The 100-month *Swift* Catalogue of Supergiant Fast X-ray Transients

P. Romano
INAF/IASF Palermo

L. Ducci, H.A. Krimm, D.M. Palmer, P. Esposito, S. Vercellone,
P.A. Evans, C. Guidorzi, V. Mangano, J.A. Kennea,
S.D. Barthelmy, D.N. Burrows, N. Gehrels

Outline

The *Swift* Supergiant Fast X-ray Transients Project

- Definitions
- Results:
  - panchromatic outbursts and XRT follow-ups
  - arcsecond localizations
  - long term monitoring campaigns

The 100 month Swift catalogue of SFXT

- Motivations
- Source sample selection
- Data sample
- Results

A *Swift* legacy

- SFXT Flare prediction calculation

The *Swift* SFXT Project

Supergiant Fast X-ray Transients: HMXBs with

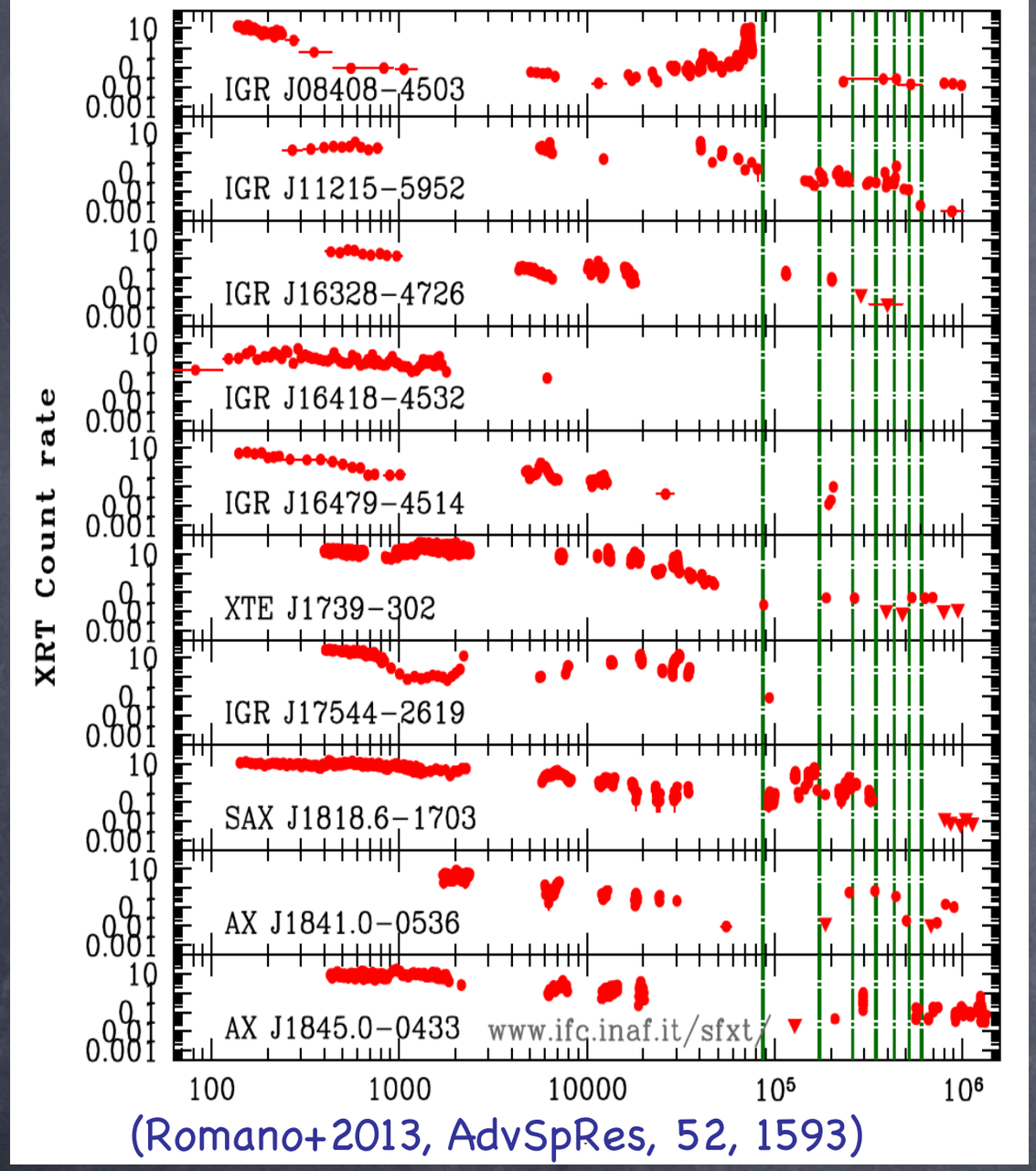
- -OB SG companions
- -hard X-ray outbursts
  - -lasting 0.5-few hours
  - -luminosity increases by 3-5 orders of magnitude (up to 10^{36}-10^{37} erg s^{-1})
  - -spectra resembling NS HMXBs (absorbed power laws with exponential cutoffs).
  - -Some are pulsars, maybe they all host NSs
  - -outburst mechanism?

Flare = enhanced emission generally lasting for a few hours

Outburst = composed of several flares and lasts for about a day or more

Confirmed **SFXT** vs SFXT **Candidate**: ID of IR/OPT companion

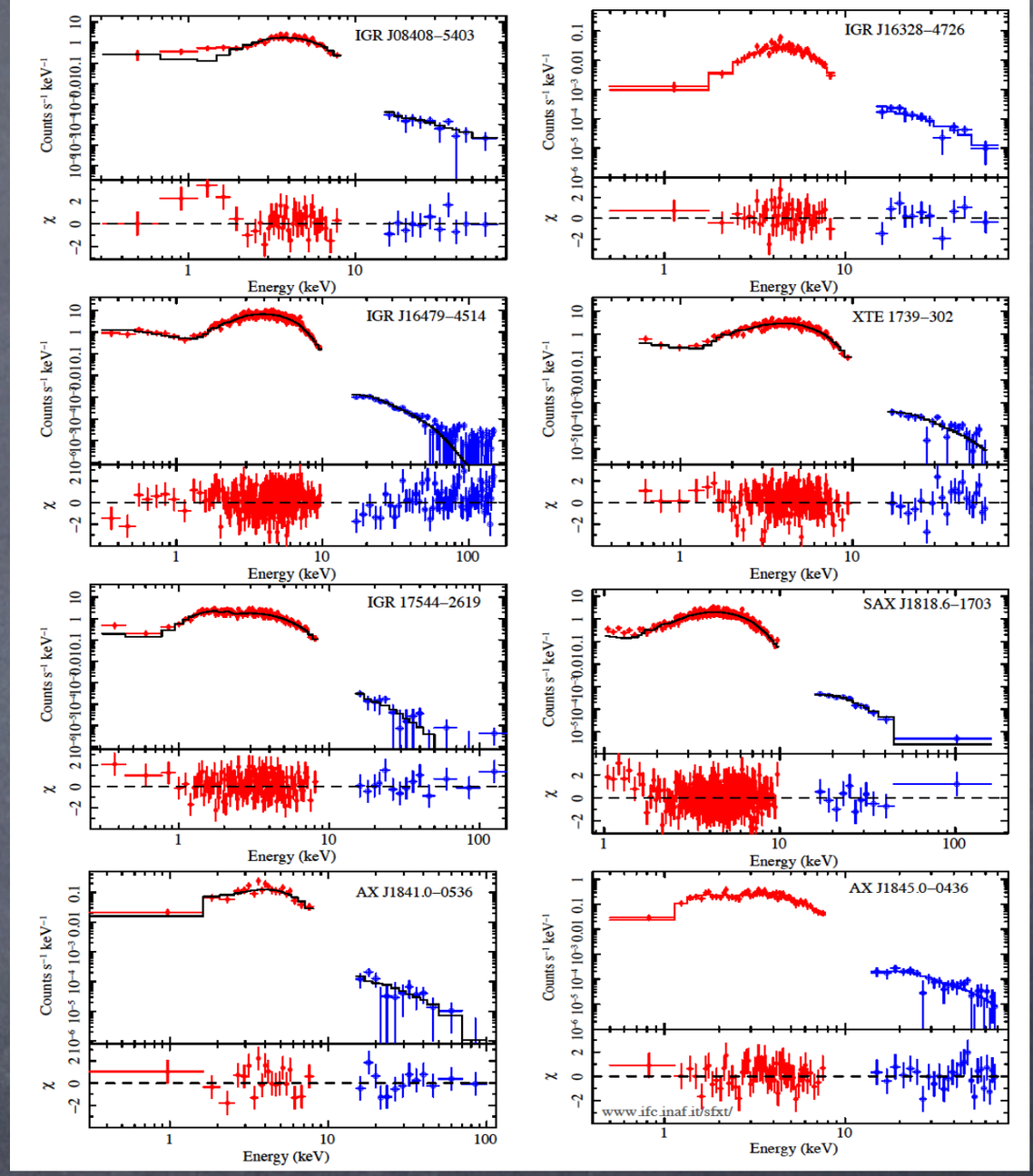
SFXT Outbursts



(Romano+2013, AdvSpRes, 52, 1593)

