Two years of INTEGRAL Core Program observations of the bright bursting LMXB GX 3+1: discovery of a variable non-thermal Comptonization component.

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History of GX 3+1

- Discovered in 1964 (Bowier et al. 1965);
- Classified as atoll source on the basis of its erratic time variability properties (Hasinger & van del Klis 1989);
- Soft X - ray spectrum similar to Z sources (kTe ~3 keV, t ~10) (Oosterbroek et al. 2000);
- X-ray luminosity (~0.2 L_{Edd}) intermediate between Z and atoll sources (Kuulkers & van der Klis 2000);
- Emission of type I X-ray bursts with photospheric radius expansion (Kuulkers & van der Klis 2001);
- Color-Color Diagram: featureless (spot like)

INTEGRAL Data set

CP2003:

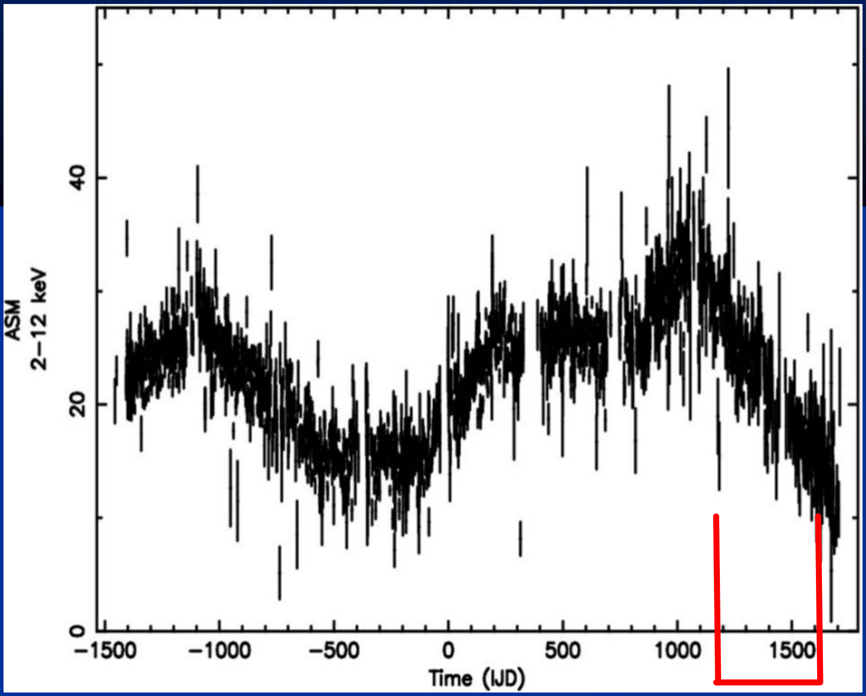
- Epoch 1
  - JEM-X2 (42 ScW, Texp=7.8x10^{4} s);
  - ISGRI (498 ScW, Texp=7.35x10^{5} s).
- Epoch 2
  - JEM-X2 (164 ScW, Texp=5.04x10^{5} s);
  - ISGRI (593 ScW, Texp=1.17x10^{6} s).

CP2004:

- Epoch 1
  - JEM-X2 (99 ScW, Texp=1.12x10^{5})
  - ISGRI (280 ScW, Texp=3.77x10^{5}).
- Epoch 2
  - JEM-X1 (44 ScW, Texp=7.59x10^{4} s)
  - ISGRI (351 ScW, Texp=4.75x10^{5} s).

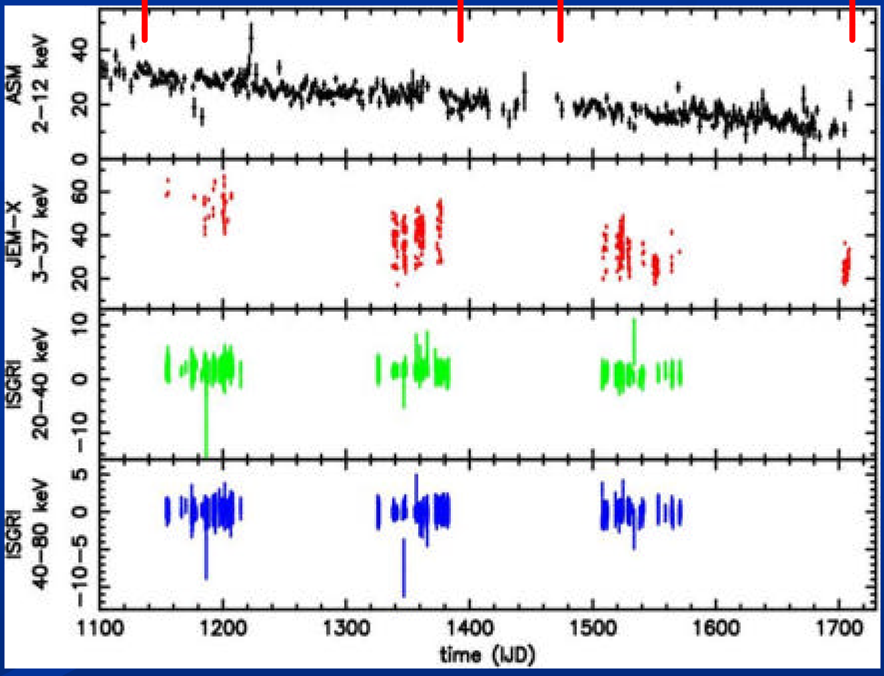
In the analysis we selected for JEM-X data only the ScW with off-axis angle < 3.5 deg.

