Investigating **S**upergiant **F**ast **X**-ray **T**ransients within the *XMM-Newton* project

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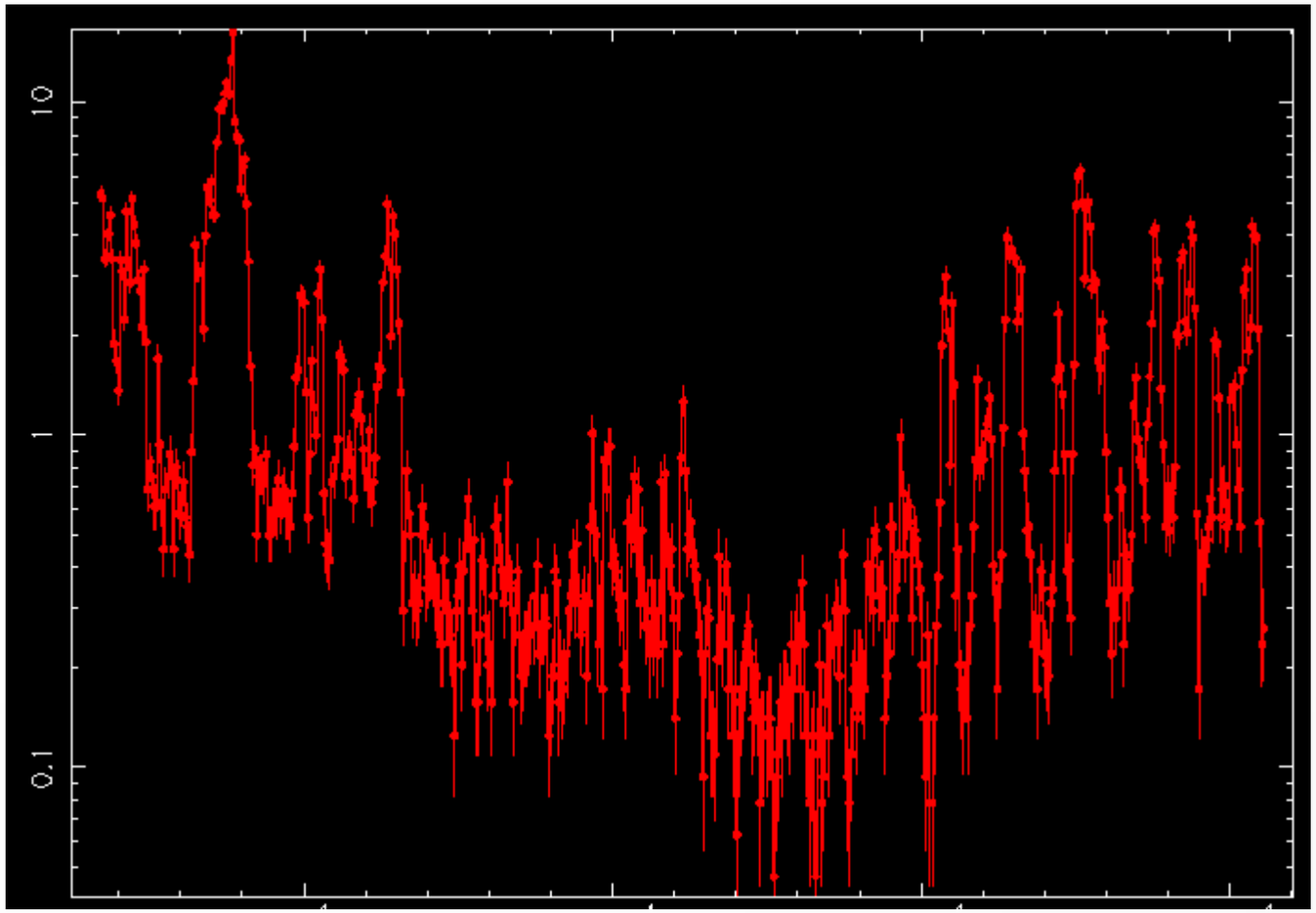
X-ray Astronomy 2019
September 8-13, 2019, CNR/INAF Research Area, Bologna

Example of a **SFXT** light curve

In *arbitrary units*, since X-ray flares are observed even outside outbursts, at all X-ray luminosities

SFXTs are a sub-class of
High Mass X-ray Binaries
with
O or B type supergiant + NS



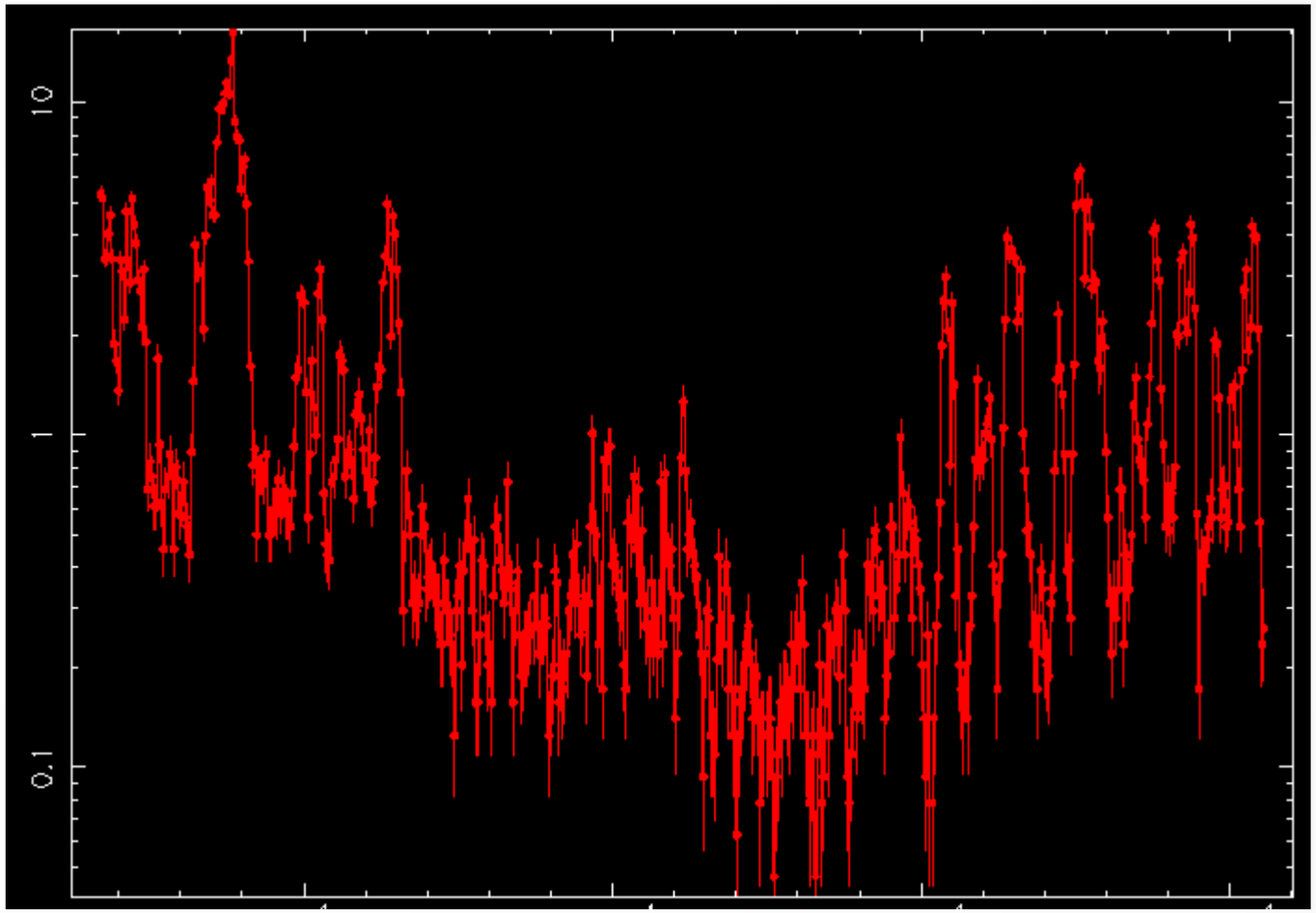
The observed, full range of SFXT variability is
Lx ~ 10^{32} – 10^{38} erg/s

Two are the main theoretical competing models proposed to explain SFXTs:

the quasi-spherical settling accretion regime (Shakura et al. 2012, 2014, 2017) and the propeller effect (Grebenev & Sunyaev 2007; Bozzo et al. 2008)

Aim of our work is to characterize the flares:

Exploitation of the ***XMM-Newton*** archival observations of SFXTs to pick out flares and measure flare properties:
- **durations**,
- **rise** and **decay** times,
- intervals of time between two consecutive flares (**waiting times**)
- **peak Lx** and emitted **energies**



Why XMM-Newton?

