Spectral Analysis of the eclipsing source MXB 1659-298

Rosario Iaria
T. Di Salvo, S.M. Mazzola, L. Burderi, A.F. Gambino, A. Sanna,T. Bassi, A. Riggio

Dipartimento di Fisica e Chimica
Università degli Studi di Palermo

12th INTEGRAL Conference and 1st AHEAD Gamma-ray workshop

12 Feb 2018

Outline

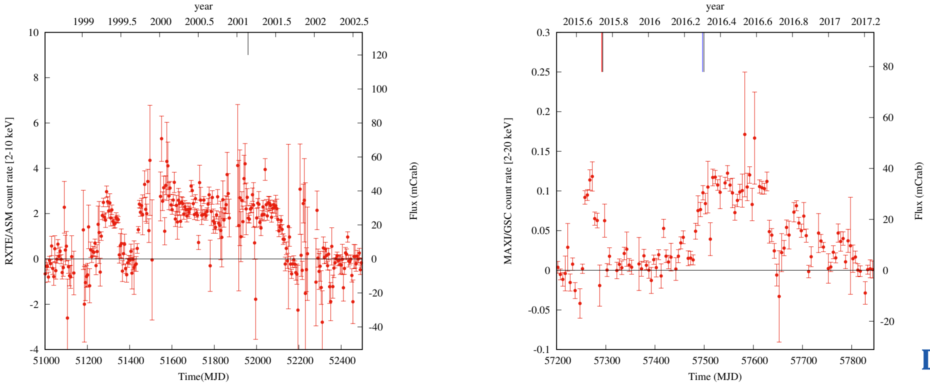
MXB 1659 is a transient source

The source was discovered in 1976. From its discovery it was in outburst three times.

- From 1976 to 1978
- From 1999 to 2002 (observed with **RXTE, BeppoSAX and XMM-Newton**)
- From 2015 to 2017 (observed by **MAXI, XMM-Newton, Swift/XRT and NuSTAR**

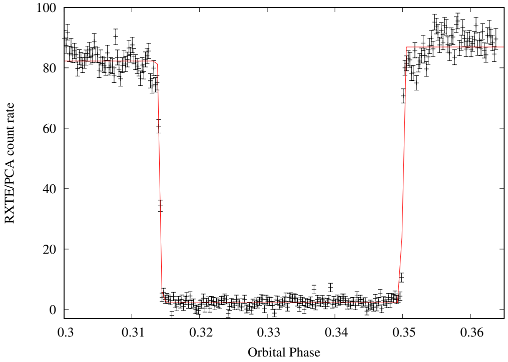
The 1999-2002 and 2015-2017 outbursts

The left panel shows the 1999-2002 outburst monitored by RXTE/ASM
The right panel shows the 2015-2017 outburst monitored by MAXI/GSC

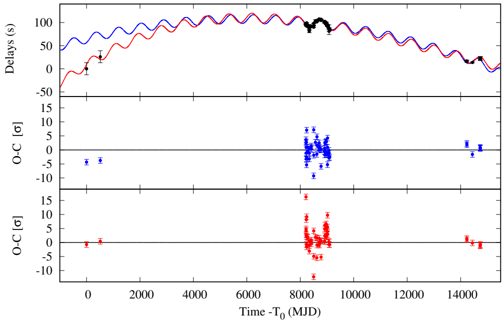


What else about MXB 1659

- The source shows total eclipses, the orbital period $P = 7.116$ hr
- The source shows type-I X-ray bursts



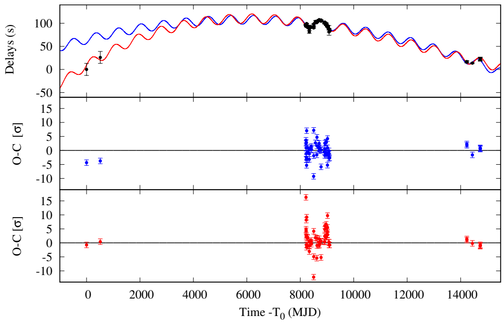
Example of an eclipse observed by the RXTE/PCA instrument (observation P40050-04-16-00).
(Iaria et al., 2018, MNRAS, 473, 3490)



We estimated **59** eclipse arrival times from 1978 to 2016 which are clustered mainly in the two last outbursts.
The delays have a peculiar sinusoidal modulation that could be explained assuming that MXB 1659 is a hierarchical triple system

