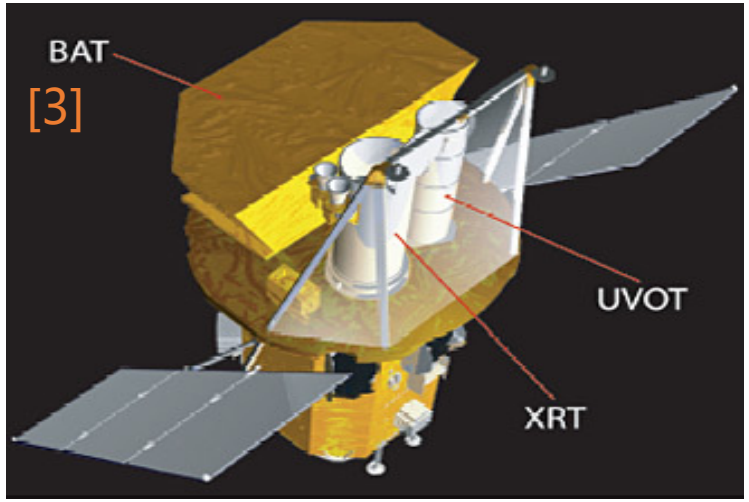
[2] XMM-Newton, 1999, ESA

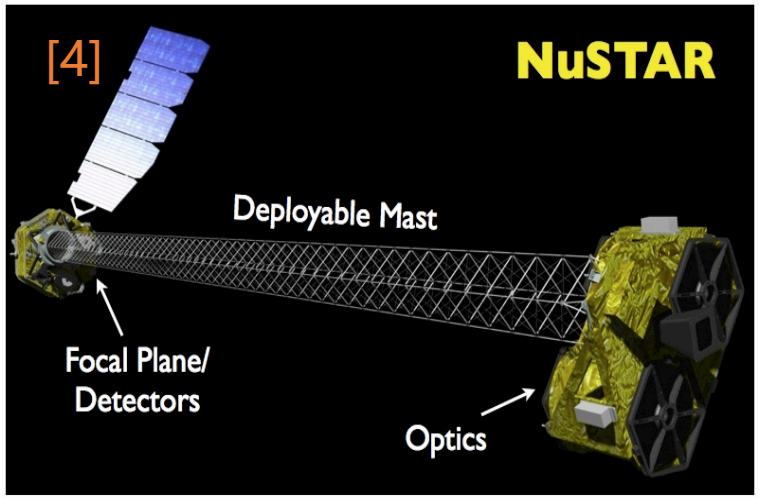
[3] Swift-XRT, 2004, NASA

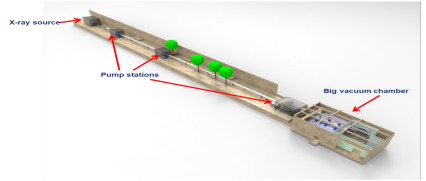
[4] NuSTAR, 2012, NASA











一、研究背景及国内外进展

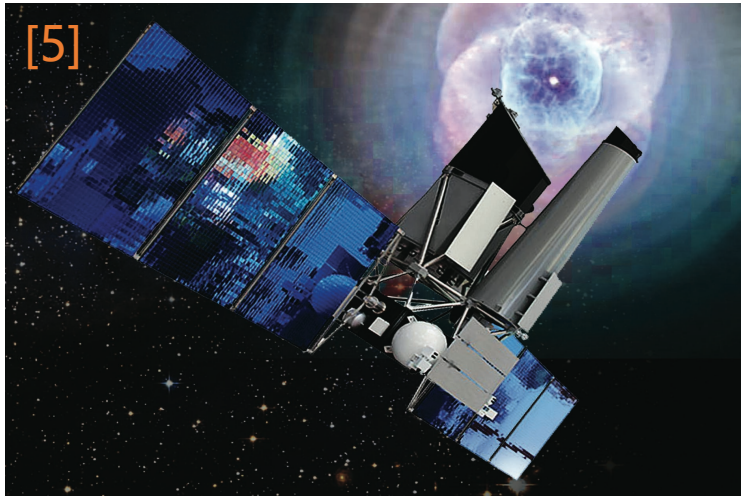
1.1 国内外X射线望远镜

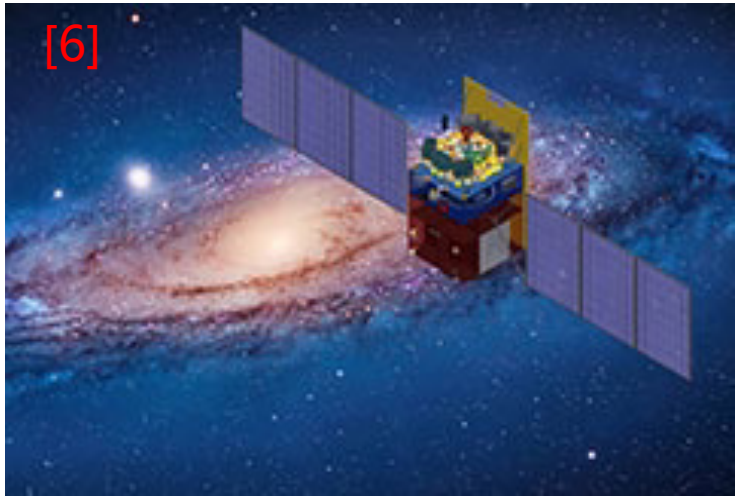
[5] eROSITA-SRG, 2019, MPE

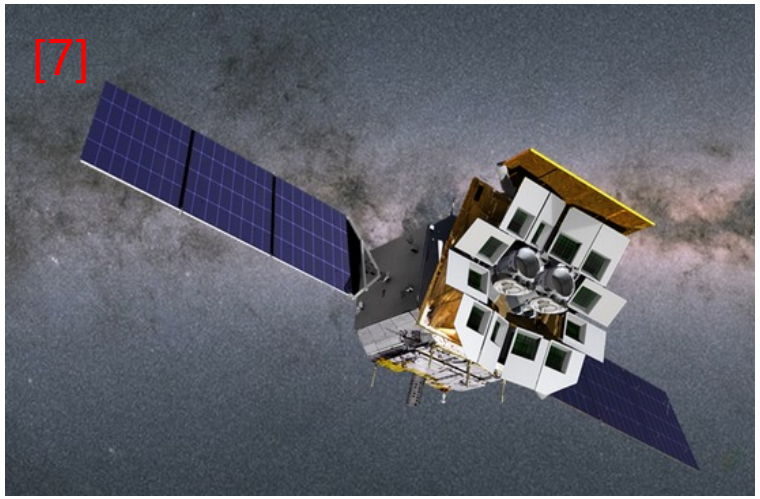
[6] HXMT, 2017, CAS

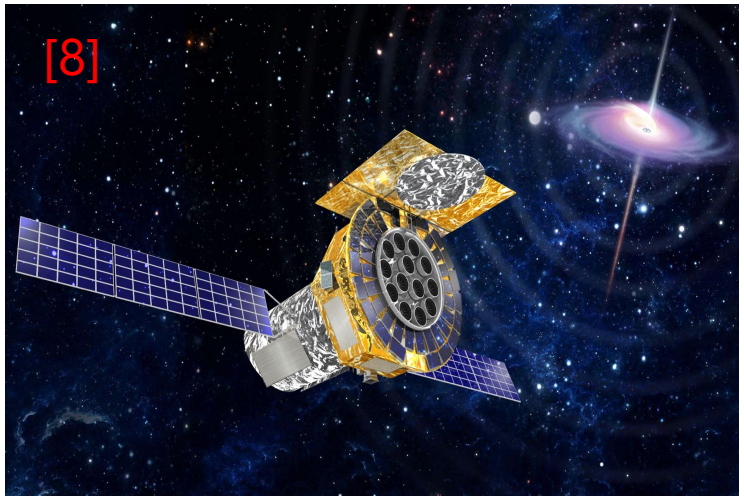
[7] Einstein Probe, 2023, CAS

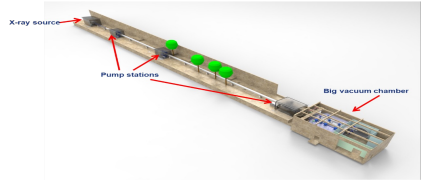
[8] eXTP, 2027, CAS





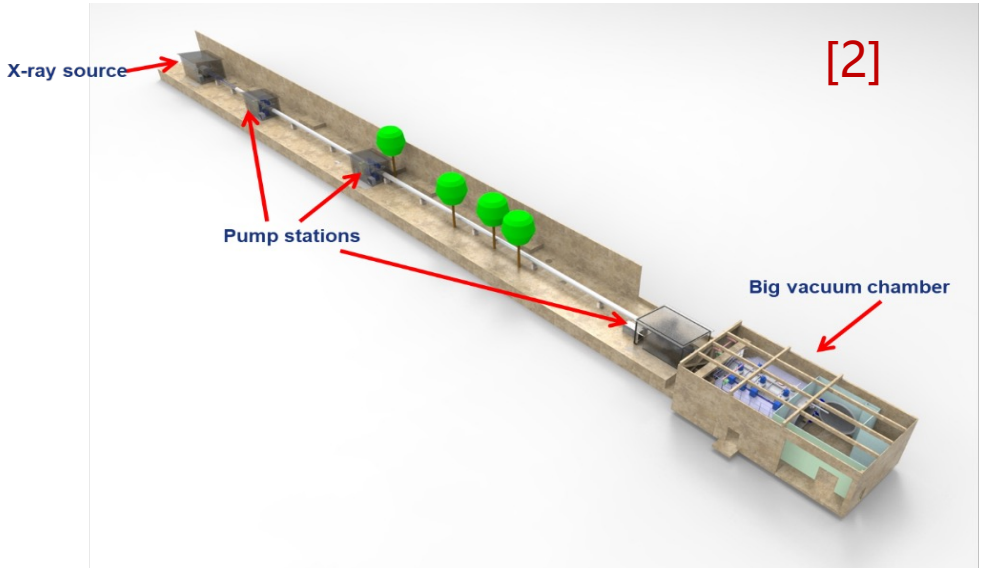




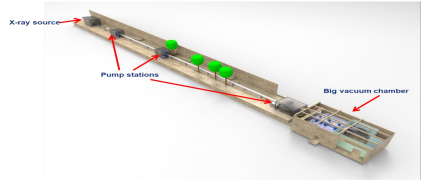


一、研究背景及国内外进展

1.2 国内外地面标定装置



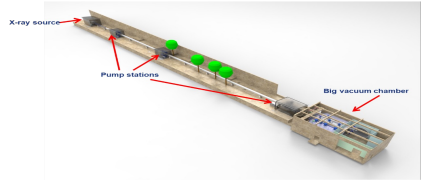
1. XRCF,NASA
2. 100XF,IHEP
3. PANTER,MPE



一、研究背景及国内外进展

装置	XRCF	PANTER	100XF-IHEP
国家	美国	德国	中国
束流管道参数	Ø4.0m*518m	Ø1.0m*130m	Ø0.6m*100m
能量范围(keV)	0.09～10	0.28～50	0.28～20
单色源类型	光栅&DCM	多靶X荧光&光栅&DCM	多靶X荧光&DCM
标定的天文卫星	Chandra, Cryogenic Mirror-Development, Hinode,NUSTAR Solar X-ray Imager, James Webb	EXOSAT, BeppoSAX, JET-X, ABRIXAS, XMM-Newton, Swift, Suzaku, eROSITA	HXMT, GECAM, EP, eXTP

[1] Bradshaw M J, et al,Optics for EUV, X-Ray, and Gamma-Ray Astronomy IX. 2019.
[2] Kegley O. X-ray & Cryogenic Facility (XRCF) Handbook.



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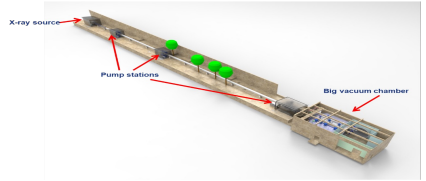
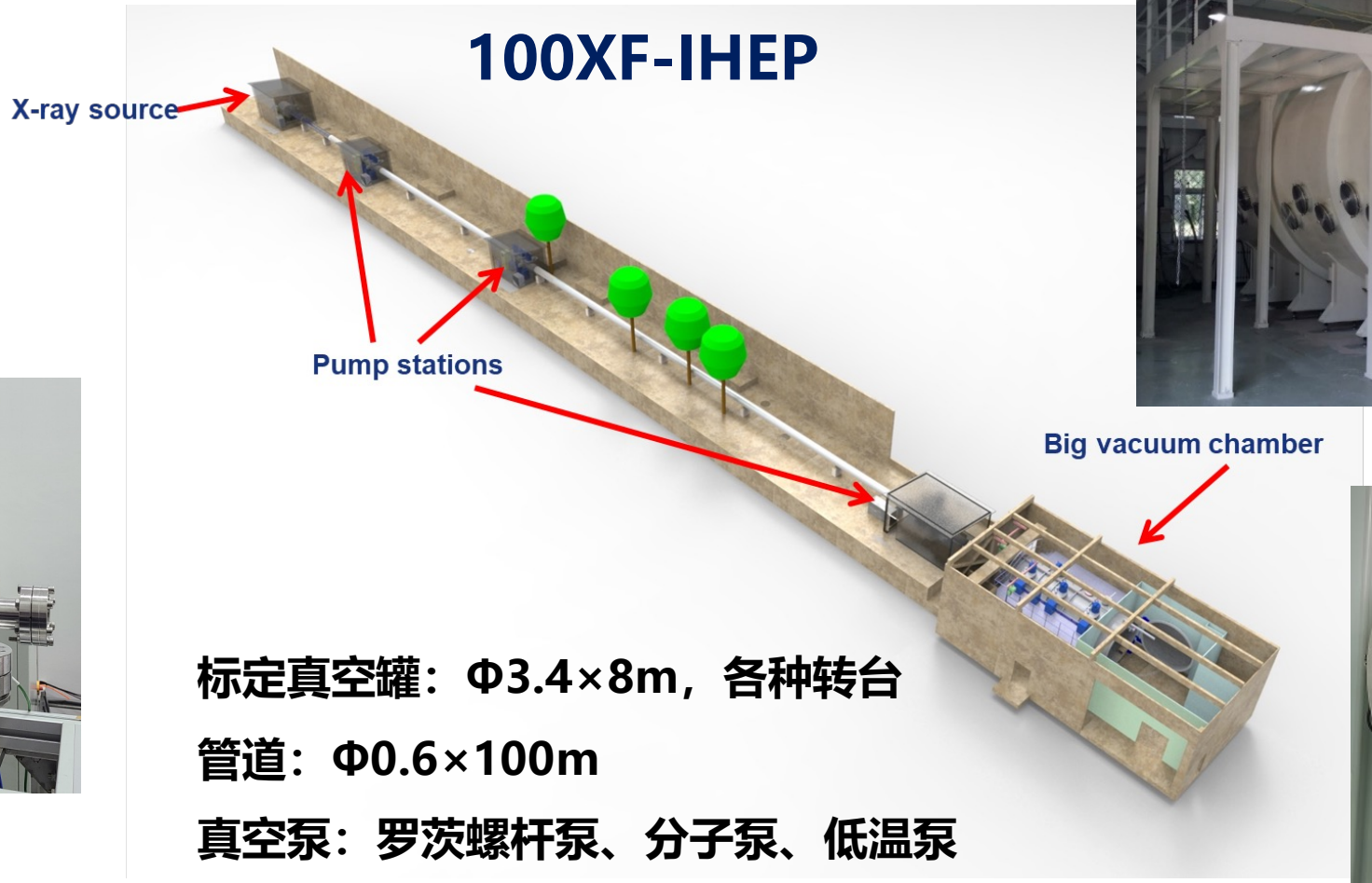


