

中国科学院
CHINESE ACADEMY OF SCIENCES



爱因斯坦探针
einstein probe

In-flight calibration of the Wide-field X-ray Telescope on board Einstein Probe

He-Yang Liu & Huaqing Cheng
on behalf of EP Science Centre

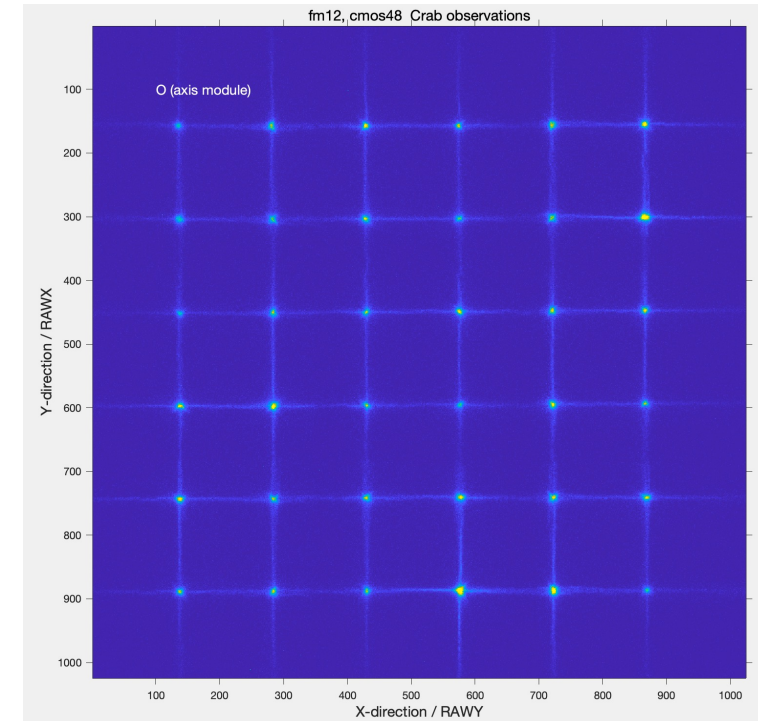
IACHEC @ Parador de La Granja 2024-05-13

Outline

- ★ Overview of the in-flight calibration observations of WXT
- ★ Key performance goals
- ★ In-flight calibration status
 - ★ point spread function and angular resolution
 - ★ positioning accuracy
 - ★ energy band
 - ★ effective area
 - ★ energy response
- ★ Future plan and issues
- ★ Summary

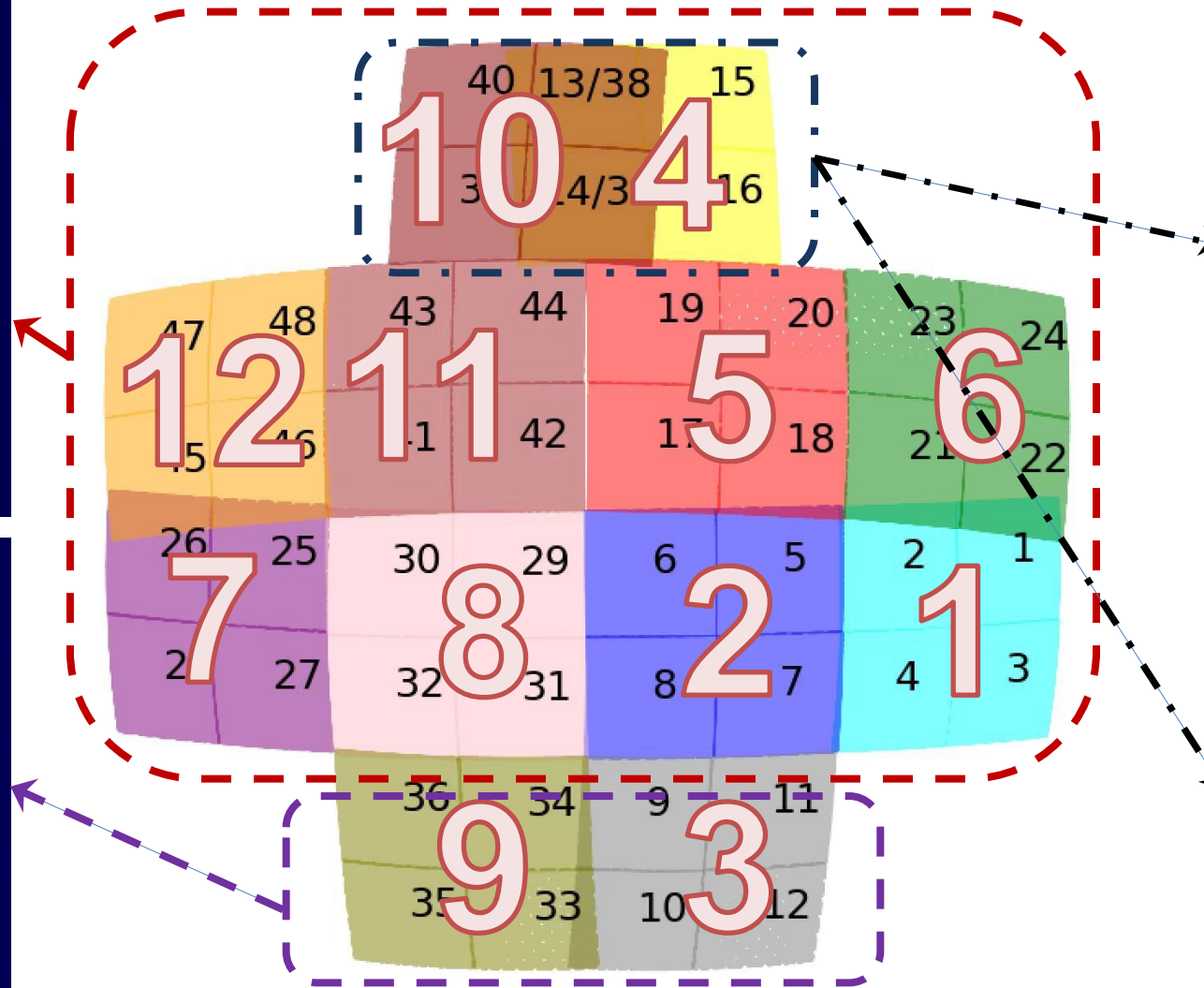
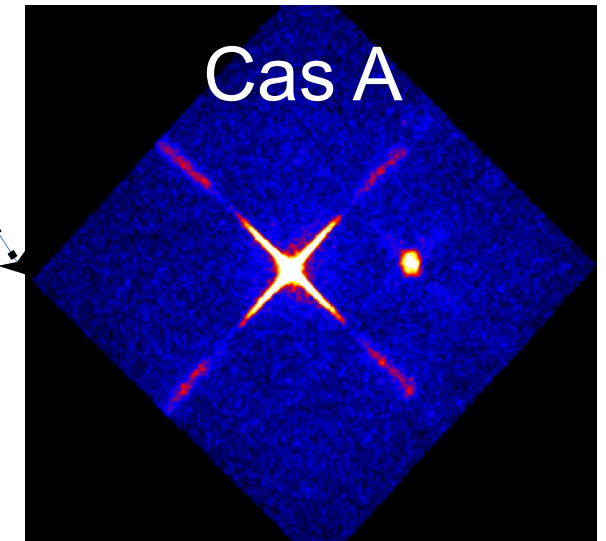
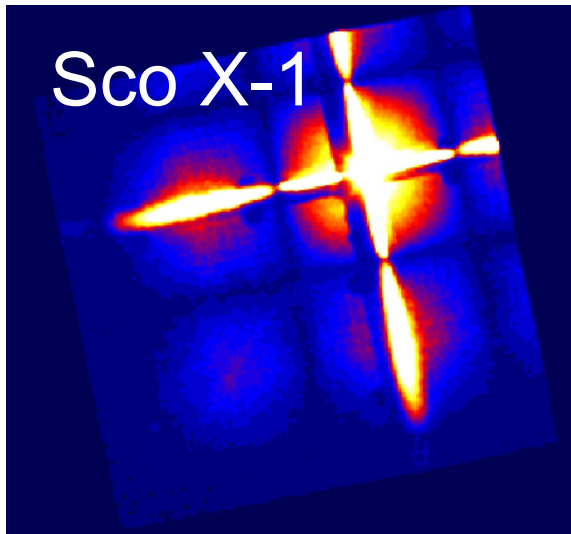
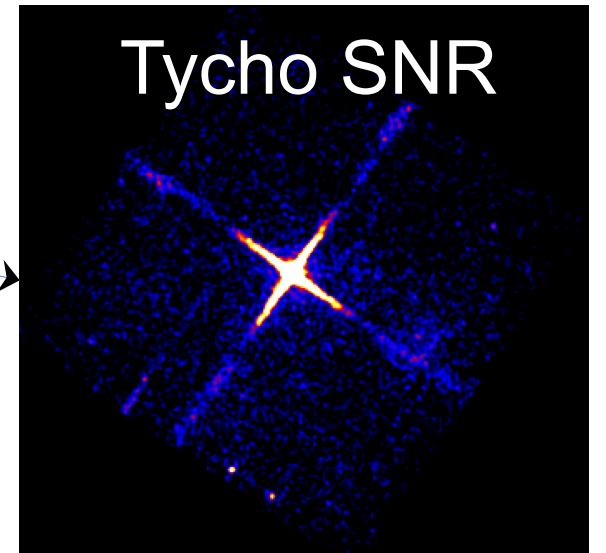
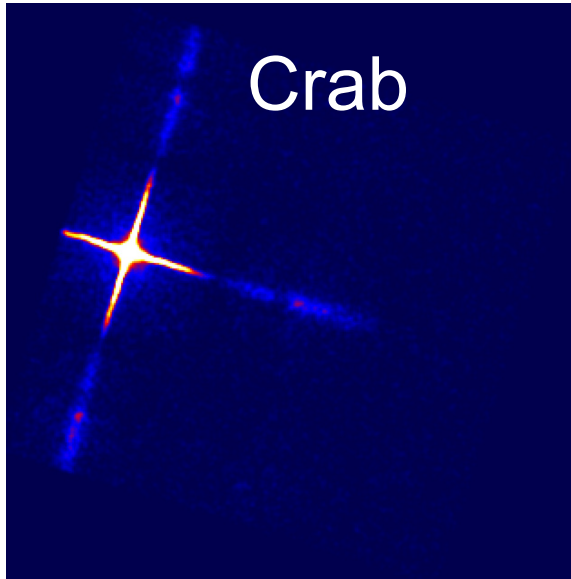
In-flight calibration observation log & schedule

