

# eXTP卫星偏振测量X射线聚焦望远镜 阵列研制进展

姜维春(IHEP)

*on behalf of the eXTP-PFA Consortium*

China, October 22, 2021

# OUTLINE

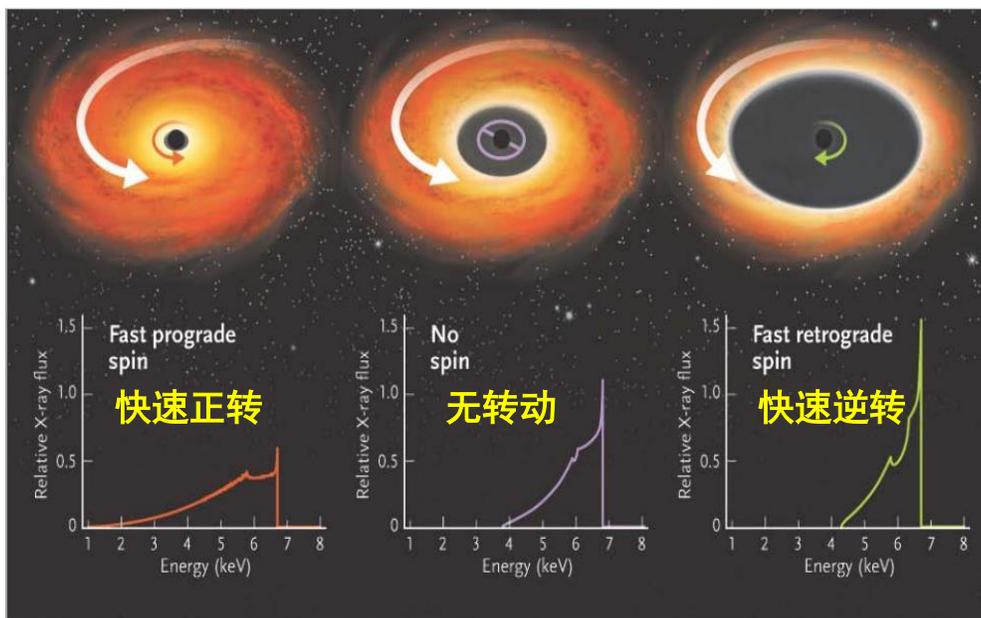
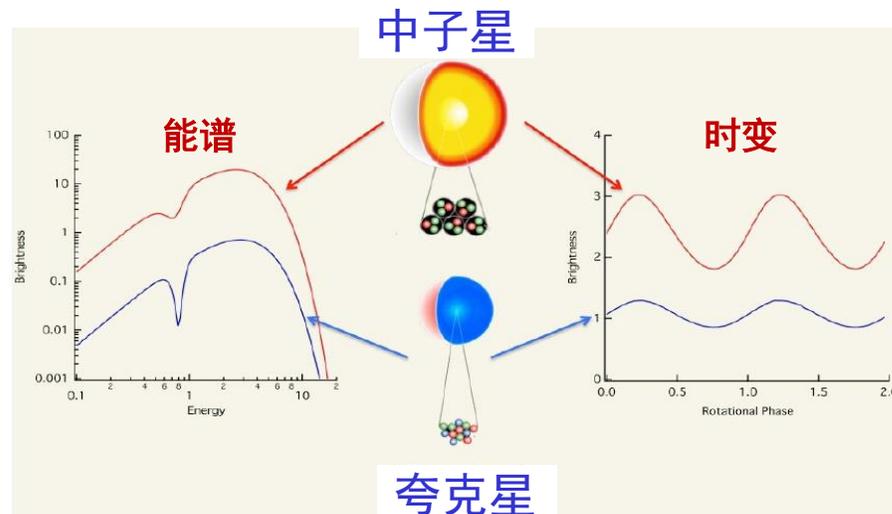


- PFA概述
- 总体指标和满足情况
- PFA研制进展及相关问题
- 总结

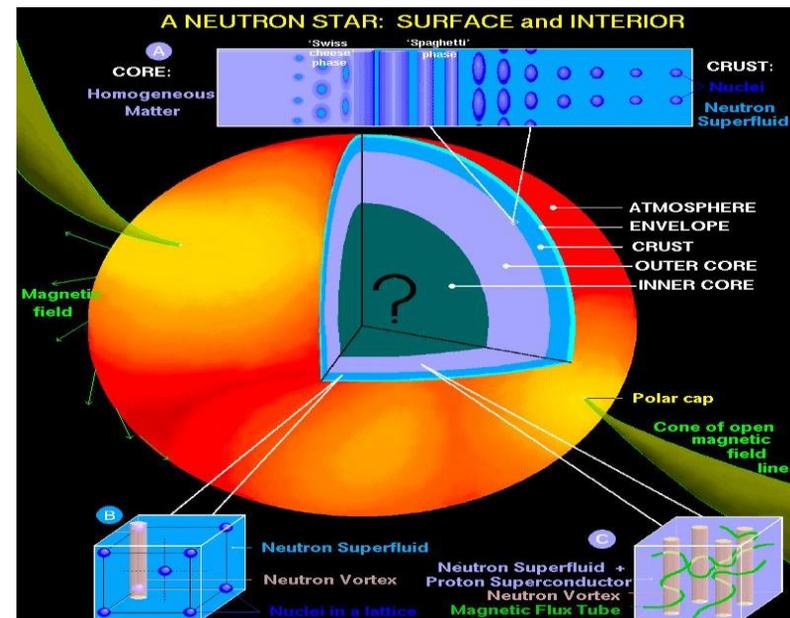
# eXTP科学主题：黑洞和中子星的核心问题

- 极端条件下的物理规律：处于黑洞极强引力场中的物质或者处于中子星表面磁场和核心区的物质；
- “一奇二星三极端”：通过观测一奇二星（黑洞、中子星和夸克星）理解三极端（引力、密度和磁场）物理规律。

$GM/c^2r \sim 1$ ,  $10^{15} \text{g/cm}^3$ ,  $10^{14} \text{Gs}$

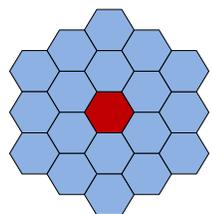
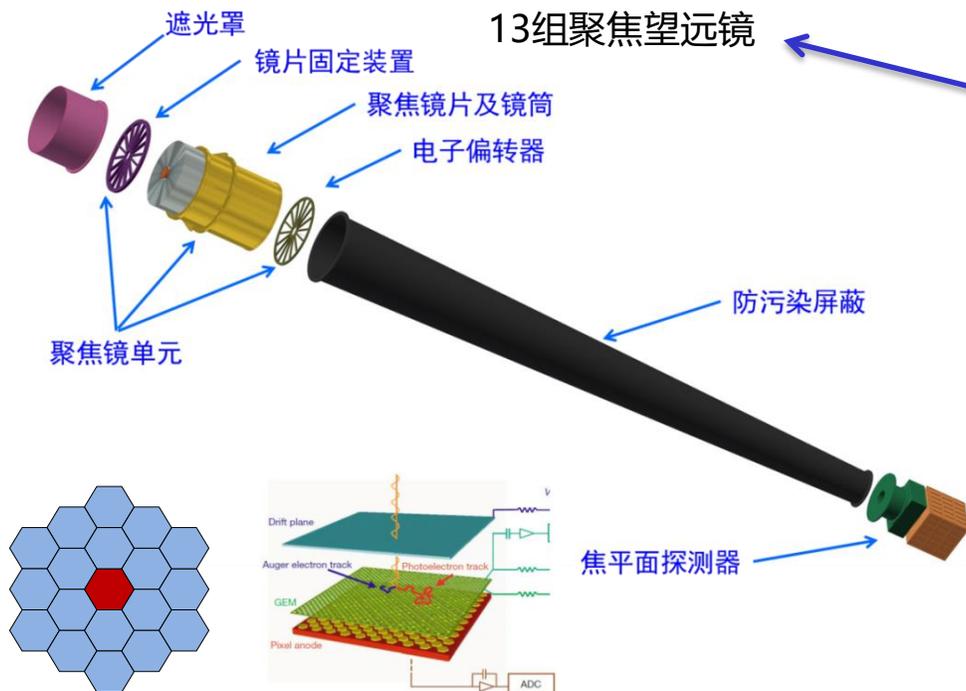


