The Broad-Band X-ray Spectrum of Cygnus X-1 Measured by INTEGRAL

Marion Cadolle Bel
Service d'Astrophysique, CEA-Saclay, France

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P. Sizun, A. Goldwurm, P. Laurent, A. Zdziarski, J. Malzac, E. Jourdain,
J-P. Roques, P. Goldoni, J. Rodriguez, C. Gouiffès & L. Foschini

Cygnus X-1

- Bright X-ray emission (1964)

- High mass X-ray binary

- 2 kpc
- orbital period: 5.6 days
- wind accretion

10 $M_\odot$ black hole

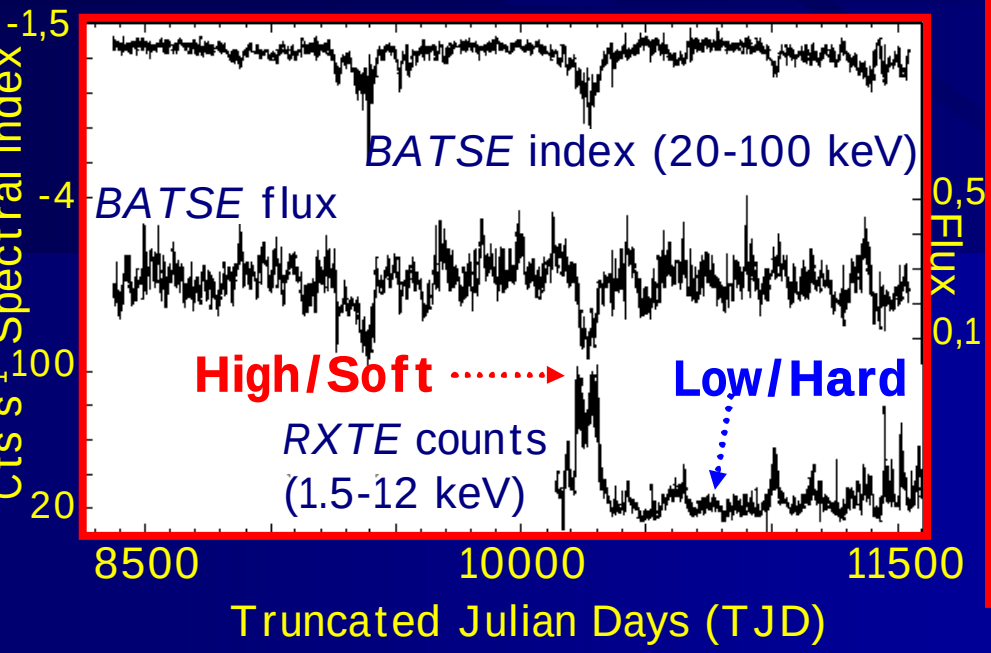
18 $M_\odot$ giant (09.7 I) companion

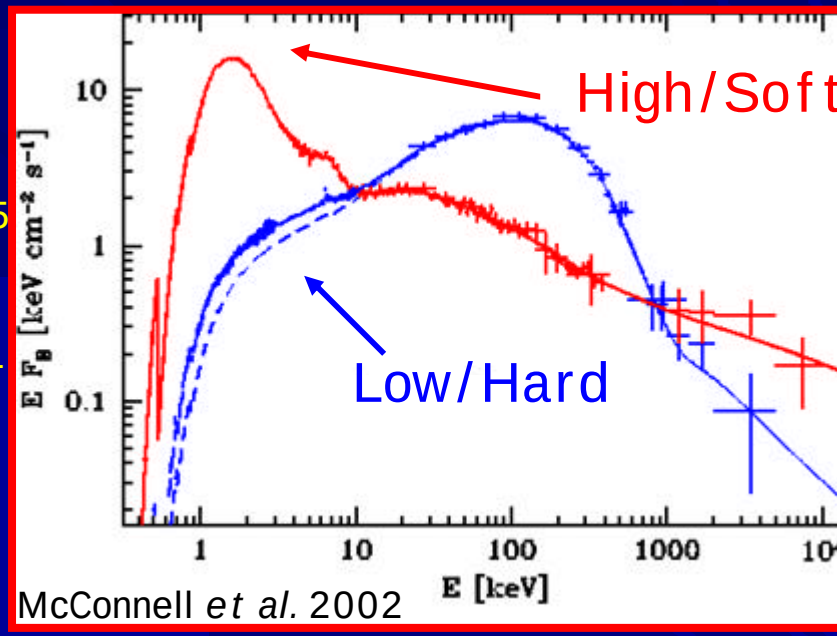
- Complex spectral-timing behaviour

- incoherent fast X-ray variability
- hard spectrum above 100 keV
- persistent X-ray emission