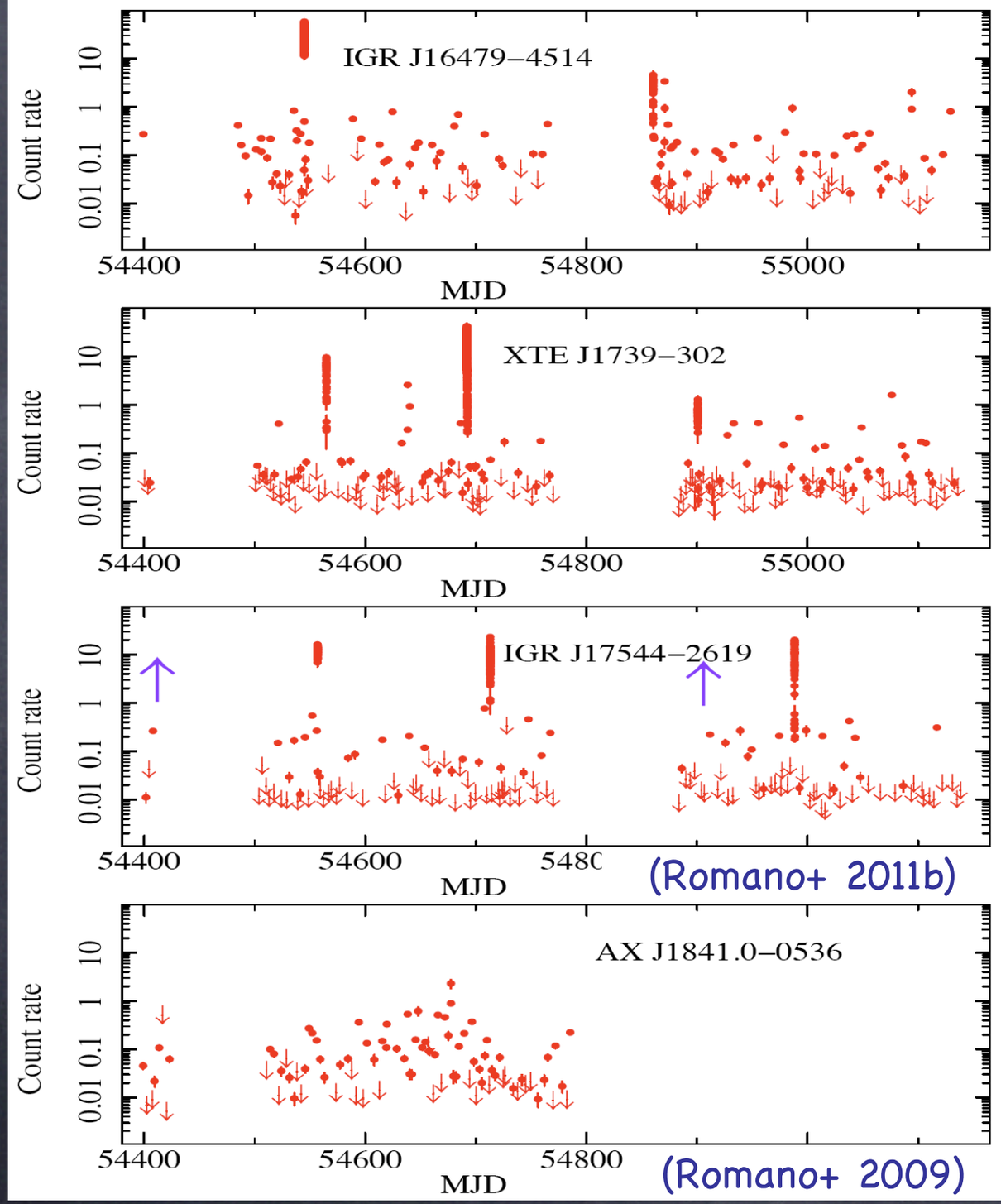
Swift/XRT light curves
at High time resolution

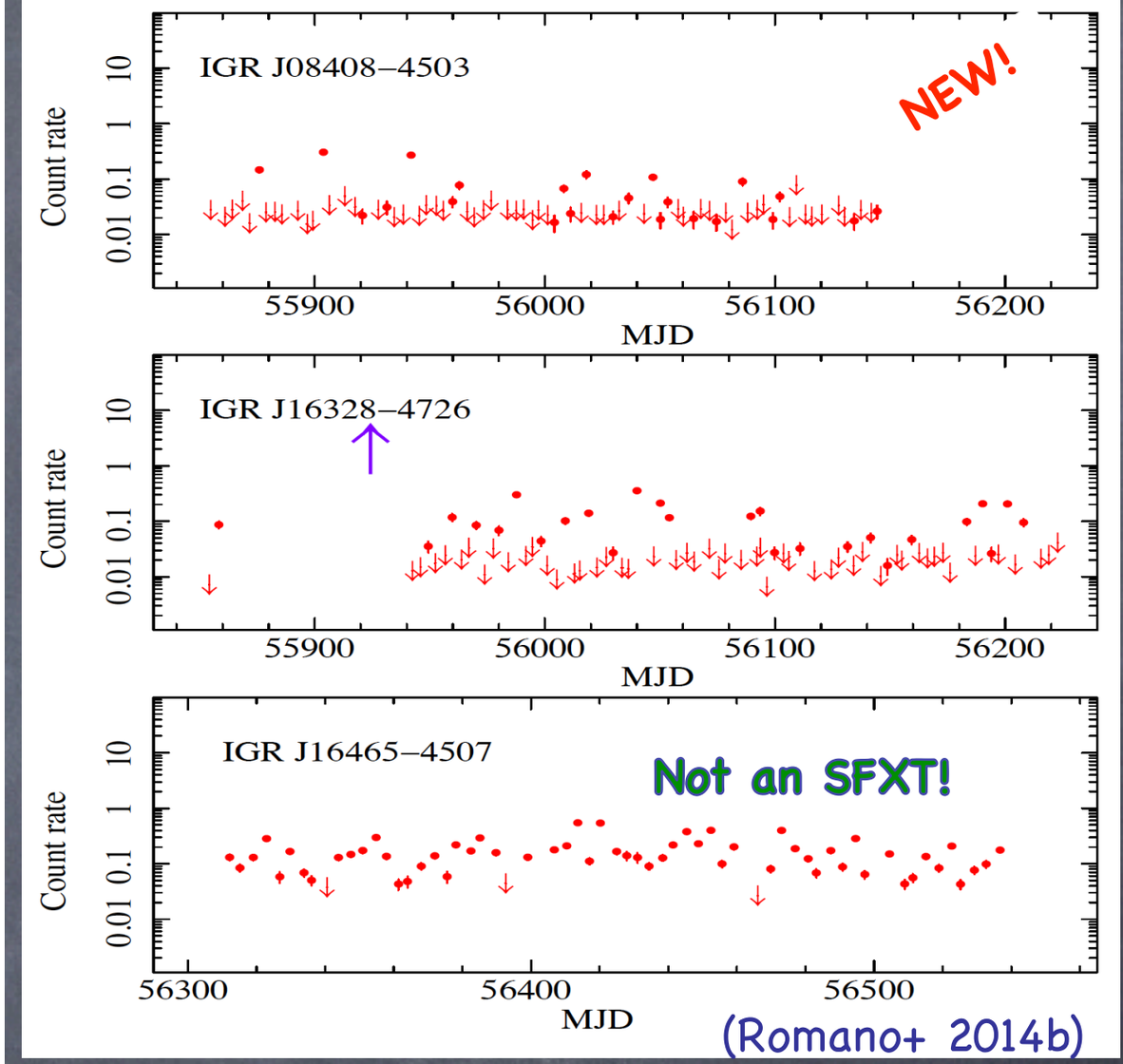
- BAT Special Functions
- Arcsecond localizations



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

Long term monitoring





- Dynamical range: 4 oom
- 1-5% of time in outbursts
- Emission outside of outbursts:
- $L \sim 10^{33} - 10^{34}$ erg s^{-1}
- Variability: days to months

Daily resolution

Catalogue Motivation

Outbursts have been triggering the BAT early since launch

But SFXTs show flares in all intensity states

BAT covers ~ 88% of the sky daily, hence ideally suited to detect flaring in hard X-ray astrophysical sources

We can leave a legacy of the recording of a thousand flares uniformly observed in the time range
2005-Feb-12 to 2013-May-31