二、单能X射线源研究

多靶源X射线荧光、单色器： 能量覆盖0.2~20 keV



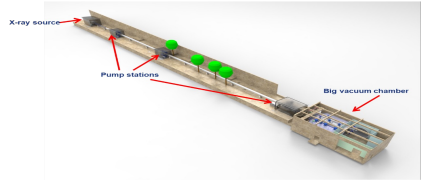
标定真空罐：Φ3.4×8m，各种转台

管道：Φ0.6×100m

真空泵：罗茨螺杆泵、分子泵、低温泵

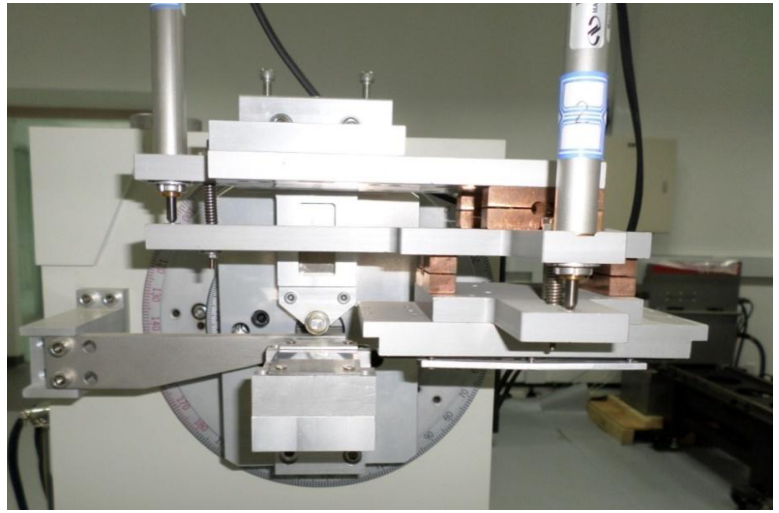
洁净度：1.0×10^{-8}g/cm^2/day

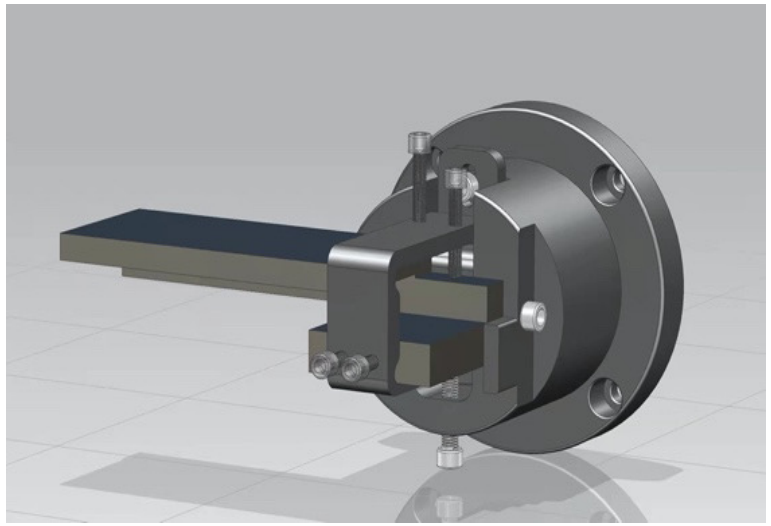
探测器：SDD、CCD

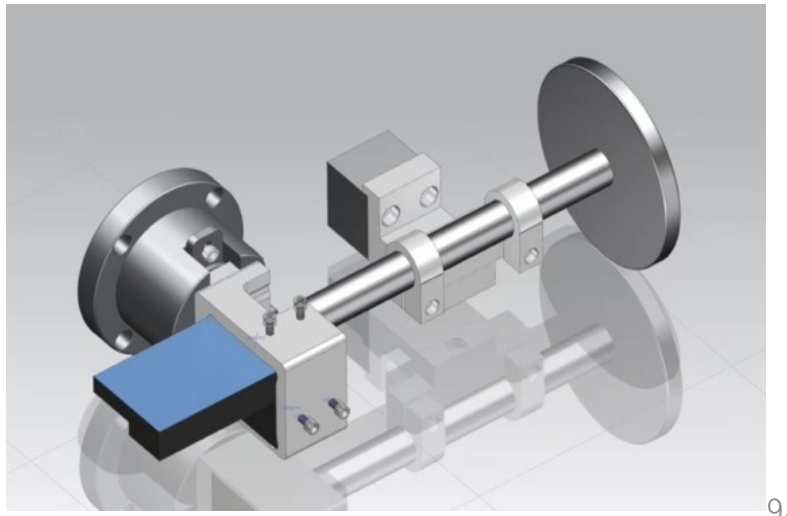


二、单能X射线源研究

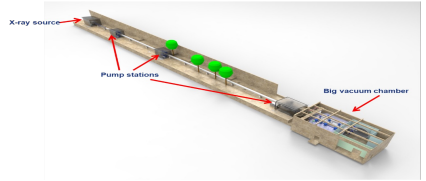
2.1 单能X射线源-晶体单色器







双晶单色器，Si晶体



二、单能X射线源研究

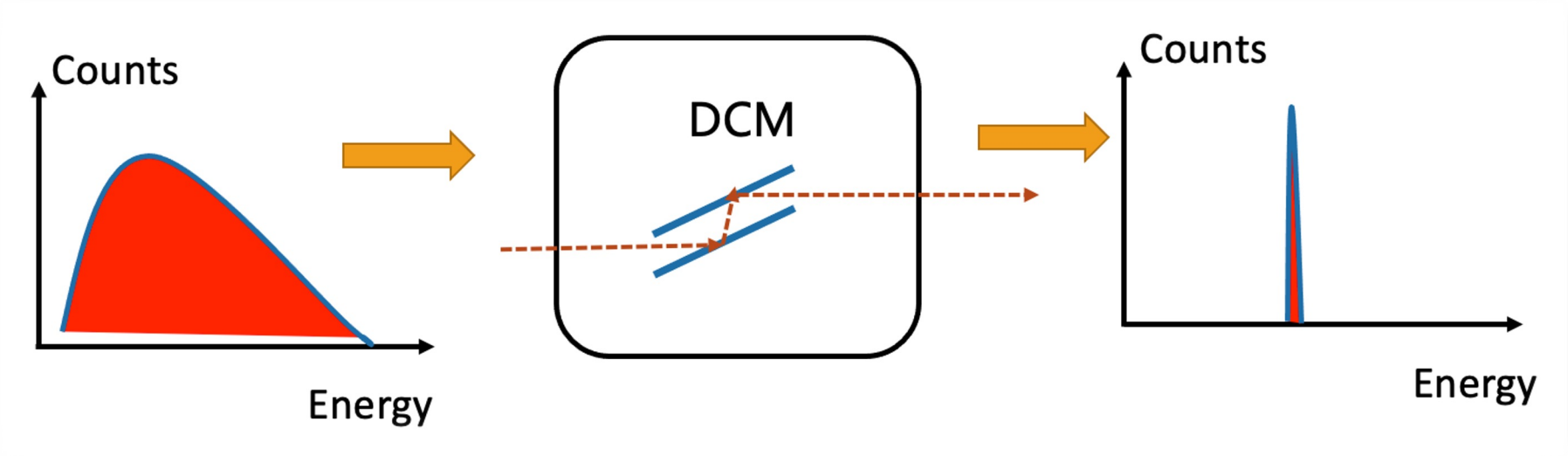
2.1 单能X射线源-晶体单色器

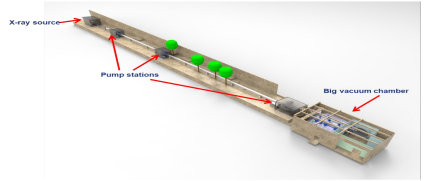
实现原理：晶体布拉格衍射

$$2d\sin\theta = n\lambda \quad (1)$$

$$E = h\nu, c = \lambda\nu \quad (2)$$

$$E = \frac{nhc}{2\,d\sin\theta} \quad (3)$$





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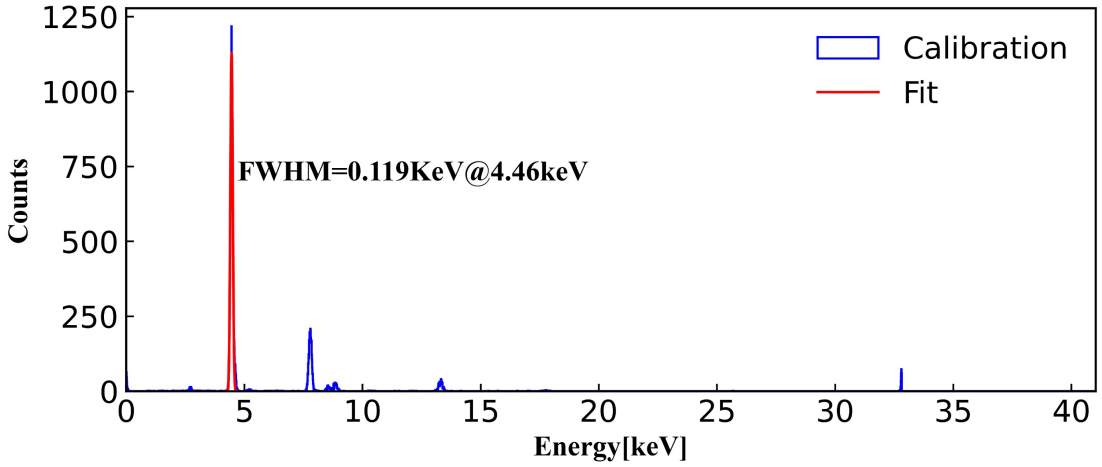
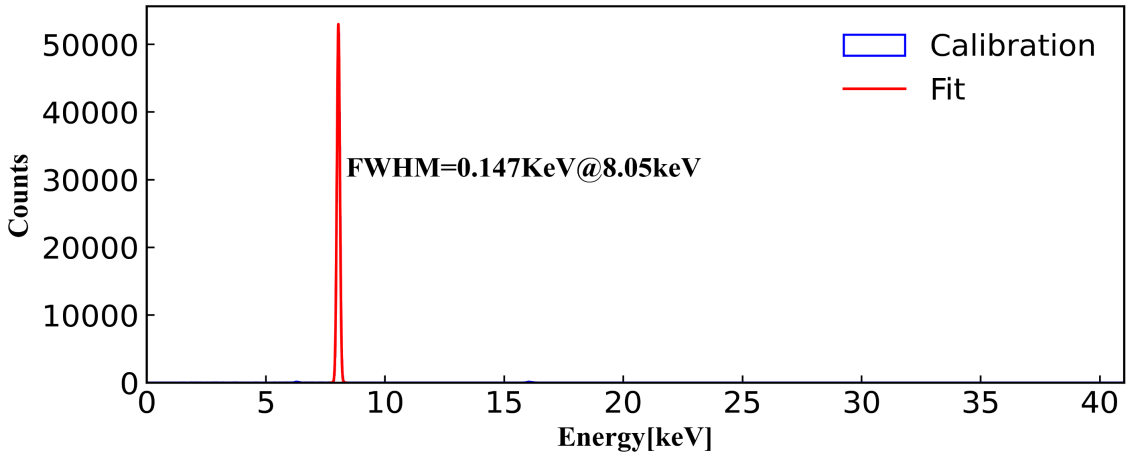
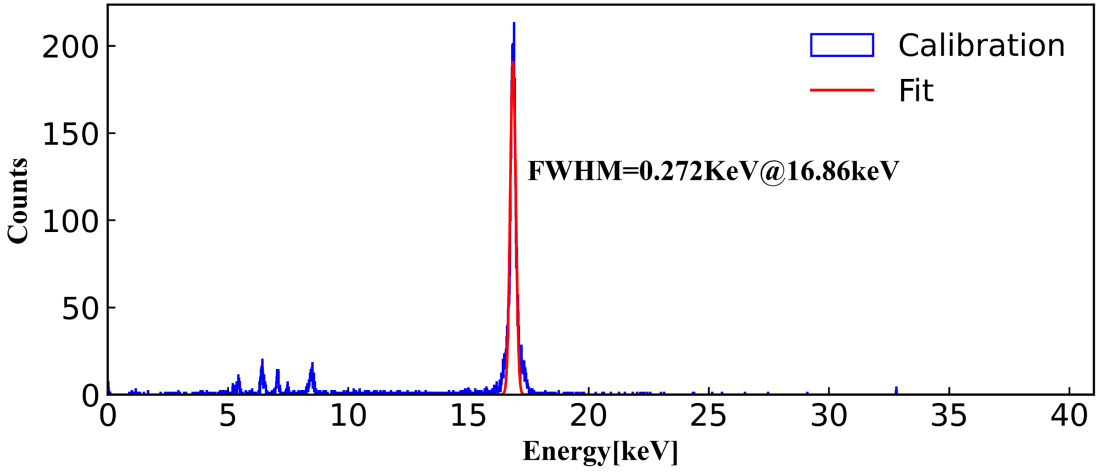
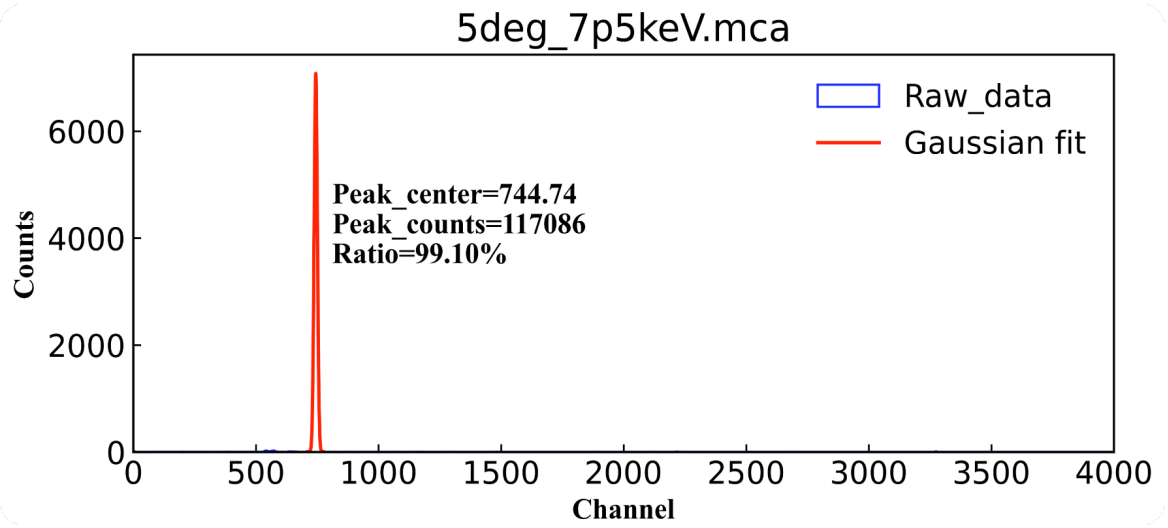
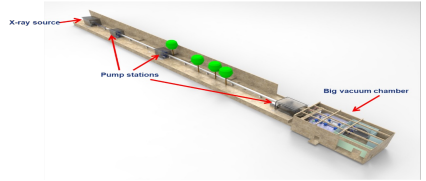
Si111晶体 4.5-16 keV











