High energy spectra of microquasars

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Five years of INTEGRAL
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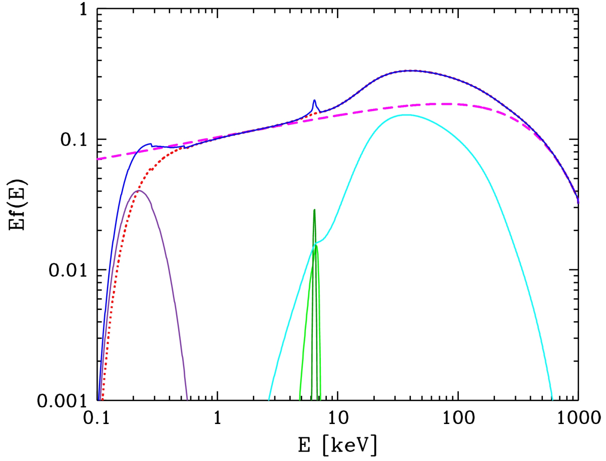
X-ray/γ-ray spectra of binaries and AGNs



INTEGRAL energy range, model ambiguities, examples:

- lower temp./larger reflection and higher temp./smaller reflection
- thermal vs nonthermal emission

Data above 300 keV needed to constrain comptonized continuum

Low-energy gamma-ray detectors on orbit

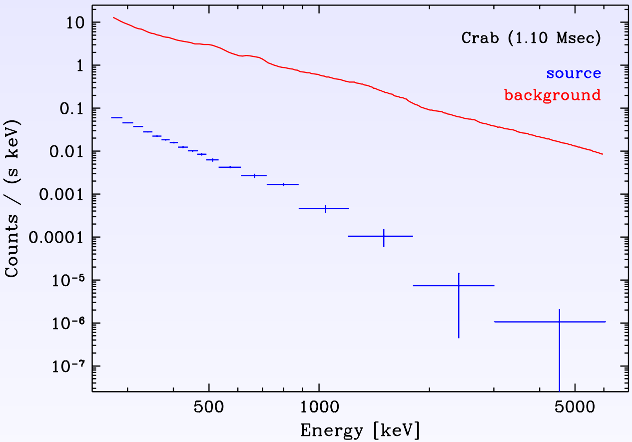
Detector	Band	Area	Volume	Material
INTEGRAL, SPI	20-8000	508	3556	HP Ge
INTEGRAL, PICsIT	170-10000	2890	8670	CsI
Suzaku, HXD/GSO	40-600	369	184	GdSiO

SPI: very good calibration, small area/volume, limited angular resolution

PICsIT: high background, good angular resolution, almost no results yet

HXD/GSO: calibration problems, limited angular resolution above 100 keV

PICsIT background and Crab spectra



Extreme conditions

- signal-to-noise ratio below 0.01
- variable, energy-dependent background
- only 0.5 counts per pixel in typical science window (Crab, 252-336 keV)

METHOD (paper for A&A , Instruments section, in preparation)

- Source count rate determined from joint PDF

Probability density function $p_k(s, b)$ for the source count rate parameter s and the background map normalization factor b in Science Window number k is defined as the product of Poisson PDFs P for all n_k active pixels

$$p_k(s, b) = \frac{1}{C_k} \prod_{i=1}^{n_k} P(N_k(i); (s\eta_k(i)\xi_k(i) + bB(i))f_k(i)), \tag{1}$$

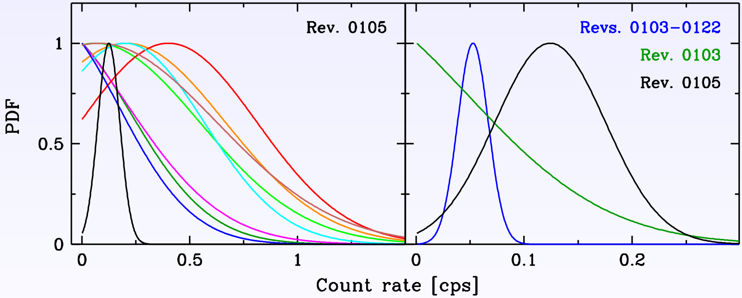
where factor C_k normalizes the PDF integral to 1, $N_k(i)$ is the number of counts measured by the i-th pixel, $\eta_k(i)$ is the PIF value for the source, $\xi_k(i)$ corrects s for the off-axis effect, $B(i)$ is the efficiency corrected background count rate given by background map applied and $f_k(i)$ converts count rates into counts space,