- First black hole prototype

Two Main Spectral States





- ***High/Soft***

Dominant soft X-ray thermal component; photon spectral index = 2.2

- ***Low/Hard (90% time)***

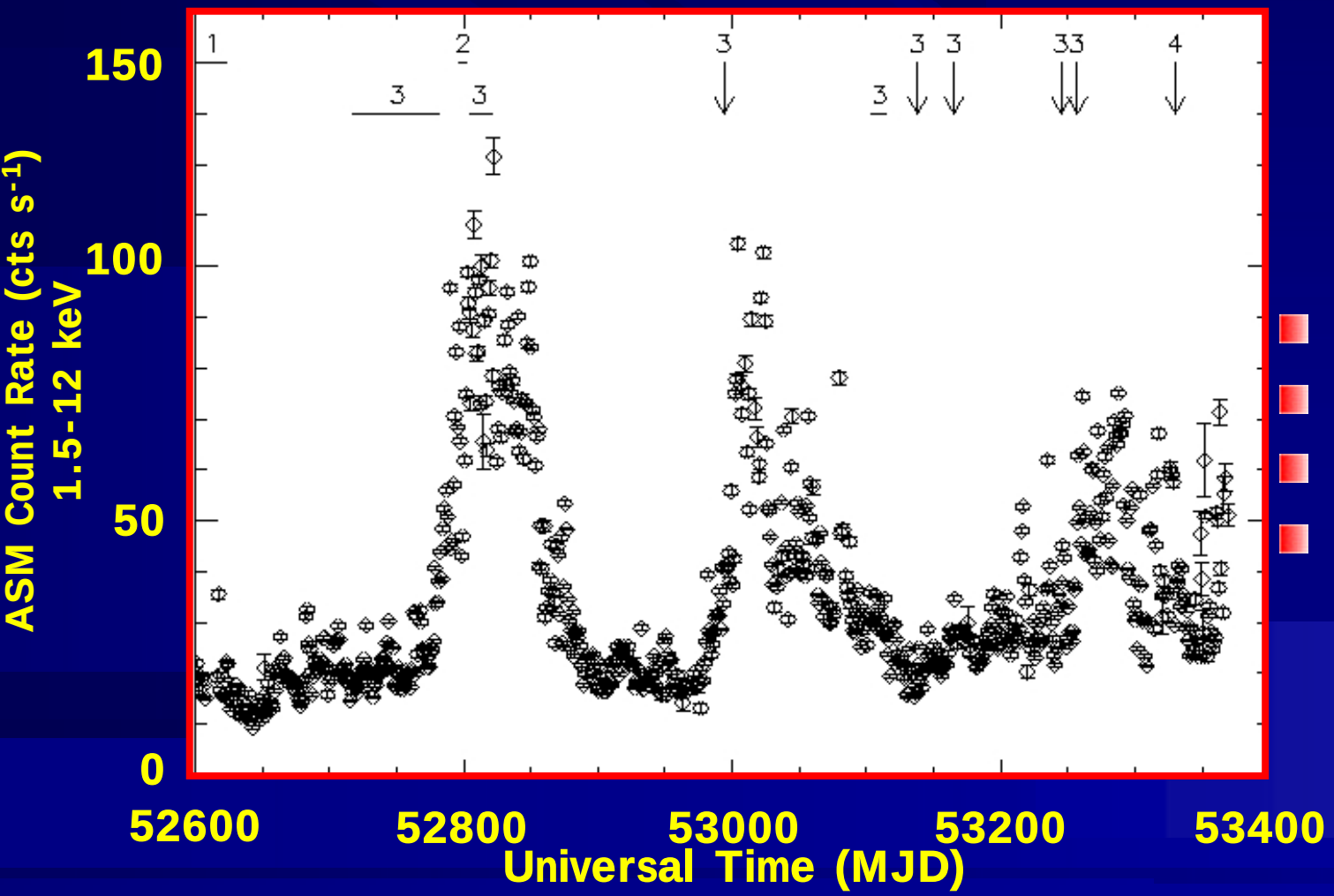
Low flux for soft X-rays, strong flux for hard photons (keV)

Photon spectral index 1.5-2, cut-off at E = 100 keV: comptonization

Observation Log

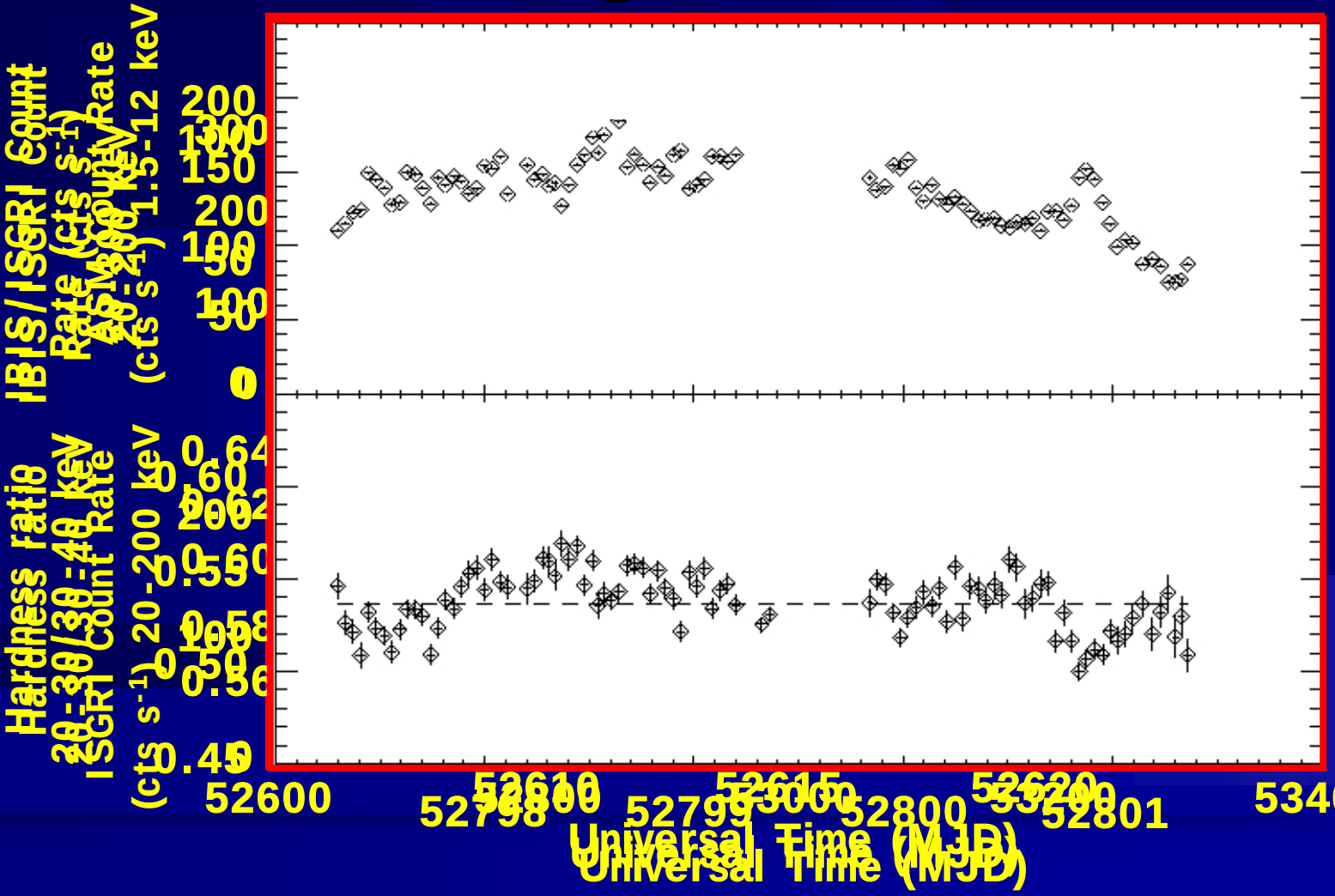
- PV-Phase (27th November - 15th December, 2002)
- GPS (between 2003, March and 2004, September)
- Open Time (7 - 11th June, 2003)
- Calibration in 2004, November 22nd