GX3+1 temporal behaviour



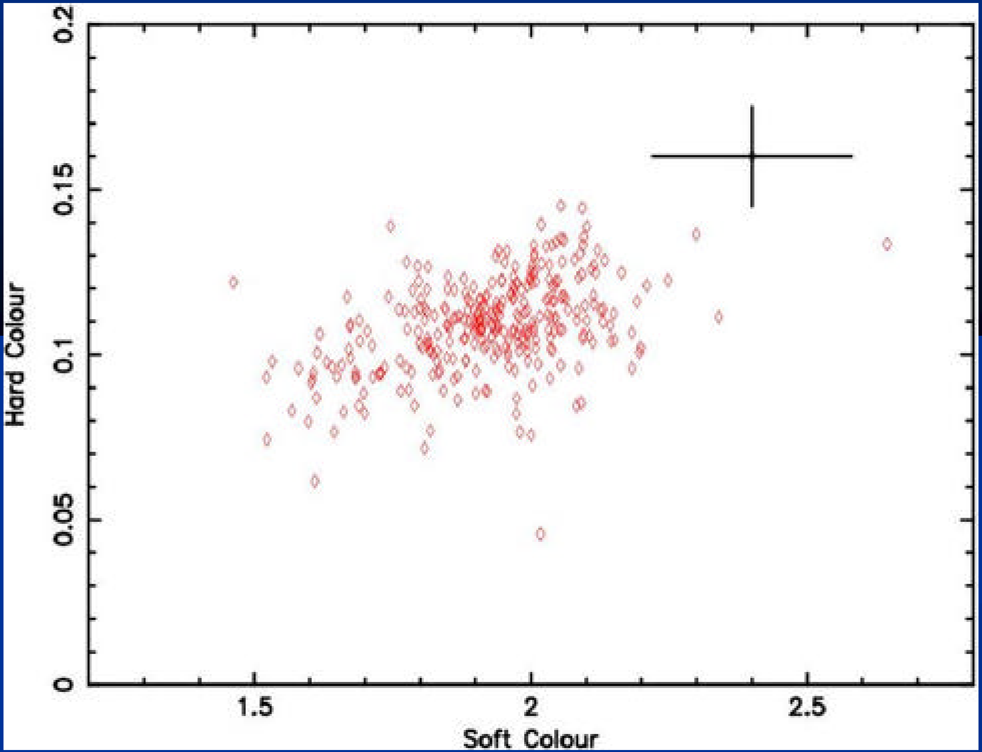
CP 2003

CP 2004



Core Program 2003/2004 observations

Color-Color diagram



One point per each ScW

No particular features observed in the diagram This substantially confirms results of previous satellites (e.g., EXOSAT)

Hard Colour = 12 - 20 keV/ 5-12 keV

Soft Colour = 5 -12 keV/ 3 - 5 keV

Data points not biased by fluctuations in the JEM-X count rate from ScW to Scw (data fluctuate +/- in the same manner in each of the four bands)