黑洞附近的极端引力效应

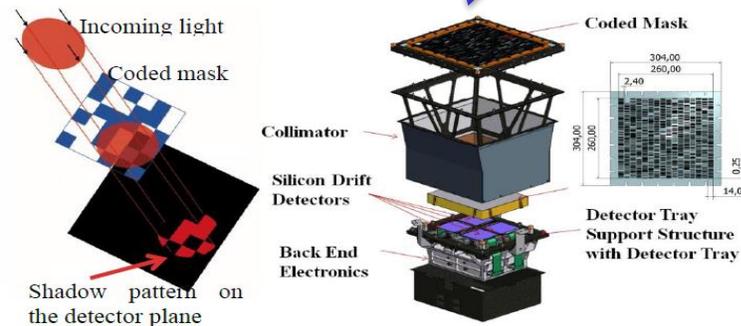
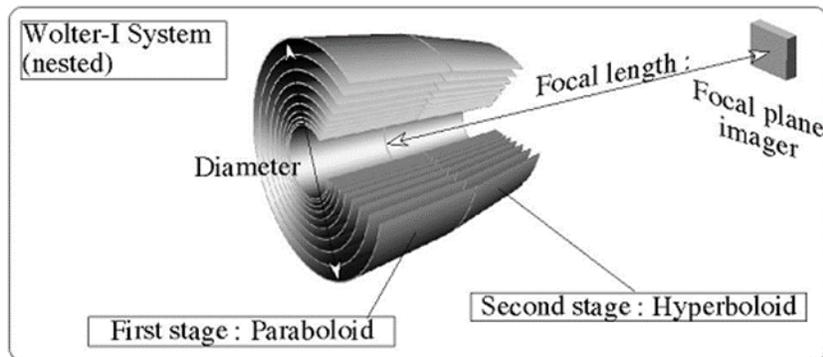
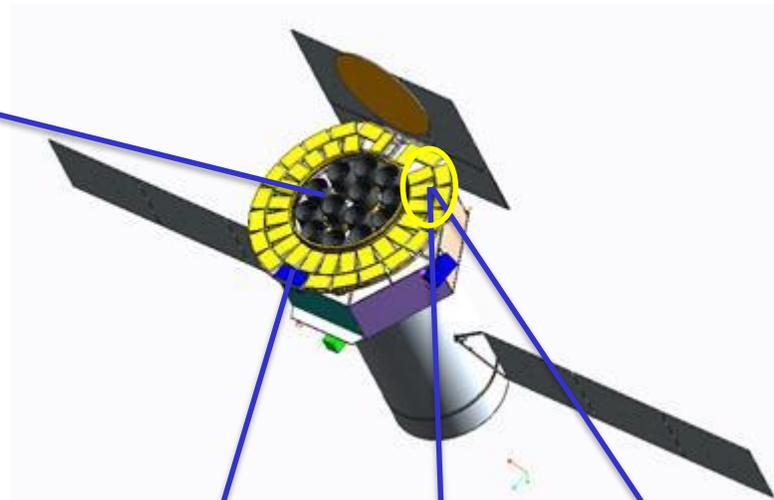
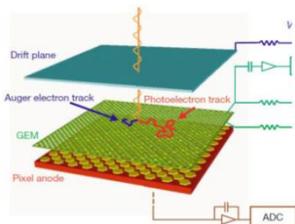


真空涨落、中子还是夸克？

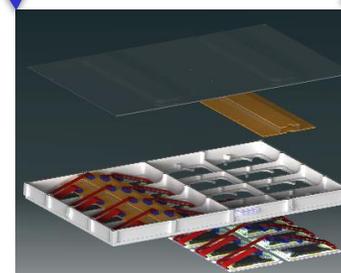
# eXTP卫星上的偏振测量聚焦望远镜阵列 (PFA)



SDD探测器 (9台) 偏振探测器 (4台)



广角监视器 (6台)

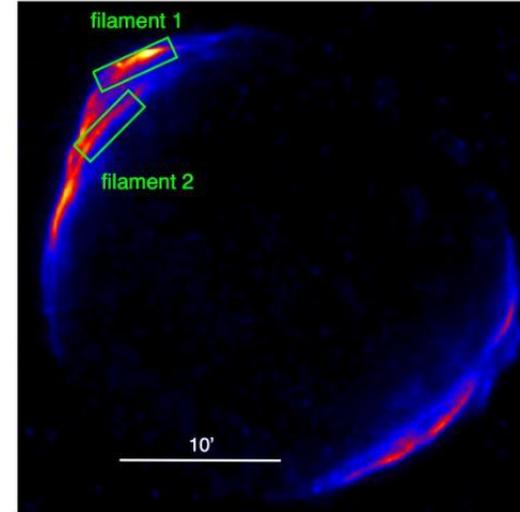


大面积准直探测器模块 (40台)

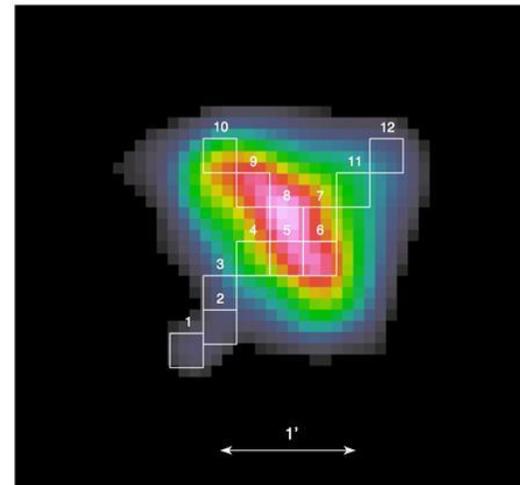
# Polarimetry Focusing Array(PFA) onboard eXTP

## ■ PFA的科学能力:

- 成像 (Imaging)
- 偏振测量 (Polarimetry)
- 时变测量 (Timing)
- 能谱测量 (Spectrometry)