High throughput and *uninterrupted* observations !

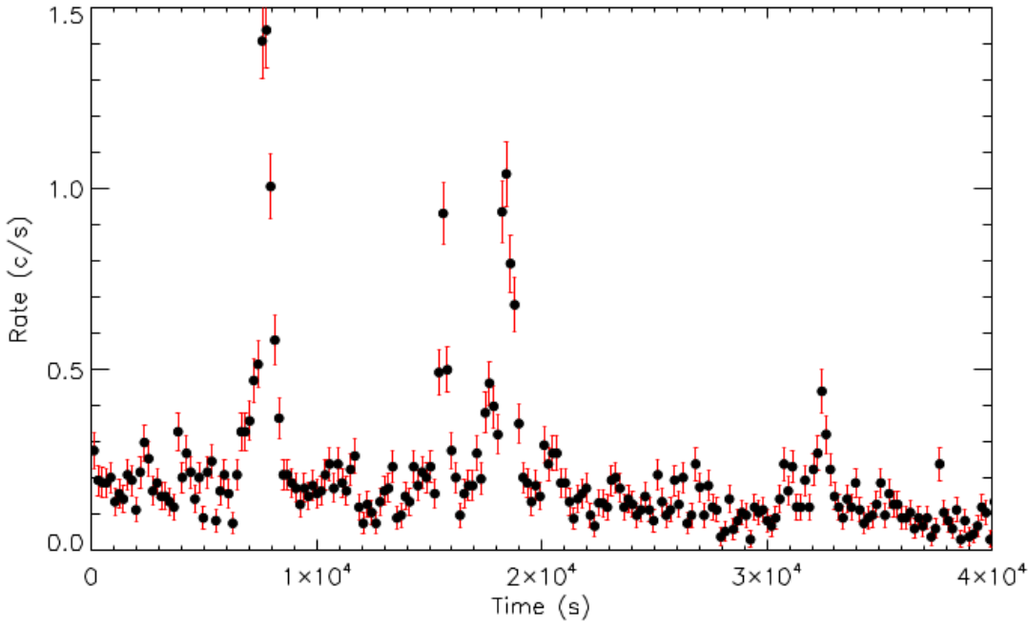
How to pick out flares ?

How to pick out flares ?

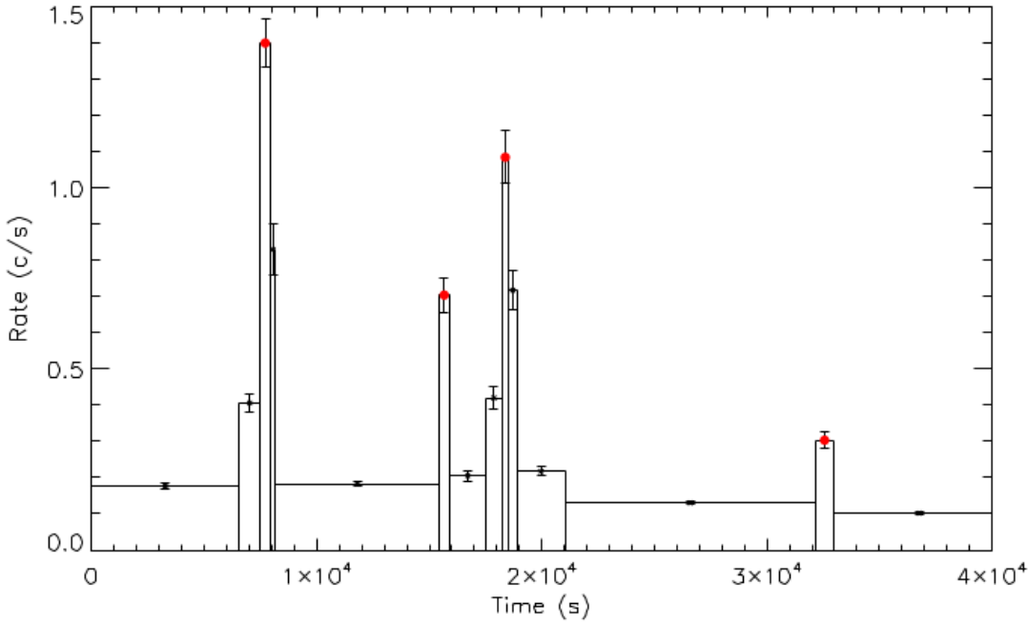
How many buildings can you see in the Bologna’s skyline?

Instead of fitting churches with towers,
or taking insignificant chimneys for towers ...

EPIC pn light curves



uniform bin time



segmented in Bayesian blocks (**B.b.**, hereafter)

adaptively binned

piecewise constant light curves

They retain only the significant variability

Time (s)

XMM-Newton observations of **SFXTs**

The **Bayesian block light curves** are among the **products** made publicly available **by the EXTraS project** (De Luca et al. 2017) funded within the EU/FP7 framework, aimed at extracting from the XMM-Newton archive the temporal information of all sources observed by EPIC cameras

We investigated the EPIC pn, B.b. light curves of 9 SFXTs (2003-2014).

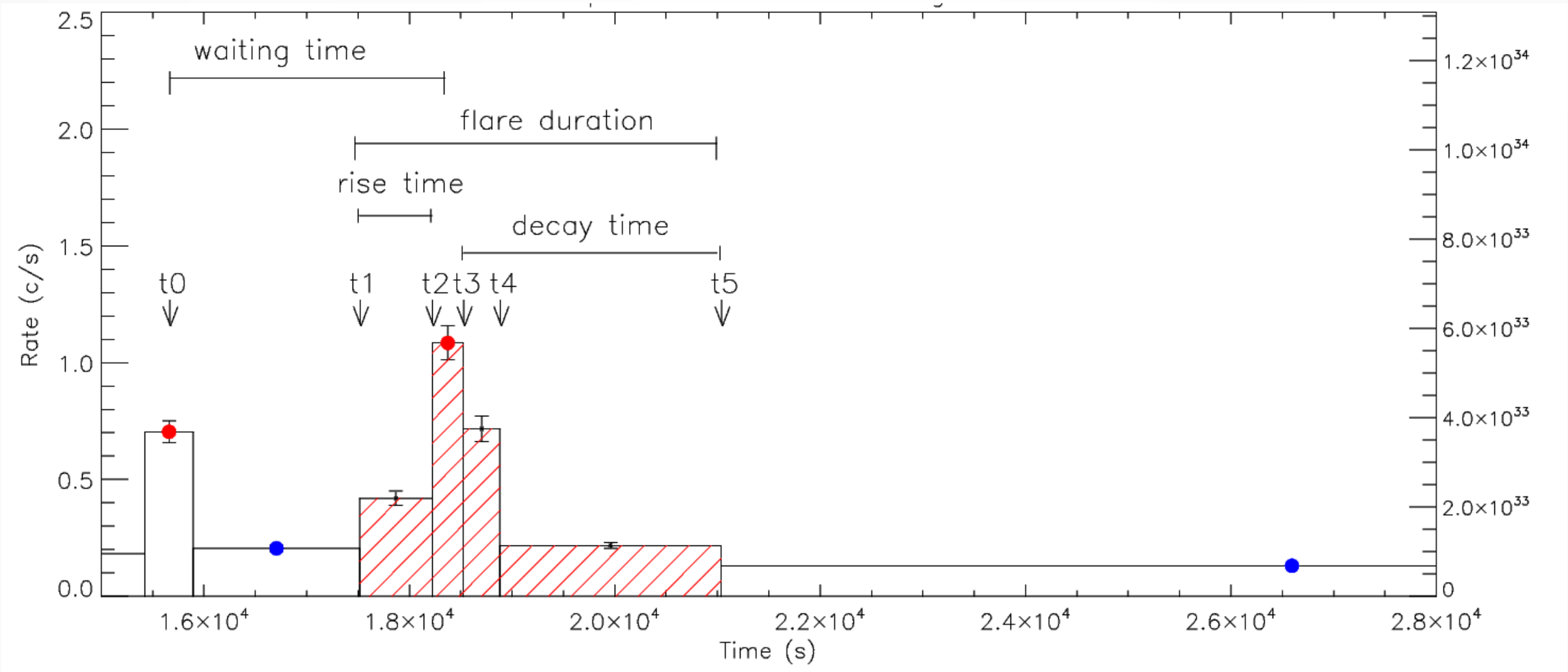
All XMM observations were GO, but 2 ToOs , with a Texp from 11 to 58 ks.

