Swift and the Supergiant Fast X-ray Transient outburst factory

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Outline

- **SFXTs and classical SG-HMXBs**

- **Long-term monitoring** results of 16 sources
  - out of outburst: dynamical range
  - Inactivity Duty Cycle
  - Differential and Cumulative Luminosity Distributions

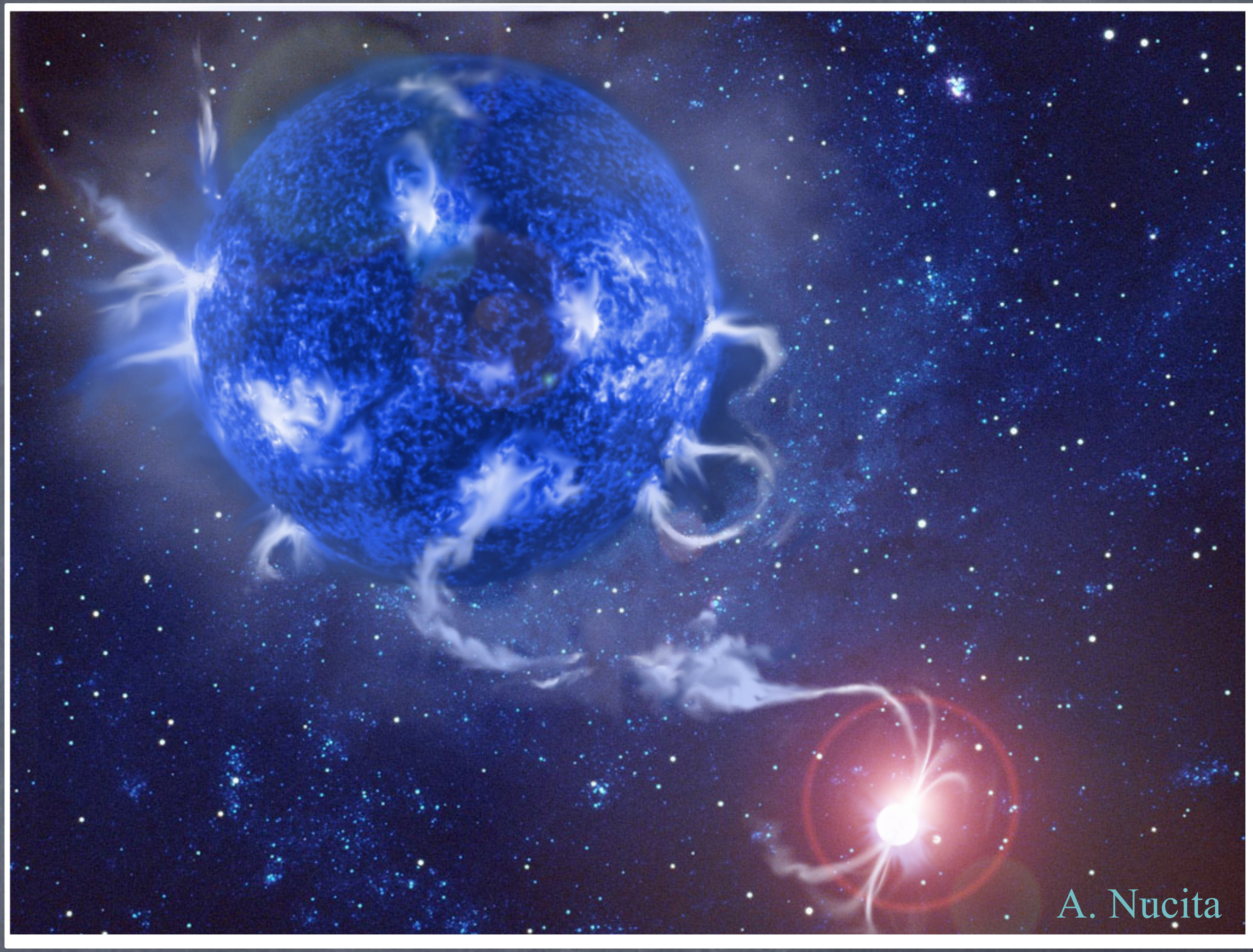
- **Outbursts and follow-ups**
  - true dynamical range
  - outburst mechanisms ?
  - Giant outburst of IGR J17544-2619 (2014-10-10)

SFXTs

- HMXBs with OB SG companions

  $V_\infty \sim 1000\text{–}3000$ km s^{-1}
  $\dot{M}_W \sim 10^{-6}\text{–}10^{-5}\ M_\odot\ yr^{-1}$

- 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; $P_{orb} \sim 3\text{–}50$d
- Most emission from wind accretion

Supergiant Fast X-ray Transients

1. **Outburst mechanism?**

2. **Why/How do SFXTs differ from classical HMXBs?**

- **Wind properties (clumps)** (In't Zand 2005, Negueruela+ 2008; Walter & Zurita Heras 2007; Sidoli+ 2007; Chaty 2013)
  SFXTs: denser clumps in SFXTs

- **Centrifugal/magnetic gating** (Grebenev+2007, Bozzo+2008, Ducci+ 2010; Lutovinov+ 2013)
  SFXTs: slower rotations, higher B fields
  regime switches triggered by NS+moderately dense clumps
  ΔL up to 10^5 with x5 mass loss rate, $P_{spin} > 10^3$s, B~10^{14}G

- **Quasi-Spherical accretion/subsonic settling accretion**
  +magnetic reconnection between the NS and the supergiant field transported by its wind (Shakura+ 2012, 13, 14…)
  depending on cooling, reduction by a factor of 3-30 in accretion rate
  SFXTs: winds with lower mass loss rate from SG
  or higher/lower velocity/density density. Triggers from B in wind

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 & 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)

✔BAT Special Functions 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

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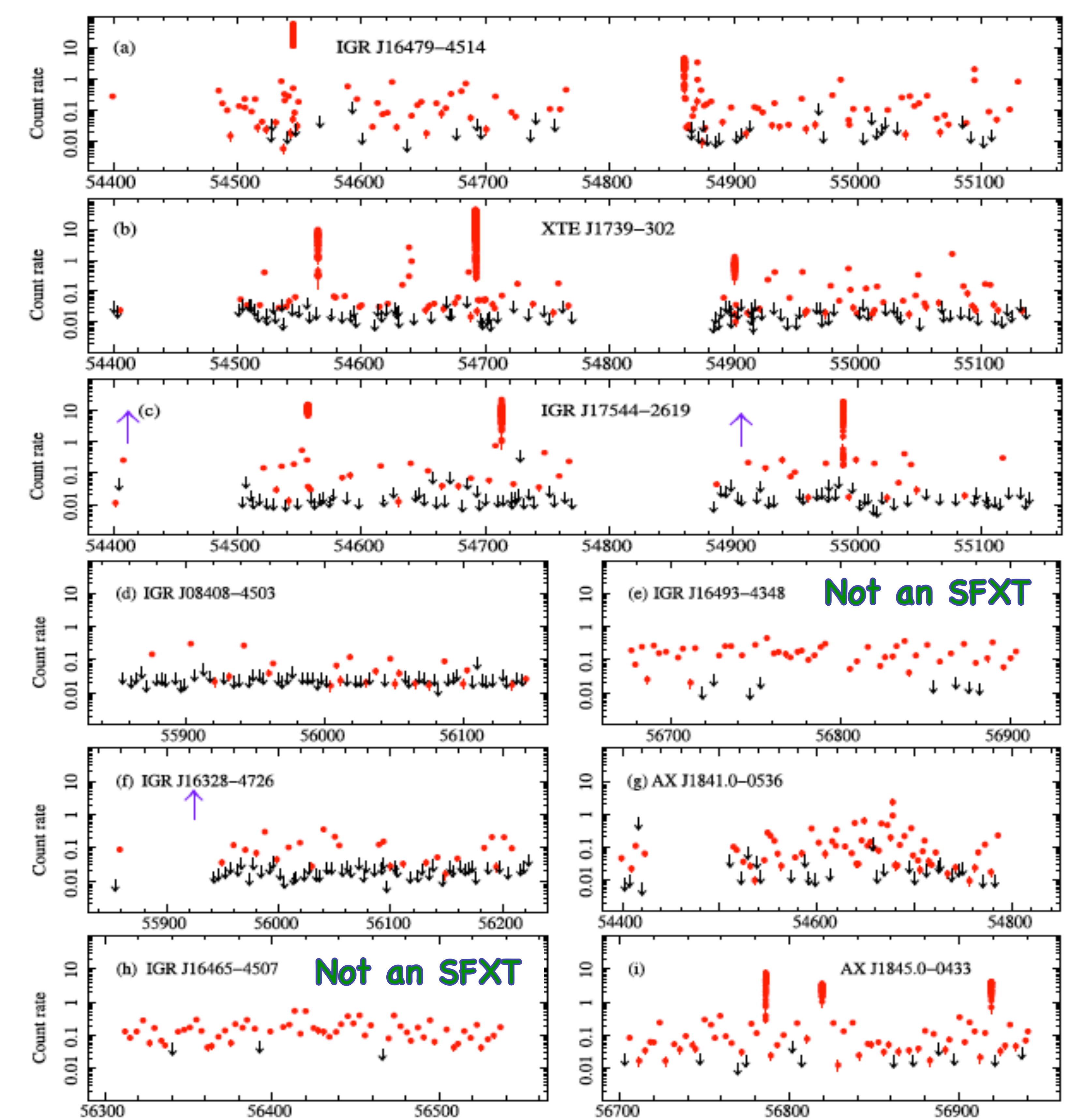
IGR J08408-4503	82 obs/74 ks	(2011-2012)	Romano+ 2011a (MNRAS,410,1825)
IGR J16328-4726	98 obs/88 ks	(2011-2014)	Romano+ 2014b (A&A,568,A55)
IGR J16465-4507	65 obs/57 ks	(2013)	Romano+ 2014c (A&A,572,A97)
IGR J16493-4348	65 obs/53 ks	(2014)	Bozzo+2015 (AdvSpRes, 55, 1255)
AX J1845.0-0433	80 obs/69 ks	(2014)	Romano 2015b (JHEAp,7,126)

NEW
+2 SFXTs (2016, WIP)
+3 SGXBs (2 in 2015 and 1 in 2016) control sample

Long term monitoring



(Romano 2015b)

