IACHEC

International Astrophysical Consortium for High Energy Calibration





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 band

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

Among other calibration targets considered:is PSR B1509-58, the pulsar in the «Hand-of-God» SNR proposed by Frank Haberl as a «standard candle» at the 1st IACHEC meeting (Iceland, 2006). Relevant for future missions like XRISM, Athena...

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An important milestone paper on G21.5-0.9

Satellite	Det	xsect	Abun	E-band	NH	ph. Index	Norm (2-10)	$\chi 2\nu$	Obse	rved Flux	(10 ⁻⁸ erg/	cm ² /s)
				for fit	10 ²¹ cm ²		10 ⁻⁸ erg/cm ² /s		0.5-2	2-10	20-50	50-100
Suzaku	XIS	bcmc	wilm	1.0-10.0	4.61±0.10	2.070±0.008	2.239±0.012	1.19	-	2.170	-	-
			angr	1.0-10.0	3.19±0.07	2.077±0.008	2.244±0.012	1.19	-	2.169	-	-
	PIN		angr	12.0-70.0	3.19 (fixed)	2.110±0.007	2.267±0.023	1.03	_	-	1.039	_
RXTE	HEXTE	bcmc	angr	20-240	3.19 (fixed)	2.087±0.008	1.929 ± 0.027	0.99	-	-	0.928	0.657
XMM	pn	bcmc	angr	1.0-10.0	2.41 *0.03	$2.107^{+0.004}_{-0.009}$	1.876+0.003	1.31	-	1.827	_	_
INTEGRA	SPI	bcmc	angr	22-100	3.19 (fixed)	2.123±0.014	±	0.7	-	-	1.04	0.73
RXTE	PCA			3-50	3.19 (fixed)	2.114	2.4018	2.63	-	2.320	1.09	-
Swift	BAT	bcmc	angr	30-100	3.19 (fixed)	2.10±0.06	1.74±0.25	0.82	_	_	0.82	0.57

• We are going to do the same thing to G21.5-0.9, 3C58 and PSR1509+58... Presented by Ishida-san, 2007

Among other calibration targets considered: is PSR B1509-58, the pulsar in the «Hand-of-God» SNR proposed by Frank Haberl as a «standard candle» at the 1st IACHEC meeting (Iceland, 2006). Relevant for future missions like XRISM, Athena...

ACIS XIS0 XIS1 XIS3 XRT MOS1MOS2 pn

Soft-band

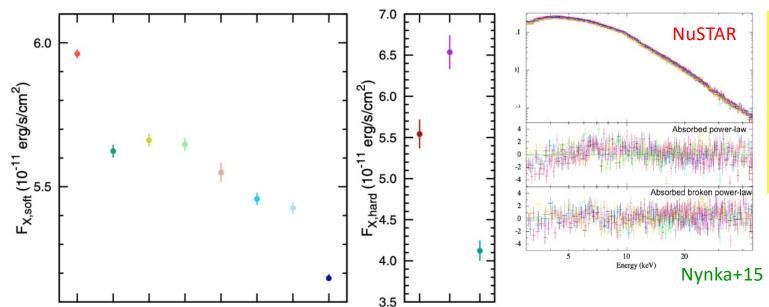
G21.5-0.9

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,...)

PCA PINISGRI

Hard-band



Tsujimoto+15

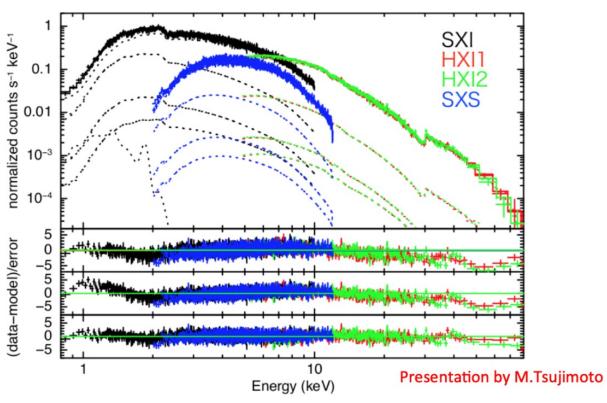
Hitomi data published in 2018, PASJ by Hitomi Coll.

