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Non-thermal SNR WG

Non-Thermal SNR WG:

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Agenda:

- J. Rodi: Soft Gamma-ray Observations of the Crab with INTEGRAL/IBIS-PICsIT
- L. Natalucci: Update on the Crab multi-epoch project
- G21.5-019 plan update (discussion)

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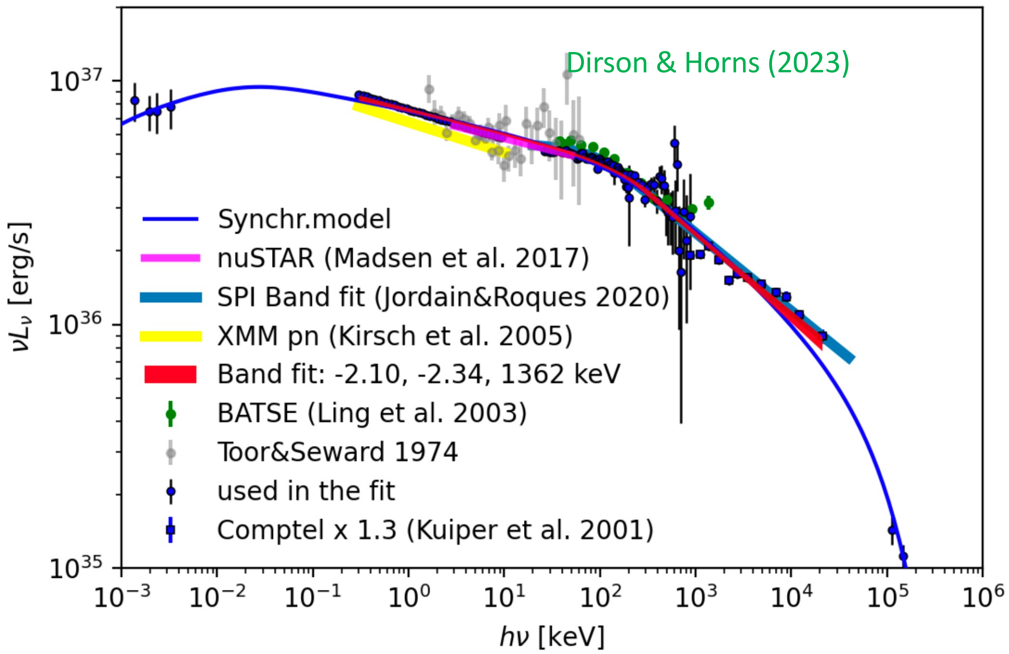
Crab broadband spectrum

- Broadband spectrum up to Mev-Gev:

Recent summary in Dirson & Horns (2023)

$$\frac{dN}{dE} = N_0 \begin{cases} \left(\frac{E}{100\,\mathrm{keV}}\right)^{\Gamma_1} e^{-E/E_0} & \text{if } E \leqslant E_0(\Gamma_1 - \Gamma_2), \\ \left[\frac{(\Gamma_1-\Gamma_2)E_0}{100\,\mathrm{keV}}\right]^{\Gamma_1-\Gamma_2} e^{\Gamma_2-\Gamma_1} \left(\frac{E}{100\,\mathrm{keV}}\right)^{\Gamma_2} & E > E_0(\Gamma_1 - \Gamma_2). \end{cases}$$

grbm model as a Crab standard?



- Craig's model to support observations in the 0.1-100 keV (including soft X-ray):
  see Craig's report at IACHEC '24
  https://iachec.org/wp-content/presentations/2024/NICER-IACHEC-Crab-RefModel-2024.pptx