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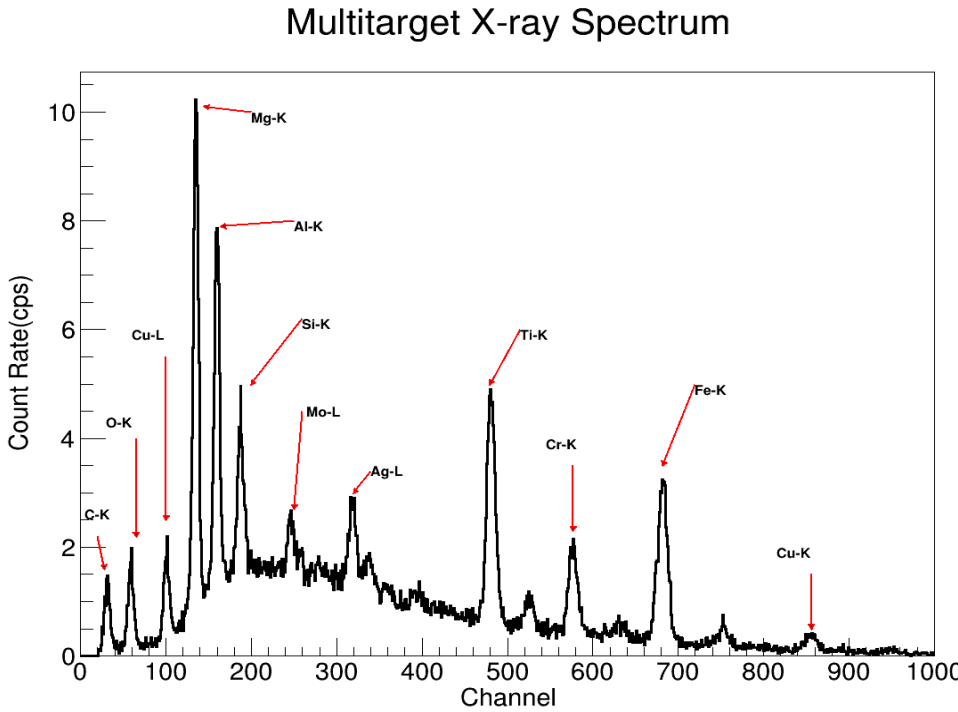
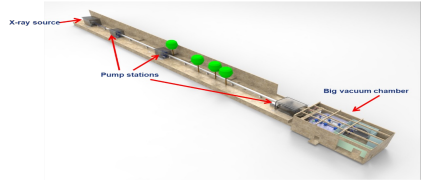
2.1单能X射线源-特征X射线荧光



电子轰击靶材料，产生特征X射线



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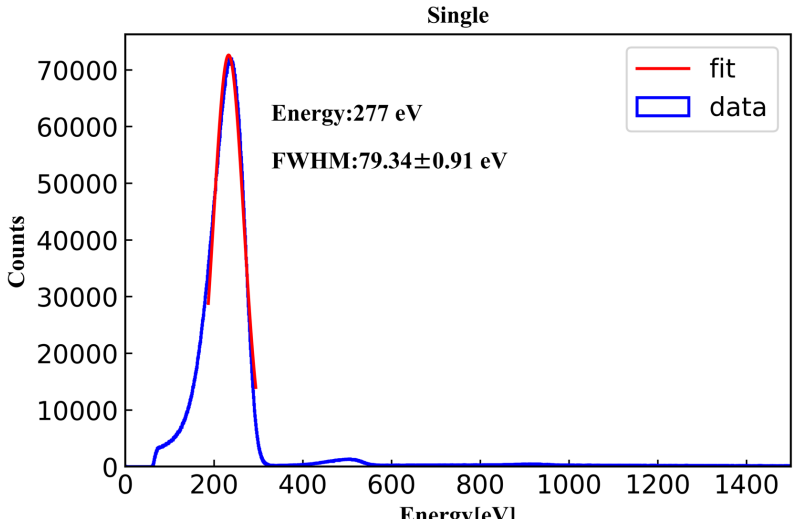
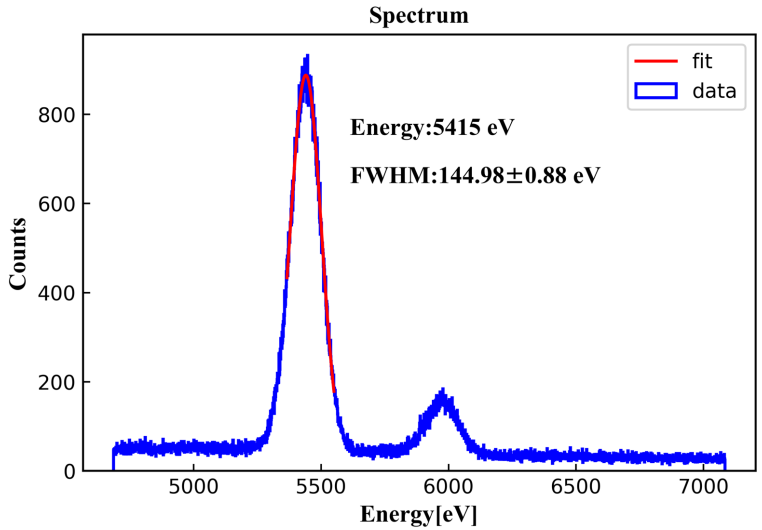
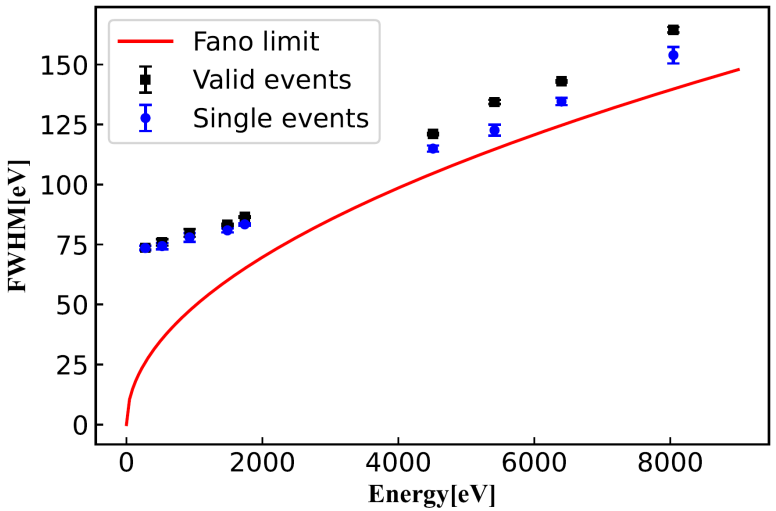
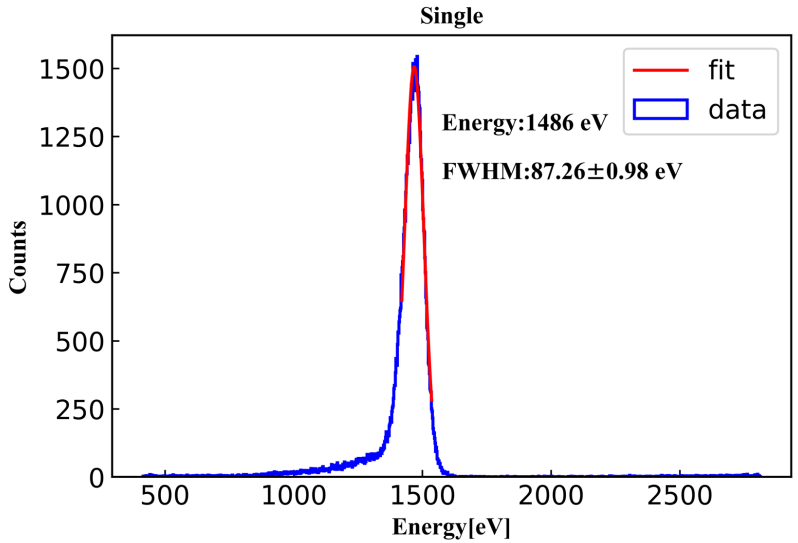
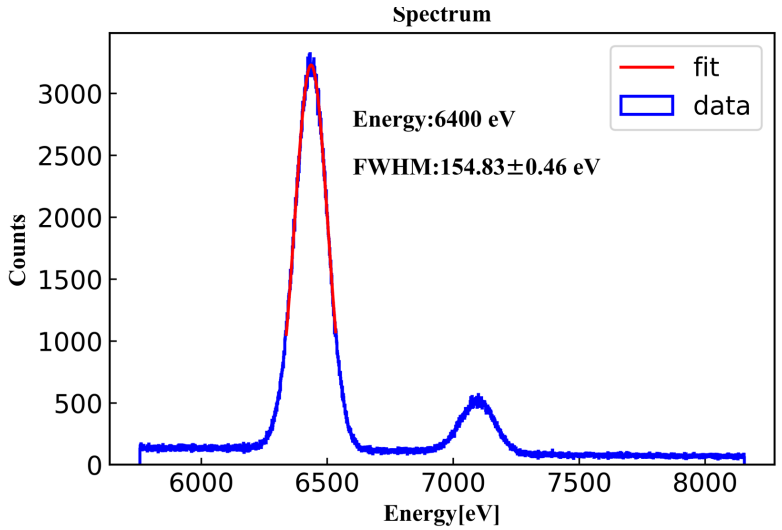


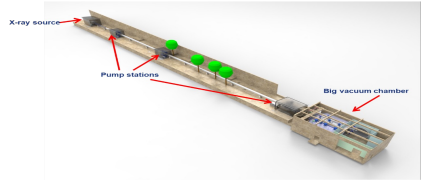








靶材：Ag、Mo、Cu、Fe、Cr、Ti、Al、Mg、SiO_2、C，能量覆盖0.2~20 keV



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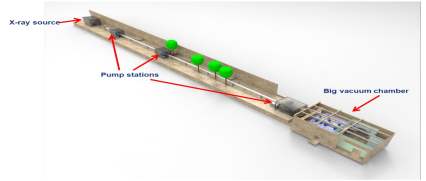
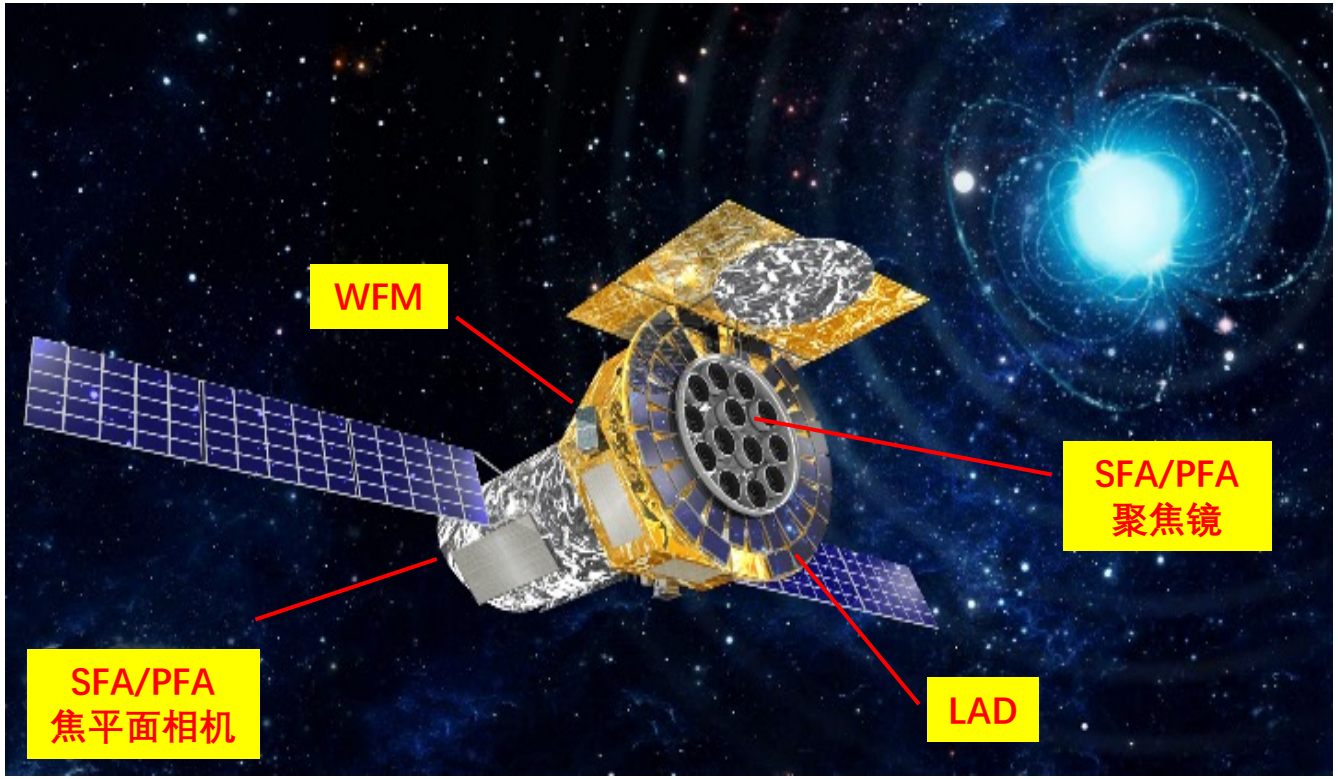
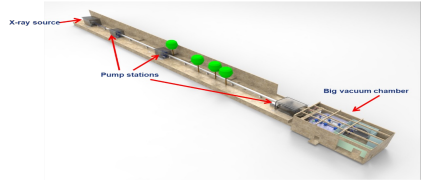