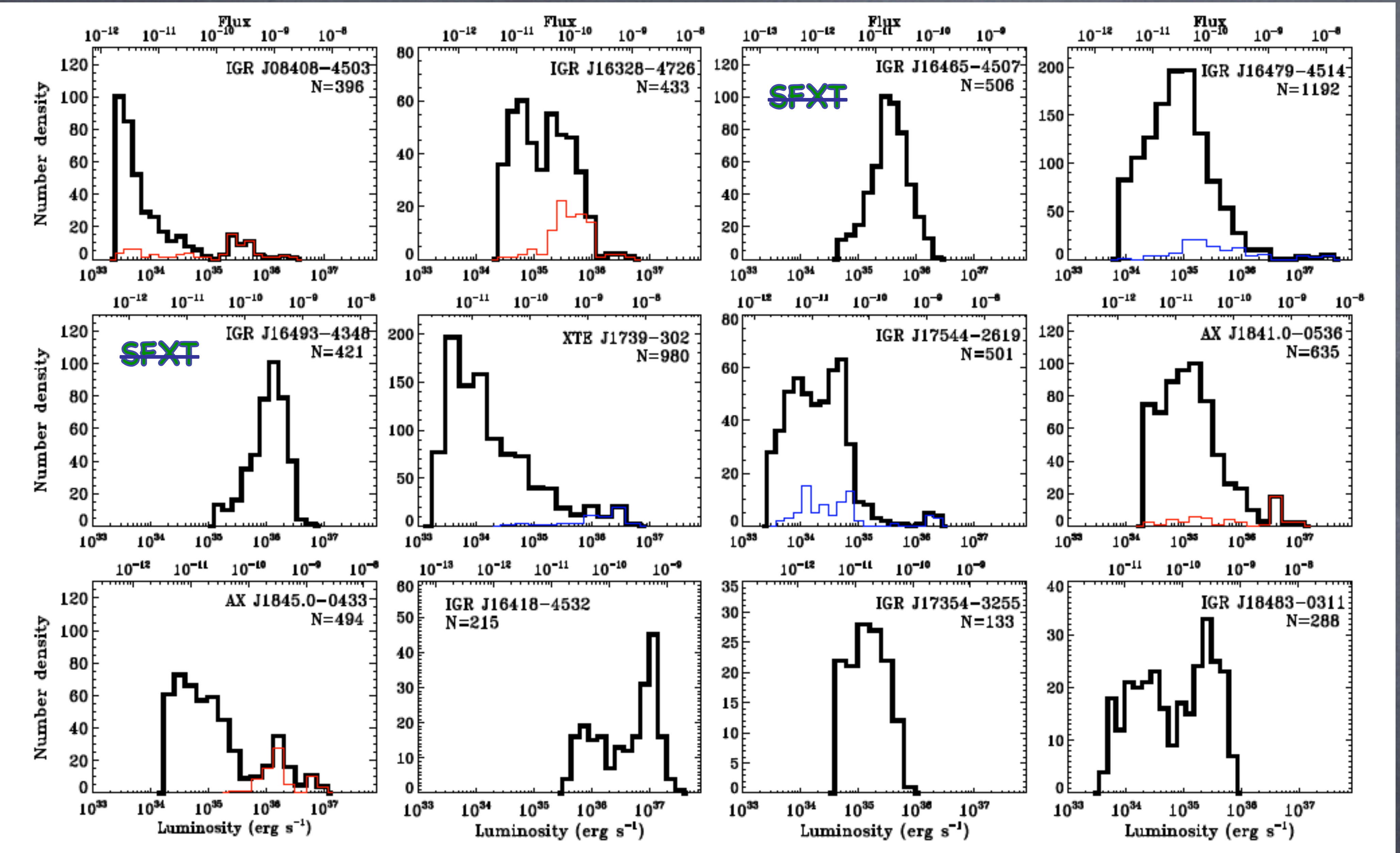
Daily resolution

- 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



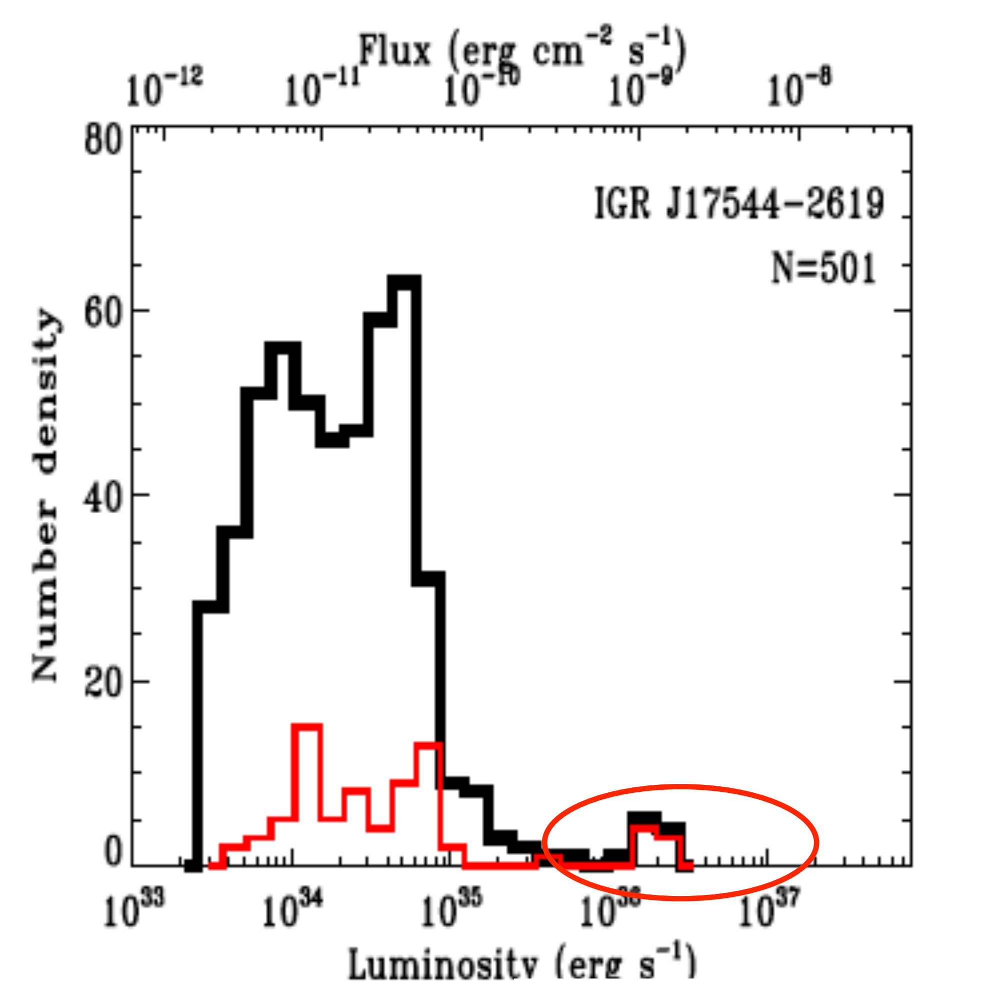
(Sidoli+2008, Romano+2009c, Romano+ 2011b, Romano+2014b, Romano 2015b)

different populations of flares

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

Differential L distros

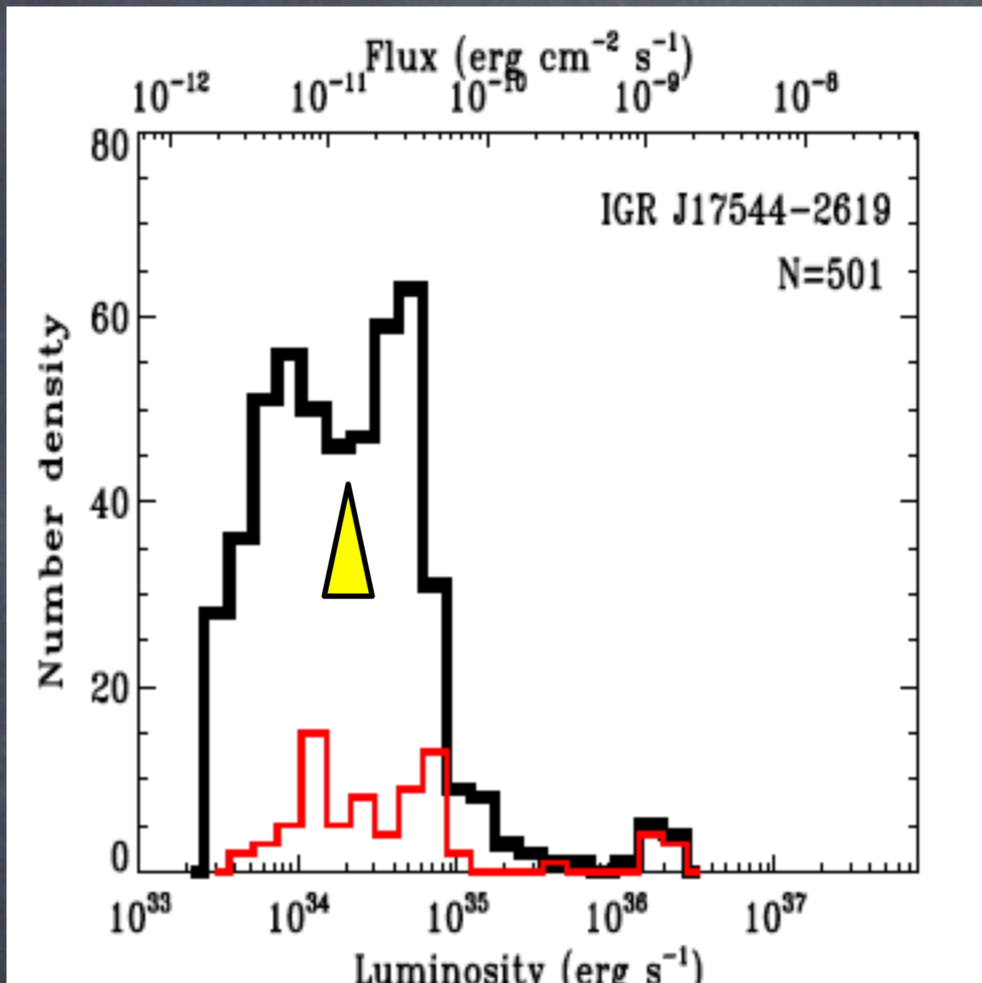


(Romano+ 2014b)

First population

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

Differential L distros



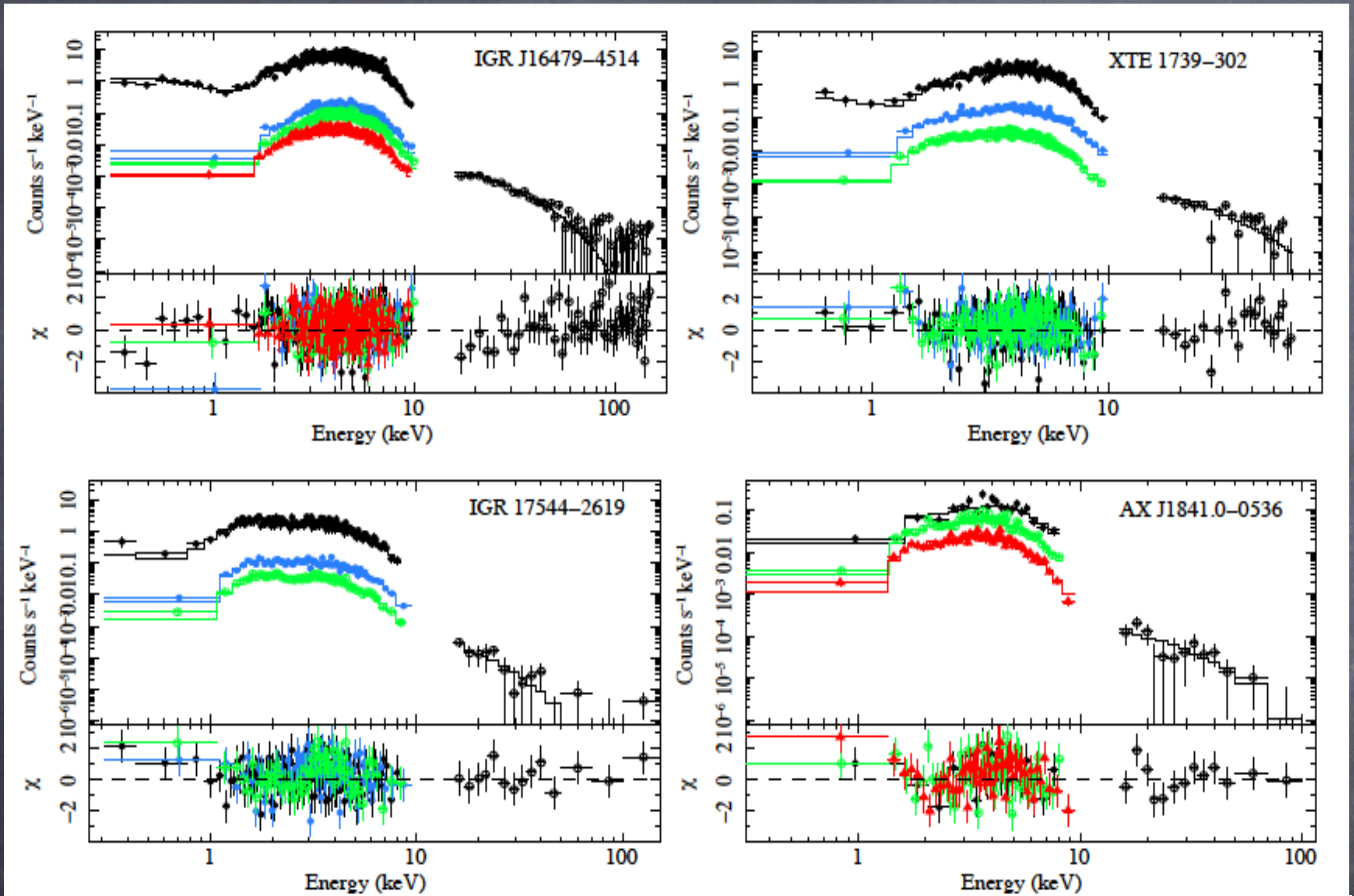
(Romano+ 2014b)