For the strongest object in the field of view all weaker sources can be incorporated into the background map (tested with simulations for 7 objects with hard ISGRI spectra in Galactic Centre)

METHOD

- Source count rate determined from joint PDF

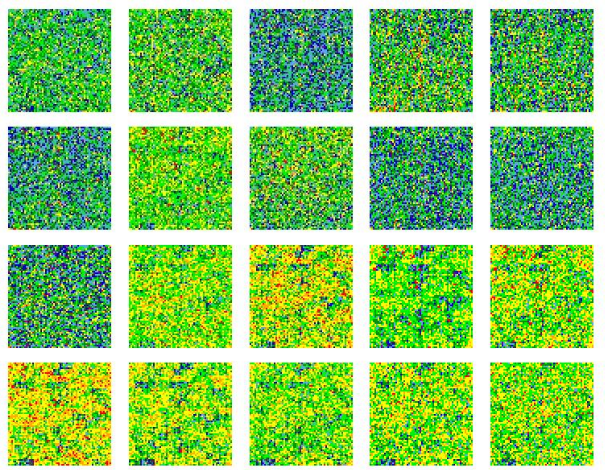
Examples of background-integrated PDFs for GRS 1758-258, 298-319 keV band



METHOD

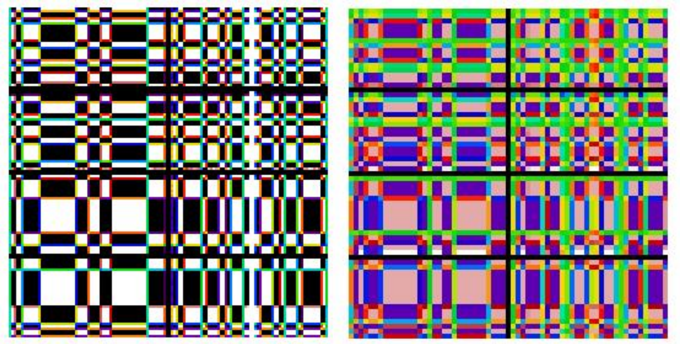
- Source count rate determined from joint PDF
- Background map for a given revolution (only dithering data)

Background difference shadowgrams, 253-356 keV,
Revs. 0070-0090 - Rev. 0079

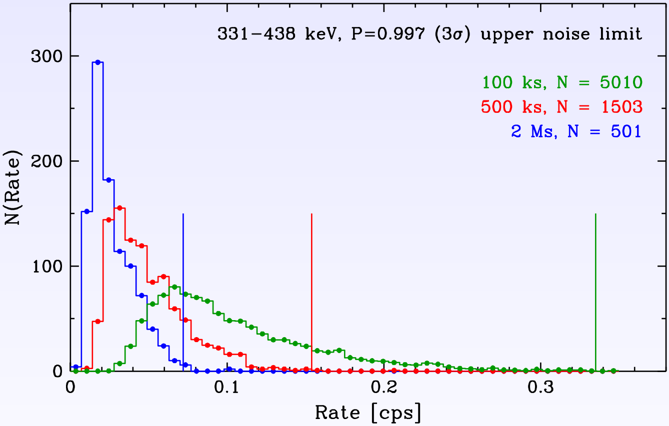


METHOD

- Source count rate determined from joint PDF
- Background map for a given revolution (observation)
- Energy dependent PIF, ISGRI absorption, off-axis correction

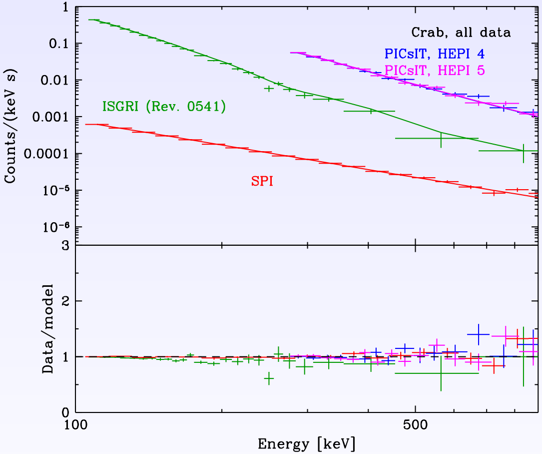


PICsIT noise level estimate (detection reliability)