Several papers on Chandra observations (most recent: Guest, Safi_Harb & Tang, arXiv.1810.01461

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.

G21.5: Hitomi data

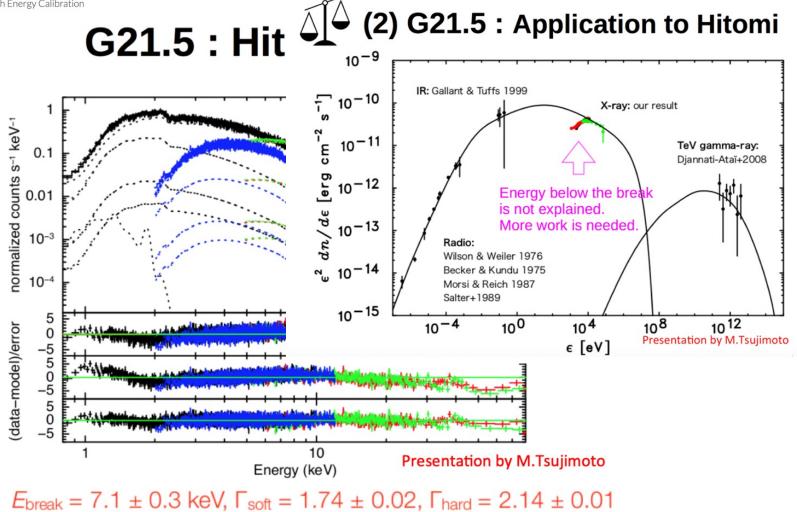


 $E_{\text{break}} = 7.1 \pm 0.3 \text{ keV}, \Gamma_{\text{soft}} = 1.74 \pm 0.02, \Gamma_{\text{hard}} = 2.14 \pm 0.01$

The Hitomi spectrum of G21.5-0.9 presented at the Non-thermal SNR WG during IACHEC 2018

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PSR B1509-58 (in the Hand-of-God)

Young radio pulsar, 150ms spin period. Energetic, spin down power ~1.7x10³⁷ erg/s

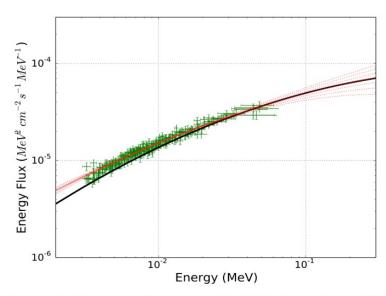


Figure 7. Energy spectrum of our NuSTAR observation and that from Cusumano et al. (2001). The green points are NuSTAR data. The solid black curve is the result of Cusumano et al. (2001). The solid red curve is the NuSTAR logpar spectral model, and the dotted curves are its 1, 2 and 3σ ranges.

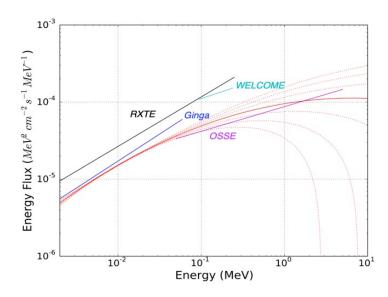


Figure 8. Energy spectrum of NuSTAR data and previous X-ray observations. The solid red line is the NuSTAR logpar spectral model, and the dotted red lines are its 1, 2 and 3σ ranges. The solid black line, solid cyan line, solid blue line, and solid magenta line, from top to bottom, are X-ray spectra observed by RXTE, WELCOME, Ginga and GSSE, respectively.