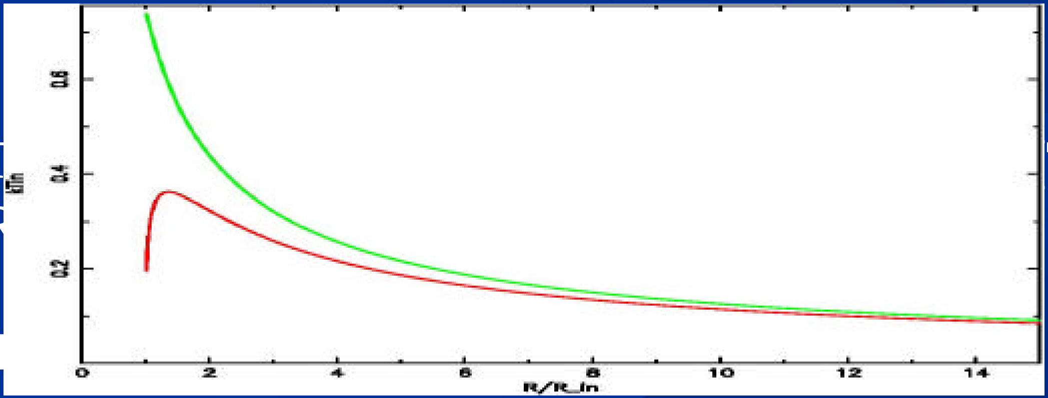
Spectral analysis

- ✓ **Four epochs (2 in 2003, 2 in 2004);**
- ✓ **Systematic error 2 % included for both JEM-X and ISGRI;**
- ✓ **Working only on energy bins with S / N = 3**

Spectral models adopted

EZDISKBB **accretion disk model with zero torque condition at $R=R_{in}$**

DISKBB **most used accretion disk model (Mitsuda et al.1984)**



COMPT **Titarchuk 1994)**

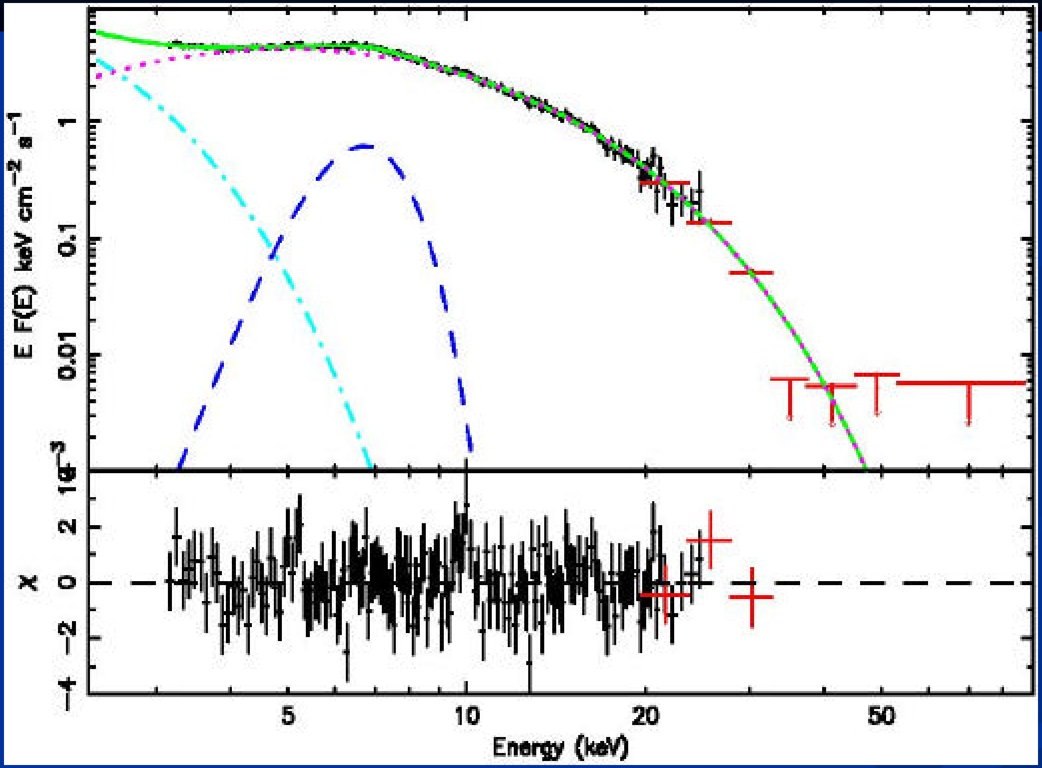
EQPAIR

GAUSS

Spectral results

2003, Epoch I:

Model applied : WABS (EZDISKBB+COMPTT+GAUSSIAN)



N_H = 1.7 x 10^{22} cm^{-2} (fixed)
kT_{in} (keV) = 0.41 [0.35 - 0.55]
$R_{in}(\cos i)^{1/2}$ = 222 [200- 300]
kT_s (keV) = 1.13 [1.11 - 1.15]
kT_e (keV) = 3.12 [3.00 – 3.25]
t = 7.78 [7.32- 8.03]