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

✔ long term behaviour is intermediate state of accretion

Out of Outburst
Intensity-selected spectroscopy



(Romano+ 2009c, Romano+2011a,c)

hard power-laws (Γ~1-2)

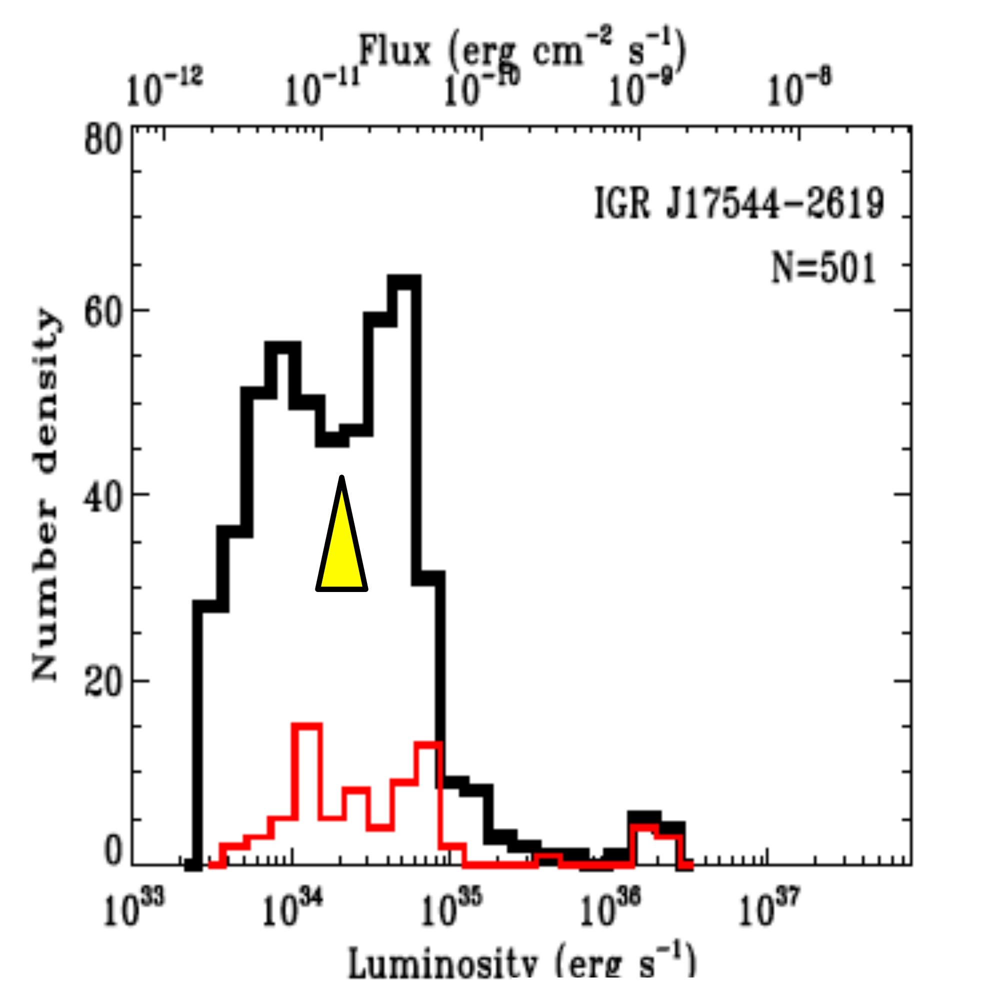
L_X~10^{33}-10^{34} erg s^{-1}

Similar to outburst (softer)
=>
Same process...

Accretion over several oom in Luminosity!!!

The lowest luminosity level we could reach with *Swift*:
Lx = 4×10^{32} erg s^{-1} in XTE J1739-302, Lx = 3×10^{32} erg s^{-1} in IGR J17544-2619

Differential L distros



(Romano+ 2014b)

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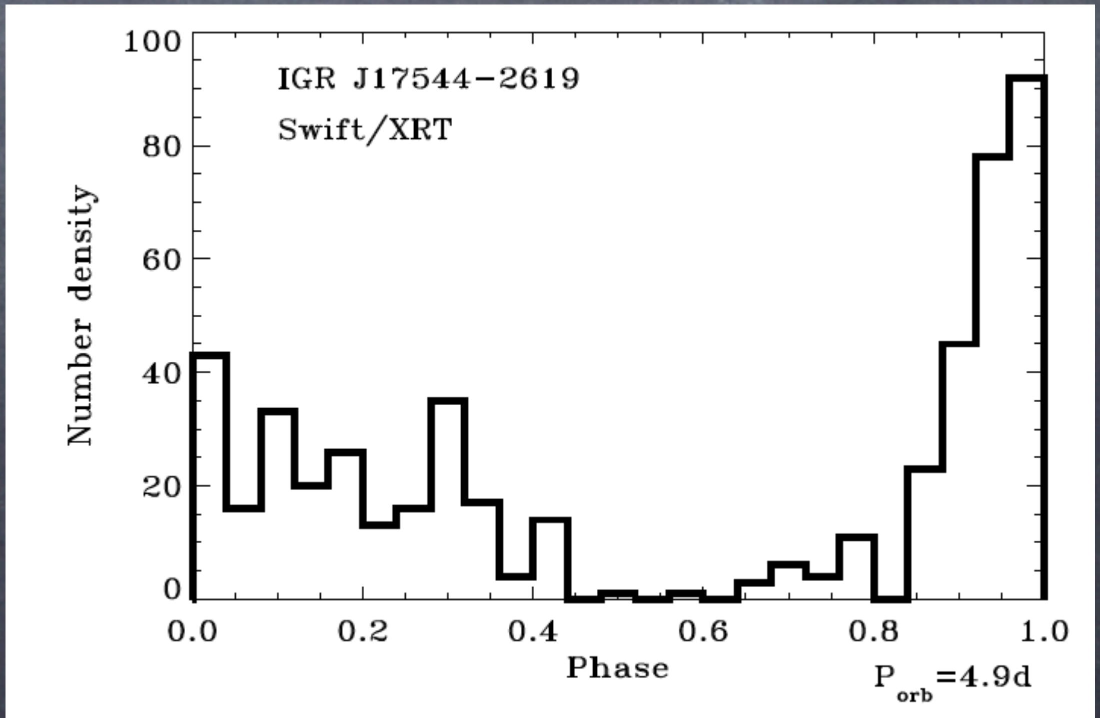
✔ Most probable observed flux
1-3x10^{-11} erg cm^{-2} s^{-1}
(2-10 keV, unabsorbed) so that

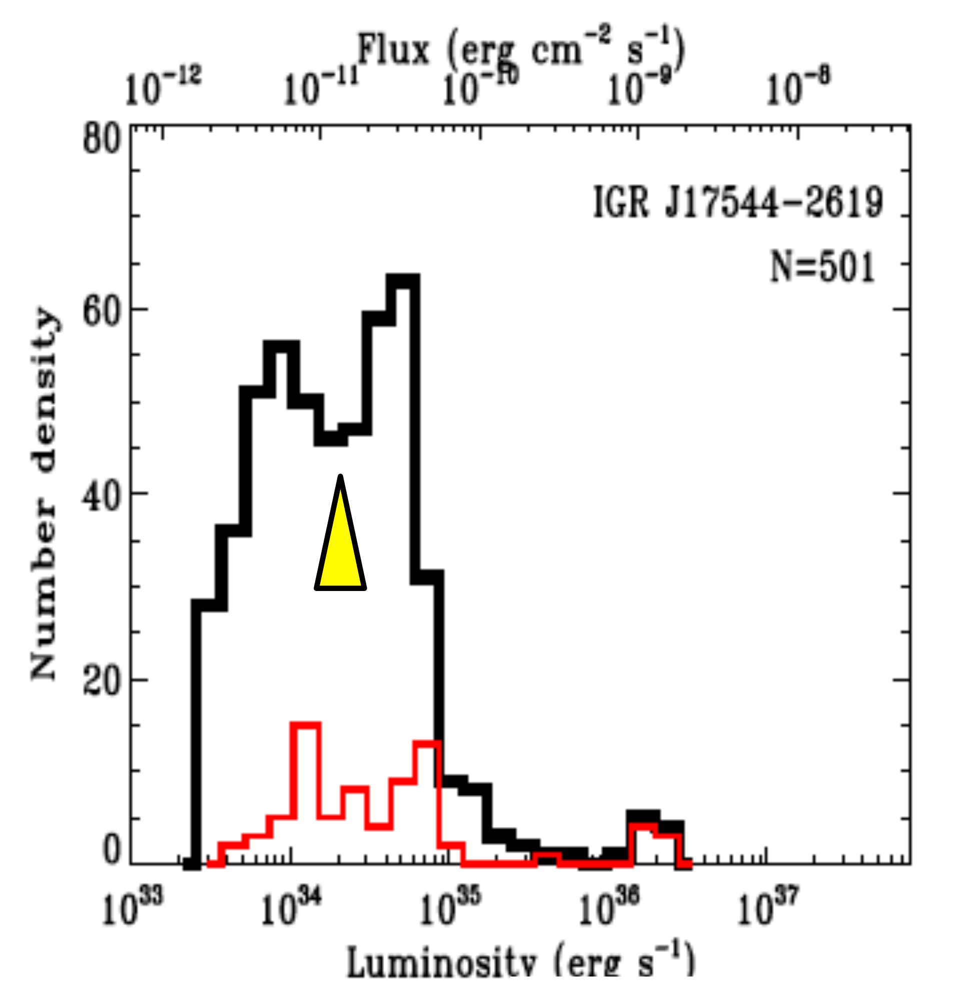
✔ long term behaviour is intermediate state of accretion

L~10^{33} – 10^{34} erg s^{-1}

most probable flux (when det.) from peak of DLD
tool for planning new obs.
as is the distribution of detections with orbital phase



Differential L distros



(Romano+ 2014b)

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$1\text{–}3\times10^{-11}$ erg cm^{-2} s^{-1}
(2–10 keV, unabsorbed) so that

