Supergiant Fast X-ray Transients with eXTP

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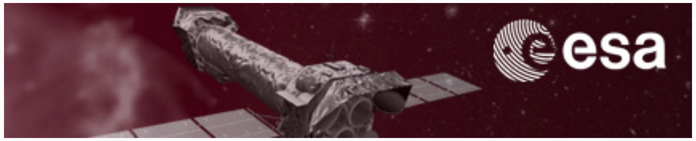
For Neil Gehrels
Captain of a tight but happy ship

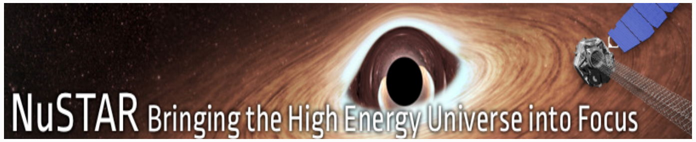
High Throughput X-ray Astronomy in the eXTP Era, Rome, Feb 6-8 2017

Outline

Observations of SFXTs

- Outbursts / bright flares
- Intermediate states
- Low states
- Emission/cyclotron lines
- Periods: Orbital, and Superorbital
- Periods: Spin

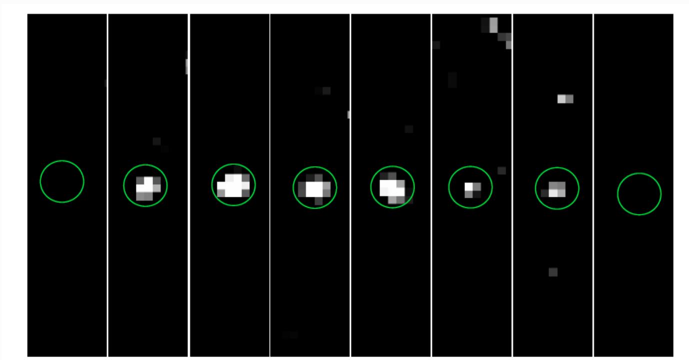




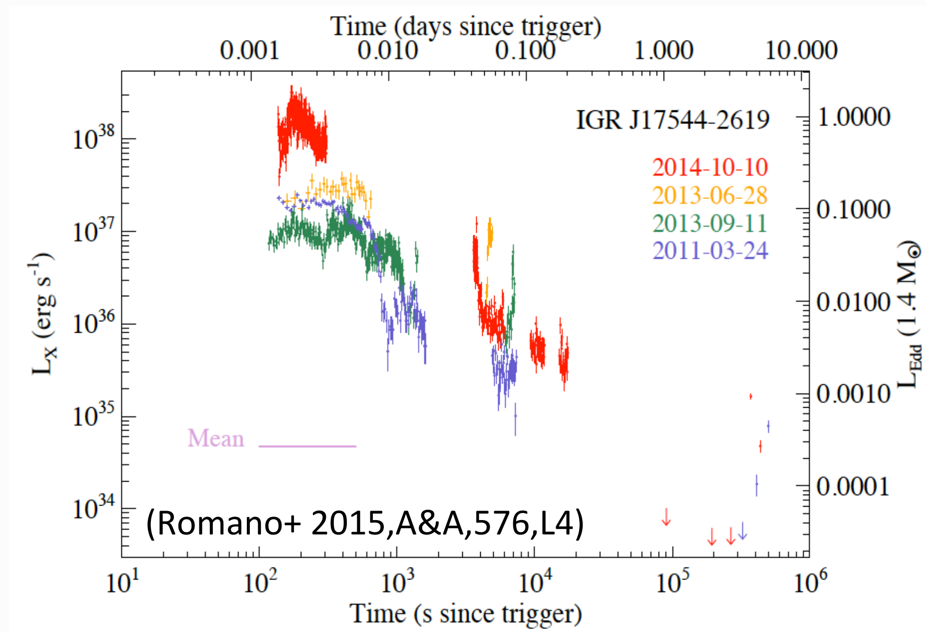
eXTP, with its combination of large collecting area and energy resolution in a wide energy band (0.2-50 keV) and large FoV will dramatically deepen the knowledge of SFXTs

SFXTs as fast hard transients

- Discovered by large area instruments (e.g. INTEGRAL/ ISGRI, Swift/BAT) – only >20 keV
  (see e.g., Sguera+ 2005, 2006, 2008; Grebenev+ 2007; Leyder+ 2007)



(Sguera+2005,A&A 444, 221)



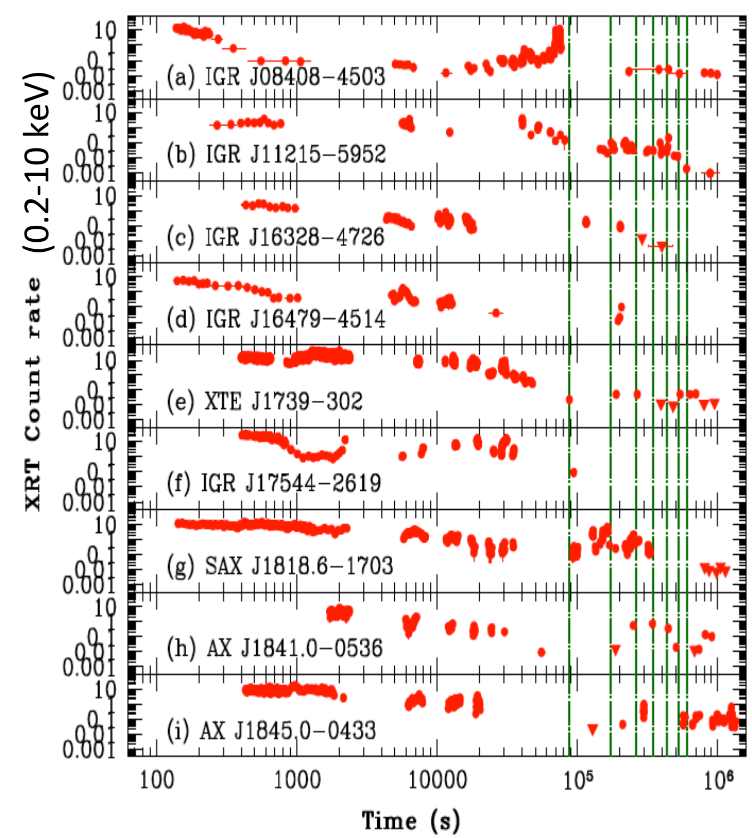
- flares peaking at 10^{36}-10^{38} erg s^{-1} (hr)
- spectrum during flare ~ accreting NS
- a few SFXTs are X-ray pulsars (P_{spin} < 10^3 s), probably NSs; P_{orb}~ 3-50 d
- large X-ray dynamic range (3-6 orders of magnitude)
- association with OB supergiant companions. Most emission from wind accretion.
- Sample: ~10 SFXTs, ~10 candidates

SFXTs as 'slower' soft transients

- Discovered by large area instruments (e.g. INTEGRAL/ ISGRI, *Swift*/BAT) – only >20 keV
  (see e.g., Sguera+ 2005, 2006,2008; Grebenev+ 2007; Leyder+2007)

(Romano, 2015, JHEAP,7,126)

- Fast follow-up by *Swift*/XRT revealed a rich phenomenology in the soft X-rays but
  XRT has low effective area and reduced timing capabilities
  to search for pulsations
  (Romano+ 2007—2016; Sidoli+ 2007—2009, Farinelli+2011)



SFXTs as hard to catch transients

- Discovered by large area instruments (e.g. INTEGRAL/ISGRI, *Swift*/BAT) – only >20 keV
  (see e.g., Sguera+ 2005, 2006,2008; Grebenev+ 2007; Leyder+2007)