751 ScWs from empty fields observations, Revs. 0280-0346
25 standard dithering PIFs
2 Ms exposure in total
N test runs for a given exposure

INTEGRAL, ISGRI/SPI/PICsIT cross-calibration for Crab above 100 keV



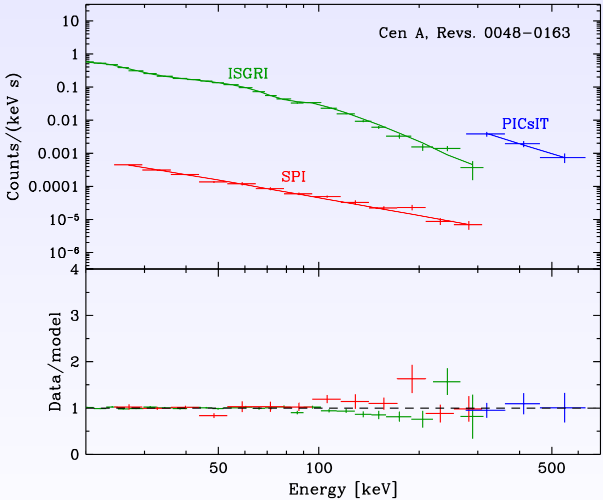
power-law, 100-1000 keV (without ISGRI): $\Gamma = 2.20(1)$

f_{ISGRI}=0.86, $f_{PICsIT,HEPI4} = 0.797(14)$, $f_{PICsIT,HEPI5}$=0.808(13)

power-law (SPI: 283-854 keV): Γ=2.16(8)

power-law (PICsIT: 277-816 keV): Γ=2.14(6)

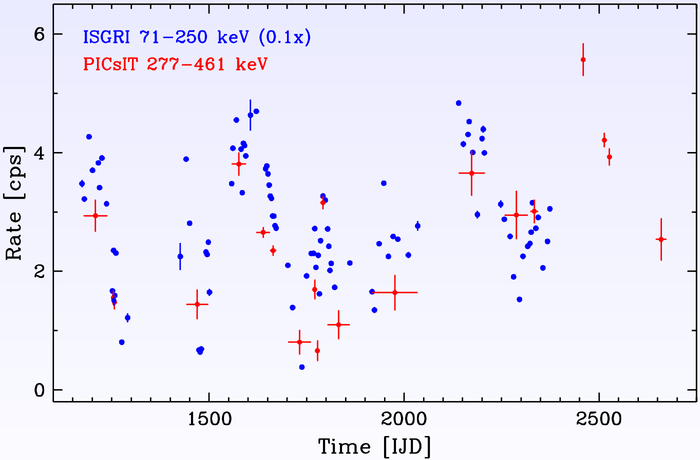
INTEGRAL, ISGRI/SPI/PICsIT cross-calibration for Cen A