Chen+16



PSR B1509-58 (in the Hand-of-God)

Young radio pulsar, 150ms spin period. Energetic, spin down power ~1.7x10³⁷ erg/s

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			

LITCI GY (MCV)

Figure 7. Energy spectrum of our NuSTAR observation and that from Cusumano et al. (2001). The green points are NuSTAR data. The solid black curve is the result of Cusumano et al. (2001). The solid red curve is the NuSTAR logpar spectral model, and the dotted curves are its 1, 2 and 3σ ranges.

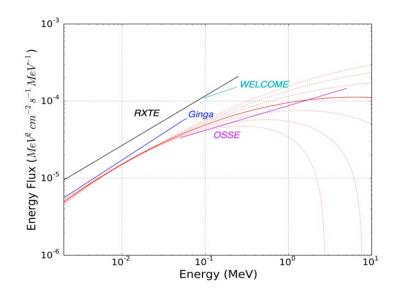


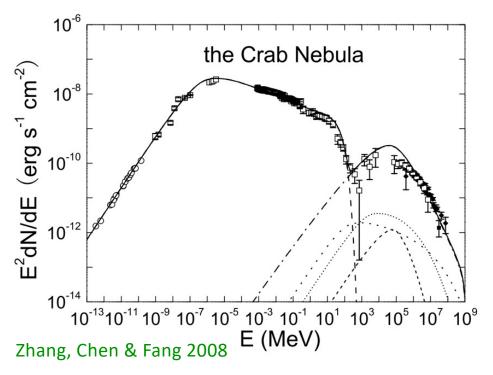
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The Crab

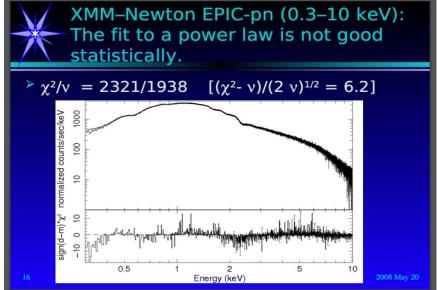
High quality spectra throughout all wavelenght, used as a standard calibration source in the hard band (~few keV

to ~Mev and beyond)



Crab spectrum in X-rays. Is it a PL in the X-ray band? (see M.Weisskopf talk,

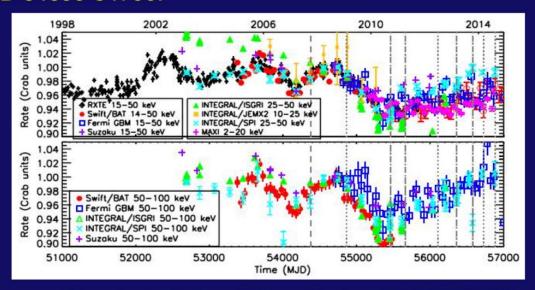
"So you think the Crab is described by a power-law spectrum", IACHEC 2008)



The Declining Crab

Presented by G. Case

 Light curves for each instrument are normalized to its average rate from MJD 54690-54790.



(Thanks to Colleen Wilson-Hodge [NASA/MSFC])

- Instruments on four separate spacecraft show ~7% decline in Crab flux from August 2008-July 2010!
- From mid-2010 to end of 2015, Crab mostly recovered

IACHEC 2017





Methodology

- 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
- Total of 9 nearly simultaneous epochs (2005-2016).
- Broken power law model, with E_{br} ~100 keV
- Broad band spectral fitting

Instr.			
XIS PIN GSO PCA IBIS SPI NuSTAR EPIC	10-25, 10-25, 10-25,	25-80 25-80^ 25-80 25-80, 25-80,	100-300 100-300 100-300
GBM BAT		(25-80) , 25-80	100-300

