IACHEC

International Astrophysical Consortium for High Energy Calibration

Lorenzo Natalucci
for the IACHEC Non-thermal SNR Working Group

Report Fall 2021

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International Astrophysical Consortium for High Energy Calibration

Current WG e-mail list

Andy Beardmore, Giancarlo Cusumano, Larry David, Jelle Kaastra, Manabu Ishida, Keith Jahoda, Elisabeth Jourdain, Keiichi Maeda, Andrew Read, Richard Rotschild, Taka Sakamoto, Kristin Madsen, Brian Grefenstette, Gary Case, Dipankar Bhattacharya, Craig Markwardt, Yukikatsu Terada, Xiabo Li, Liming Song, James Rodi, Lucien Kuiper, Paul Plucinsky, Masahiro Tsujimoto, M.Y.Ge, Jeremy Drake, Herman Marshall, Vinay Kashyap, Matteo Guainazzi

If interested to join, please contact: lorenzo.natalucci@inaf.it

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WG goals and history of main events

It mainly aims at the cross-calibration analysis of G21.5-0.9 (mainly below 10 keV) and of the Crab spectra (mainly above 10 keV).

- Define a reference model for cross-calibration in the energy band from soft X-rays to hard X-rays
- Analyse observational data in the context of cross-calibration. Extract ratios for instrument renormalisation in different energy bands

The WG started its activities in 2007 (Lake Arrowhead). Initial chairperson: Manabu Ishida

An important milestone is reached in 2010 (chairperson: M.Tsujimoto) with publication of cross-cal paper on G21.5-0.9

Preliminary discussion on: PSR B1509-58, the pulsar in the «Hand-of-God» SNR

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Updates since May

- Major calibration updates from NuSTAR and INTEGRAL/ISGRI
- New calibration of NICER using Crab raster observations. Progress in NuSTAR/Nicer comparison?
- Updated Crab dataset
- Discussion about to start a new project based on Crab pulsed spectrum (what missions?)
- G21.5-0.9 calibration model: planning more work to analyse multi-mission data. Need to kickoff a sub-group
- Forthcoming cross-cal project on PSRB1509-58

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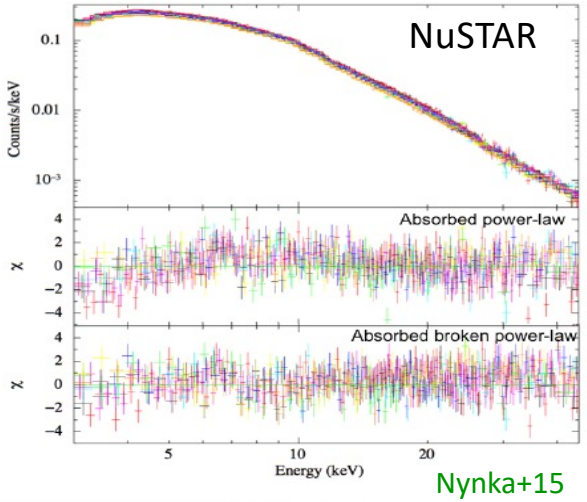
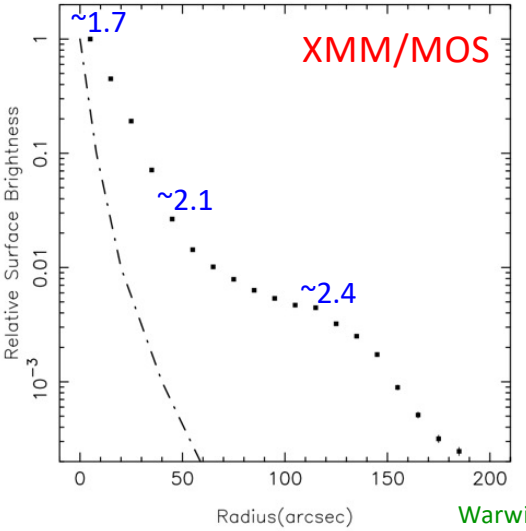
G21.5-0.9

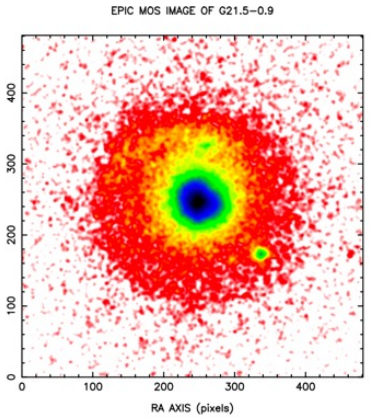
- Compact plerionic nebula, routinely observed in the X-ray band (typically 0.1-10 keV). Faint in the hard X-rays (~mCrab)
- Important calibration source for all X-ray instruments including future missions (XRISM, Athena,… more)



Nynka+15



Warwick+01



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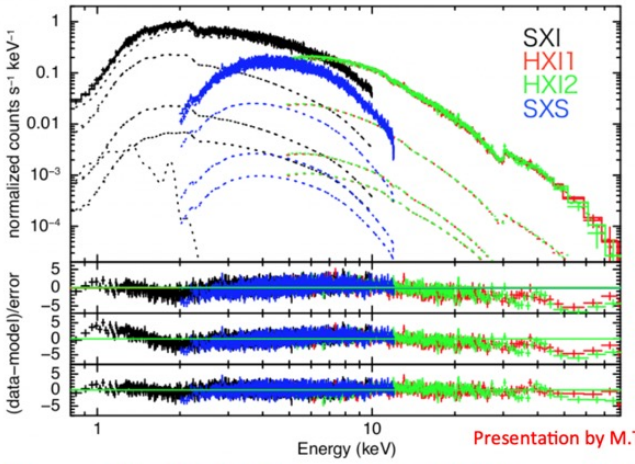

Hitomi

E_{break} = 7.1 ± 0.3 keV, Γ_{soft} = 1.74 ± 0.02, Γ_{hard} = 2.14 ± 0.01

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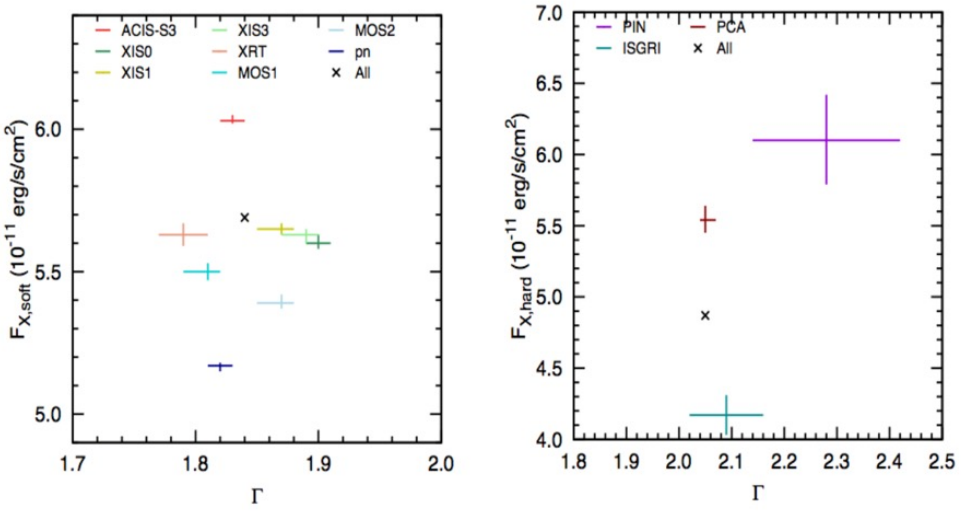
G21.5-0.9 cross-cal paper

In the soft X-ray band, results are broadly consistent with other measurements (e.g. 3C273).
Different situation for the hard band: for example, PIN/ISGRI flux ratio=1.3 but for the Crab we find ~10-12%



Scatter plot of PL fit parameters for *soft-band* and *hard-band* instruments. (Tsujimoto et al., A&A 2010)

Presented by M. Tsujimoto

G21.5

- We had one paper on this (Tsujimoto+11)
- Motivations for a new paper.
  - New data accumulated: NuSTAR, Hitomi, INTEGRAL, etc.
  - New calibration results. e.g., Hard-band response (8-12 keV) improved for XIS0,3.
  - New model (Energy break)
- We can prepare a new paper with a focus on >~5 keV range.