三、空间X射线望远镜标定

enhanced X-ray Timing and Polarization-eXTP



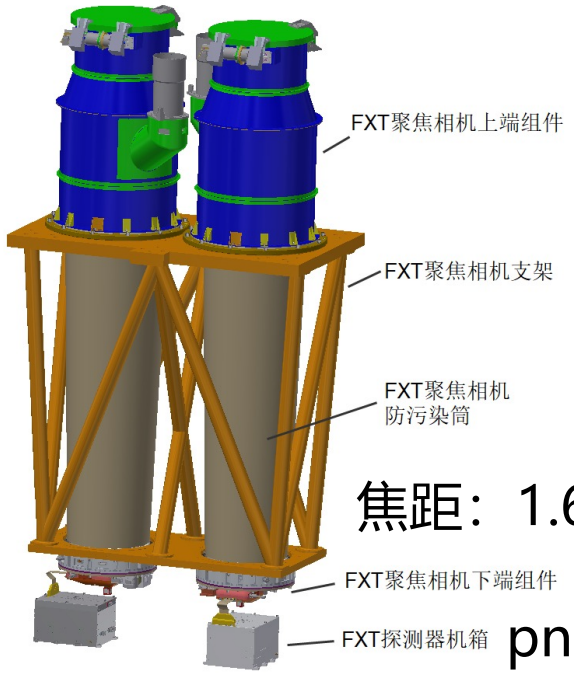
SFA/PFA-Wolter-I type聚焦望远镜镜（共13组）



三、空间X射线望远镜标定

Einstein probe-EP

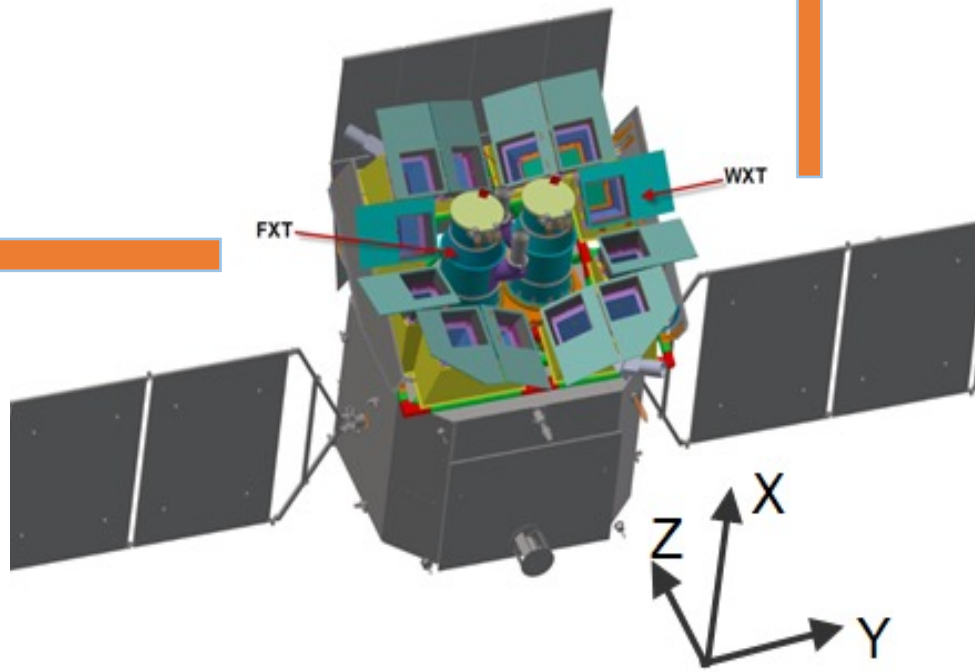
2组采用Wolter-I型掠入射光学的后随X射线望远镜（Follow-up X-ray telescope，FXT，IHEP）

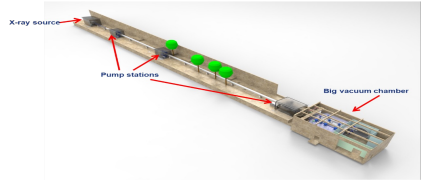


焦距：1.6m

pnCCD

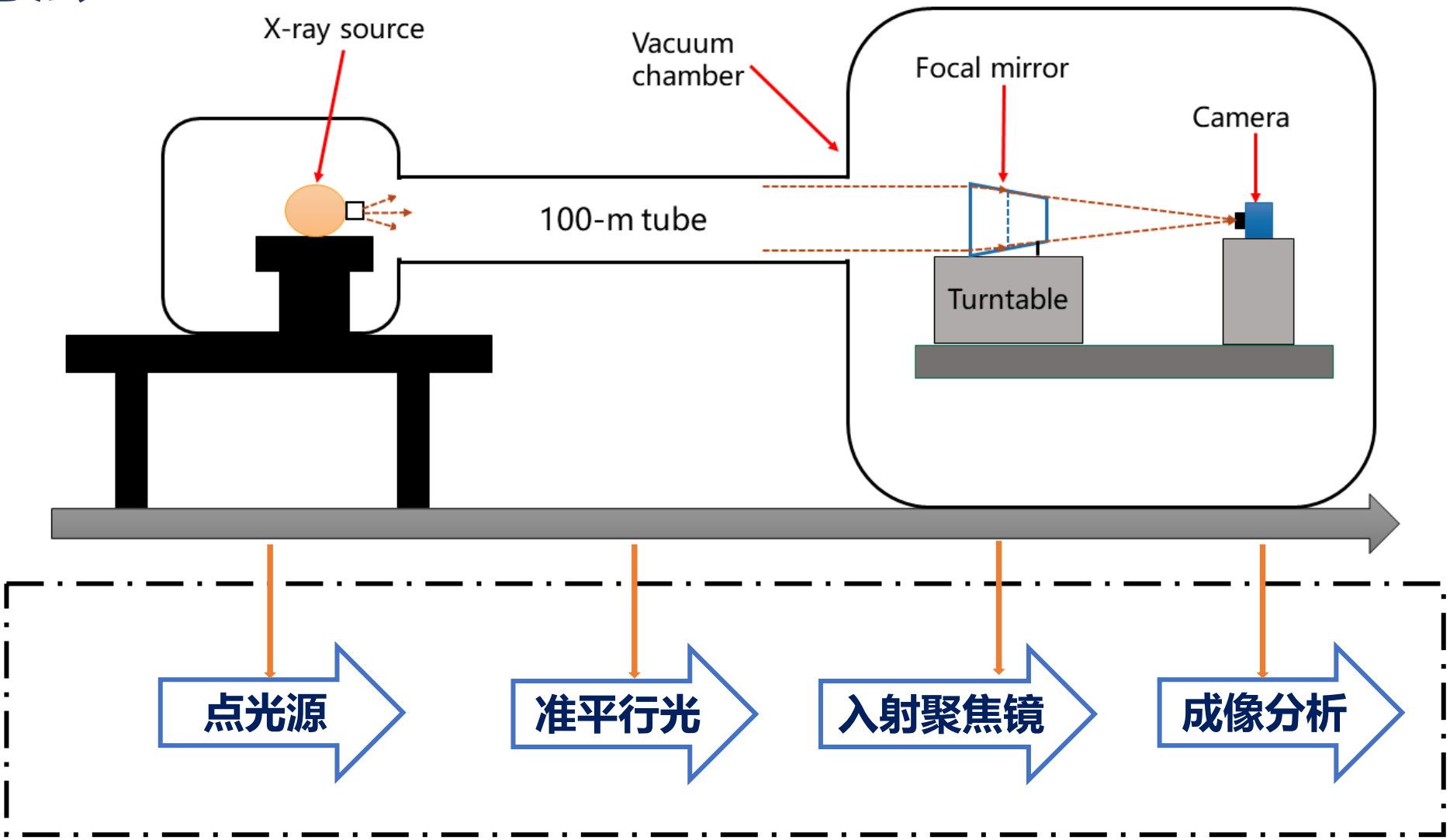
12台基于龙虾眼微孔聚焦成像技术的宽视场X射线望远镜（Wide-field X-ray Telescope, WXT, NAO）

