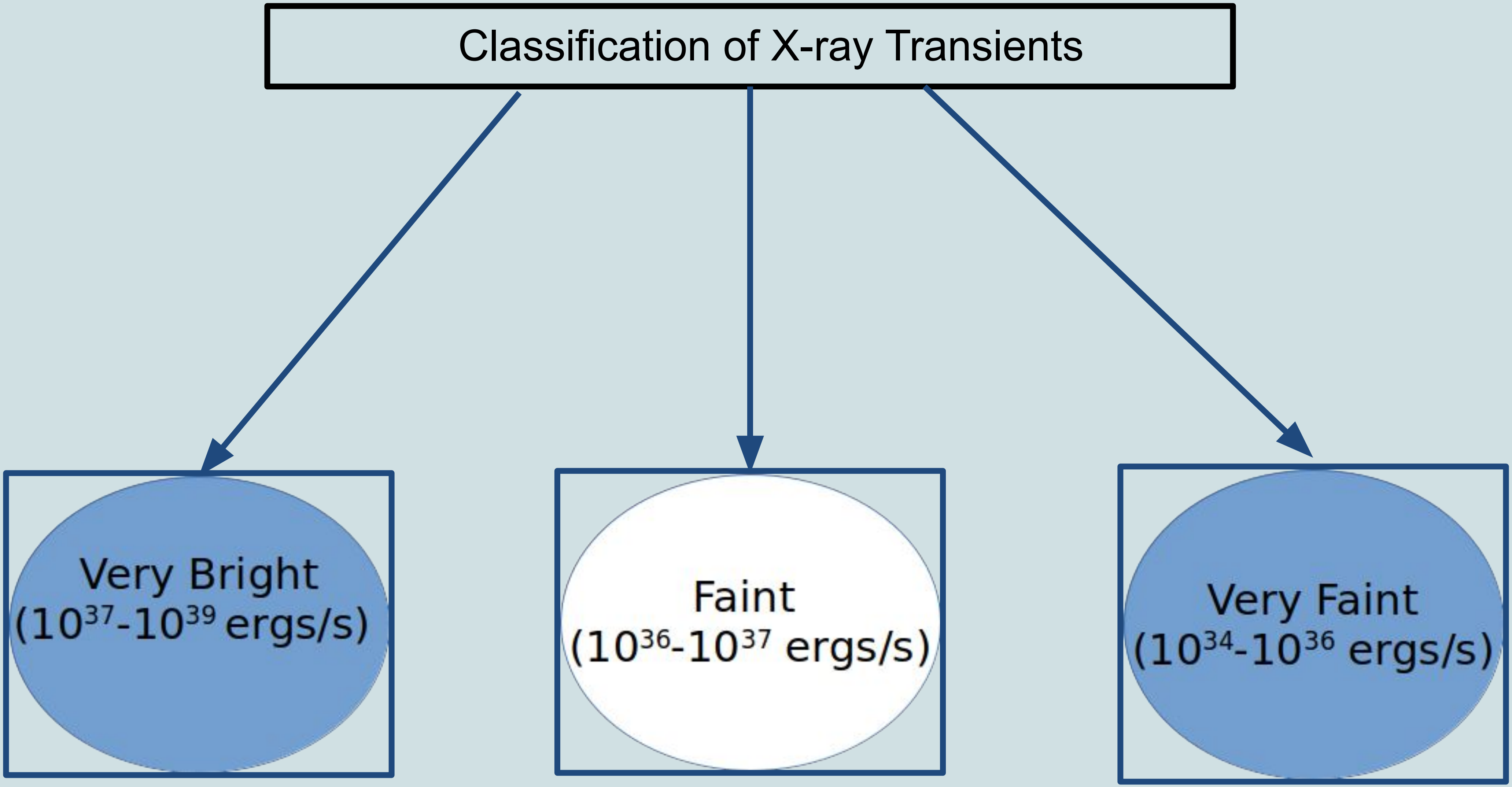
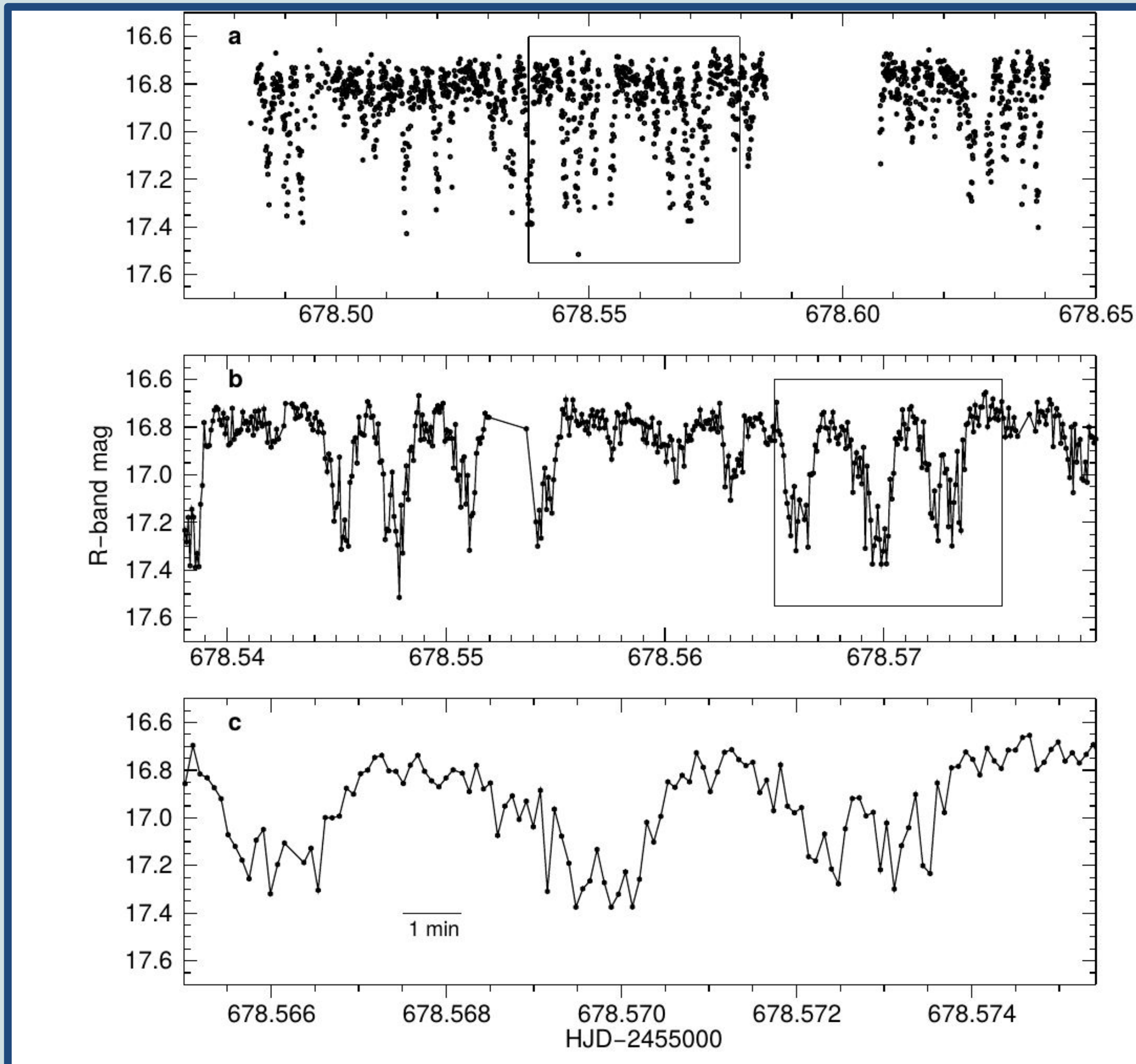
Multi-band look