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The Crab multi-mission project

- Results exclusively based on the analysis of nearly simultaneous periods
- Emphasis on the hard band (>10 keV)
- Instruments already on board: XIS, PIN, GSO, PCA, IBIS/ISGRI, SPI, NuSTAR, (EPIC-pn), GBM, BAT, ASTROSAT/CZTI (new)
- Total of 9 nearly simultaneous epochs (2005-2016).
- Broken power law model, with E_{br} ~100 keV
- Broad band spectral fitting: energy range is essentially the operative range of the instrument

Instr.	Energy Bands (keV)
XIS	3–10
PIN	10–25, 25–80
GSO	25–80^ 100–300
PCA	3–10, 10–25, 25–80
IBIS	25–80, 100–300
SPI	25–80, 100–300
NuSTAR	3–10, 10–25, 25–80
EPIC	3–10
GBM	(25–80), 100–300
BAT	25–80

^for GSO, E >40 keV

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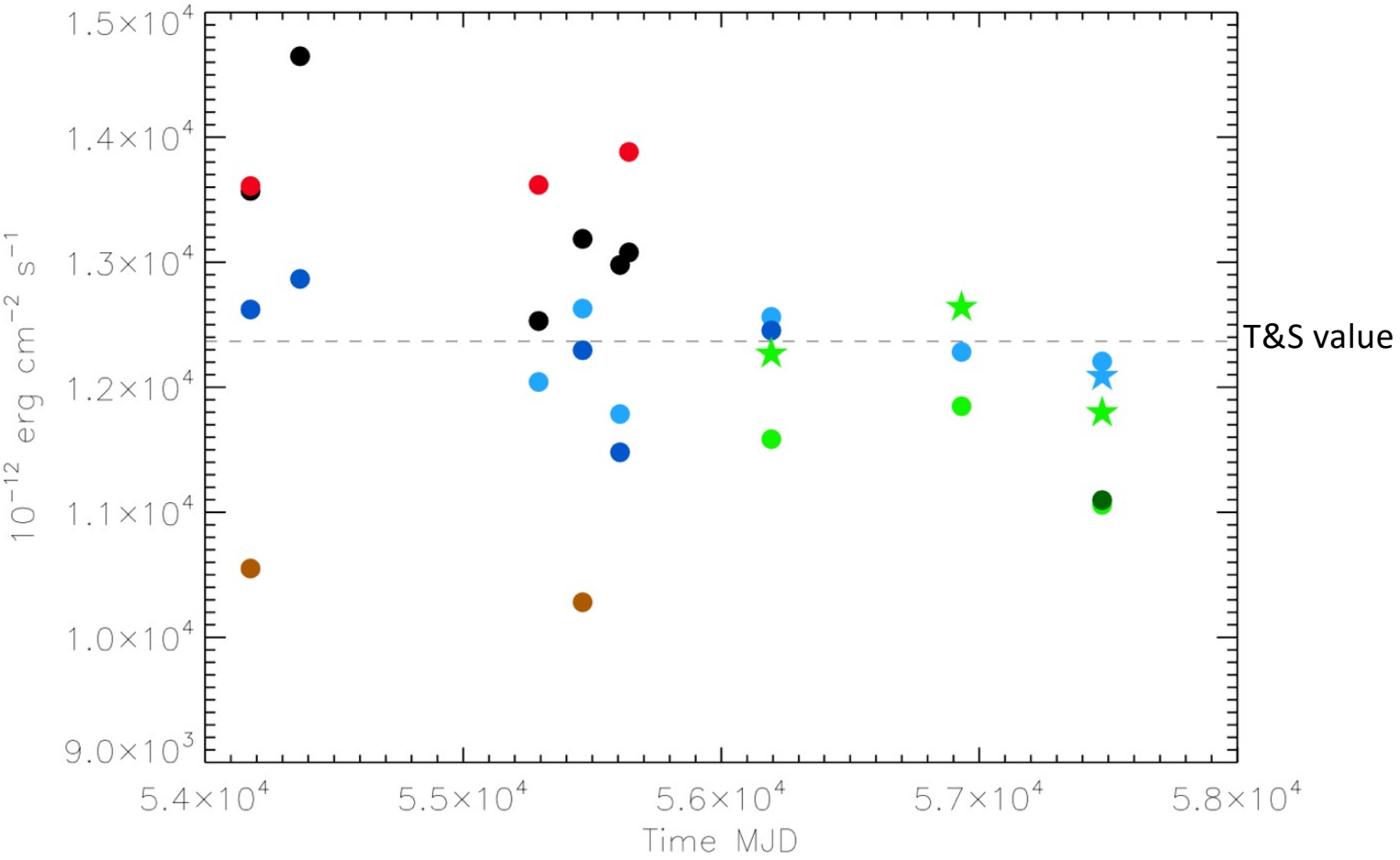
Flux history 25-80 keV



PCA

PIN

Nustar

Astrosat/CZTI

SPI

ISGRI

BAT

★ = calibration update

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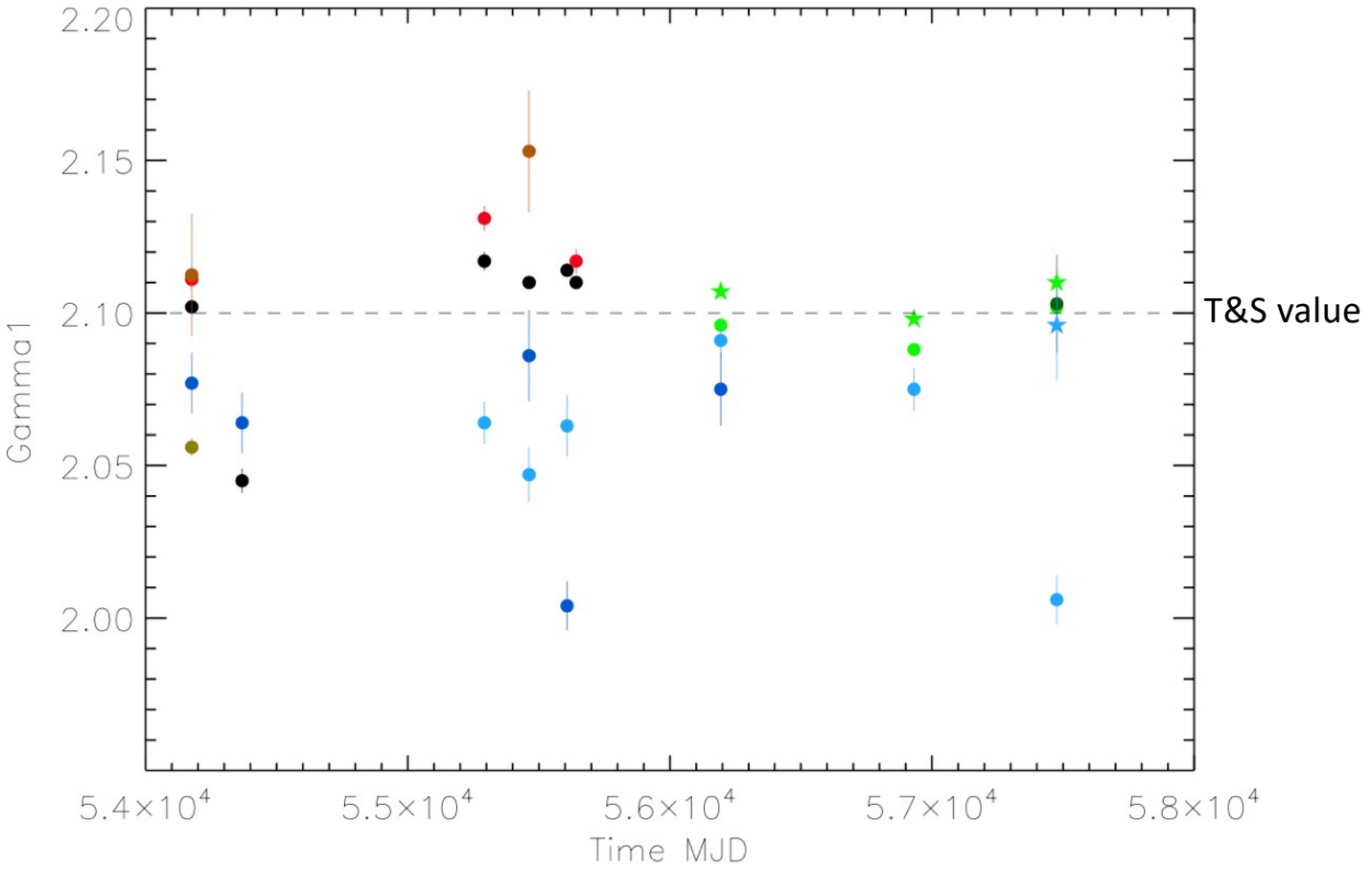
Spectral slope (Γ, E<Ebreak)