We infer an orbital period of the 3rd body of 2.3 yr and a third body mass of 21 M_J

(See also Jain Chetana et al., 2018)

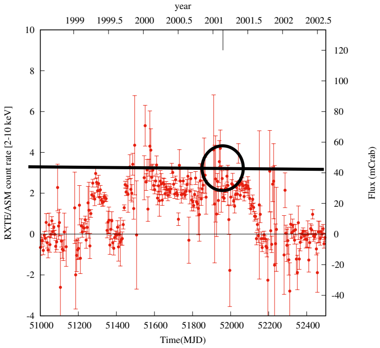


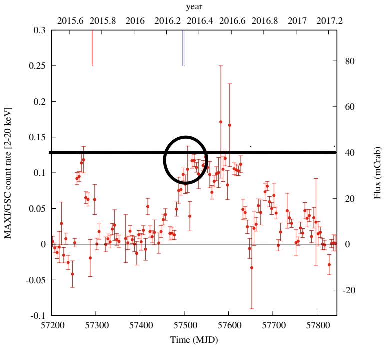
From the analysis of the delays and of the eclipse's shape we infer:

- Orbital period $P = 7.1161099(3)$ hr
- Orbital period derivative $\dot{P} = -8.5(1.2) \times 10^{-12}$ s s^{-1}
- Companion star mass between 0.3 and 0.9 $M_{\odot}$ (weak constrain)
- inclination angle of the system $i = 72 \pm 3$ degrees.

To analyse the **high-flux persistent spectrum** (excluding type-I X-ray burst and eclipses) we used:

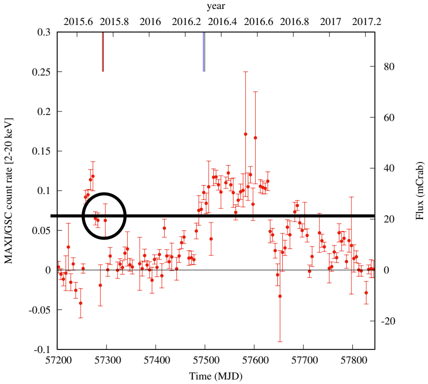
- the XMM observation taken in 2001. Flux close to 40 mCrab. [RGS1+RGS2,Epic-PN]
- the NuSTAR observation taken in 2006. Flux close to 40 mcrab. [FPMA+FPMB]
- two Swift/XRT observations taken 1 day before and 1 day after the Nustar observation (flux close 40 mCrab)



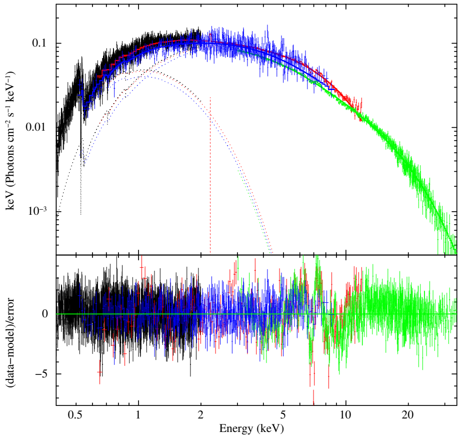


To analyse the **low-flux persistent spectrum** (excluding type-I X-ray burst and eclipses) we used:

- the XMM observation taken in 2005.Flux close to 20 mCrab [RGS1+RGS2, Epic-PN]
- the NuSTAR observation taken in 2005. Flux close to 20 mcrab [FPMA+FPMB]

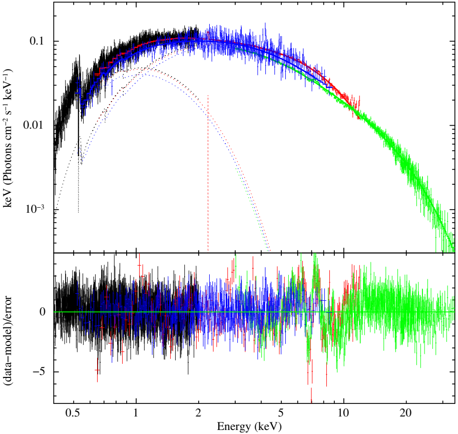


The high-flux broadband spectrum of MXB 1659



- Black spectrum, RGS1+RGS2, exp. time 34.6 ks
- Red spectrum, Epic-PN, exp. time 12.8 ks
- Green spectrum, NuSTAR FPMA+FPMB, exp. time 92.8 ks
- Blue spectrum, two Swift/XRT observations, exp. time 1.4 ks