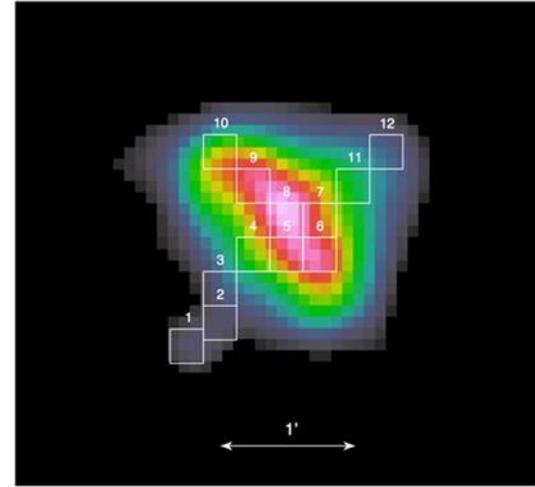
Simulating results of the imaging polarization for the SN1006



Simulating results of the imaging polarization for crab

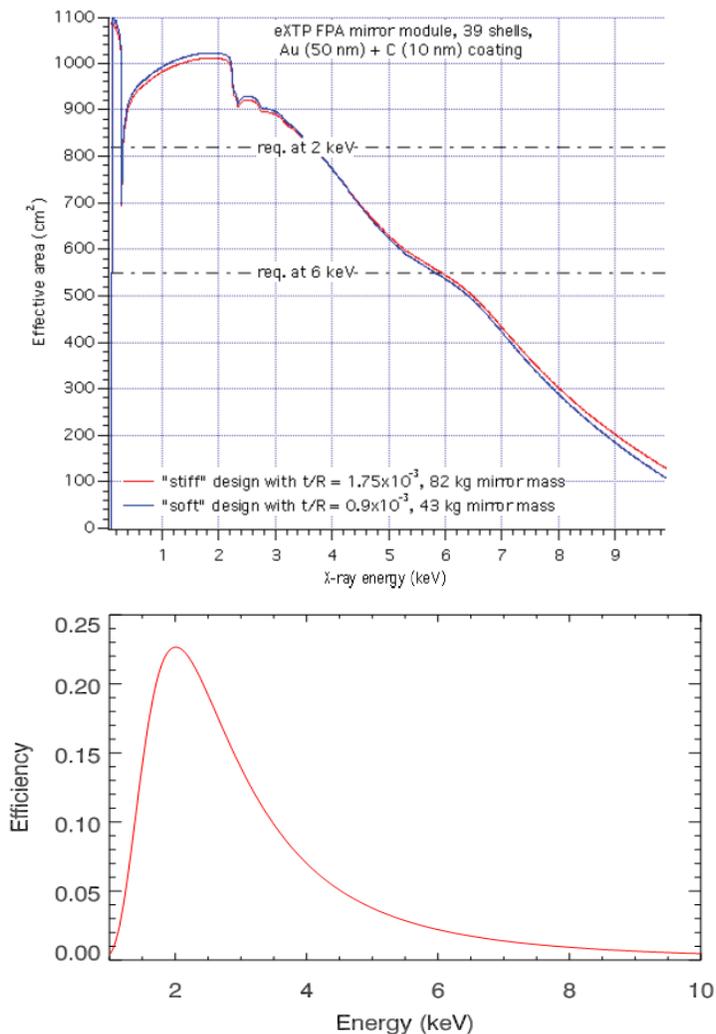
# PFA 技术指标

参数	PFA	
	指标要求	目标
有效面积（给定的能量为 $E \pm 0.5\text{keV}$ ，下同）	380cm <sup>2</sup> @3keV	420cm <sup>2</sup> @3keV
有效面积测量精度（knowledge）	≤ 10% (TBC)	≤ 5% (TBC)
能量范围（keV）	2-8	2-10
能量测量精度（knowledge）	≤ 1%	≤ 0.8%
能量分辨（FWHM，寿命末期）	25%@5.9keV	20%@5.9keV
视场（FWHM，@3 keV）	≥ 8x8'	
角分辨@2keV	30"(HPD)	15"(HPD)
响应稳定性 ( $\Delta P/P$ )	≤ 5%	≤ 2%
源定位精度（天球坐标系）	5" (1 $\sigma$ )	
时间分辨（ $\mu\text{s}$ ）	≤10	≤8
绝对时间精度（ $\mu\text{s}$ ）	≤4	
死时间	≤10% @ 1 Crab (TBC)	≤3% @ 1 Crab
死时间测量精度（knowledge）	≤ 10%	
本底	bkg(2-8 keV) ≤ 0.1 cts/s/cm <sup>2</sup> /det <sup>-1</sup>	bkg(2-8 keV) ≤ 0.05 cts/s/cm <sup>2</sup> /det <sup>-1</sup>
本底测量精度（knowledge）	≤0.5% @ 2-8 keV	≤0.25% at 2-8 keV
可持续观测的源强度	≥ 1 Crab	≥ 2 Crab
偏振灵敏度（MDP@2-8keV）	3% (10 <sup>6</sup> s, 1mCrab)	2% (10 <sup>6</sup> s, 1mCrab)
残余调制	≤1%	
偏振角测量精度（天球坐标系）	≤1° (@ 95% 置信度)	
相机安装方位角间隔	90°	
模块化特性（由于单元失效造成的面积损失）	¼	