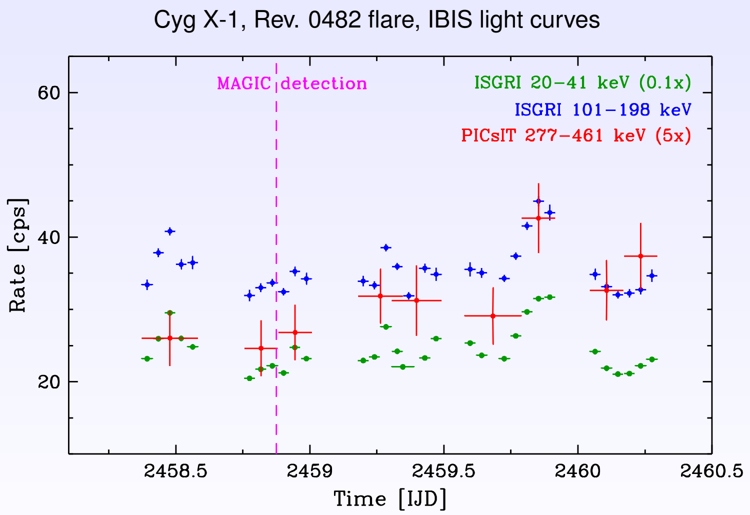


power-law (ISGRI $<$ 120 keV, SPI $<$ 300 keV): $\Gamma = 1.79(2)$

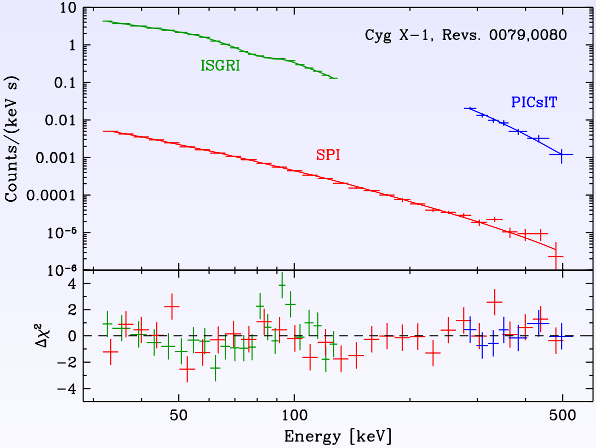
$f_{ISGRI} = 0.83(2)$, $f_{PICsIT} = 0.87(10)$

Cyg X-1, IBIS light curves



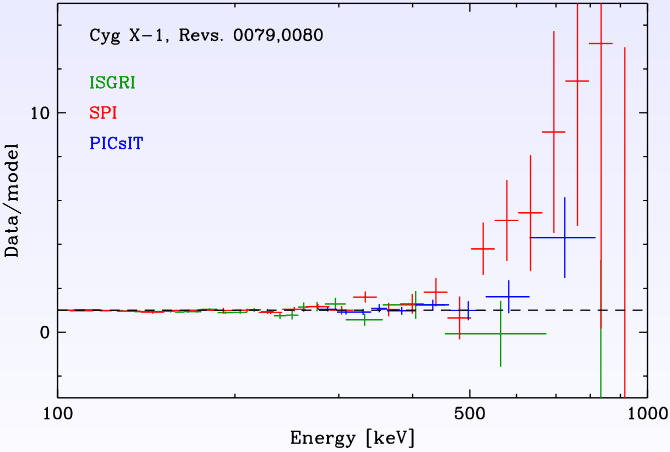

Cyg X-1, Rev. 0482 flare, IBIS light curves
MAGIC detection
ISGRI 20−41 keV (0.1x)
ISGRI 101−198 keV
PICsIT 277−461 keV (5x)
60
40
20
Rate [cps]
2458.5
2459
2459.5
2460
2460.5
Time [IJD]

Cyg X-1, Revs. 0079,0080, INTEGRAL high energy spectra

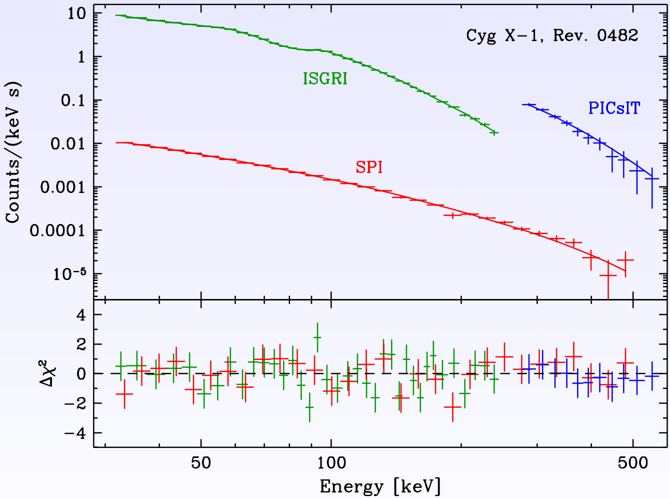


compps: kT_e = 125(12), τ = 0.81(9), $\Omega/2\pi$ = 1.12(17)
M. Cadolle Bel et al., 2006: 111(6), 0.57(3), 0.60(5)

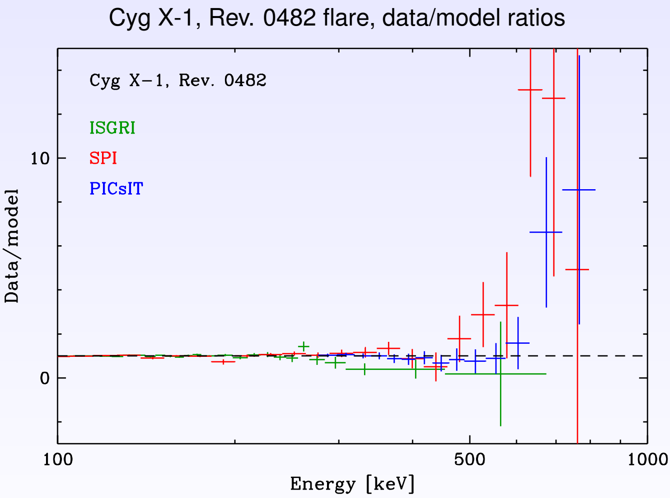
Cyg X-1, Rev. 0079,0080, data/model ratios