Exploring the X-ray Transient and variable Sky

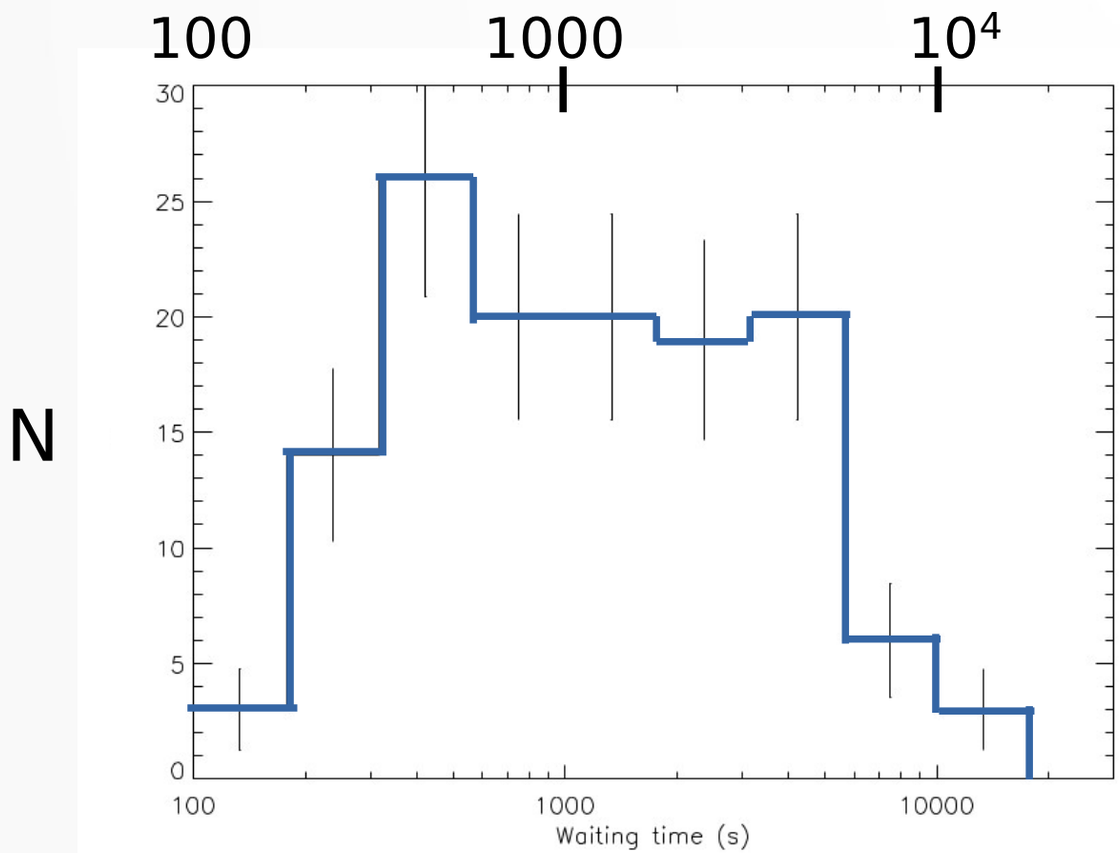
EXTraS website: http://www.extras-fp7.eu
LEDAS astronomical data archive: https://www88.lamp.le.ac.uk/extras/archive

Segmented light curves: defining important quantities

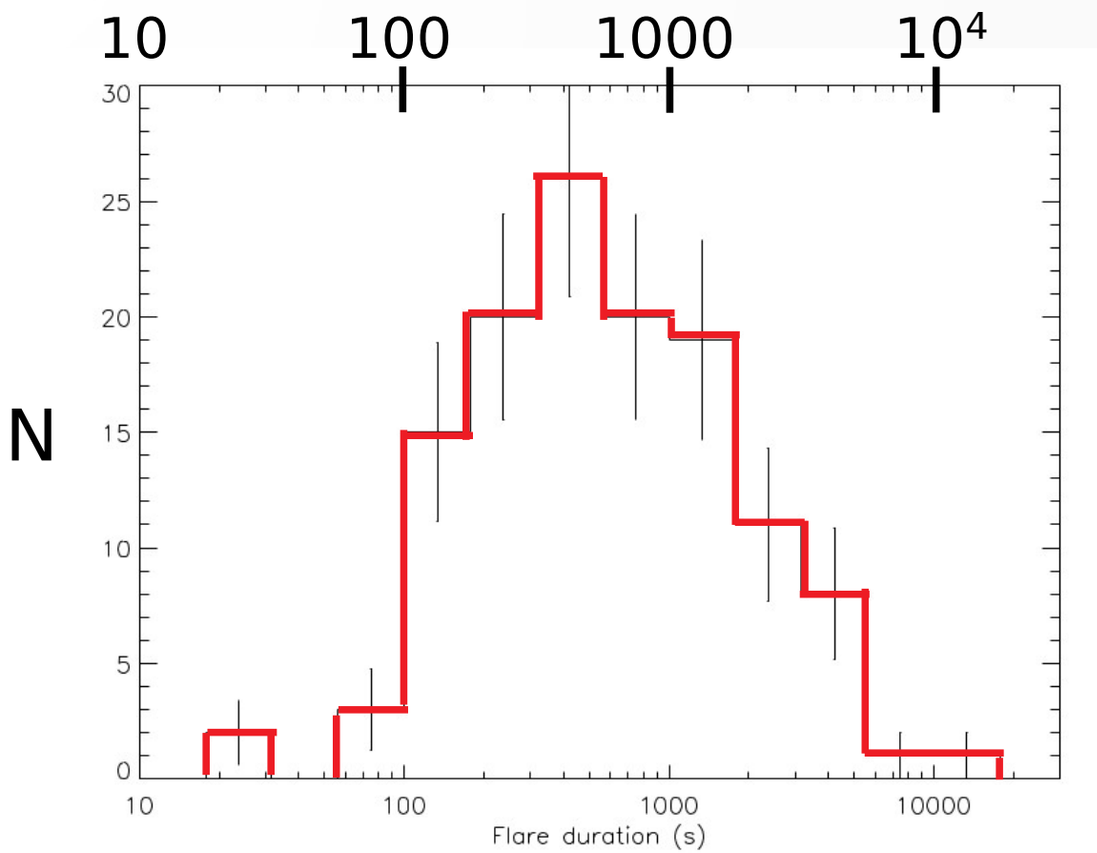
Flare peak = local maximum in the B.b. lightcurve → we picked out 144 flares
With an average Lx from 1e32 to 1e36 erg/s