ASM Light Curve



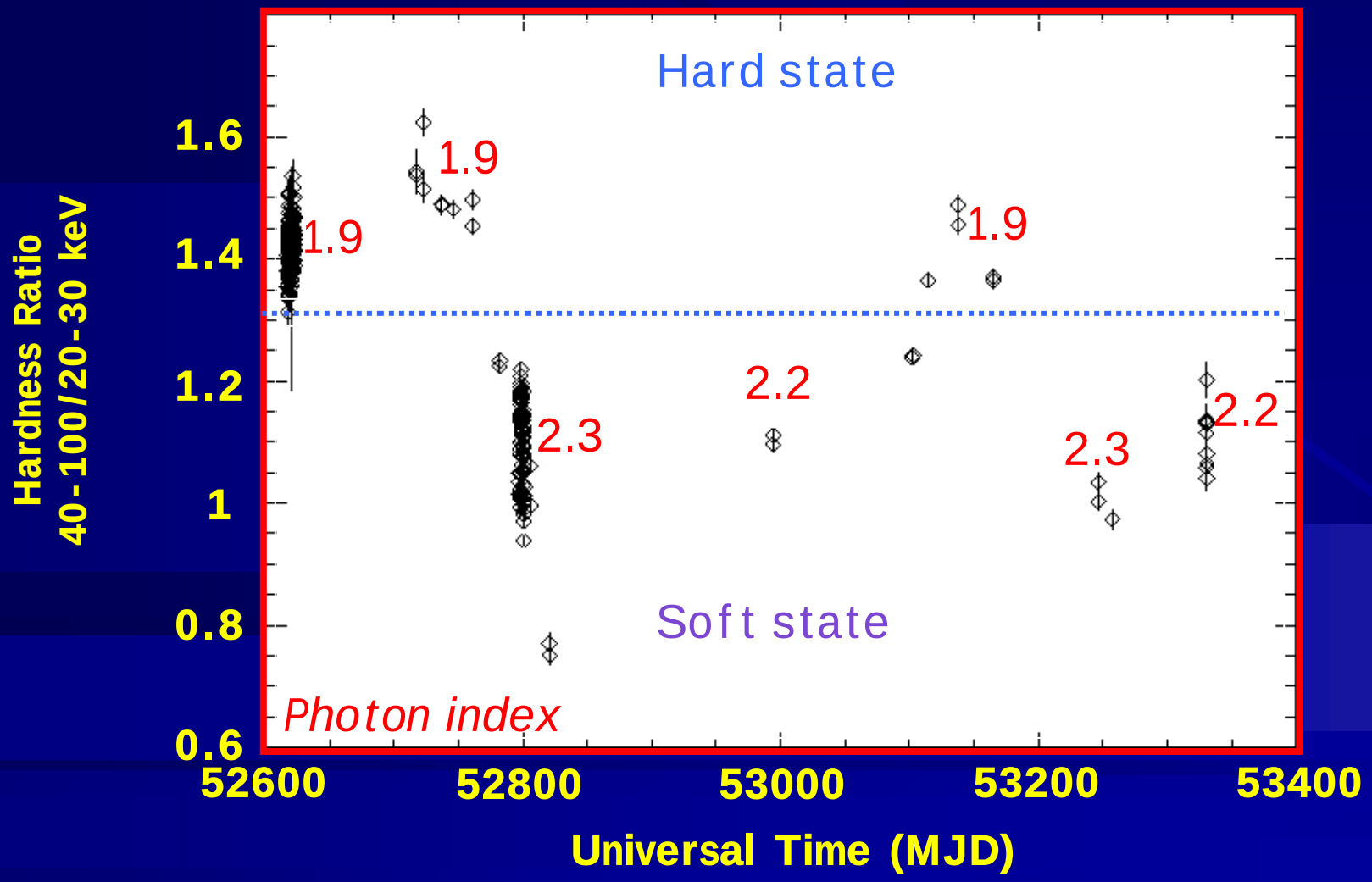
Spectral transitions probably occurring

Zoom on IBIS/ISGRI Light Curves and Hardness Ratio

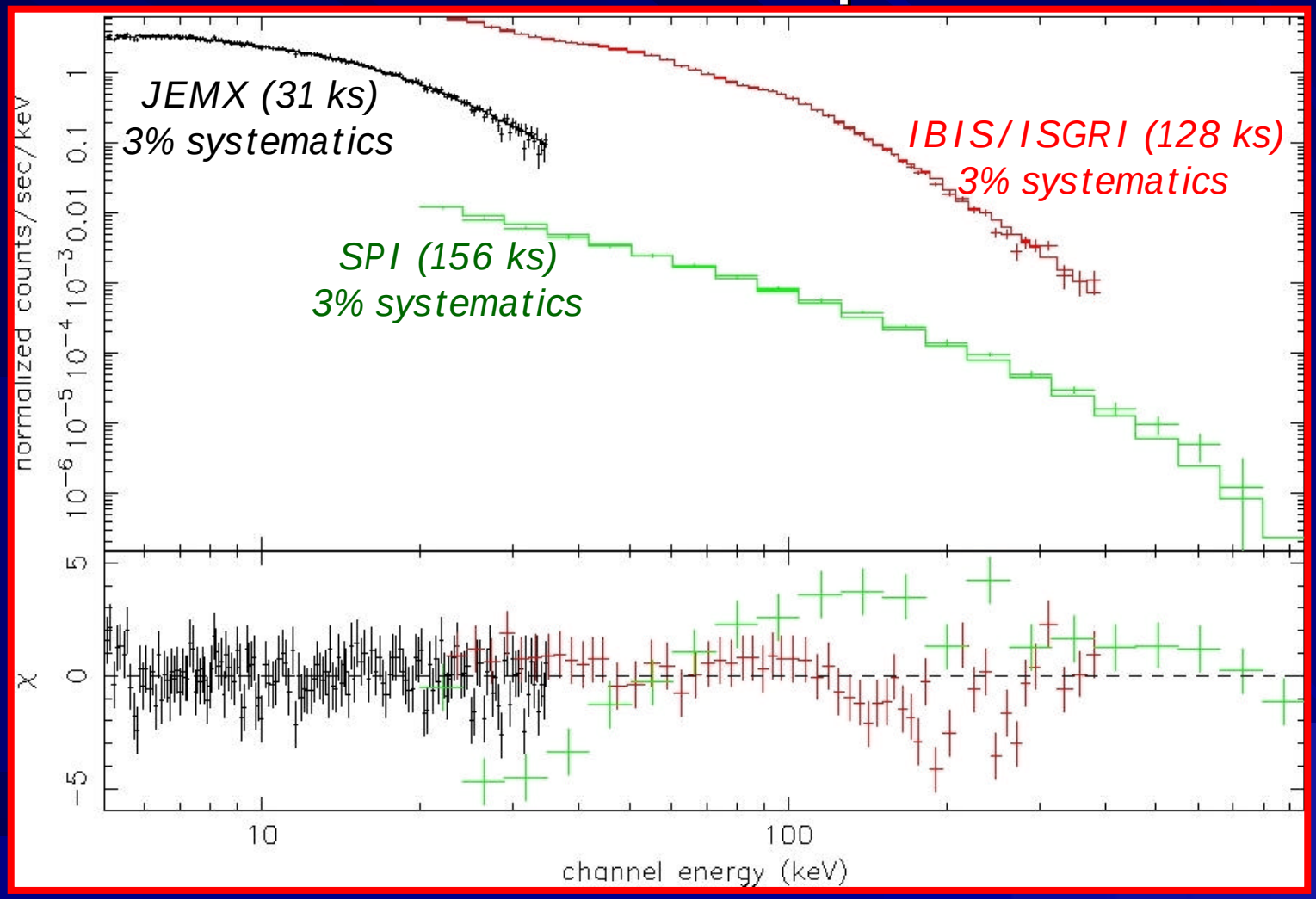


Changes in IBIS/ISGRI → Corresponding hardness ratio ?

Corresponding Hardness Ratio



December 02 Spectra



$kT = 93\ ^{+18}_{-12}$ keV

$\tau = 1.5 \pm 0.2$

$\chi^2_{red} = 1.70$ (dof = 219)