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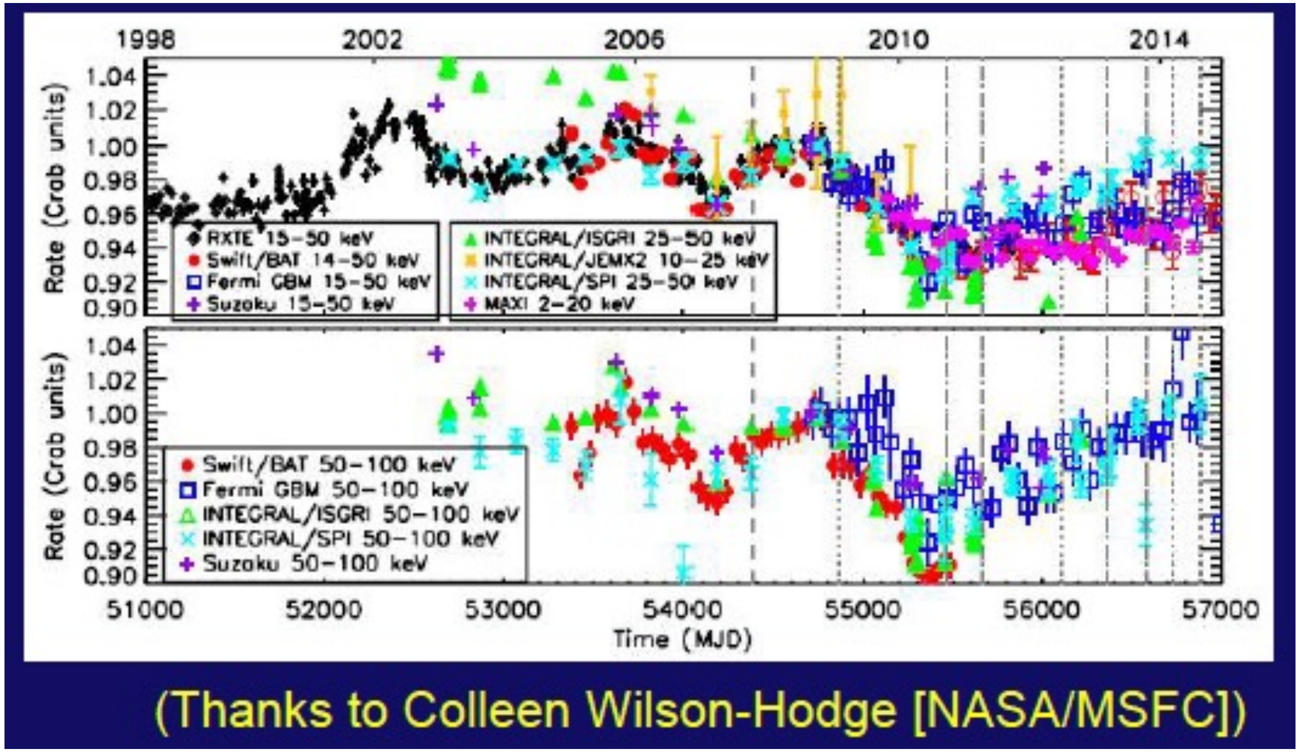
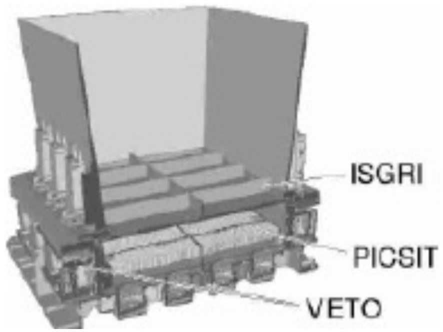
Update of the Crab multi-epoch project

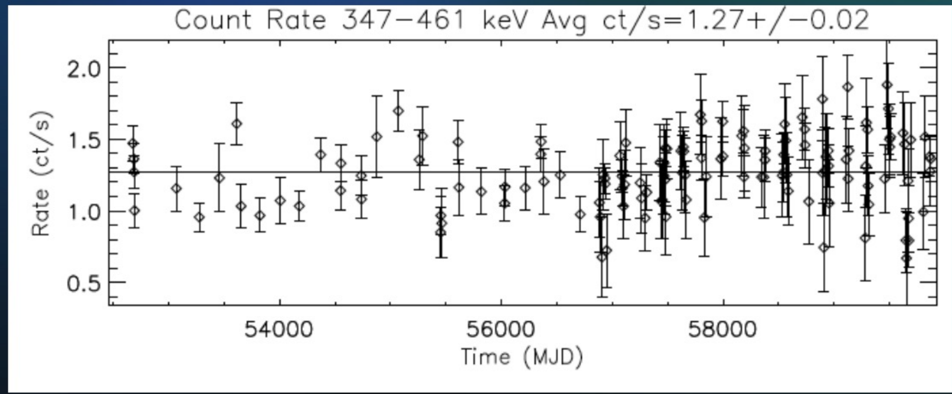


Results for IBIS/PiCSIT (0.3-4 MeV)