PCA
XIS
PIN
NuSTAR
Astrosat/CZTI
SPI
ISGRI
BAT

★ = calibration update


Crab & instruments calibration
New reports

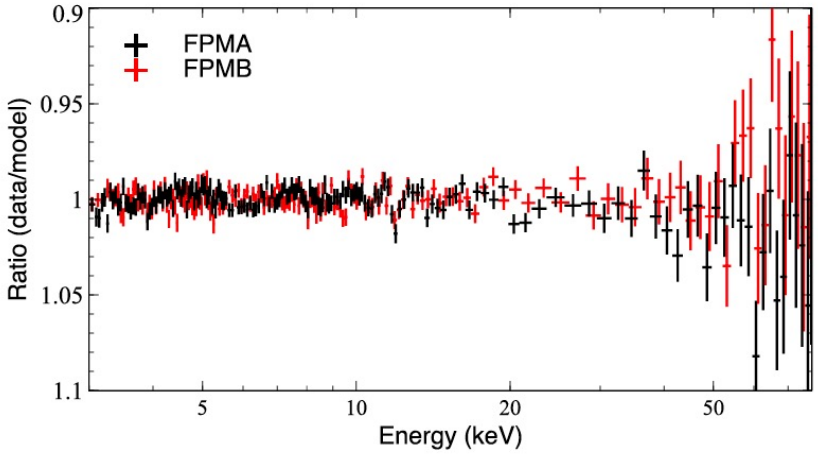
NuSTAR Calibration Update

Kristin K. Madsen & Brian Grefenstette

And the NuSTAR SoC

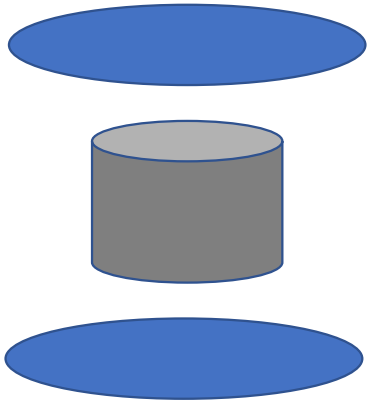
2012 In-flight Calibration

- Implemented a 15% increase in effective area to decrease the flux
- Focused Crab model:
  - Gamma = 2.1
  - N = 8.5



3C 273			
FPMA	1.52 ± 0.09	40.3 ± 0.6	1.0
FPMB	1.68 ± 0.09	41.3 ± 0.7	1.02 ± 0.02
ACIS HEGTS	1.52 ± 0.05	44.6 ± 1.0	1.10 ± 0.03
FPMA	1.66 ± 0.02	40.9 ± 0.3	1.0
FPMB	1.66 ± 0.02	42.5 ± 0.3	1.04 ± 0.01
XIS0	1.64 ± 0.03	40.6 ± 0.3	0.99 ± 0.01
XIS1	1.69 ± 0.03	40.4 ± 0.3	0.99 ± 0.01
XIS3	1.66 ± 0.03	41.6 ± 0.3	1.02 ± 0.01
FPMA	1.65 ± 0.03	40.9 ± 0.4	1.0
FPMB	1.66 ± 0.03	42.4 ± 0.4	1.04 ± 0.01
XRT	1.55 ± 0.06	42.4 ± 1.2	1.04 ± 0.03
FPMA	1.63 ± 0.04	39.8 ± 0.6	1.0
FPMB	1.68 ± 0.04	41.3 ± 0.6	1.04 ± 0.02
MOS1	1.47 ± 0.04	40.7 ± 0.4	1.02 ± 0.02
MOS2	1.46 ± 0.04	39.0 ± 0.4	0.98 ± 0.02
pn	1.59 ± 0.02	37.0 ± 0.2	0.93 ± 0.01
Instrument	Γ	Flux 20–40 keV (10^{-12} erg cm^{-2} s^{-1})	Relative Flux
FPMA	1.73 ± 0.06	60.4 ± 1.4	1.0
FPMB	1.83 ± 0.06	60.6 ± 1.4	1.0 ± 0.03
HXD	1.75 ± 0.02	68 ± 3	1.12 ± 0.03