Round	Calibration item	Target	Calibrated module	Observational date
1	Energy response	Cas A, Tycho	4, 10	2024/1/19 - 2024/1/25
	PSF, angular resolution	Crab	10 modules (except Module 3 & 9)	2024/1/25 - 2024/3/8
	Positioning accuracy			
	Energy band			
	Effective area			
2	PSF, angular resolution	Sco X-1	3, 9	2024/5
	Positioning accuracy			
	Energy band			



Scanning the detectors (6x6)
by targeting on the Crab

In-flight calibration observations

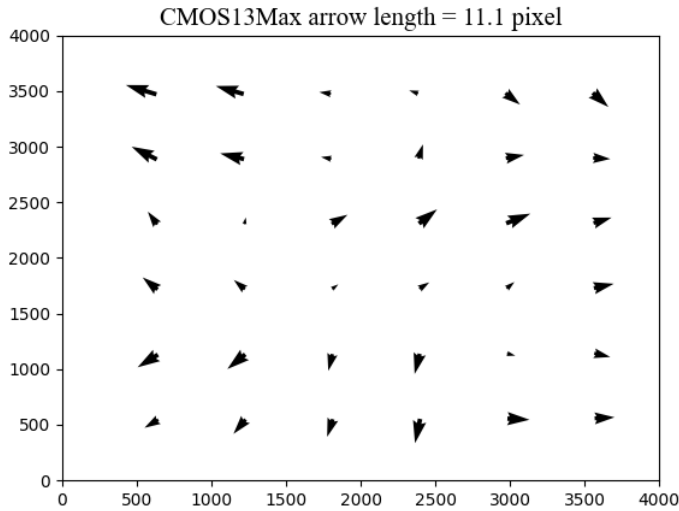


Key Performance Goals

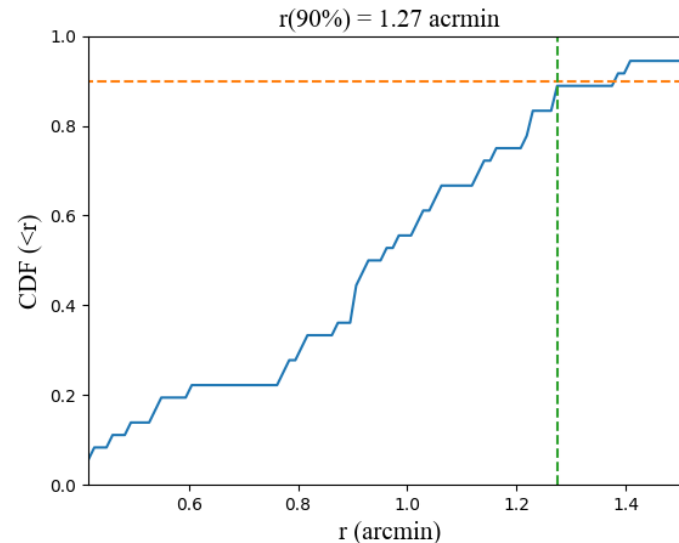
No.	Calibration item	Goal	Requirement of systematics/precision
1	Positioning Accuracy	≤ 2 arcmin (J2000, 90% C.L.)	-
2	Energy band	0.5 – 4 keV	-
3	Effective area	≥ 2 cm ² @1keV	$\leq 20\%(1\sigma)$
4	Angular resolution	≤ 5 arcmin @1keV	-
5	Energy resolution	≤ 170 eV @1.25 keV	$\leq 20\%(1\sigma)$