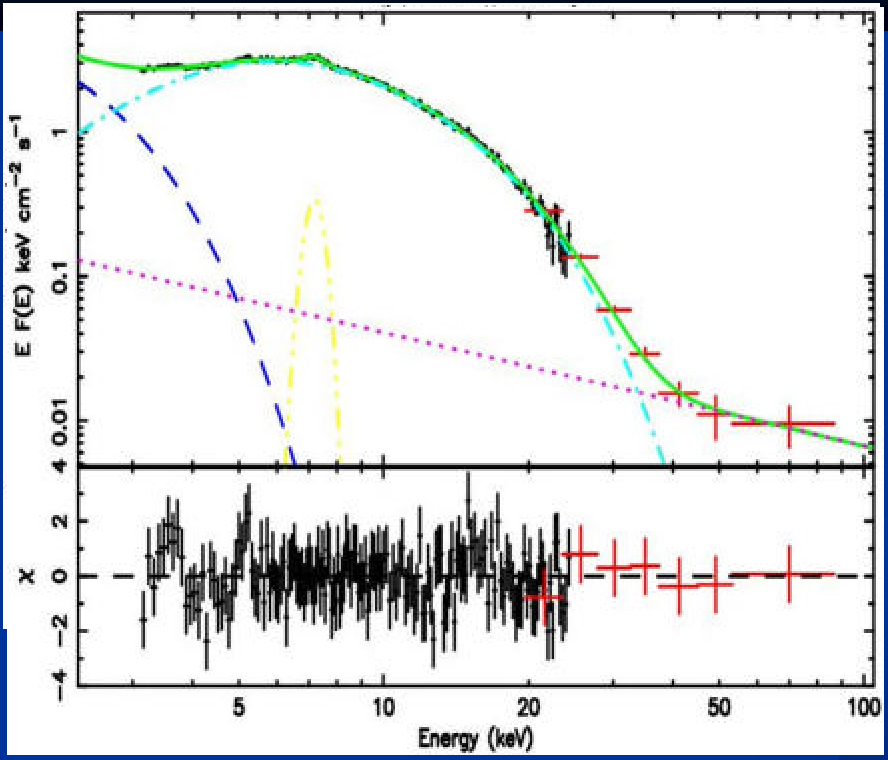
L_x ~ 1.1×10^{38} erg/s ~0.57 L_{Edd} !!
assuming M_{NS} =1.4 x M_{SUN}

?^{2} /dof = 130/137

Spectral results

2003, Epoch II:

same model WABS (EZDISKBB+COMPTT+GAUSSIAN)



kT_{in} (keV) = 0.45 [0.37 - 0.54]

$R_{in}(\cos i)^{1/2}$ = 115 [37- 9]

kT_s (keV) = 1.16 [1.14 - 1.21]

kT_e (keV) = 2.87 [2.73 – 3.01]

t = 9.57 [9.17- 10.44]

? = 2.78 [1.83 – 3.54]

L x ~ 4.1x10^{37} erg s ~0.21 L_{Edd}

?^{2}/dof = 136/14

To overcome the fenomenological approach (power-law) :

test of a hybrid Comptonization model in the place of COMPTT + PL:

Utilization of EQPAIR (Coppi 1999)

All micro-physics treated in self-consistent way

Equation of a thermal/non-thermal plasma:

$$N(\gamma) = \begin{cases} f_{th}(\gamma) = A\gamma\sqrt{\gamma^2 - 1}\, e^{-\frac{(\gamma-1)m_e c^2}{kT_e}} & 1 \leq \gamma \leq \gamma_{min} \\ f_{nth}(\gamma) = B\gamma^{-p} & \gamma_{min} < \gamma \leq \gamma_{max} \end{cases}$$

