The *Swift* Supergiant Fast X-ray Transient Project

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For Neil Gehrels
Captain of a tight but happy ship

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Outline

- **SFXTs and classical SG-HMXBs**

- **Long-term monitoring** results of 17 sources
    - out of outburst: dynamical range
    - Inactivity Duty Cycle
    - Differential and Cumulative Luminosity Distributions

- **Outbursts and follow-ups**
    - true dynamical range
    - outburst mechanisms ?
    - Giant outburst of IGR J17544-2619 (2014-10-10)

- **The 100-month Swift catalogue of SXFTs**
    -perspectives for future missions

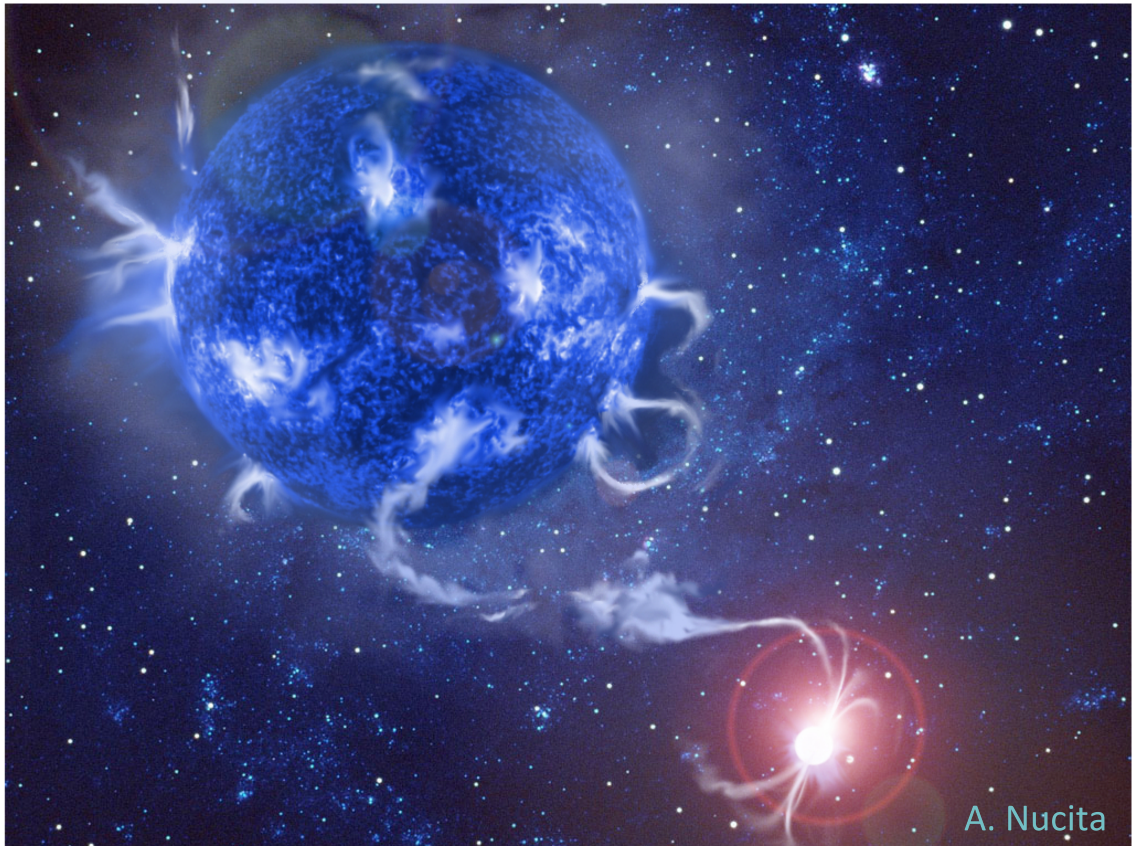
SFXTs

- HMXBs with OB SG companions

  $V_\infty \sim 1000\text{-}3000$ km s^{-1}

  $\dot{M}_W \sim 10^{-6}\text{–}10^{-5}\ M_\odot\ \mathrm{yr}^{-1}$

- hard X-ray outbursts (Smith+ 2004, Sguera+ 2005, Negueruela+ 2006)
  - lasting 0.5-few hours
  - luminosity increases by 3-5 orders of mag (up to ~ 10^{37} erg s^{-1}) cfr. classical 10-50



- spectra ~ NS HMXBs (absorbed power laws with exponential cutoffs)
- some pulsars (Pspin < 10^3 s), probably NSs; P_{orb} ~ 3-50d
- Most emission from wind accretion

Sample: ~10 SFXTs, ~10 candidates

The *Swift* campaigns

<u>monitor long term properties with XRT **(soft X-ray)**</u>

2 or 3 obs /source/week, 1 ks each (several campaigns)

<u>catch outbursts</u> & follow them until source undetected

IGR J16479-4514	144 obs/160 ks (2007-2009)	Sidoli+ 2008 (ApJ,687,1230)
XTE J1739-302	184 obs/206 ks (2007-2009)	Romano+ 2008 (ApJ,680,L137)
IGR J17544-2619	142 obs/143 ks (2007-2009)	Sidoli+ 2008 (ApJ,690,120)
AX J1841.0-0536	88 obs/97 ks (2007-2008)	Romano+ 2009c (MNRAS,399,2021)
		Romano+ 2011a (MNRAS,410,1825)

✔<u>BAT Special Functions</u> SFXTs as slewable-to sources (arcsecond localizations)

Long term behaviour usually studied with coded mask large FOV hard X-ray monitors (Integral/IBIS & Swift/BAT)

(The 100-month *Swift* Catalogue of SFXTs Romano+2014a,A&A,562,A2)

only catch the brightest portion of any transient event

The *Swift* campaigns

monitor long term properties with XRT **(soft X-ray)**

2 or 3 obs /source/week, 1 ks each (several campaigns)