Source Sample

Name	P_{spin} (s)	P_{orb} (d)	P_{sup} (d)	Eclipse	e	Spectral Type
IGR J08408−4503	-	35?	-	N	-	O8.5Ib(f)
IGR J11215−5952	186.78 ± 0.3	164.6	-	N	-	B0.7Ia
IGRJ 16328−4726	-	10.076 ± 0.003	-	N	-	O8Iafpe
IGRJ 16418−4532	1209.12 ± 0.42	3.73886 ± 0.00003	14.730 ± 0.006	Y	-	BN0.5Ia
IGR J16465−4507	228 ± 6	30.243 ± 0.035	-	N	-	B0.5Ib/O9.5Ia
IGR J16479−4514	-	3.3193 ± 0.0005	11.880 ± 0.002	Y	-	O8.5I
XTE J1739−302	-	51.47 ± 0.02[a]	-	N	-	O8Iab(f)
IGR J17544−2619	71.49 ± 0.02	4.926 ± 0.001	-	N	> 0	O9Ib
SAX J1818.6−1703	-	30 ± 0.1	-	N	0.3–0.4	09I-B1I
AX J1841.0−0536	4.7394 ± 0.0008?[b]	-	-	N	-	B1Ib
AX J1845.0−0433	-	5.7195 ± 0.0007	-	N	< 0.37	O9.5I
IGR J18483−0311	21.0526 ± 0.0005[c]	18.545 ± 0.003	-	N	0.4	B0.5Ia/B0-B1Iab

- "SFXT" Sample definition challenging
- From the literature, based on evidence of bright flares (peak L >~ 10^{36} erg s^{-1}) recorded by ASCA, RXTE, INTEGRAL, and *Swift*

Data Sample

BAT Triggers (T)

(Fenimore et al 2003, AIP Conf Ser, 662, 491)

SFXTs trigger BAT like GRBs do

- RATE: short (<64ms), long (<24s), in 4 energy bands
- IMAGE: (>64s, 15-50 keV)

SFXTs are generally image triggers from known sources

Special Functions will command slew and GRB-like response.

BAT Transient Monitor (D,o)

(Krimm et al 2013, ApJS, 209, 14)

- BAT covers ~ 88% of the sky daily, ideal to detect flaring in hard X-ray astrophysical sources
- Daily average and orbit-level light curves (15-50 keV)

- collected all detections >5 σ
- 2005-Feb-12 to 2013-May-31 (MJD 53413- 56443).

Subsamples (D) and (o)

Data Sample

BAT on-board detections (d)

-We considered all on-board detections >~ 5 σ

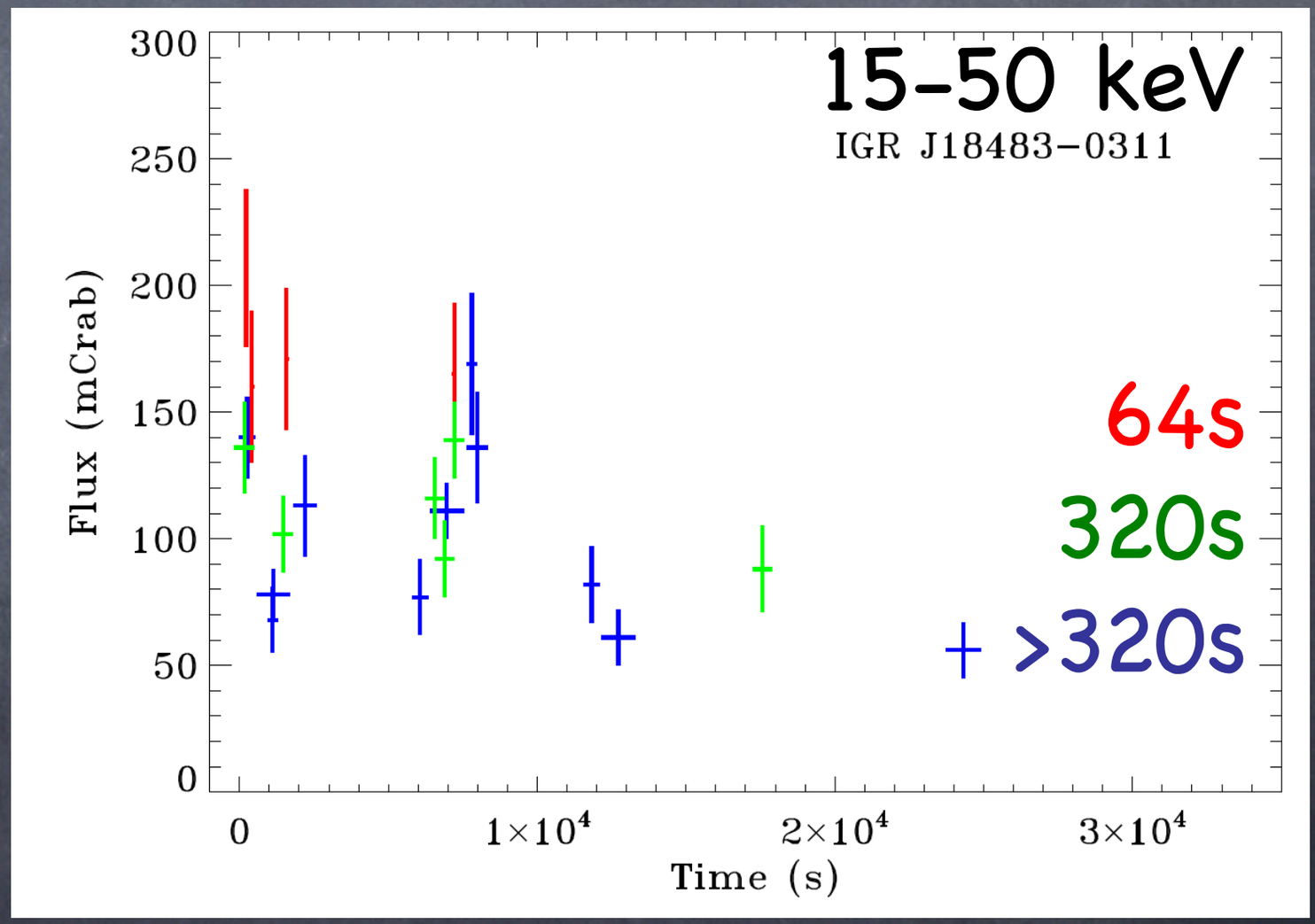
-selected those within 4 arcmin of each source

-2005-Feb-12 to 2013-May-31 (MJD 53413- 56443).

Subsample (d).

Example of on-board data

Given the cut in σ:
catalogue is a
flux limited sample
of flares.



Detections: Total Numbers

Total numbers
- -BAT (T)riggers
- -BATTM (Daily)
- -BATTM (orbital)
- -on-boar(d)

Several detections per day

Name	BAT on-board triggers	BATTM $> 5\sigma$ daily	BATTM $> 5\sigma$ orbital	BAT on-board detections
Flag	T	D	o	d
IGR J08408−4503	7	4	7	50
IGR J16328−4726	2	0	4	4
IGR J16418−4532	3	5	17	19
IGR J16465−4507	0	1	1	1
IGR J16479−4514	8	39	75	147
XTE J1739−302	8	5	39	124
IGR J17544−2619	5	12	32	90
SAX J1818.6−1703	5	8	23	54
AX J1841.0−0536	4	8	24	48
AX J1845.0−0433	3	3	11	17
IGR J18483−0311	1	41	34	124
Totals	46	126	267	678

Detections: Total Numbers

Total numbers
- -BAT (T)riggers
- -BATTM (Daily)
- -BATTM (orbital)
- -on-boar(d)

Several detections per day => Total number of days sources were detected

Name	BAT on-board triggers	BATTM $> 5\sigma$ daily	BATTM $> 5\sigma$ orbital	BAT on-board detections
Flag	T	D	o	d
IGR J08408−4503	7 (6)	4	7 (5)	50 (8)
IGR J16328−4726	2	0	4 (3)	4 (2)
IGR J16418−4532	3	5	17 (16)	19 (10)
IGR J16465−4507	0	1	1 (1)	1(1)
IGR J16479−4514	8 (7)	39	75 (61)	147 (50)
XTE J1739−302	8 (7)	5	39 (29)	124 (37)
IGR J17544−2619	5	12	32 (23)	90 (22)
SAX J1818.6−1703	5	8	23 (17)	54 (14)
AX J1841.0−0536	4	8	24 (16)	48 (17)
AX J1845.0−0433	3	3	11 (8)	17 (9)
IGR J18483−0311	1	41	34 (24)	124 (35)
Totals	46(43)	126	267 (203)	678 (205)