SFXT flare timescales

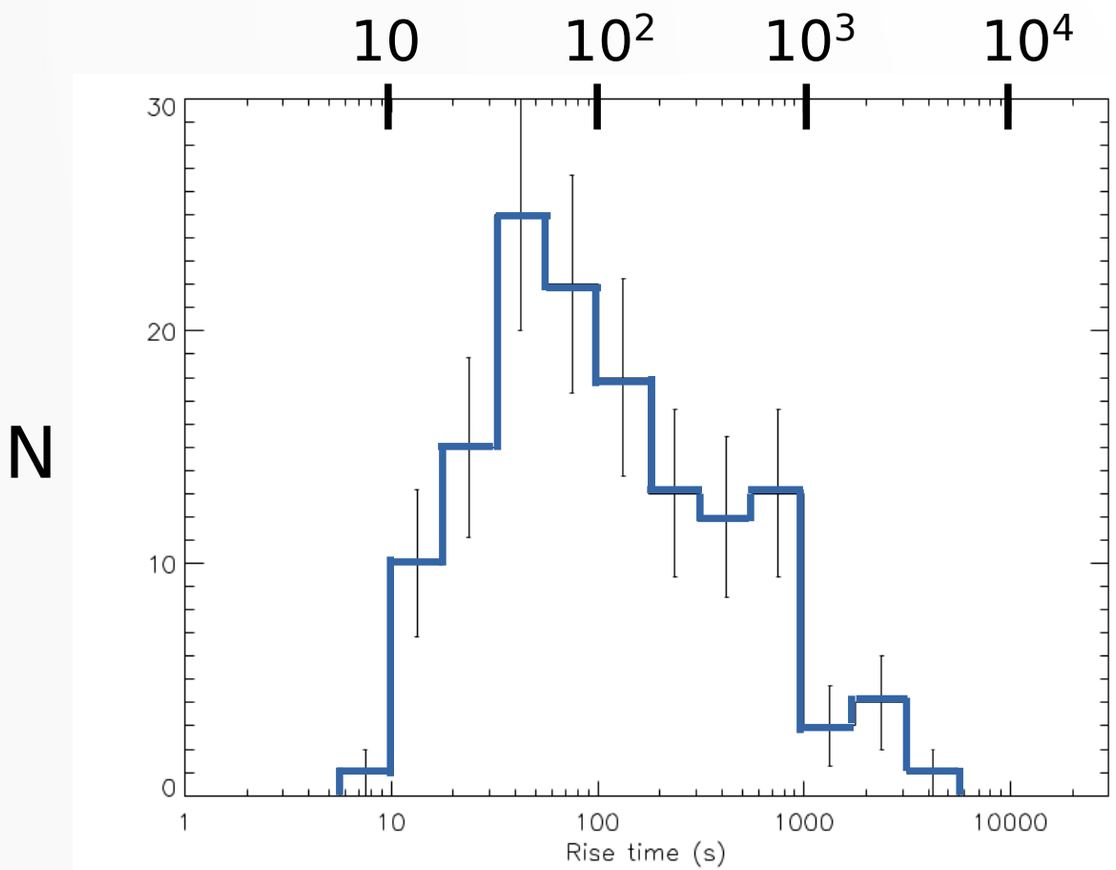


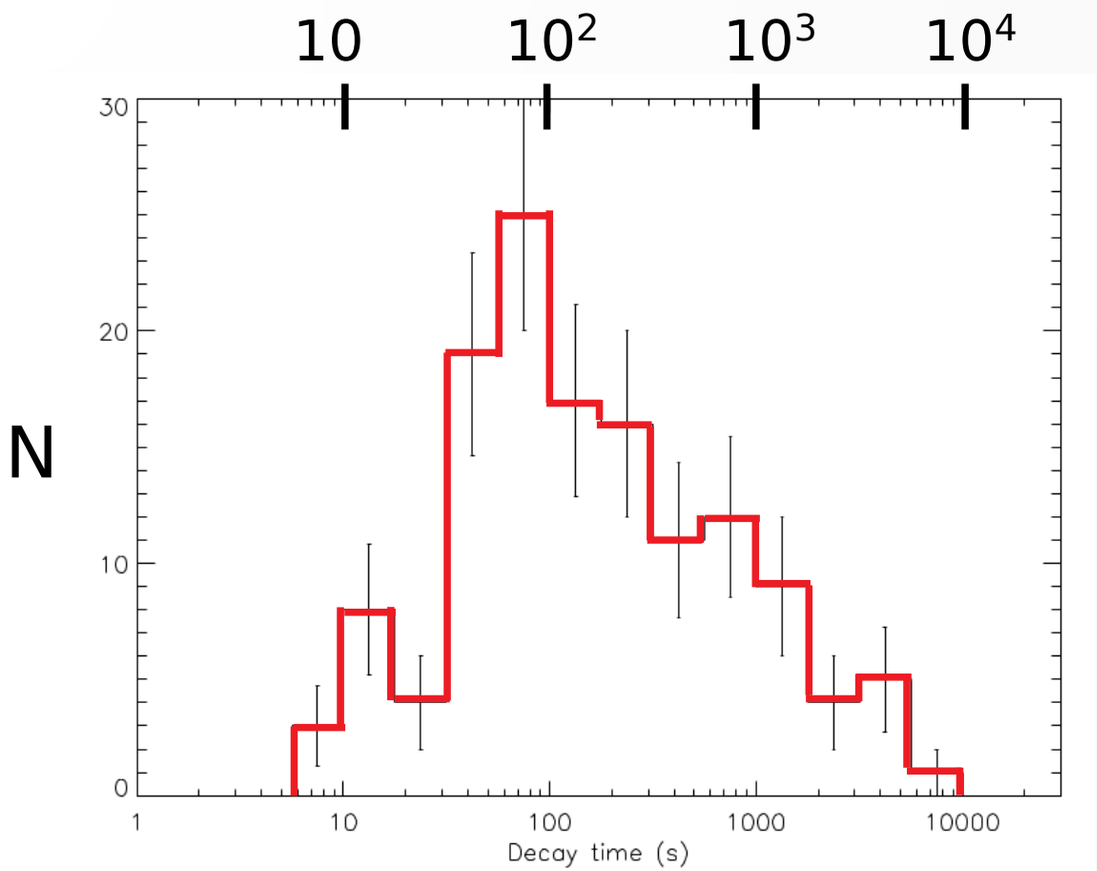
Waiting time (s)



Flare duration (s)