^for GSO, E >40 keV



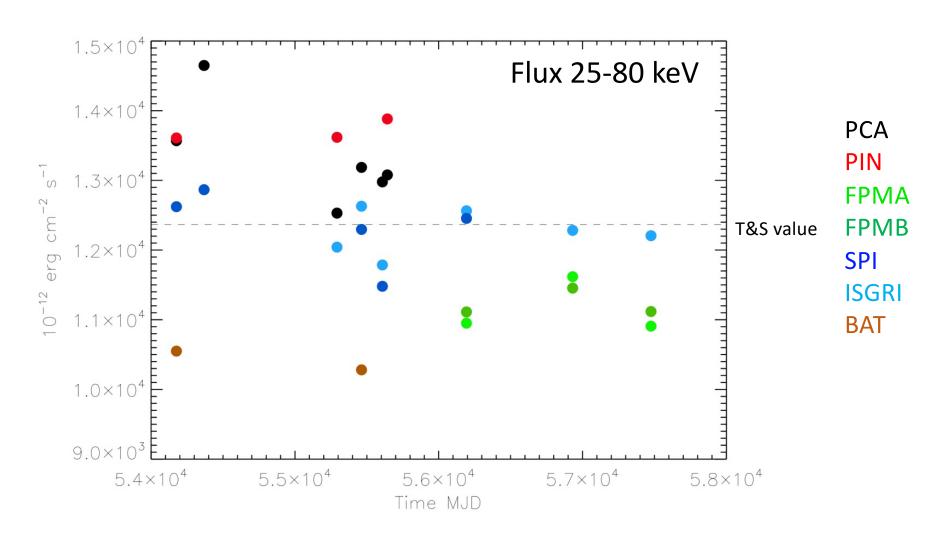
Spectral fitting

- Individual fits to all instrument spectra for the 9 epochs with observations spaced by <1week
- Model fitted is absorbed (Tbabs) power-law, and broken PL for instruments crossing the 100 keV band
- Fitting range is essentially the operative range of the instrument
- N_h is a free parameter for LE spectra
- E_{break} is a free parameter for HE spectra



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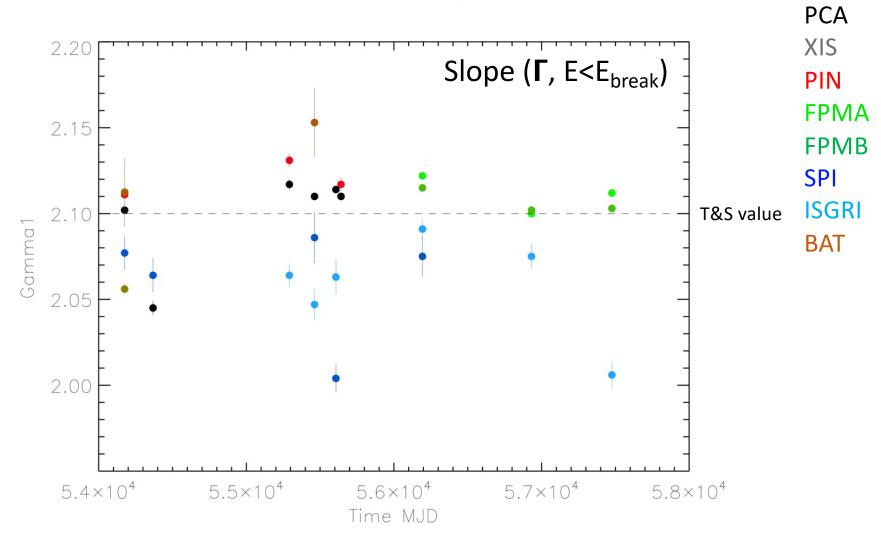
Preliminary results 1/2