Model = absorbed black body disc + comptonization

Adding then reflection + gaussian components

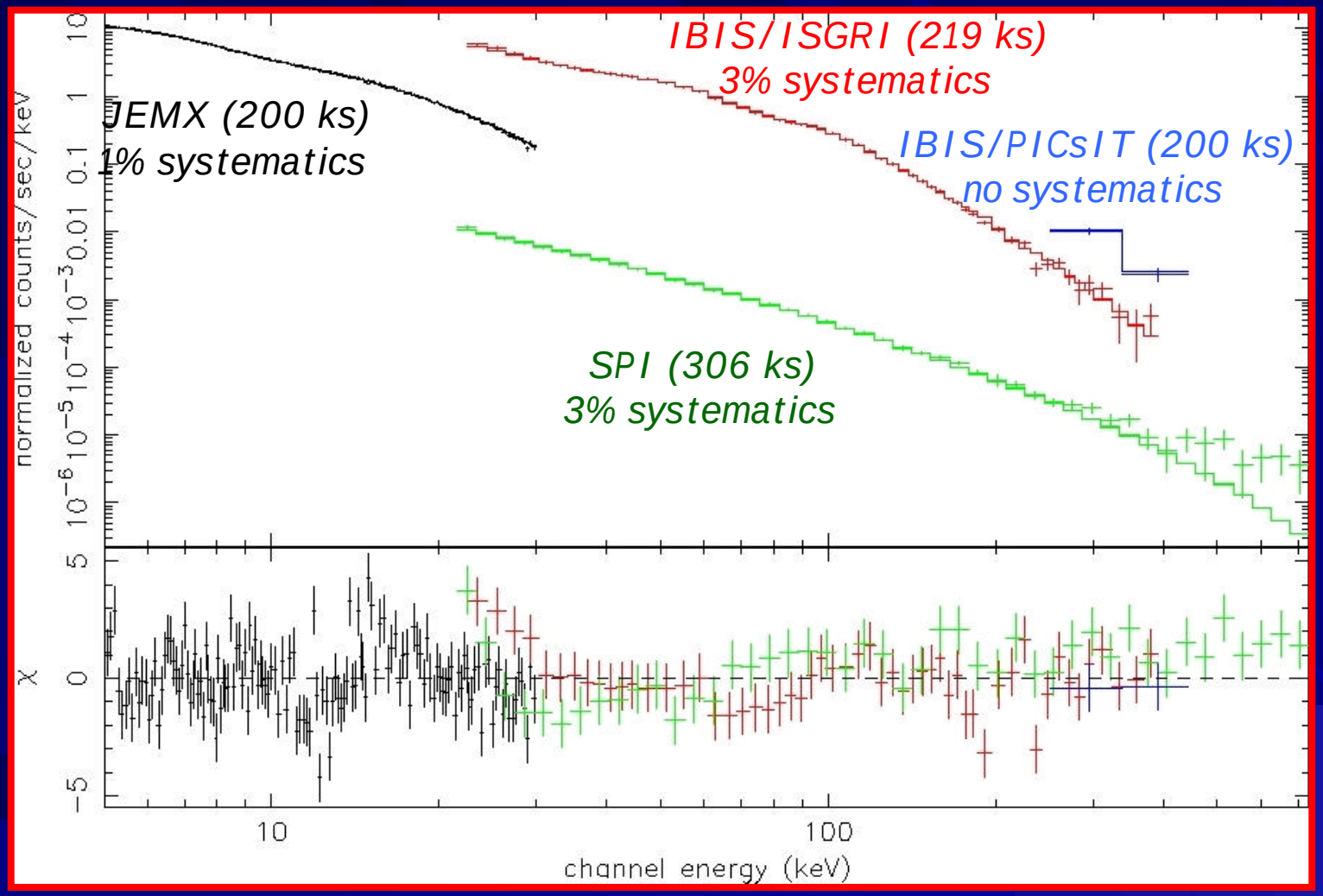
weak disc component ~ 0.2 L_{tot}

$L_{0.5-10\ keV} \sim 3.8\ 10^{36}$ erg s^{-1}

Fe line 6.4 ± 0.4 keV not well constraine

EW = 223 eV; reflection 0.38 ± 0.05

June 03 Spectra



kT = 104 ± 16 keV

t = 0.3 ± 0.1

χ^2 = 1.88 (dof = 230)