catch outbursts & investigate relationship with classical systems

Source	Observations	Years	Reference
IGR J16479-4514	144 obs/160 ks	(2007-2009)	Sidoli+ 2008 (ApJ,687,1230)
XTE J1739-302	184 obs/206 ks	(2007-2009)	Romano+ 2008 (ApJ,680,L137)
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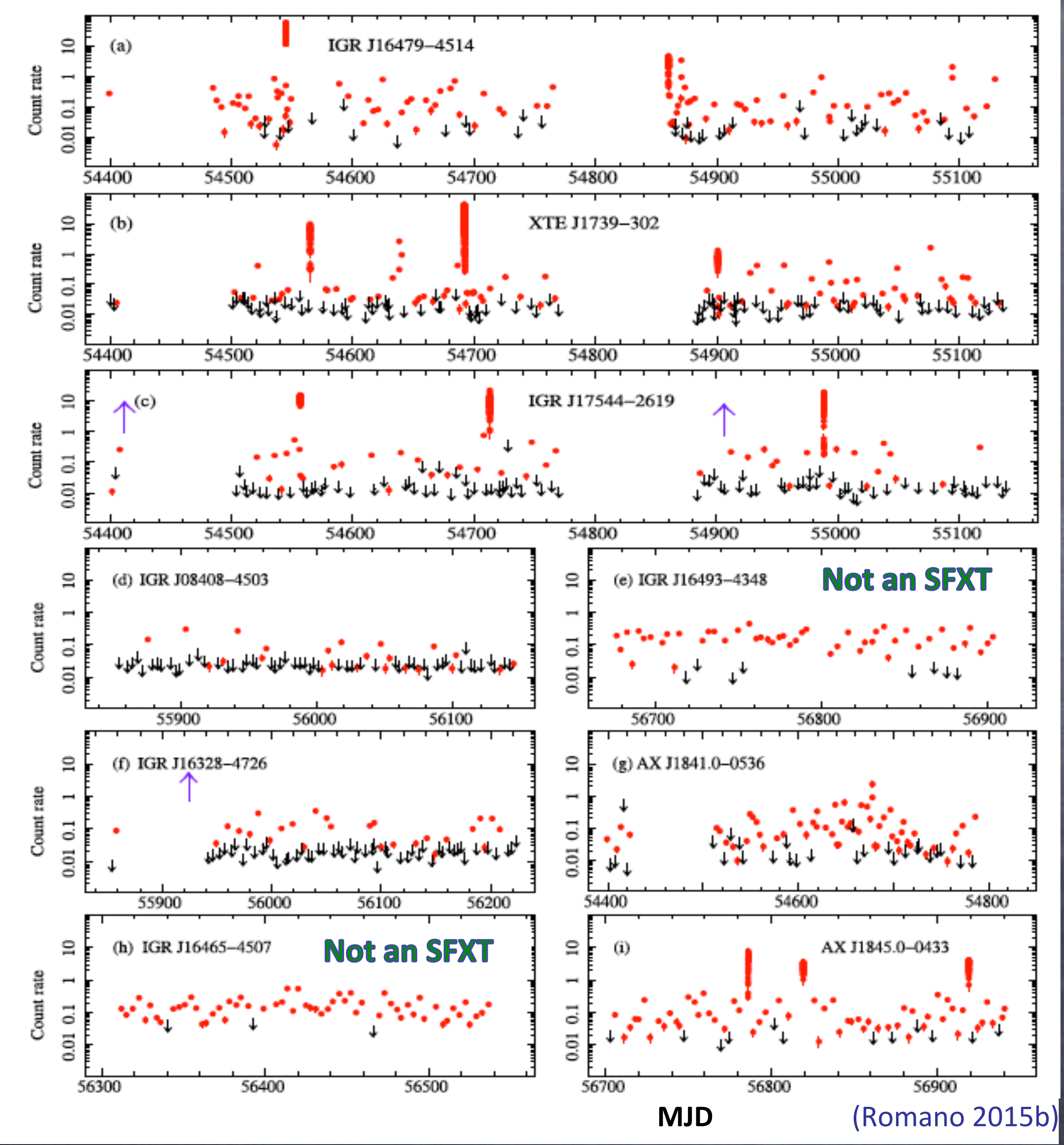
			Romano+ 2011a (MNRAS,410,1825)
IGR J08408-4503	82 obs/74 ks	(2011-2012)	Romano+ 2013 (AdvSpRes, 52, 1593)
IGR J16328-4726	98 obs/88 ks	(2011-2014)	Romano+ 2014b (A&A,568,A55)
IGR J16465-4507	65 obs/57 ks	(2013)	Romano+ 2014c (A&A,572,A97)
IGR J16493-4348	65 obs/53 ks	(2014)	Bozzo+2015 (AdvSpRes, 55, 1255)
AX J1845.0-0433	80 obs/69 ks	(2014)	Romano 2015b (JHEAp,7,126)
IGR J18462−0223	80 obs/69 ks	(2015, WIP)	
IGR J18175−2419	20 obs/20 ks	(2016)	Romano+ 2016, (A&A,593, A96)

NEW

Source	Observations	Years	
4U J1907+097	65 obs/57 ks	(2015, WIP)	+3 SGXBs control sample
IGR J19140+0951	65 obs/60 ks	(2015, WIP)	+3 SGXBs control sample
IGR J16393−4643	150 obs/130 ks	(2016, WIP)	+3 SGXBs control sample

Long term monitoring



(Romano 2015b)

Daily resolution

- Outbursts!!!
- Dynamical range: 4omm excl. J16465 J16493
- Emission outside of outbursts
- Variability: days to months

Minute resolution

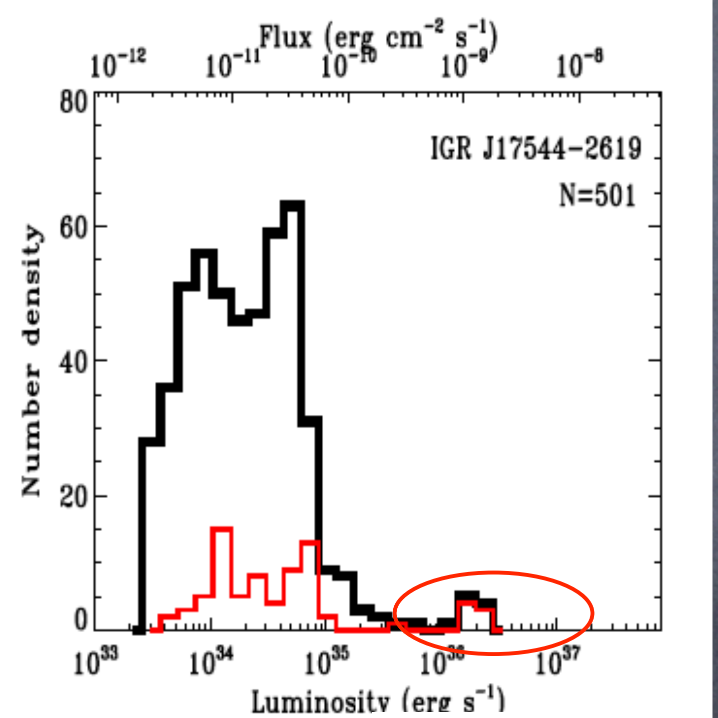
- variability observed on all timescales and intensity levels
- short timescales 1 order of magnitude (1 ks, down to 0.1cps)
- evidence for clumps

Differential L distros

(Romano+2014b,A&A,568,A55)

Yearly campaigns are statistically representative of the long-term soft X-ray properties of SFXTs + observations are independent

First assessment of time spent @ different L



(Romano+ 2014b)

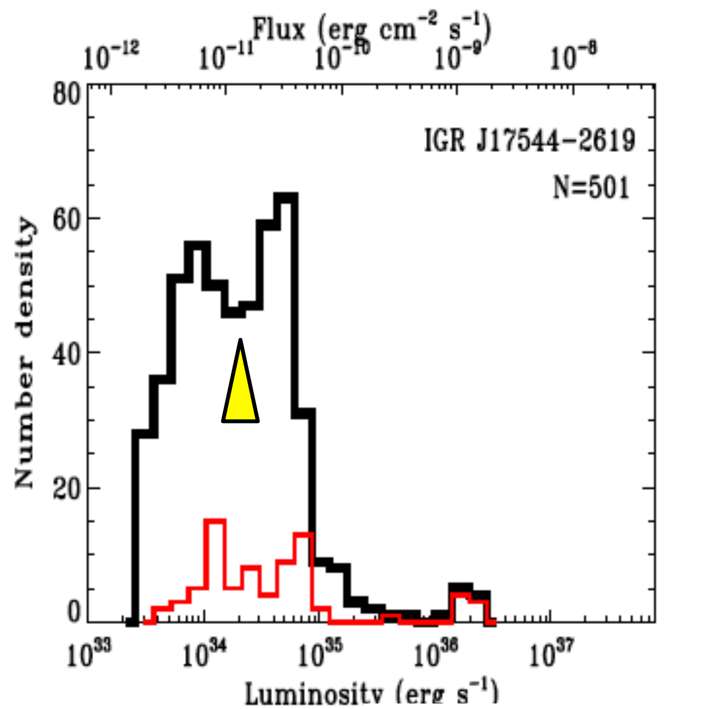
First population

different populations of flares

✔ 3-5% of time spent in bright outbursts (RARE!!)

Differential L distros

(Romano+2014b,A&A,568,A55)



(Romano+ 2014b)

✔ 3-5% of time spent in bright outbursts (RARE!!)