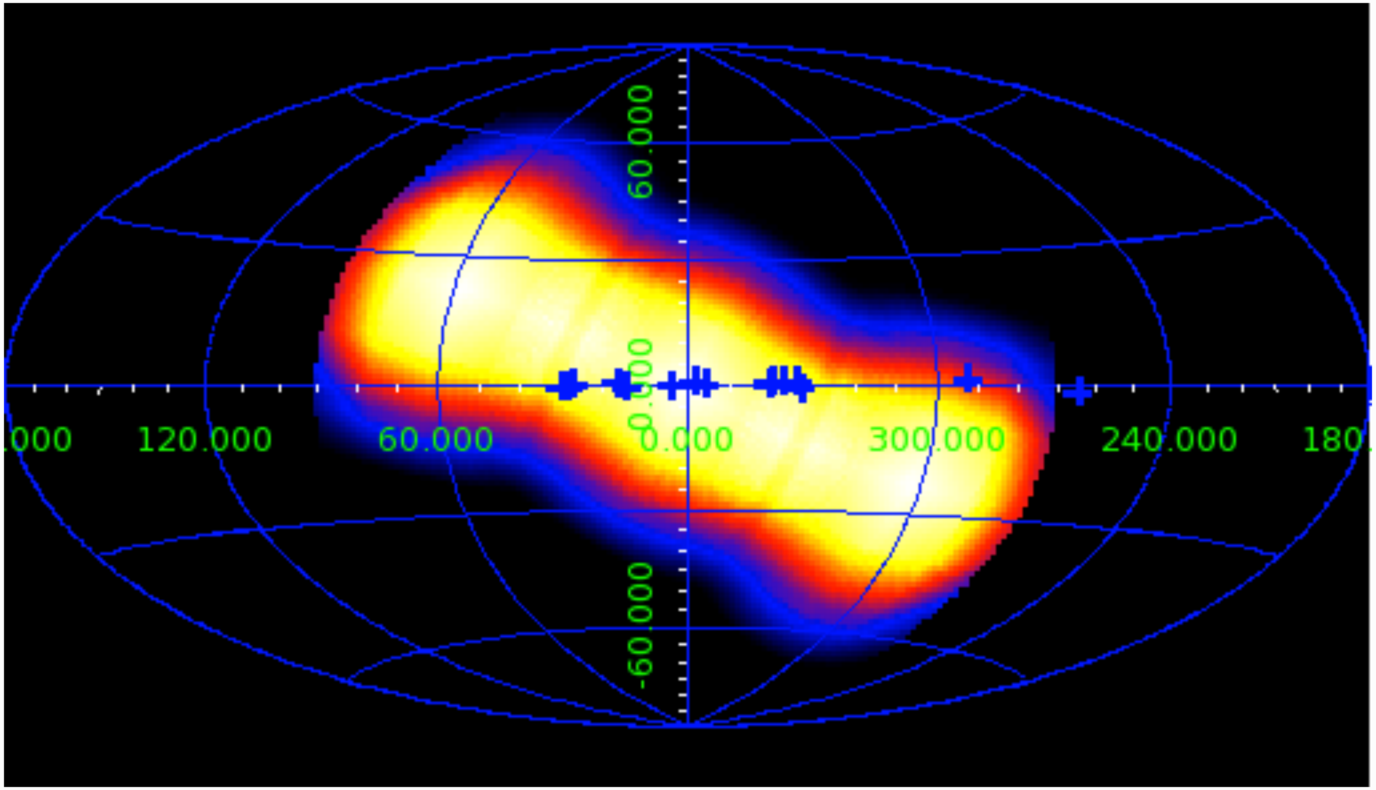
- Fast follow-up by *Swift*/XRT (0.2-10 keV), revealed a rich phenomenology in the soft X-rays but XRT has low effective area and reduced timing capabilities to search for pulsations
  (Romano+ 2007—2016; Sidoli+ 2007—2009;Farinelli+2011)

- Pointed observations by focusing instruments (*Chandra, Suzaku, XMM-Newton, NuSTAR*) significantly increased knowledge at <10 keV (iron lines, variable absorption, clumps, ionization...) but catching a bright flare requires extreme luck!
  (in't Zand 2005; Rumpy+ 2009; Bozzo+ 2011,Bhalerao+2015,Bozzo+2016)

What are the perspectives for SFXTs from eXTP?

SFXTs with WFM: monitoring

Chances to catch an outburst/bright flare with WFM?



photon-collecting area for a pointing toward the Galactic Center

WFM **monitoring**:
All SFXTs in one shot when pointing toward the Galactic center

SFXTs with WFM: flares

Predicted number of bright flares (in excess of 100 mCrab)
by using the *The 100-month Swift catalogue of SFXTs* (Romano+2014,A&A,562,A2)

NAME	3yr	5yr
IGRJ08408-4503	3	4
IGRJ16465-4507	0	1
IGRJ16479-4514	30	51
XTEJ1739-302	16	27
IGRJ17544-2619	14	22
SAXJ1818.6-1703	9	16
AXJ1841.0-0536	10	17
AXJ1845.0-0433	4	7
IGRJ18483-0311	13	23
IGRJ16328-4726	1	2
IGRJ16418-4532	6	11
total--------------	109	185

In 5 (3) years we can expect
>~ 185 (100) bright flares from known SFXTs

This is a **lower limit** because it is based on BAT

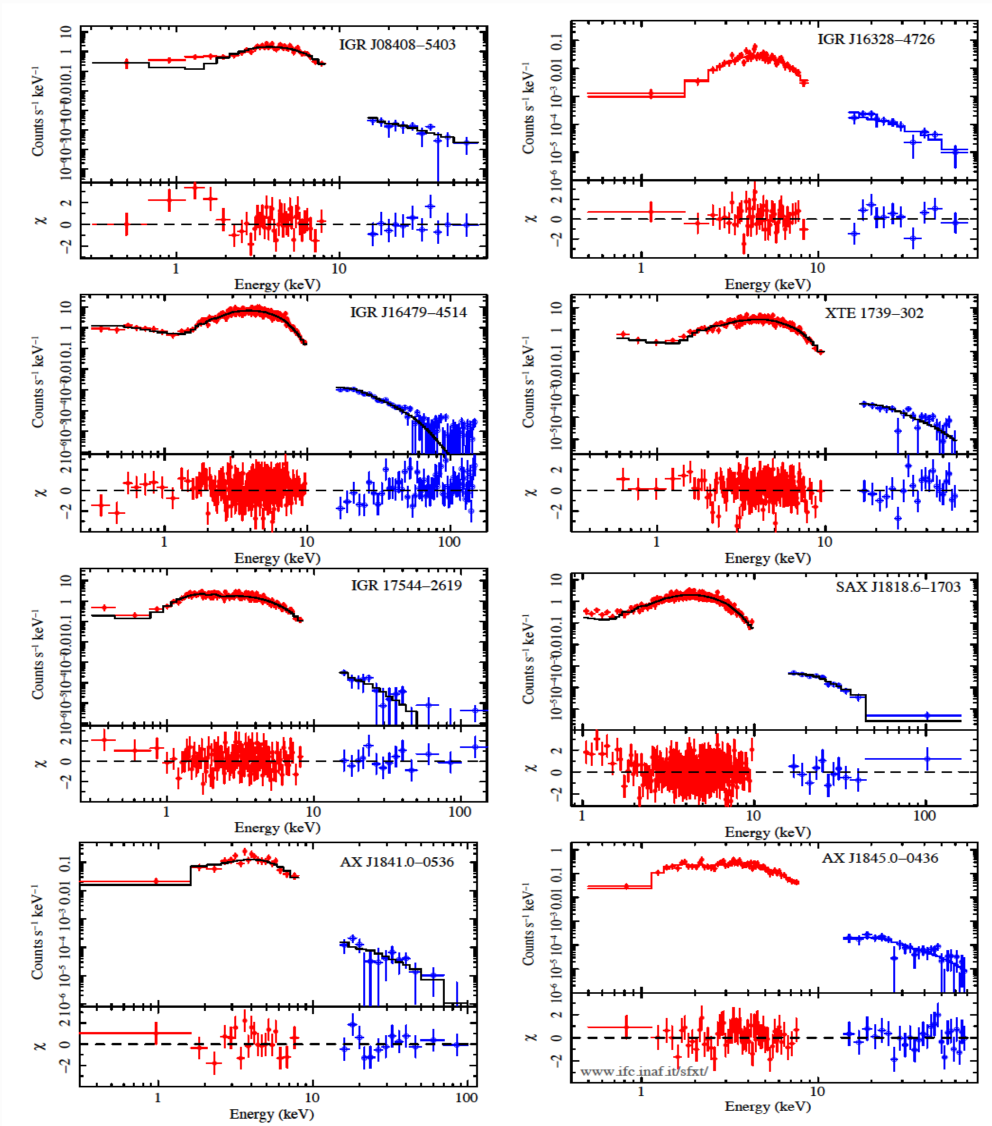
- which sensitivity is lower than the WFM
- the instantaneous FOV is smaller

And we expect to **discover** many more SFXTs!