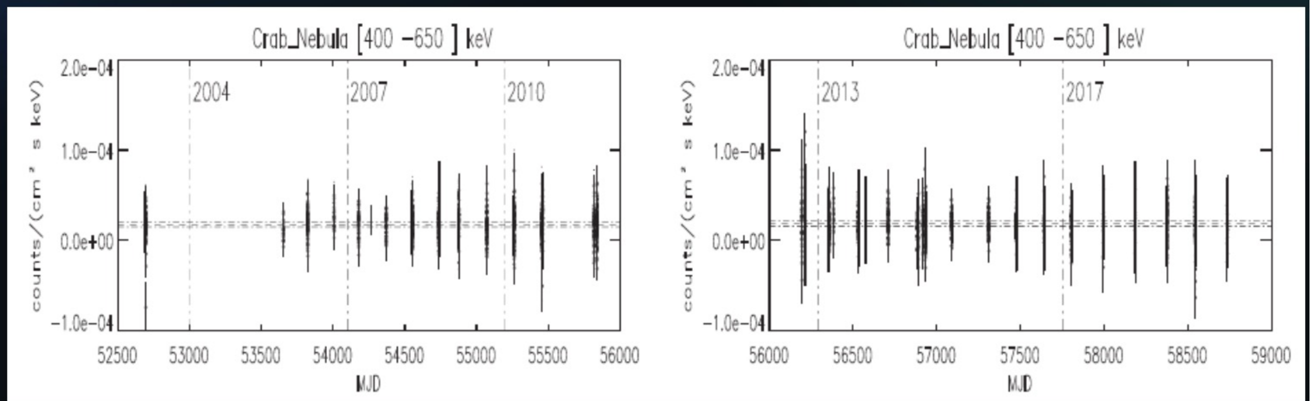


James Rodi's presentation

- PICsIT light curves in 347 – 461 keV E band
  - Revolutions time scale (~2 – 3 days)
  - Consistent with constant flux

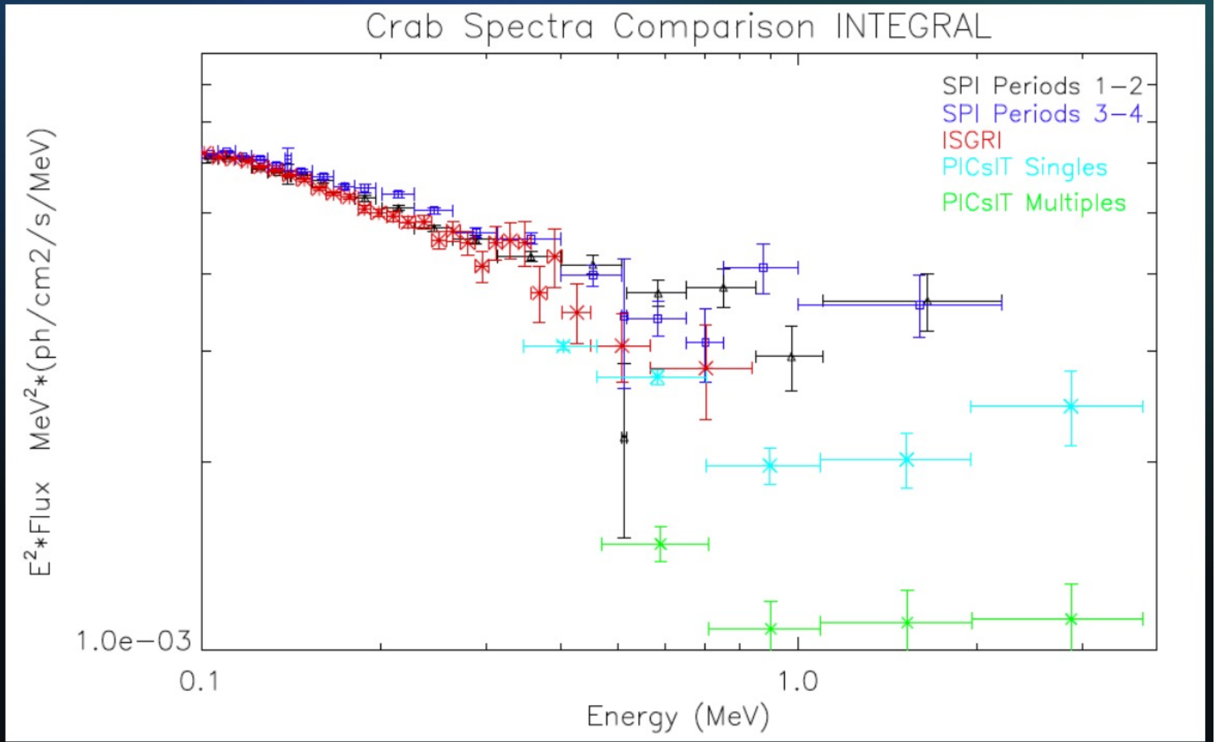


- SPI 400-650 leV light curve
  - ~0.5 – 1 hr time scale
  - Consistent with constant



INTEGRAL Crab Spectrum

- SPI spectrum (Jourdain & Roque 2020) vs PICsIT vs ISGRI OSA11.2
  - ISGRI ~3 Ms from rev 39-1089
  - ISGRI cross-calibration with SPI until 511 keV (Pedros, ISDC)
  - Not clear calibration >511 keV