✔ Most probable observed flux
$1\text{-}3\times10^{-11}$ erg cm^{-2} s^{-1}
(2-10 keV, unabsorbed) so that

✔ long term behaviour is intermediate state of accretion

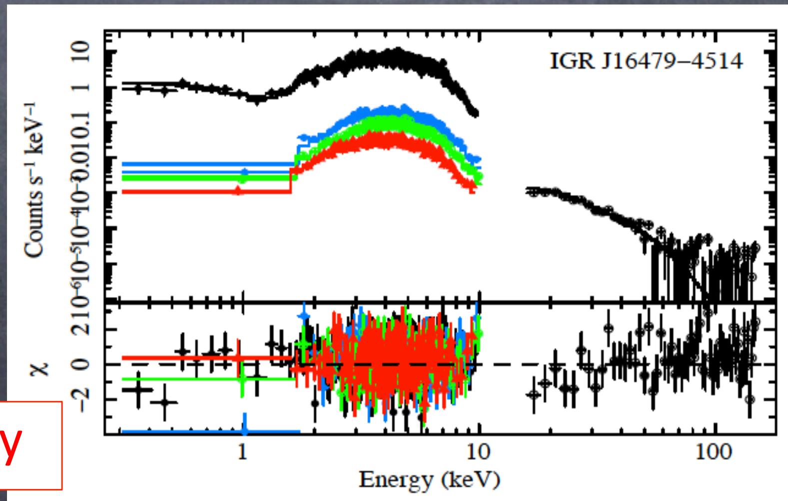
$L\sim10^{33} - 10^{34}$ erg s^{-1}

Out of Outburst Intensity-selected spectroscopy: power-laws (Γ~1-2)

Similar to outburst (softer) =>

The lowest luminosity reached:

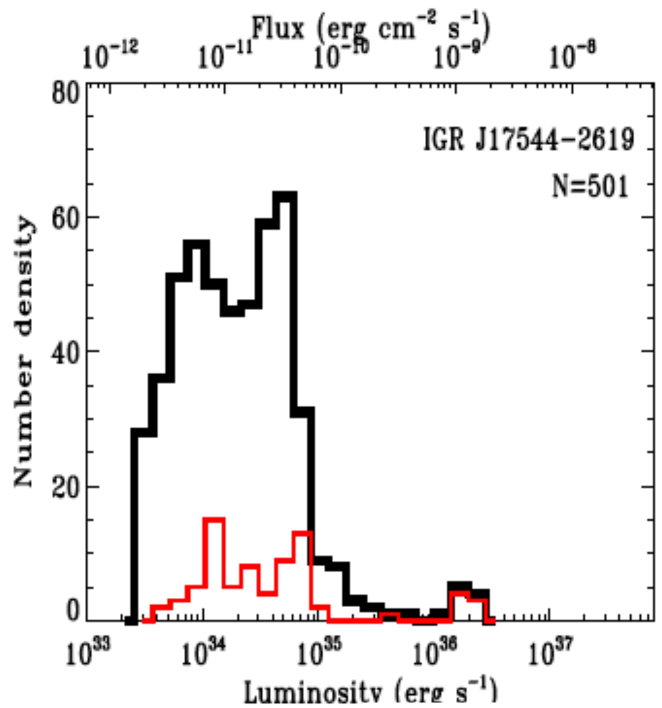
$L_x = 3\times10^{32}$ erg s^{-1} in IGR J17544-2619



Accretion over several oom in Luminosity

Differential L distros

(Romano+2014b,A&A,568,A55)



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$1\text{-}3\times10^{-11}$ erg cm^{-2} s^{-1}
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✔ long term behaviour is intermediate state of accretion

L~10^{33} – 10^{34} erg s^{-1}

4 orders of magnitude in dynamic range

✔ Non detections:
Inactivity Duty Cycle

$$\mathrm{IDC} = \Delta T_{\Sigma} / [\Delta T_{\rm tot}\,(1 - P_{\rm short})]$$

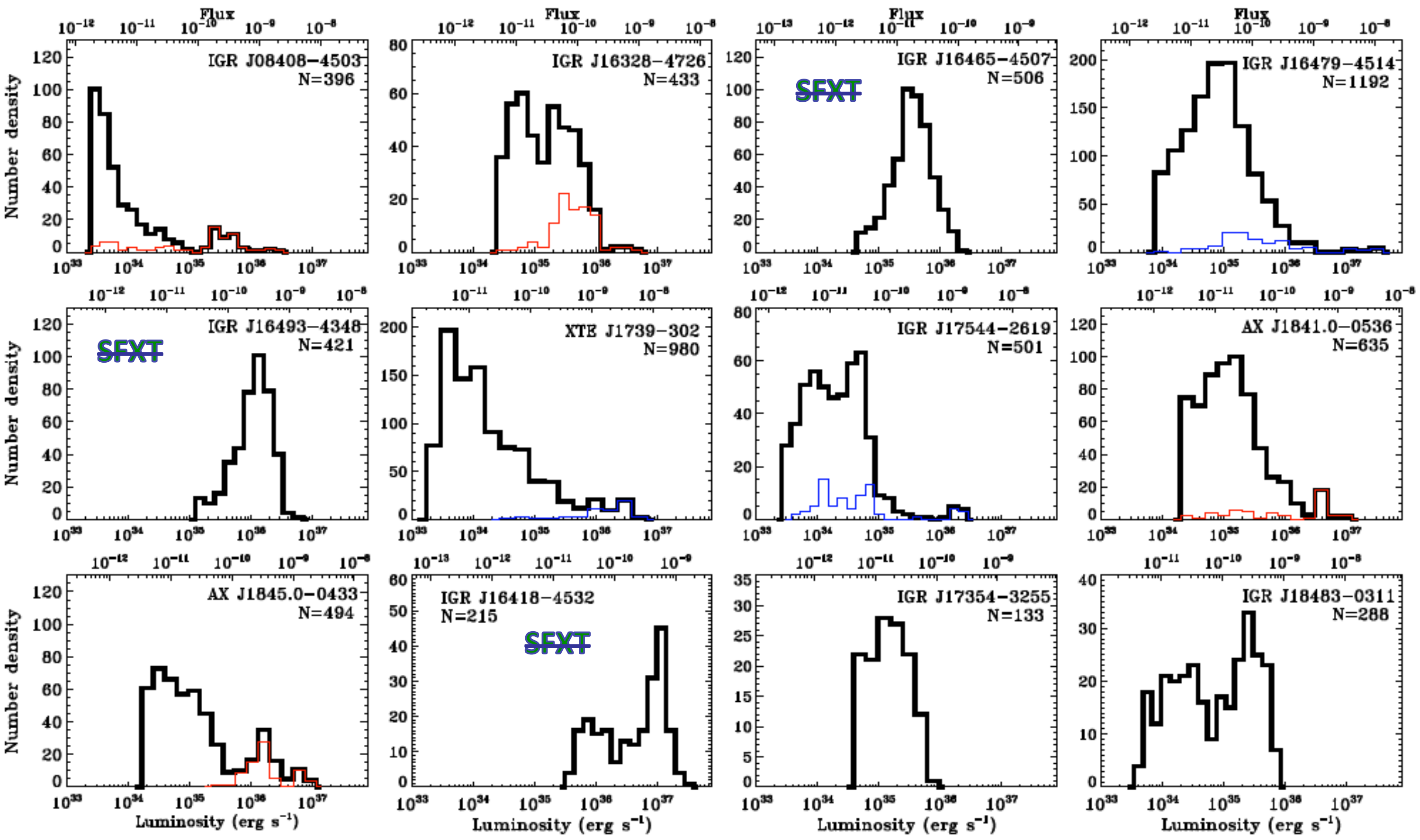
time a source spends undetected down to a flux $1\text{-}3\times10^{-12}$ erg cm^{-2} s^{-1}

ΔT_{Σ} = total expo(>900s) where 3σUL only obtained;
$\Delta T_{\rm tot}$=total expo
$P_{\rm short}$=%(expo < 900s)

IDCs quite large for SFXTs,
small for classical systems

DLDs: SFXTs vs classical

(Romano+2014b,A&A,568,A55)