The 100-month Catalogue

Full catalogue (ASCII/FITS)

fv: Summary of SFXT_BAT_catl.fits in /Users/pat/Work/Swift/data/Sfxt_Swift/Catalog_sfxt/Bat/

File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header / Image / Table
1	NoName	Binary	12 cols X 1117 rows	Header / Hist / Plot / All / Select

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

File Edit Tools Help

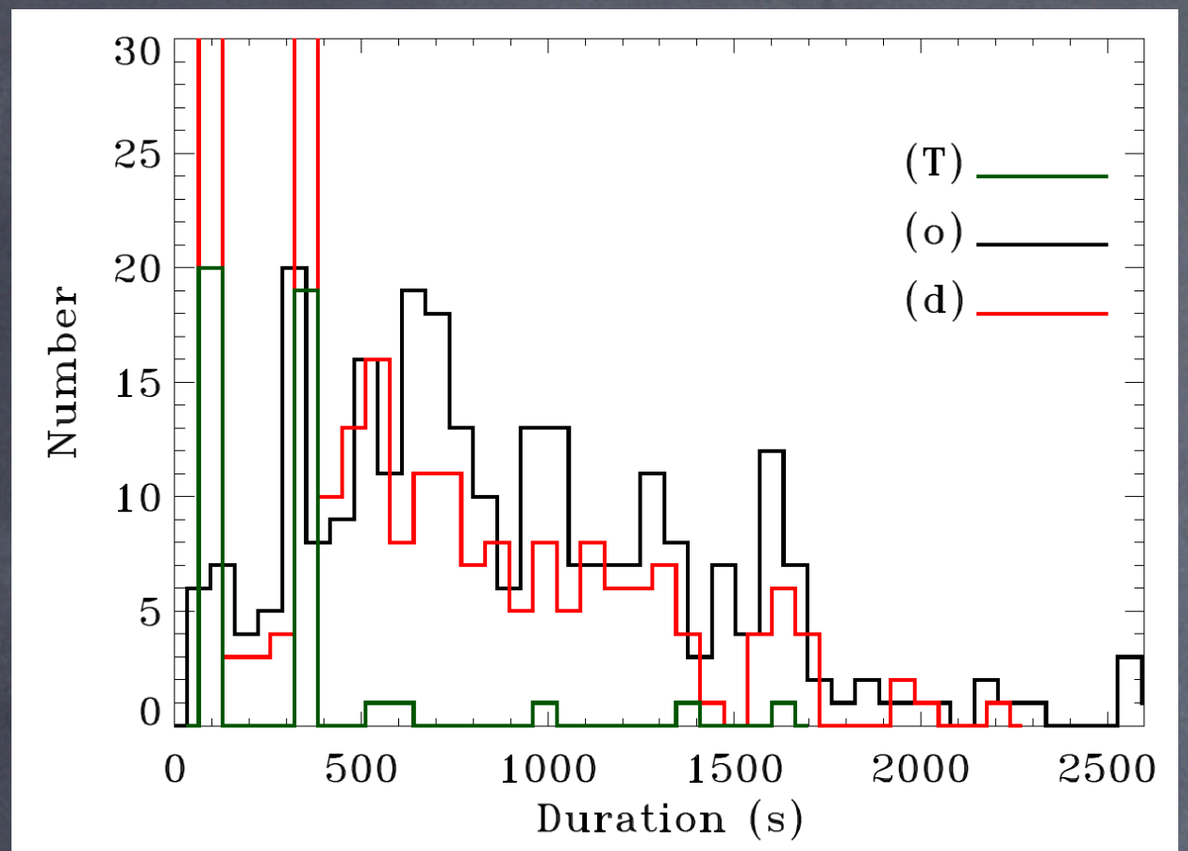
Select	UNIQ_NUM	SOURCE	FLAG	YEAR	DOY	MJD	UTDATE	UTTIME	DURATION	SIGMA	FLUX	TRIGNUM
All	I4	18A	A1	I4	I3	D20	10A	8A	E s	E	E mCrab	J
Invert	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	1	IGRJ08408-4503	D	2008	265	5.473000000000E+04	2008-09-21	00:00:00	8.640000E+04	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

1117 flares on 11 sources

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

- 46 BAT (T)riggers (43 outbursts)
- 126 BATTM (Daily)
- 267 BATTM (orbital)
- 678 on-boar(d)

Flare ensemble properties

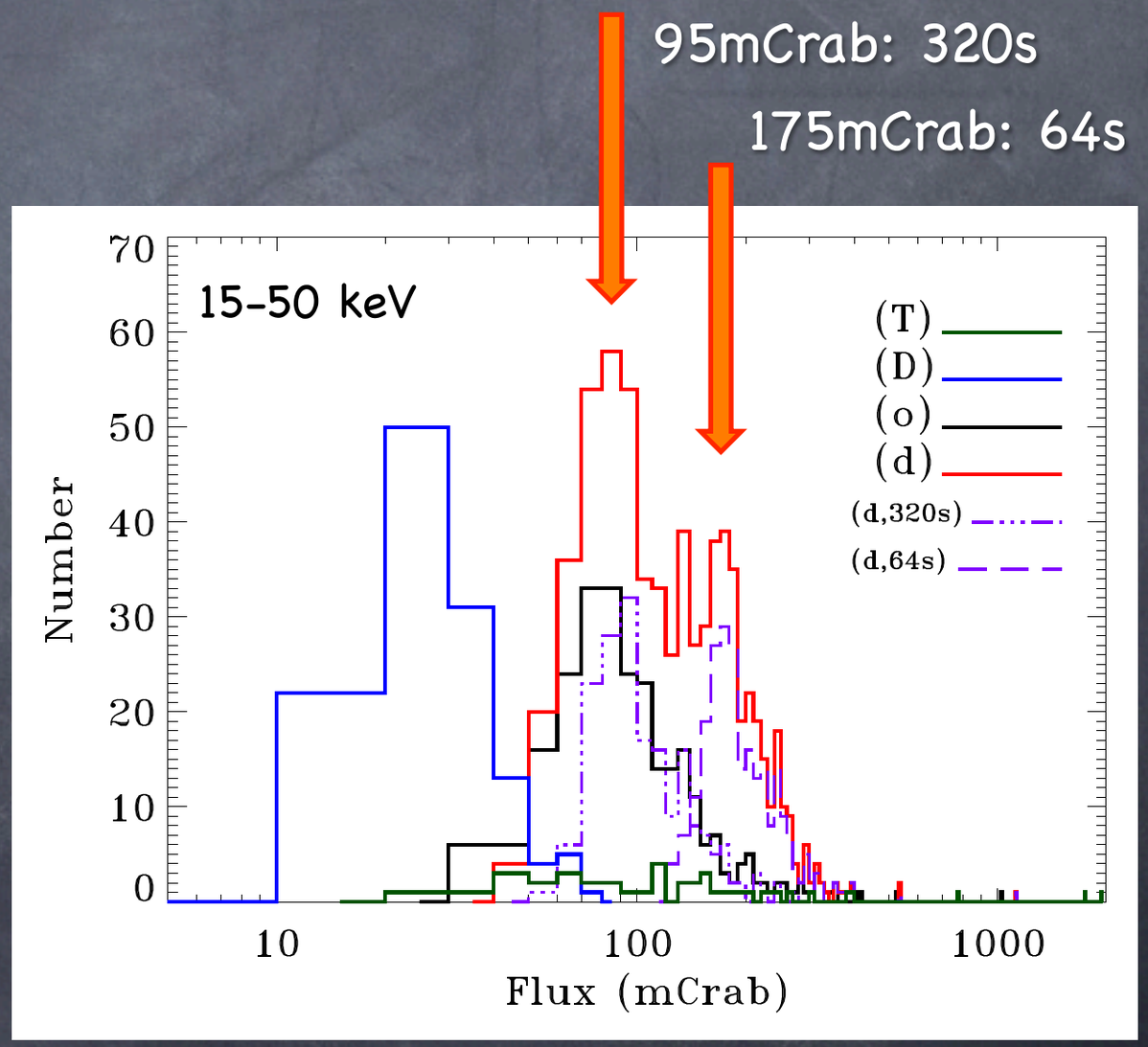


Durations

- -means: 285s(T), 900s(o), 350s(d)
- -Image duration used as a proxy for flare duration,
- => two peaks