James Rodi's presentation

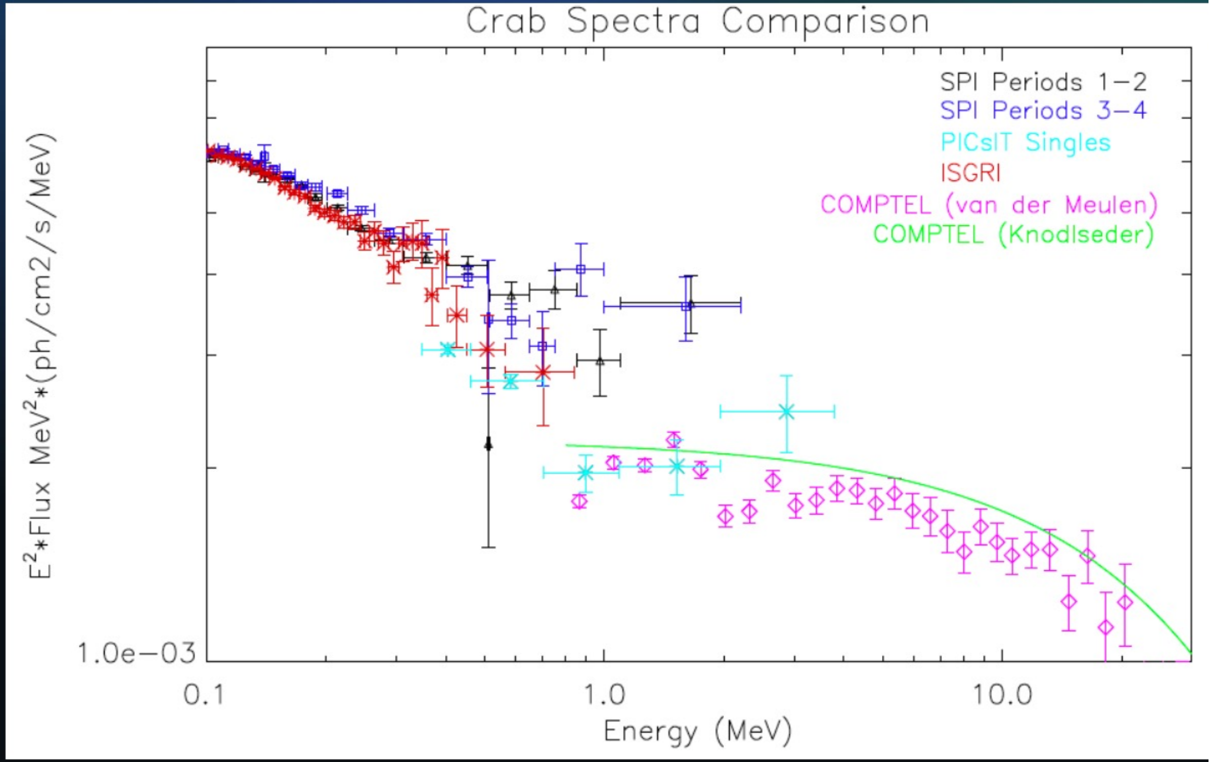
Crab Spectrum

- SPI spectrum (Jourdain & Roque 2020) vs PICsIT single vs ISGRI vs COMPTEL (van der Meulen 1998; Knodlseder 2022)
- COMPTEL spectrum Γ= 1.97,

 E_c= 28.9 MeV (van) ;

Γ= 2.00, E_c= 39.1 MeV (Knod)

- PICsIT >1.2 MeV, Γ=1.7 ± 0.3



James Rodi's presentation

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Crab project summary

- Analysis of historical data plus data from currently operational missions. Follow-on of the Kirsch+05 paper
- Using multi-mission data across *nearly simultaneous* periods. Currently 18 epochs spanning 2005-2020.
- Emphasis on the hard band? (>10 keV)
- Data/results from many instruments on board *Suzaku* (XIS & HXD), Rxte (PCA), *Integral* (IBIS/ISGRI & SPI), *NuSTAR*, *XMM* (EPIC-pn), *Fermi* (GBM), *Swift*(BAT), *HXMT*(LE,ME,HE), *Astrosat*(CZTI),…
- Broad band spectral fitting:

  powerlaw for E<100 keV,

  bknpow (E_{br} ~100 keV) & *grbm* for E>100 keV

Astronomy & Astrophysics manuscript no. output
May 11, 2025

Cross calibration of hard X-ray instruments using the high energy source in the Crab Nebula