at the black hole X-ray transient Swift J1357.2-0933 and discovery of the Millihertz X-ray variability in the X-ray light curves

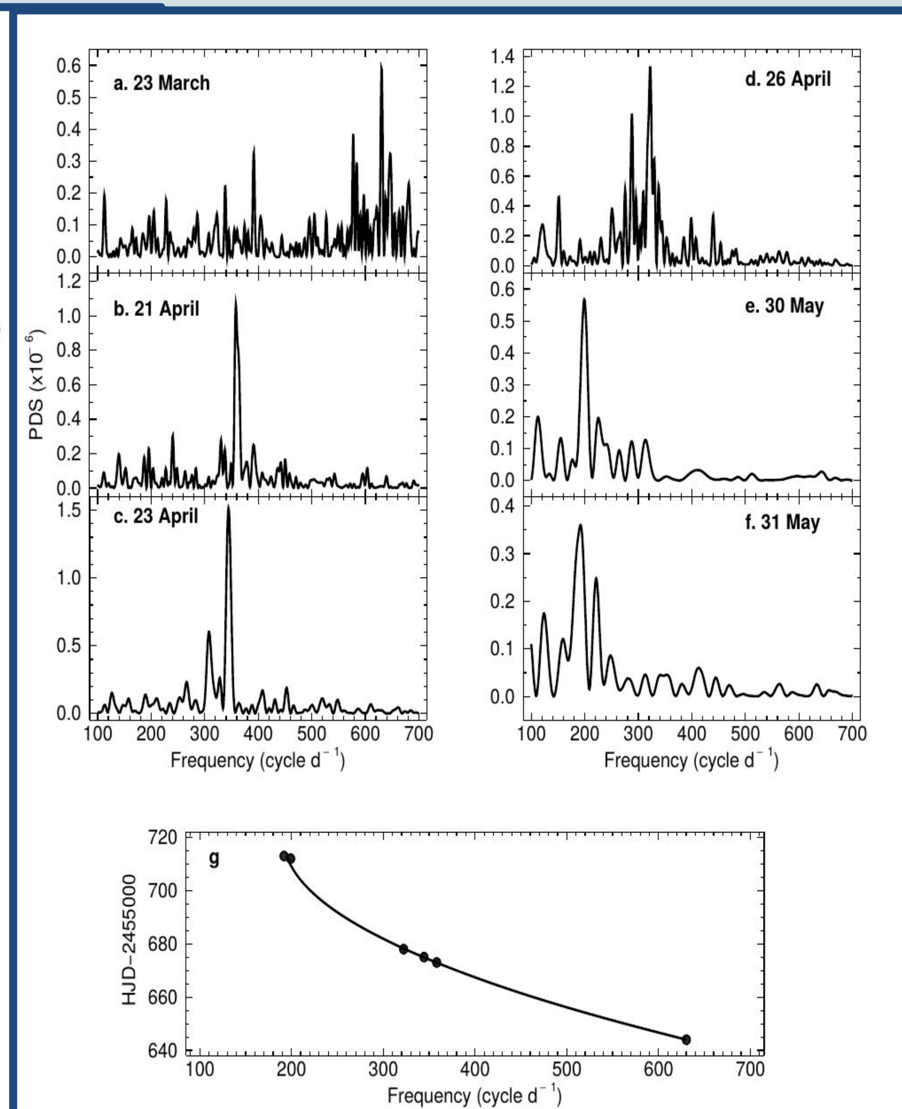
Aru Beri