SFXT flare timescales

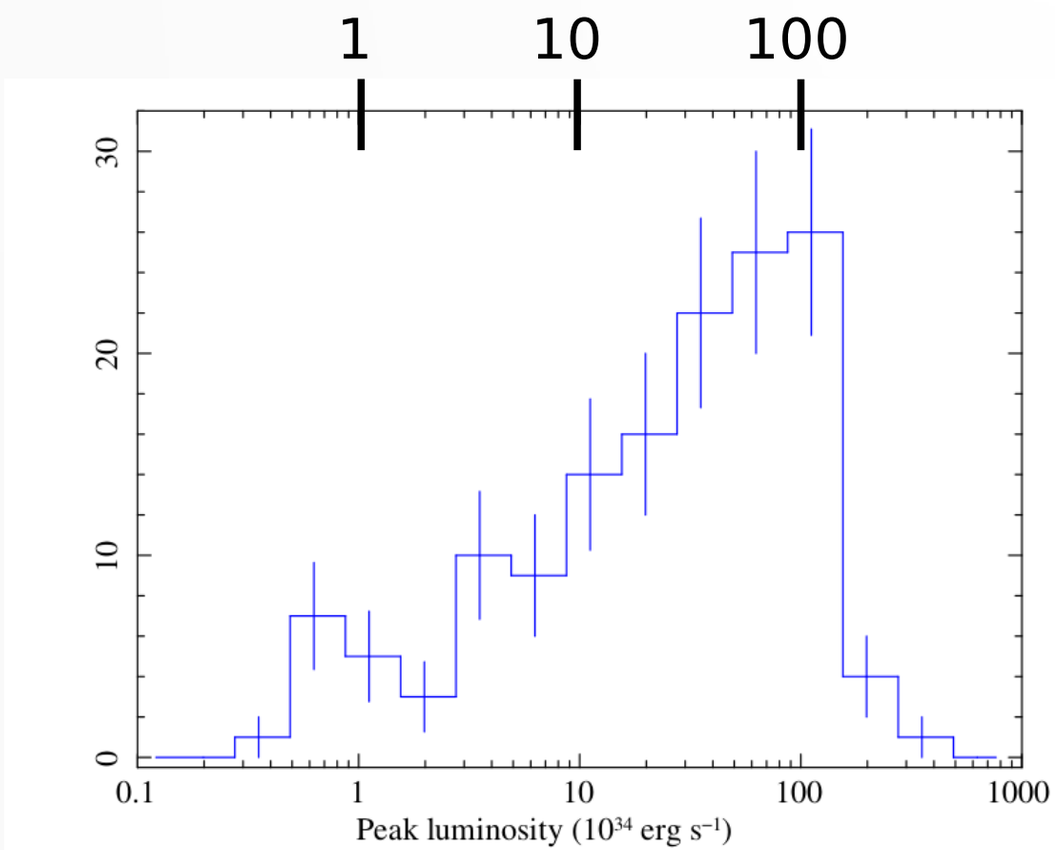




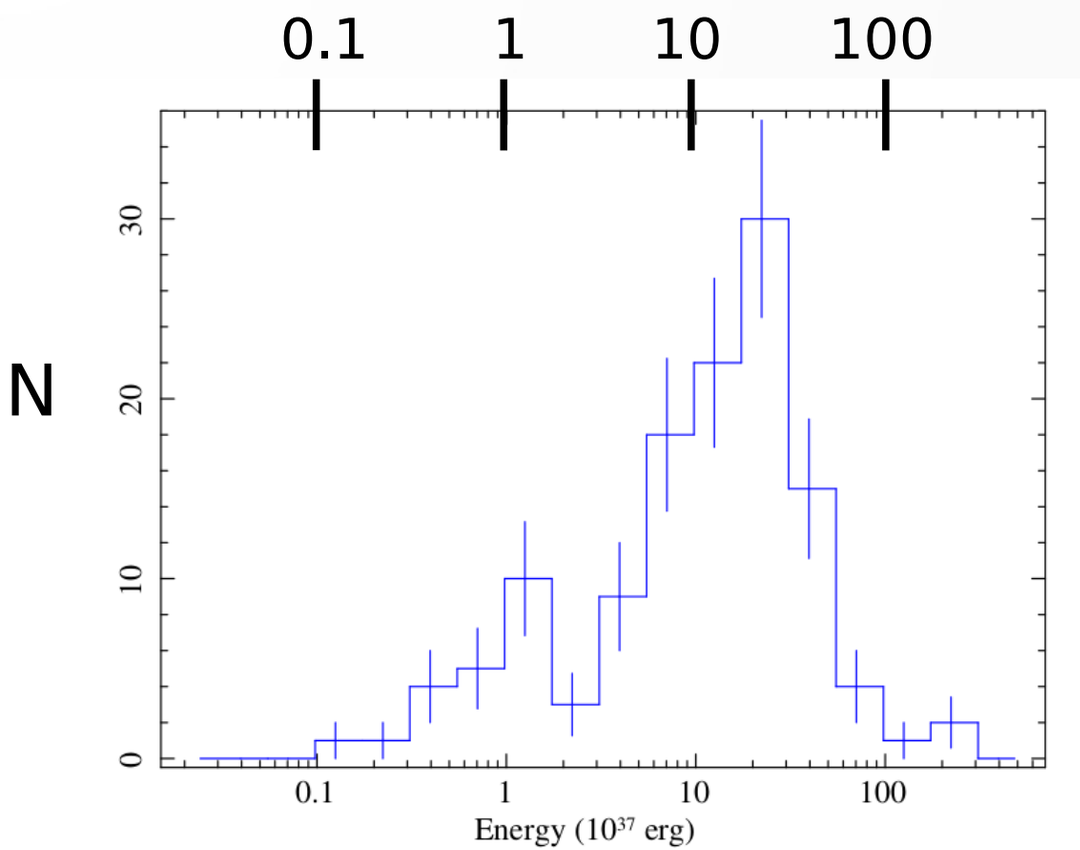
Rise time (s)

Decay time (s)

Flare peak luminosity & emitted energy



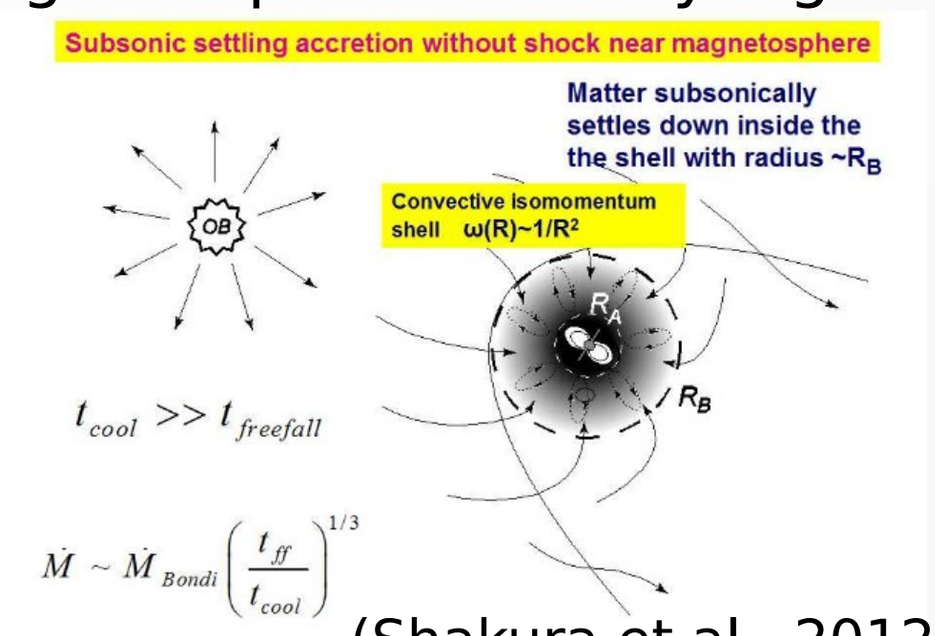
Peak Lx (10^{34} erg/s)



Energy (10^{37} erg)

Quasi-spherical settling accretion Rayleigh-Taylor Instability (RTI)

- Since the average Lx from the SFXT flares we investigated is in the range 10^{32} – 10^{36} erg/s, the **quasi-spherical settling accretion** regime in slowly rotating neutron stars is applicable
- The plasma enters the NS magnetosphere via **R**ayleigh-**T**aylor **i**nstability

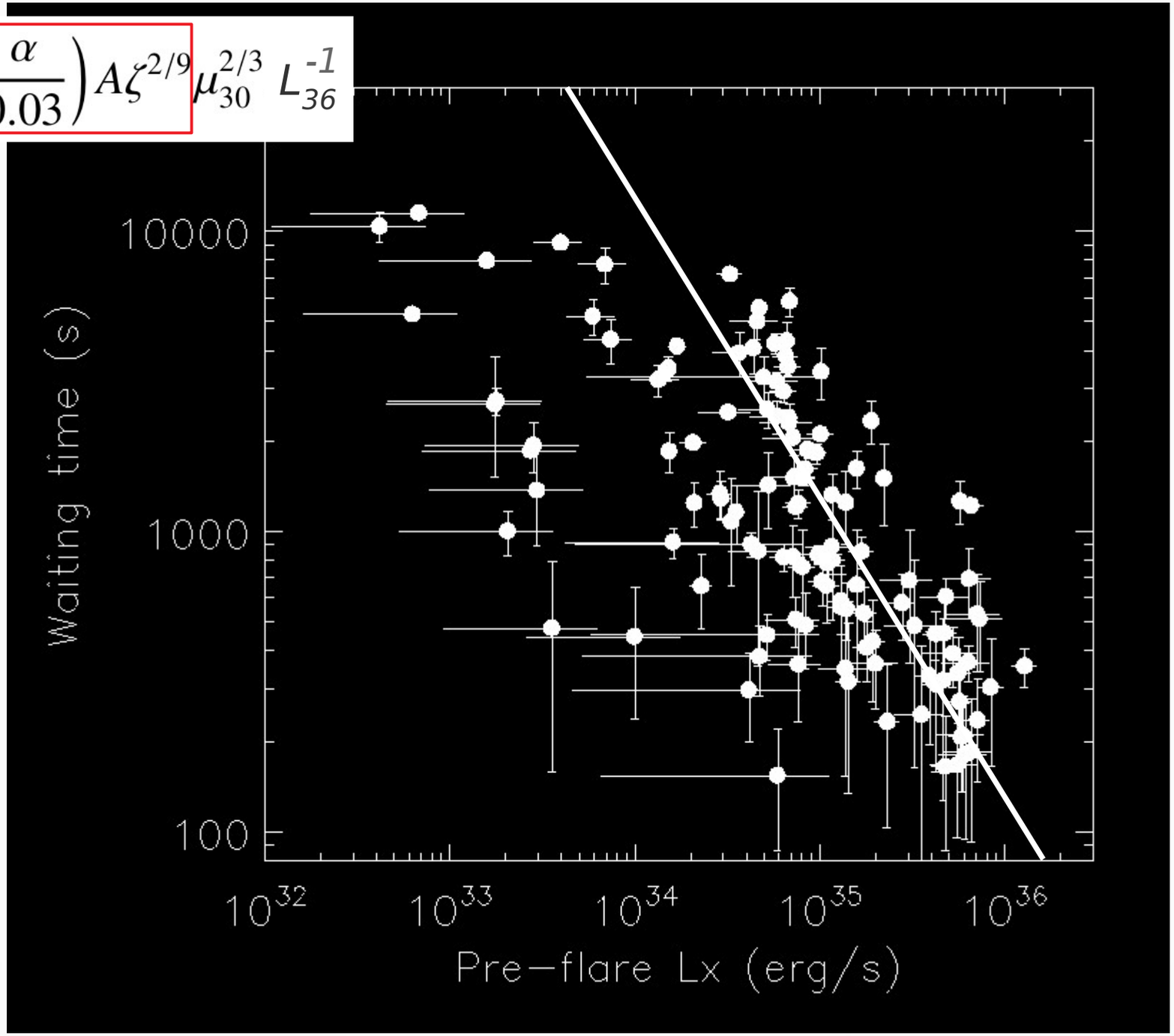


(Shakura et al., 2012; 2017)