95mCrab: 320s

175mCrab: 64s



Fluxes

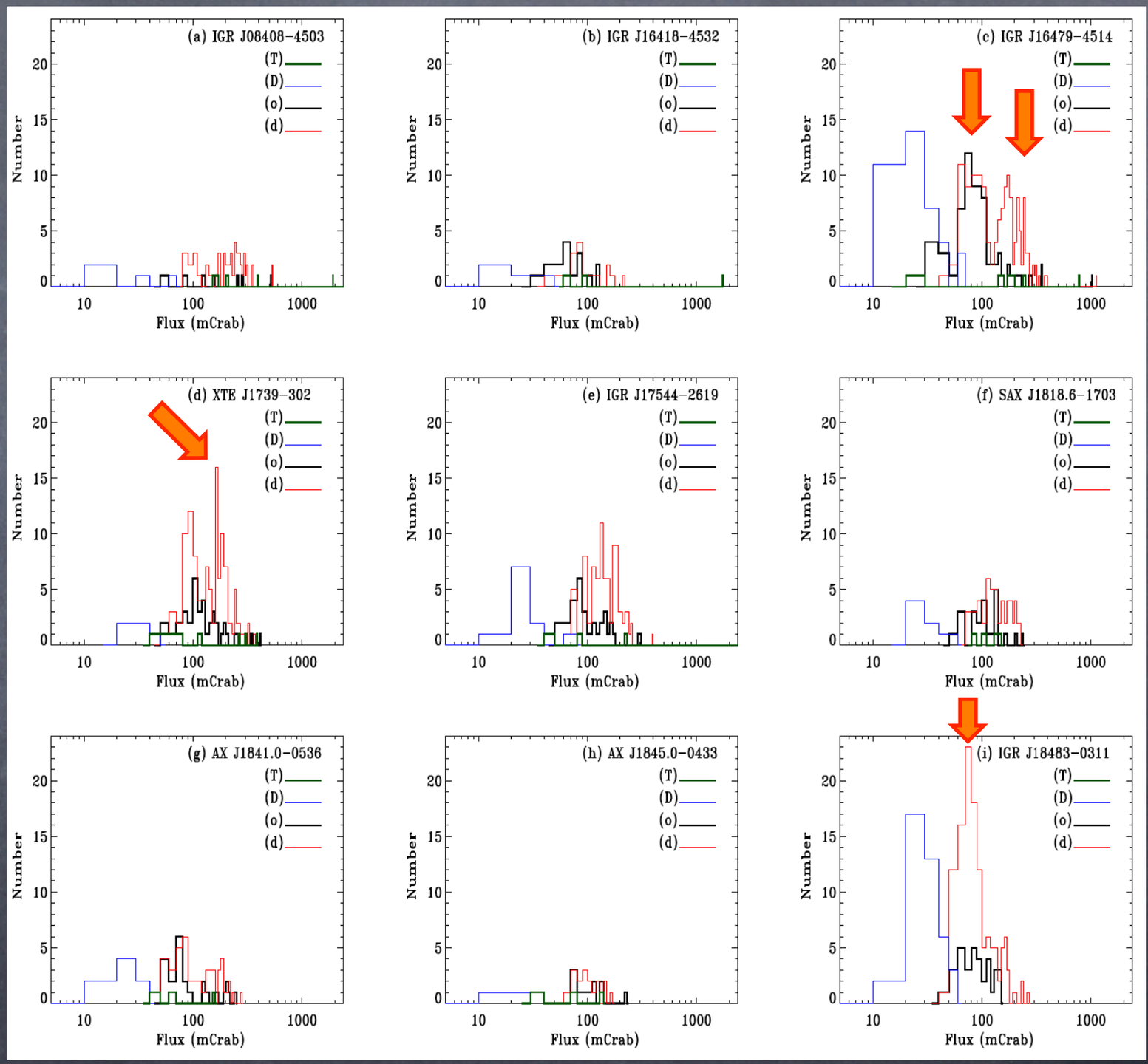
- -low end @~15mCrab (D)
  - $L \sim 6 \times 10^{35}$ erg s^{-1} (at 5kpc)
- -high end @1.9Crab (T)
  - $L \sim 7 \times 10^{37}$ erg s^{-1}
- -overall median: 105mCrab
  - $L \sim 4 \times 10^{36}$ erg s^{-1}
- -two peaks in on-boar(d)

Flux distributions

For individual sources

- derive prevailing timescale:

- XTE J1739−302
  stronger 64s peak
  >~ 64 s flare length
- IGR J16479−4514
  2 equivalent peaks
  >~ 320 s flare length
- IGR J18483−0311
  stronger 320s peak
  >~ 320 s flare length



Population of flares:
short (x100 s)
bright (~100 mCrab
$L \sim 4 \times 10^{36}$ erg s^{-1}) events

≠ soft X-ray

Flare Orbital Distribution

Clustering of flares

indirect measure of outburst length

even when low-level emission undetected

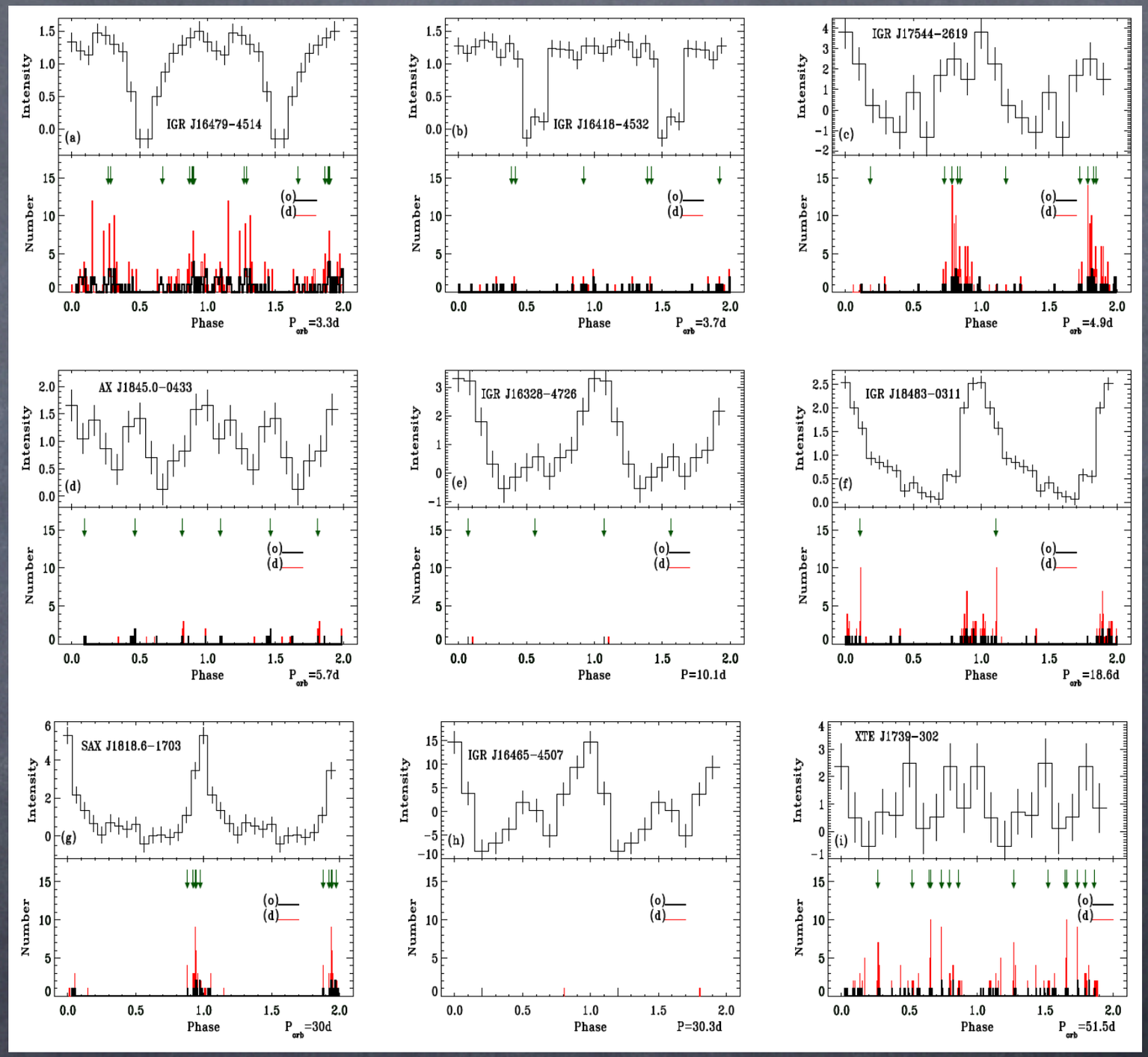
Top: folded BATTM(o)

Bottom: (T), (o), (d)