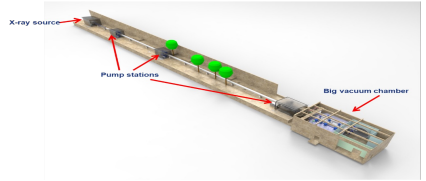




三、空间X射线望远镜标定

3.1 实验方法



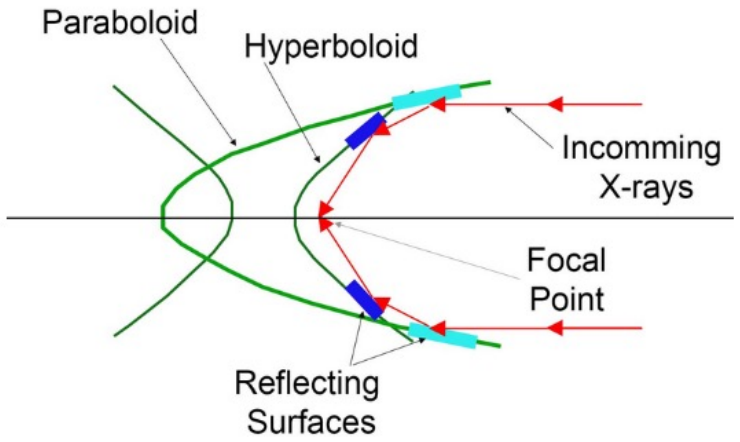


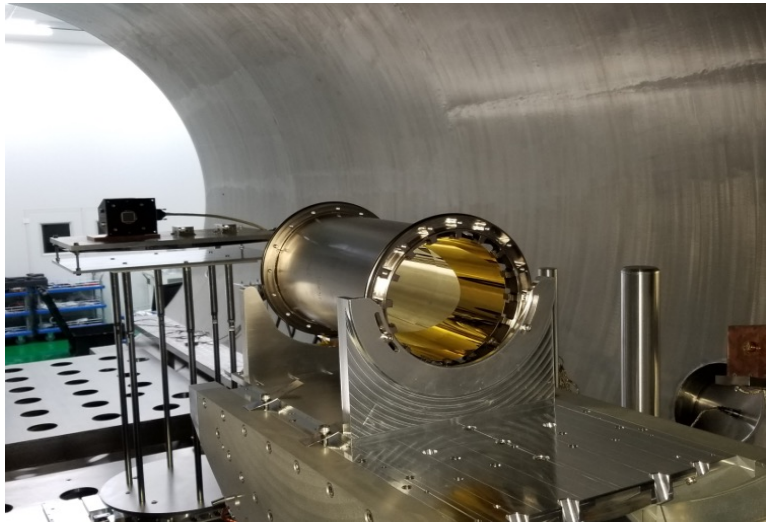
三、空间X射线望远镜标定

3.2 标定内容

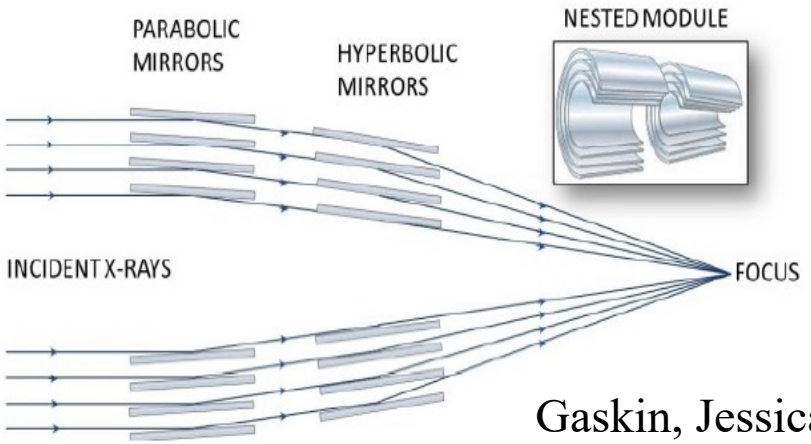
Wolter-I型聚焦镜

单层镜片

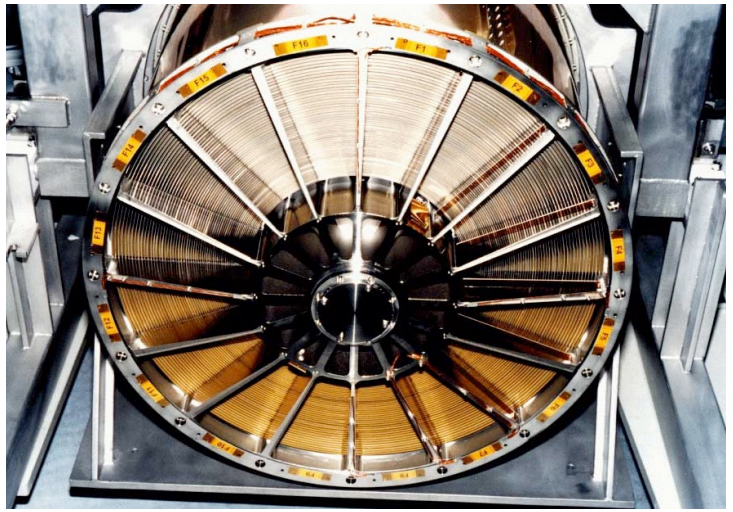




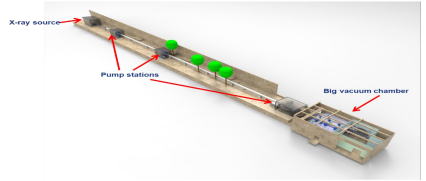
多层嵌套镜片组



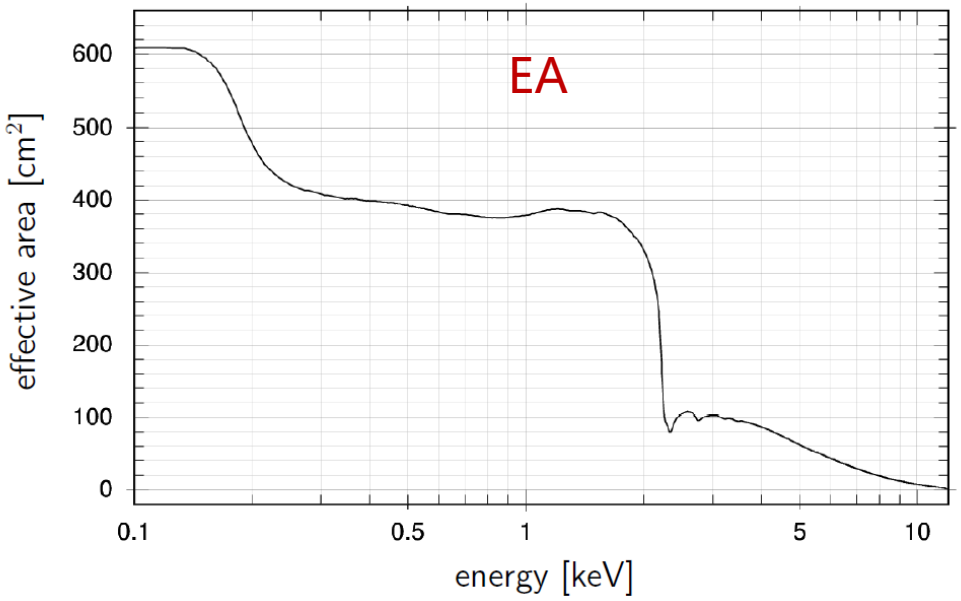
Gaskin, Jessica, et al

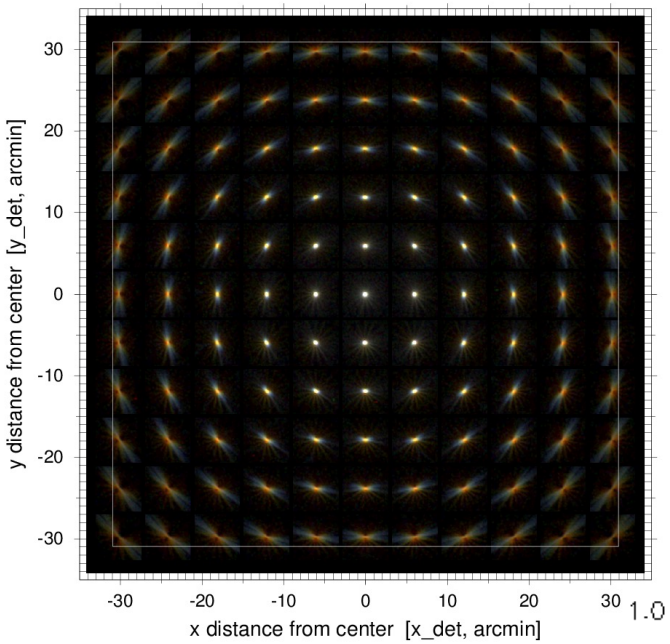


https://www.cosmos.esa.int/web/xmm-newton

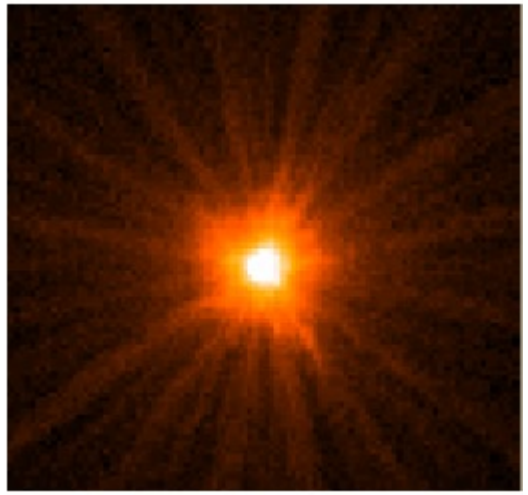


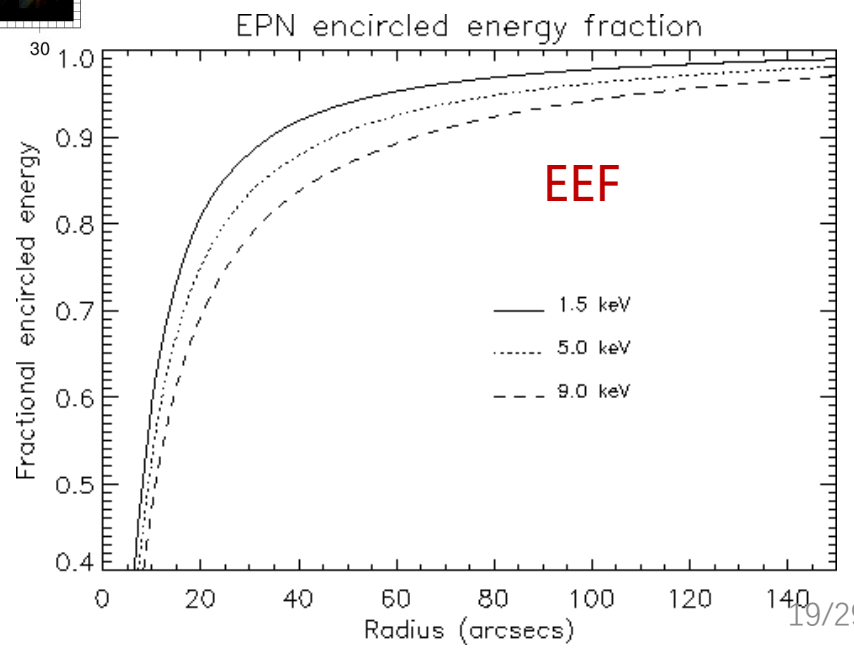
三、空间X射线望远镜标定





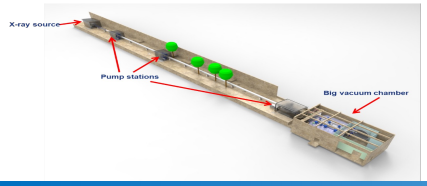
PSF





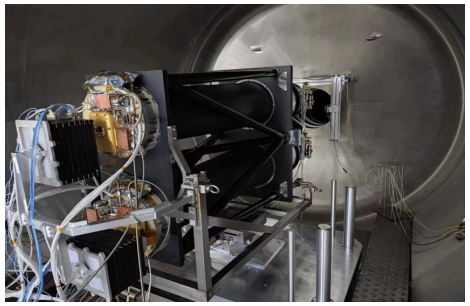
- ✓ 有效面积：Effective area
- ✓ 渐晕：Vignetting
- ✓ 点扩展函数：Point Spread Function(PSF)
- ✓ 角分辨：Half-Power Diameter(HPD)(50%)

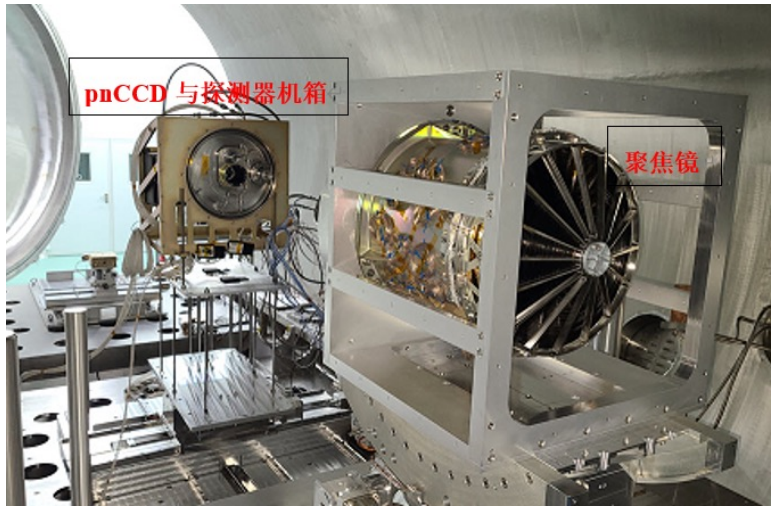
[1] Dennerl, Konrad, et al. "The calibration of eROSITA on SRG.
[2] https://heasarc.gsfc.nasa.gov/docs/xmm/uhb/onaxisxraypsf.html