Instrument components

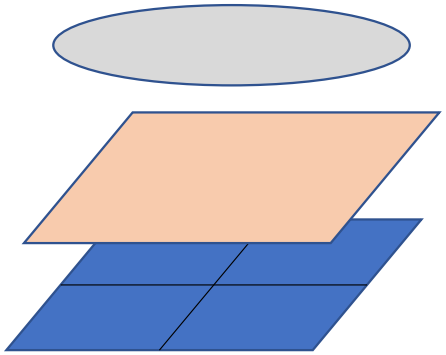


MLI cover *

Multilayer Optic

MLI cover

ARF



Stray-light data

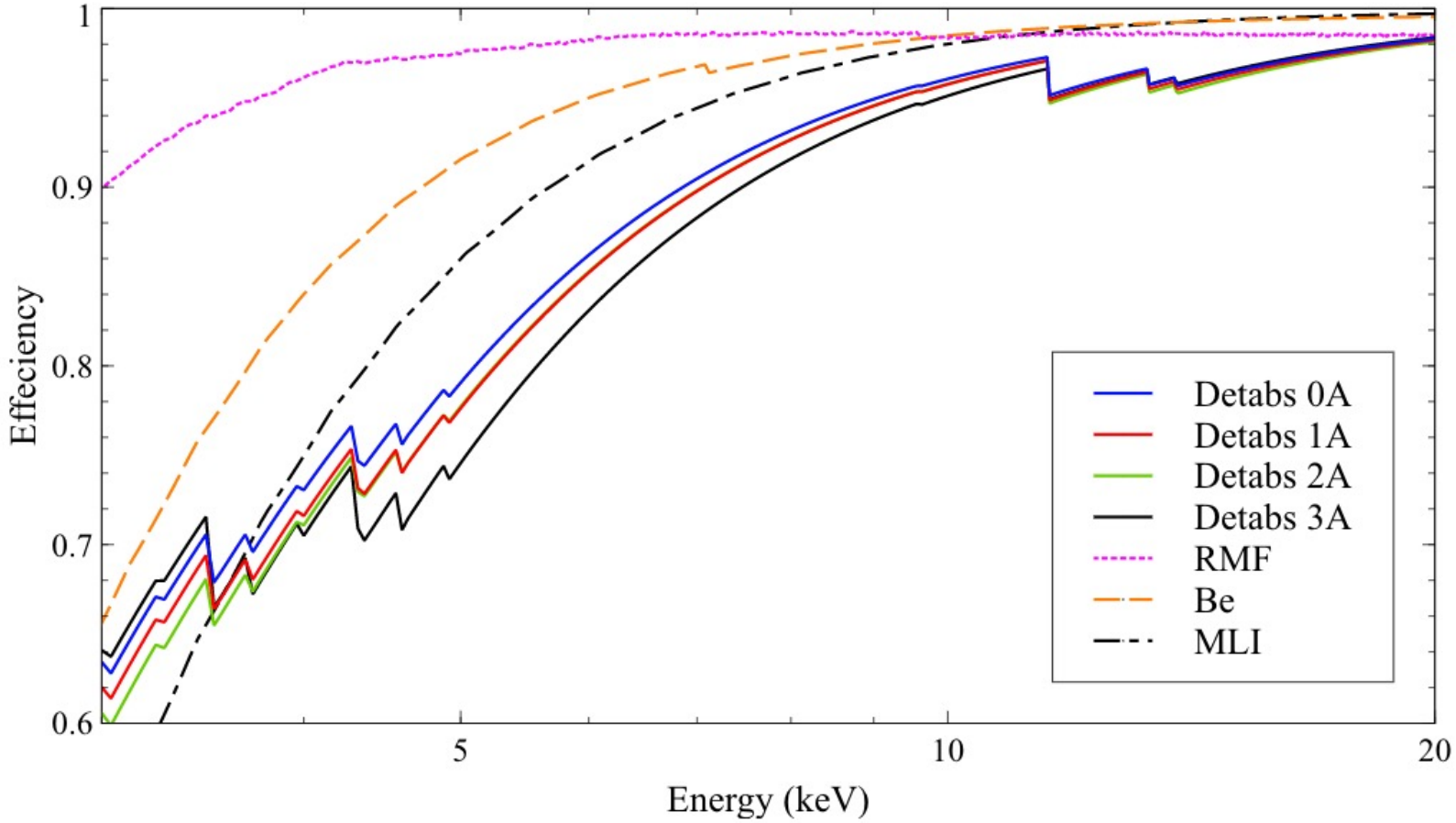
Be window*

Detector absorption layer

CZT Detector

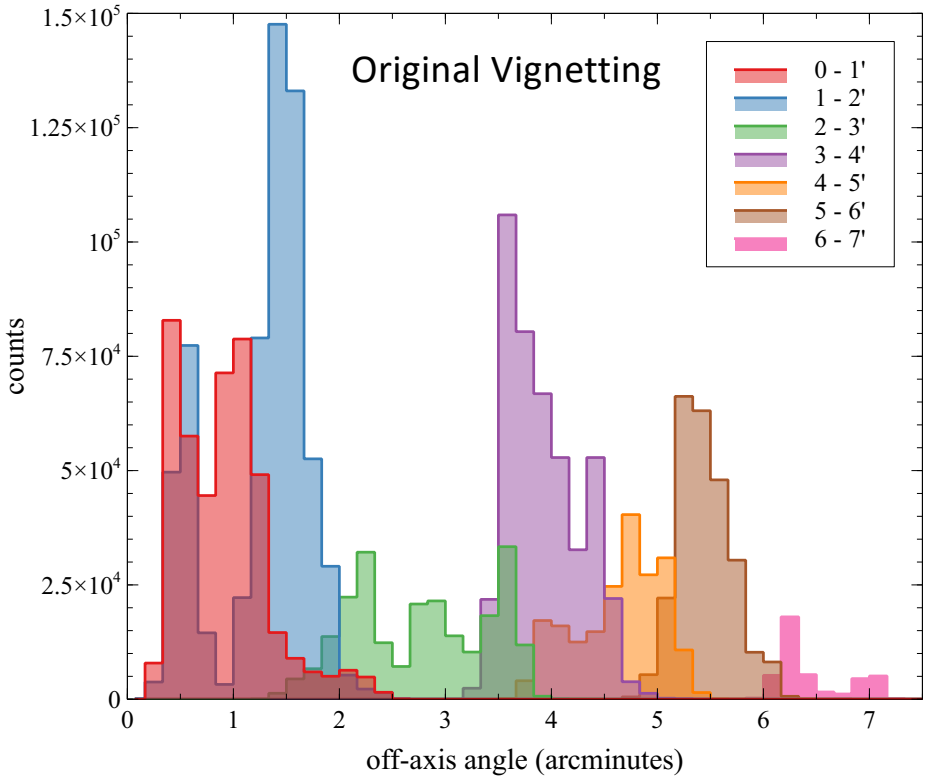
RMF

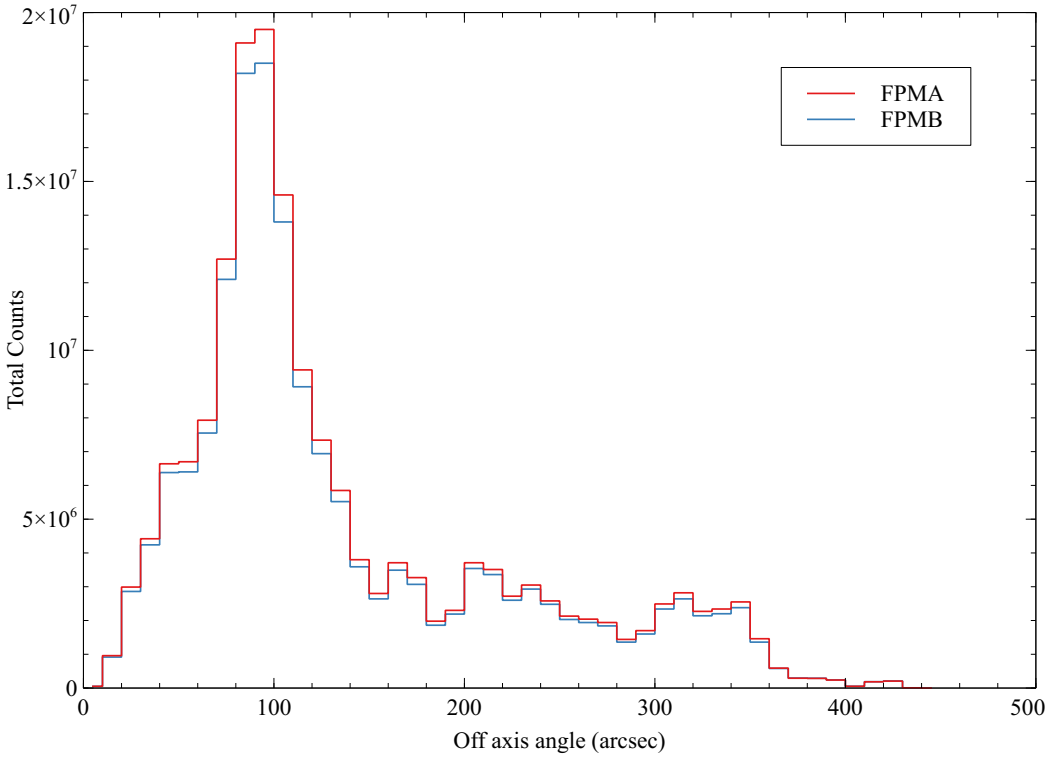
* Presumed constant


Effeciency
Energy (keV)
1
0.9
0.8
0.7
0.6
5
10
20
Detabs 0A
Detabs 1A
Detabs 2A
Detabs 3A
RMF
Be
MLI