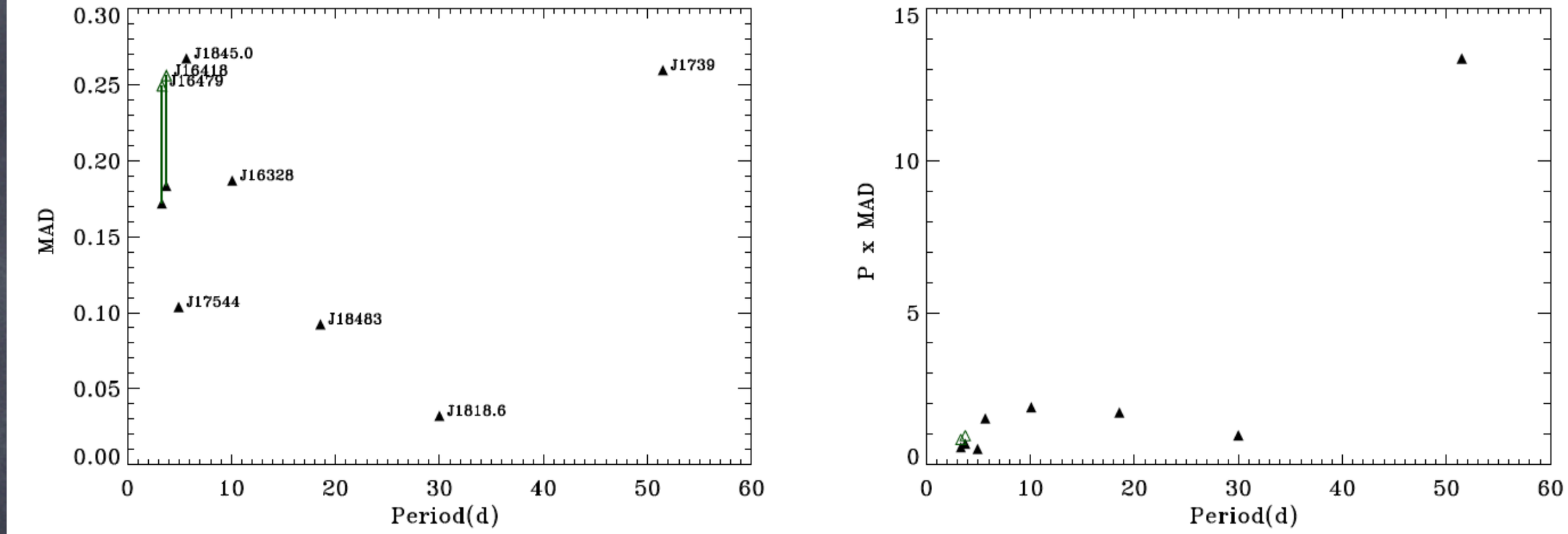
Trend for Clustering increasing with P_{orb}:

Tight ~circular orbits at short P_{orb}

Wider, eccentric orbits at long P_{orb}



Flare Orbital Clustering

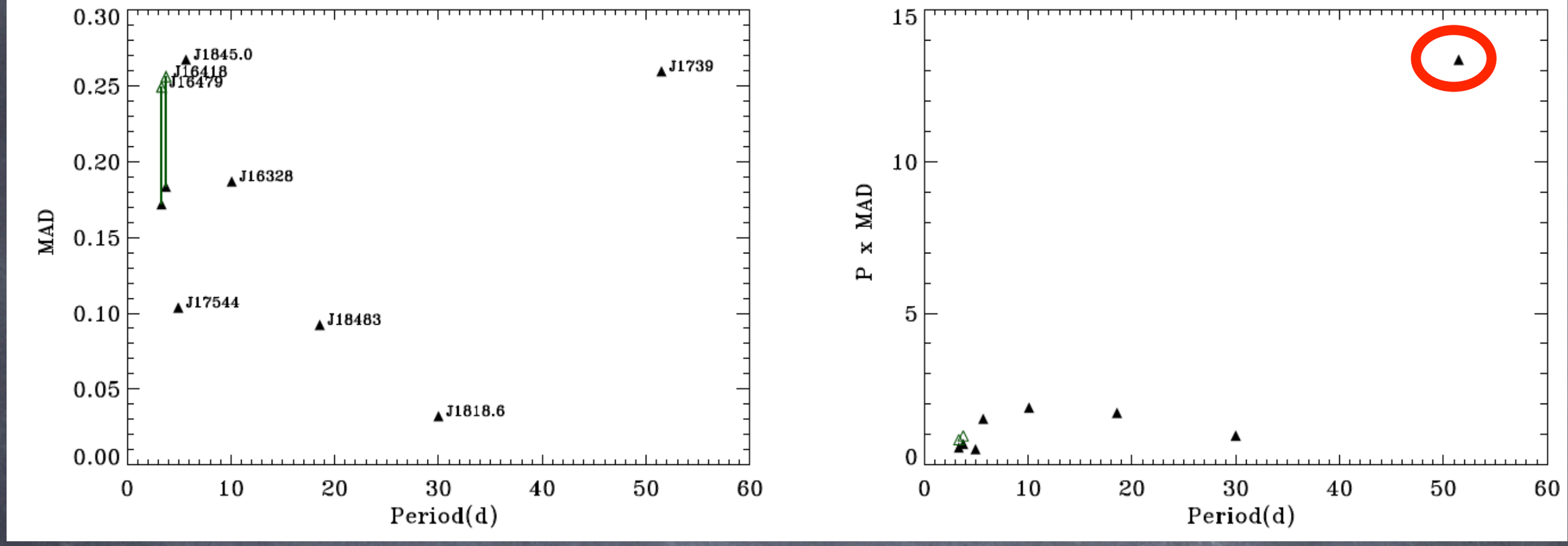


Trend for Clustering increasing with P_{orb}:
Tight ~circular orbits at short P_{orb}
Wider, eccentric orbits at long P_{orb}

$$\text{Mean Absolute Deviation} = \frac{1}{N}\sum_{j=0}^{N-1}|x_j - \bar{x}|$$

MAD (phase) measure of clustering
MAD x Porb (d) measure of duty cycle

Flare Orbital Clustering



Trend for Clustering increasing with P_{orb}:
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MAD (phase) measure of clustering
MAD x Porb (d) measure of duty cycle

Future Perspectives

Planning for future missions (hard X monitors)

- -Estimate outcomes
- -Plan observations

Seasonal observability
Extrapolate observed # flares on a 5-year baseline

At 5σ (one orbit): flux > 1.46×10^{-9} erg cm^{-2} s^{-1} (15-150 keV)

(8.24×10^{-10} cgs in 15-50 keV)

Expected number of flares in excess of 1.46×10^{-9} erg cm^{-2} s^{-1} (15–150 keV band) for a 5-year mission from the SFXT sample.

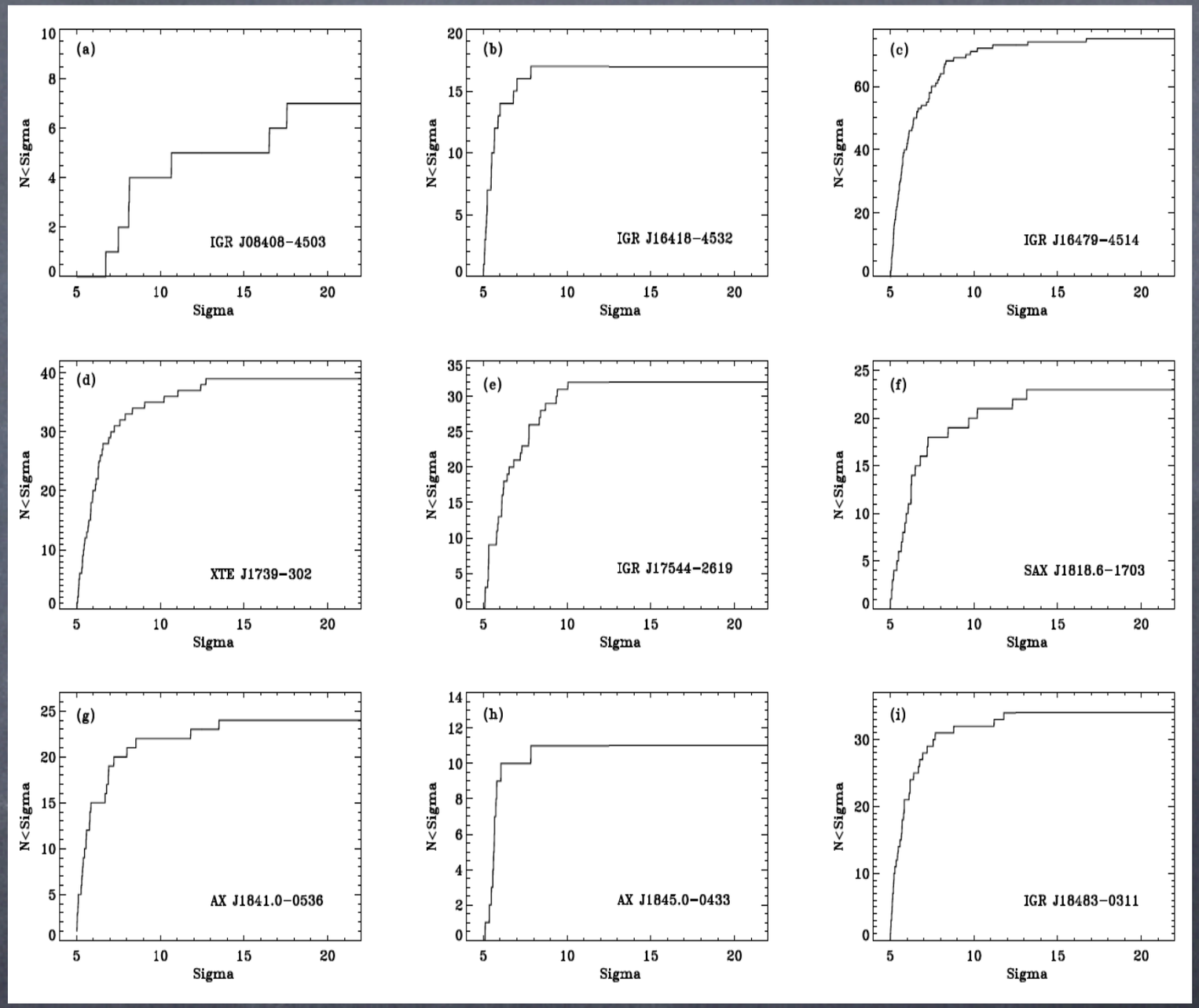
Name	Seasonal visibility[a]	Number of Flares (o)[b]
IGR J08408–4503	0.90	4
IGR J16328–4726	0.90	2
IGR J16418–4532	0.88	11
IGR J16465–4507	0.91	1
IGR J16479–4514	0.87	51
XTE J1739–302	0.87	27
IGR J17544–2619	0.85	22
SAX J1818.6–1703	0.86	16
AX J1841.0–0536	0.87	17
AX J1845.0–0433	0.90	7
IGR J18483–0311	0.90	23
Totals		185