XXX[1], and friends

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ABSTRACT

Context. Since at least five decades the Crab nebula is a useful source of calibration for high energy astronomy. Its brightness and remarkable stability is routinely used to monitor, correct and normalize the response of X-ray to soft γ-ray telescopes flying on satellites. In more recent years it was discovered that the source is subject to significant flux variations. In the hard X-ray range, variability with a time scale of ~months was detected with a relatively small amplitude ($\leq 10\%$).
Aims. The extensive monitoring performed on this source by different operational satellites, allows to perform a useful cross-calibration by joint analysis of their observational data. We focus in particular on the the hard X-ray (10 keV) band, but also investigate the link with the results at lower energies.
Methods. We discuss the framework of the current observational results for absolute flux measurements and the spectral models, which best describe the individual instruments data. Data are grouped into different epochs in which observations performed by a set of three or more instrument are separated by less than $\sim 1-2$ weeks. The spectral analysis is performed for each epoch separately and this allows to minimise the bias due to the long-term variability of the source. The cross-calibration is then analyzed for each epoch using two empirical spectral models based on (broken) power law and on log-parabola shape, respectively.
Results.
Conclusions. TBW.

Key words. Instrumentation: detectors – X-rays: general – Astronomical instrumentation, methods and techniques – X-rays: individuals: Crab

1. Introduction

The Crab Nebula is one of the best studied astrophysical sources. It has been extensively investigated at all wavelenghts (see e.g. Bühler & Blandford 2014) being known for long to be one of the most stable X-ray sources in the sky. It consists of a synchrotron nebula with a pulsar located approximately at its center. A strong wind of electrons and positrons is produced by the pulsar and propagates in its surroundings. The resulting pulsar wind nebula (PWN) expands in a region that is located within the inner shell of the supernova ejecta. Relativistic electrons in the nebula are known to emit synchrotron and inverse Compton (IC) radiation. The IC component has its peak of emission in the GeV while the synchrotron emission spectrum has a break in the soft to medium gamma-ray band. Most probably this feature indicates a corresponding break in the spectrum of the synchrotron emitting electrons. *AGILE* and *Fermi* have detected variability with episodes of enhanced emission on the time scale of days (Abdo et al. 2011; Tavani et al. 2011; Arakawa et al. 2020). This variability is not modulated by the pulsar period and must originate inside the nebula and, most important for us, is not accompanied by an evident luminosity enhancement in the X-rays. On the other hand, in the hard X-rays a variability exists with an amplitude range of a few % on time scale of months/years (Wilson-Hodge et al. 2011; Kouzu et al. 2013). Several models are attempting to explain the origin of the γ-ray flares and discover the site of their emission region (Bednarek & Idec 2011; Weisskopf et al. 2013; Machabeli et al. 2015). These recent reports of variability have questioned the role of the Crab as a standard candle in the high energy domain (i.e. keV X-rays to ~GeV γ-rays), see e.g. Meyer et al. (2010). However, the Crab is still an excellent reference source for calibration due to its continuous and featureless synchrotron spectrum. In the soft X-rays its shape is very similar to a power law (PL). The inner structure of the nebula has been revealed by the first remarkable images provided by Chandra (Weisskopf et al. 2000) Spatially resolved spectroscopy shows that, when integrated in small size regions, the X-ray emission spectra have a PL shape with spatially dependent spectral index (Willingale et al. 2001; Mori et al. 2004). As a consequence, the globally integrated spectrum should not expected to be a PL (Weisskopf et al. 2010).
At harder X-ray energies, typically above 10 keV, the Crab has been studied mostly without any spatial resolution capability, first by balloon observations (Toor & Seward 1974) and then by instruments flown on satellites. Up to 2000, the most remarkable measurements are those of *CGRO*/BATSE (Ling & Wheaton 2003), *CGRO*/Comptel and *BeppoSAX* (Kuiper et al. 2001). In the new century we have available many observations: in particular we focus on results obtained with *RXTE*, *INTEGRAL*, *Swift*, *Suzaku*, *Fermi*, *NuSTAR*, *AstroSat*, *Hitomi* and *Insight-HXMT*. Of main interest for this work is the fact that due to its stable and relatively simple spectral shape, the Crab Nebula source has been used extensively to correct for instruments mis-calibrations and so far, only a few instruments have provided absolute measurements.
A complexity is related to the spectral modeling of the Crab

Current contact list

- *NuSTAR*: K.Madsen
- *INTEGRAL*: E.Jourdain, L.Natalucci
- *Suzaku*: Y. Terada (HXD), Y. Kanemaru (XIS)
- *HXMT* (all instruments): Xiaobo Li
- *RXTE* (PCA), *Swift* (BAT): C. Markwardt (also *NICER*)
- *RXTE* (HEXTE), R. Rotschild, K.Pottschmidt
- *Astrosat*: D. Bhattacharya (TBC)
- *XMM-Newton*: F. Fuerst (TBC)
- *Fermi*/GBM: C. Wilson-Hodge
- *NinjaSat* = Amira Aoyama