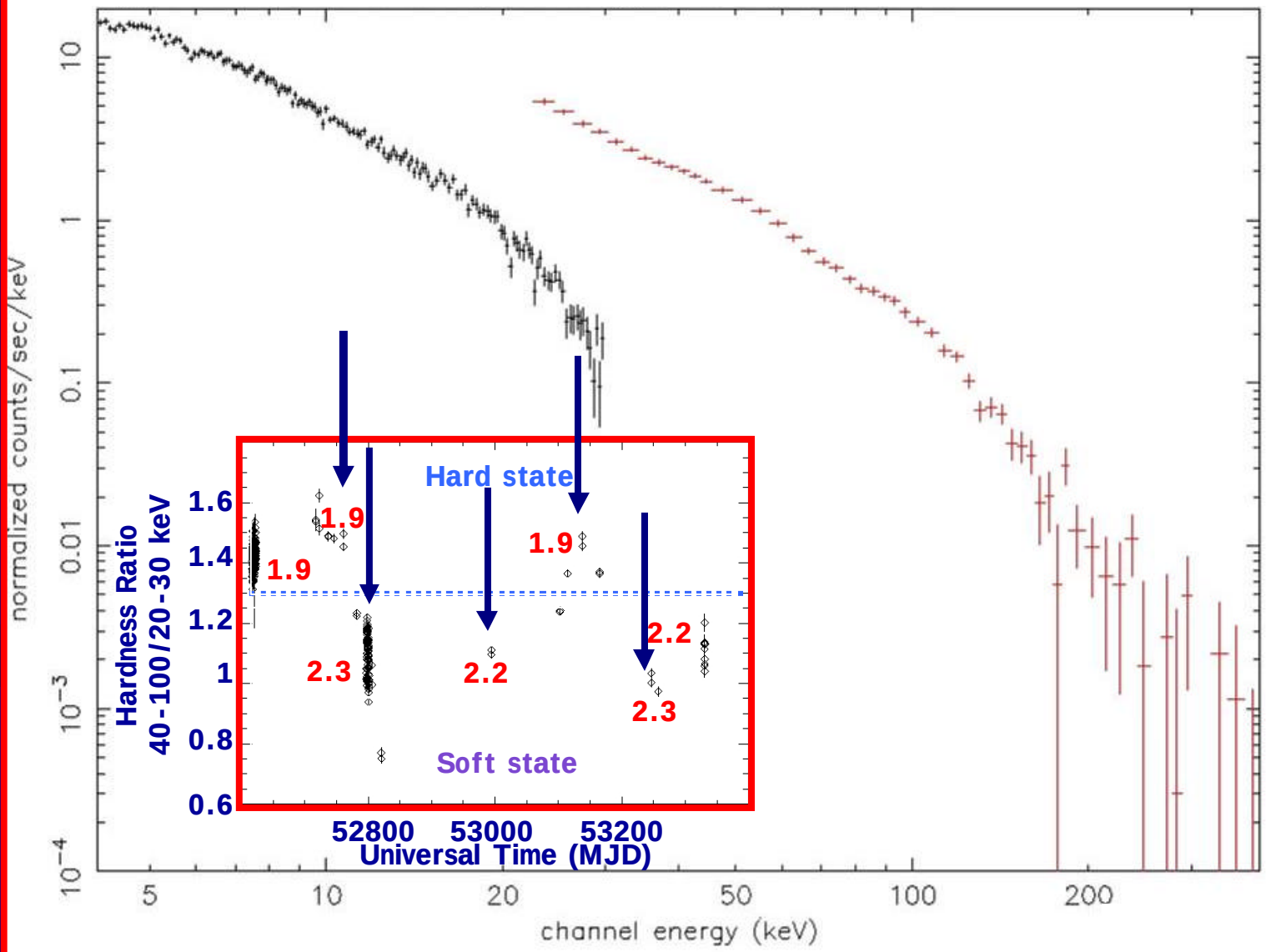
disc: kT_{in} = 1.22 keV, comp. ~ 0.4 L_{tot}