1. Positioning Accuracy

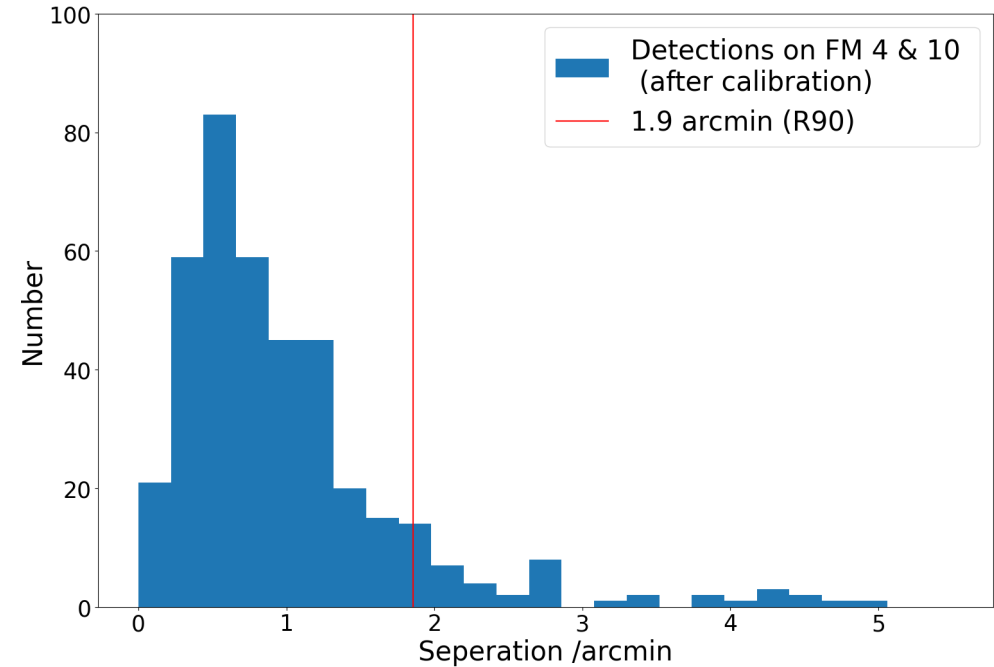
- ★ 10 modules (except 3 & 9) calibrated via Crab observations **Highest priority!**
- ★ Goal: better than 2 arcmin (J2000, 90% C.L.)
- ★ Method: calibration of the rotation matrix and non-linear corrections with a PSF scan in 6x6 mesh grid



Pos. offset of the PSF within FoV quadrant



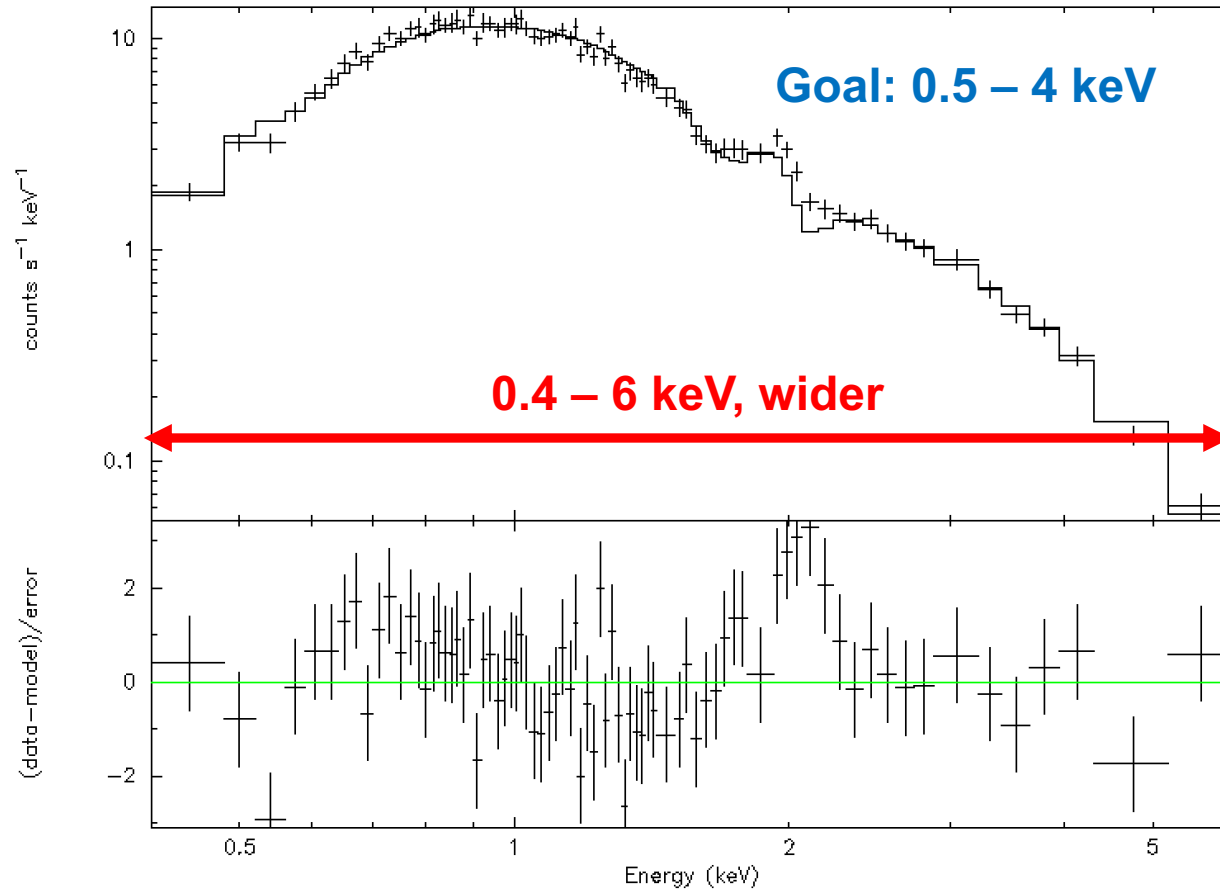
CDF of non-linear residual



Assessing pos. accuracy with real observational data after calibration

By now positioning accuracy better than 2 arcmin (J2000,90% C.L.)