The current dataset

2005-2024

Epoch	Period (MJD)												
A	53628-53654			PIN	GSO		PCA	ISGRI	SPI				
B	53983-54007			PIN	GSO		PCA	ISGRI	SPI				
C	54170-54181		XIS	PIN	GSO	BAT	PCA		SPI				
D	54365-54370						PCA	ISGRI	SPI				
E	54705-54735			PIN	GSO		PCA	ISGRI	SPI			GBM	
F	55057-55069						PCA	ISGRI	SPI			GBM	
G	55250-55259						PCA	ISGRI	SPI				
H	55289-55295			PIN	GSO		PCA	ISGRI				GBM	
I	55461-55464					BAT	PCA	ISGRI	SPI			GBM	
J	55604-55611						PCA	ISGRI	SPI			GBM	
K	55637-55647			PIN	GSO		PCA					GBM	
L	56191-56196			(PIN)	(GSO)					NuSTAR		GBM	
M	56931-56932	EPIC						ISGRI	(SPI)	NuSTAR		GBM	
N	57472-57479							ISGRI		NuSTAR	CZTI		
O	58023-58027									NuSTAR	CZTI		HXMT
P	58932-58946							ISGRI	SPI		CZTI		HXMT
Q	59851-59854							ISGRI	SPI	NuSTAR			HXMT
R	60544-60557							ISGRI	SPI	NuSTAR	CZTI		

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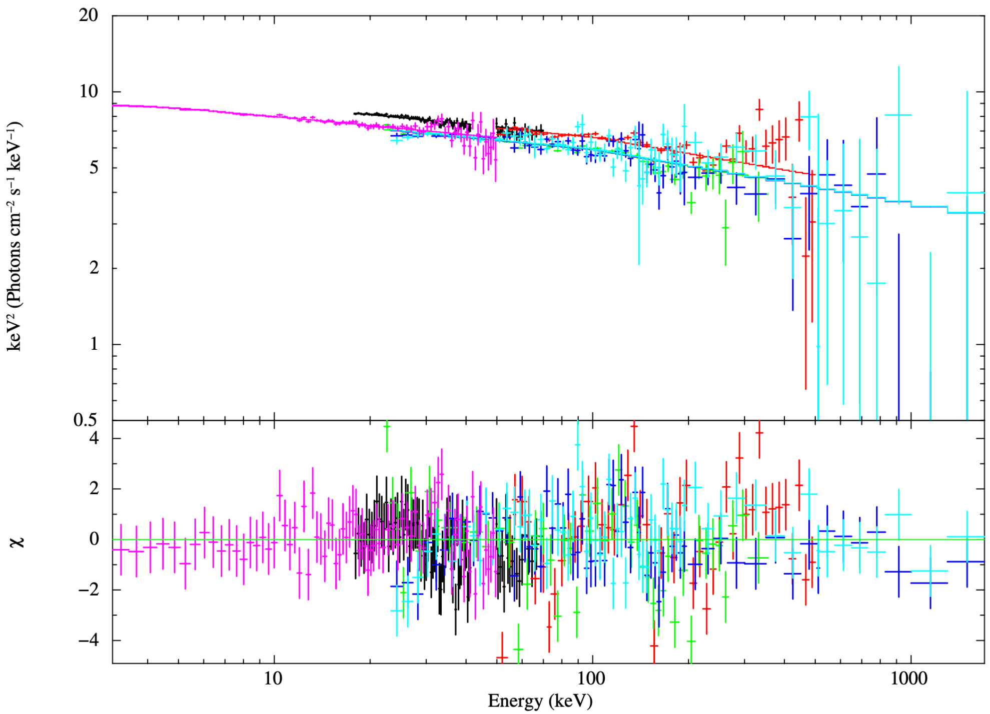
The current dataset

2005-2024

tel:53983-54007

Epoch	Period (MJD)						
A	53628-53654			PIN	GSO		P(
B	53983-54007			PIN	GSO		P(
C	54170-54181		XIS	PIN	GSO	BAT	P(
D	54365-54370						P(
E	54705-54735			PIN	GSO		P(
F	55057-55069						P(
G	55250-55259						P(
H	55289-55295			PIN	GSO		P(
I	55461-55464					BAT	P(
J	55604-55611						P(
K	55637-55647			PIN	GSO		P(
L	56191-56196			(PIN)	(GSO)		
M	56931-56932	EPIC					
N	57472-57479						
O	58023-58027						
P	58932-58946						
Q	59851-59854						
R	60544-60557						



The hard X-ray spectrum obtained from the Crab Nebula observations performed at epoch C. Data are fitted with a broken PL model and a systematic error of 1% is added to each bin.

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Energy bands vs instruments

Table 3. The four energy bands used for the cross-calibration study, ordered by instrument.