$L_{0.5\text{-}10\ keV}$: 6.6 10^{36} ergs s^{-1}

Fe line 7.1 ± 0.1 keV well defined

EW = 190 eV; reflection 0.58 ± 0.05

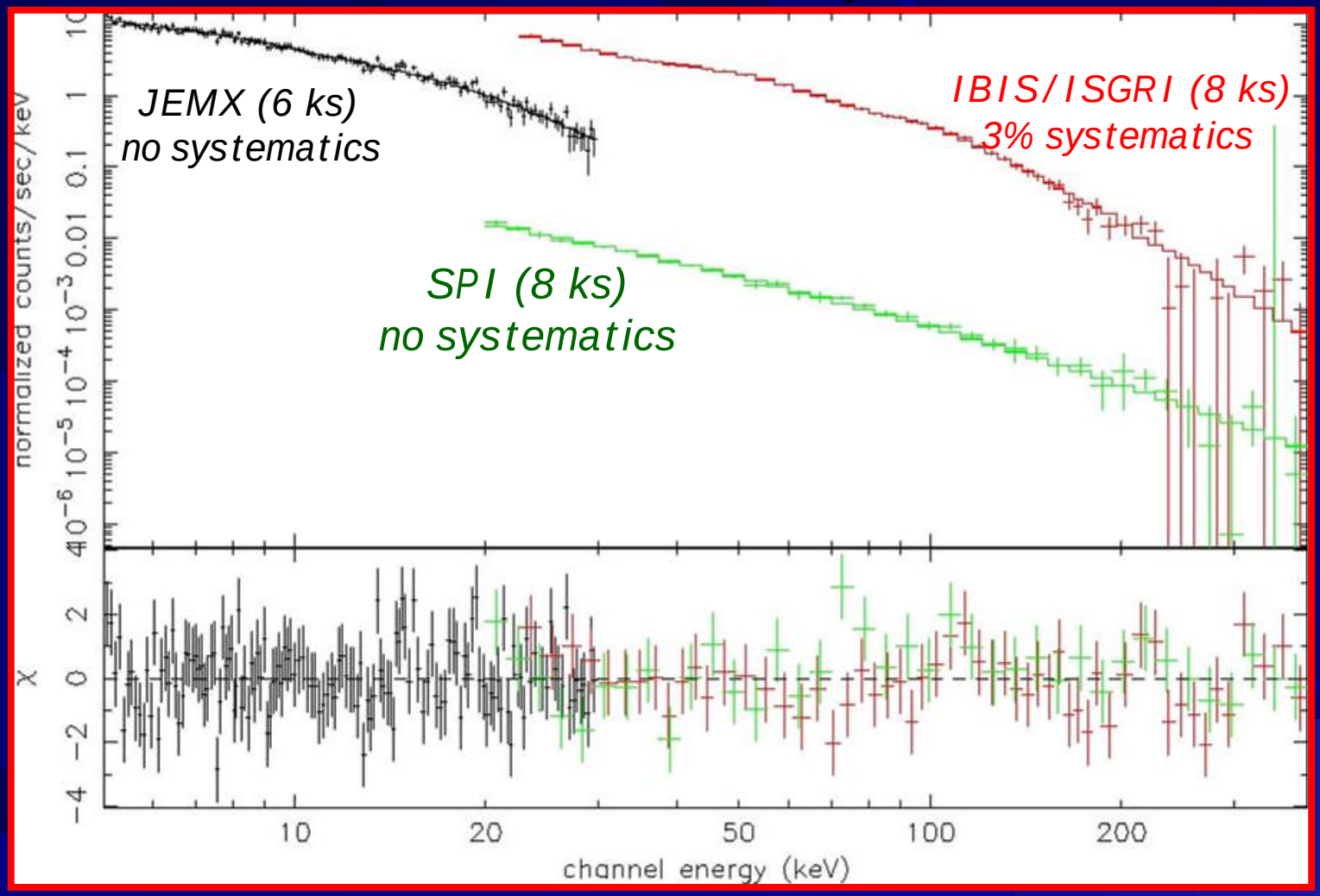
GPS 03-04 Spectra



Preliminary Spectral Parameters in GPS 03-04

Group / Parameters	Gr. 1	Gr. 2	Gr. 3	Gr. 4	Gr. 5
kT (keV)	59±20	106±49	61±20	57±10	113±72
t	2.5±0.5	0.3±0.2	0.6±0.3	2.5±0.1	0.2±0.1
Disc (kT_{in})	weak	1.5 keV	1.1 keV	weak	1.4 keV
$L_{0.5\text{-}10\ keV}$	0.2 L_{tot}	0.4 L_{tot}	0.4 L_{tot}	0.4 L_{tot}	0.5 L_{tot}
Fe line (keV)	6.3±0.3 (bad)	6.7±0.8 (bad)	7.1±0.1 (good)	6.0±0.5 (bad)	7±2 (bad)
EW (eV)	557	297	89	721	469
Reflection angle	0.4±0.1	0.8±0.2	0.3±0.1	0.3±0.1	0.4±0.2
$?^2_{réd}$ (dof=185)	1.02	1.08	1.02	0.78	1.45
→	HARD	SOFT	SOFT	HARD	SOFT

November '04 Spectra



kT = 94 ± 44 keV

t = 0,4 ± 0.2

$?^2_{réd}$ = 1,05 (dof = 209)

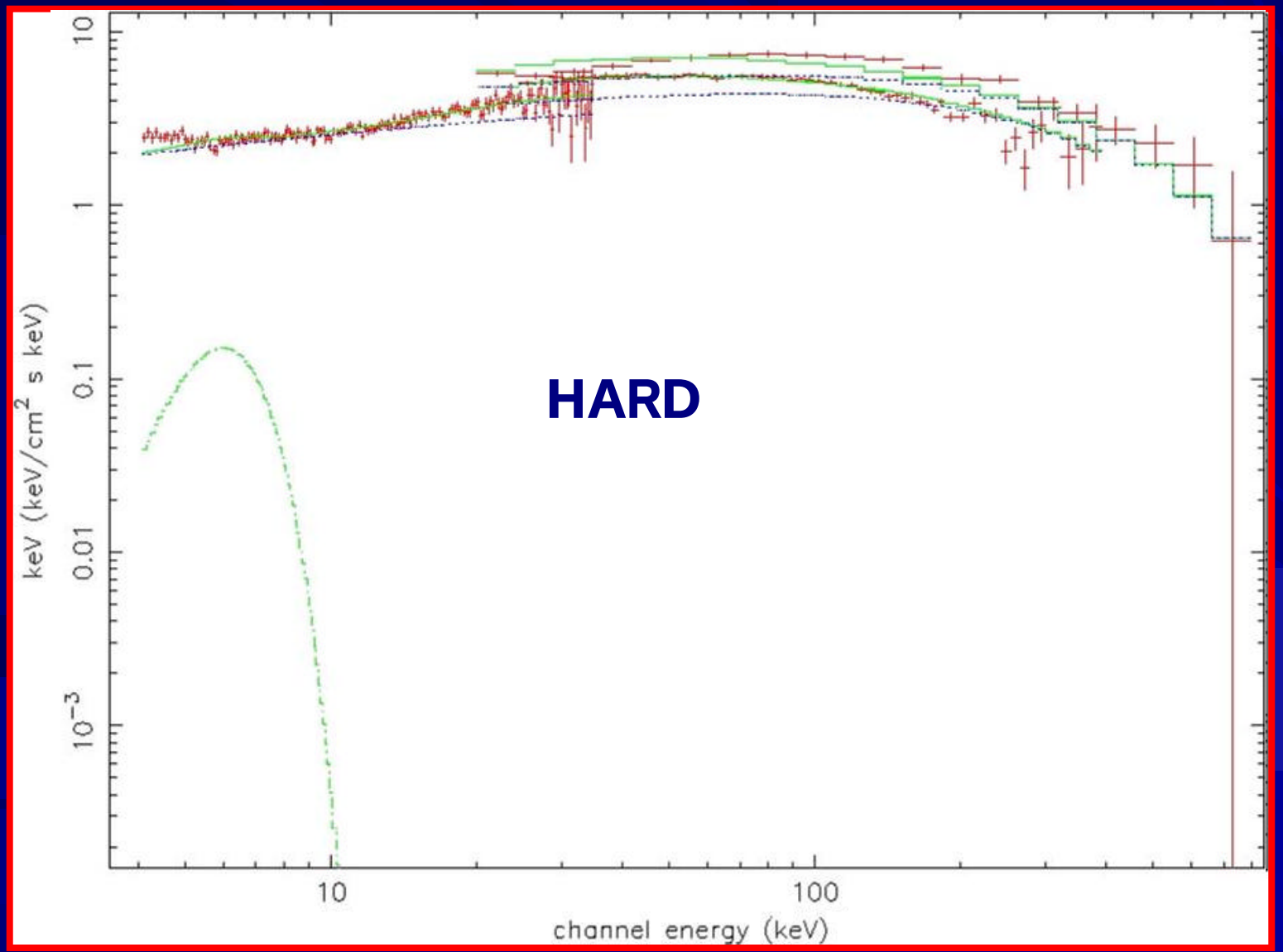
disc: kT_{in} = 1.27 keV, comp. ~ 0.4 L_{tot}