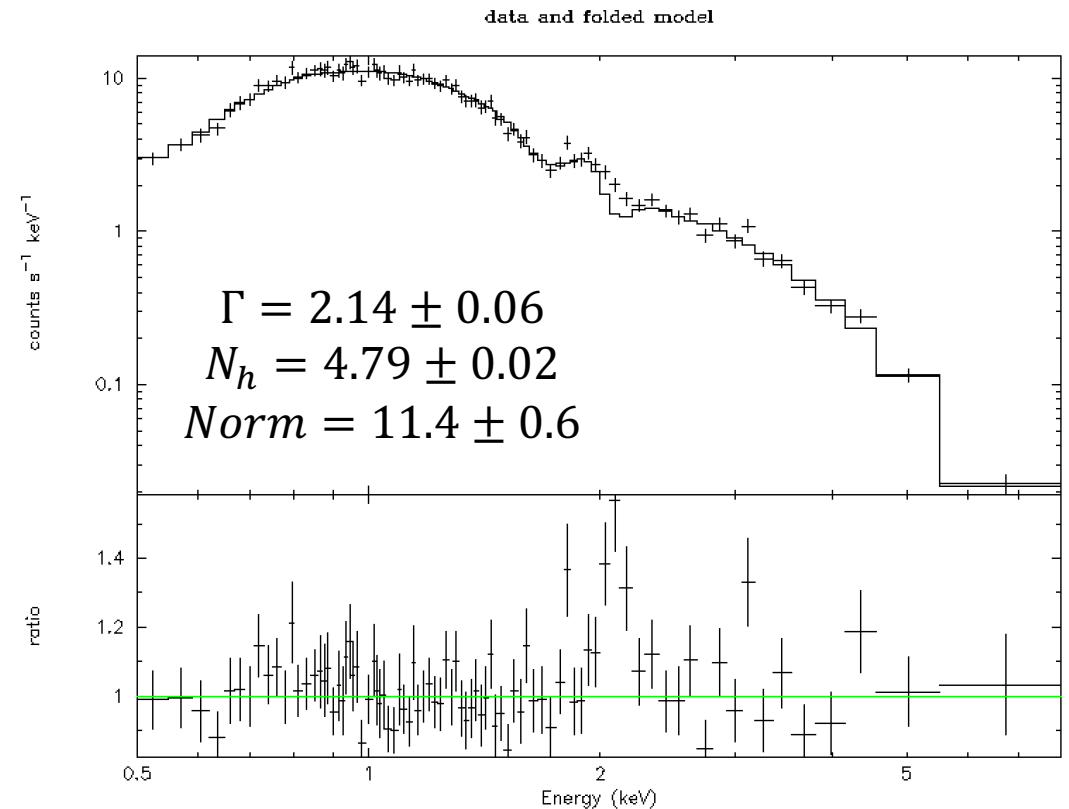
2. Energy band



Spectral analysis of the Crab nebula
(along the center direction, FM1, CMOS3)

3. Effective Area

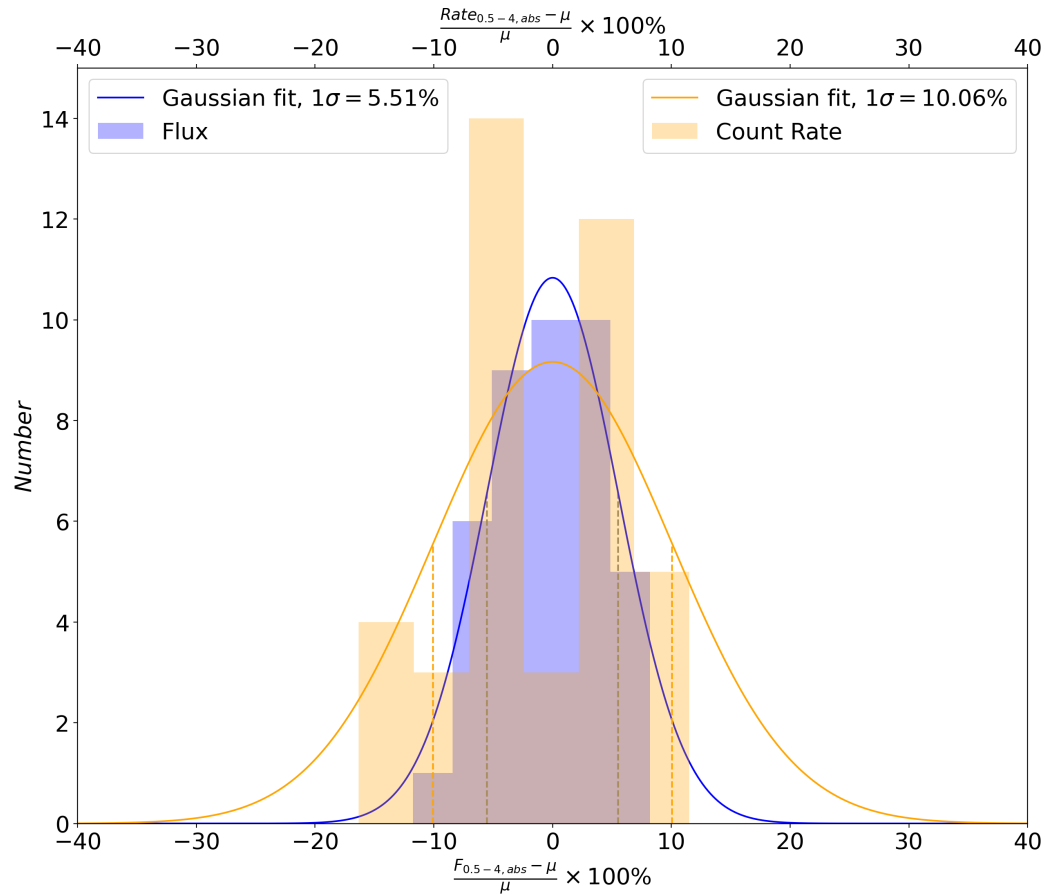
- ★ Modules: 10 modules (except 3&9)
- ★ Goals:
 - ★ Absolute effective area $\geq 2 \text{ cm}^2 @ 1 \text{ keV}$
 - ★ Precision (systematics) better than 20% (1σ)
- ★ Method:
 - ★ Estimate the absolute effective area via on-axis observations
 - ★ Estimate the systematics via on-axis and off-axis observations



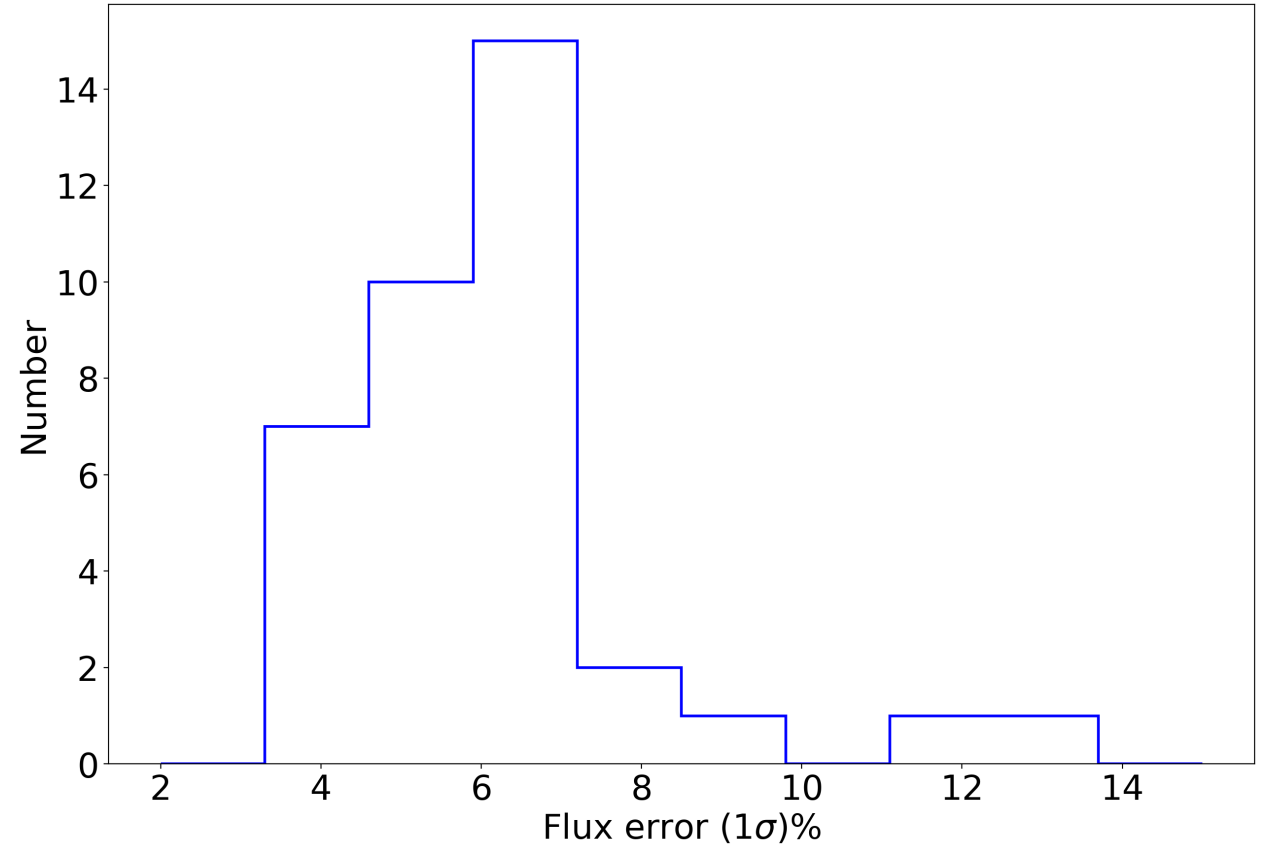
**Crab spectral fitting along center direction
(FM1, CMOS3)**