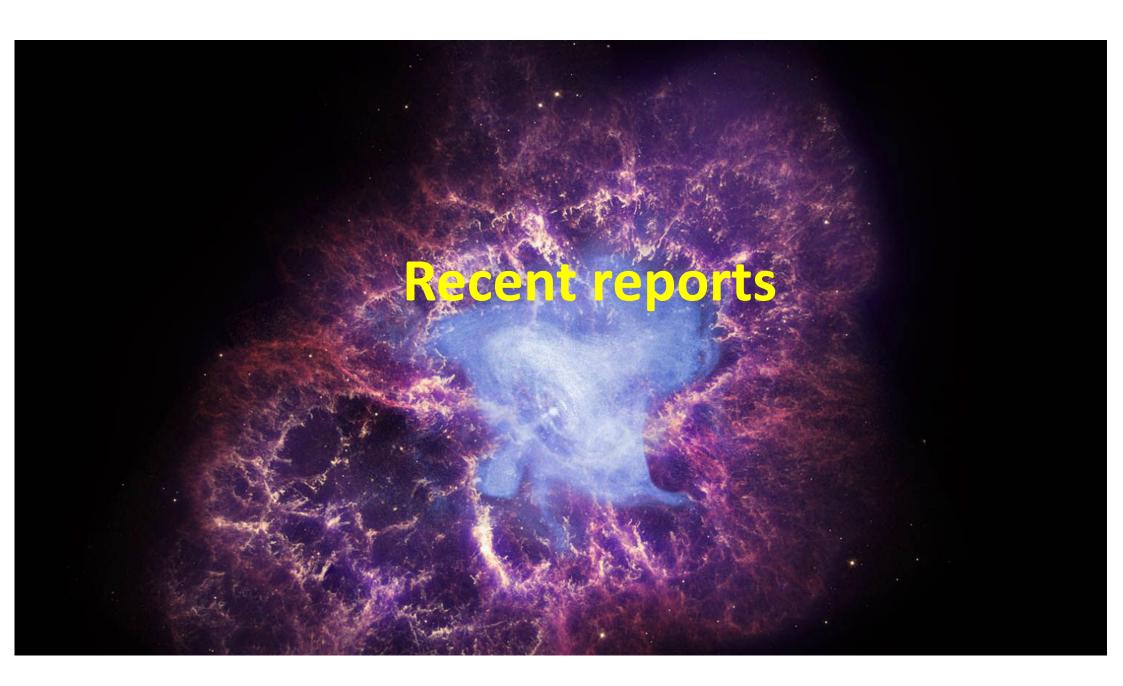




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Preliminary results 2/2

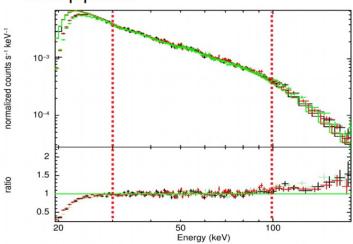






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Use level2 data or process level1 data using the CZTI pipeline



- CZTI crab spectra during 2018-2020 ratio with powerlaw of index 2.1
- Good agreement in 30 100 keV, flux within ~10% of NuStar: Presently usuable for spectroscopy
- Deviations in 20-30 keV and in 100-180 keV

ASTROSAT/CZTI

Timing Performance

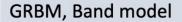
Time resolution: 20µsec

Clock stability: 3µsec rms

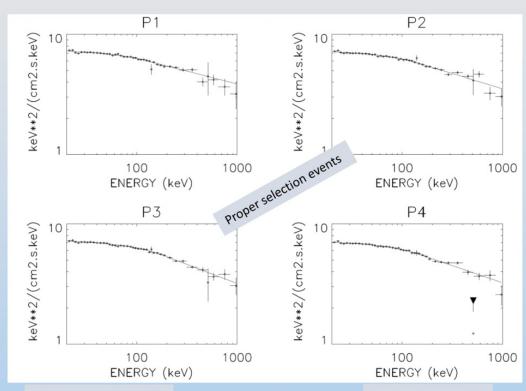
• fixed offset : -650 \pm 70 μ s w.r.t.