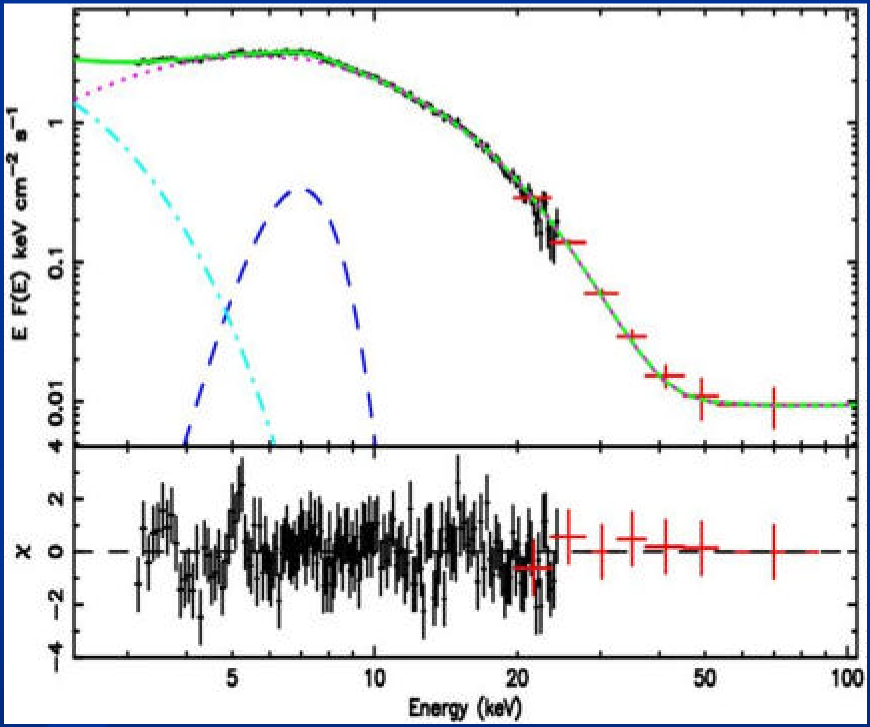
Electrons with ? > ?$_{min}$ have t$_{Compton}$ < t$_{Thermalization}$

If we utilize a "thermal" version of EQPAIR :

kT_{in} (keV) = 0.44 [0.43 - 0.46]
$R_{in}(\cos i)^{1/2}$ = 98 [97 – 100]
kT_s (keV) = 0.95 [0.10 – 0.06]
kT_e (keV) = 2.8 (not free parameter)
t = 9.3 [9.0 – 9.5]

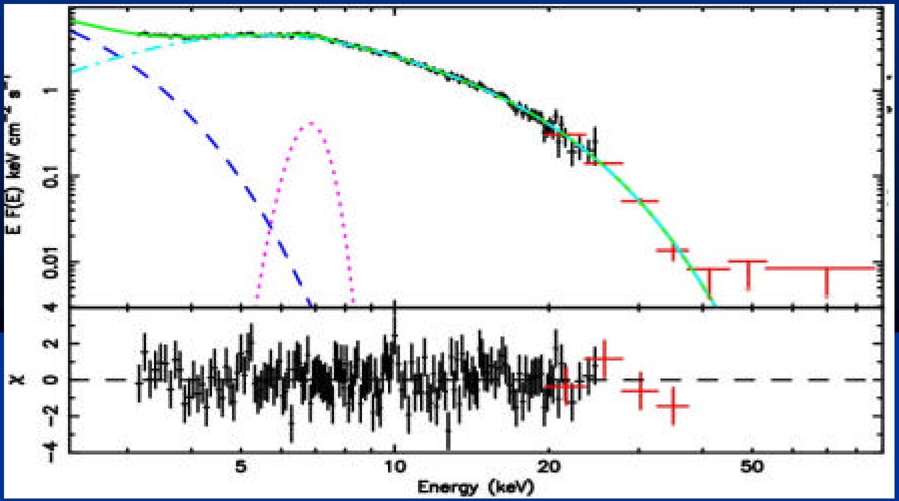
p = 0.95 [0.85 – 1.87]
$?_{min}$ = 1.3 (fixed)
$?_{max}$ = 12 (fixed)

$?^2$ /dof = 136/144

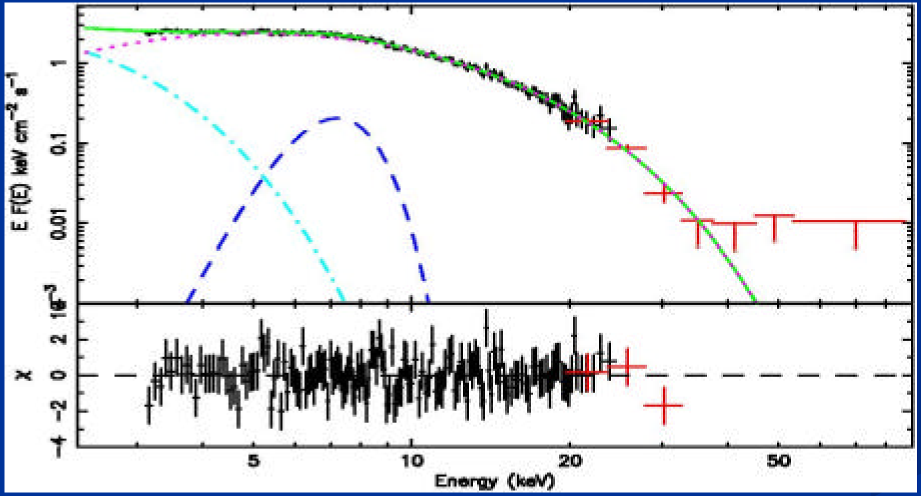


Spectral results: 2004

JEM-X2 + ISGRI



JEM-X1 + ISGRI



No hard excess in both Epoch I and II of 2004

Usual model DISKBB (or EZDISKBB) plus THERMAL Comptonization well fits the data...