Notes. [(a)] Fraction of year during which each source was observed because of several visibility constraints, including Sun constraints. [(b)] Uncertainties are of the order the Poisson error on the quoted number.

Future Perspectives

At any given σ:
use cumulative distributions of σ (σ)

Individual plots => prediction for # flares for a given flux

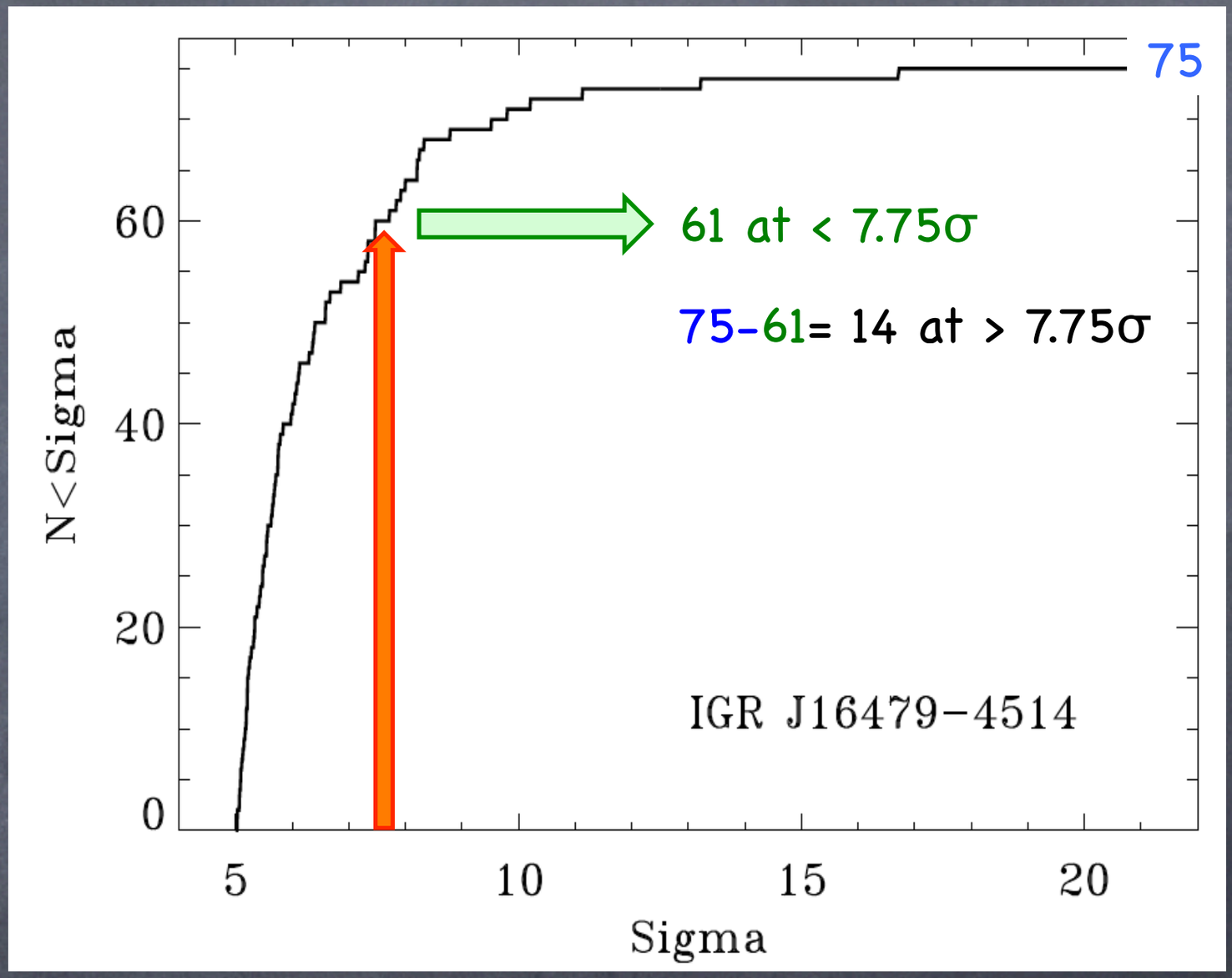


Future Perspectives

Example: estimate
flares > 100 mCrab
(15-50 keV)

Corresponding to 7.75 σ
= 2.3×10^{-9} erg cm^{-2} s^{-1}
(15-150 keV)

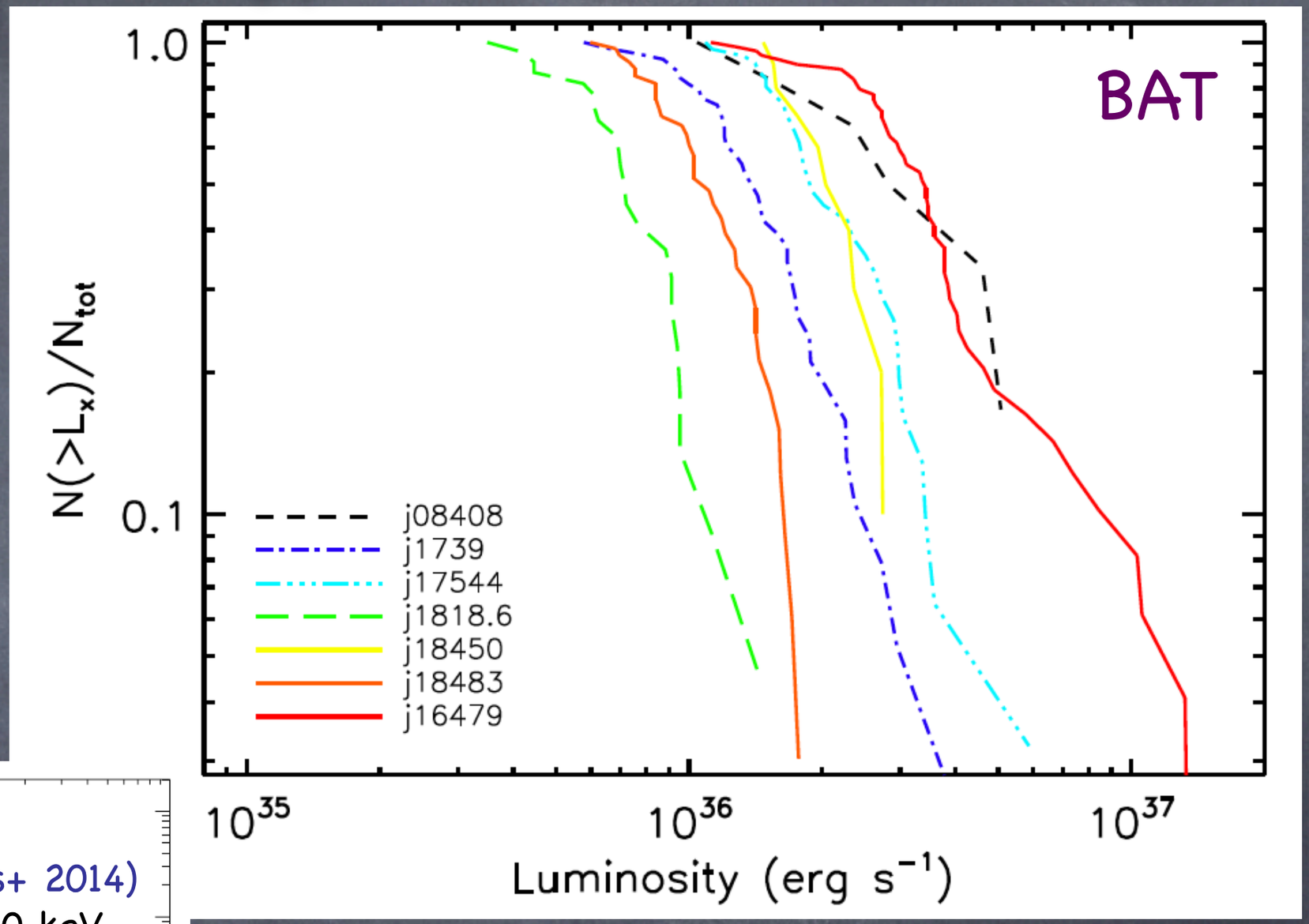
14 @ > 7.75 σ
Seasonal visibility:
10 flares in 5yr