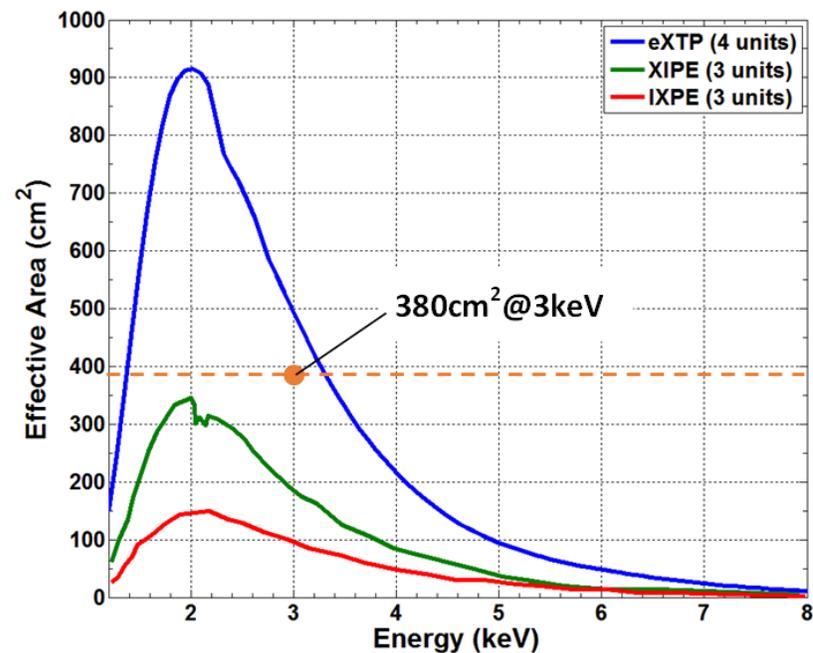


# Effective Area of PFA

Effective Area (on-axis) /module



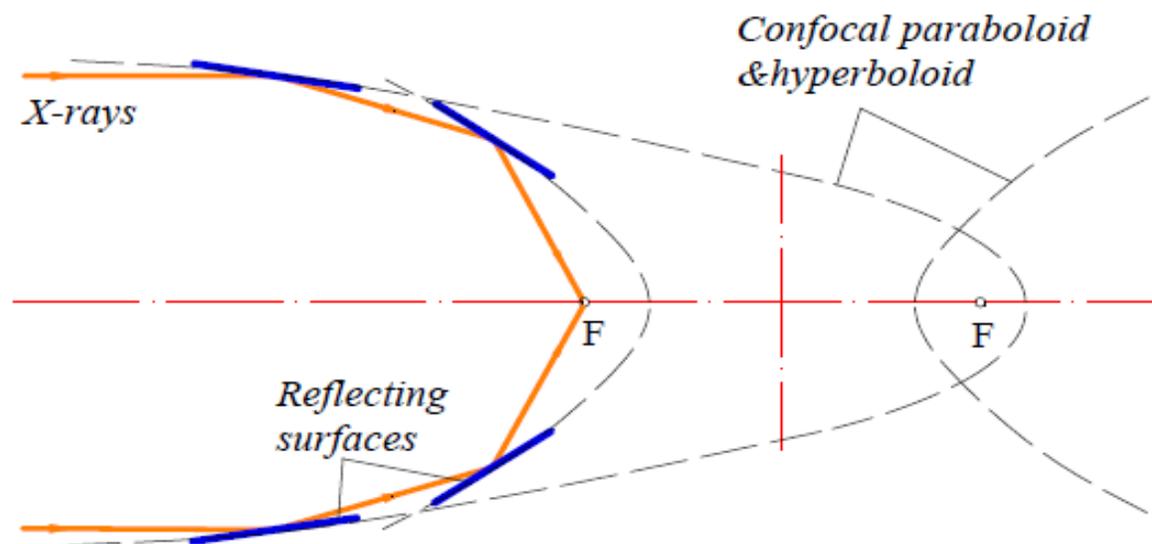
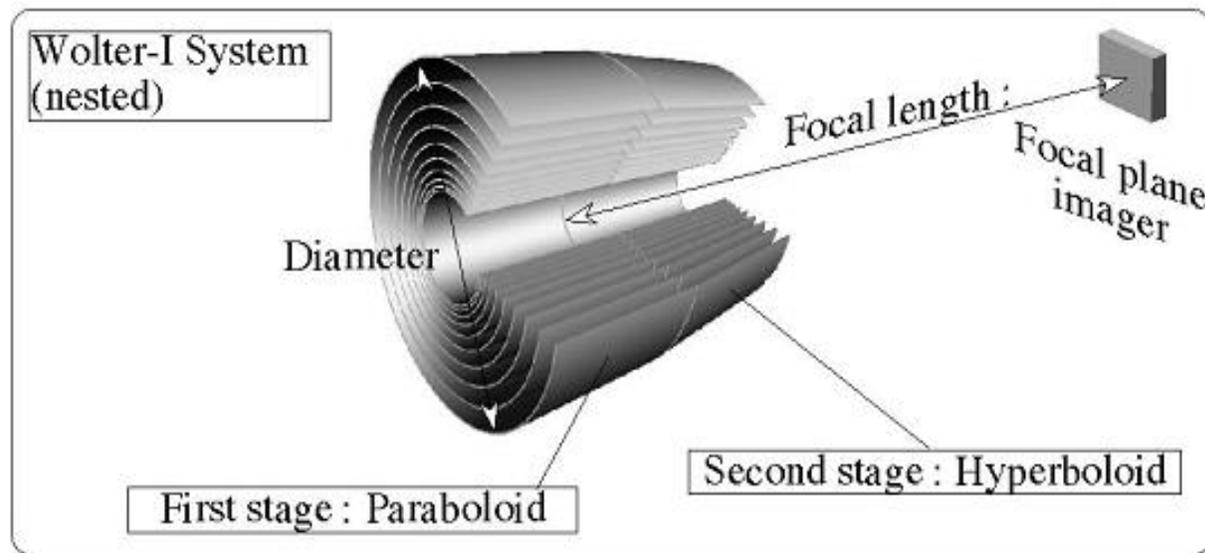
Effective Area of PFA(4 units)



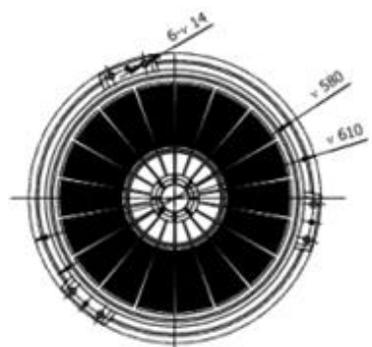
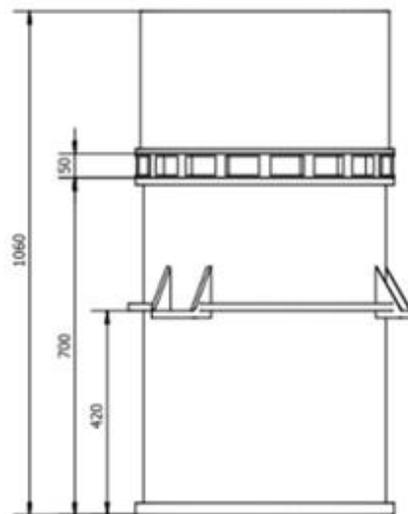
每个聚焦镜的在轴光学收集面积要满足：  
 $\geq 890 \text{cm}^2 @ 3 \text{keV}$

50 $\mu\text{m}$ 铍窗GPD的探测效率

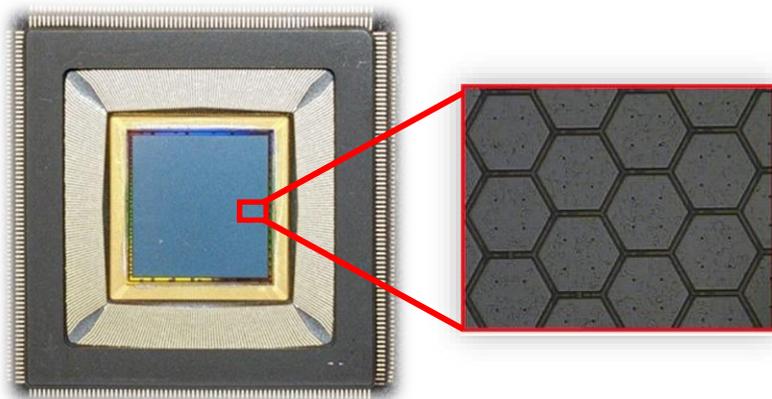
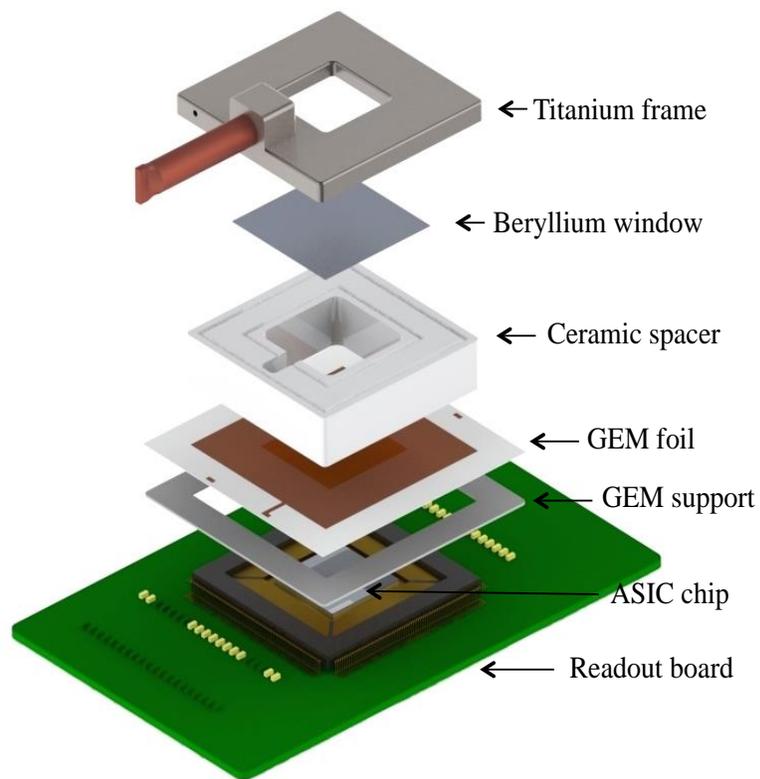
# PFA聚焦光学设计方案