✔ long term behaviour is intermediate state of accretion

L~10^{33} – 10^{34} erg s^{-1}

4 orders of magnitude in dynamic range

✔ Non detections:
Inactivity Duty Cycle

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

IDCs quite large for SFXTs, small for classical systems

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

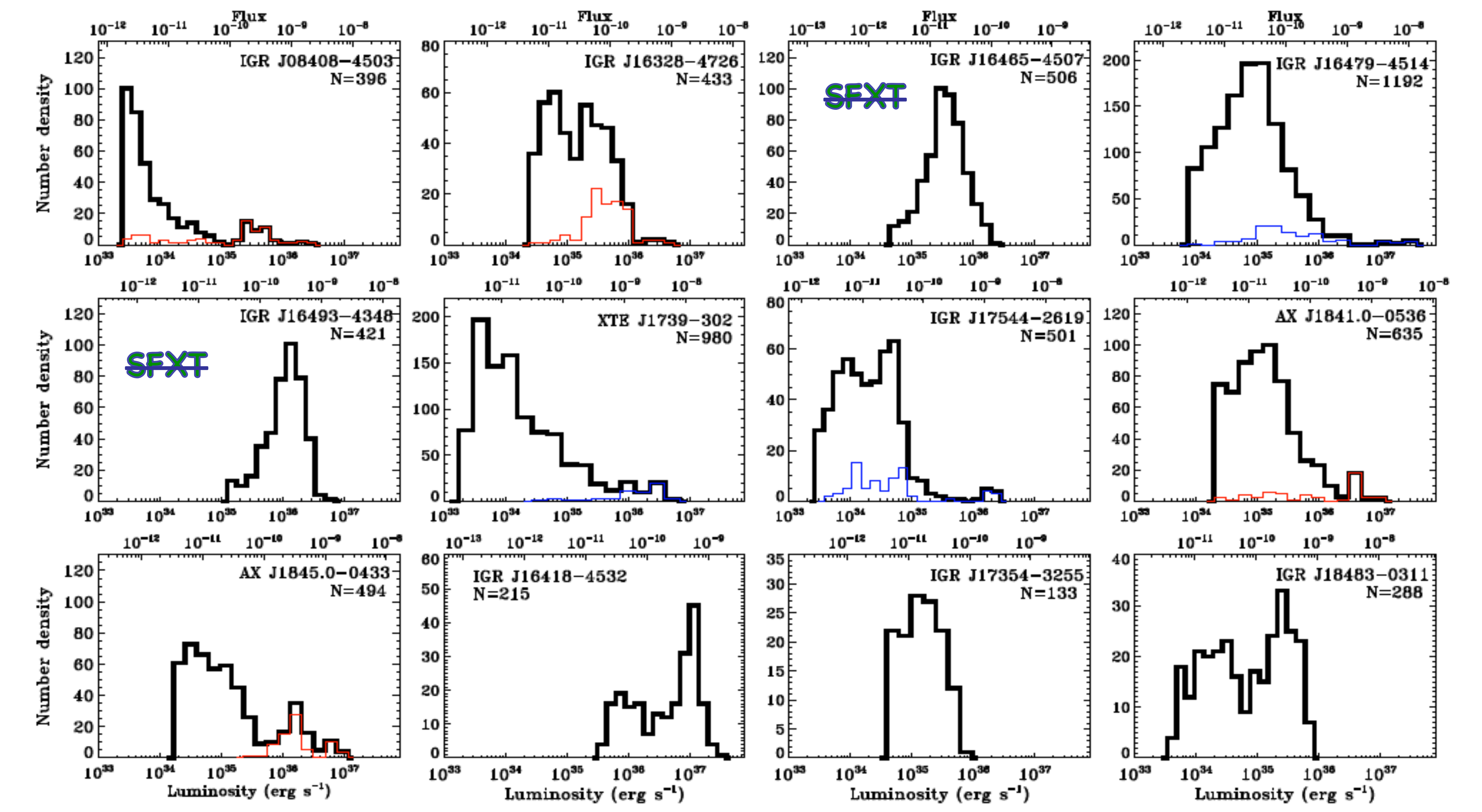
ΔT_{Σ} = total expo(>900s) where 3σ UL only obtained;

ΔT_{tot}=total expo

P_{short}=%(expo < 900s)

DLDs: SFXTs vs classical

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



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

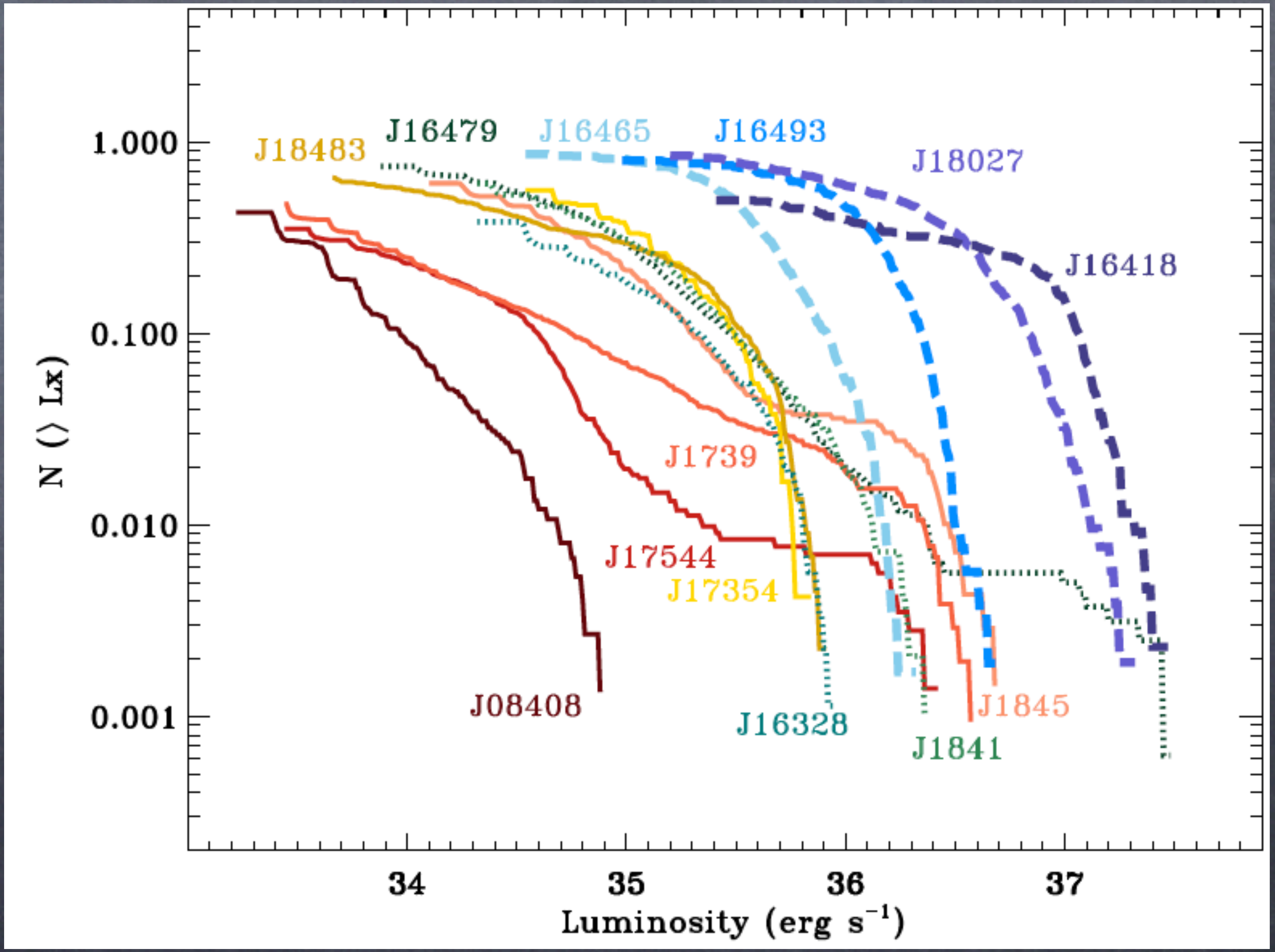
SFXTs: different populations of flares,
larger DR
fainter than classical systems

favours inhibition mechanisms (also see Lutovinov+ 2013)