The simulated effective area curve (built based on ground calibration) provides a reasonable description to the in-flight effective area, i.e. $\sim 3 \text{ cm}^2 @ 1 \text{ keV}$ (ground values)

Effective Area: systematics



Count rate and derived flux of Crab (FM2, CMOS5)

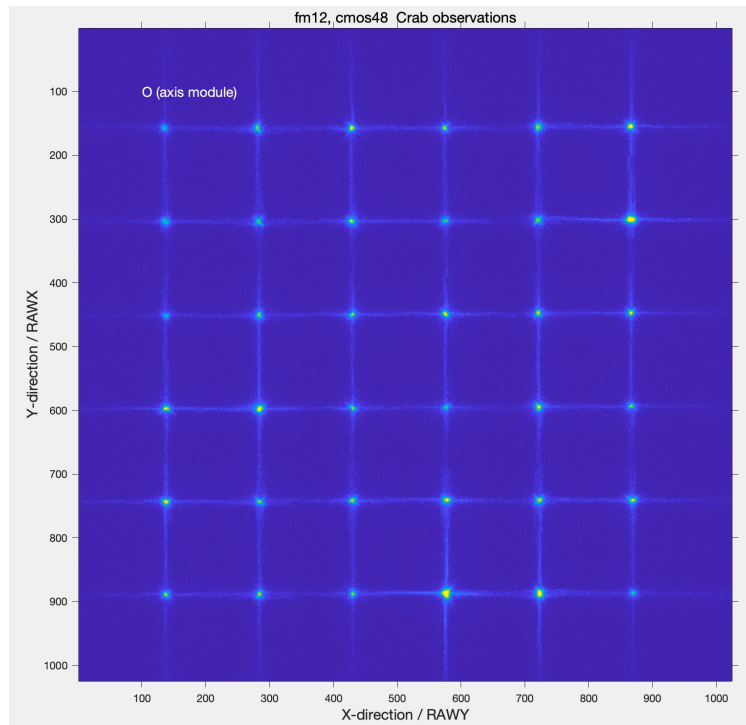


Distribution of flux error (systematics) of the effective area

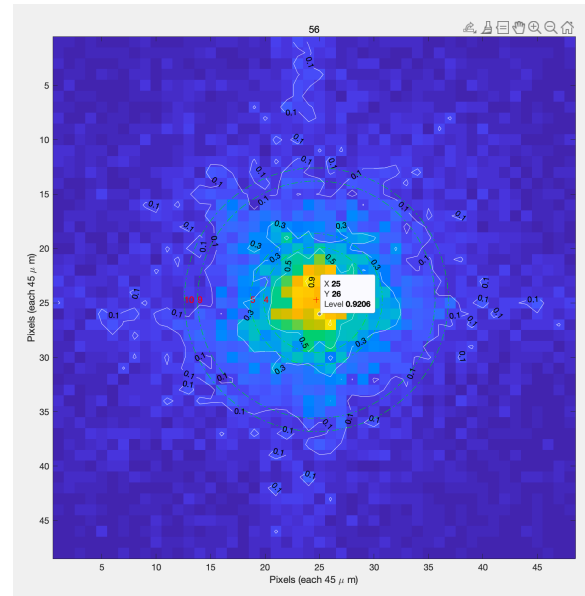
The systematics of the effective area is generally less than 10%(1 σ).

4. PSF and angular resolution

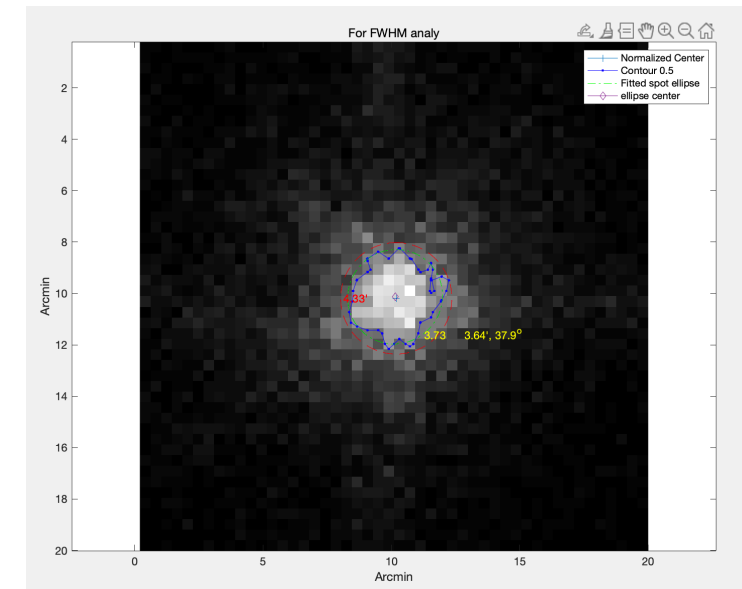
- ★ 10 modules (except 3 & 9) calibrated via Crab observations
- ★ Goal: angular resolution ≤ 5 arcmin@1keV
- ★ Method: PSF extraction and analysis with elliptical function



PSF 6x6 scanning array(FM12, CMOS48)