Fermi-LAT

(Basu et al. 2020)



$$A(E) = \begin{cases} A(E) = K(E/100)^{\alpha_1} \exp(-E/E_c) & if E < E_c(\alpha_1 - \alpha_2) \\ A(E) = K[(\alpha_1 - \alpha_2)E_c/100]^{(\alpha_1 - \alpha_2)} (E/100)^{\alpha_2} \exp(-(\alpha_1 - \alpha_2)) & if E > E_c(\alpha_1 - \alpha_2) \\ & \text{INTEGRAL/SPI} \end{cases}$$



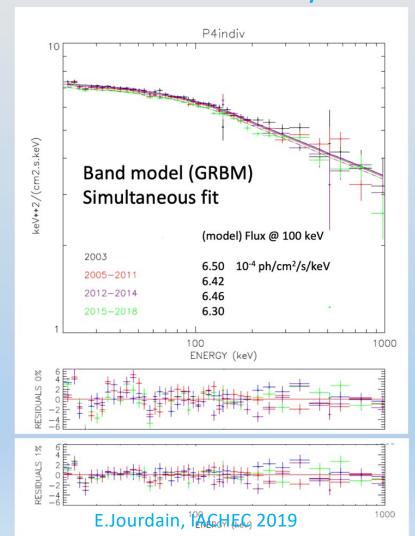
GRBM, Band model

0.5 % syst.

Broken PL model

Period Number	α_1	Ec keV	α_2	χ^2
P1 446 ks	2.00		2.22	77.01 (39)
P2 1.94 Ms	2.01	620	2.25	82.4 (39)
P3 1.82 Ms	2.0	602	2.32	71.9 (39)
P4 2.2 Ms	1.99	505	2.28	85.9 (39)
Tot	2.0	572.3	2.27	351.2 (165)

Period Number	α_1	Eb	α_2	$\chi 2$
		keV		
P1 446 ks	2.06	66.0	2.19	83.7 (39)
P2 1.94 Ms	2.08	61.2	2.23	92.9 (39)
P3 1.82 Ms	2.08	93.0	2.27	107.6 (39)
P4 2.2 Ms	2.07	82.8	2.26	104.8 (39)
Tot	2.08	86.0	2.25	426.08 (165)

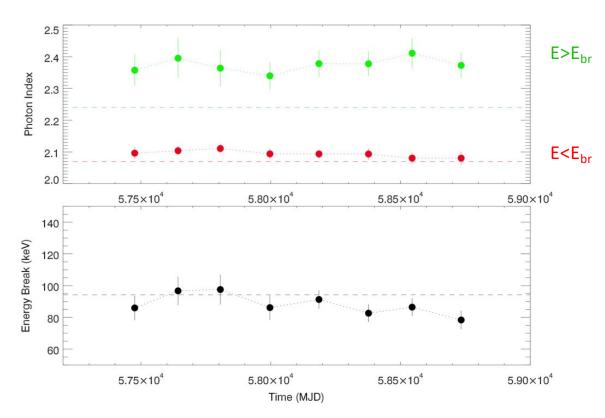




IBIS/ISGRI OSA11 – Crab Fitting with Broken PL

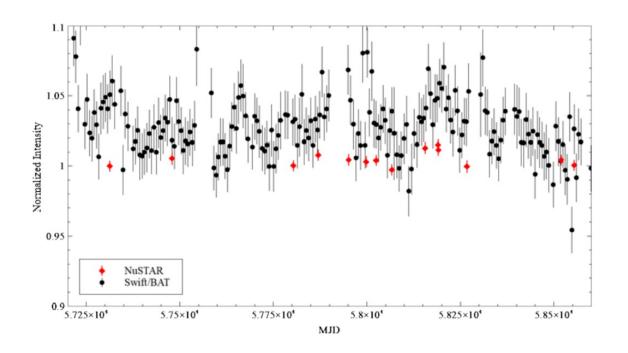
Crab spectral fitting with OSA11 new calibration (starting rev.1661)