Cumulative L Distros

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

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

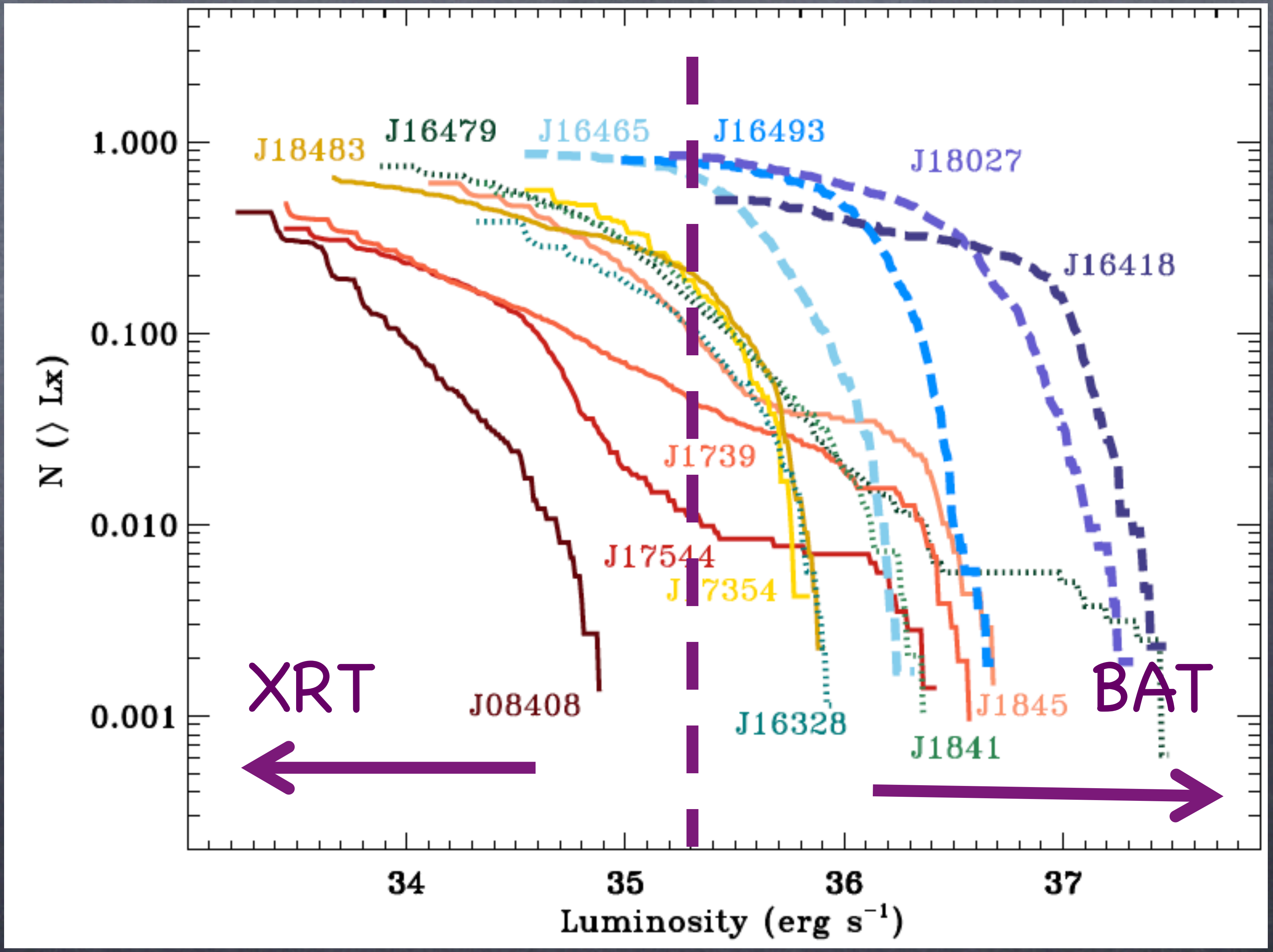


Cumulative L Distros

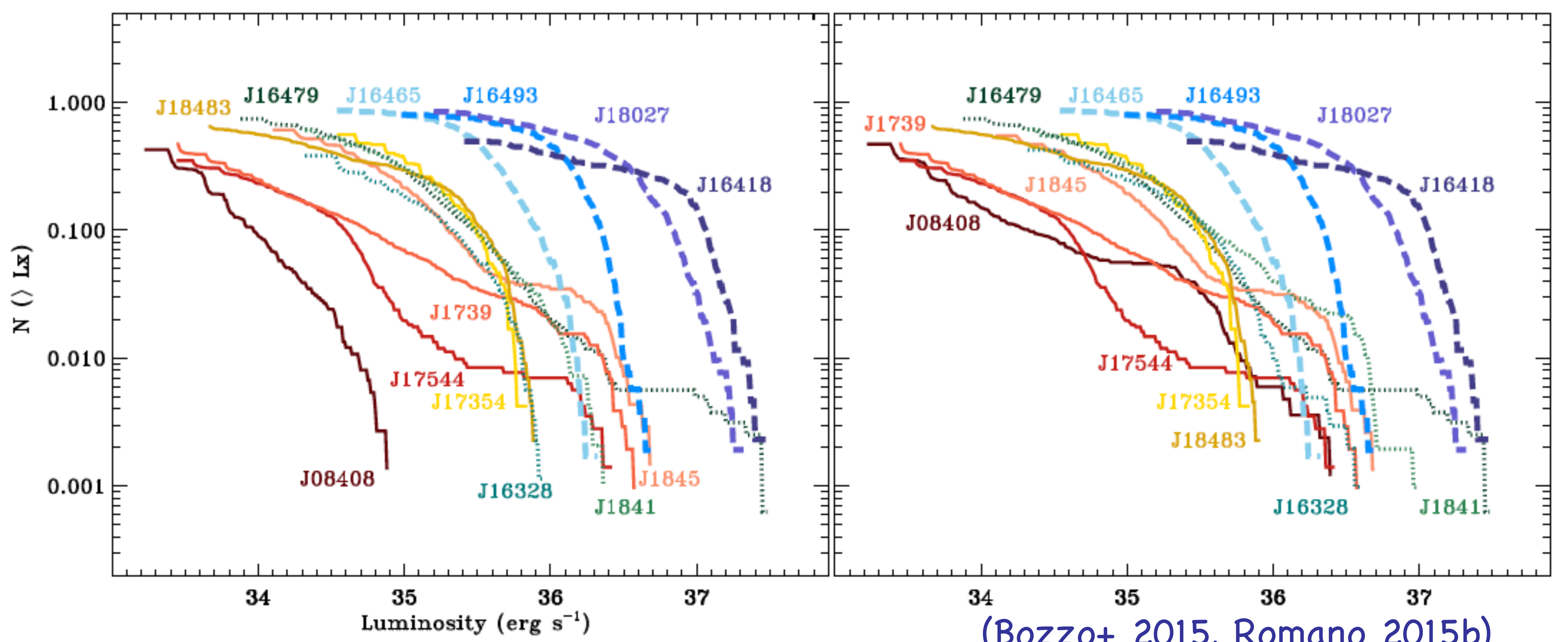
First cumulative luminosity distributions in the **soft X-ray**:

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



(Bozzo+ 2015, Romano 2015b)

classical SgXBs (- - -) are characterized by CDs with a single knee around ~10^{36}-10^{37} erg s^{-1}, while **SFXTs are systematically sub-luminous** and their distributions are shifted at significantly lower luminosities (a factor of ~10-100).

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

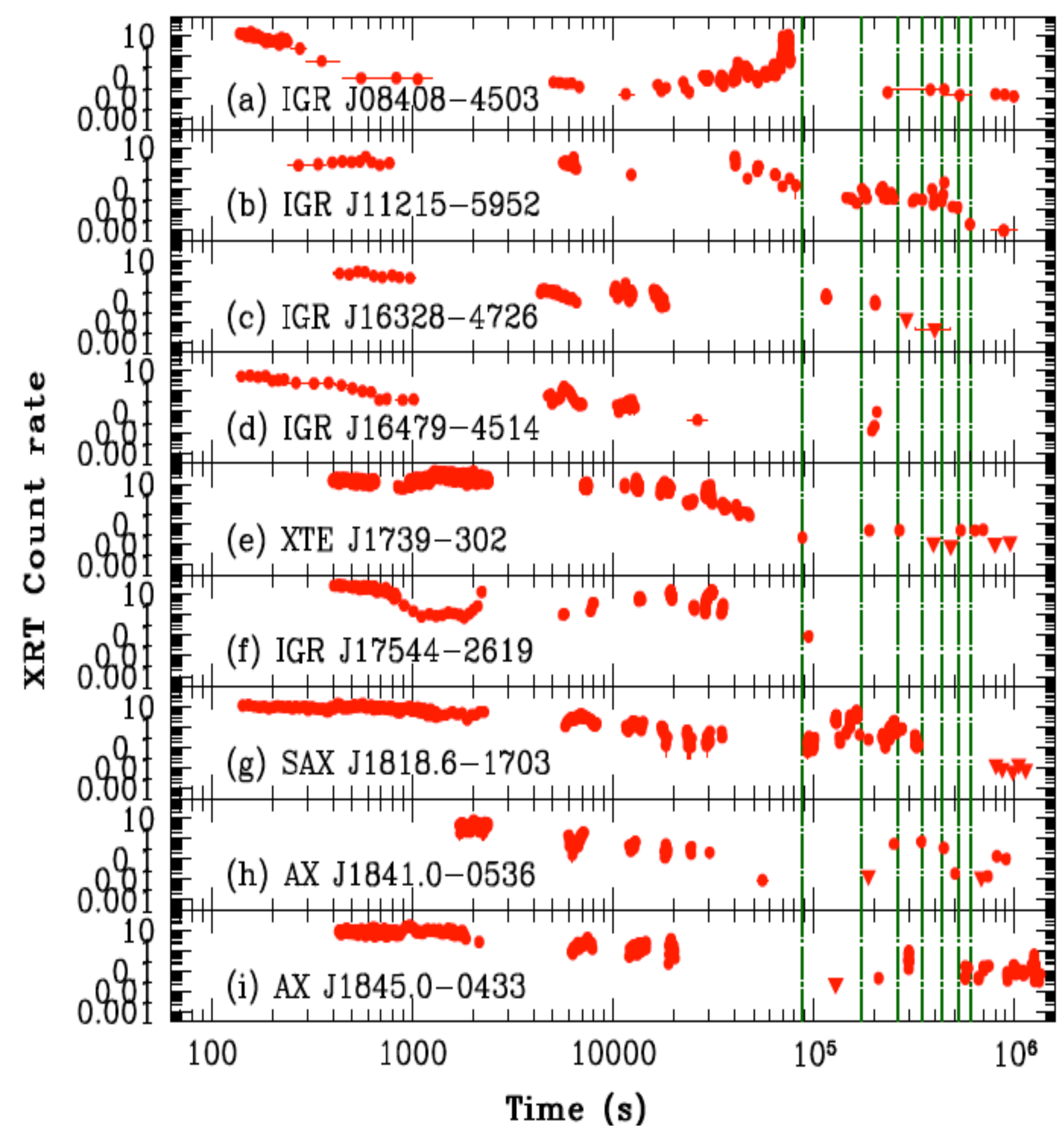
≥Week-long follow-ups

Common features:

✔outburst length > hours

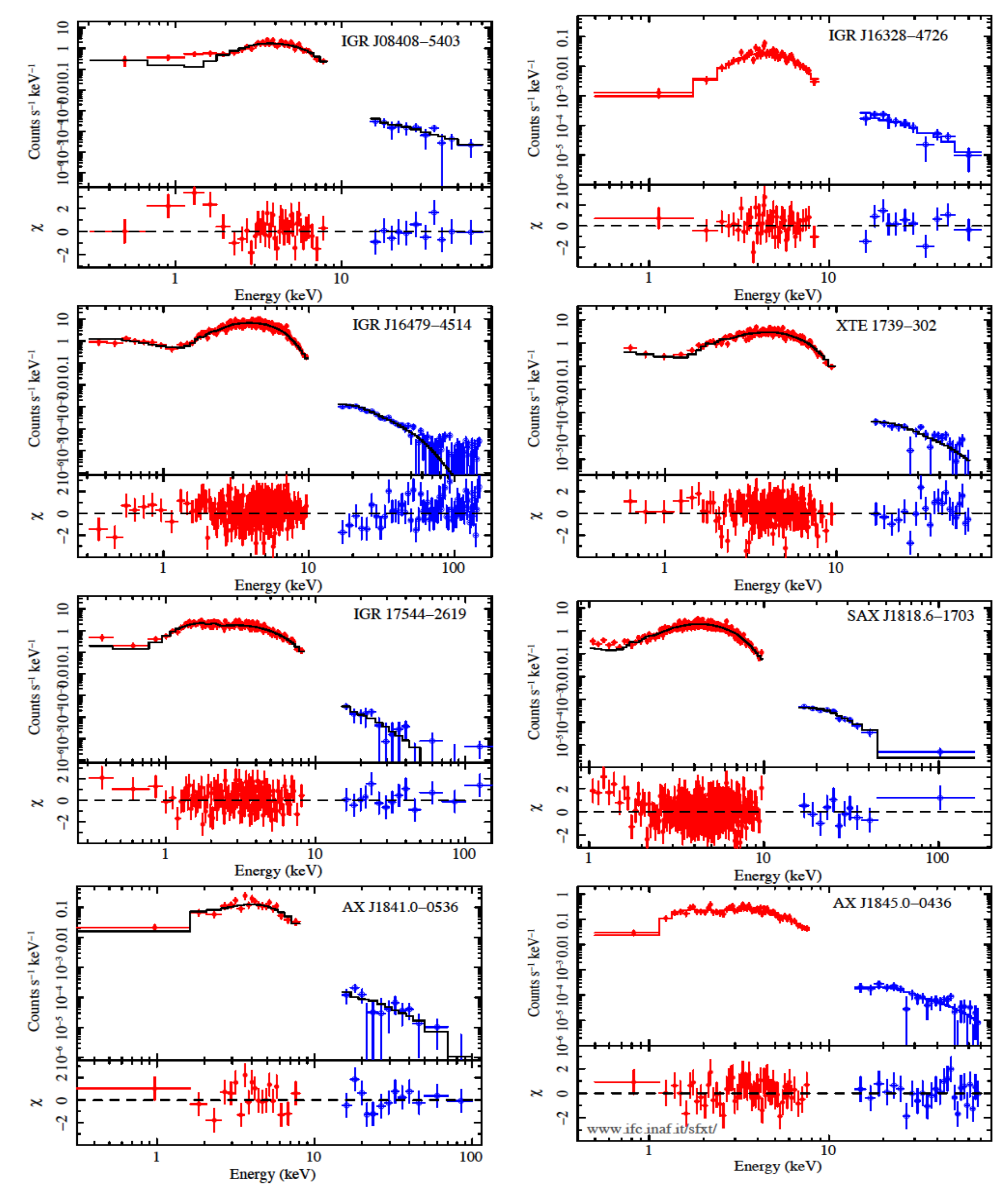
✔multiple peaked structure with lots of flares