Yet to be updated to add HEXTE, NICER,XRISM

Instrument	ΔE (keV)			
EPIC	3-10			
XIS	3-10			
PIN		10-25	25-80	
GSO			25-80	100-300
BAT			25-80	
PCA	3-10	10-25	25-80	
IBIS/ISGRI			25-80	100-300
SPI			25-80	100-300
NuSTAR	3-10	10-25	25-80	
GBM			25-80	100-300
CZTI		10-25	25-80	
HXMT/LE	3-10			
HXMT/ME		10-25		
HXMT/HE			25-80	100-300(*)

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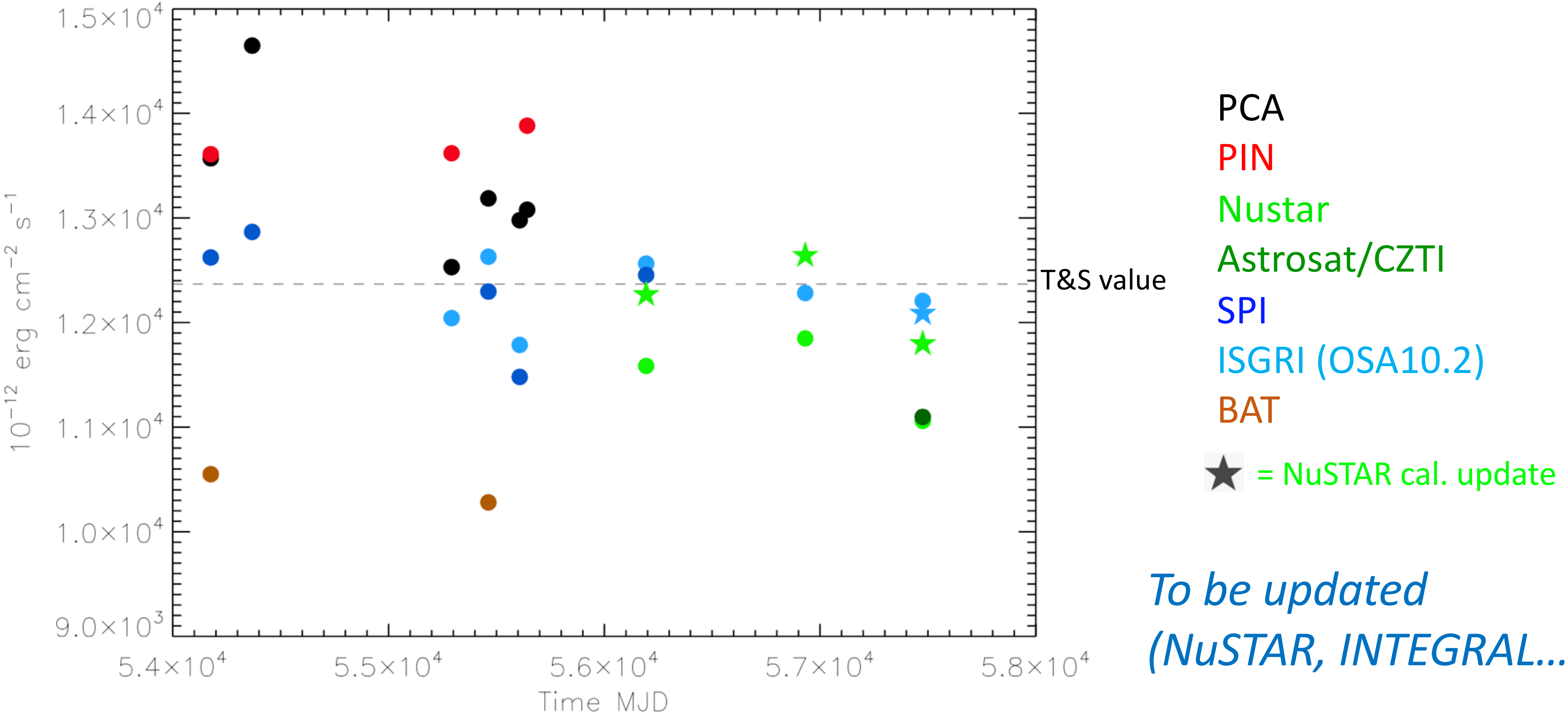
Flux history 25-80 keV



To be updated (NuSTAR, INTEGRAL…)