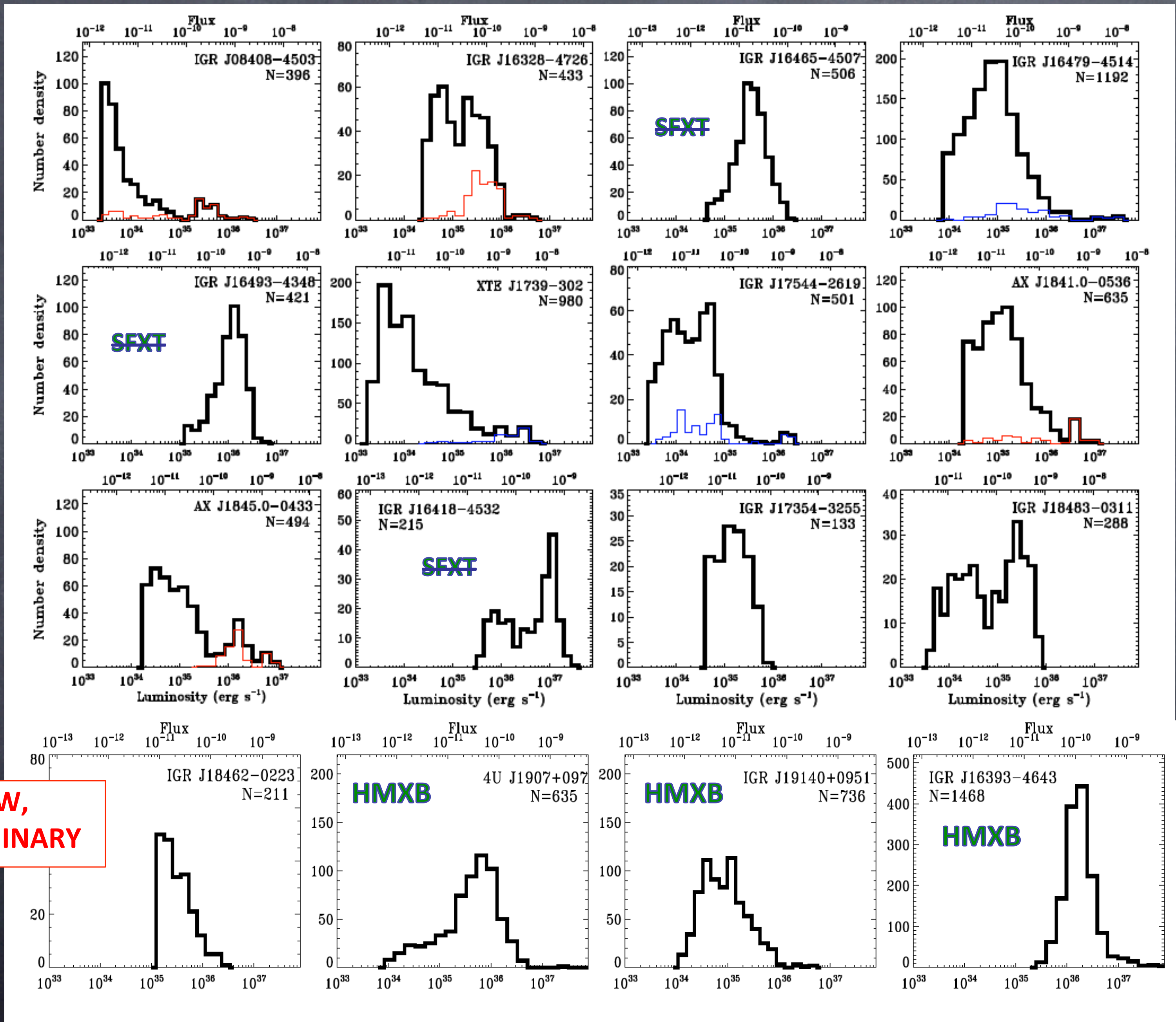
(Sidoli+2008, Romano+2009c, Romano+ 2011b, Romano+2014b, Romano 2015b)

SFXTs: - different populations of flares

- larger DR, **favours inhibition mechanisms**

- generally lower average luminosities (also see Lutovinov+ 2013)