# PFA 聚焦光学设计方案

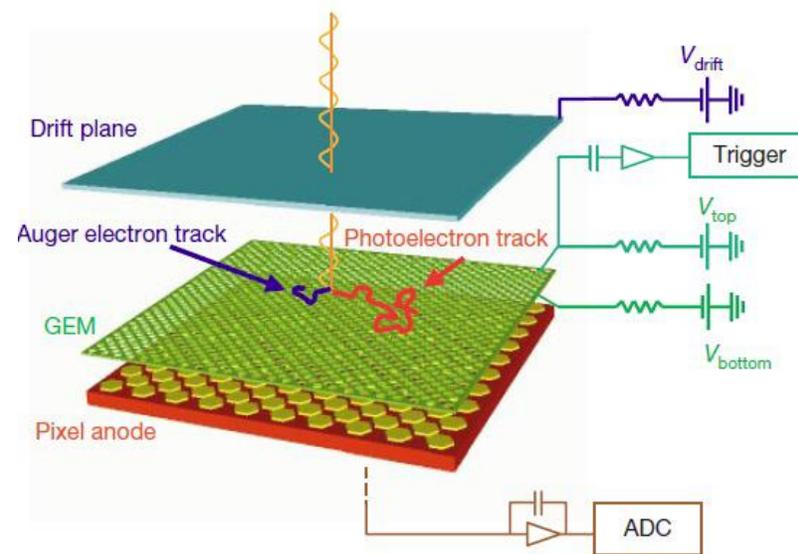


# X射线偏振测量原理

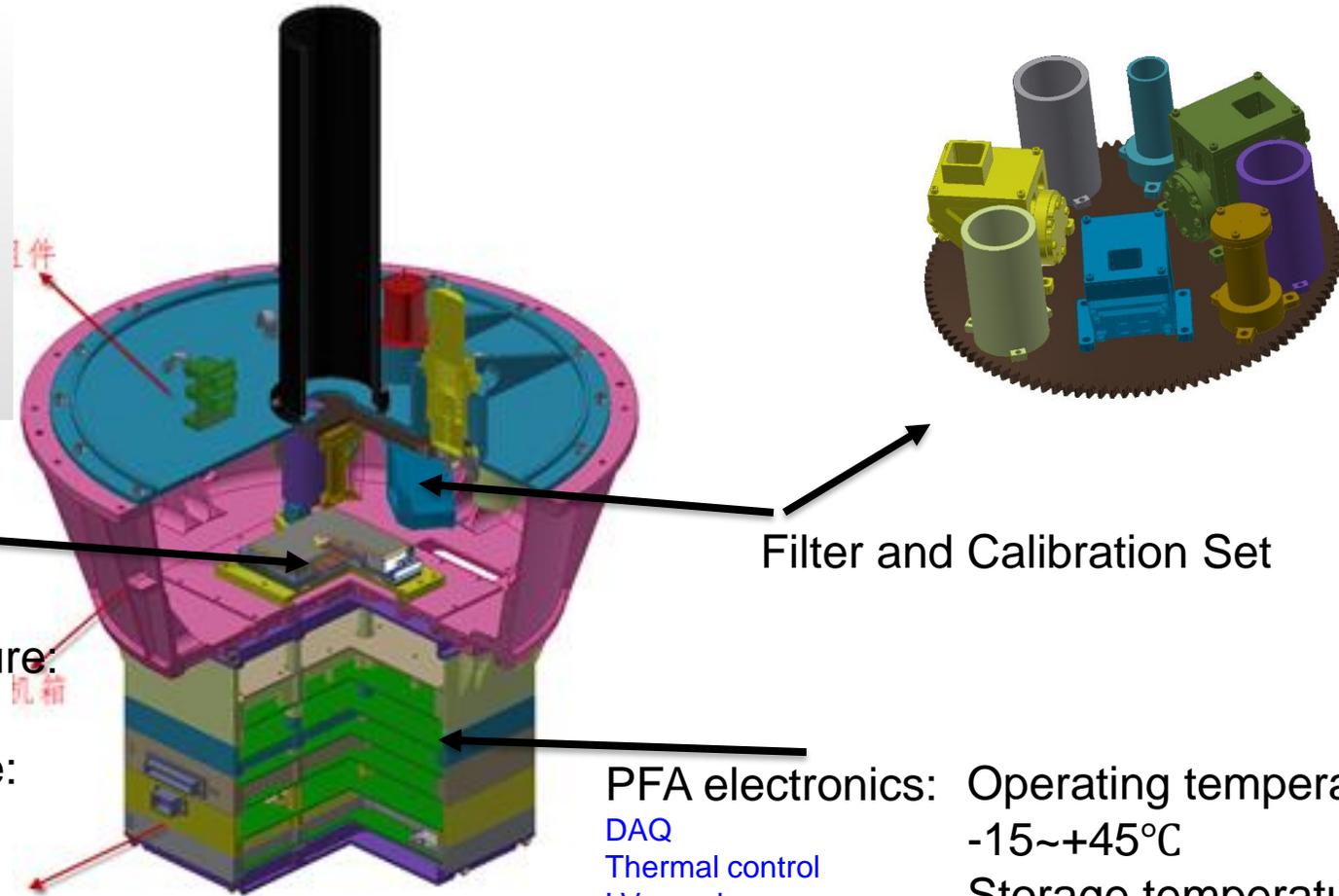
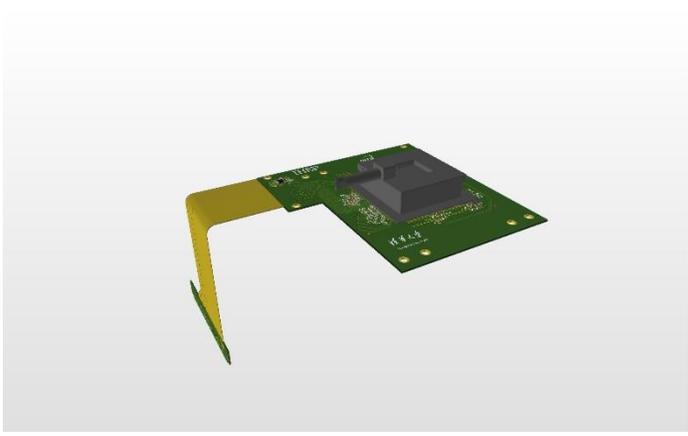


Designed by the INFN-  
 Pisa group  
 (Bellazzini et al.)