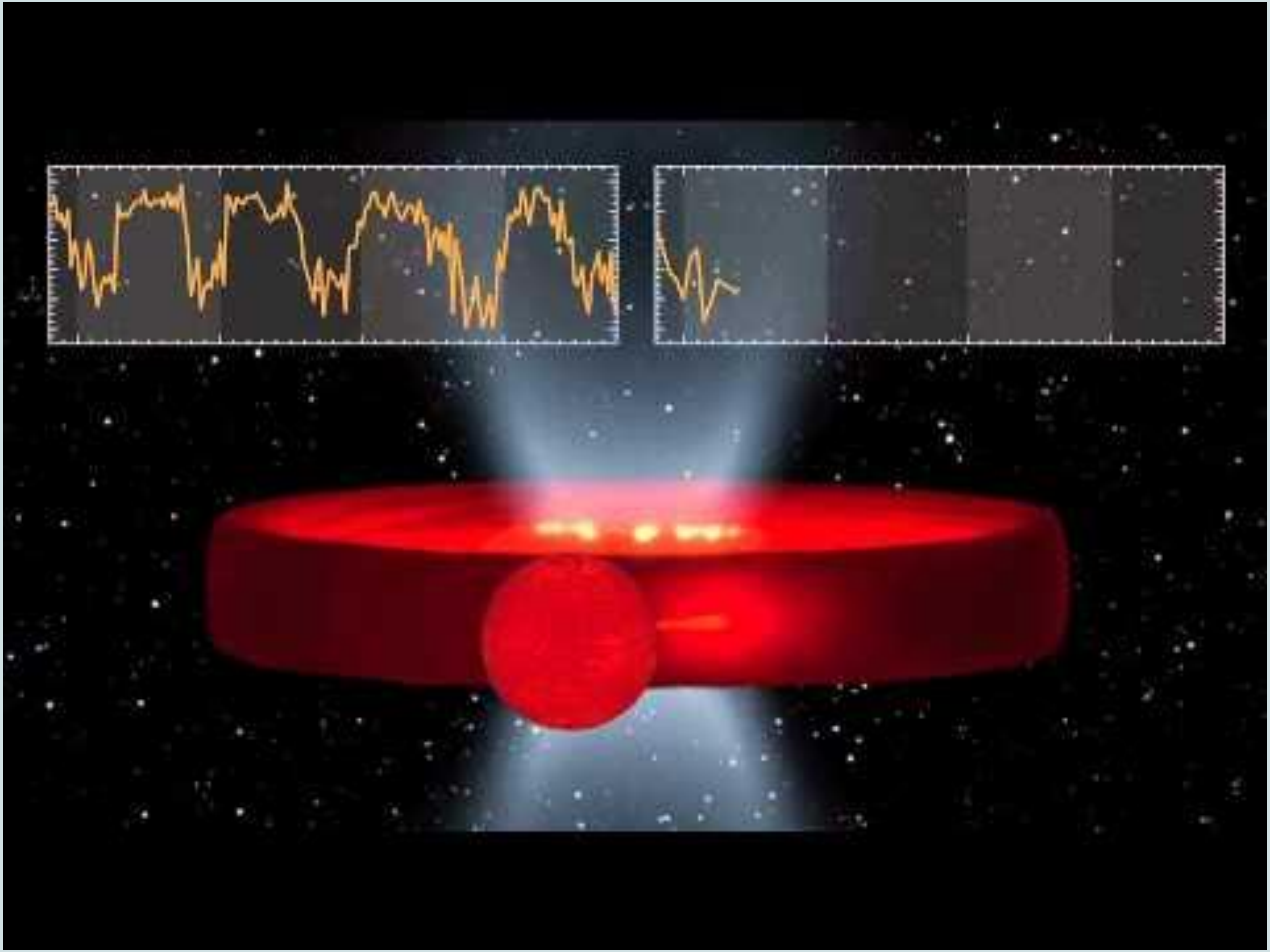
Wijnands et al. 2006

Swift J1357.2-0933: Peculiar black-hole candidate