The high-flux broadband spectrum of MXB 1659



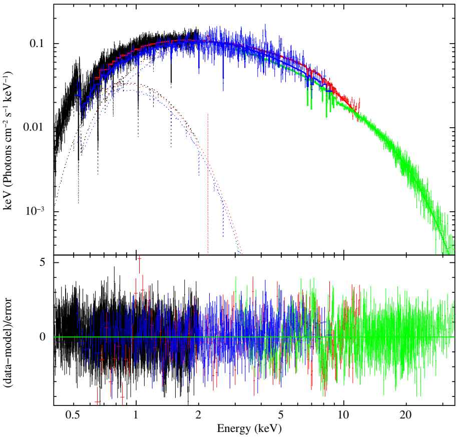
- **Abundances** Wilms et al. (2000)
- **Cross sections** Verner et al. (1996)

Initial model

TBabs*(diskbb+nthcomp)

Large residuals between 6 and 10 keV associated with the presence of ionised iron

Addition of a ionised absorber (zxipcf in XSPEC)



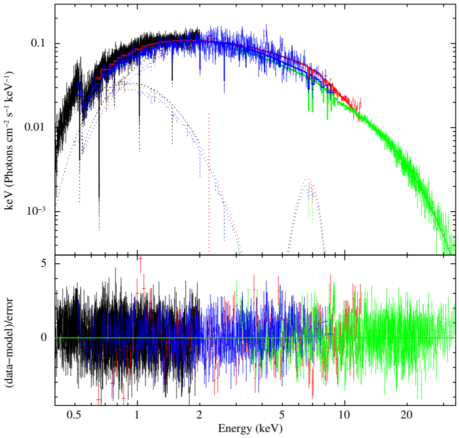
Model

TBabs*zxipcf*(diskbb+nthcomp)*(partcov*cabs)

$\chi^2(d.o.f.) = 3331(2797)$

- N_H of neutral matter 0.28×10^{22} cm^{-2}
- N_H of ionised matter 1.2×10^{24} cm^{-2}
- ionization parameter of the ionised matter $\text{Log}(\xi) \simeq 4.3$
- the ionised absorber covers 90% of the emitting source

What it happens if we add a Broad Gaussian line in the Fe-K region



Model

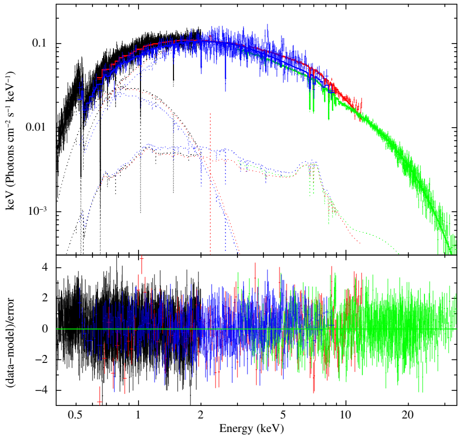
TBabs*zxipcf*(diskbb+nthcomp+gauss) *(partcov*cabs)

$\chi^2(d.o.f.) = 3252(2794)$
$\Delta\chi^2 = 79$

F-test Prob. of chance improvement 2×10^{-14}

- $E = 6.60 \pm 0.10$ keV
- $\sigma = 0.69 \pm 0.08$ keV
- $I = (1.10 \pm 0.10) \times 10^{-3}$ ph. cm^{-2} s^{-1}