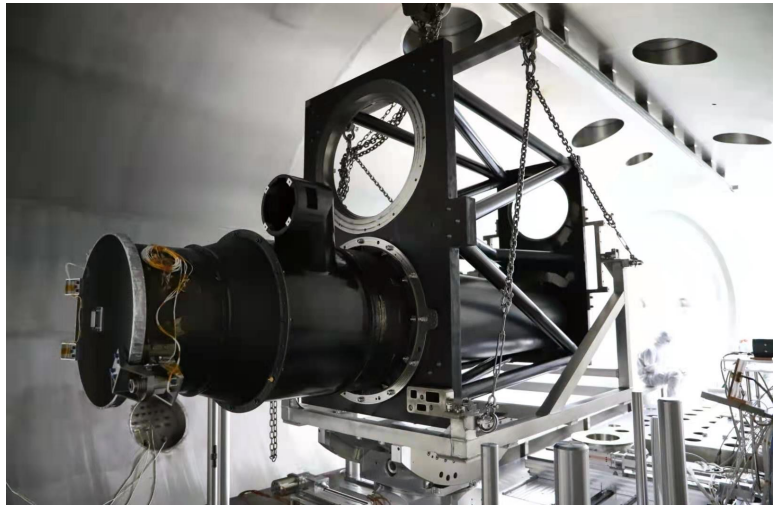


三、空间X射线望远镜标定

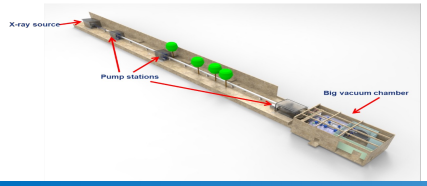
3.3 EP-FXT聚焦镜标定





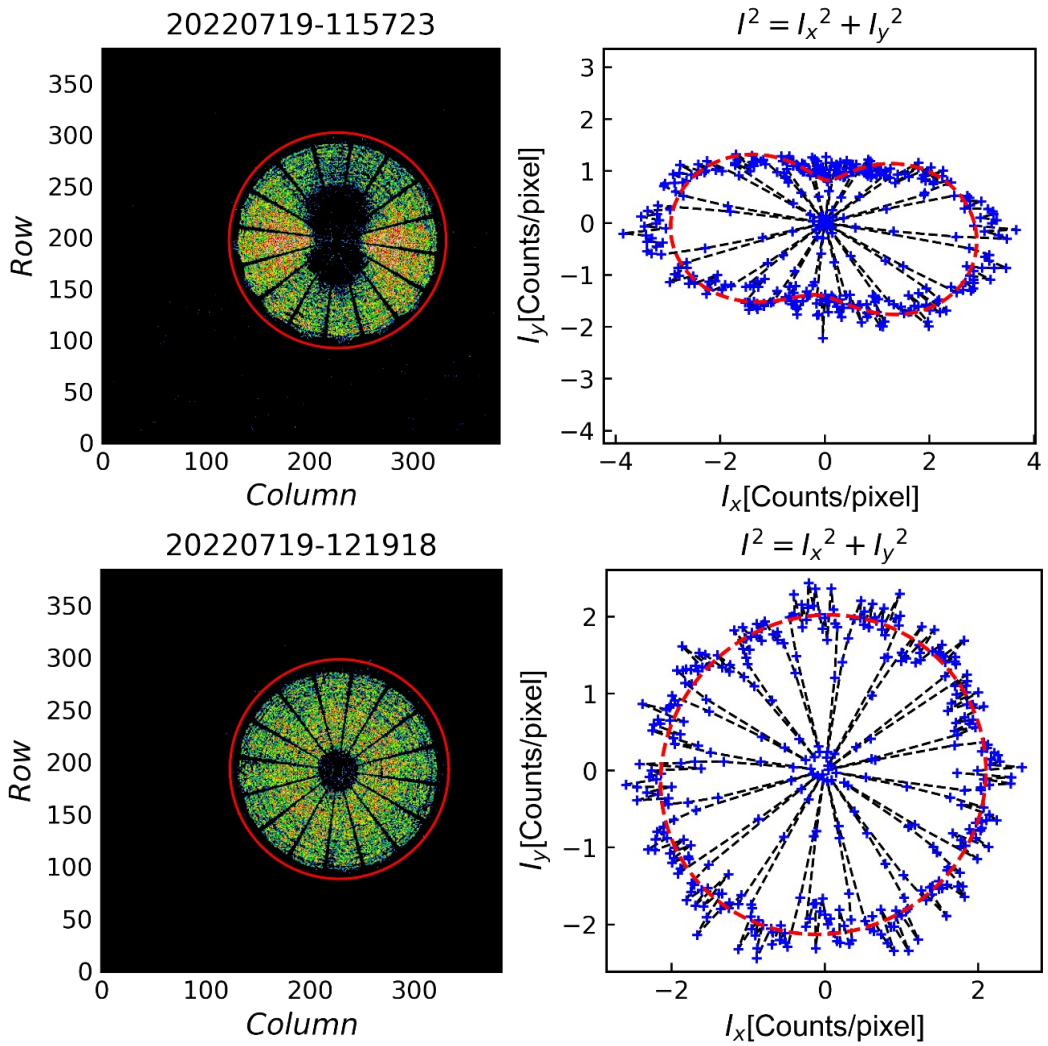


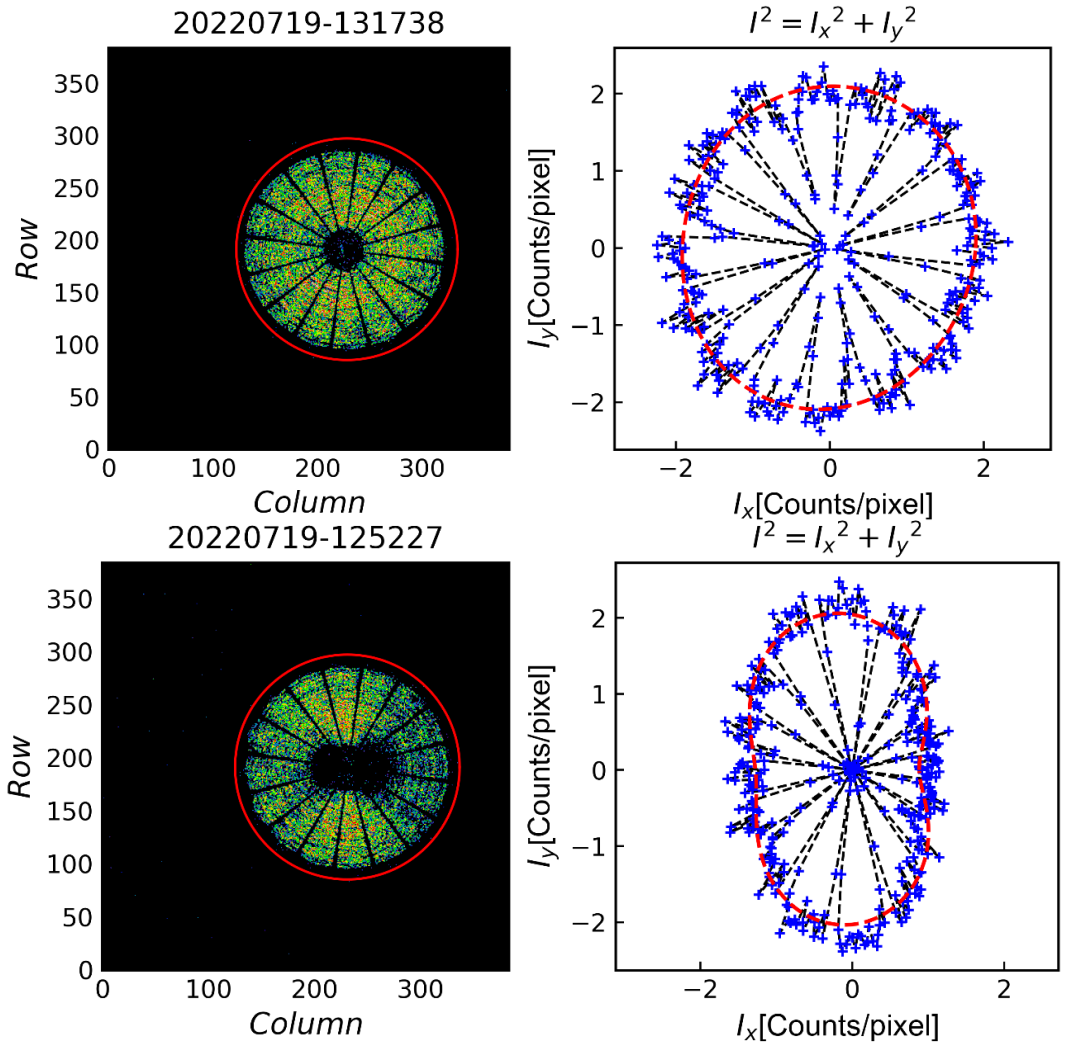
- ✓ 光轴对准
- ✓ 焦点寻找
- ✓ 渐晕：Vignetting
- ✓ 角分辨：Half-Power Diameter, HPD（50%）
- ✓ 点扩展函数：Point Spread Function(PSF)
- ✓ 有效面积：Effective area