Ducci+ 2014, A&A, 568, A76:
$N(SFXTs) = 37^{+53}_{-22}$

Swift observations of outbursts

Swift
Catching Gamma-Ray Bursts on the Fly



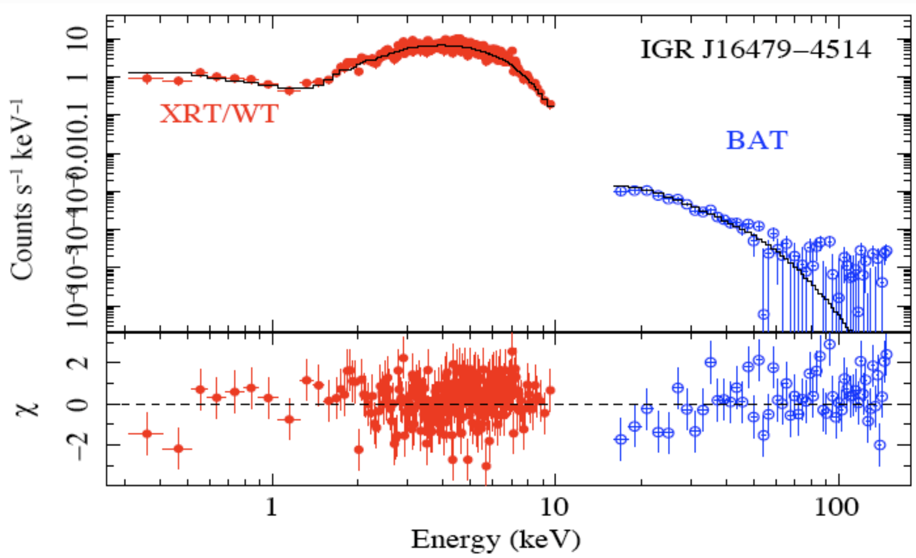
(Romano 2015, JHEAP, 7, 126)

Broad-band spectroscopy during outburst (XRT+BAT)
0.3-10 keV + 15-150 keV

✔absorption
& spectral cut-off

✔comparison with
models for accreting NS

Swift observations of outbursts



(Romano+2008,ApJ,680,L137)

Cutoff power-law model:

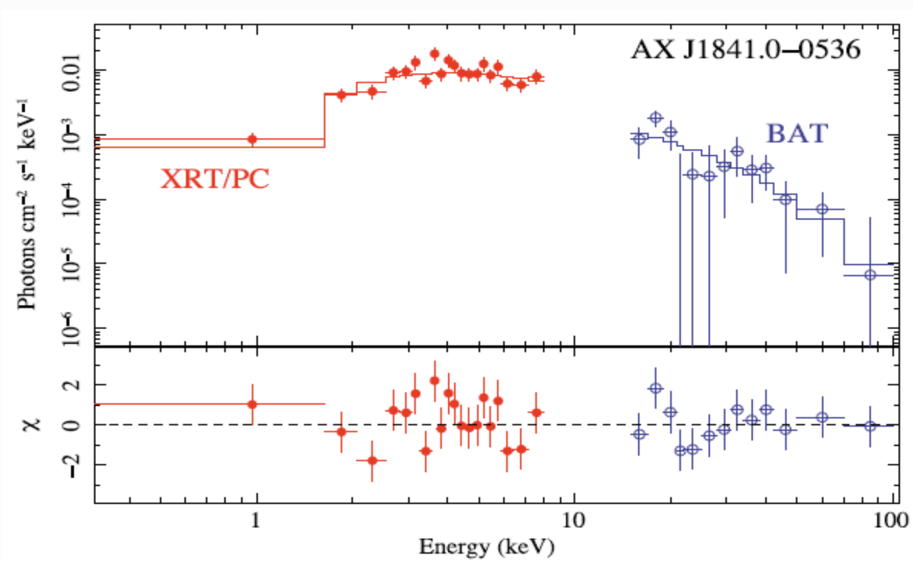
$N_H = 6.49517 \times 10^{22}$ cm^{-2}

Γ = 0.972905

E_c = 13.5007 keV

Norm = 0.961163

$Flux_{2\text{-}10keV} = 5.9 \times 10^{-9}$ erg cm^{-2} s^{-1}



(Romano+2011,MNRAS,412,L30)

Cutoff power-law model:

$N_H = 2.18897 \times 10^{22}$ cm^{-2}

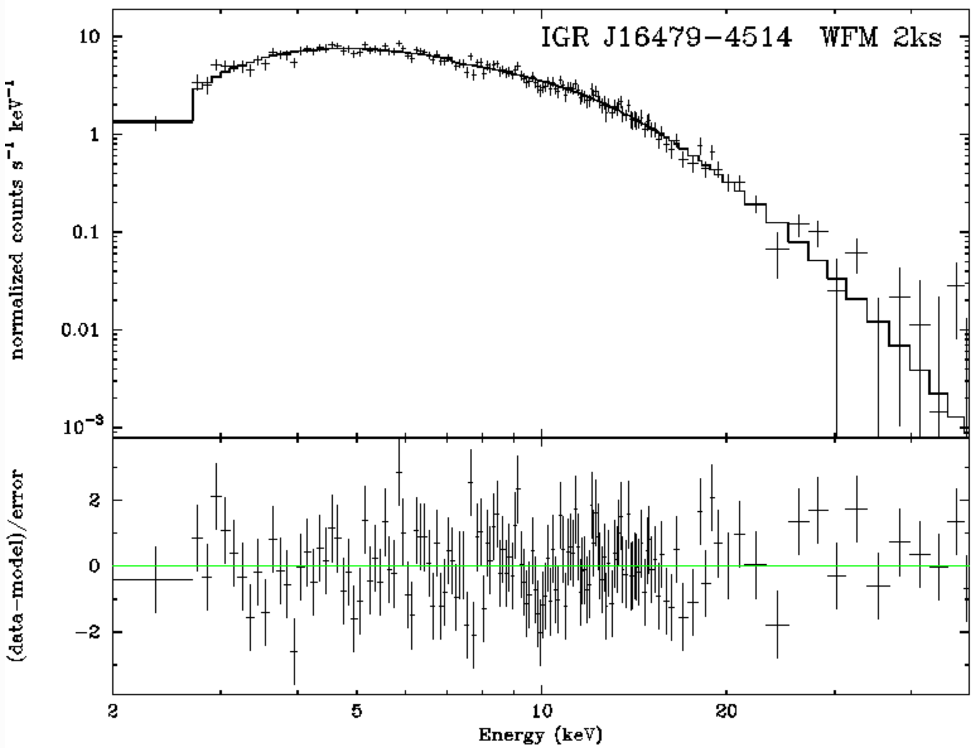
Γ = 0.221797

E_c = 16.289 keV

Norm = 1.79239E-02

$Flux_{2\text{-}10keV} = 5.5 \times 10^{-10}$ erg cm^{-2} s^{-1}

WFM simulations: outbursts



IGR J16479-4507 2ks WFM

Cutoff power-law model:

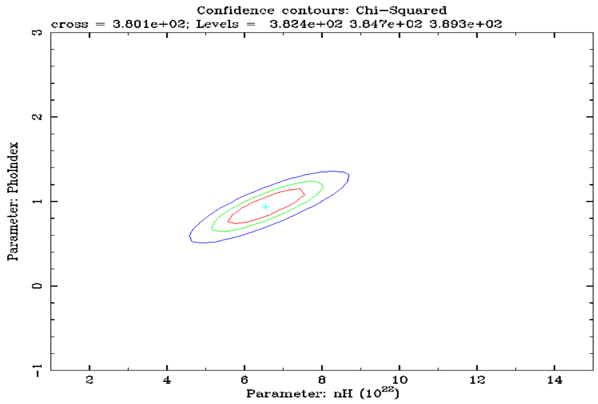
$N_H = 6.5 \times 10^{22}\ cm^{-2}$

$\Gamma = 0.98$

$E_c = 13.5$ keV

Norm = 0.961163

$Flux_{2\text{-}10keV}$ = **5.9×10^{-9}** $erg\ cm^{-2}\ s^{-1}$

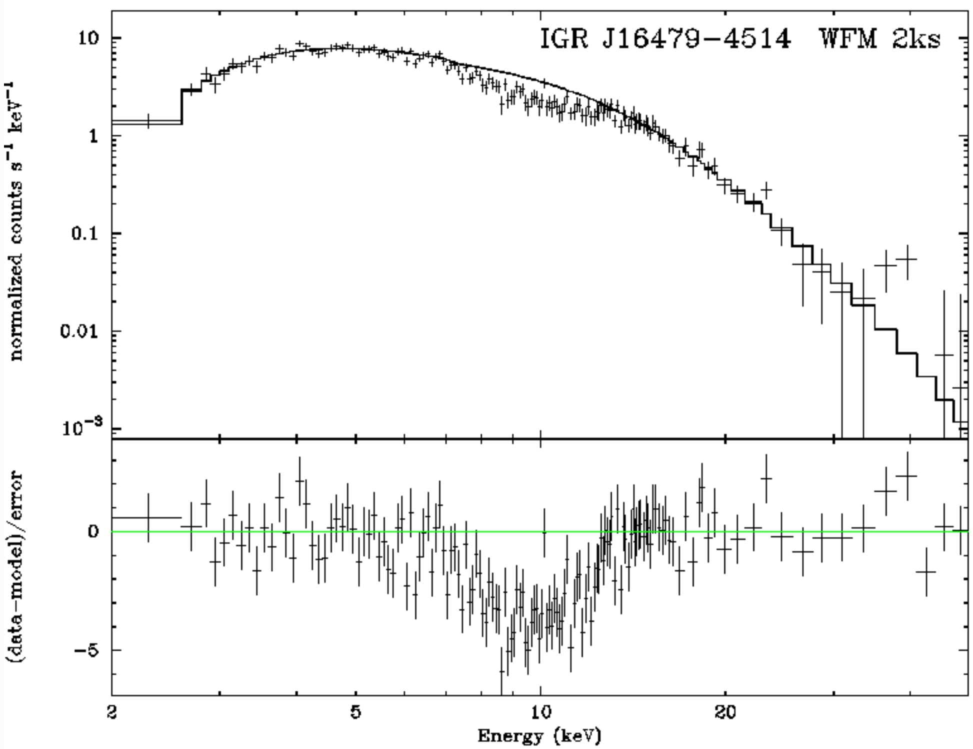


-$\Delta N_H/N_H$ within ~20% in 2ks

-$\Delta\Gamma/\Gamma$ within ~30% in 2ks

WFM allows to **follow the spectral evolution during the flare** (every few ks) with a good energy resolution and broad **UNINTERRUPTED** energy range

WFM simulations: outbursts +cyclotron lines



IGR J16479-4507 2ks WFM

Cutoff power-law model:

N_H = 6.5 x10^{22} cm^{-2}

Γ = 0.98

E_c =13.5 keV

Norm = 0.961163

$Flux_{2-10keV}$ = 5.9x10^{-9} erg cm^{-2} s^{-1}

E_{cycl} = 10 keV

σ = 1.5 keV

τ = 2

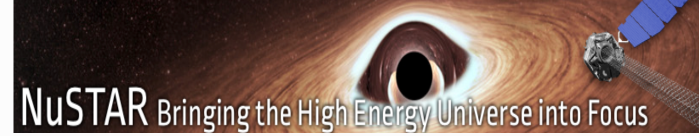
Very little is known on the SFXT magnetic field

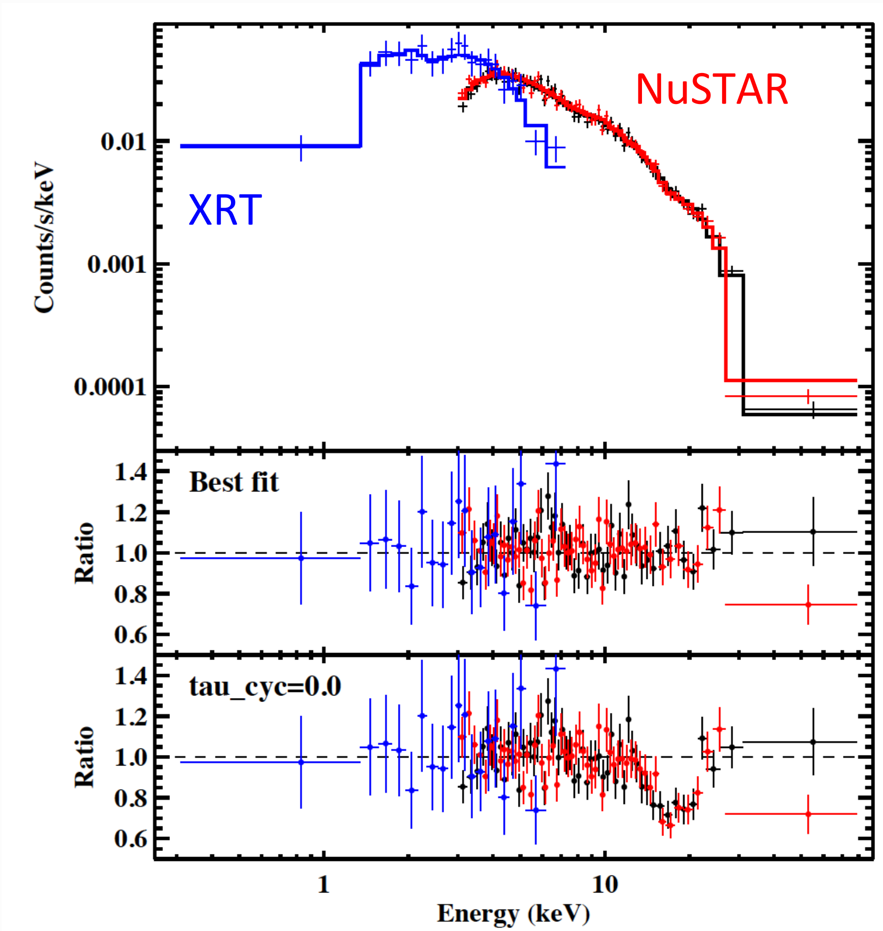
WFM might help investigating the presence of **cyclotron lines** that previously might have been undetected due to: - lack of energy coverage/instruments overlap