Detecting Area: 12mm×12mm  
 Pixel distance: 50 $\mu$ m, 352×300 pixels  
 Noise level: 50e<sup>-</sup>



# PFA焦平面相机设计



GPD

Filter and Calibration Set

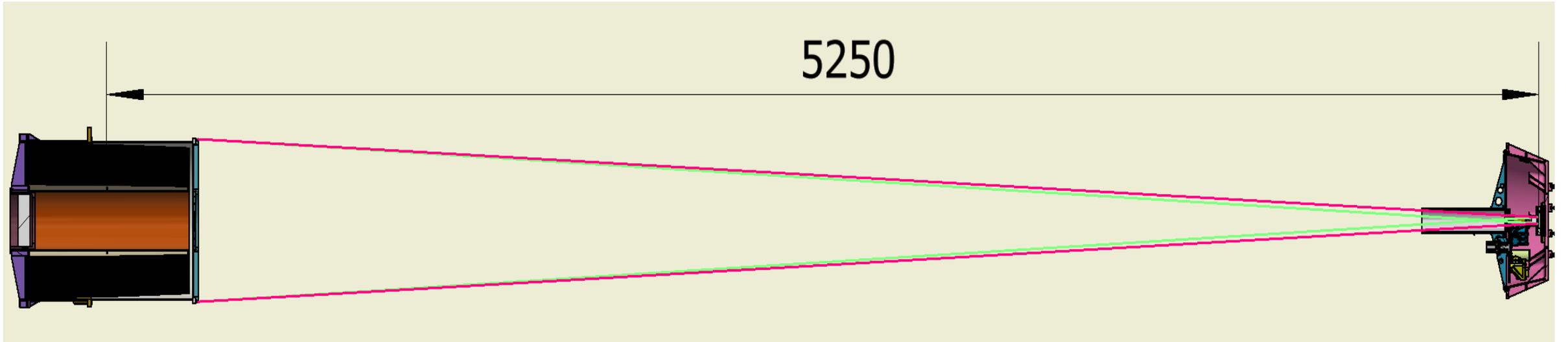
Operating temperature:  
(15~25) ±1°C  
Storage temperature:  
-5~+45°C

PFA electronics: Operating temperature:  
-15~+45°C  
Storage temperature:  
-20~+55°C

- DAQ
- Thermal control
- LV supply
- HV supply

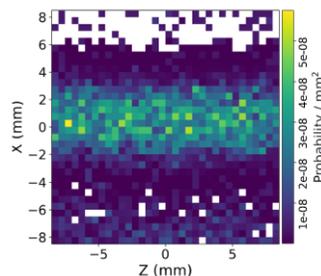
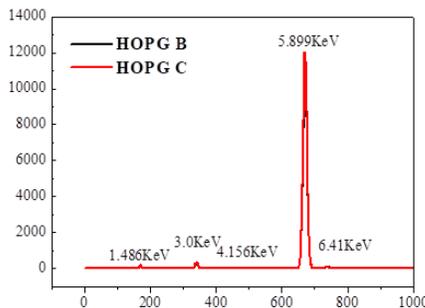
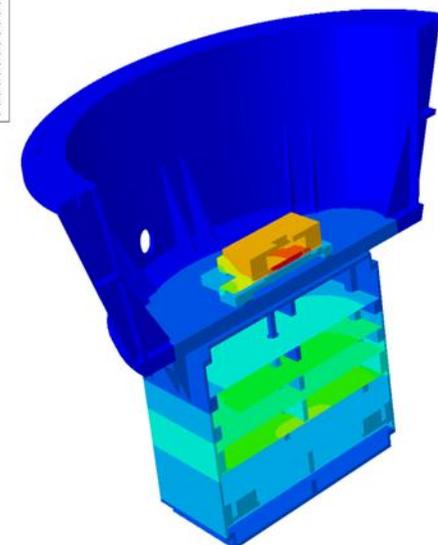
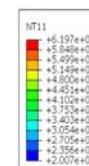
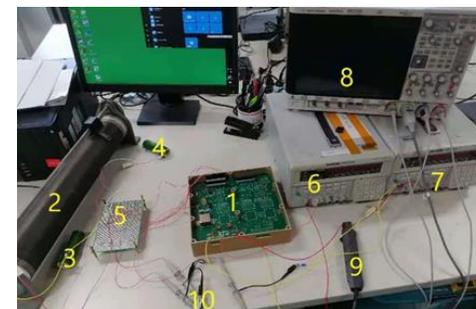
# PFA总体方案设计

- 防标定源杂散X射线与降本底设计



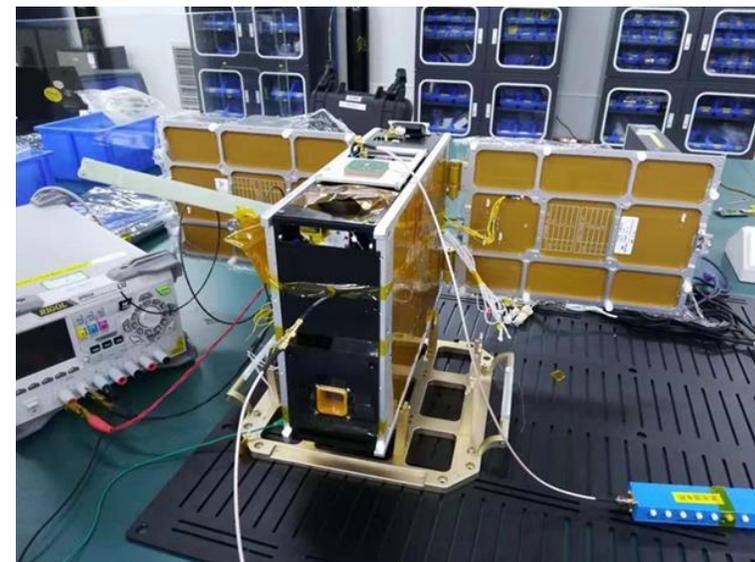
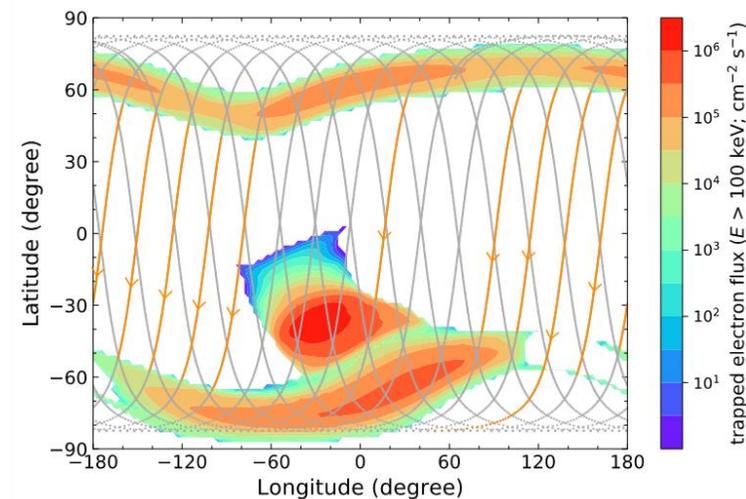
# PFA载荷相关研制进展