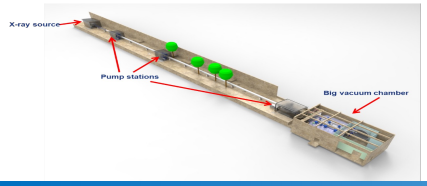


三、空间X射线望远镜标定

➢ 聚焦镜正样标定-光轴对准1：计算拟合光子圆周分布强度



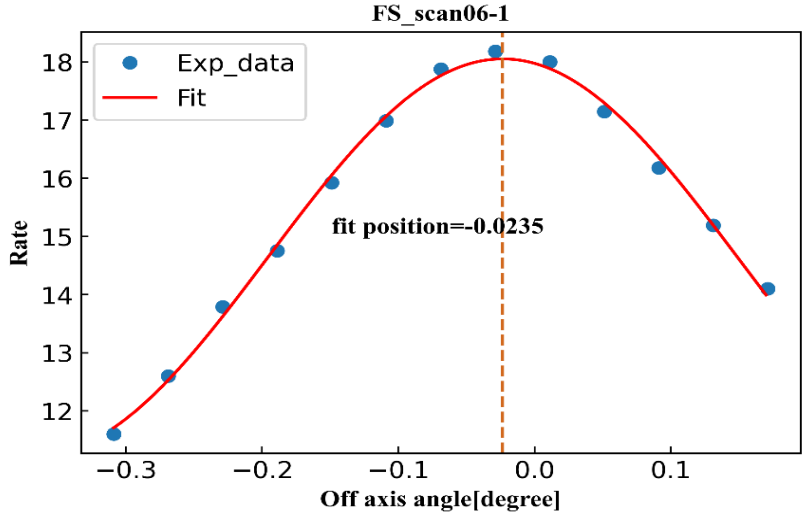


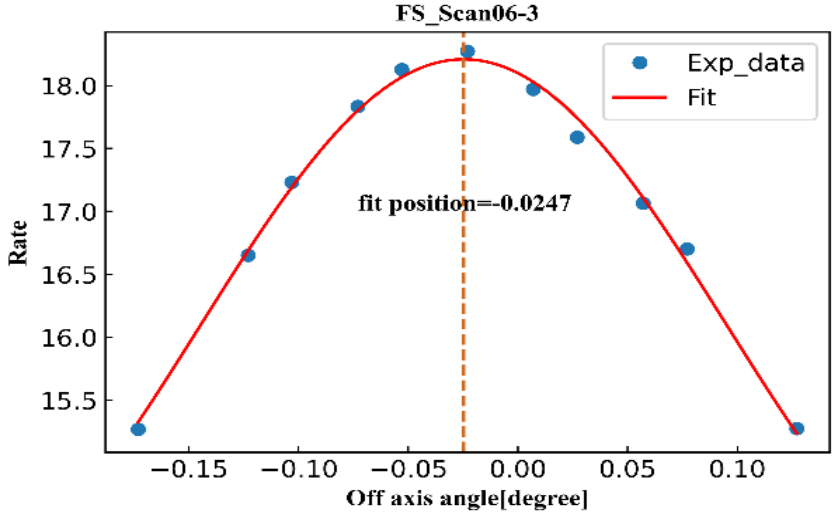


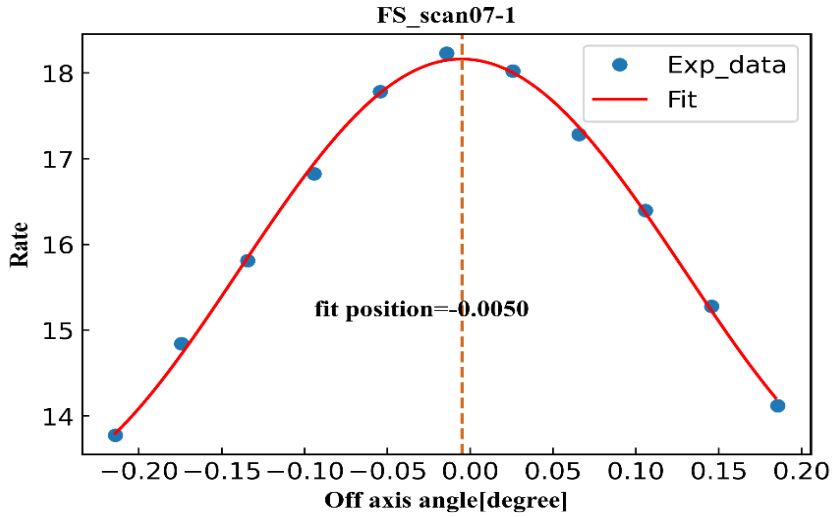
三、空间X射线望远镜标定

➢ 聚焦镜正样标定-光轴对准2 ：拟合不同偏轴角计数率分布

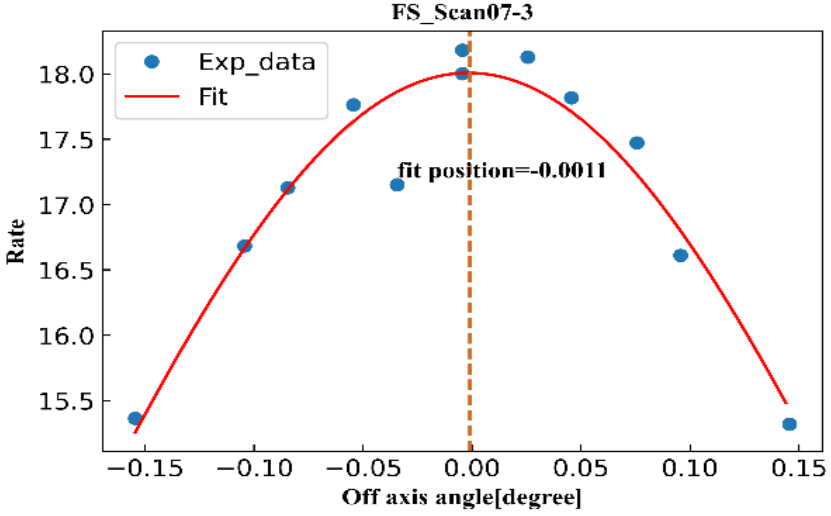
俯仰

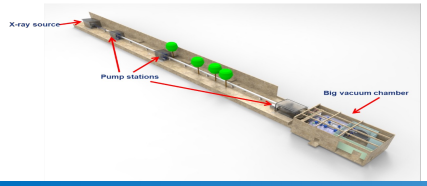






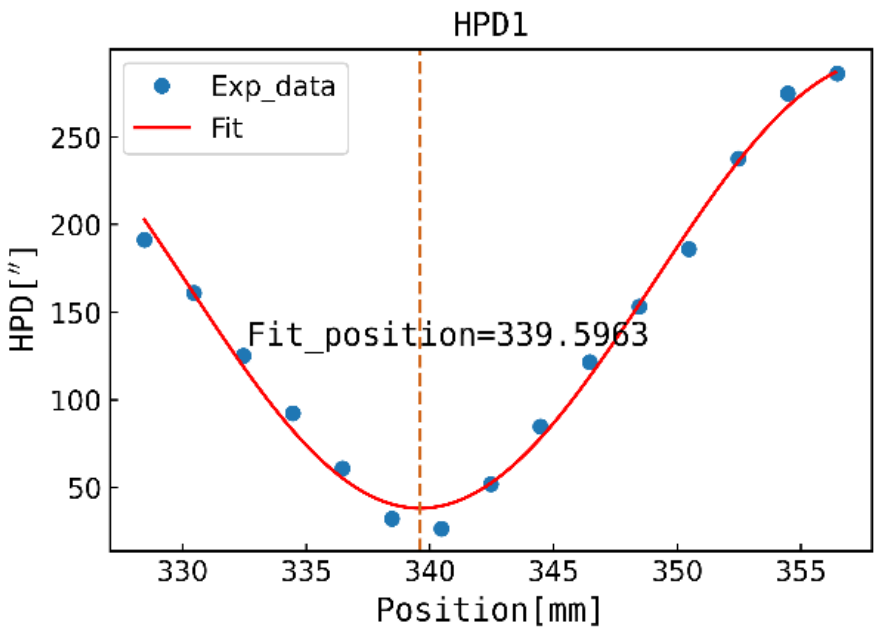
旋转

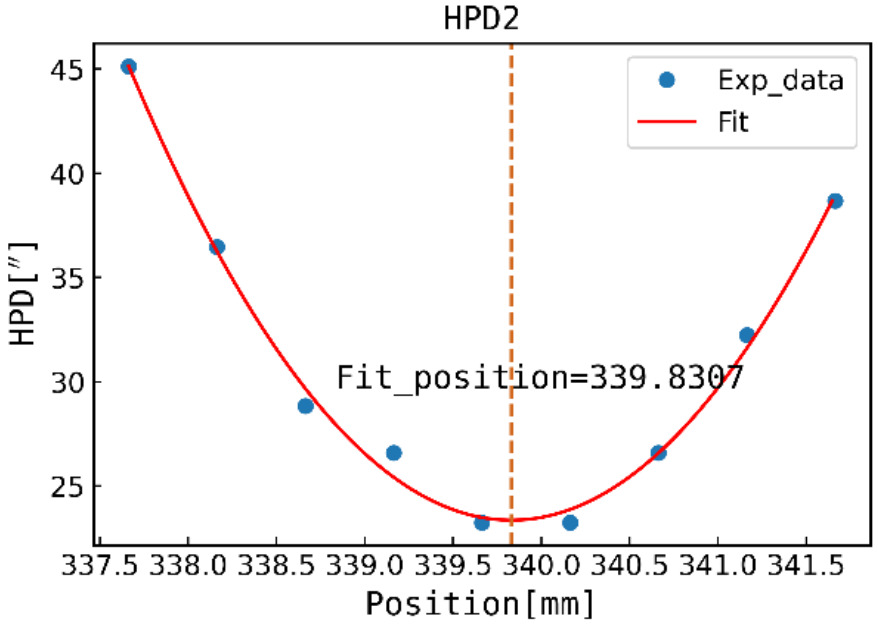


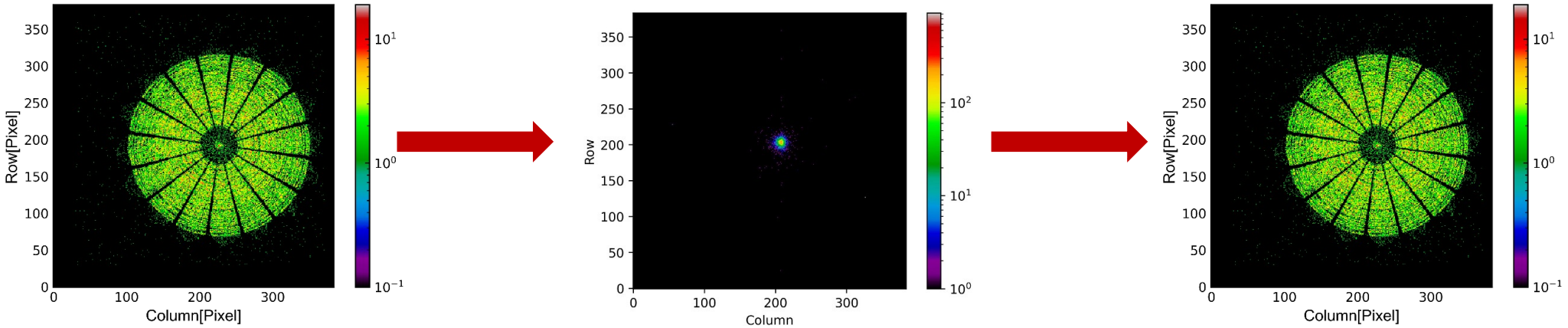


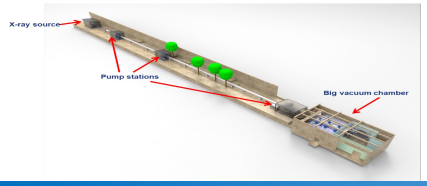
三、空间X射线望远镜标定

➢ 聚焦镜正样标定-寻焦点 ： 拟合HPD随距离变化曲线



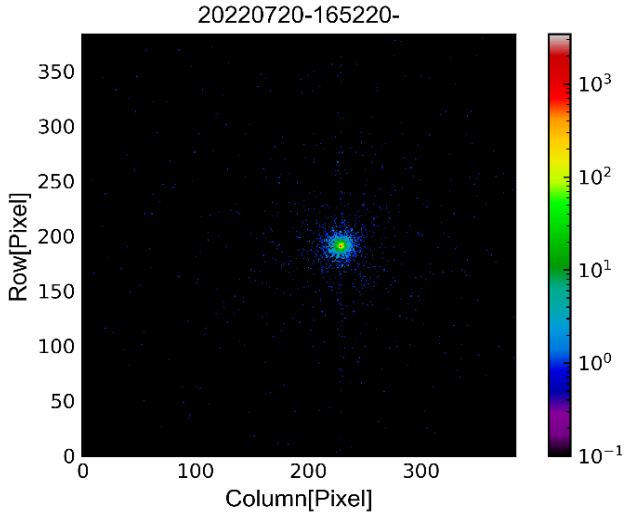


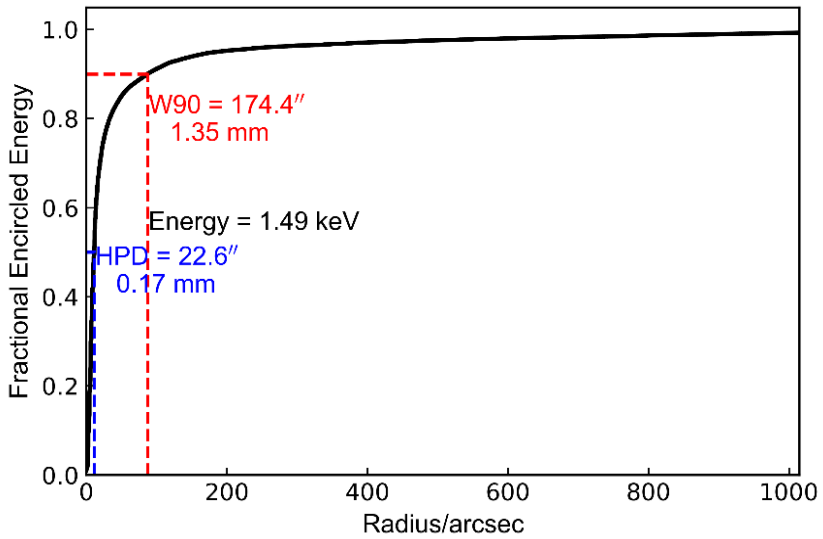


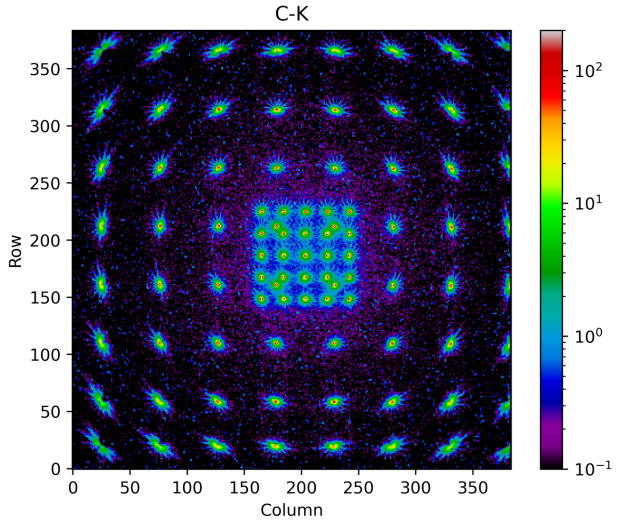


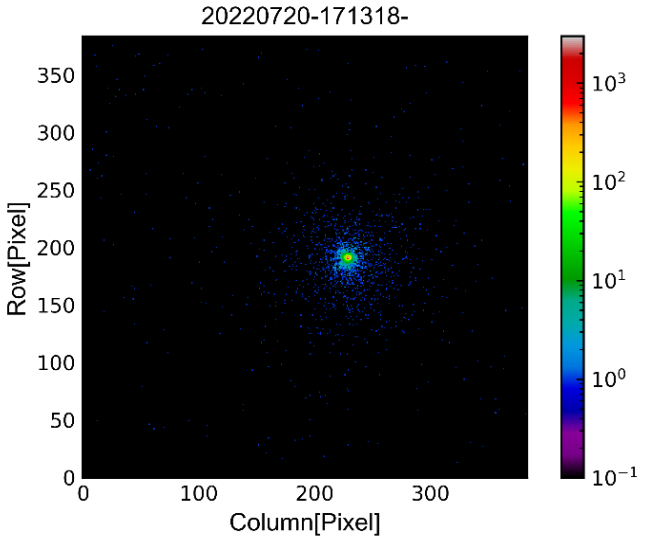
三、空间X射线望远镜标定

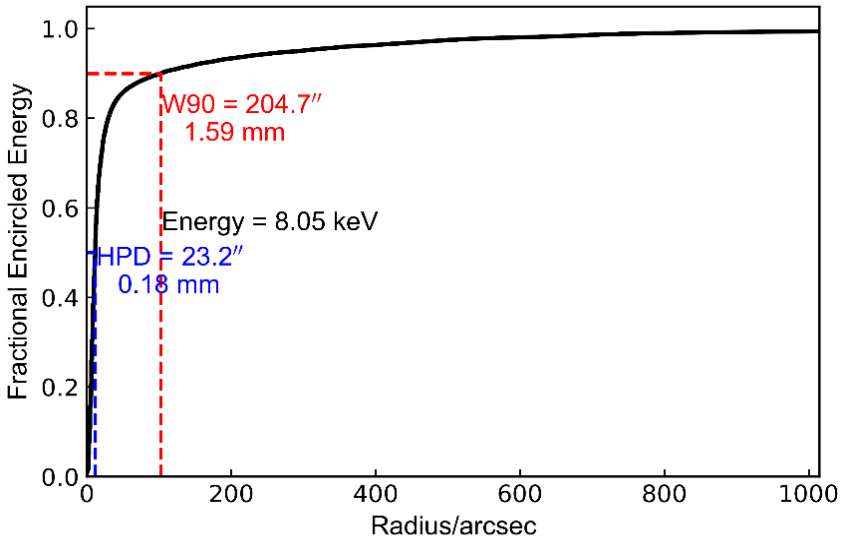
➢ 聚焦镜正样标定-PSF、角分辨

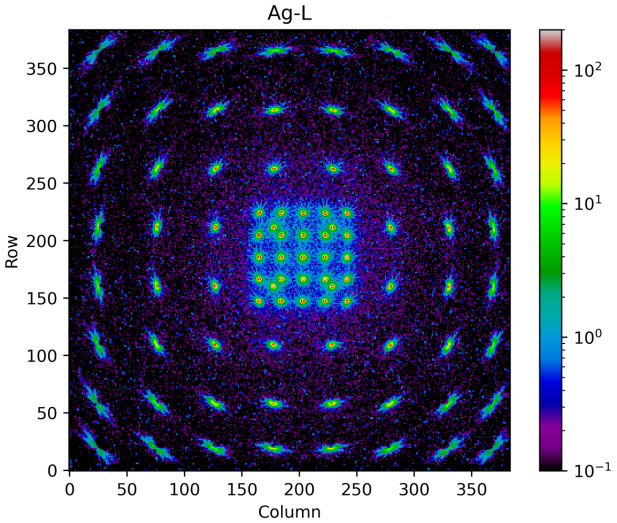


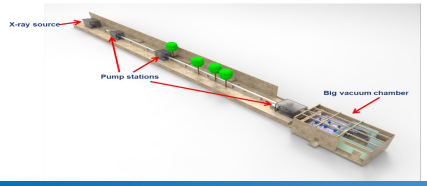






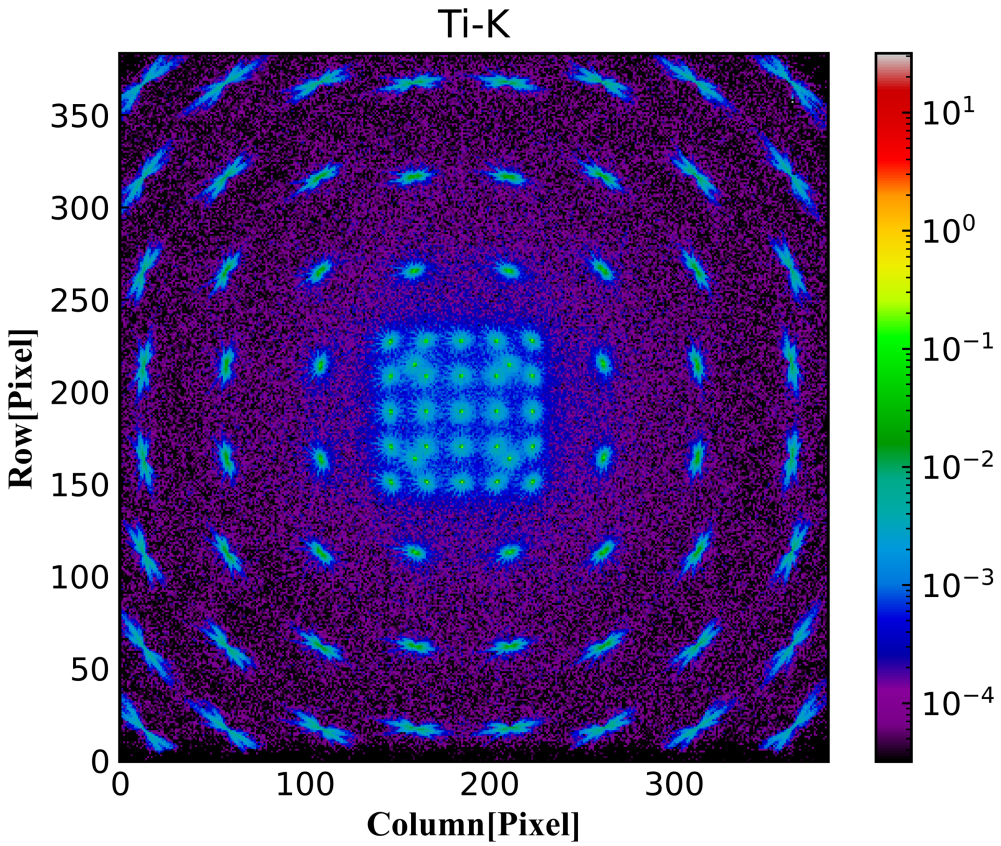






三、空间X射线望远镜标定

➢ 聚焦镜正样标定-PSF、角分辨



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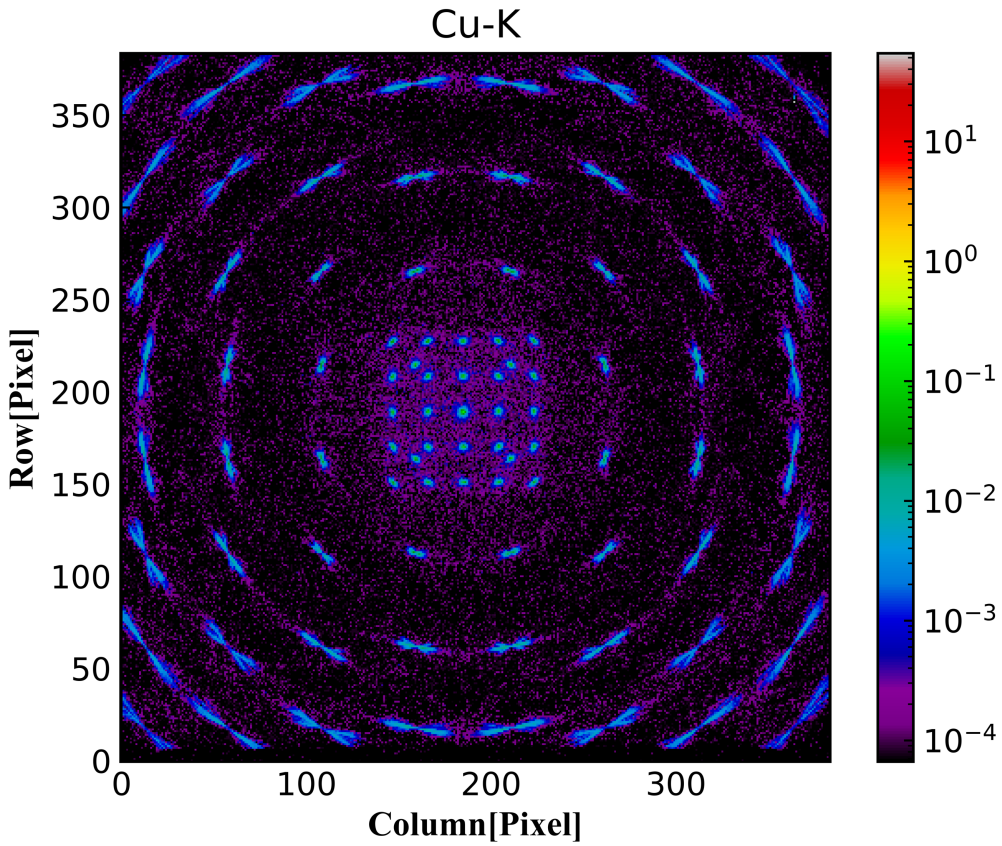
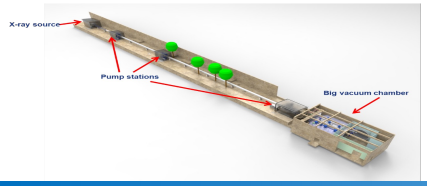
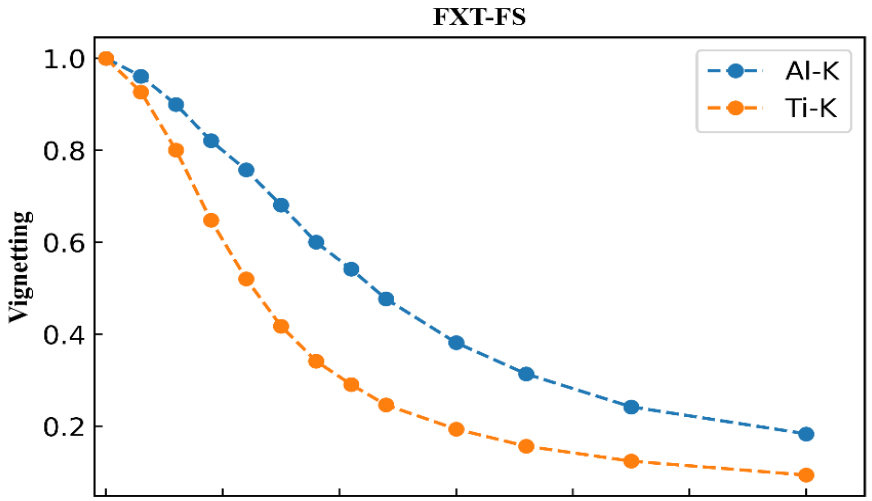