$$\Delta T \approx 130[\mathrm{s}]\left(\frac{\alpha}{0.03}\right) A\zeta^{2/9}\mu_{30}^{2/3}\, L_{36}^{-1}$$

dimensionless RTI param. $\lesssim 1$

L_{36} = *Pre-flare luminosity*



NS magnetic moment

$\mu = 10^{30}[\mathrm{G\,cm^3}]\mu_{30}$

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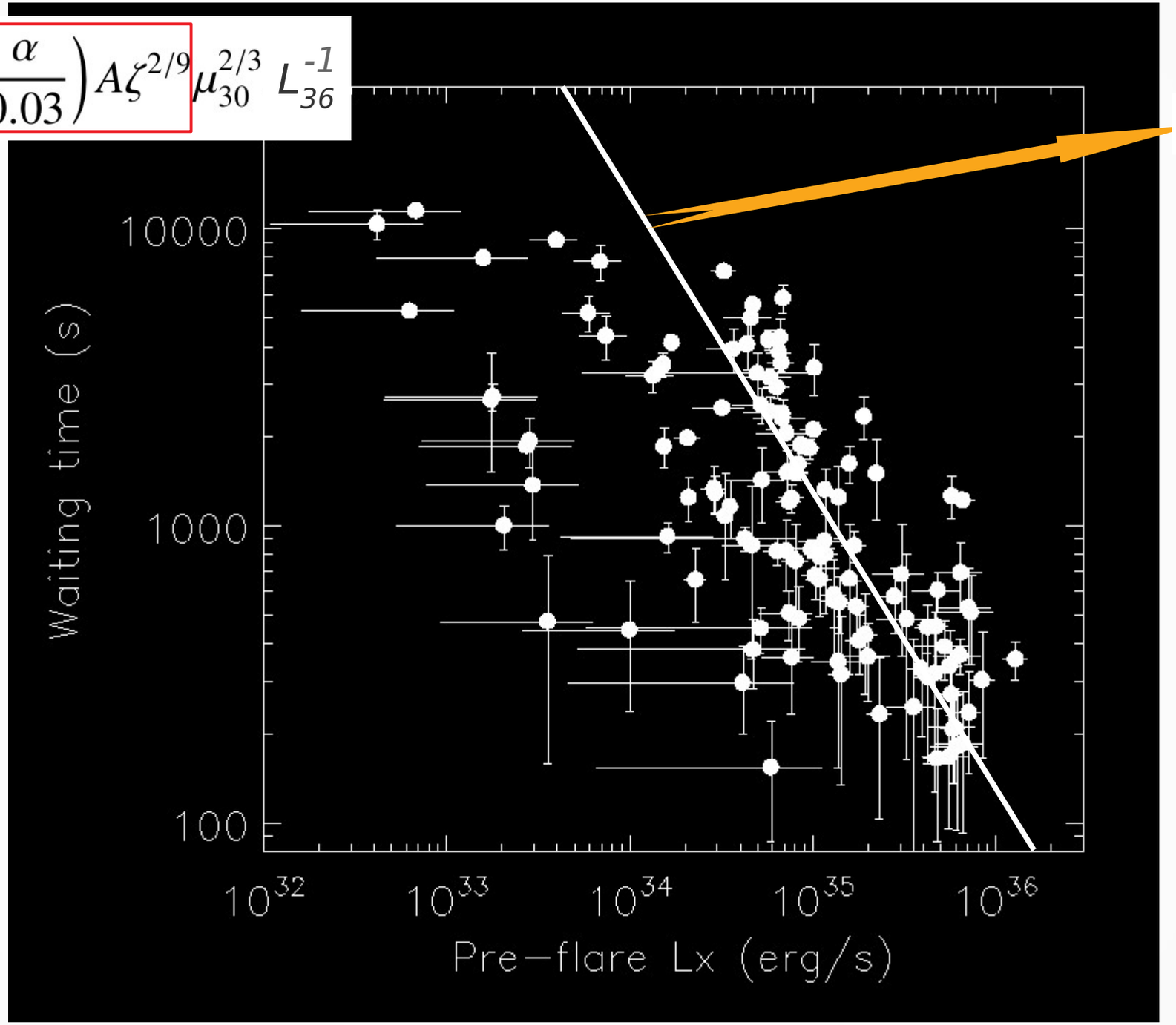

Waiting time

$\Delta T = 130\ L_{36}^{-1}$ [s]

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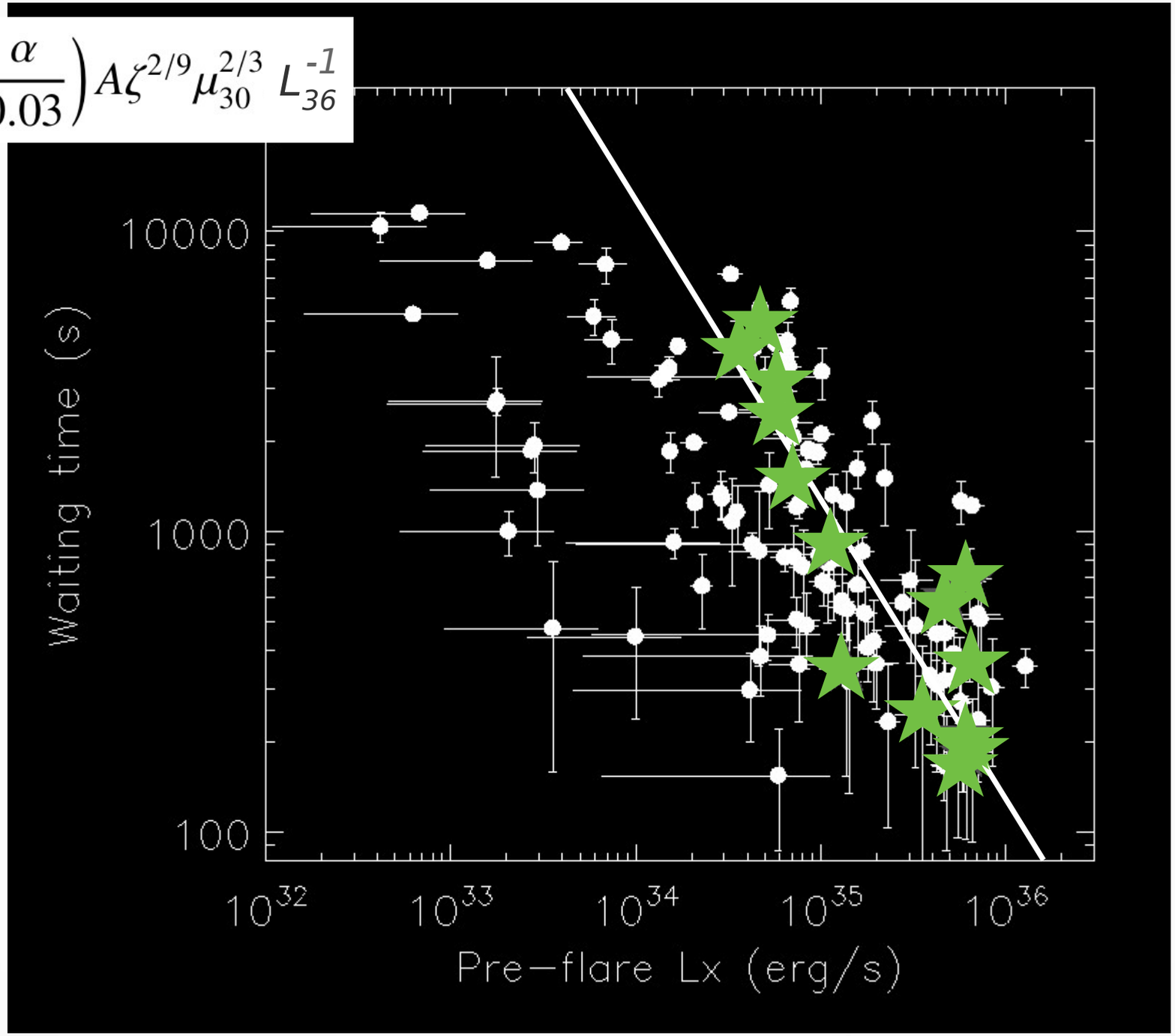