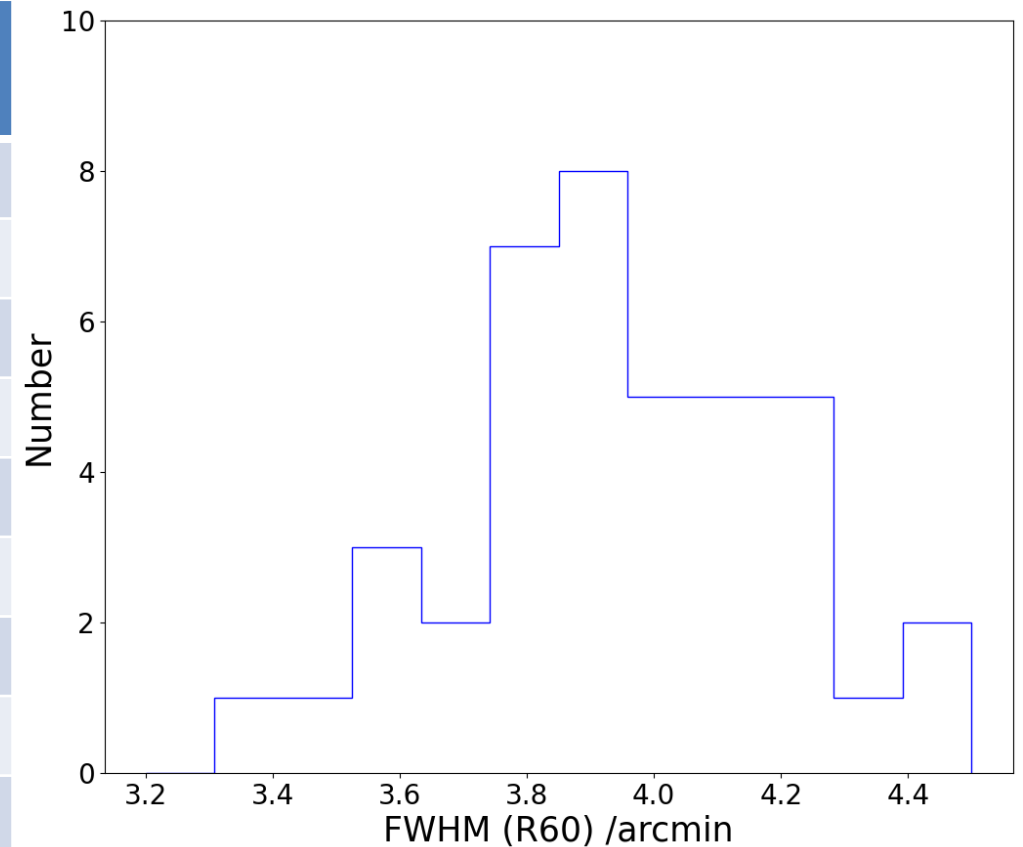


PSF analysis
(elliptical fitting, method identical to that employed on ground)



PSF: angular resolution

FM ID	Detector 1 (R60)	Detector 2 (R60)	Detector 3 (R60)	Detector 4 (R60)
1	4.1	4.0	4.0	3.9
2	4.2	4.1	4.2	3.8
4	4.0	4.0	3.7	4.4
5	4.3	4.1	4.0	4.3
6	3.8	3.8	4.0	3.5
7	3.8	4.2	3.9	3.8
8	3.7	3.9	3.6	3.8
10	4.4	4.2	3.6	4.2
11	3.9	3.6	3.3	3.9
12	3.9	4.3	3.9	3.8

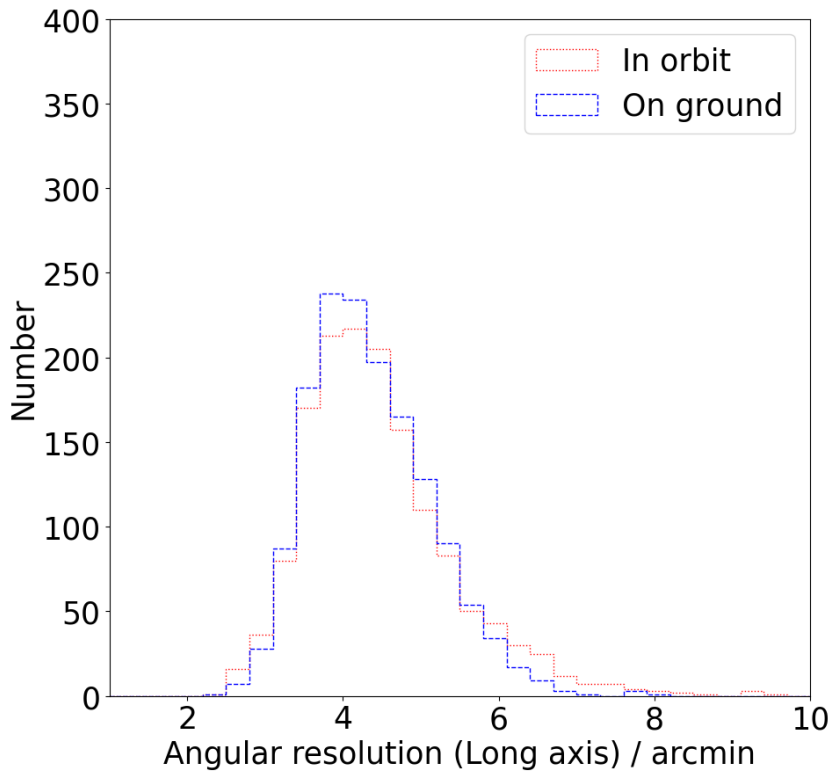


Distribution of the FWHM R60 value

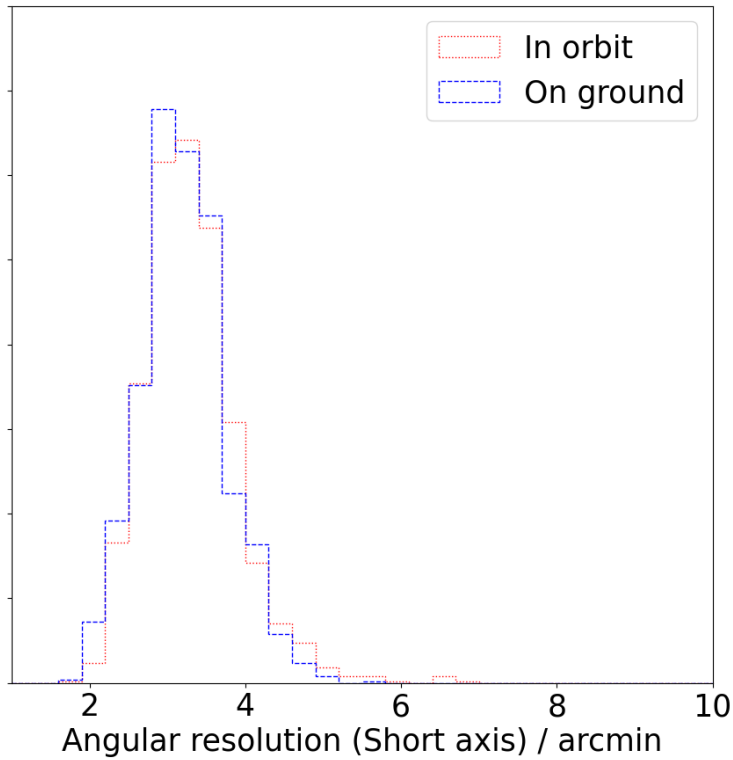
Summary of the FWHM
(R60: the 60 percentile)

The angular resolutions mostly fall within 5 arcmin, fulfilling our goals.