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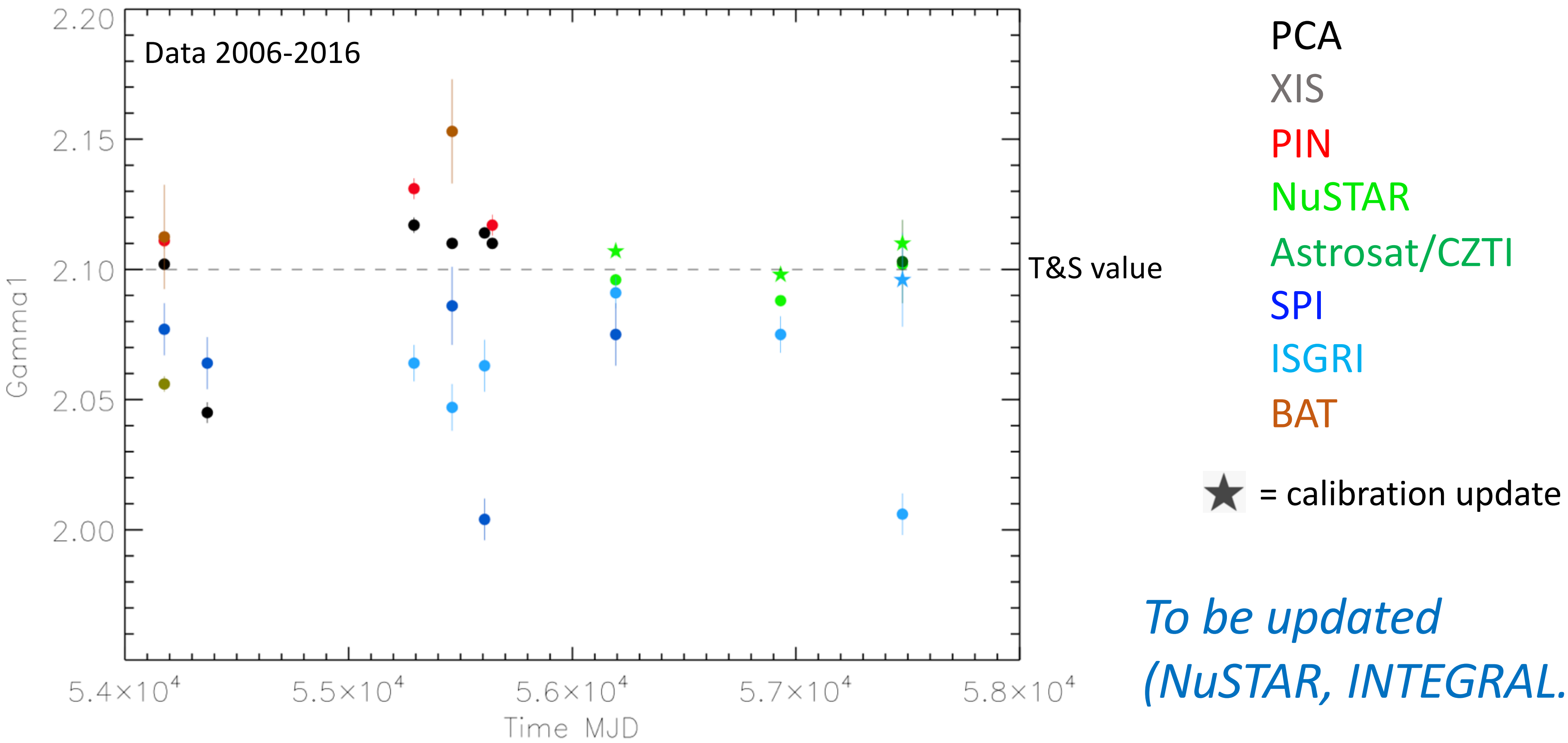
Spectral slope (Γ, E<Ebreak)



To be updated (NuSTAR, INTEGRAL...)

Crab, to-do next (a proposal)

- **Update the current dataset**

INTEGRAL: ISGRI (OSA-11 cal), SPI(TBD), Swift/BAT (more epochs)

New data for HEXTE, NICER, XRISM?

Confirm data availability for Epochs O (2017) & P (2020):

SPI, NuSTAR, CZTI, HXMT

- **Setup a common repository for data & responses (Wiki, owncloud?,…)**
- **Manuscript**

Section 2, instrument calibration description: BAT, PCA, CZTI, Insight-HXMT

Section 4, data selection and analysis: all instruments

Section 5, include final plots and tables

- **Follow-on with a few (~2/3) telecons to ease progress along next year**

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G21.5-0.9

- Spectrum is not a simple power-law (need to update cross-cal after 2010's paper)
- Goal: Define the curved spectrum as an IACHEC standard
- Coordinator: Yugo Motogami
- Cont(r)acts:

  Chandra = Nick Durham

  XMM = Ivan Valtchanov

  NuSTAR = Kristin Madsen

  Hitomi = Masahiro Tsujimoto

  Integral = James Rodi

  Swift = Jamie Kennea / Andy Beardmore

  XRISM = Yoshiaki Kanemaru

  EP = Juan Zhang

WG decision: Organise a KO meeting (remote) early: ~ June '25