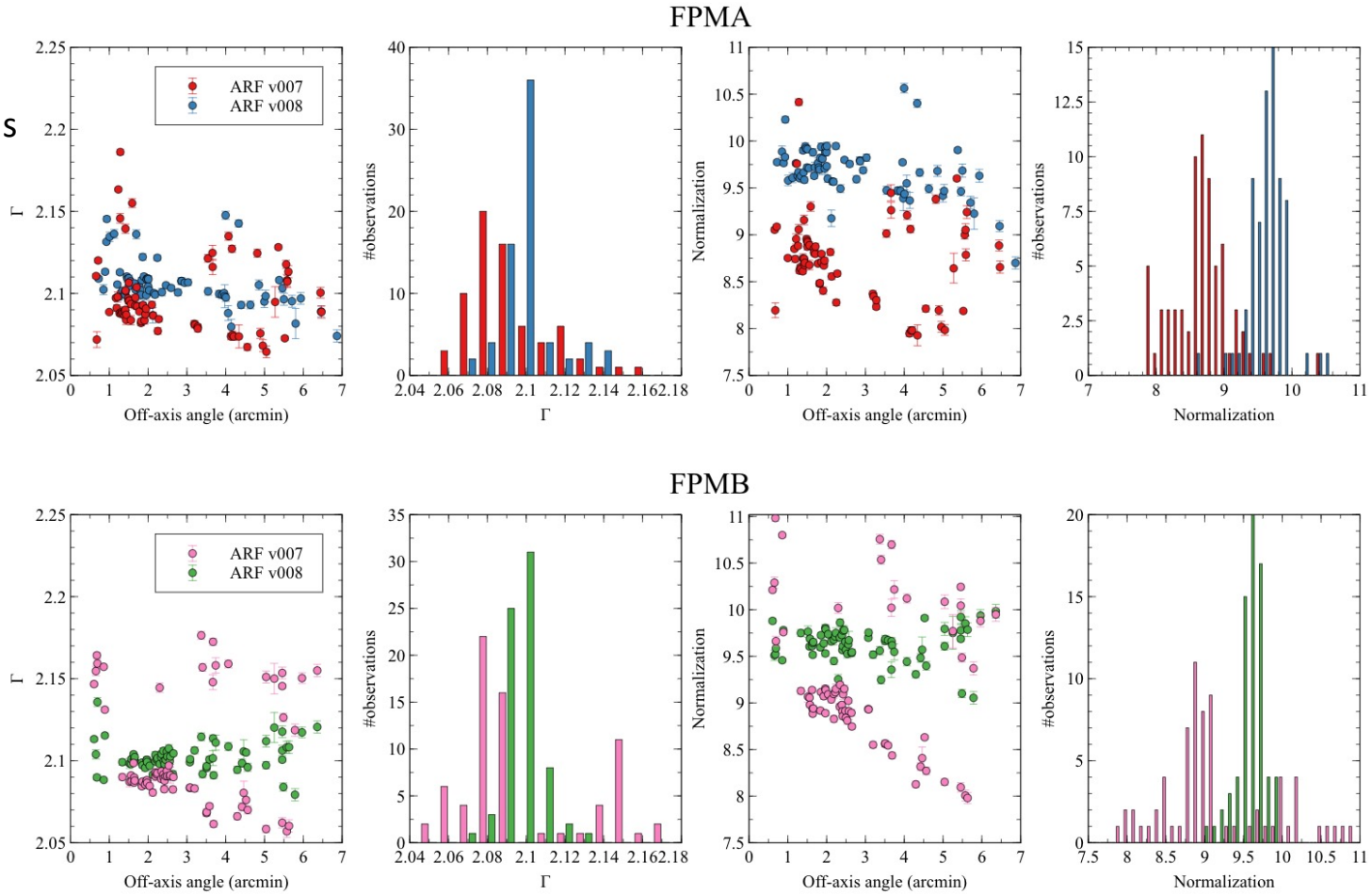
ARF fitting

Off-axis distribution from individual observations





71 focused
Crab observations



Relative model components

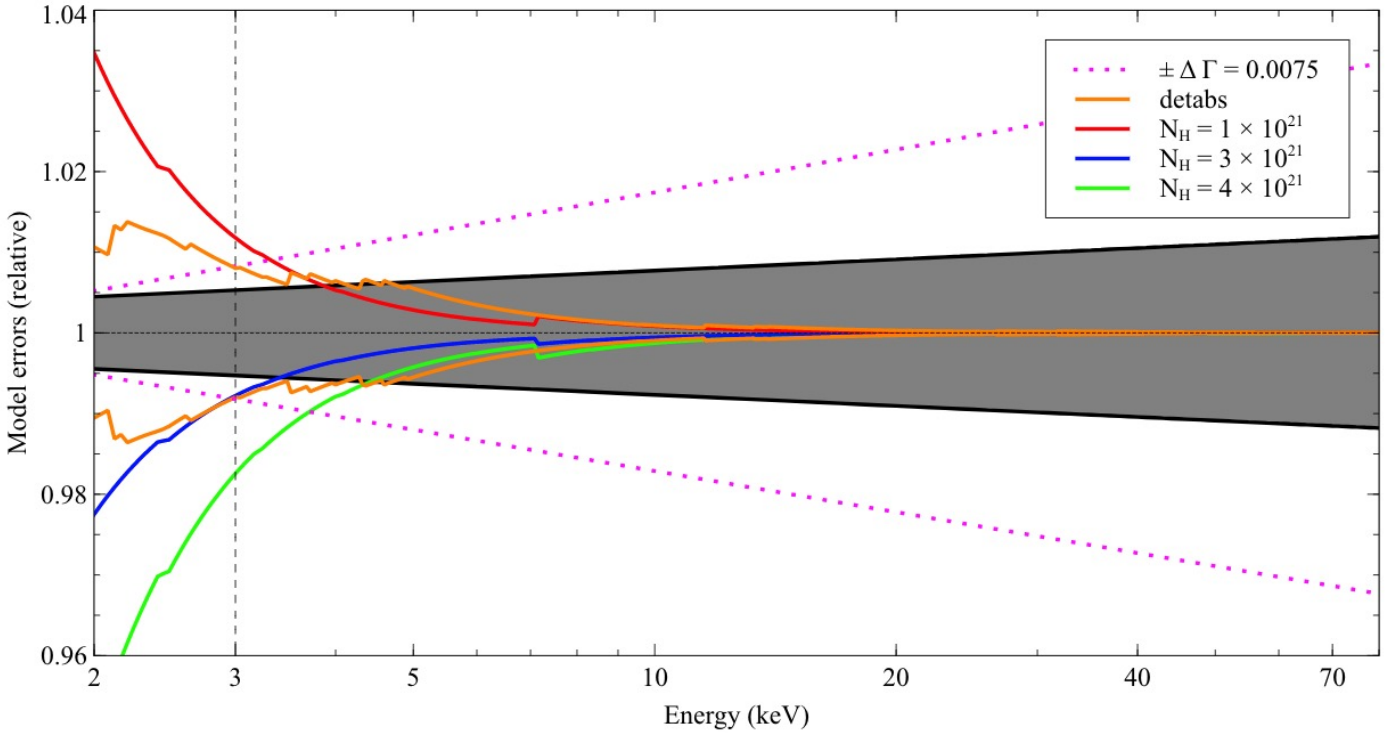


Table 7. Mean and standard deviation of all focused Crab observations between $1'$–$4'$.

Module	Γ	Normalization ($\mathrm{keV}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$)	Flux (3–10 keV) (10^{-8} ergs $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$)
ARF v007			
Crab†	2.1	8.5	1.38
FPMA	2.097 ± 0.023	8.74 ± 0.44	1.42 ± 0.033
FPMB	2.103 ± 0.033	9.20 ± 0.71	1.49 ± 0.042
ARF v008			
Crab†	2.013	9.69	1.57
FPMA	2.104 ± 0.013	9.66 ± 0.23	1.56 ± 0.026
FPMB	2.105 ± 0.009	9.68 ± 0.19	1.56 ± 0.028

† Canonical Crab values used for the calibration.

NICER Analysis Workshop

May 2021

NICER

Neutron star Interior Composition ExploreR

NICER New Software Release

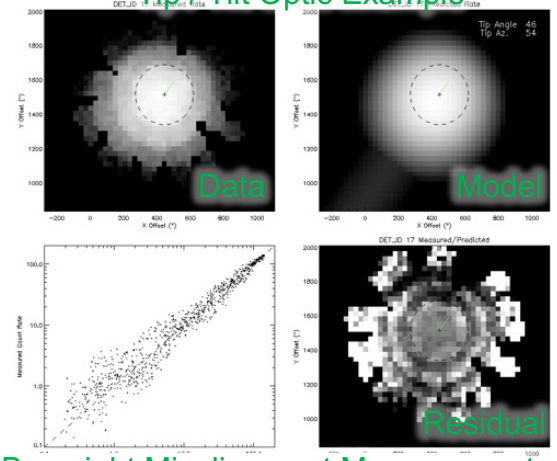
Craig Markwardt (NASA/GSFC)
on behalf of NICER Team

NASA GSFC MIT KAVLI INSTITUTE DTU BROAD REACH MOOG

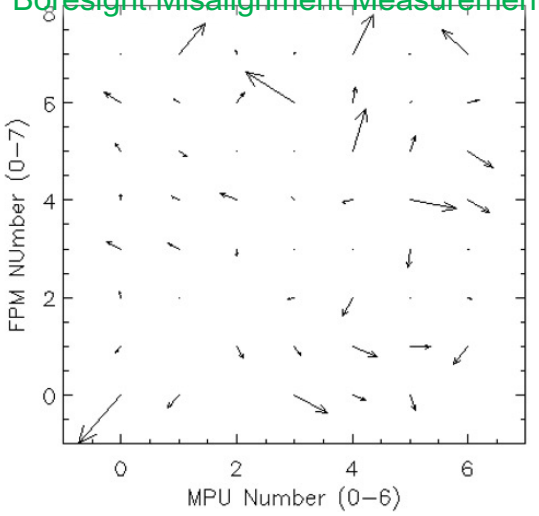
NICER Calibration Updates (xti20210707)

- Major NICER calibration update released July 2021
- Addition of response matrix calculator tasks (nicerarf & nicerrmf) versus to pre-calculated responses
- Based on analysis of existing NICER Crab raster observations
  - Ray-tracing data
  - Tip-tilt & boresight misalignment of optics included
- Capability for off-axis and diffuse targets

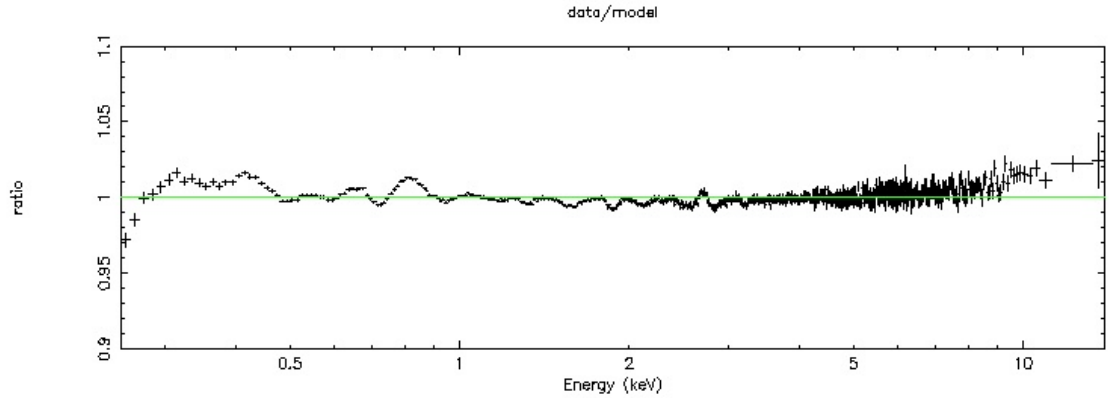
Tip / Tilt Optic Example



Boresight Misalignment Measurement



NICER Crab Performance



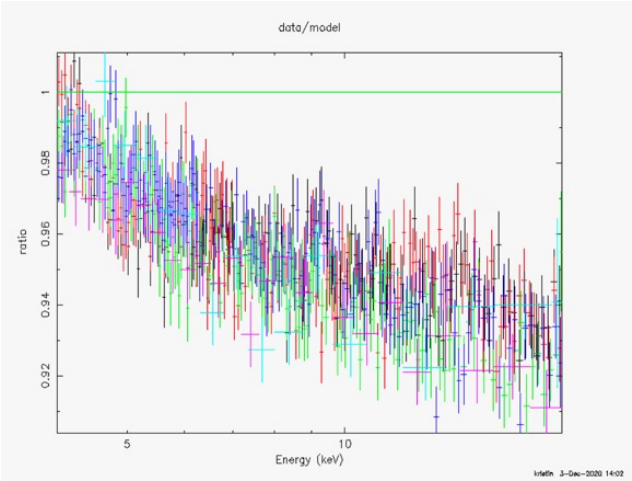
- Kaastr et al 2009 Nebula + Pulsar model
- Crab residuals <1.5% over 0.4-10 keV range
- No strong residual features at known astrophysical / detector positions

What is the Canonical Crab Model?