- 光学部分完成首个纯镍镜筒的试制
- PFA焦平面工程样机研制
  - 电子学完成第一版（原理样机）功能调试，后续将进行匹配有性能GPD的测试；
  - 电子学第二版（工程样机）正在设计、加工
  - 完成机构设计和初步力学分析
  - 确定热控方案并完成初步热分析
  - PFA高压电源和在轨偏振源关键技术攻关
  - GPD中ASIC粘片工艺
- 利用机器学习进行了电子径迹重建算法的初步探索
- 进行了数据压缩算法的研究，并应用到立方星载荷的MCU中

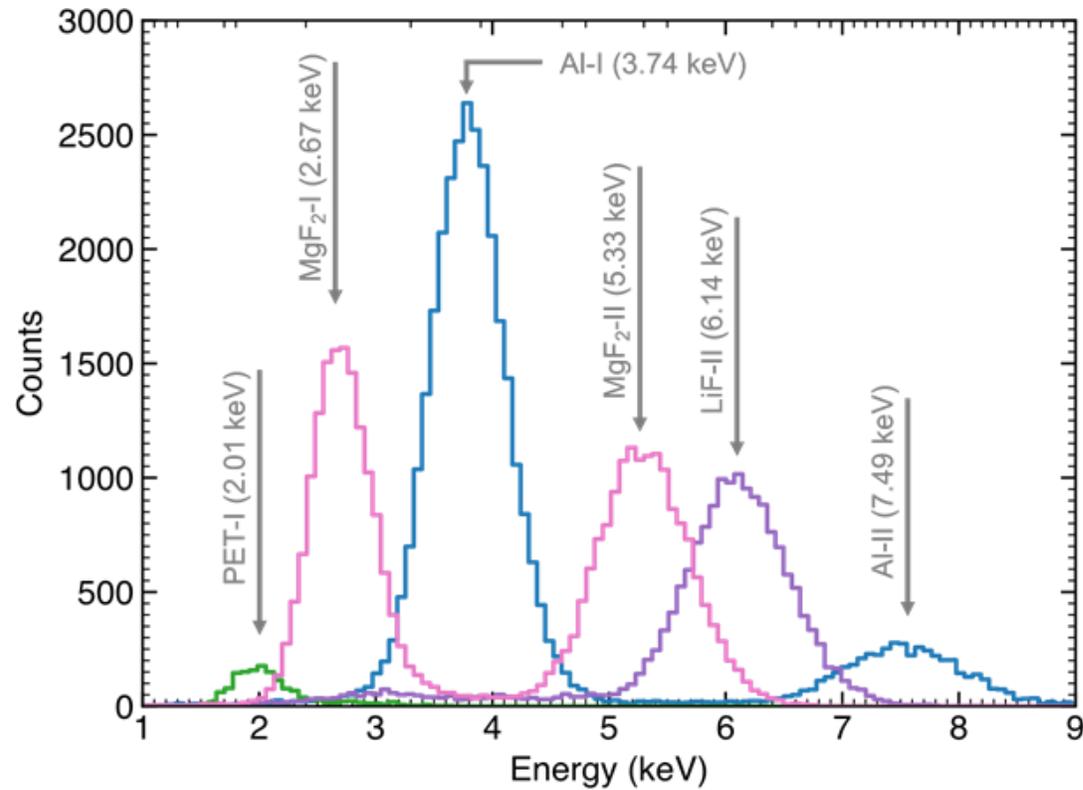


# PFA载荷相关研制进展

- 100 $\mu\text{m}$ 铍窗GPD搭载“铜川一号”立方星飞行验证（2018年10月29日发射，至今工作正常）
- 50 $\mu\text{m}$ 铍窗GPD（第二颗）在轨飞行验证（2022年择机发射）
  - 更新设计，提高了电源的适应性，
  - 增加了数据压缩功能，减小了数据传输带宽和采集事例的死时间，
  - 增加了死时间记录功能，可以更直接的获取死时间，进行死时间修正。



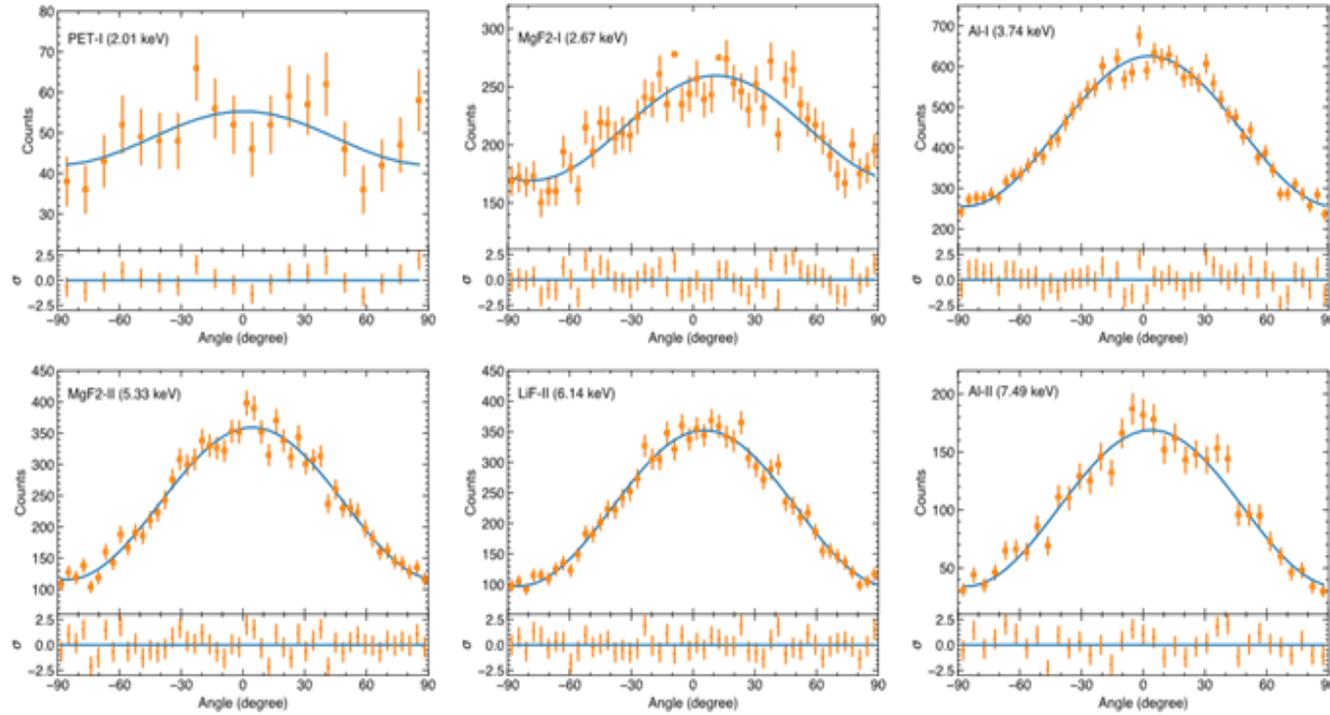
# Energy resolution of GPD



Crystal	Order	E (keV)	FWHM/E	$\mu$
PET	I	2.01	$0.230 \pm 0.008$	$0.136 \pm 0.047$
MgF <sub>2</sub>	I	2.67	$0.230 \pm 0.002$	$0.211 \pm 0.015$
Al	I	3.74	$0.201 \pm 0.001$	$0.420 \pm 0.009$
MgF <sub>2</sub>	II	5.33	$0.175 \pm 0.002$	$0.513 \pm 0.012$
LiF	II	6.14	$0.164 \pm 0.001$	$0.568 \pm 0.010$
Al	II	7.49	$0.165 \pm 0.006$	$0.665 \pm 0.022$