IGR J11215-5952

$$\left(\frac{\alpha}{0.03}\right) A\zeta^{2/9}\mu_{30}^{2/3}$$

~ 1

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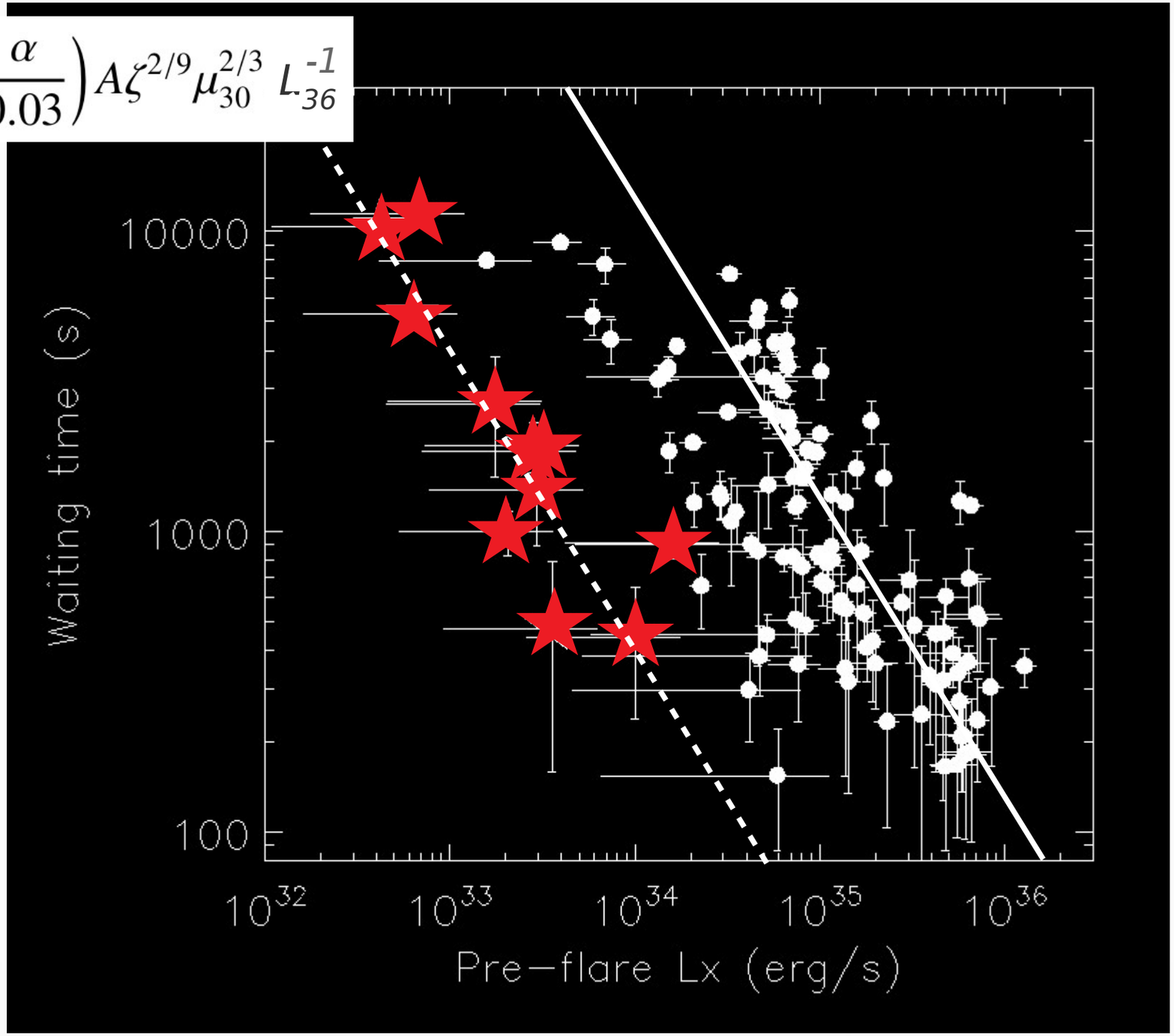


XTE J1739-302

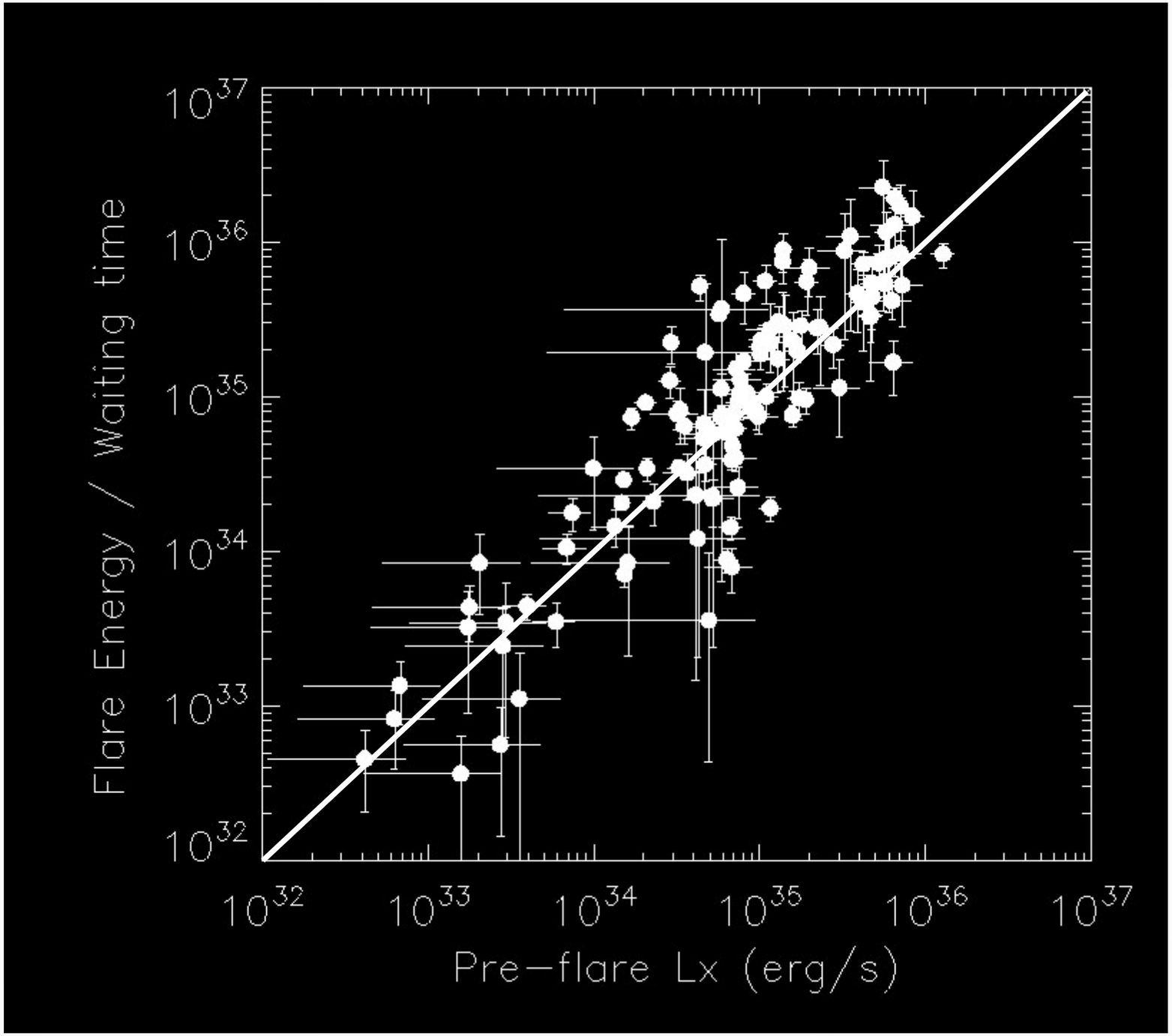
$$\left(\frac{\alpha}{0.03}\right) A\zeta^{2/9}\mu_{30}^{2/3}$$

~ 0.03

$$\frac{\Delta E}{\Delta T} = Lx$$

Pre-flare luminosity

Note that this ratio of the Energy emitted during flares and the Waiting time does **not depend on unknown RTI parameters**