Reflection from the inner accretion disk



Model

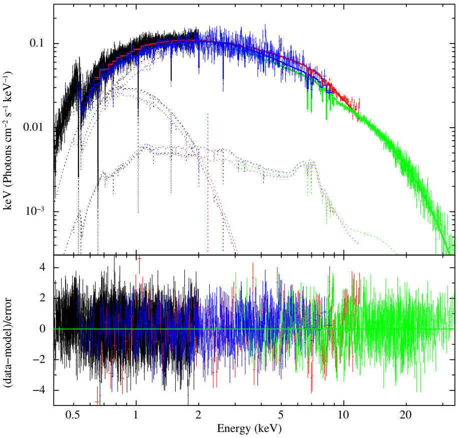
TBabs*zxipcf*(diskbb+nthcomp+ reflection) *(partcov*cabs)

where reflection is

rdblur*rfxconv*nthcomp

$\chi^2(d.o.f.) = 3228(2794)$

Reflection from the inner accretion disk



rdblur parameters

- $Betor10 < -1.4$
- $R_{in} = 60^{+60}_{-30}$ Grav. radii
- $R_{out} = 2800$ (fixed) Grav. radii
- incl. angle 72 deg (Iaria et al., 2018)

rfxconv parameters

- $\Omega/2\pi = 0.22^{+0.12}_{-0.05}$
- $\text{Log}(\xi) = 2.80^{+0.20}_{-0.10}$

The best-fit values of the other components

diskbb parameters

- kT$= 0.30$ keV
- $R_{disk} = 70 \pm 7$ km

nthcomp parameters

- $\Gamma = 1.71 \pm 0.05$ (obs. 2001),
  $\Gamma = 2.16 \pm 0.02$ (obs. 2016)
- $kT_{bb} = 0.43 \pm 0.02$ keV (obs. 2001),
  $kT_{bb} = 0.57 \pm 0.01$ keV (obs. 2016)
- $kT_e = 2.00 \pm 0.03$ keV (obs. 2001),
  $kT_e = 3.66 \pm 0.04$ keV (obs. 2016)

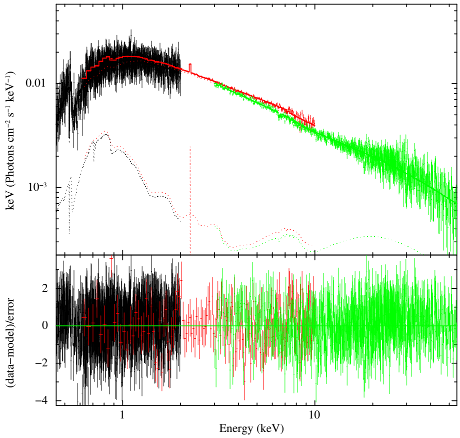
N_H of neutral matter

- $N_H = (0.275 \pm 0.010) \times 10^{22}$ cm^{-2}

zxipcf parameters

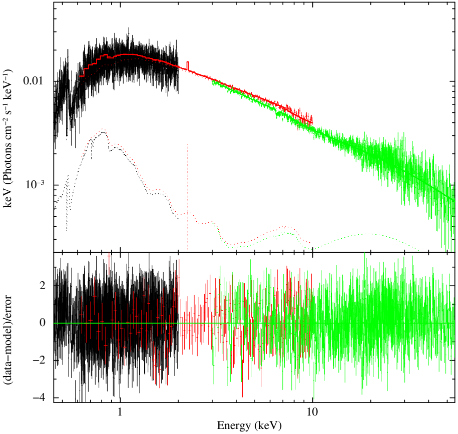
- $N_H = (6 \pm 1) \times 10^{23}$ cm^{-2}
- covering fraction 100
- $\text{Log}(\xi)_{IA} = 4.37 \pm 0.04$ (obs. 2001),
  $\text{Log}(\xi)_{IA} = 4.15 \pm 0.05$ (obs. 2016),

The low-flux broadband spectrum of MXB 1659



- Black spectrum, RGS1+RGS2, exp. time 68.7 ks
- Red spectrum, Epic-PN, exp. time 26 ks
- Green spectrum, NuSTAR FPMA+FPMB, exp. time 44.3 ks

The low-flux broadband spectrum of MXB 1659



No need of a diskbb component!

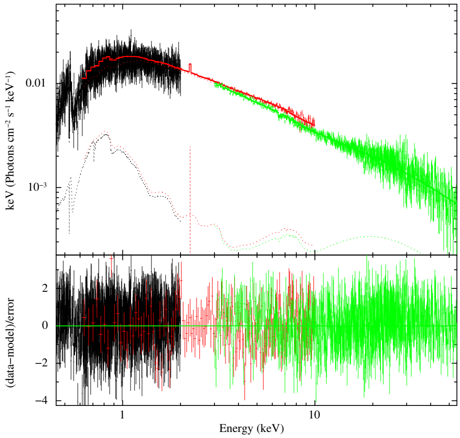
$\chi^2(d.o.f.) = 2359(2270)$

Model

TBabs*zxipcf*(nthcomp+reflection)(partcov*cabs)

Note that the reflection component is needed to fit the NuSTAR data between 10 and 40 keV, where the Compton hump is present!