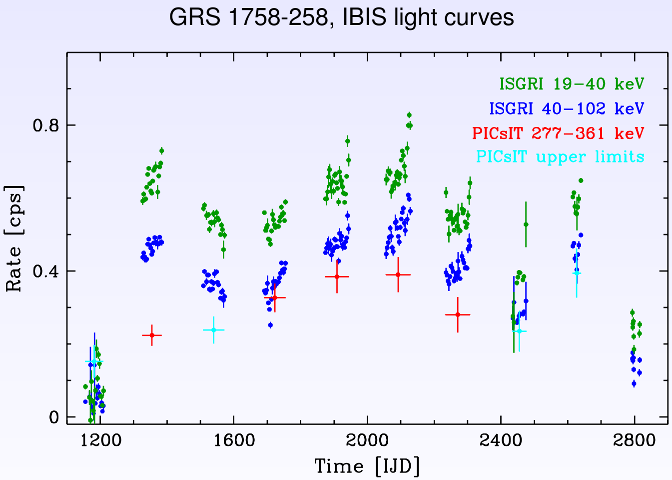


Cyg X-1, Rev. 0482 flare, INTEGRAL high energy spectra

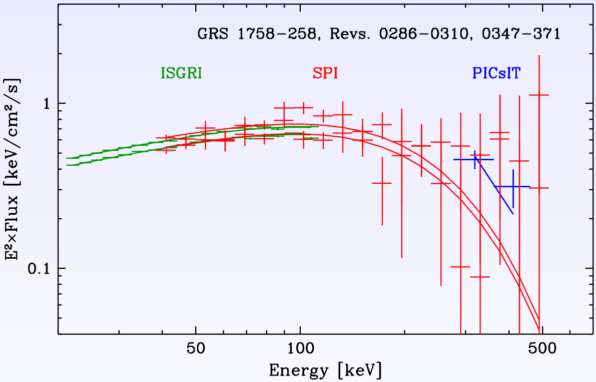


compps: kT_e = 88(7), τ = 1.04(10), $\Omega/2\pi$ = 1.01(20)
fit above 200 keV: kT_e = 76(32), τ = 1.05(46)


Cyg X-1, Rev. 0482 flare, data/model ratios
Cyg X−1, Rev. 0482
ISGRI
SPI
PICsIT
Data/model
10
0
100
500
1000
Energy [keV]

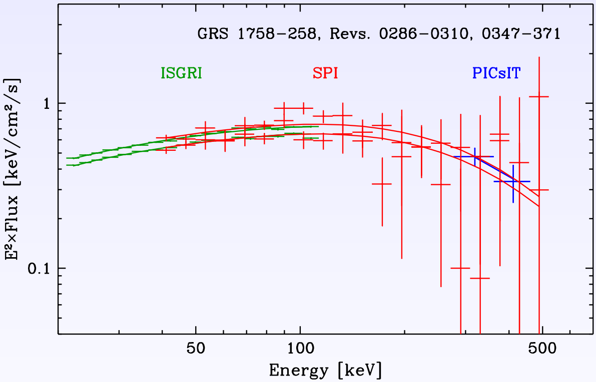

GRS 1758-258, IBIS light curves
ISGRI 19−40 keV
ISGRI 40−102 keV
PICsIT 277−361 keV
PICsIT upper limits
Rate [cps]
0
0.4
0.8
1200
1600
2000
2400
2800
Time [IJD]

GRS 1758-258, bright state spectra



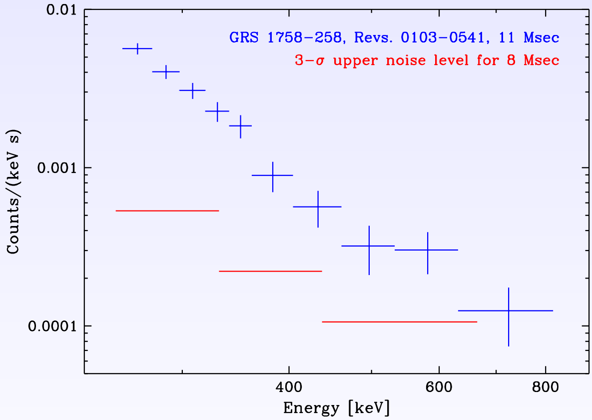
compps, thermal electrons: $f_{PICsIT} > 2$?