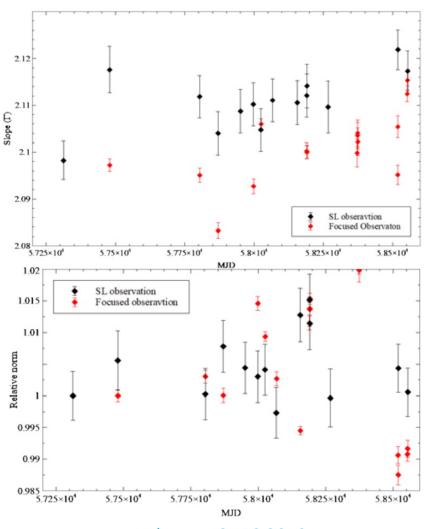
Dashed lines show the values for the OSA10 reference model



L.Natalucci, WG virtual meeting, 7 May 2021

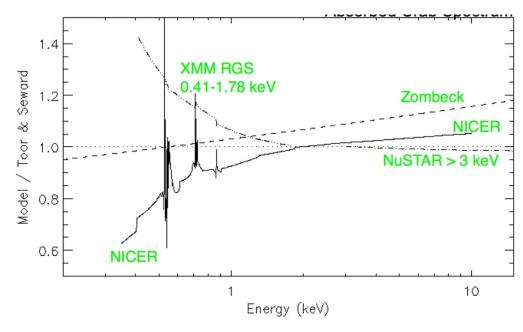
NuSTAR - Crab





K.Madsen, IACHEC 2019

NICER



Power Law	NuSTAR (3-50 keV)	NICER (0.25-10 keV)	Difference
Norm	9.71	9.19	-5.3%
Index	2.106	2.105	0.001

- Basis of comparison is Toor & Seward (1978) result, extended to lower energies
- NICER agrees with NuSTAR to with ~5%
- Very significant differences between XMM RGS (Kaastra et al. 2009) and NICER
 - These are primarily driven by minor differences in absorption and dust scattering which lead to large apparent differences in flux

C.Markwardt, IACHEC virtual, 2020

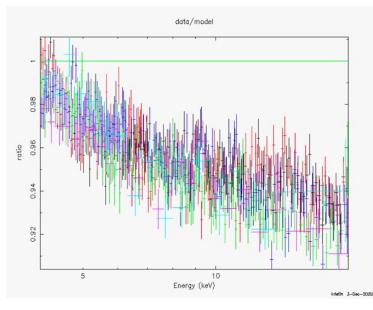
NICER and NuSTAR

by K.Madsen

• Used the Nicer Crab model on NuSTAR Stray-Light (SL) data:

TBvarkrabs*xscatm(curv*powerlaw + crab_pulsar)

- "tbvarkrabs" modified version of tbabs which includes the edge profiles measured directly by Kaastra et al 2009. Use "tbvarabs" instead with no parameter changes needed for NuSTAR.
- "xscatm" dust scattering halo. Excluded because NuSTAR SL includes all of the Crab flux.
- "crab_pulsar" and "curv" taken from Kaastra

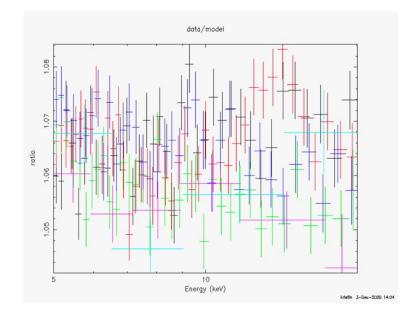


LEFT:

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.





Summary

- Activity of WG continues to be focused on Crab and G21.5
- Good primary standards also for new missions
- NuSTAR absolute measurements of the Crab spectrum in SL mode (flux recalibration expected?)
- New studies of G21.5 model and comparison with NuSTAR and Chandra

To follow (actions):

- include Hitomi & ASTROSAT Crab spectra for 2016 & more recent epochs
- Publication of Crab multi-year project
- G21.5-0.9: data analysis for Chandra, XMM, NuSTAR, Hitomi, INTEGRAL, SWIFT for new project