- poor spectral resolution
- too long integration times

WFM well suited to discover these features with integration times as low as 2ks

NuSTAR observations of a cyclotron line



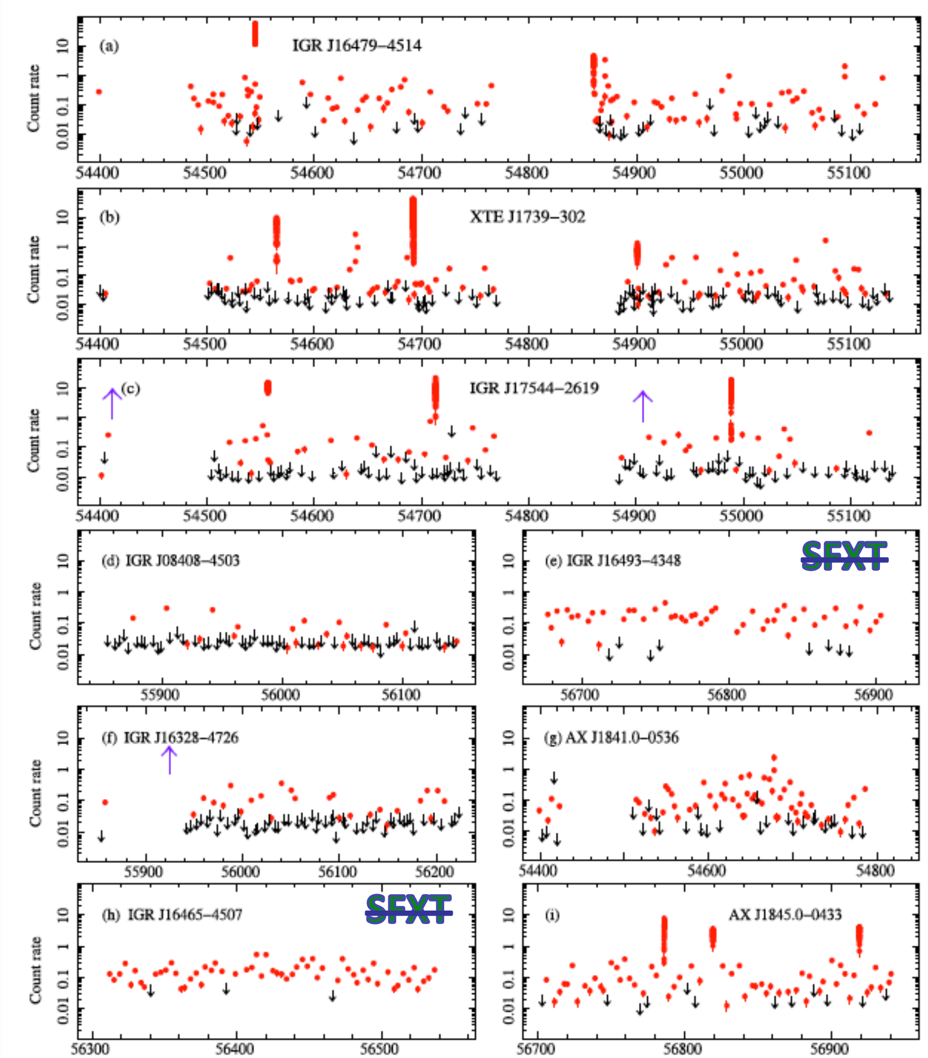


IGR J17544-2619
(Bhalerao+2015, MNRAS, 447,2274)

Joint fit to *NuSTAR* and *Swift*/XRT data with bbodyrad + nthcomp as continuum
$\mathrm{Flux}_{2\text{-}10\mathrm{keV}} = 1.3\times10^{-11}$ erg cm^{-2} s^{-1}

E_{cycl}=16.9 ± 0.3 keV
Width =1.7 ± 0.6 keV

Swift/XRT long term monitoring



MJD (Romano, 2015, JHEAP,7,126)

Daily resolution

- Bright outbursts
- Dynamical range: 4-5 orders of magnitude (excl. 16465 and 16493, non SFXTs)
- **Emission outside of outbursts**
- variability:
  days to months

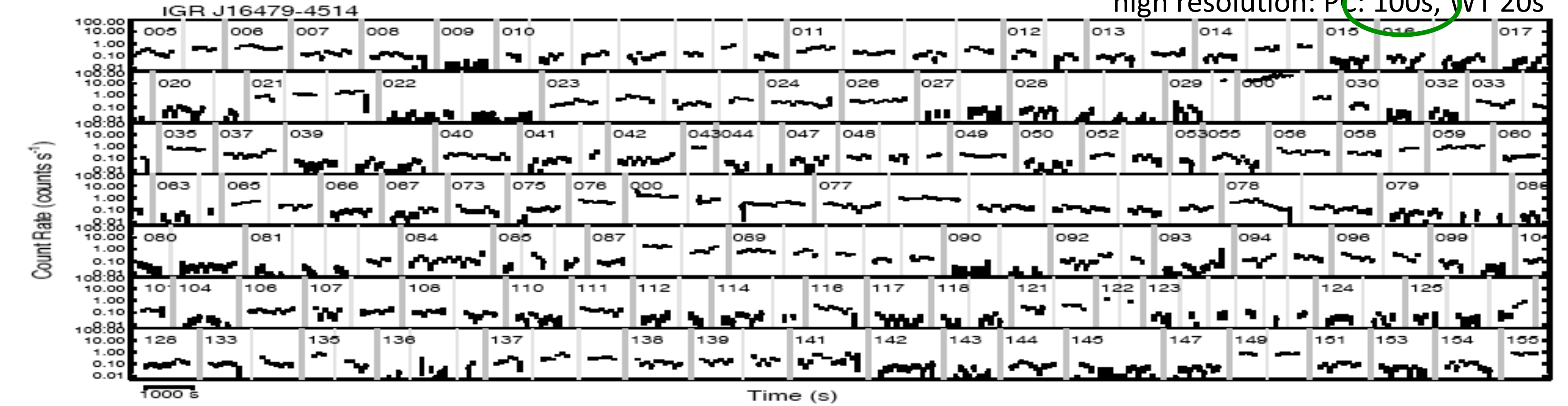
Minute resolution

- Variability observed on all timescales and intensity levels
- Short timescales 1 order of mag. (1 ks, down to 0.1cps)
- Evidence for clumps

Swift/XRT detailed light curves

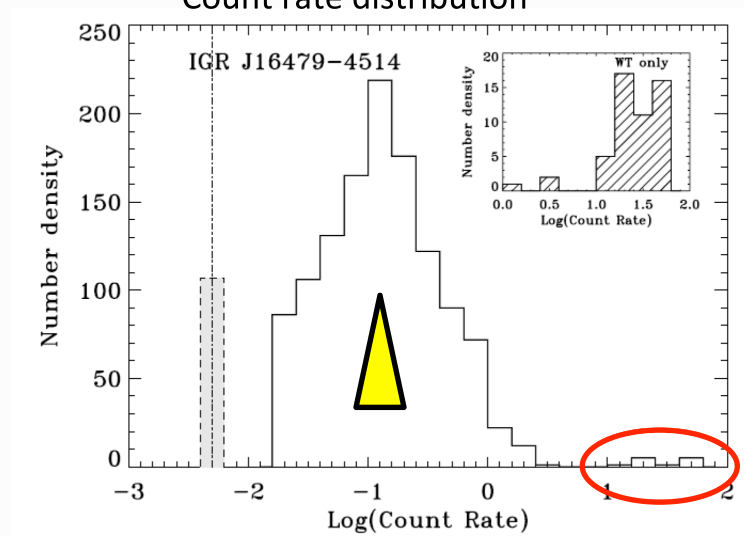
(Romano+2011,MNRAS,410,1825)

high resolution: PC: 100s, WT 20s



- ✔3-5% of time spent in bright outbursts
- ✔variability observed on all timescales and intensity levels
- ✔short timescales 1 order of magnitude (1 ks, down to 0.1 counts s^{-1})
- **✔Most probable 2-10 keV observed flux: $1\text{-}3\times10^{-11}$ erg cm^{-2} s^{-1}**
- ✔ long term behaviour is intermediate state of accretion L~$10^{33} – 10^{34}$ erg s^{-1}

Count rate distribution



XRT and XMM-Newton states

(Romano+2009,MNRAS,399,2021; 2011,MNRAS, 410,1825)

Table 8. XRT spectroscopy of the three SFXTs (2007–2009 data set).

Name Absorbed power law	Spectrum	Rate (counts s^{-1})	N_H (10^{22} cm^{-2})	Parameter Γ	Flux[a] (2–10 keV)	Luminosity[b] (2–10 keV)	χ^2_ν/d.o.f.[c] C-stat (per cent)
IGR J16479−4514	High	>0.55	$8.2^{+0.8}_{-0.7}$	$1.1^{+0.2}_{-0.2}$	120	5	1.2/193
	Medium	[0.22–0.55[	$8.6^{+0.8}_{-0.8}$	$1.3^{+0.2}_{-0.2}$	53	2	0.9/197
	Low	[0.06–0.22[	$7.1^{+0.6}_{-0.6}$	$1.4^{+0.2}_{-0.1}$	17	0.7	1.0/205
	Very low[d]	<0.06	$3.3^{+0.4}_{-0.0}$	$1.8^{+0.3}_{-0.2}$	1.3	0.04	302.5(99.5)
XTE J1739−302	High	>0.405	$3.7^{+0.5}_{-0.4}$	$0.8^{+0.2}_{-0.1}$	120	1	1.0/160
	Medium	[0.07–0.405[	$3.8^{+0.4}_{-0.4}$	$1.4^{+0.1}_{-0.1}$	18	0.2	0.9/164
	Very low[d]	<0.07	$1.7^{+0.1}_{-0.0}$	$1.4^{+0.2}_{-0.2}$	0.5	0.004	321.9(98.6)
IGR J17544−2619	High	>0.25	$1.9^{+0.3}_{-0.2}$	$1.3^{+0.1}_{-0.1}$	46	0.8	1.0/118
	Medium	[0.07–0.25[	$2.3^{+0.3}_{-0.3}$	$1.7^{+0.2}_{-0.2}$	14	0.3	1.0/108
	Very low[d]	<0.07	$1.1^{+0.1}_{-0.0}$	$2.1^{+0.2}_{-0.2}$	0.2	0.003	183.1(85.1)