GRS 1758-258, bright state spectra



compps, hybrid dist. electrons: $f_{PICsIT} \approx 1$

GRS 1758-258, mean bright state spectrum



GRS 1758-258 in 277-383 keV: 70 mCrab source

20-30 mCrab objects should be detected up to 500 keV with 10 Msec exposure

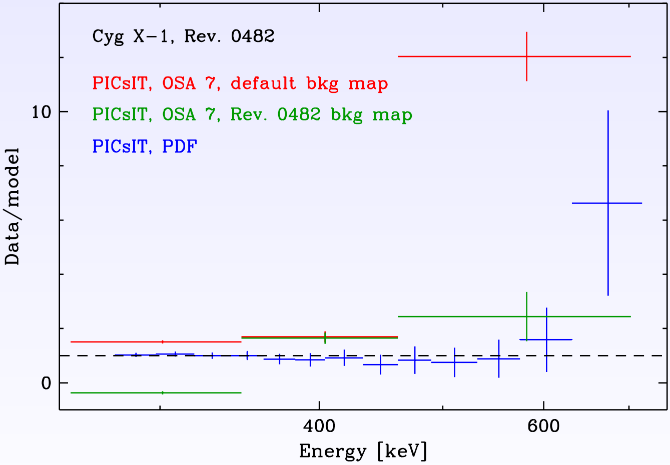
Detected and potential PICsIT sources

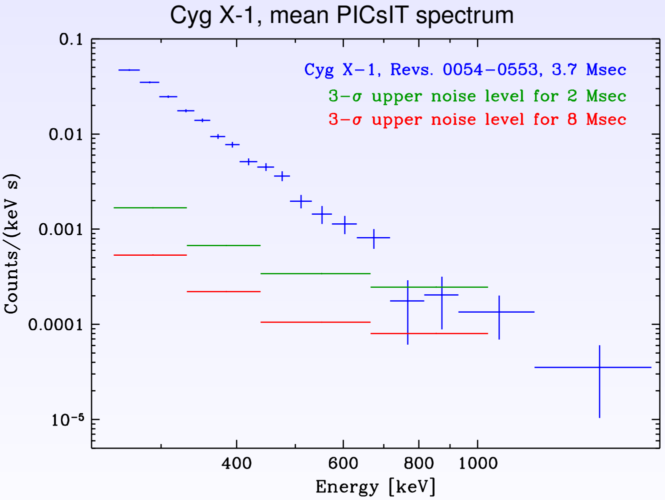
Detected	Almost detected	Candidates
Crab	3C 273	PSR B1509-58
Cyg X-1	NGC 4945	NGC 4151
Cen A	1E 1740.7-2941	...
GRS 1758-258		
GRS 1915+105		
XTE J1550-564 (outburst)		
GRO J1655-40 (outburst)		
GX 339-4 (outburst)		

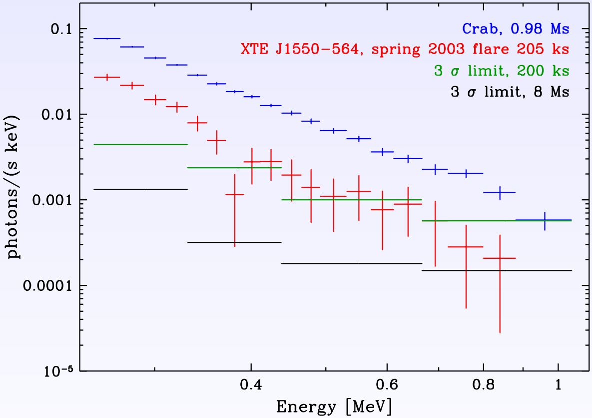
CONCLUSIONS

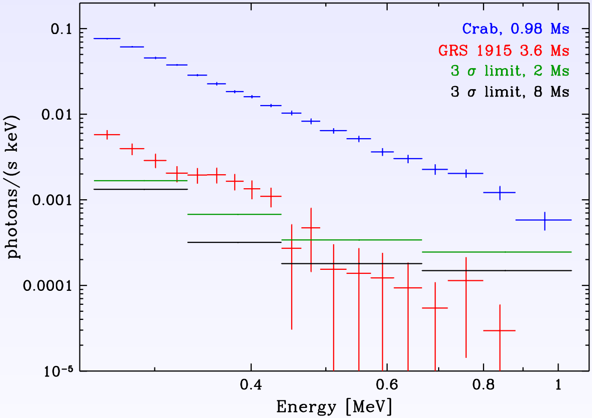
- PICsIT can provide valuable results
- Cyg X-1 INTEGRAL spectra: thermal comptonization
- Cyg X-1 no hard tail detected up to 600 keV
- GRS 1758-258 INTEGRAL spectra: hybrid thermal/non-thermal emission