✔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

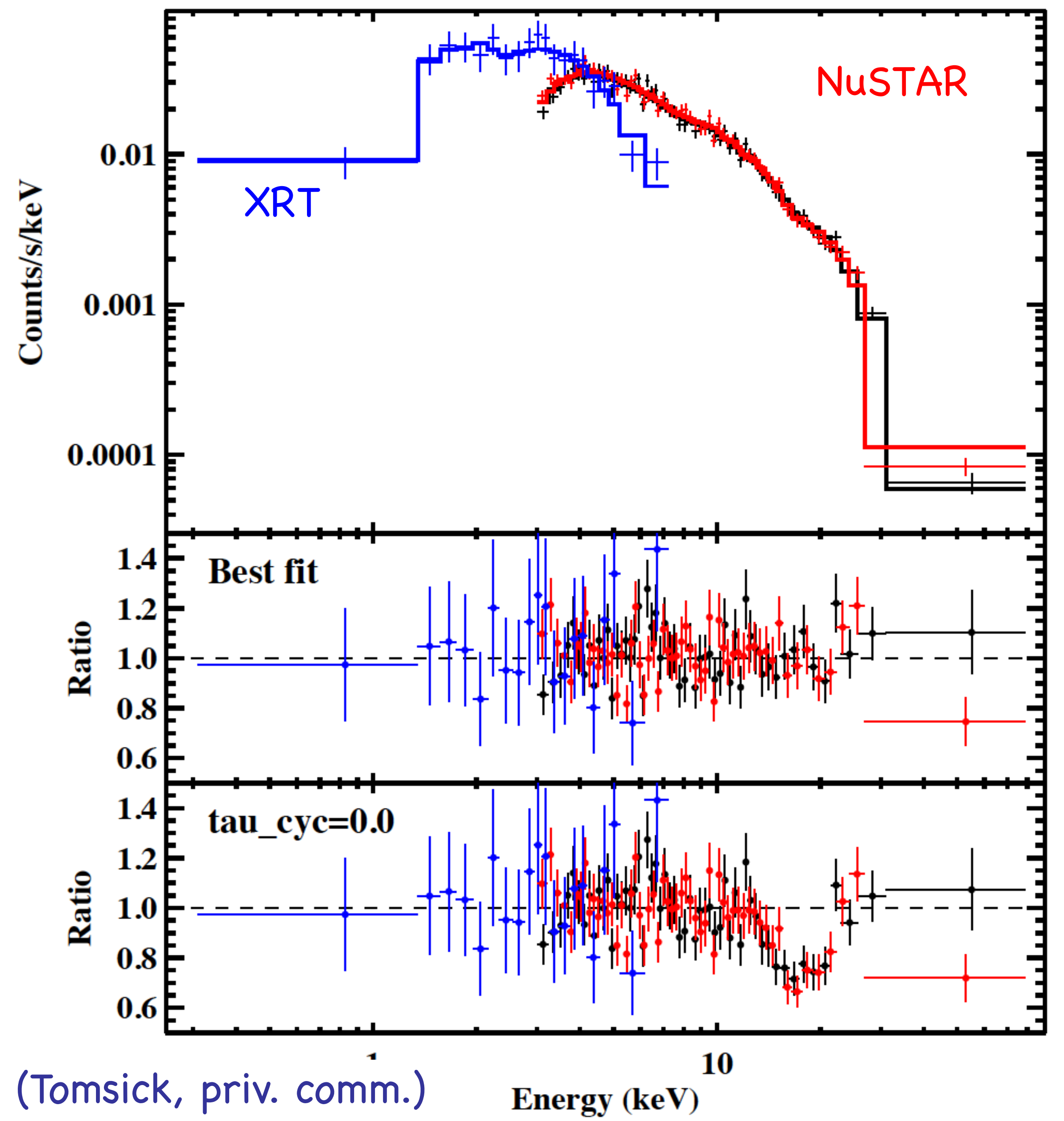
✔absorption
& spectral cut-off

✔comparison with
models for accreting NS

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

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

IGR J17544-2619



(Tomsick, priv. comm.)

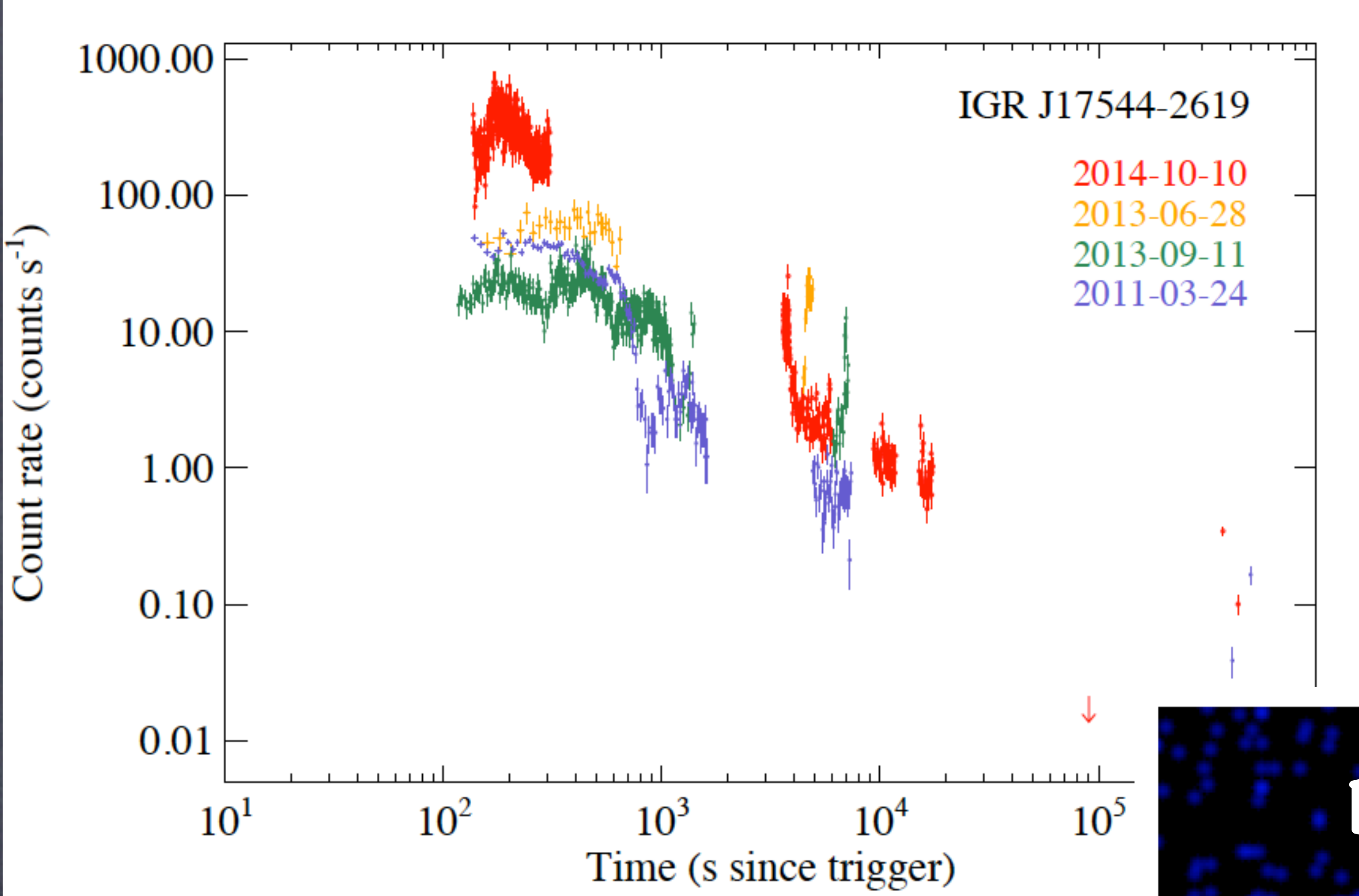
NuSTAR observation
IGR J17544-2619
(Bhalerao, Romano+2015, MNRAS, 447,2274)

Detection of a cyclotron line:
E~17 keV
B~1.5x10^{12} G

Excluding magnetar nature for the prototype

The giant outburst

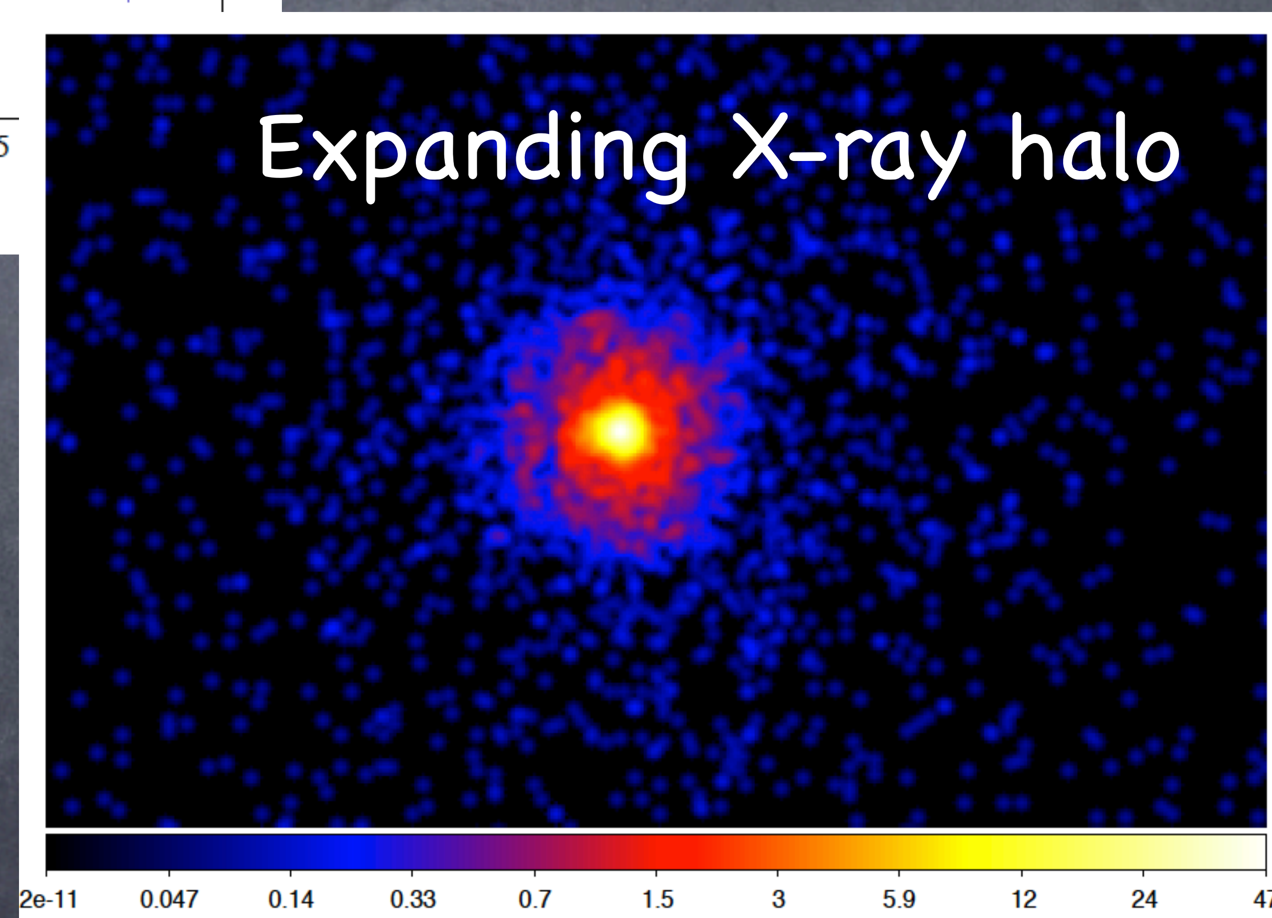
(Romano+2015a,A&A,576,L4)