1.2×10^{-10}

1.3×10^{-12}

5×10^{-13}

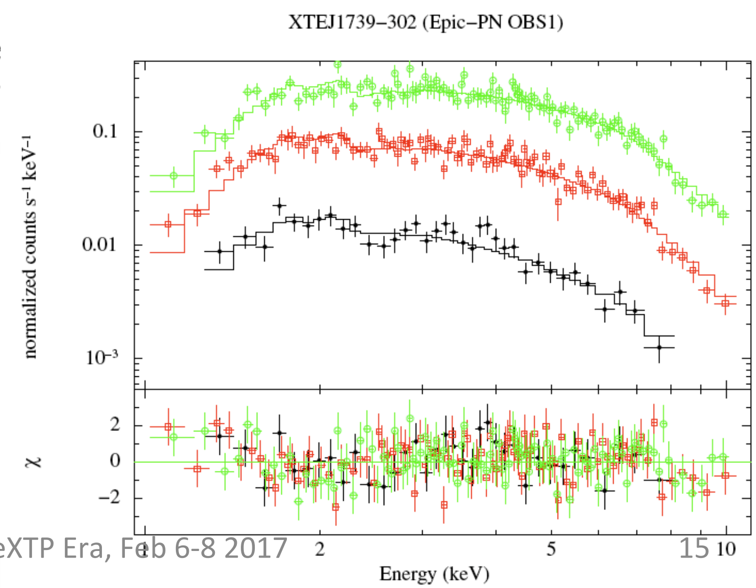
[a]Average observed 2–10 keV fluxes in units of 10^{-12} erg cm^{-2} s^{-1}.
[b]Average 2–10 keV X-ray luminosities in units of 10^{35} erg s^{-1} calculated adopting distance
[c]Reduced χ^2 and d.o.f., or C-stat and percentage of realizations (10^4 trials) with statistic >
[d]Fit performed with the constrained column density (see Section 6).

(Bozzo+2010, A&A, 519,A6)

	OBS1			OBS2		
cts/s	<0.1	0.1–0.4	>0.4	<0.1	0.1–0.4	>0.4
N_H[a]	$2.9^{+0.5}_{-0.6}$	2.7 ± 0.3	2.6 ± 0.3	$4.1^{+0.7}_{-0.6}$	$3.2^{+0.3}_{-0.2}$	3.5 ± 0.4
Γ	1.8 ± 0.3	1.4 ± 0.1	1.1 ± 0.1	1.8 ± 0.3	1.2 ± 0.1	1.0 ± 0.1
F_{obs}[b]	$4.7^{+0.9}_{-3.2}$	$32.2^{+3.4}_{-7.1}$	$123.8^{+10.0}_{-20.7}$	$9.3^{+1.2}_{-6.9}$	$42.0^{+4.5}_{-7.6}$	$153.6^{+13.7}_{-26.5}$
χ^2_{red}	1.08	1.11	1.00	0.74	1.04	1.00
d.o.f.	33	93	105	34	132	89
EXP.[c]	18	10	3	10	11	2

Notes. The model used to fit the data is an absorbed CUTOFFPL (we fixed the cutoff energy at 13 keV, see text for details). [(a)] in units of 10^{22} cm^{-2}. [(b)] Observed flux in the 0.5–10 keV energy band in units of 10^{-13} erg cm^{-2} s^{-1}. [(c)] Exposure time in ks.

5×10^{-13}



SFXTs with WFM: High/Intermediate/low states

WFM Exposure times required for a 5 σ detection in the different states
(in Romano+2009, 2011, by scaling sensitivity of the WFM)

State	High (not flare) (ks)		Med state (ks)		Low state (ks)	
IGR J16479-4507	3.3	1.2×10^{-10}	16.0	5.7×10^{-11}	161	1.7×10^{-11}
XTE 1739-302	4.8	1.2×10^{-10}	210.	1.8×10^{-11}	-	1.3×10^{-13}
IGR J18410-0435	12.4		59.0		543	
IGR J17544-2619	42.5		412.		-	

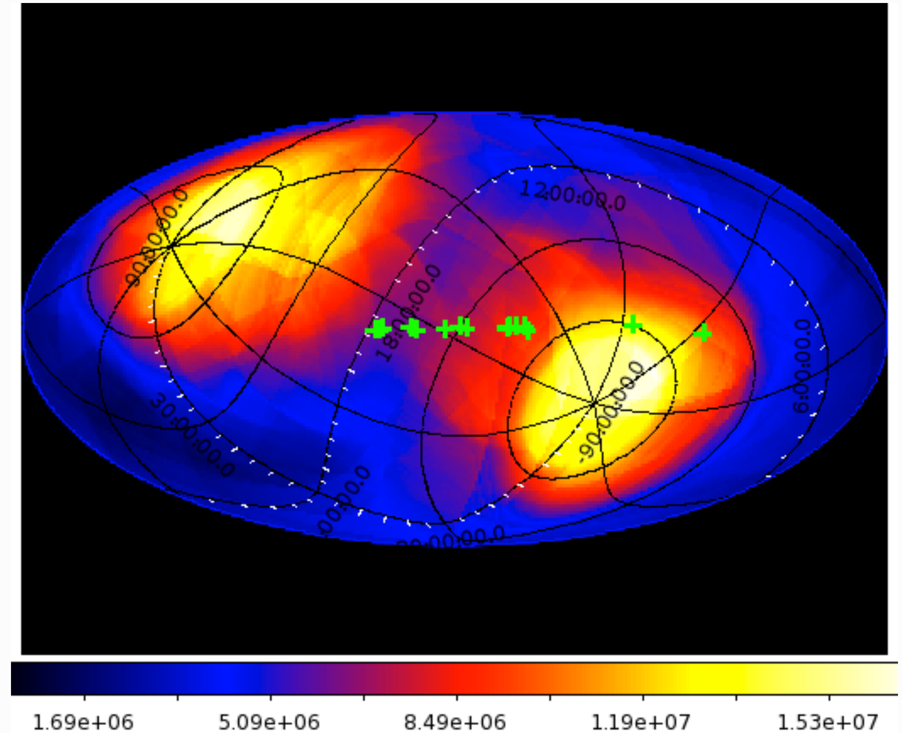
We expect to have up to **several detections per day** per object
A very good monitoring of these objects "for free"!

WFM → ~**daily broad band monitoring** of all SFXTs
→ Determination of **Orbital and Superorbital periods**

SFXTs with WFM: low states

WFM limiting fluxes for a 5 σ detection

NAME	Expo (5yr,s)	Limit Flux (5yrs, erg/cm^2/s)
IGR J08408-4503	5.5E7	2.6E-12
IGR J11215-5952	6.5E7	2.4E-12
IGR J16465-4507	4.2E7	3.0E-12
IGR J16479-4514	4.2E7	3.0E-12
XTE J1739-302	3.6E7	3.2E-12
IGR J17544-2619	3.5E7	3.2E-12
SAX J1818.6-1703	3.1E7	3.4E-12
AX J1841.0-0536	3.1E7	3.5E-12
AX J1845.0-0433	3.0E7	3.5E-12
IGR J18483-0311	3.0E7	3.5E-12
IGR J16195-4945	4.4E7	2.9E-12
IGR J16207-5129	4.5E7	2.9E-12
IGR J16328-4726	4.2E7	3.0E-12
IGR J16418-4532	4.2E7	3.0E-12
IGR J17354-3255	3.7E7	3.2E-12
AX J1820.5-1434	3.1E7	3.5E-12



- 1yr exposure map
- sample of expected pointings (RXTE program)
- Pointing constraints (Sun, thermal, orbital)