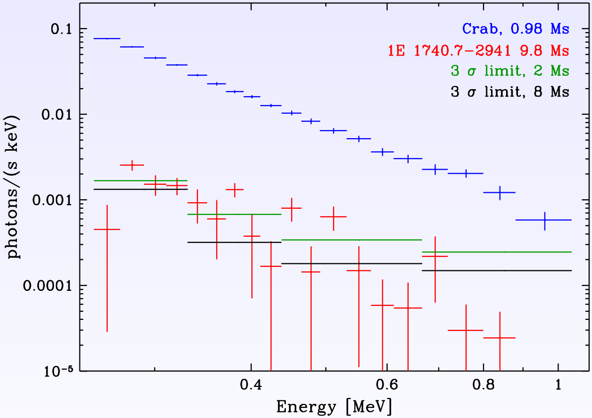
Cyg X-1, Rev. 0482 flare, PDF and OSA 7 PICsIT spectra, data/model ratios

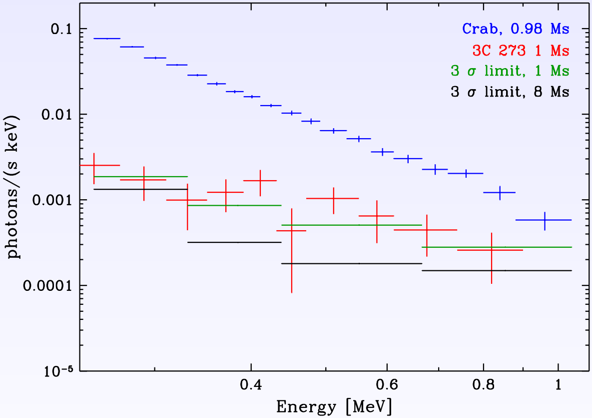


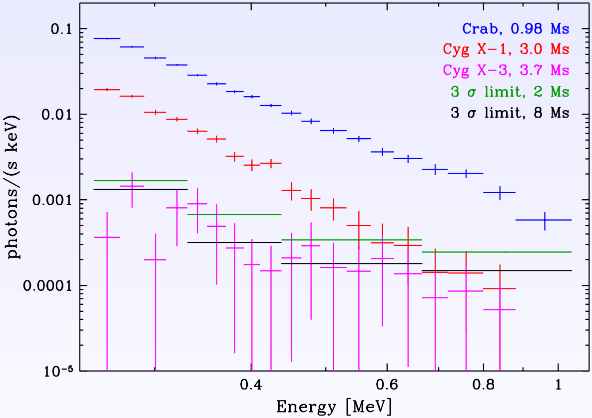

Cyg X-1, mean PICsIT spectrum
Cyg X−1, Revs. 0054−0553, 3.7 Msec
3−σ upper noise level for 2 Msec
3−σ upper noise level for 8 Msec
Counts/(keV s)
0.1
0.01
0.001
0.0001
10⁻⁵
400
600
800
1000
Energy [keV]

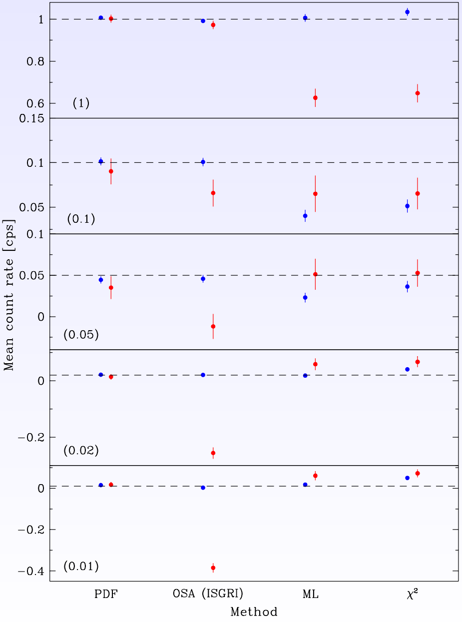

Crab, 0.98 Ms
XTE J1550−564, spring 2003 flare 205 ks
3 σ limit, 200 ks
3 σ limit, 8 Ms
photons/(s keV)
0.1
0.01
0.001
0.0001
10⁻⁵
0.4
0.6
0.8
1
Energy [MeV]