Differential L distros



NEW, PRELIMINARY

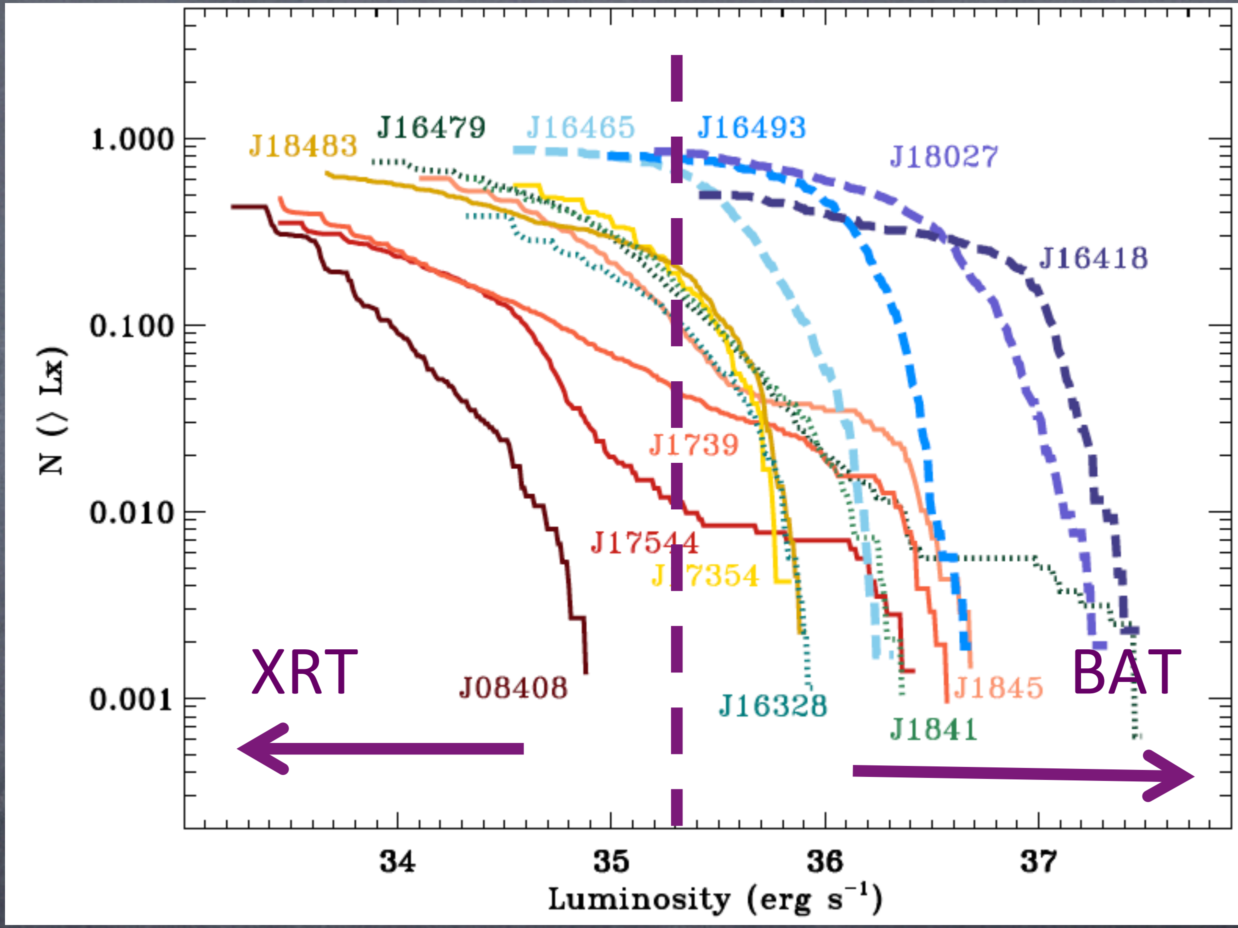
different populations of flares

Cumulative L Distros

First cumulative luminosity distributions in the **soft X-ray**

BAT tracks the emission down to a few **10^{35} erg s^{-1}**

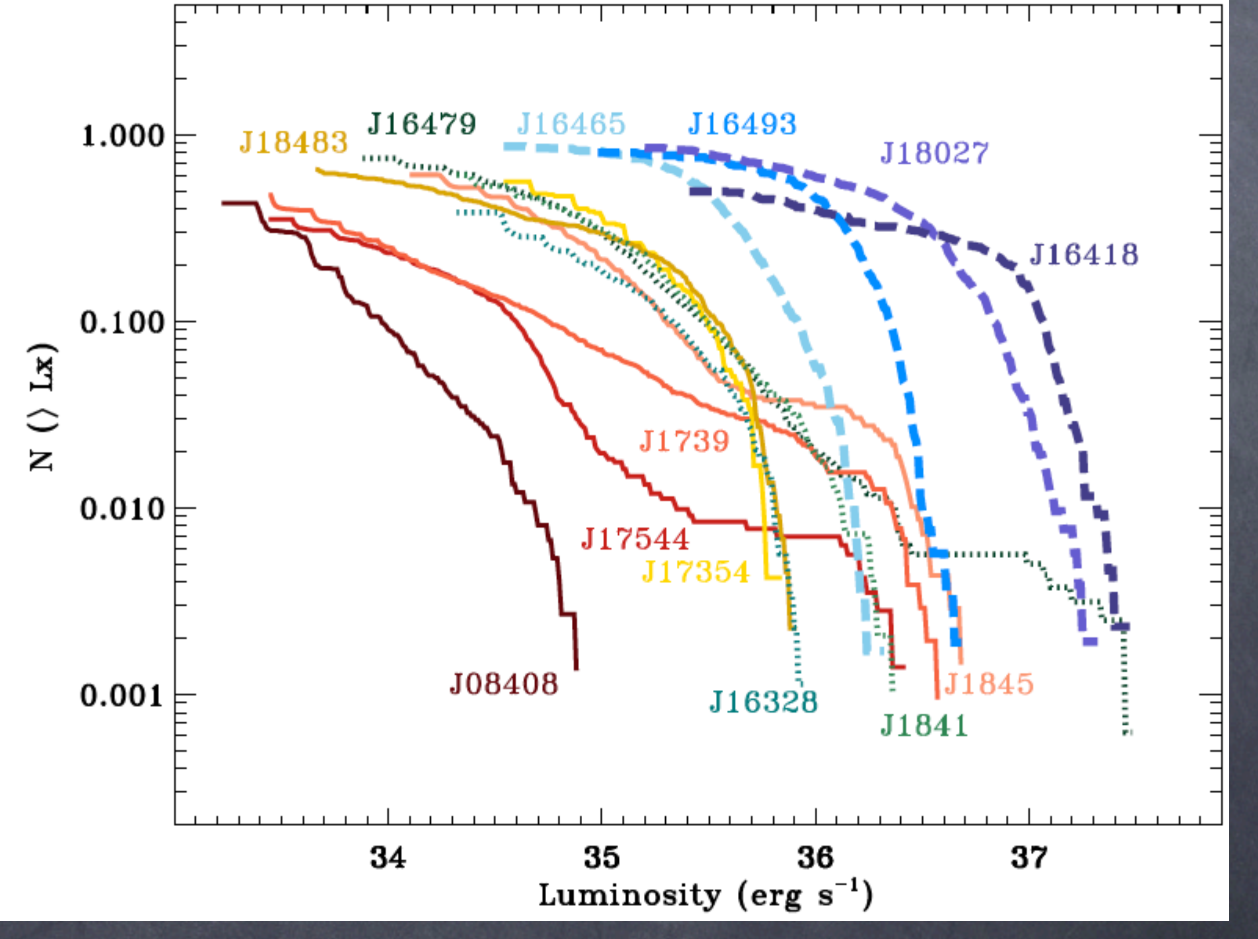
XRT reaches down to **~10^{33} erg s^{-1}**



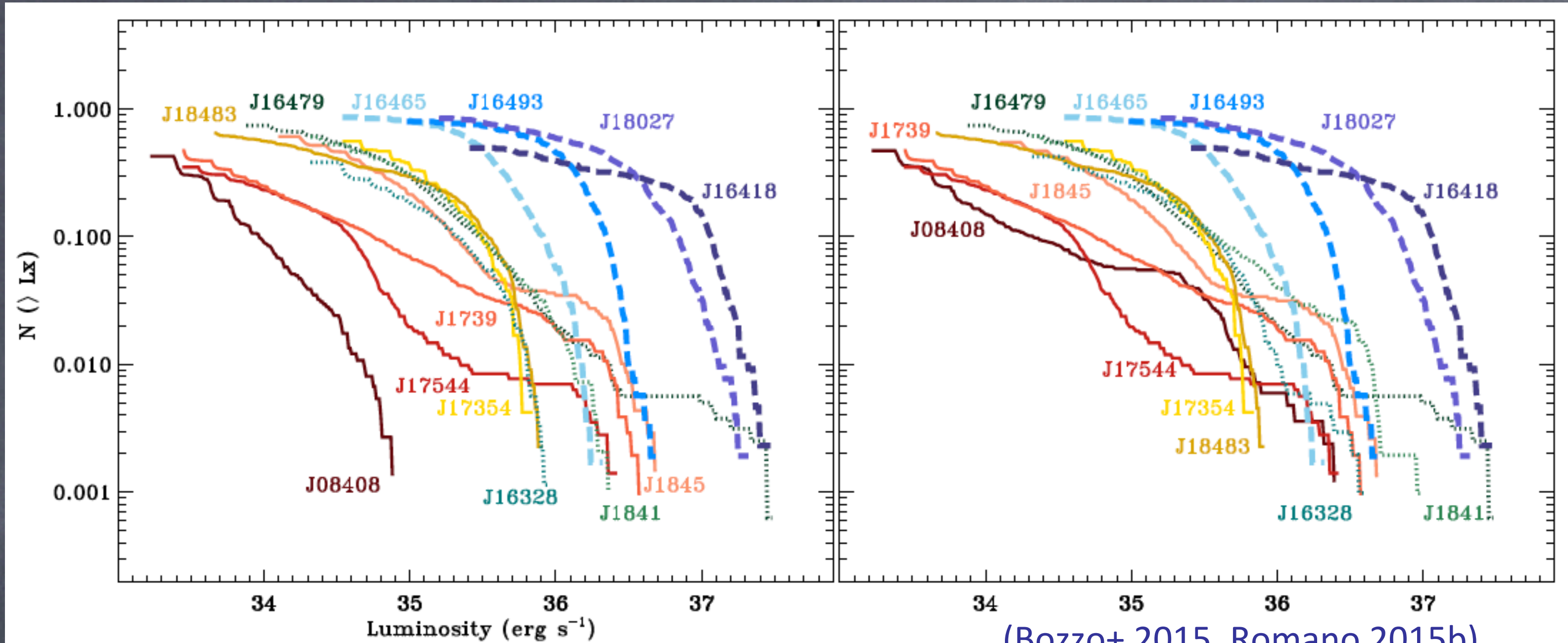
Cumulative L Distros

classical SgXBs (- - -) CDs with a single knee at ~10^{36}-10^{37} erg s^{-1} knee position depending on P_{orb}

SFXTs are systematically sub-luminous and their distributions are shifted at significantly lower luminosities (a factor of ~10-100).