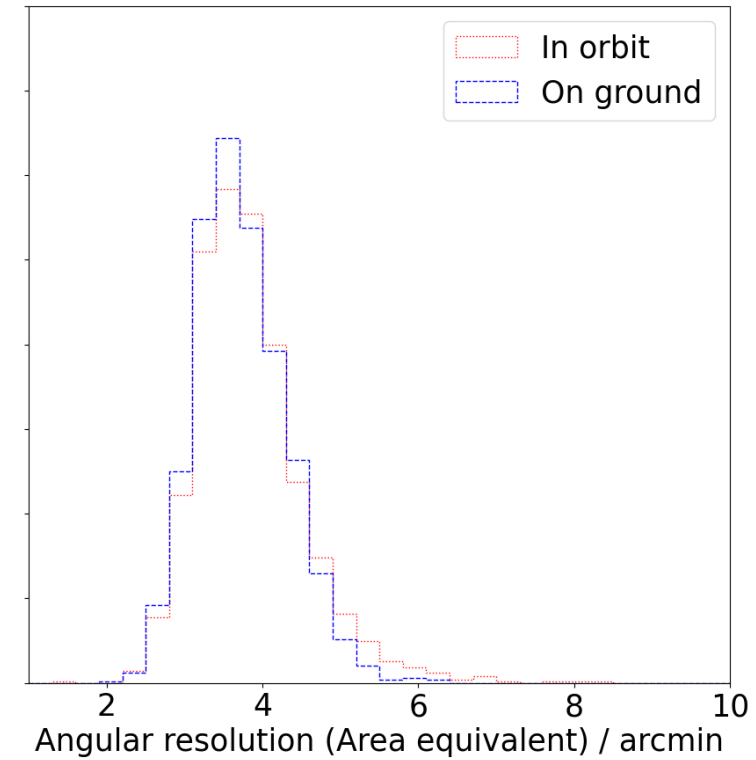
In-flight angular resolution vs. Ground values



FWHM in long-axis direction



FWHM in short-axis direction



FWHM (area-equivalent radius)

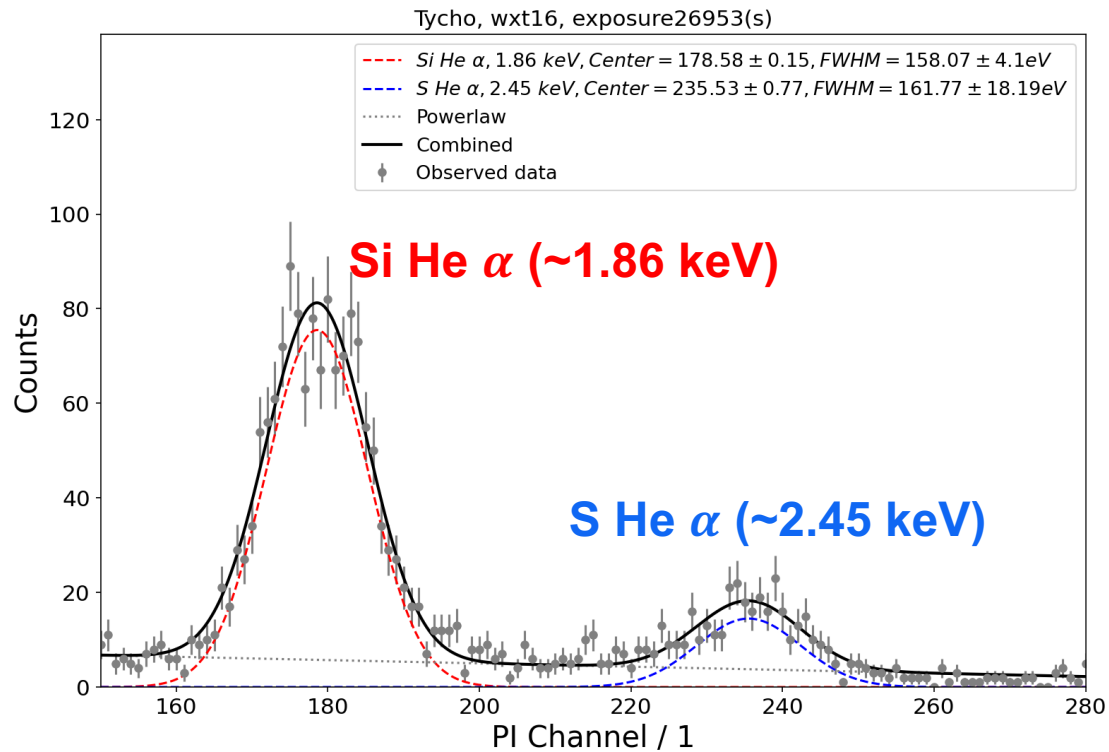
No noticeable degradation in the imaging quality was found after launch.

5. Energy response of the CMOS detectors

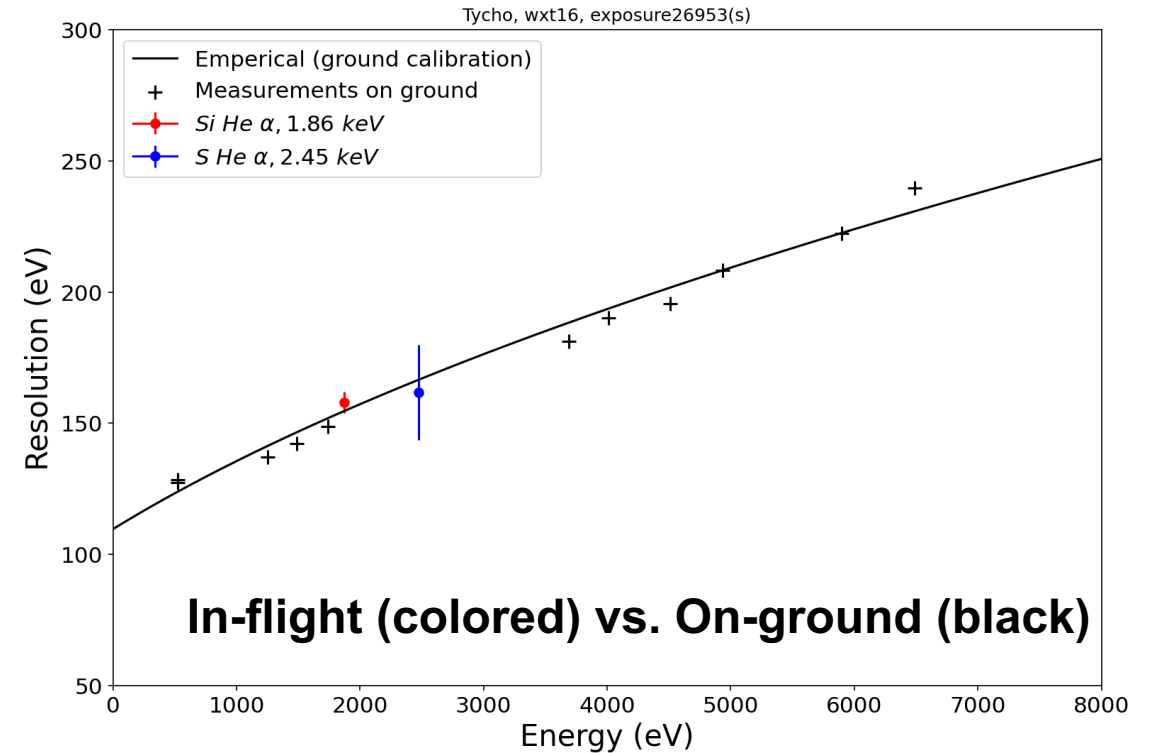
- ★ Modules: 4&10
- ★ Goals:
 - ★ Energy resolution ≤ 170 eV @1.25 keV (Mg $K\alpha$)
 - ★ Measurement precision better than 20% (1σ)
- ★ Method:
 - ★ Perform emission line analysis to Tycho spectra
 - ★ Estimate the resolution at 1.25 keV by extrapolation

Energy response of the CMOS detectors

* Analysis on Tycho spectrum



Spectral analysis of (stacked) spectrum of Tycho (FM4, CMOS16)



Energy resolution (compared with ground measurements, FM4, CMOS16)

No obvious variations in GAIN and energy resolution for most of the detectors after launch.