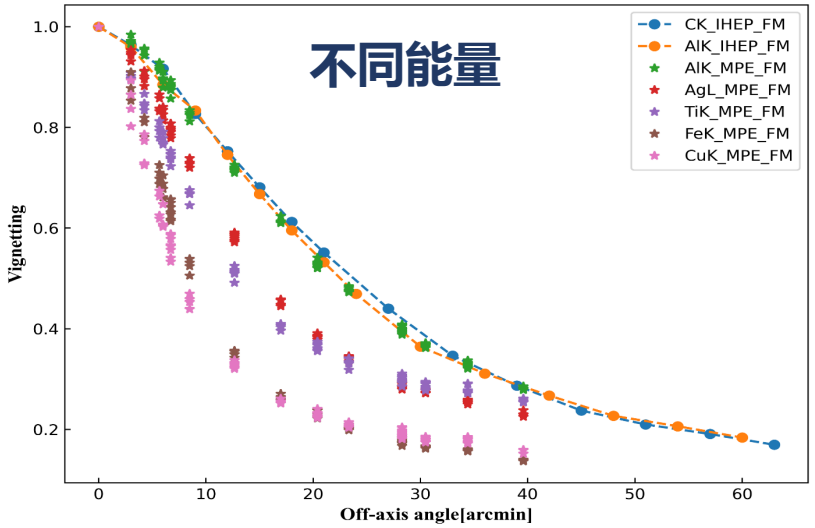
8.04 keV

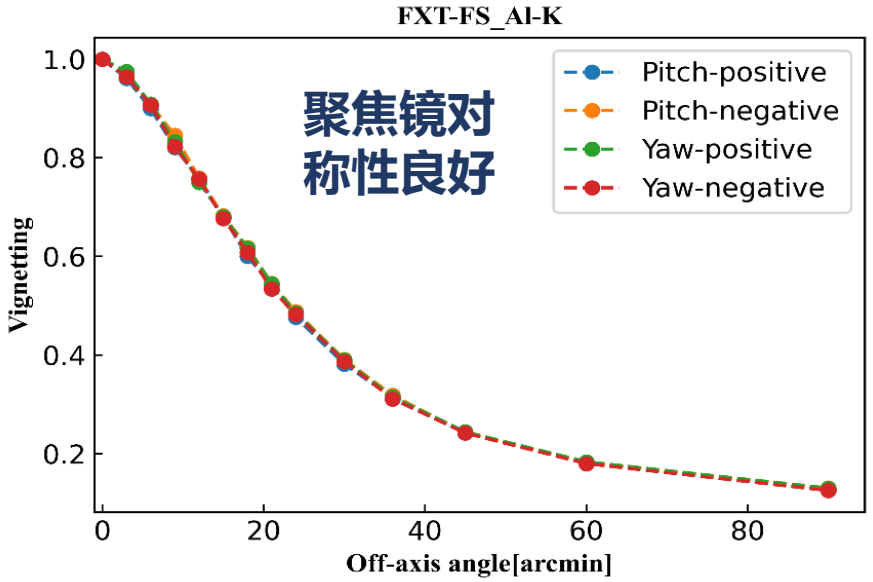


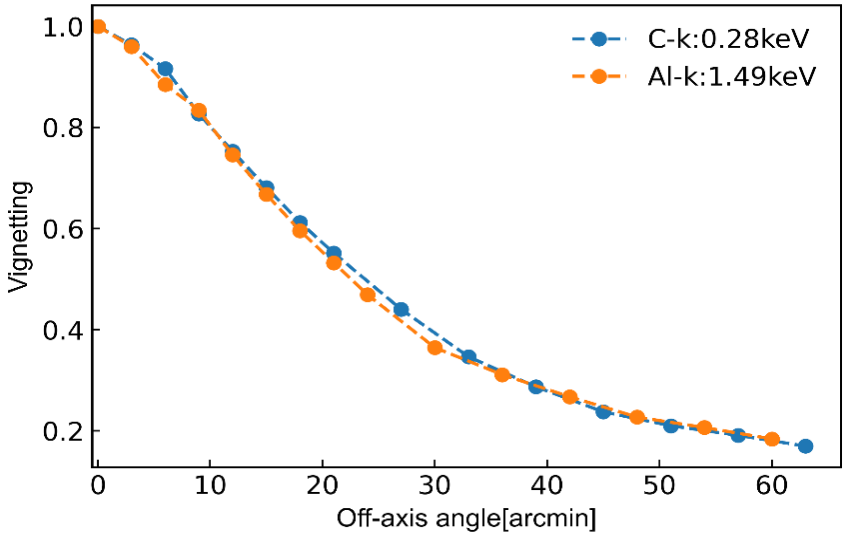
三、空间X射线望远镜标定

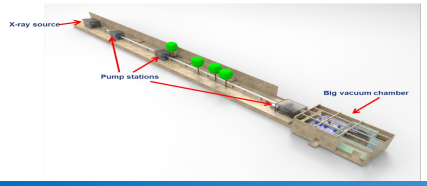
➢ 聚焦镜正样标定-Vignetting





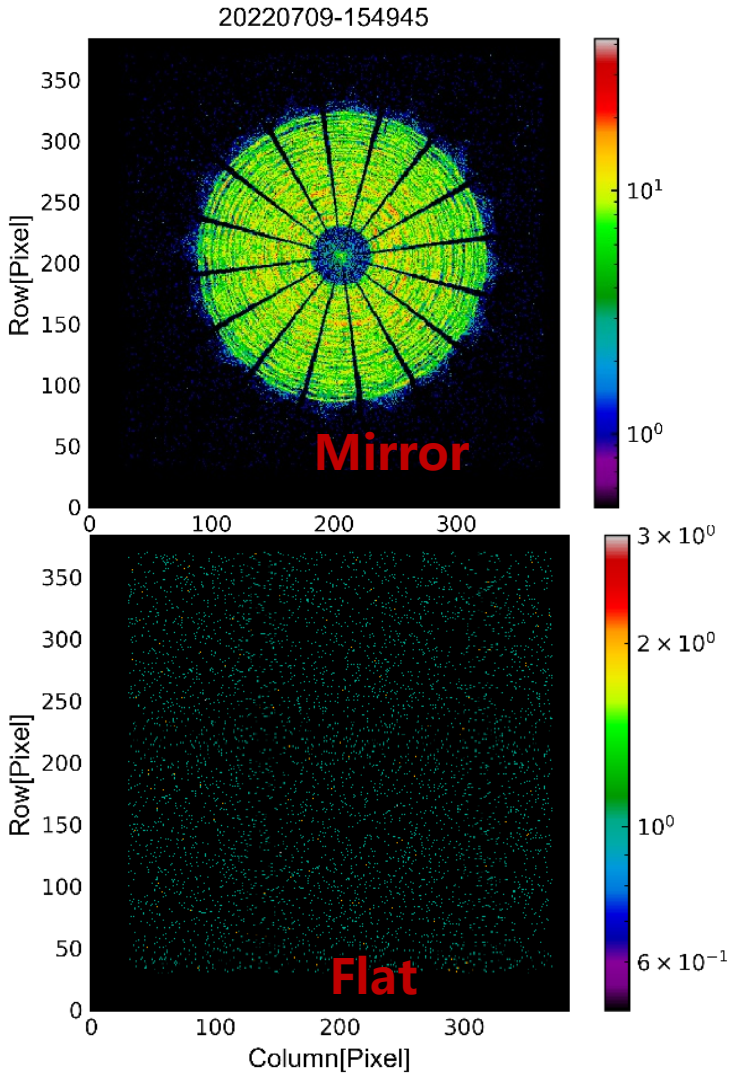






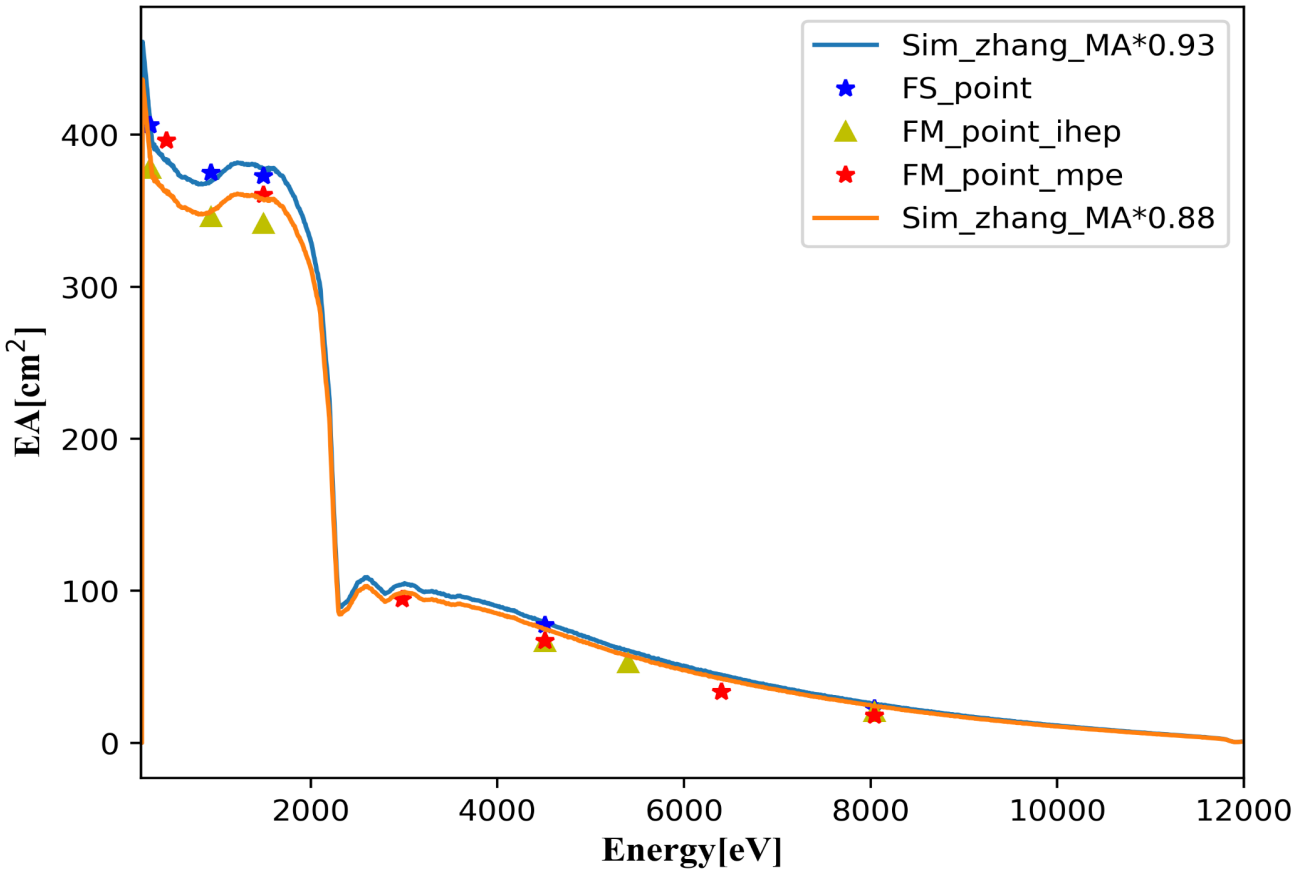
三、空间X射线望远镜标定

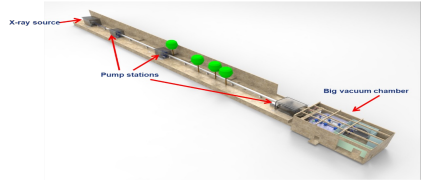
➢ 聚焦镜正样标定-有效面积



计算方法

$$A_{eff} = \frac{cts_mirror}{cts_flat} * A_{det} * D * G$$





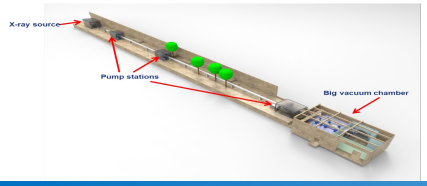
目 录

① 研究背景及国内外进展

② 单能X射线源研究

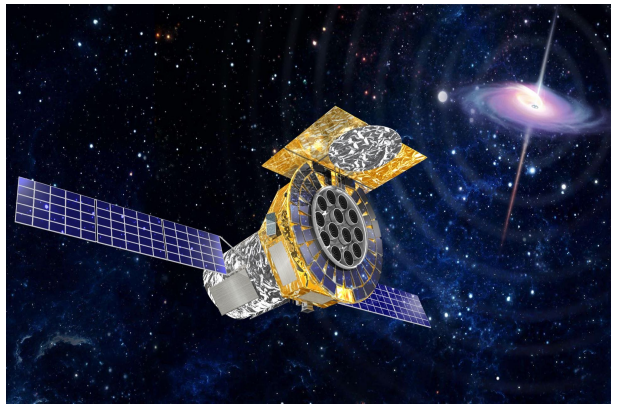
③ 空间X射线望远镜标定

④ **总结与展望**



四、总结与展望

- 介绍了X射线天文卫星发展及其载荷地面标定，以及我国的百米X射线标定装置；
- 研制了能量0.2-20 keV单能X射线源，可以用于各种X射线探测器、聚焦镜的测试标定；
- 完成了国内首个大型Wolter-I型X射线聚望远镜EP-FXT的地面测试标定;
- 预期可以为我国未来各种X射线天文卫星载荷及光学组件进行精密可靠的地面测试标定。



eXTP

CATCH

谢谢！