- NICER has used Kaastra et al's (2009) model
  - tbvarabs*xscat(curv*powerlaw + **crab_pulsar**)
- Crab pulsar model based upon Kuiper et al (2001), which combines BeppoSAX LECS (>0.1 keV), MECS & PDS as well as Compton GRO

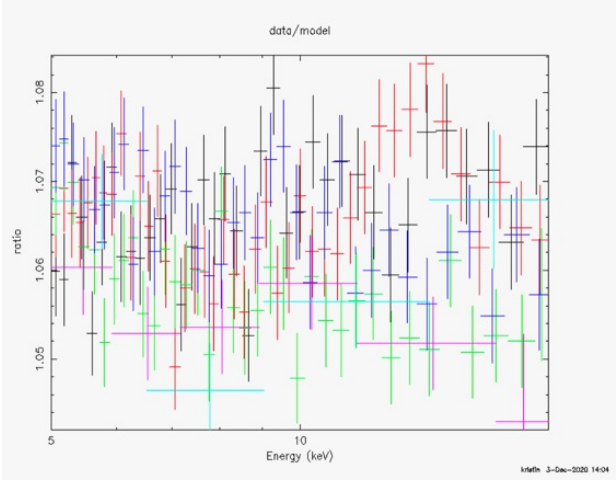
$$F_{\rm p} = 726E^{-1.276}{\rm e}^{-0.074x^2} + 1464E^{-1.165}{\rm e}^{-0.159x^2} + 2021E^{-2.022},$$

- NICER uses this pulsar model "as-is" with no change; NuSTAR???



LEFT:
NICER Crab model applied as-is on NuSTAR SL. No fitting.

RIGHT:
pulsar norm = 0 then we can agree on the the slope and the ratio between NuSTAR/model ~ 1.065.



Is pulsar component right? Worth looking at pulsed spectrum?

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

ISDC

OSA11.2-beta: ISGRI

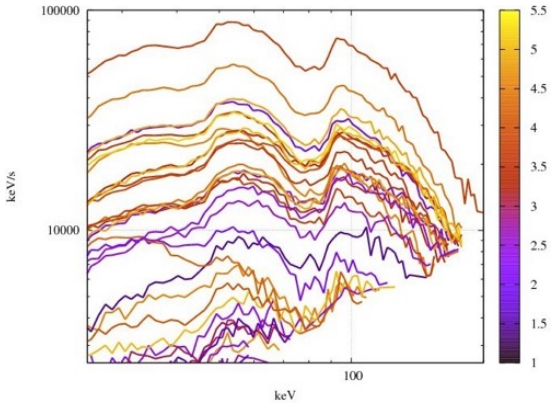
Volodymyr Savchenko

Sardinia, October 14 2021

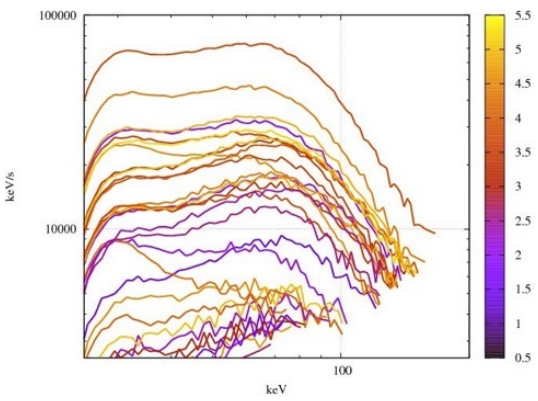
OSA10 issues

- Spectra of one or two bright sources quite different from Crab are not reconstructed correctly
- Big discrepancies after ~2017, hard or impossible to correct with OSA10 approach (ad-hoc efficiency, fitting ARF)
- Line positions of some cyclotron line sources, Her X-1 sometimes (rarely) mismatch strongly
- Presumably, ARF should represent effective area, not electronic issues.
  - ISGRI Efficiency: from **detected events** to **reconstructed rates** (done by OSA internally)
  - RMF+ARF: from **reconstructed rate** to **flux** (done in expect out of OSA)
- Long-term reconstructed rate stability (e.g. Crab)
- Can we understand ISGRI detector, and make physical, continuous model at least for some parts? This should make spectra smoother, predictions more absolute.
- Understand detector polarization, fast (~several hours) and historic

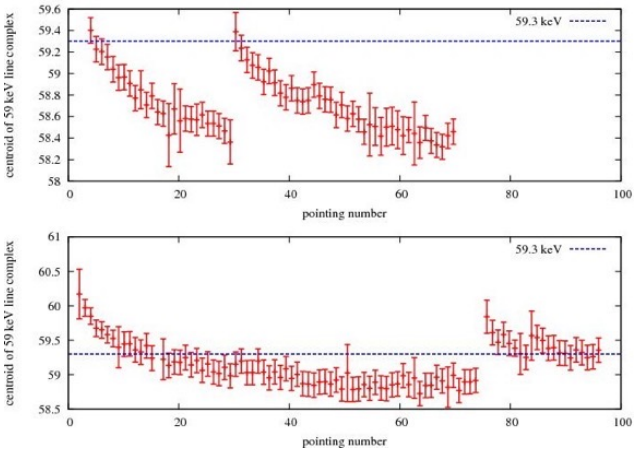
OSA10



OSA11

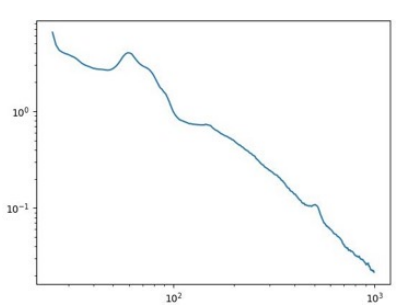


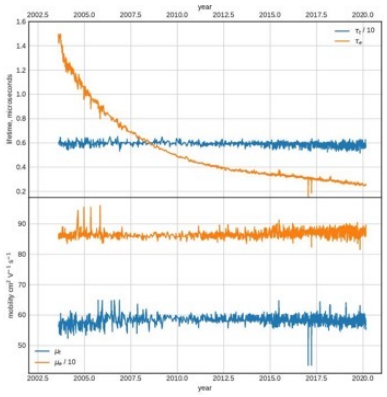
Detector polarization



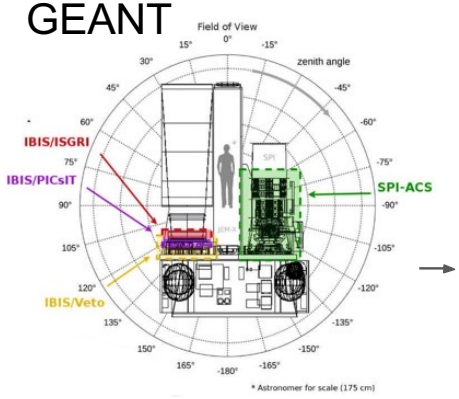
Calibration

Fit charge loss model to background





GEANT



Fit low-energy RMF and efficiency

3ML Multi-Mission Maximum Likelihood Framework

OSA

Reconstruct **deposited "photon" energies**

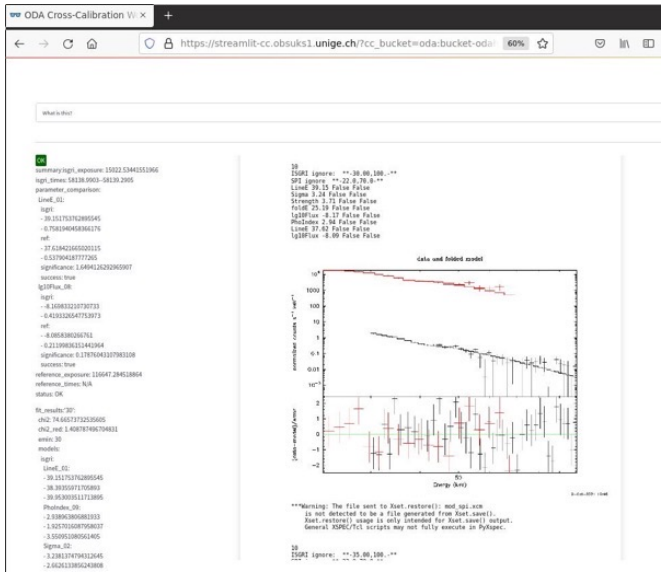
Reconstruct **"equivalent" count rates** dividing by efficiency

Fit detector plane with model shadows

Verification

No ARF fitting for now
(even if it's not necessarily a bad thing)

Fitting spectra
(xspec)



Verification machinery

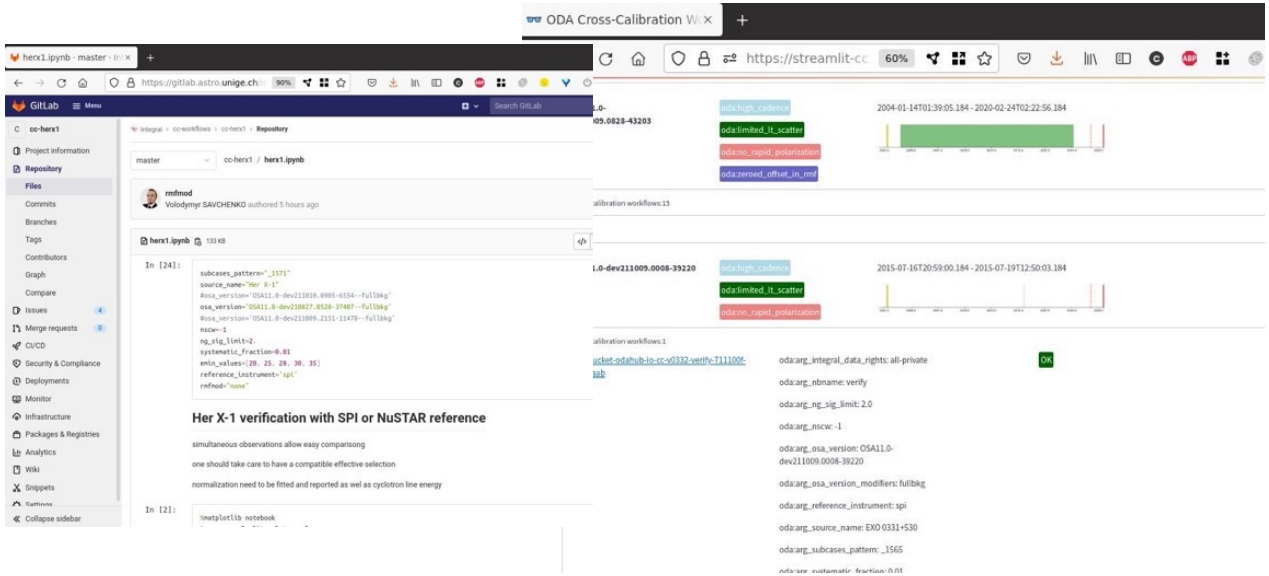
Jupyter notebooks with extra annotations: conventional “modern” technologies, ready to be public. Only concern is data rights for some workflows/results.