$L_{0.5\text{-}10\ keV}$: 6.8 10^{36} ergs s^{-1}

Fe line 7.8 ± 0.6 keV well defined

reflection 0.35 ± 0.15

Spectra comparisons in E^2 f(E) December 02 and June 03



Conclusions

- Evolutions from hard (December 02, GPS) to soft states (June 03, GPS) thanks to combined JEMX, IBIS and SPI spectra

- Probably intermediate states instead of real soft states

(conclusion also supported by radio observations, see Malzac *et al.* 04

- Comptonization models work well (typical for such a black hole)

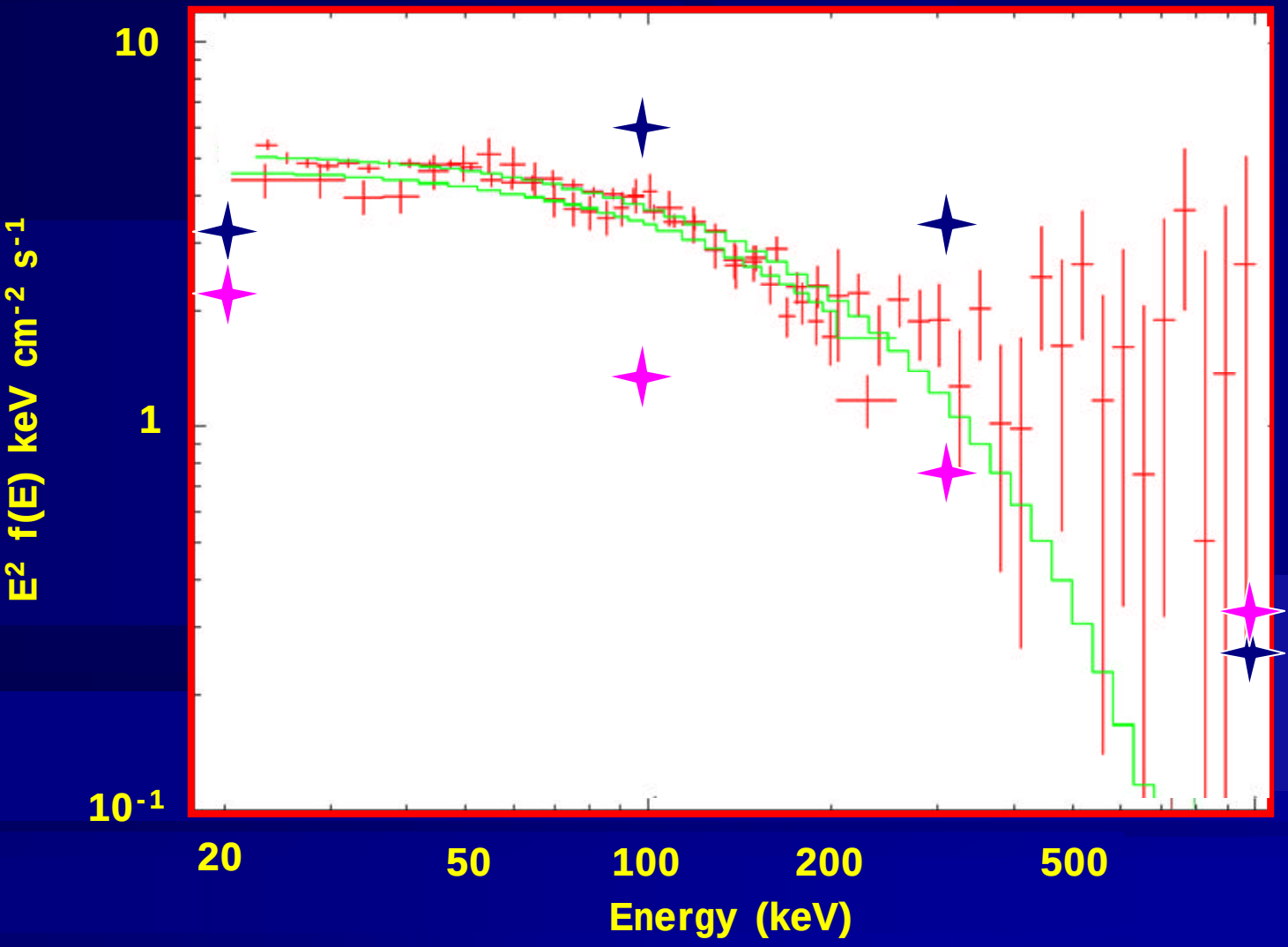
- Fe lines and reflection values consistent with precedent studies

- Future work:

- Other models (eqpair, compps, …) to be tested on all available data
- SPI high-energy data significance requires investigation
- Study of fast variability (QPOs)

Thanks for your attention !