2014-10-10
Brightest burst
ever recorded from
IGR J17544-2619

Or any other SFXT

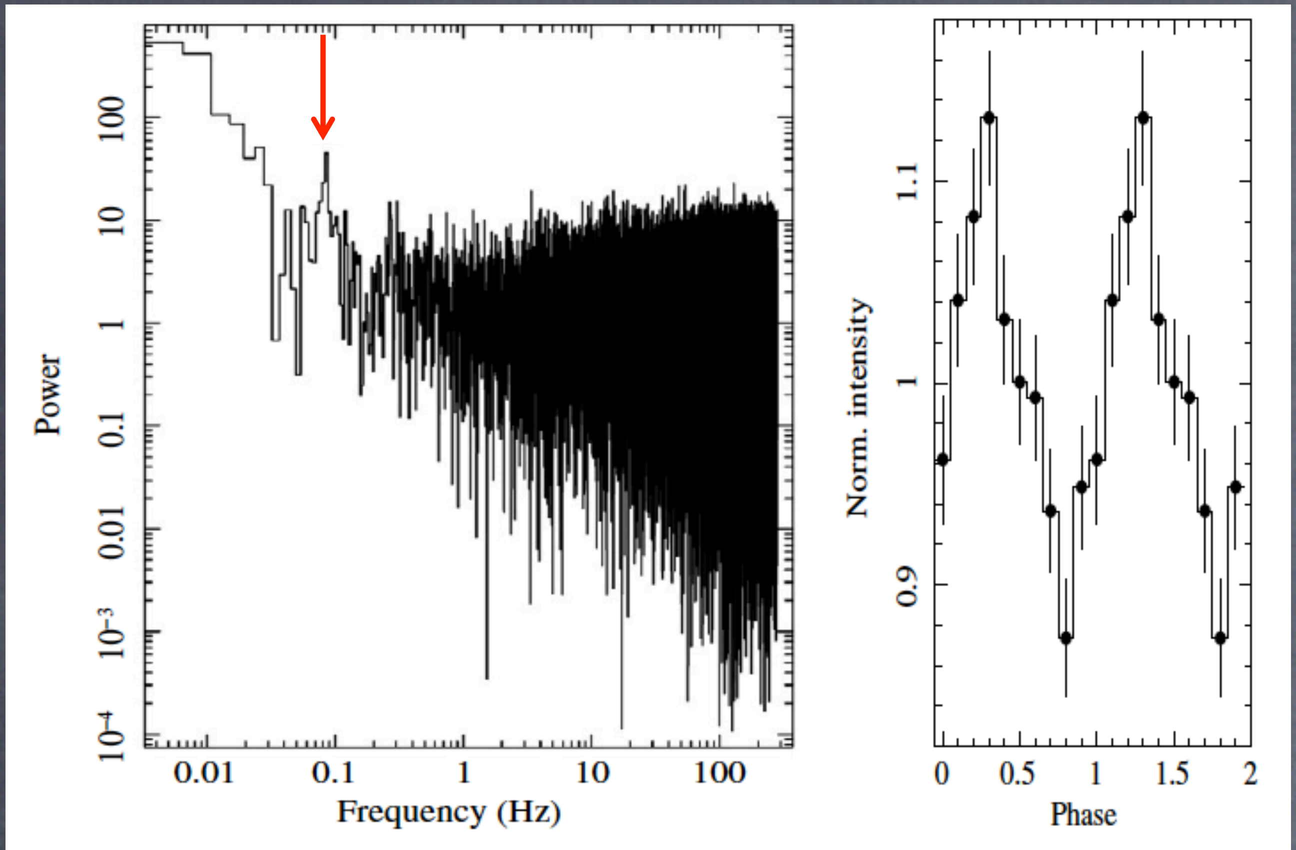
Peak count rate
(0.3-10 keV)
~ 668 counts s^{-1}



(Tiengo+ in prep)

Pulsations at 11.6s

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

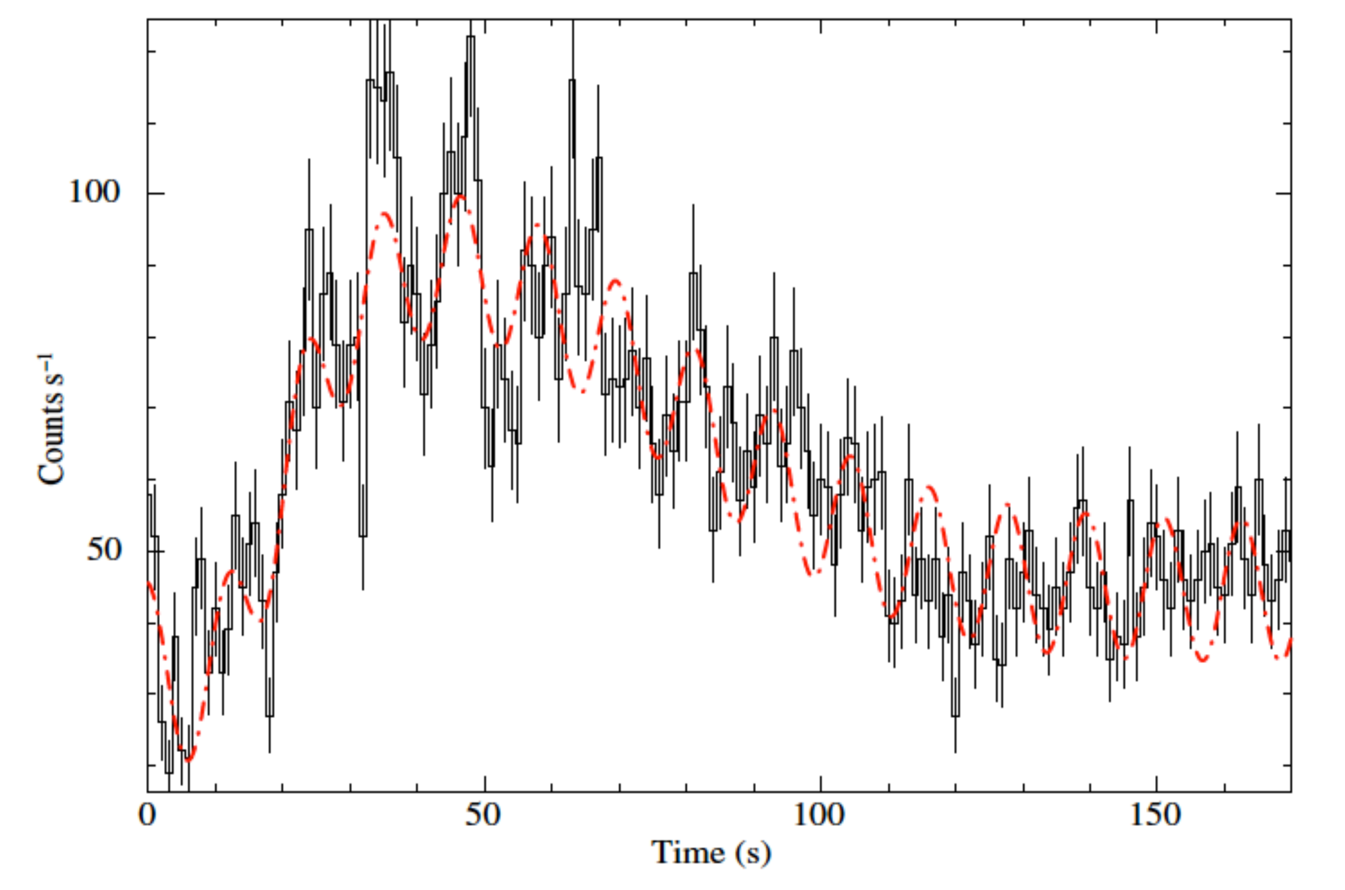


Power spectrum of early data
Peak at 0.086Hz
P=11.58+/-0.03s
Cannot distinguish from QPO

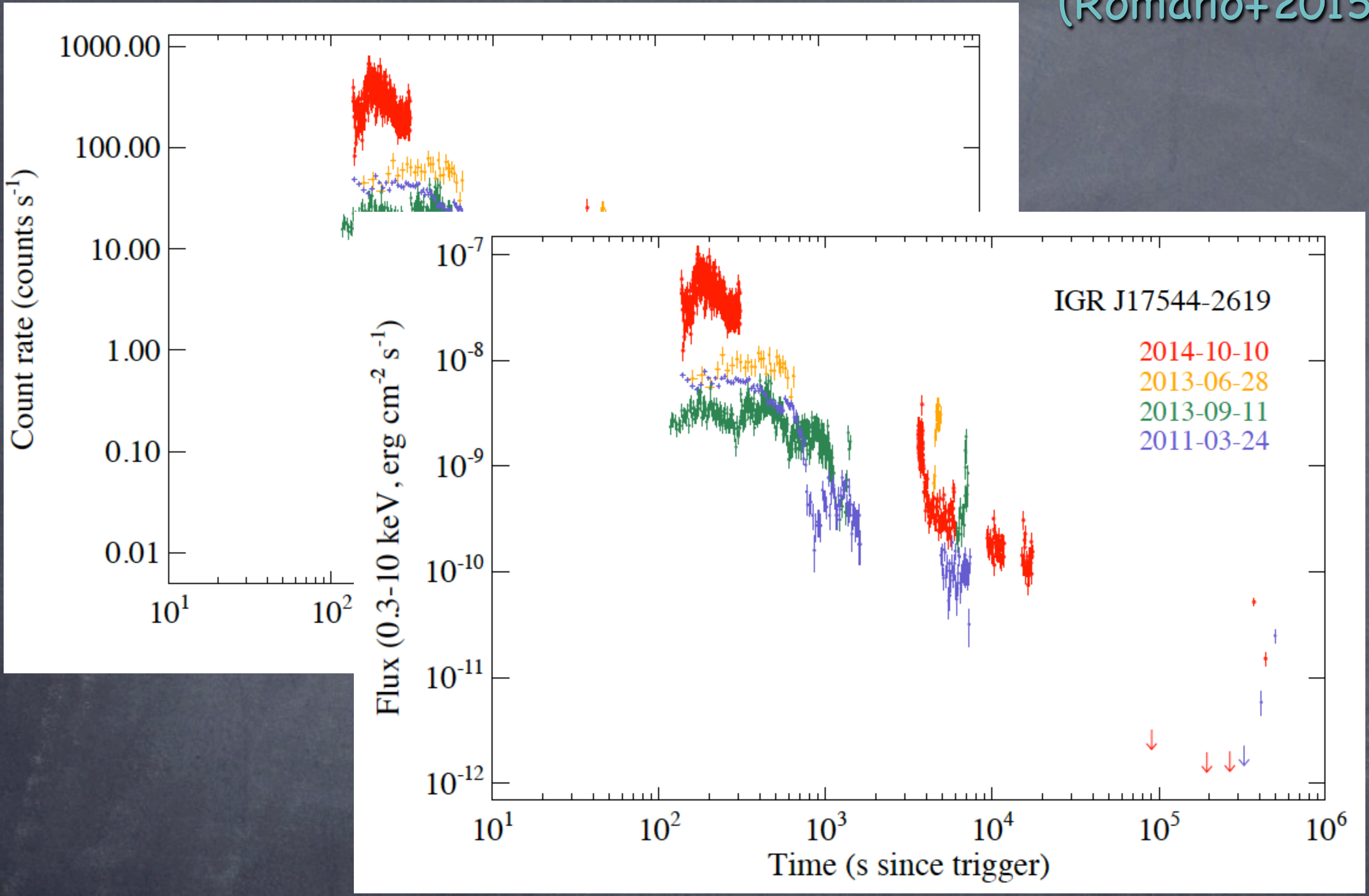
Pulsed profile sinusoidal
(rms pulsed fraction ~10%)