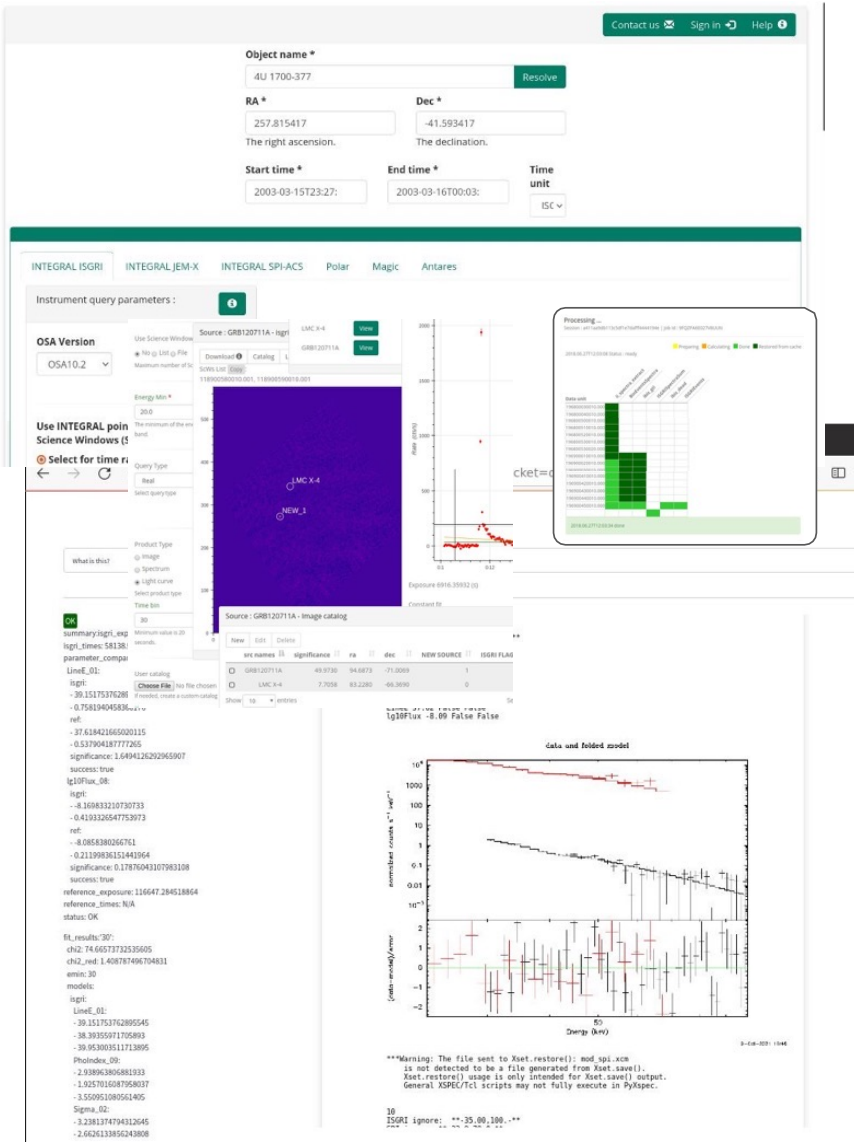
Can be run on one of numerous compatible platforms: **binder**, **googlecollab**, **Renku** (EPFL), **DataLabs** (ESA)

Can also fetch other data sources, especially web-based analysis (INTEGRAL and not).

Pluggable, fetching and fitting parts can be replaced.

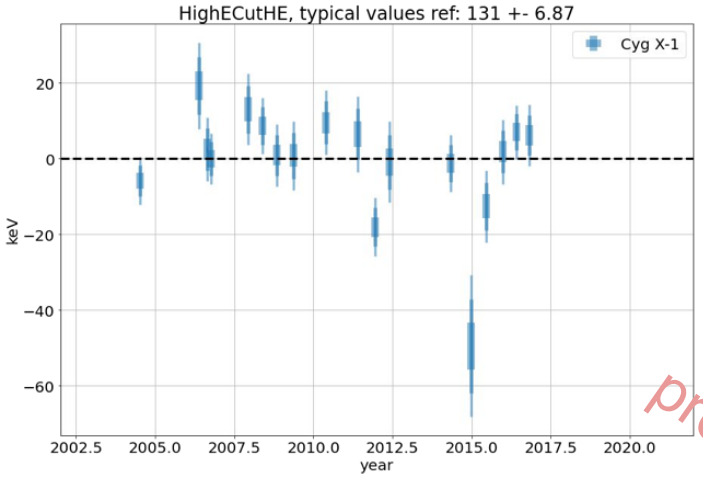
Is run automatically in response to new OSA or data.

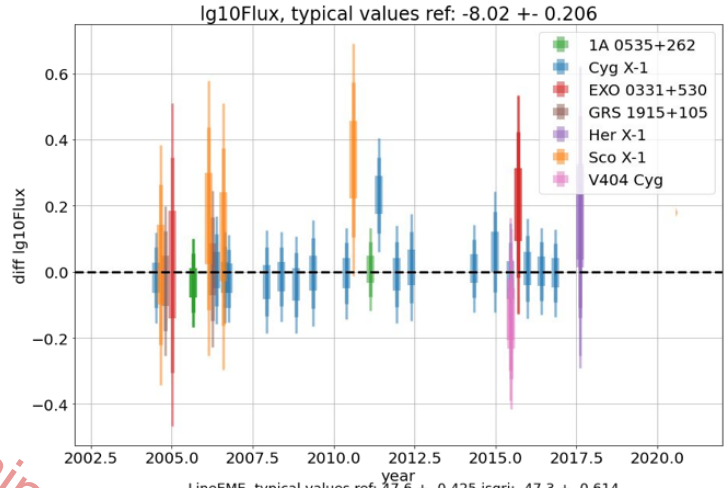


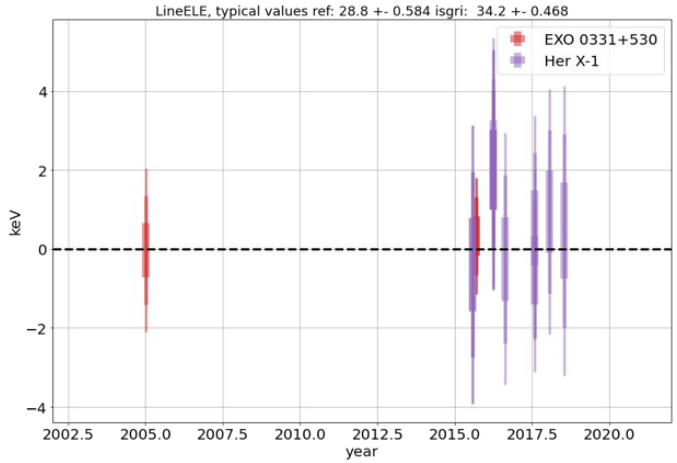


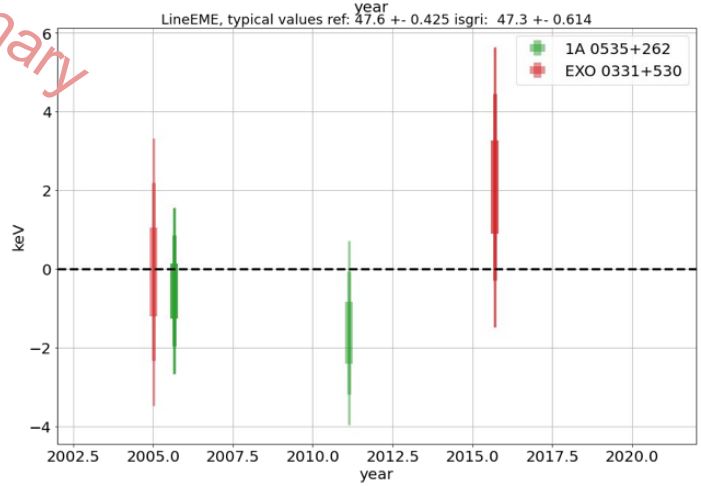
Aggregated results: High-energy reconstruction and flux