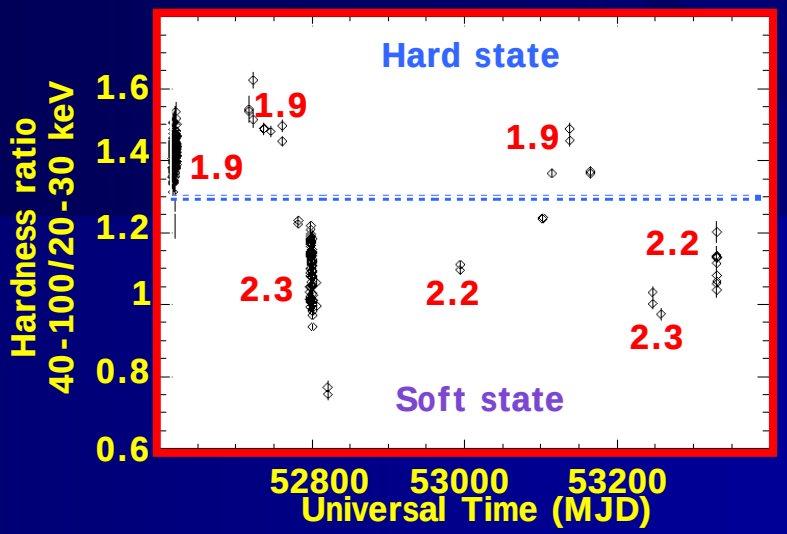
Spectra comparisons in E^2 f(E) December 02 and June 03



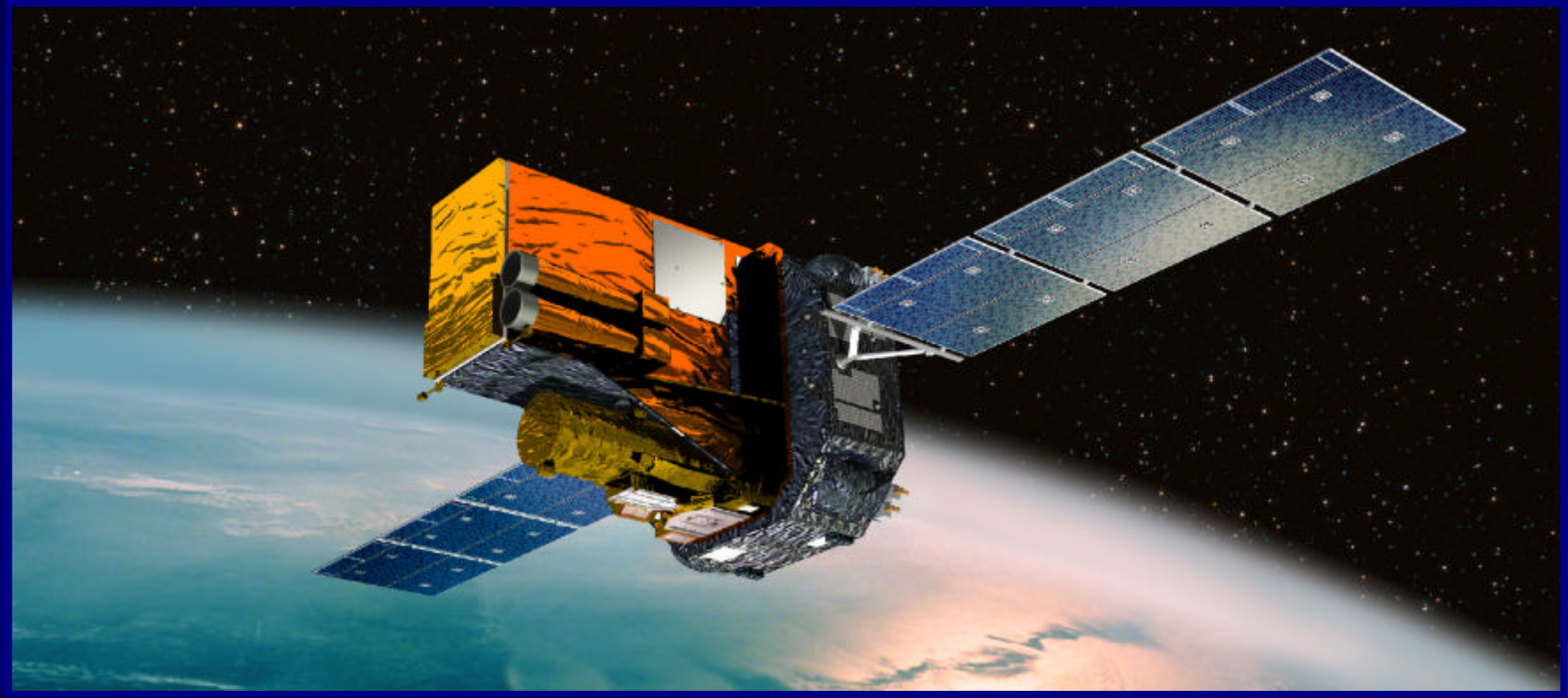
McConnell *et al.* 02 (CGRO, BeppoSAX)

LHS

HSS


Hard state
Soft state
1.9
1.9
1.9
2.3
2.2
2.2
2.3
Hardness ratio
40-100/20-30 keV
1.6
1.4
1.2
1
0.8
0.6
52800
53000
53200
Universal Time (MJD)

The INTEGRAL Satellite



- INTERnational Gamma Ray Astrophysical Laboratory (ESA)
- Imager IBIS (2 detectors ISGRI, PICsIT): 13 keV to 10 MeV
- Spectrometer (SPI): 20 keV to 8 MeV
- Large energy coverage

Spectral Parameters

- Gr. 1 $?^2_{réd} = 1.02$ (dof = 185) HARD

kT = 59 ± 20 keV, t = 2.5 ± 0.5, weak disc component ~ 0.3 L_{tot}

Fe line 6.3 ± 0.3 keV not well defined, reflection ~ 0.35 ± 0.07

- Gr. 2 $?^2_{réd} = 1.08$ (dof = 185) SOFT

kT = 106 ± 49 keV, t = 0.3 ± 0.2, kT_{in} = 1.46 keV, comp. ~ 0.5 L_{tot}

Fe line 6 ± 2 keV not well defined, reflection ~ 0.8 ± 0.2

- Gr. 3 $?^2_{réd} = 1.02$ (dof = 185) SOFT

kT = 61 ± 20 keV, t = 0.6 ± 0.3, kT_{in} = 1.11 keV, comp. ~ 0.5 L_{tot}

Fe line 7.1 ± 0.1 keV well constrained, reflection ~ 0.3 ± 0.1

- Gr. 4 $?^2_{réd} = 0.78$ (dof = 185) HARD

kT = 57 ± 10 keV, t = 2.5 ± 0.05, weak disc component ~ 0.3 L_{tot}

Fe line 6.0 ± 0.5 keV not well defined, reflection ~ 0.28 ± 0.04

- Gr. 5 $?^2_{réd} = 1.45$ (dof = 185) SOFT

kT = 113 ± 72 keV, t = 0.2 ± 0.1, kT_{in} = 1.41 keV, comp. ~ 0.6 L_{tot}

Fe line 6 ± 2 keV not well defined, reflection ~ 0.36 ± 0.21