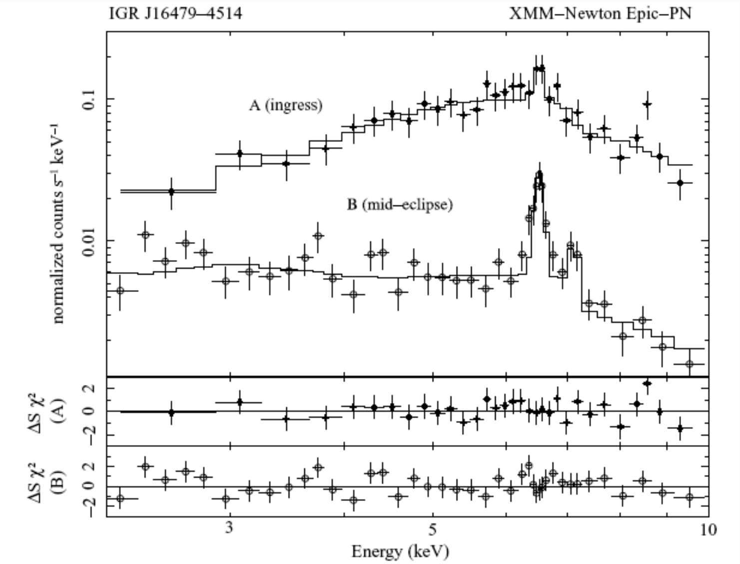
WFM → throughout the mission **WFM can probe** SFXT states down to a few **$\sim 3\times10^{-12}$ erg cm^{-2} s^{-1}** luminosities of **$L\sim10^{32}$ erg s^{-1}** ~ quiescence

WFM simulations summary

SFXT with WFM

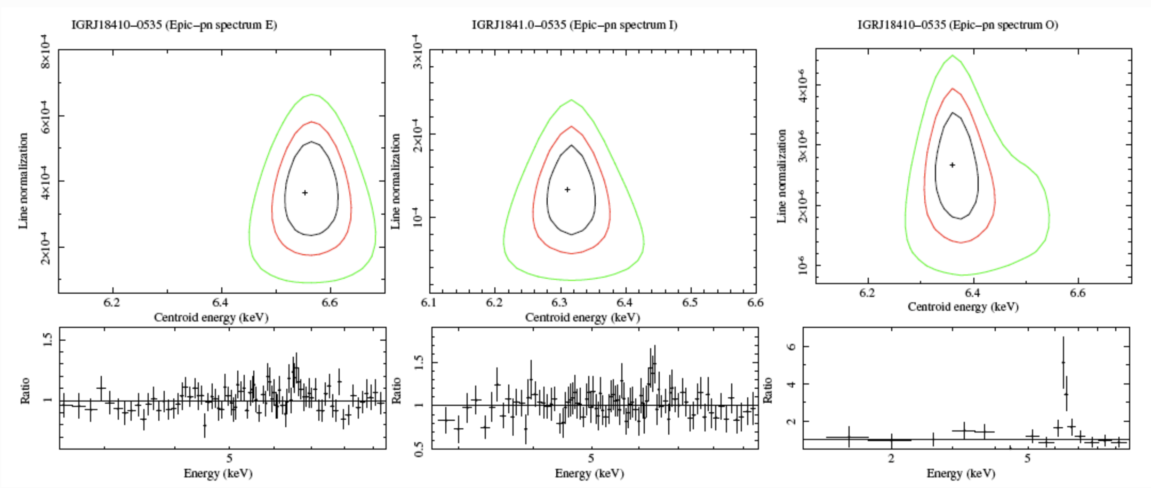
- **ideal to catch (110-185) short bright outbursts** that reach $Flux_{2\text{-}10keV} \sim 6\times10^{-9}$ erg cm^{-2} s^{-1}
  - $\Delta N_H/N_H$ and $\Delta\Gamma/\Gamma$ within ~30% in 2ks
  - Comparable with *Swift*/XRT
- intermediate short flares $Flux_{2\text{-}10keV} \sim 10^{-9}$ erg cm^{-2} s^{-1}
  - $\Delta N_H/N_H$ and $\Delta\Gamma/\Gamma$ ~50% in >=5ks
- difficult below $Flux_{2\text{-}10keV} \sim 10^{-9}$ erg cm^{-2} s^{-1} (since outburst lasts ≤ 5ks) but
- Can offer ~**daily broad band monitoring** of all SFXTs
  - P_{orb} & $P_{superorb}$
- **throughout the mission** WFM can probe SFXT states down to a few **~3x10^{-12} erg cm^{-2} s^{-1}** or **L~10^{32} erg s^{-1}** ~ quiescence

Lines in SFXTs



IGR J16479-4514 in eclipse
(Bozzo+2008, MNRAS,391,L108)

N_H = 35.2461 x10^{22} cm^{-2}
Γ = 0.98
Norm = 0.002
KαNorm=4.62569 x10^{-5}
$Flux_{2\text{-}10keV}$ = 1x10^{-11} erg cm^{-2} s^{-1}

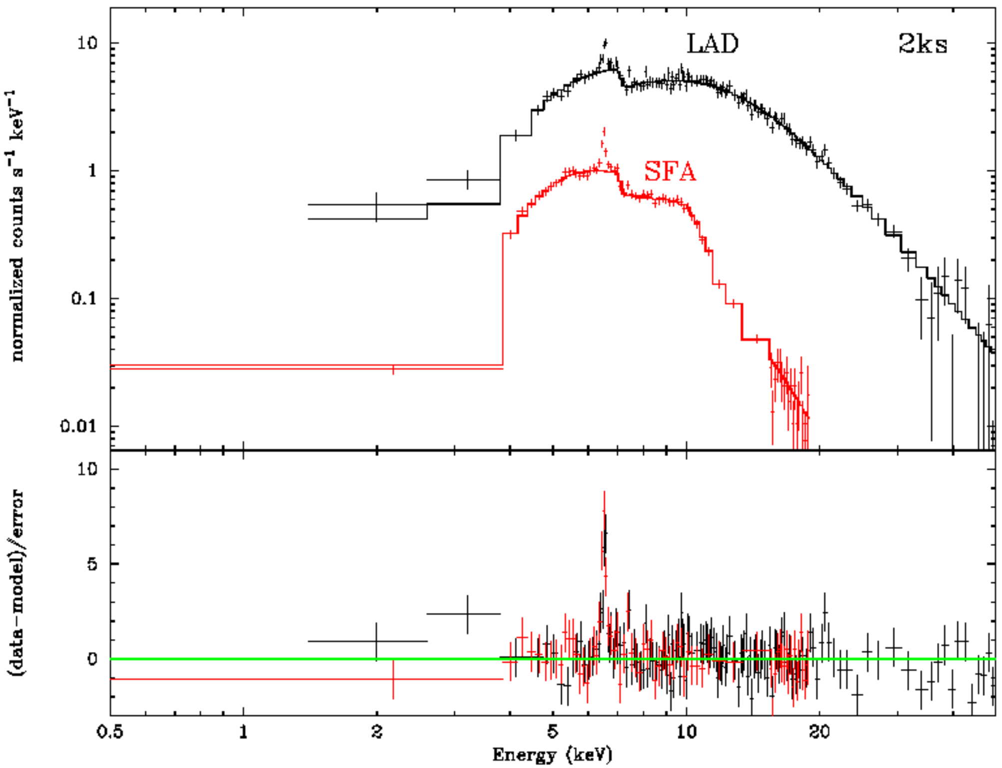


AX J1841-0536 clump ingestion
(Bozzo+2011, A&A,531,A130)

N_H = 10.9191 x10^{22} cm^{-2}
Γ =1.08471
Norm = 0.04666
KαNorm=2x10^{-4}
$Flux_{2\text{-}10keV}$ = 3.2x10^{-10} erg cm^{-2} s^{-1}

LAD + SFA simulations: SFXT lines 1 (eclipse)