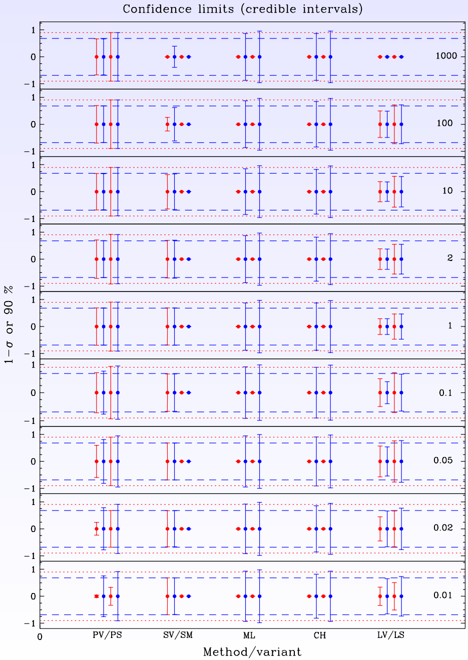

Crab, 0.98 Ms
GRS 1915 3.6 Ms
3 σ limit, 2 Ms
3 σ limit, 8 Ms
photons/(s keV)
Energy [MeV]
0.1
0.01
0.001
0.0001
10⁻⁵
0.4
0.6
0.8
1

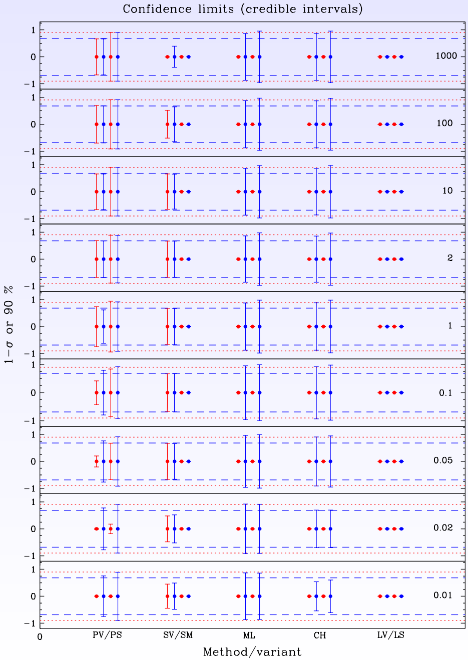

Crab, 0.98 Ms
1E 1740.7−2941 9.8 Ms
3 σ limit, 2 Ms
3 σ limit, 8 Ms
photons/(s keV)
0.1
0.01
0.001
0.0001
10⁻⁵
0.4
0.6
0.8
1
Energy [MeV]


Crab, 0.98 Ms
3C 273 1 Ms
3 σ limit, 1 Ms
3 σ limit, 8 Ms
0.1
0.01
0.001
0.0001
10⁻⁵
photons/(s keV)
0.4
0.6
0.8
1
Energy [MeV]


Crab, 0.98 Ms
Cyg X−1, 3.0 Ms
Cyg X−3, 3.7 Ms
3 σ limit, 2 Ms
3 σ limit, 8 Ms
0.1
0.01
0.001
0.0001
10⁻⁵
photons/(s keV)
0.4
0.6
0.8
1
Energy [MeV]


Mean count rate [cps]
1
0.8
0.6
(1)
0.15
0.1
0.05
(0.1)
0.1
0.05
0
(0.05)
0
−0.2
(0.02)
0
−0.2
−0.4
(0.01)
PDF
OSA (ISGRI)
ML
χ²
Method


Confidence limits (credible intervals)
1−σ or 90 %
1000
100
10
2
1
0.1
0.05
0.02
0.01
PV/PS
SV/SM
ML
CH
LV/LS
Method/variant


Confidence limits (credible intervals)
1000
100
10
2
1
0.1
0.05
0.02
0.01
1 − σ or 90 %
PV/PS
SV/SM
ML
CH
LV/LS
Method/variant