...but parameters of the emission line are still doubtfull
(s ~ 1.7 keV for JEM-X2)
(s ~ 1.1 keV for JEM-X1)

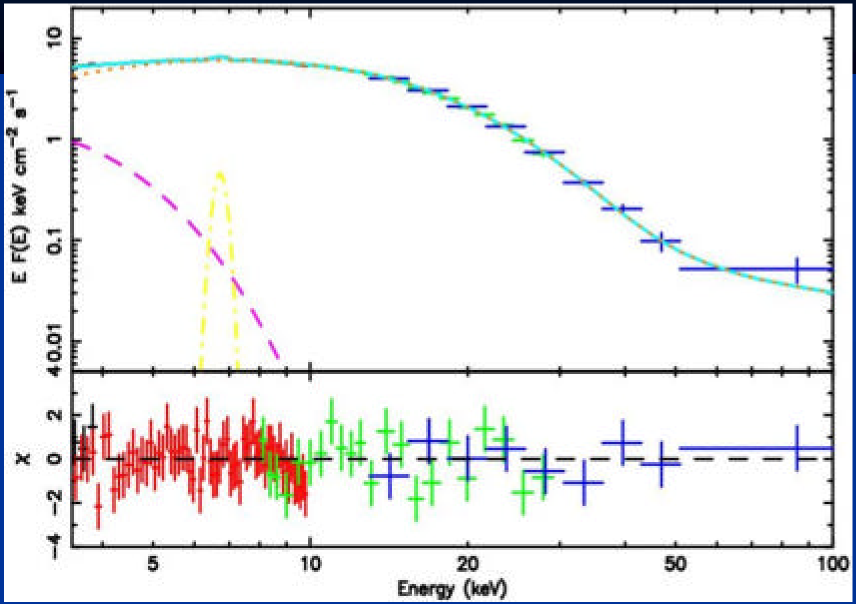
L x ~ $3.7\text{x}10^{37}$ erg s ~ 0.2 Ledd

does not change

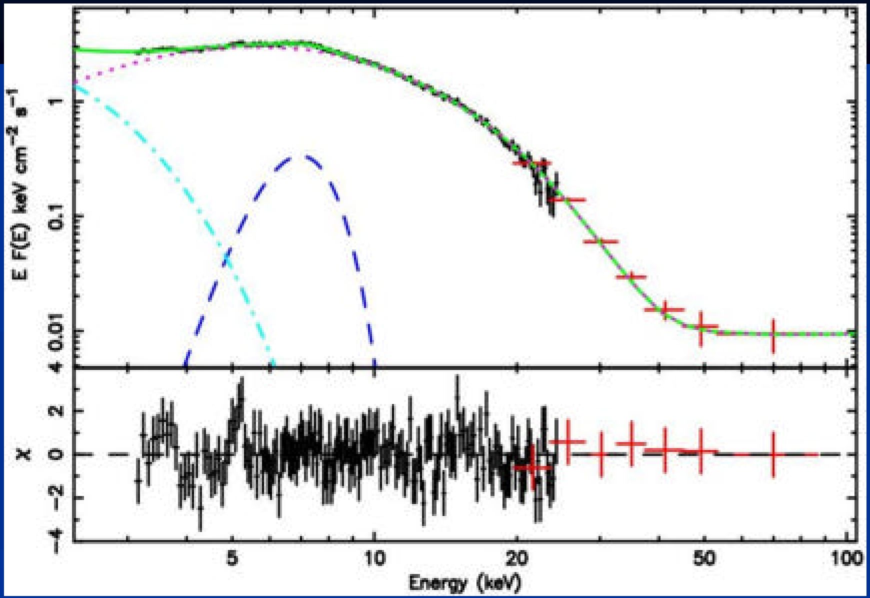
First implications

Strong similarity between transient hard X ray emission from Z sources and excess observed in GX 3+1:

GX 17+2 (Z source, BeppoSAX data)
Farinelli et al. 2005

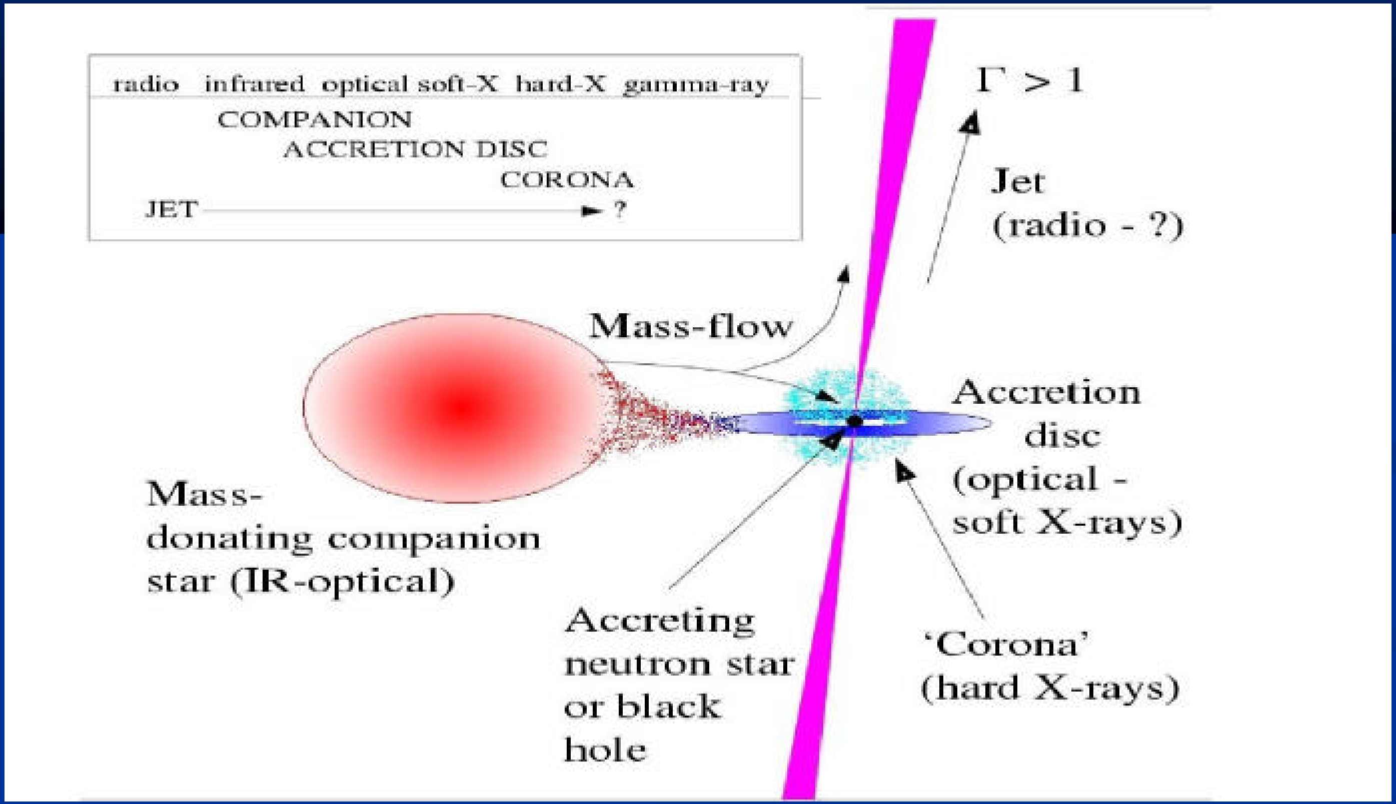


GX 3+1 (Atoll source)
Farinelli et al. 2005 (in preparation)



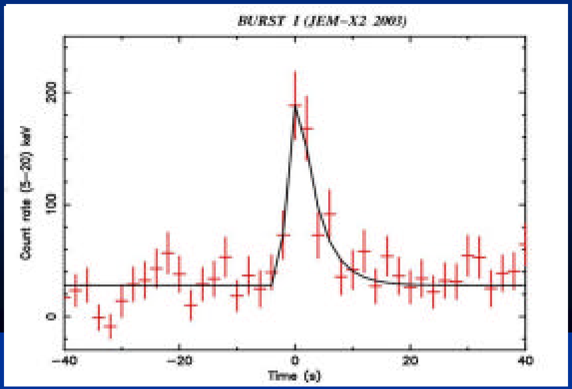
From a spectral point of view, GX 3+1 is much more a Z source than an atoll...... this was previously know, but a non-thermal like transient hard X-ray emission is new !! This further links GX 3+1 to Z sources........