The low-flux broadband spectrum of MXB 1659



rdblur parameters

- $Betor10 = -3.0 \pm 0.3$
- $R_{in} < 7$ Grav. radii
- $R_{out} = 290$ (fixed) Grav. radii
- incl. angle 72 deg (Iaria et al., 2018)

rfxconv parameters

- $\Omega/2\pi = 0.48 \pm 0.06$
- $\mathrm{Log}(\xi) = 1.99 \pm 0.10$

The best-fit values of the other components

nthcomp parameters

- $\Gamma = 1.99 \pm 0.02$
- $kT_{bb} < 0.06$ keV
- $kT_e > 130$ keV

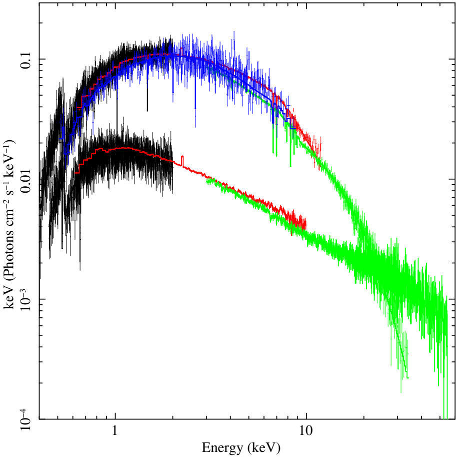
N_H of neutral matter

- $N_H = (0.329 \pm 0.008) \times 10^{22}$ cm^{-2}

zxipcf parameters

- $N_H = (1.4 \pm 0.1) \times 10^{23}$ cm^{-2}
- covering fraction $(25 \pm 2)\%$
- $\mathrm{Log}(\xi)_{IA} = 1.98 \pm 0.05$ (XMM), $\mathrm{Log}(\xi)_{IA} = 3.0 \pm 0.3$ (NuSTAR),

Comparison of low and high-flux spectra



Flux and Luminosity of the high-flux spectrum

- 0.1-100 keV Unabs. Flux 2.2×10^{-9} erg cm^{-2} s^{-1} (excluding neutral and ionised absorber)
- 0.1-100 keV Unabs. Luminosity 2.8×10^{37} erg s^{-1} (distance to the source 10 kpc)

Flux and Luminosity of the low-flux spectrum

- 0.1-100 keV Unabs. Flux 4.4×10^{-10} erg cm^{-2} s^{-1} (excluding neutral and ionised absorber)
- 0.1-100 keV Unabs. Luminosity 5.5×10^{36} erg s^{-1} (distance to the source 10 kpc)

The geometry of the inner region of the system

High-Flux spectrum

- inner radius of the accretion disk $R_{disk} = 200 \pm 20$ km
- reflecting region between $R_{in} = 140^{+140}_{-70}$ km and $R_{in} = 6400$ km
- optical depth of the Comptonized corona between 8 and 15
- $\Omega/2\pi = 0.22^{+0.12}_{-0.05}$ **compatible with a spherical corona with a radius that is smaller by a factor 0.8 than the reflecting radius of the accretion disk (Dove et al., 1997)**
- ionization of the reflection skin $\text{Log}(\xi) = 2.80^{+0.20}_{-0.10}$

Low-Flux spectrum

- No disk detected
- reflecting region between from the NS surface to 690 km
- optical depth of the Comptonized corona < 0.7
- $\Omega/2\pi = 0.48 \pm 0.06$ **compatible with a spherical corona with a radius equal to the reflecting radius of the accretion disk (Dove et al., 1997)**
- ionization of the reflection skin $\text{Log}(\xi) = 1.99 \pm 0.10$