Cumulative L Distros

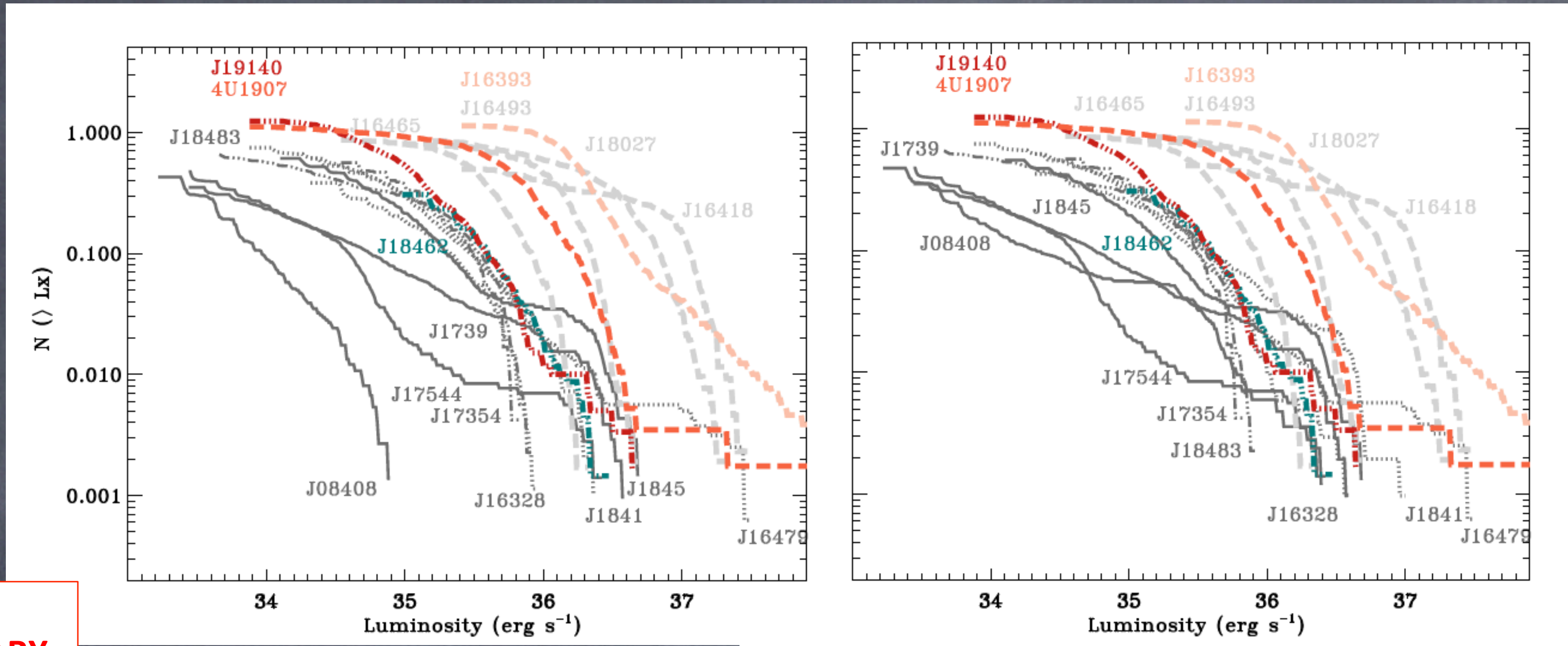


(Bozzo+ 2015, Romano 2015b)

IDCs and differential luminosity distributions used to discriminate between classical systems and SFXTs because SFXTs have generally lower average luminosities

Classical systems: accretion from structured wind
SFXTs: magnetic/centrifugal gates or quasi-spherical settling accretion regimes

Cumulative L Distros



NEW, PRELIMINARY

IDCs and differential luminosity distributions
used to discriminate between classical systems and SFXTs
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Classical systems: accretion from structured wind
SFXTs: magnetic/centrifugal gates or
quasi-spherical settling accretion regimes

SFXT Outburst Factory

52 bright BAT flares
38 with NFI data

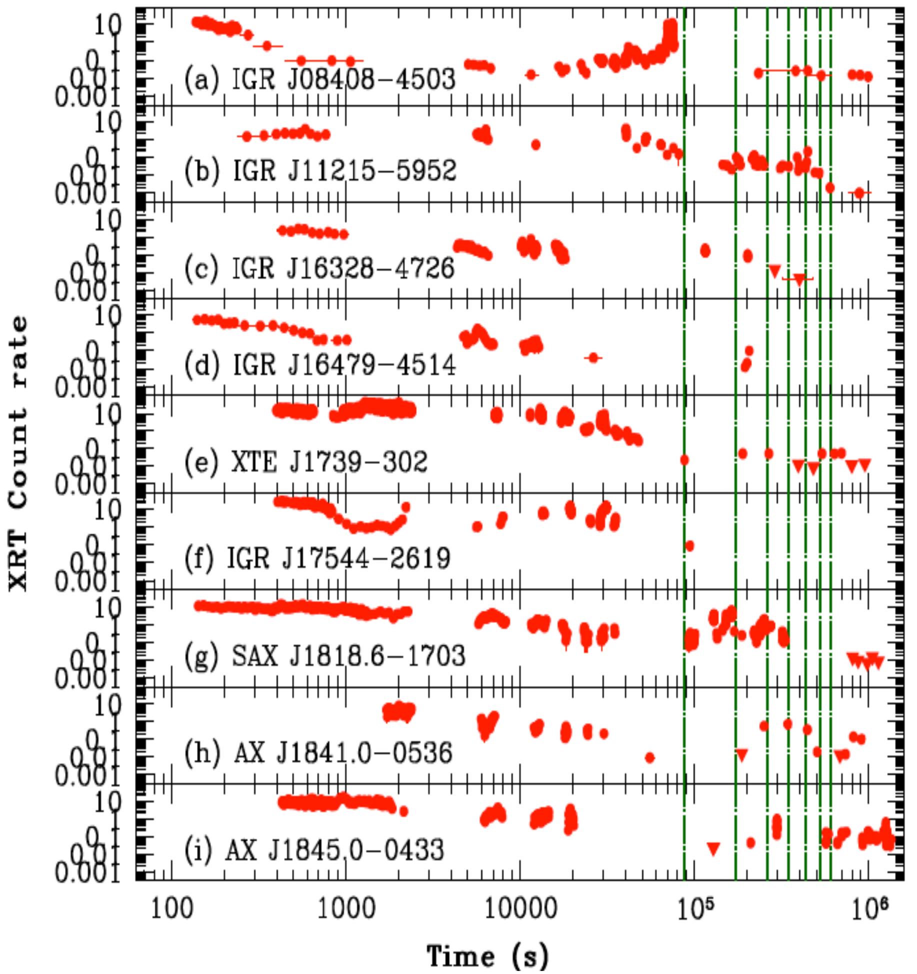
≥Week-long follow-ups

Common features:

✔outburst length > hours

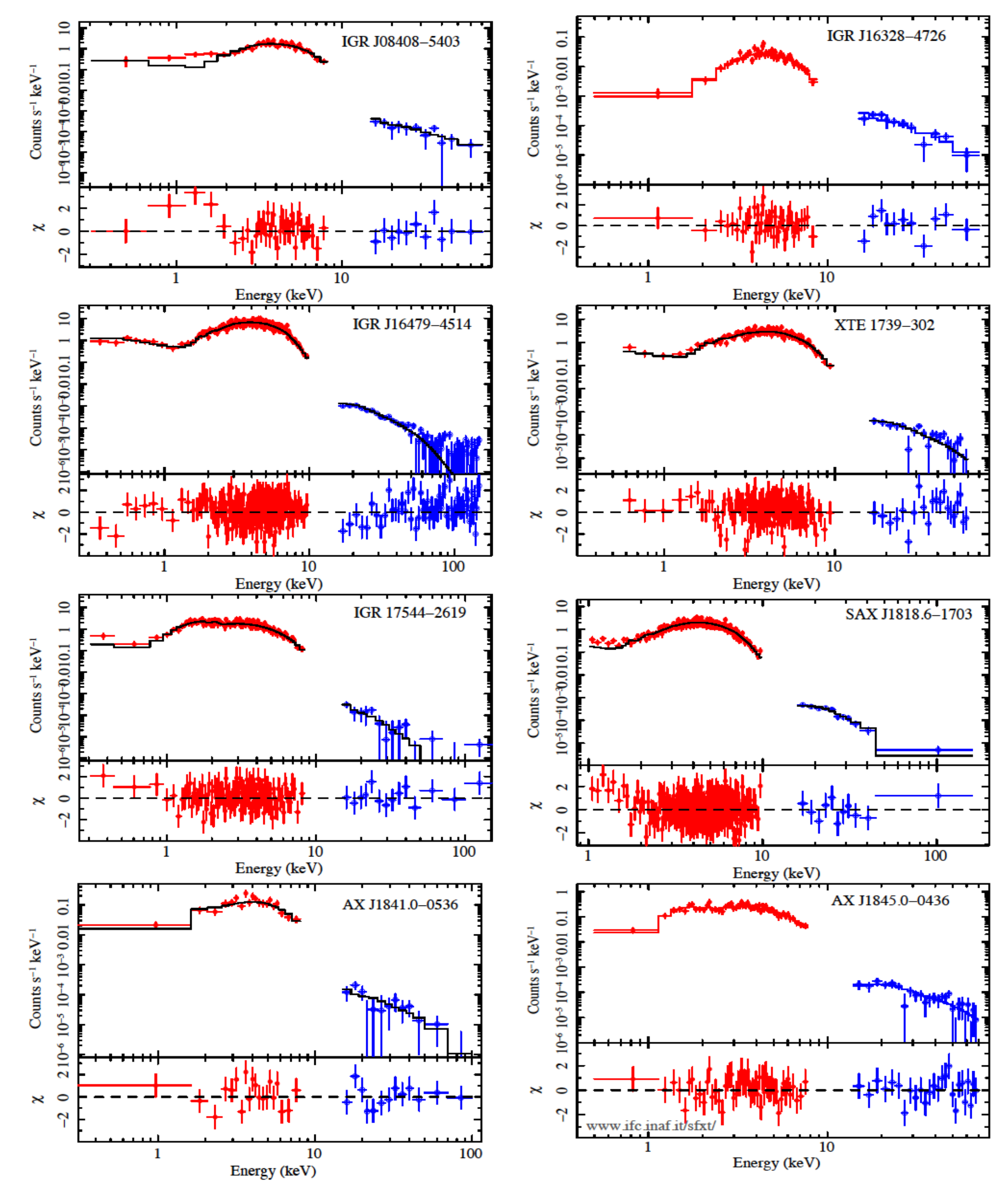
✔multiple peaked structure with lots of flares

✔dynamic range: 3 orders of magnitude



(Romano 2015b)

SFXT Outbursts



(Romano 2015b, JHEAp, 7, 126)

Broad-band spectroscopy
0.3-10 keV + 15-150 keV

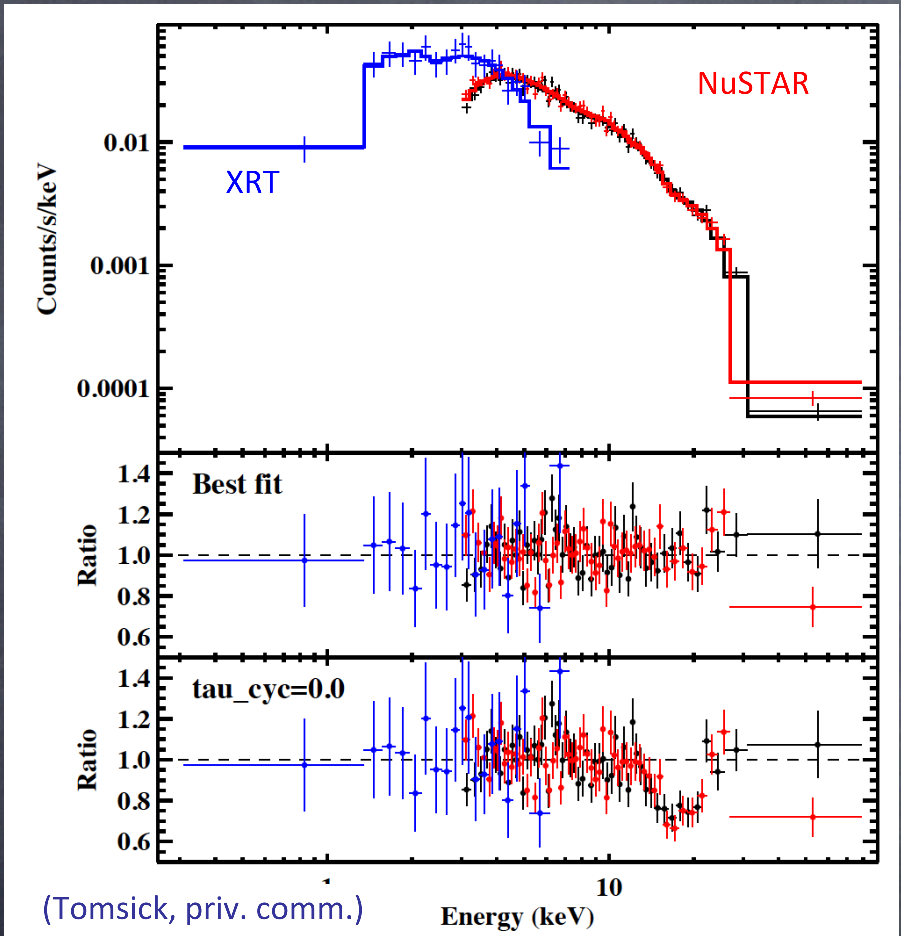
✔absorption
& spectral cut-off

✔comparison with
models for accreting NS

High energy cutoff consistent with **B~10^{12} G** (no cyclotron lines observed until 2014)

Motivated **compmag model** (Farinelli, Ceccobello, Romano & Titarchuck 2012)

IGR J17544-2619



(Tomsick, priv. comm.)

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

Detection of a cyclotron line:

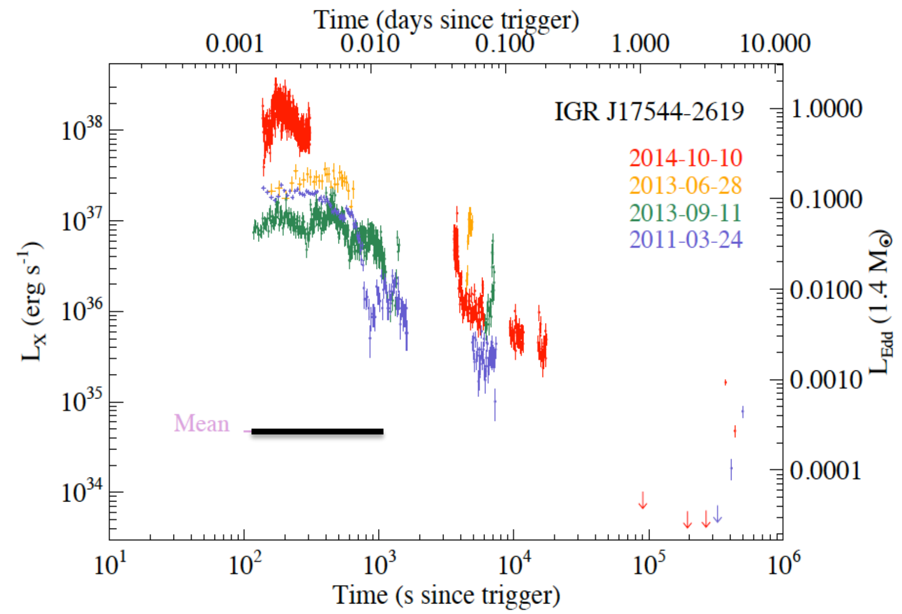
E~17 keV

B~1.5x10^{12} G

Excluding magnetar nature for the prototype

Transient accretion disk?