WT light curve fit:
const+2Gaussians
+sinusoidal

P=11.60+/-0.13s
4σ single trial



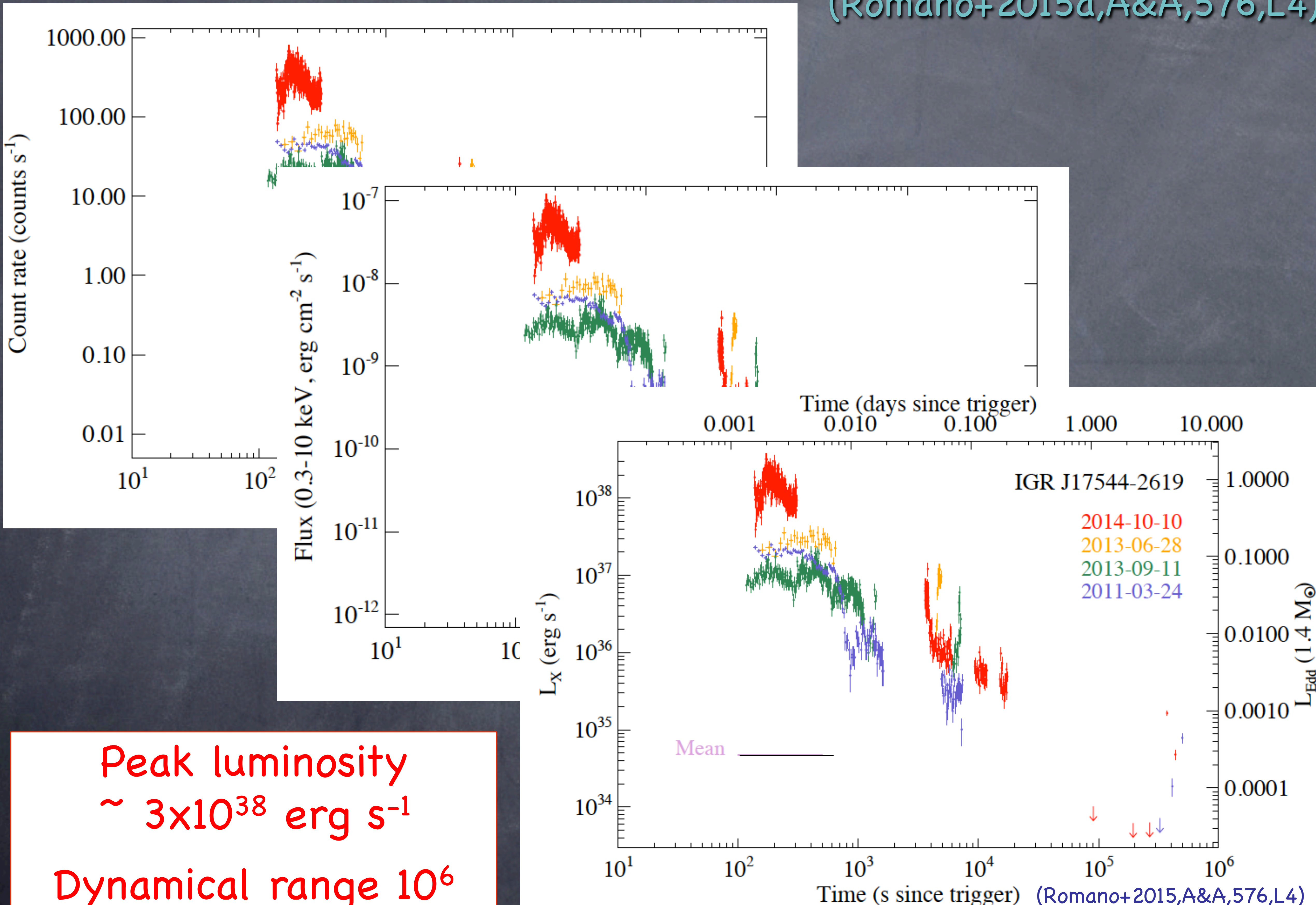
(Romano+2015a,A&A,576,L4)



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

The big, big bada booom!

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

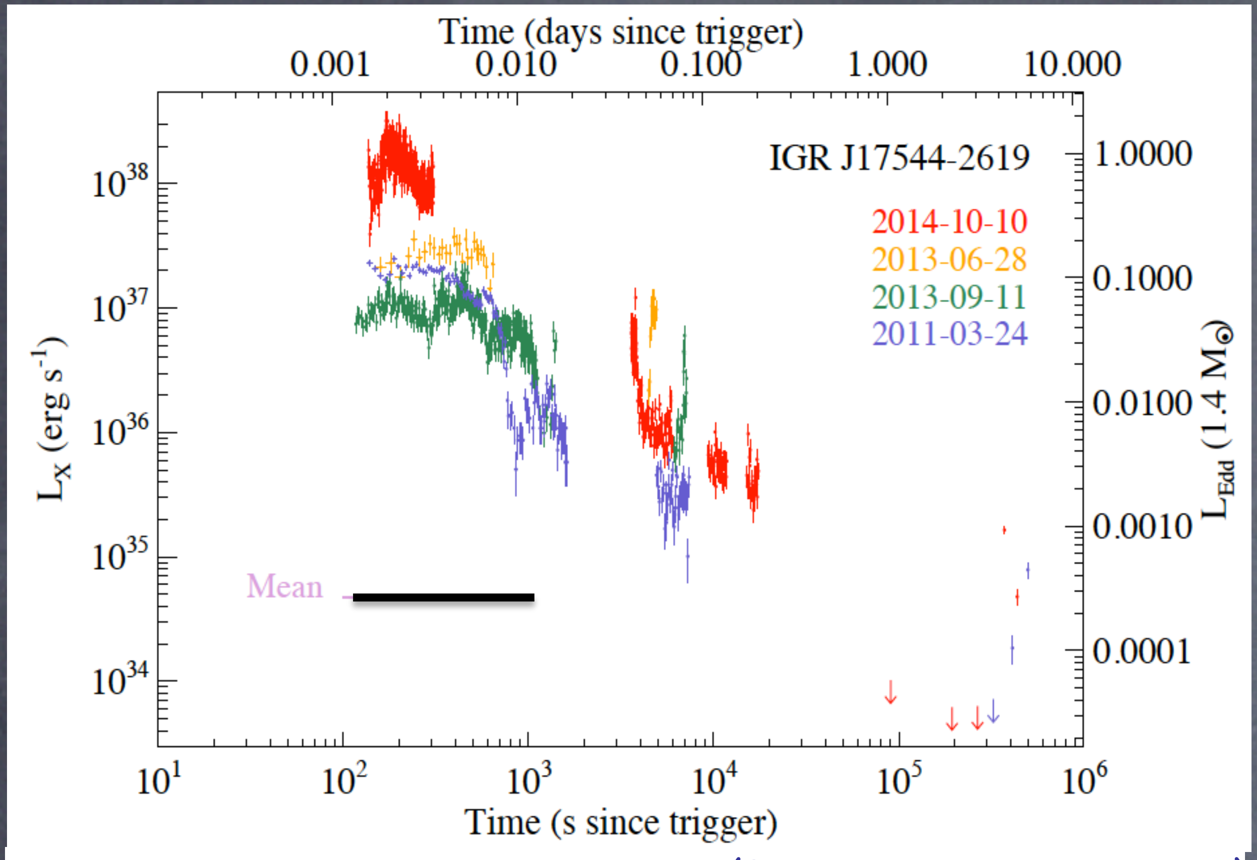


Peak luminosity ~ 3×10^{38} erg s^{-1}

Dynamical range 10^6

Transient accretion disk?

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



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

Cumulative LDs: SFXTs are underluminous wrt classical systems

- Need to inhibit accretion onto CO
- maximum achievable luminosity is direct accretion (BH)

High L reached L_{Edd}

- higher than wind accreting SGXBs

L_X~3x10^{38} erg s^{-1} can be achieved with

- ingestion of massive clump (see Bozzo+2011, but no spectral support)
- very high mass loss rate >> 10^{-6} Msun/yr (unrealistically high)

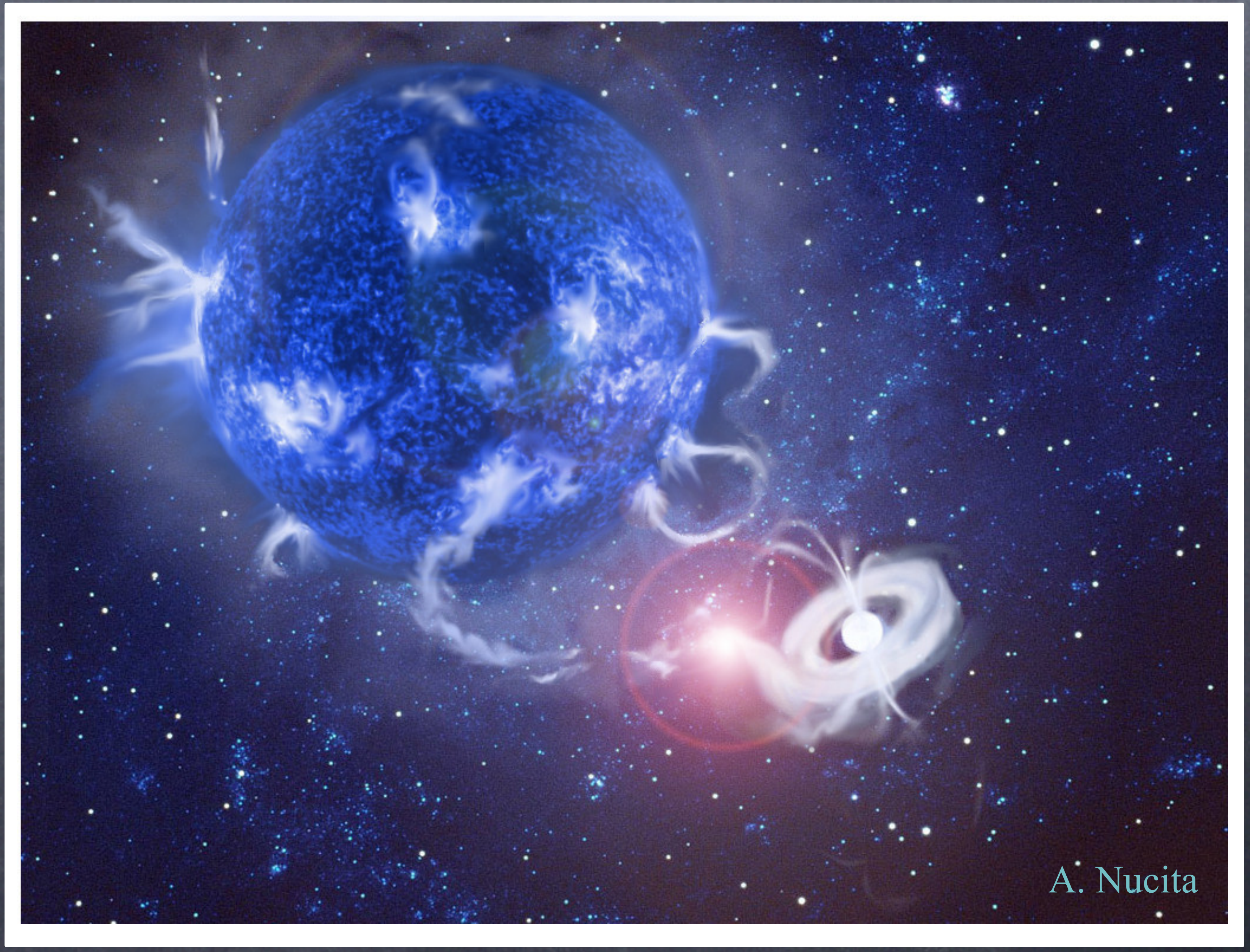
Transient accretion disk?

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

- **very low wind velocity** <~ 2×10^6 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!!!)



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/

Contact point

romano@ifc.inaf.it

Facebook Group

www.facebook.com/groups/sfxts/