The ionised absorber

High-Flux spectrum

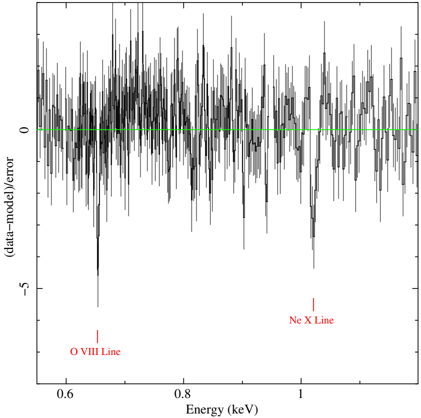
- $N_H = (6 \pm 1) \times 10^{23}$ cm^{-2}
- covering fraction 100%
- ionization between
  $\text{Log}(\xi)_{IA} = 4.37 \pm 0.04$ and
  $\text{Log}(\xi)_{IA} = 4.15 \pm 0.05$

Low-Flux spectrum

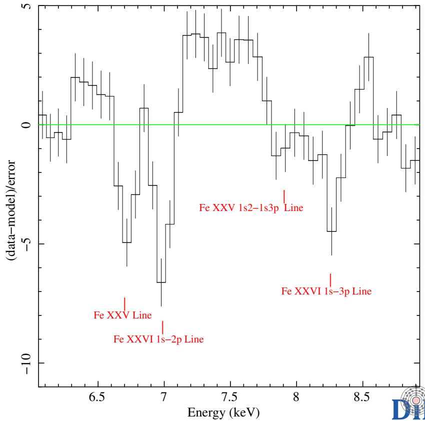
- $N_H = (1.4 \pm 0.1) \times 10^{23}$ cm^{-2}
- covering fraction (25 ± 2)%
- ionization between
  $\text{Log}(\xi)_{IA} = 1.98 \pm 0.05$ and
  $\text{Log}(\xi)_{IA} = 3.0 \pm 0.3$

The observed absorption lines in the High-flux spectrum

RGS12



EPIC-PN



The observed Fe absorption lines in the High-flux spectrum

1. Using the receipt of Kotani et al. (2000) we estimated the curves of growth of Fe XXV and Fe XXVI finding a kinematic temperature of $KT_{kin} = 100 \pm 45$ keV
2. Since the ionization parameter of the absorber is $\mathrm{Log}(\xi) \simeq 4.36$ we estimated that the thermal temperature of the absorber in which the iron lines origins id $kT_{th} = 7.1$ keV (Kallman et al., 2004)
3. Using the relation $\boxed{kT_{th} + \frac{1}{3} m_{Fe} v_{bulk}^2 = kT_{kin}}$ (Yamaoka et al., 2001) we find that the turbulent velocity of the absorber is $v_{turb} = 690^{+200}_{-100}$ km s^{-1}

A Similar turbulent velocity (> 500 km s^{-1}) was observed in the region of the absorber of the eclipsing NS-LMXB AX J1745.6-2901 (Ponti et al., 2015)

We find that the Fe lines origin af a distance from the NS of $r = (1.9 \pm 0.7) \times 10^9$ cm.

The observed Ne and O absorption lines in the High-flux spectrum

1. Assuming that the ionised absorber is in hydro-dynamical equilibrium along the vertical direction
2. Assuming that the coronal models tend to have turbulent velocities which are locally proportional to the Virial theorem (Woods et al., 1996) we find that

The turbulent velocities associated with the Ne and O lines are between 590 and 740 km s^{-1} and 320 and 550 km s^{-1}, respectively.

The Ne X line origins at a distance from the NS between 1.9 $\times 10^9$ cm and 4 $\times 10^9$ cm
The O VIII line origins at a distance between 4 $\times 10^9$ cm and 10^{10} cm

Conclusions

- We studied the broadband spectrum of MXB 1659 in high and soft state finding the presence of a ionized absorber and of a reflection component
- The high-soft spectrum is similar to that of the NS-LMXB eclipsing binary AX J1745.6-2901 (Ponti et al., 2015 and references therein)
- We find that a ionised absorber with uniform ionization parameter can explain the absorption lines associated with O VIII, Ne X , Fe XXV and Fe XXVI.
- The fact that two source at high inclination angle show a reflection component should bring us to tale into account this component also in the dipping source spectra. (For example the Big Dipper X 1624, for which Iaria et al, 2006 suggested the presence of a meared relativistic line at 6.7 keV)
- **If anyone has doubt about the relativistic nature of the broad line we note that the reflection component in the hard state it is necessary to fit the Compton hump between 10 and 40 keV**

Thanks for your attention!