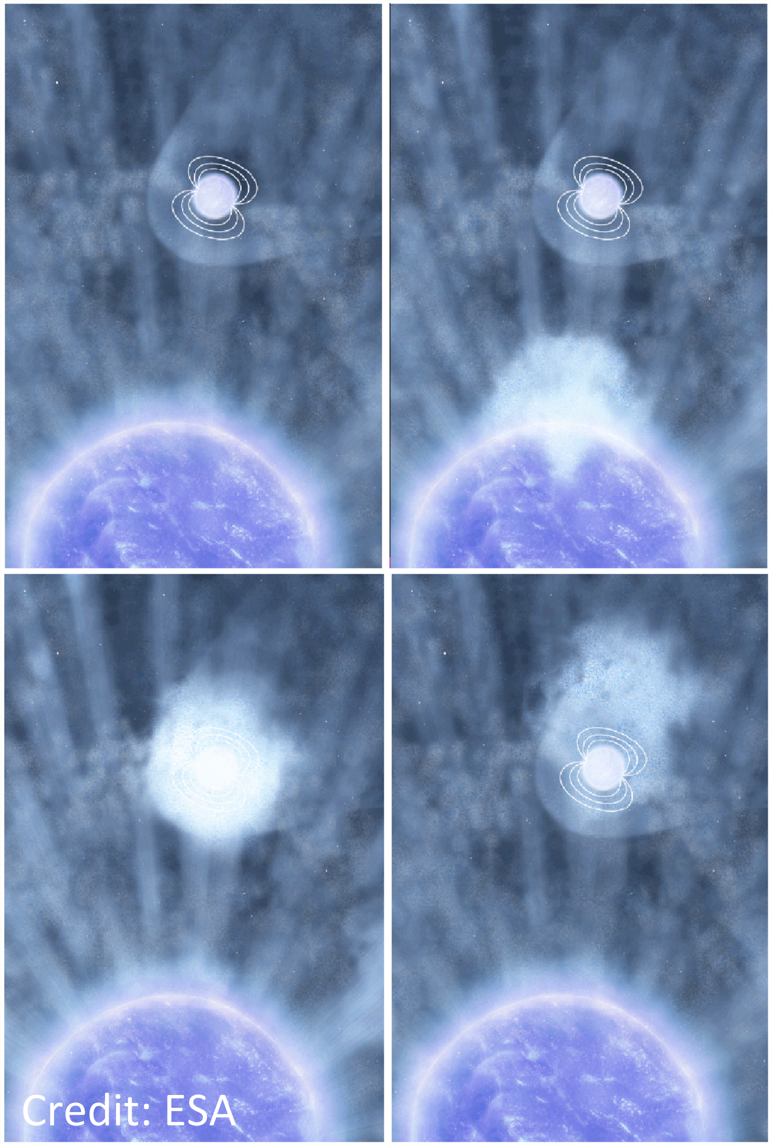
IGR J16479-4507 during an eclipse



IGR J16479-4507 2ks WFM
during eclipse
N_H = 35 x10^{22} cm^{-2}
Γ = 0.98
Norm=2x10^{-3}
KαNorm=4.6 x10^{-5}
$Flux_{2\text{-}10keV}$ = 1x10^{-11} erg cm^{-2} s^{-1}

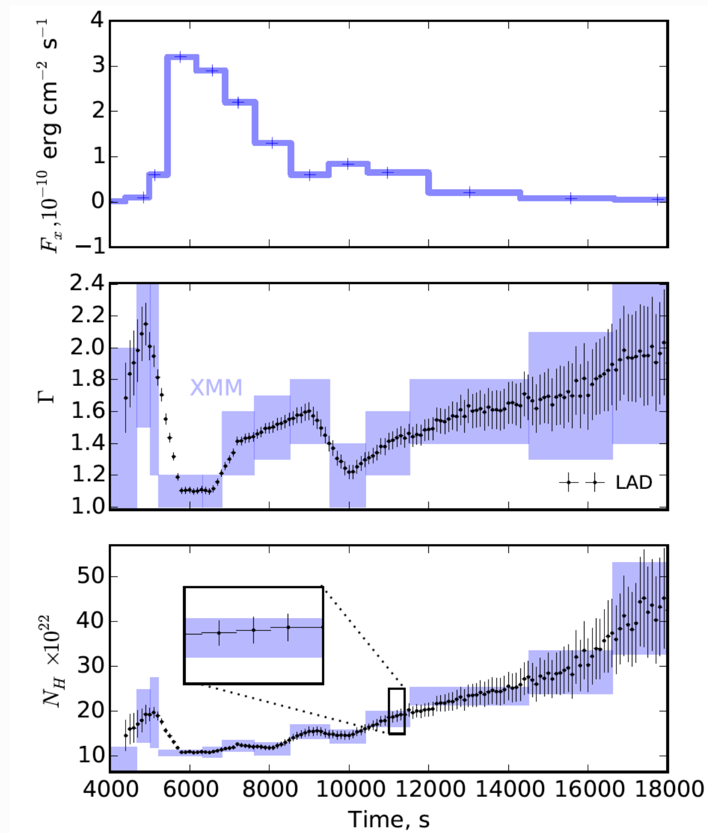
emission lines can be recovered quite nicely in **1-2 ks**
NB: Iron line as measured by XMM-Newton in 2008 in 28 ks

Lines in SFXTs



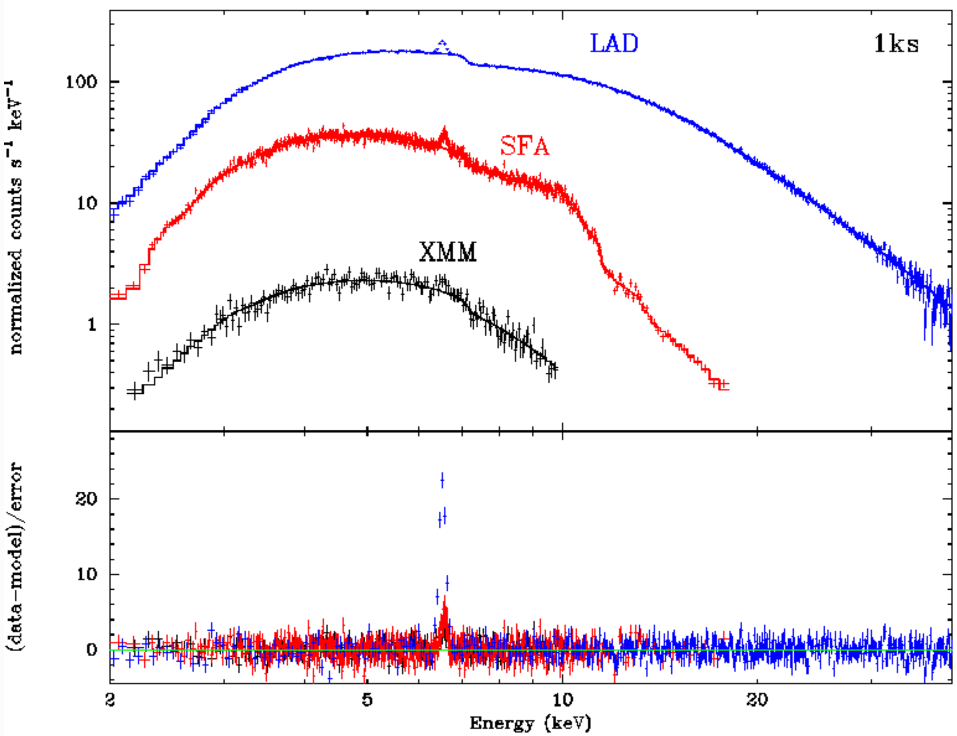
AX J1841-0536
(Bozzo+2011, A&A,531,A130)

Ingestion of a massive clump of matter by the neutron star



LAD + SFA simulations: SFXT lines 2

AX J1841-0536 during clump ingestion



AX J1841-0536 1ks LAD & SFA

N_H = 10.9191 x10^{22} cm^{-2}

Γ =1.08471

Norm = 0.04666

KαNorm=2x10^{-4}

$Flux_{2-10keV}$ = 3.2x10^{-10} erg cm^{-2} s^{-1}

emission lines can be recovered quite nicely in **1 ks** and can probe clump material ionized by the high X-ray flux

NB: compare with 1ks of XMM-Newton

eXTP

- WFM will detect hundreds of outbursts that can be studied in depth and +broad-band spectra (FOR FREE!)
- WFM will provide daily monitoring (+broad-band spectra) for bright and intermediate states (P_{orb} and $P_{superorb}$) (FOR FREE!)

- LAD & SFA fine time-resolved spectroscopy of pointed (or periodic) sources with unprecedented detail and on typical variability timescales
- Unprecedented capabilities of detecting pulsations (P_{spin})

Thanks!

Swift SFXT Project
www.ifc.inaf.it/sfxt/

Contact point
patrizia.romano@brera.inaf.it

Facebook Group
www.facebook.com/groups/sfxts/