(Romano+2015a,A&A,576,L4)



(Romano+2015,A&A,576,L4)

2014-10-10: Brightest burst ever recorded from IGR J17544-2619
Or any other SFXT

Peak CR (0.3–10keV) ~ 668 counts s^{-1}
Peak flux ~ 10^{-7} erg cm^{-2} s^{-1} ~ 2.1 Crabs

Dynamical range 10^6
Peak luminosity ~ 3×10^{38} erg s^{-1}
~ L_{Edd}

- Now challenging maximum luminosity
- maximum achievable luminosity is direct accretion (BH)

High L reached L_{Edd}

- higher than wind accreting SGXBs

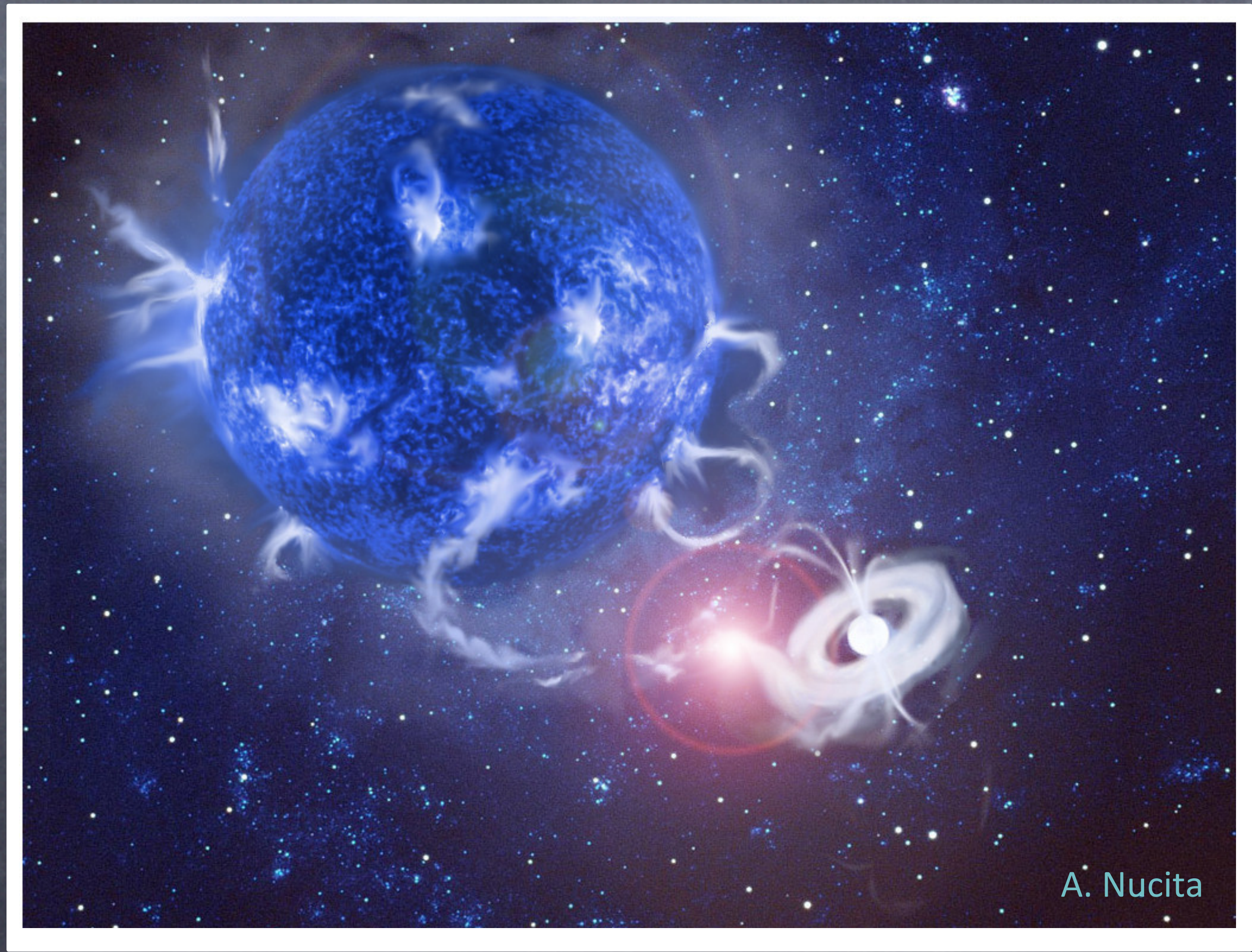
Transient accretion disk?

(Romano+2015a,A&A,576,L4)

- **very low wind velocity** <~ 2x10^6 cm s^{-1}
  due to ionization of the wind material
  -favored by short orbital period (P=4.926) and eccentric orbits

difficult to avoid
formation of
temporary accretion disk

their dissipation would
produce 10x mass accretion
rates (flares!!!)



The 100-month Catalogue

Full catalogue (ASCII/FITS)

(Romano+2014, A&A, 562, A2)

fv: Binary Table of SFXT_BAT_catl.fits[1] in /Users/pat/Work/Swift/data/Sfxt_Swift/Catalog_sfxt/Bat/

File Edit Tools Help

Select	UNIQ_NUM	SOURCE	FLAG	YEAR	DOY	MJD	UTDATE	UTTIME	DURATION	SIGMA	FLUX	TRIGNUM
	I4	18A	A1	I4	I3	D20	10A	8A	E	E	E	J
All									s		mCrab	
Invert	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	1	IGRJ08408-4503	D	2008	265	5.473000000000E+04	2008-09-21	00:00:00	8.640000E+04	6.850000E+00	1.700000E+01	999999
2	2	IGRJ08408-4503	D	2009	137	5.496800000000E+04	2009-05-17	00:00:00	8.640000E+04	5.280000E+00	1.800000E+01	999999
3	3	IGRJ08408-4503	D	2009	240	5.507100000000E+04	2009-08-28	00:00:00	8.640000E+04	5.500000E+00	3.100000E+01	999999
4	4	IGRJ08408-4503	D	2011	237	5.579800000000E+04	2011-08-25	00:00:00	8.640000E+04	1.555000E+01	6.900000E+01	999999
5	5	IGRJ08408-4503	T	2006	277	5.401261328125E+04	2006-10-04	14:45:42	1.600000E+03	8.080000E+00	8.888000E+03	232309

The 100-month *Swift* Catalogue of SFXTs, a Legacy

- ✔ 2005-Feb-12 to 2013-May-31 (MJD 53413– 56443)
  - ✔ 1117 flare from 11 SFXTs -46 BAT (T)riggers (43 outbursts) -126 BATTM (Daily) -267 BATTM (orbital) -678 on-boar(d)
- ✔ flux limit 6×10^{-10} erg cm^{-2} s^{-1} (daily) (15-150 keV)
  1.5×10^{-9} erg cm^{-2} s^{-1} (orbital, ~ 800 s)
- ✔ Flares short (x100 s), bright (~100 mCrab) events << day length
- ✔ Expected SFXTs in MW: Ducci+ 2014, A&A, 568, A76: N(SFXTs) = 37^{+53}_{-22}
- ✔ Perspectives for future missions (LOFT, eXTP…)

Perspectives for eXTP

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:
$N(SFXTs) = 37^{+53}_{-22}$

Summary and Conclusions

Swift has consistently surprised us with the unexpected

But we are still missing some key ingredients to understand SFXT variability

We have an excellent motivation to look deeper and longer:

Swift monitoring programs of SFXTs and classical HMXBs will be crucial

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

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