Differences in reconstructed parameters between ISGRI and “expectations”





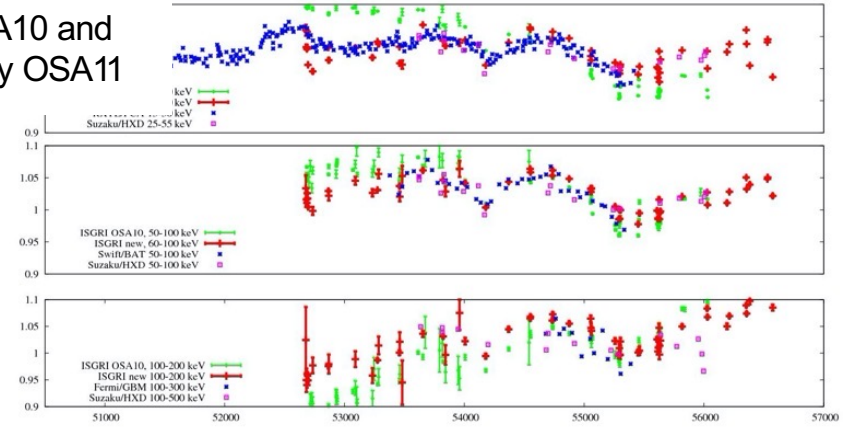


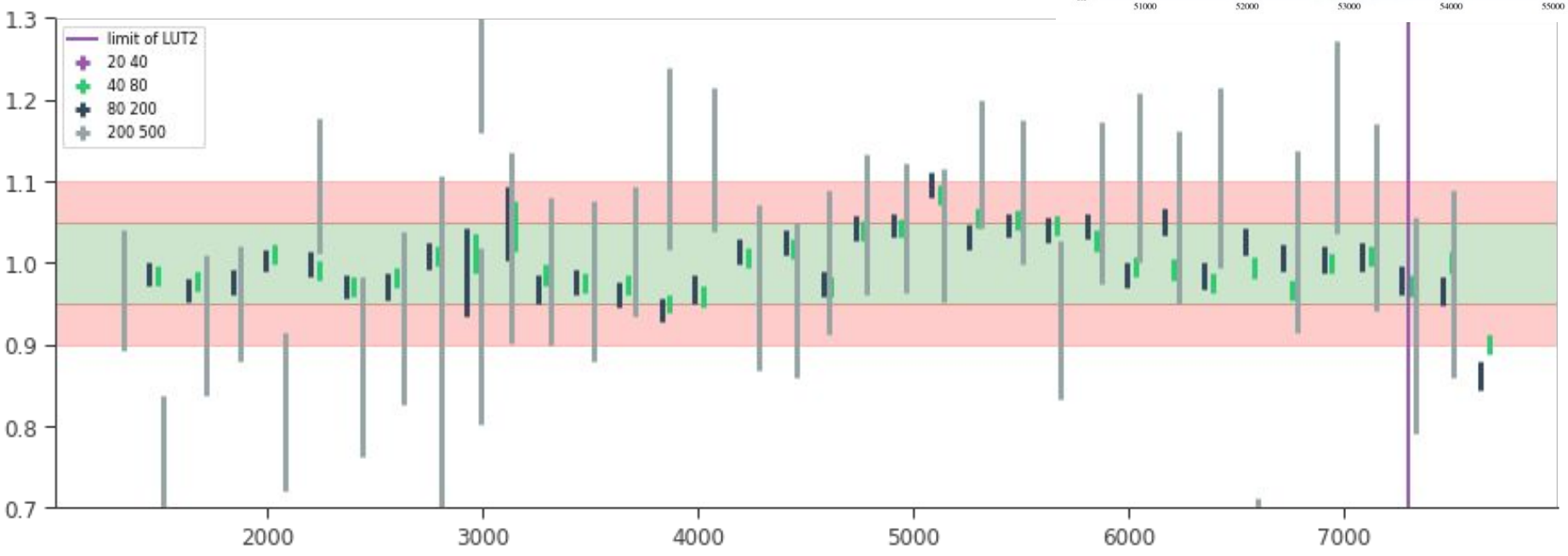


Long-term count rate: Crab

above ~60 keV - “absolute” measurement with detector model. Below - using efficiency instead of ARF.

OSA10 and early OSA11





Selection of Crab data

Ready?

No more anomalous source features (see 1A 0535+105), background spectra look the same **OK**

Cyclotron line sources consistent with reference where available **OK**

High-energy (>60 keV) rates stable from physical detector model **OK**

ARF does not change, efficiency and RMF do **OK**

Internal (to IBIS team) validation beta ready in MMODA and normal IC.

ISGRI still evolving. Need to follow until the end of the mission. **ok for now**

Rapid evolution caused by polarization is implemented, but not available in the beta. **ok for now**

Detector plane background model should be updated. **ok for now**

Calibration with PSR B1509-58/MSH 15-52
(James Rodi, INAF/IAPS)

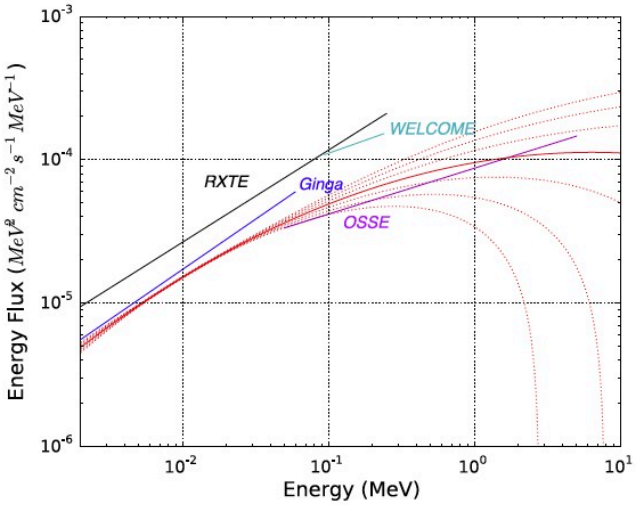
- Period of ~150 ms
- Radio Pulsar detected up TeV
- Observed by instruments from X-ray to gamma-ray
  - RXTE, XMM, HXMT, NuSTAR, INTEGRAL. Suzaku, and other missions
- Good source for both timing and flux calibration since pulsed flux is ~constant
- G21.5-0.9 cross-calibration IACHEC work by Tsujimoto et al (2011)

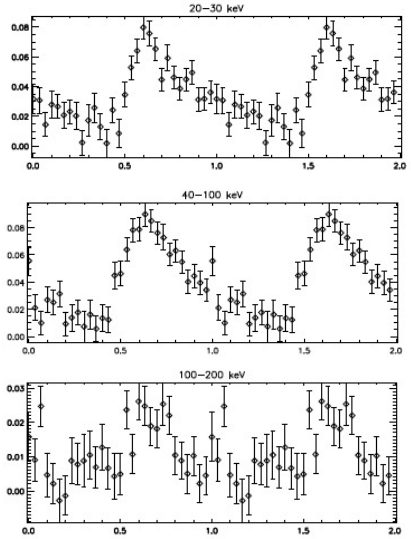
Some Previous results

- Livingstone & KASPI (2011) ~7yrs of PCA
  - Pulsed flux roughly constant
- Forot et al (2006) ~ 1.3 Ms of ISGRI
- NuSTAR obs from Chen et al. (2016)
- Early work with INTEGRAL/ISGRI with a few observations; have ~12 Ms

Predicted Pulsed Flux

Observation	Energy band (keV)	Photon Index	Flux in 3–79 keV (10^{-10} erg cm^{-2} s^{-1})
NuSTAR	3–79	1.386 ± 0.007	1.136 ± 0.018
Ginga	3–60	1.30 ± 0.05	~1.50
RXTE	2–250	1.358 ± 0.014	~2.20
WELCOME	94–240	$1.64^{+0.43}_{-0.42}$	~3.14
OSSE	50–5000	1.68 ± 0.09	~1.26
ISGRI	20-500	~1.57	~1.4





Chen et al. (2016)

IACHEC

International Astrophysical Consortium for High Energy Calibration

Summary

- Activity of WG continues to be focused on Crab and G21.5: good primary standards also for new missions
- NuSTAR new CALDB issued; INTEGRAL/ISGRI new OSA release to be implemented in the Crab dataset; possibly include new epochs & instruments
- New studies of G21.5 model (currently in stand-by): data analysis for Chandra, XMM, NuSTAR, Hitomi, INTEGRAL, Swift for new project.

To follow (actions):

- Crab dataset: include Hitomi Crab spectra for 2016 & investigate more recent epochs
- Advanced draft of Crab paper before IACHEC 2020
- G21.5-0.9: Kickoff meeting to be called soon


Thank you!