Energy response: energy resolution

- * Extrapolate from 1.86 keV and obtain the resolution @ 1.25 keV

Flight Model No.	CMOS	Resolution @ 1.25 keV	Precision(1σ) %
4	13	134.1+/-1.9	1.4
4	14	131.7+/-1.6	1.2
4	15	120.2+/-1.9	1.6
4	16	129.6+/-3.4	2.6
10	17	119.1+/-1.5	1.3
10	18	121.6+/-1.7	1.4
10	19	121.6+/-2.4	2.0
10	20	130.7+/-2.0	1.5

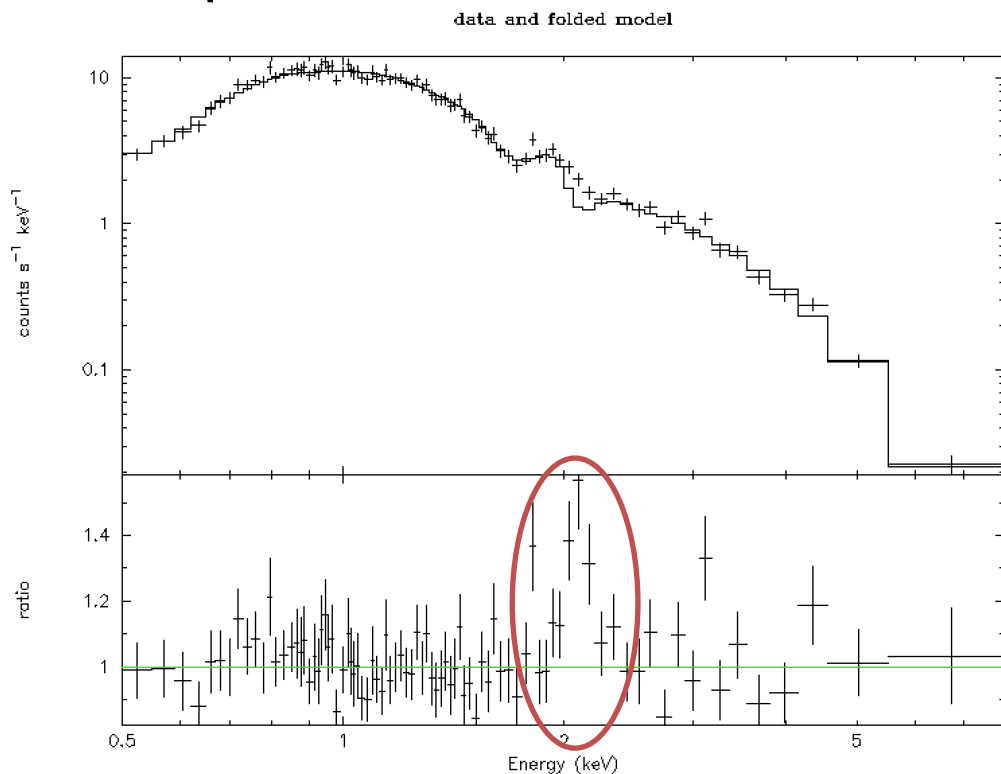
The energy resolution @1.25 keV is in range of 120-140 eV with a precision of 1-3% (1σ)

Future plans

- ★ The observations of Sco X-1 are ongoing for the calibration of FM 3 & 9 concerning PSF, spatial resolution and positioning accuracy.
- ★ Summary of the calibration and paper publication.

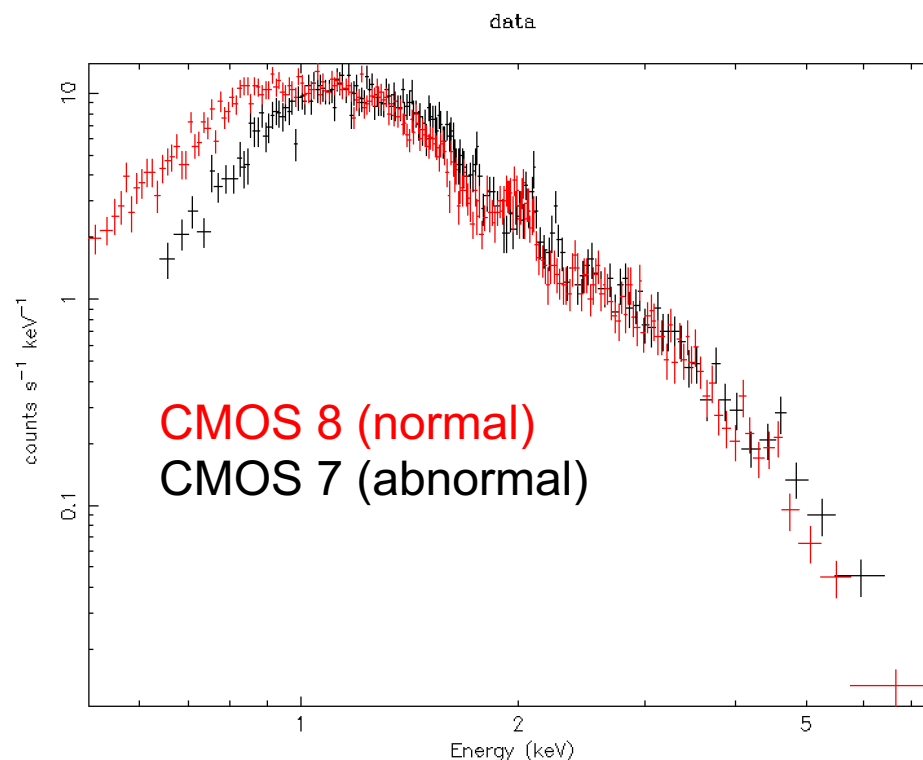
Unresolved issues

- ★ 1. The 2 keV bump in the Crab spectrum



- This feature was already found in ground calibrations and LEIA data
- Likely due to the incomplete understanding on the Iridium absorption

- ★ 2. The EC relations of two detectors (CMOS 5&7) appears to vary by a factor of 10%



- The reason for GAIN variation remains unclear
- We plan to observe Cas-A/Tycho for GAIN correction

Summary

- * Preliminary analysis of the WXT data shows
 - ★ Positioning accuracy: less than 2 arcmin (J2000, 90% C.L.)
 - ★ Angular resolution: 3.3 - 4.4 arcmin (FWHM, R60)
 - ★ Effective area: $\sim 3.0 \text{ cm}^2 @ 1 \text{ keV}$, systematics $\sim 4\text{-}13\%$ (1σ)
 - ★ Energy resolution: $\sim 120 - 140 \text{ eV} @ 1.25 \text{ keV}$, Precision $\sim 1\text{-}3\%$ (1σ)
 - ★ Detected band: 0.4 – 6 keV
- * **The in-flight performances fulfill design goals, without noticeable degradation after launch until now.**

A solid foundation for scientific discovery!

Contact:
Huaqing Cheng (EPSC)
hqcheng@nao.cas.cn
Heyang Liu (EPSC)
Liuheyang@nao.cas.cn