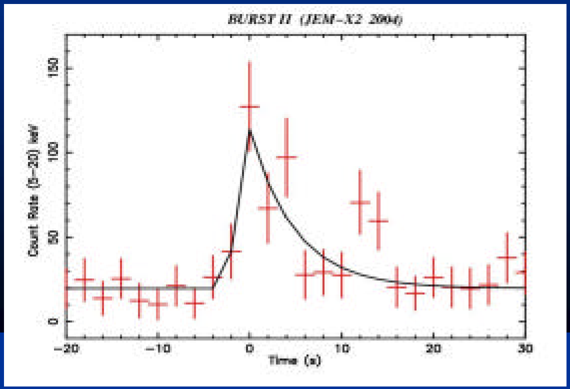
Farinelli et al. (2005) suggested that in GX 17+2, hybrid Comptonization may originate either in jets or in magnetic reconnection processes in the accretion disk.
Same hypothesis in GX 3+1: if the first one is correct.......

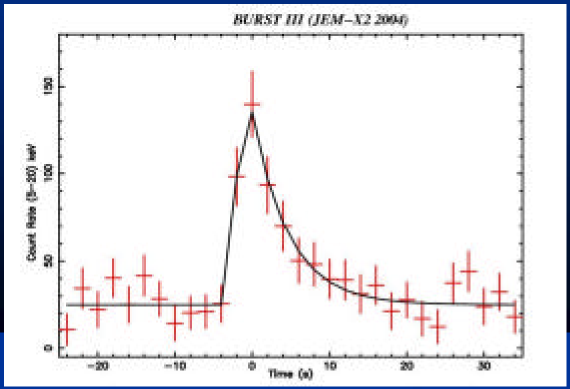


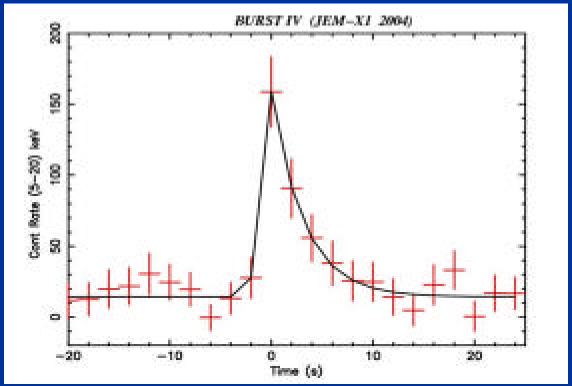
Need of simultaneous X-ray/radio observations.......

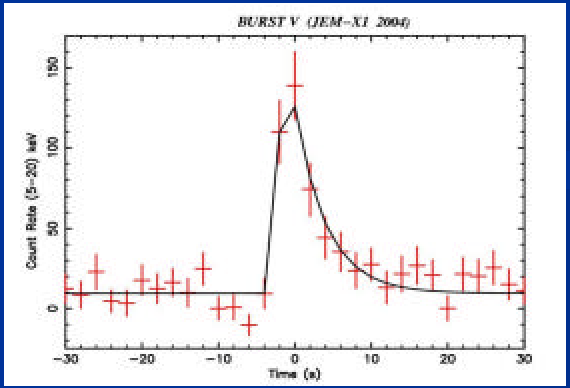
X-ray bursts

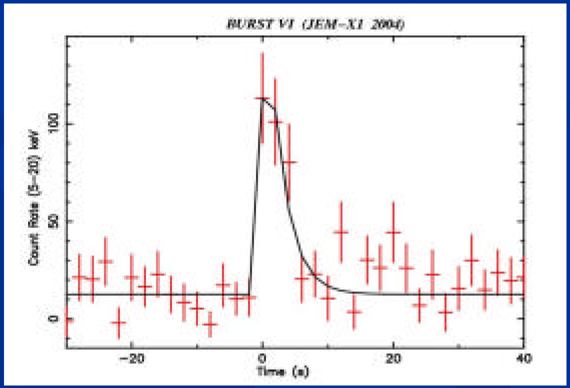












BURST model applied :

$$f(t) = \begin{cases} 0 & per \quad t < t_0; \\ N\frac{(t-t_0)}{(t_p-t_0)} & per \quad t_0 \leqslant t \leqslant t_p; \\ Ne^{\frac{-(t-t_p)}{\tau}} & per \quad t > t_p; \end{cases}$$