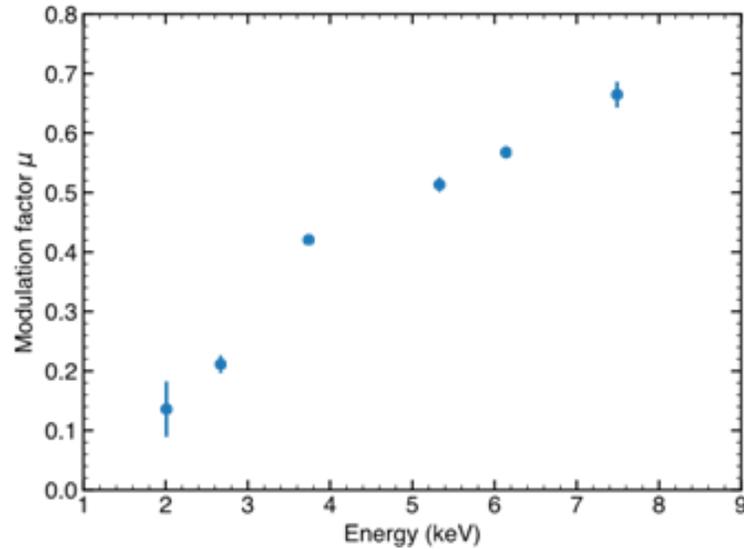
H. Feng et al. 2019

# Modulation factor of GPD

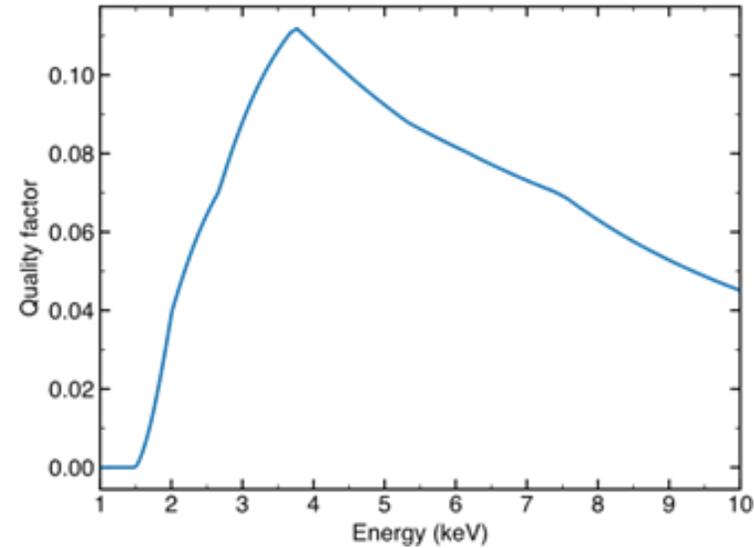


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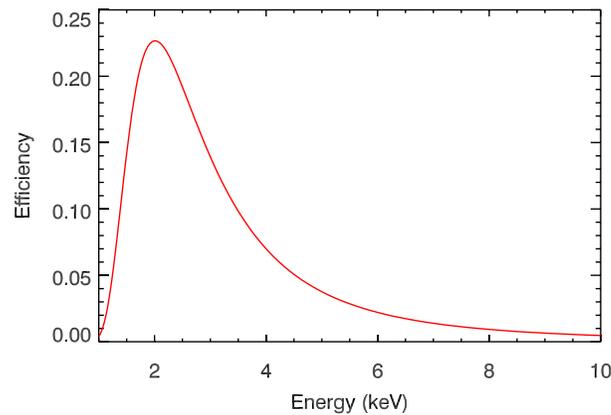
# Quality factor of GPD



Modulation factor of GPD



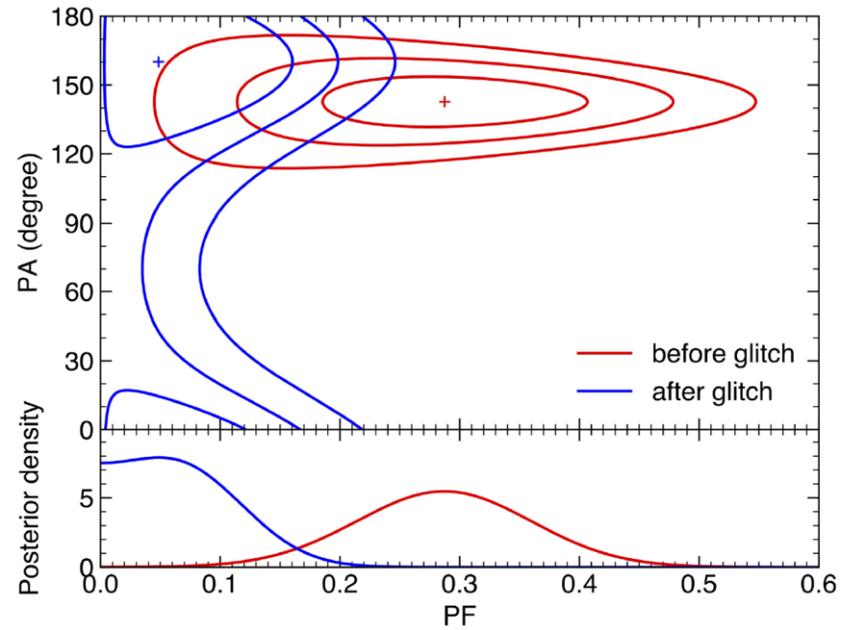
Quality factor of GPD



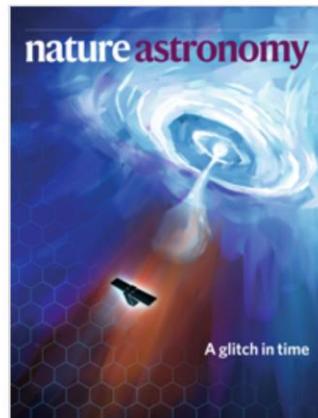
Simulation results of GPD detection efficiency

H. Feng et al. 2019

# 偏振物理的新窗口



Volume 4 Issue 5, May 2020



## A glitch in time

A CubeSat hosting the PolarLight payload has made it possible to conduct polarimetry in the soft X-ray band from space, more than 40 years after this opportunity was last available to astronomers. Hua Feng and colleagues observed the Crab, fortunately catching the pulsar during a glitch.

See [Feng et al.](#)

Thanks !