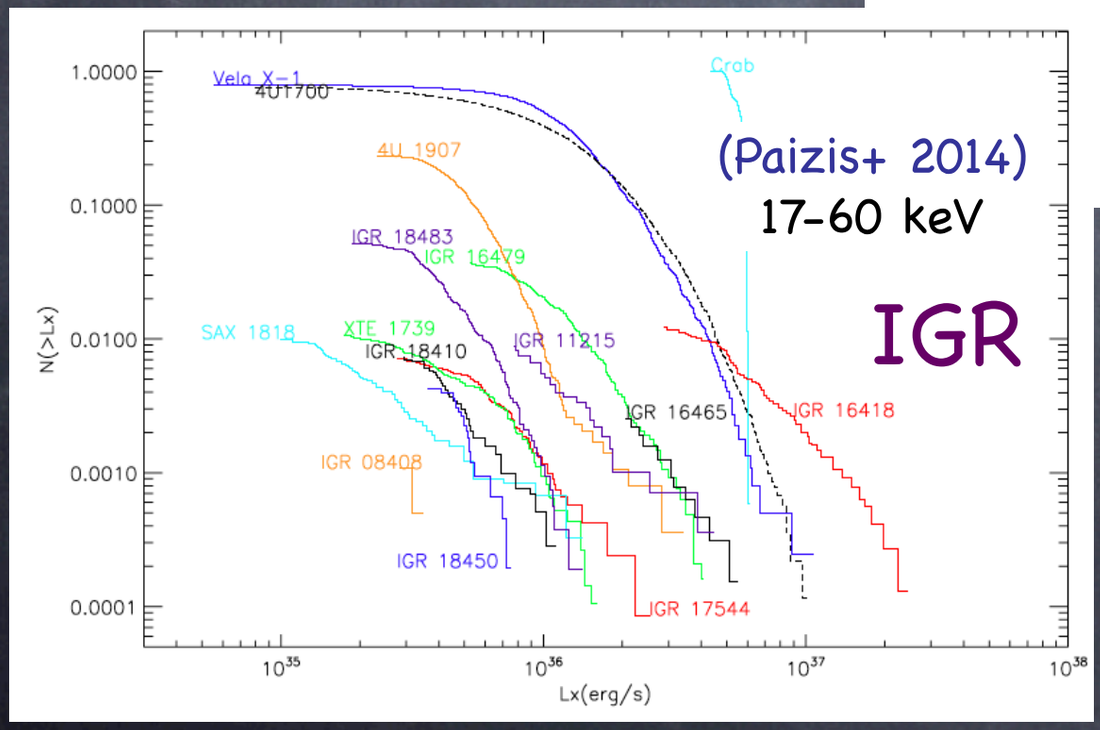


Repeat for sample
32 flares F>100 mCrab
48 flares F>90 mCrab (6.98 σ)
73 flares F>80 mCrab (6.20 σ)
130 flares F>70 mCrab (5.43 σ)

Applications

Cumulative luminosity distributions (15-50 keV)

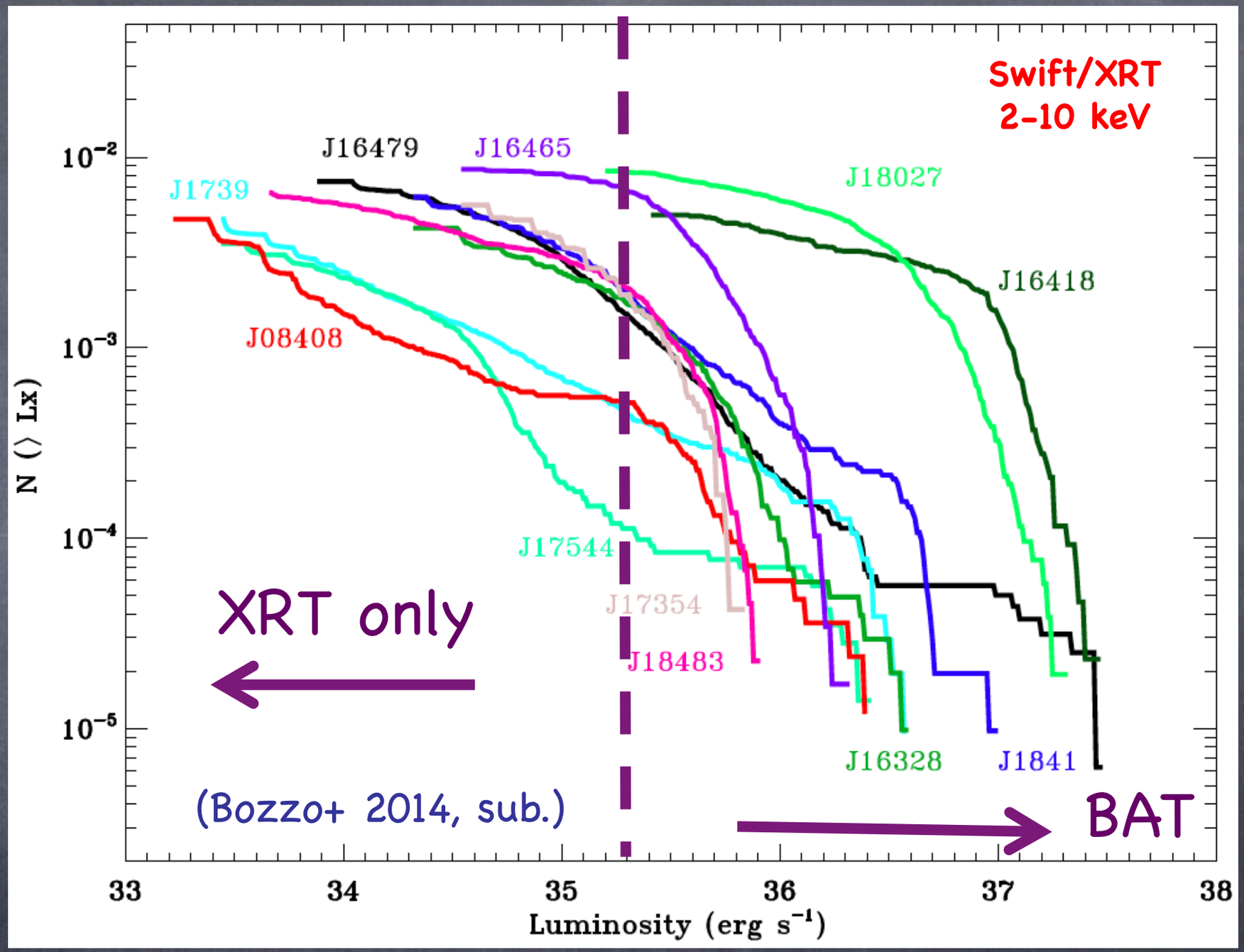




Applications

Cumulative luminosity Distributions in the soft X-ray

Will track the emission down to 10^{33} erg s^{-1}



Summary & Future

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

- ✔ 2005-Feb-12 to 2013-May-31 (MJD 53413- 56443)
- ✔ 1117 flare from 11 SFXTs
- ✔ 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
- ✔ Outbursts > day length (clustering in phase)
- ✔ Trend flare clustering (MAD) with P_{orb}

Swift SFXT Project http://www.ifc.inaf.it/sfxt/
Contact point: romano@ifc.inaf.it

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

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

Contact point:
romano@ifc.inaf.it

Thanks!