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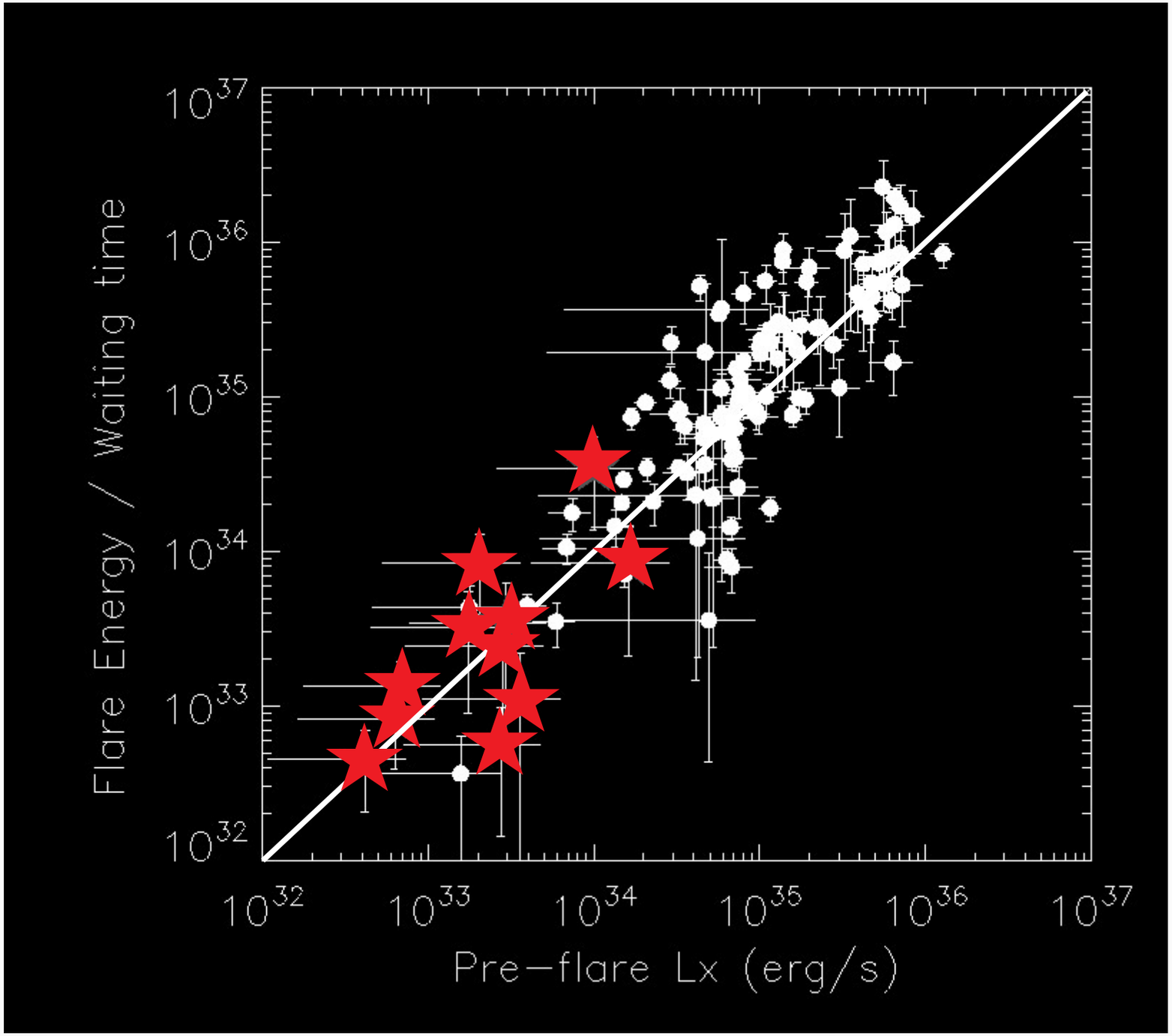

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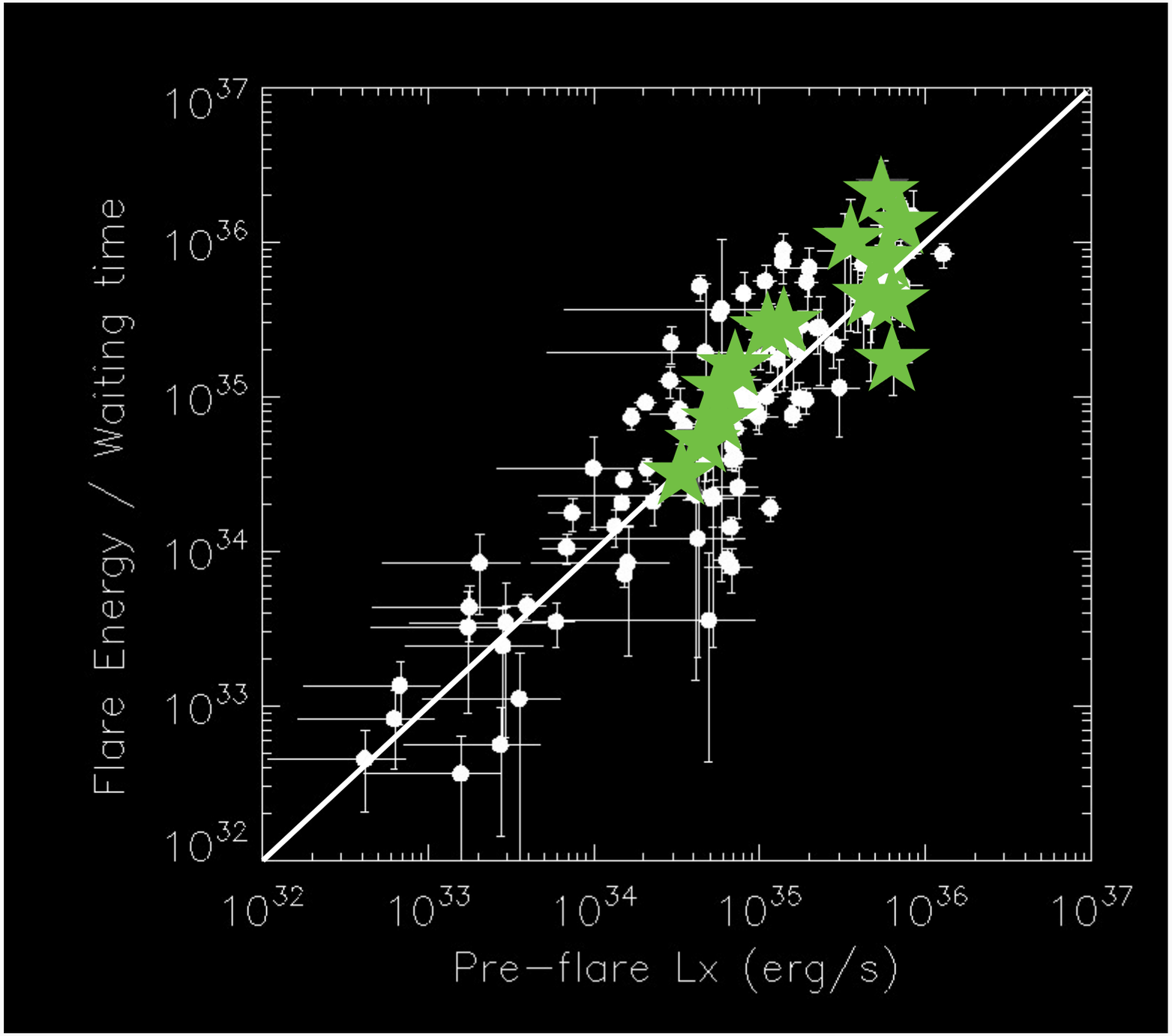

IGR J11215-5952

CONCLUSIONS

We investigated SFXT aperiodic variability by means of **Bayesian blocks EPIC pn** light curves within the **EXTraS** project (most of the light curves were already publicly available in the data base, others were built by us using the EXTraS tools)

This procedure allowed us to pick out **144 X-ray flares** (from **9 SFXTs**), spanning an X-ray luminosity from 10^{32} to $\sim 10^{36}$ erg/s

The development of **RTI** in a **quasi-spherical shell above the NS magnetosphere** (in slowly rotating NSs) **can describe** the observed properties of SFXT flares

Refs:

Sidoli, Postnov, Belfiore, Marelli, Salvetti, Salvaterra, De Luca & Esposito, 2019, MNRAS 487, 420

EXTraS project, funded within the EU/FP7 framework (De Luca et al. 2016, 2017)
EXTraS website: http://www.extras-fp7.eu
LEDAS astronomical data archive: https://www88.lamp.le.ac.uk/extras/archive