X-ray transient

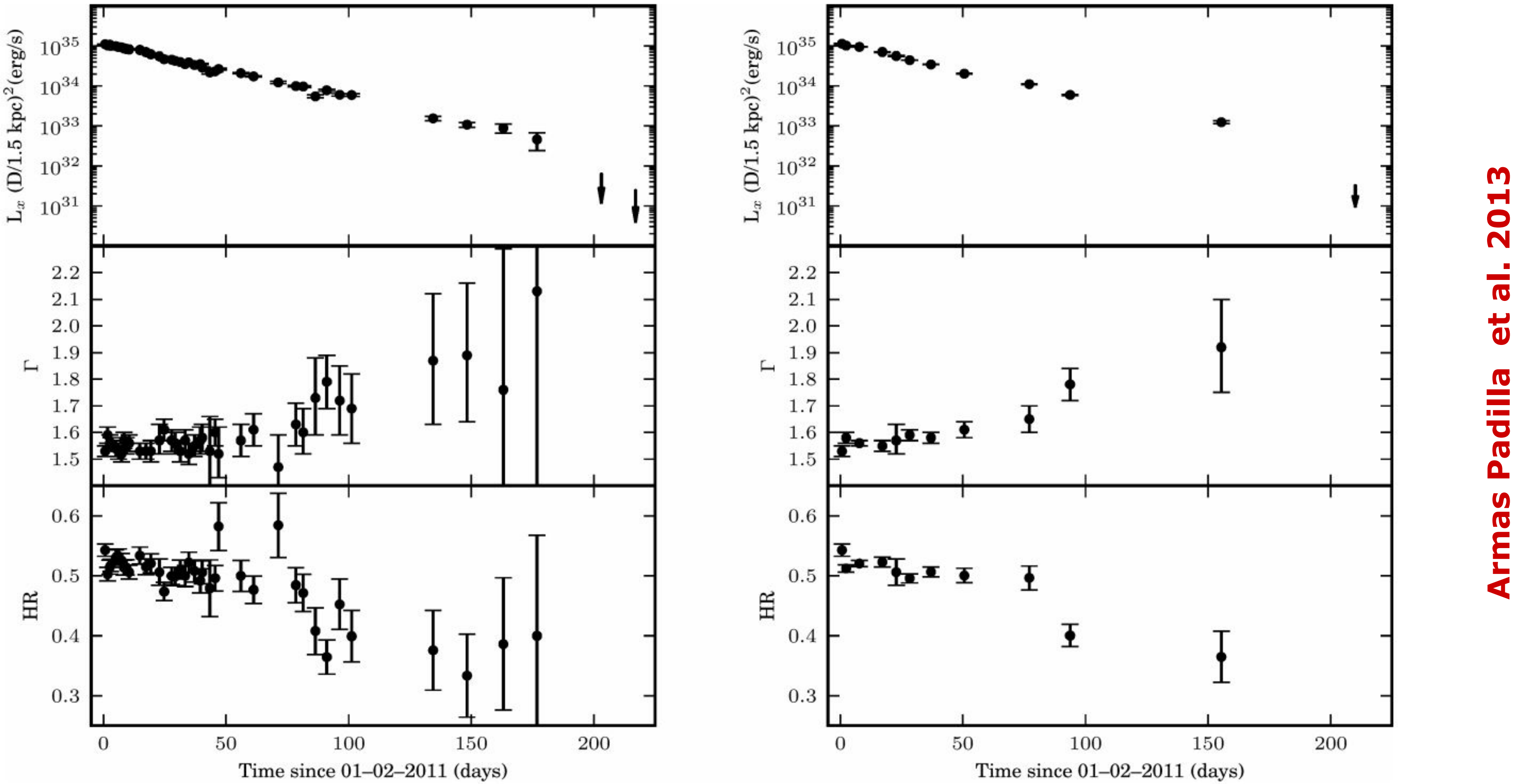




Corral-Santana et al. 2013 (Science)

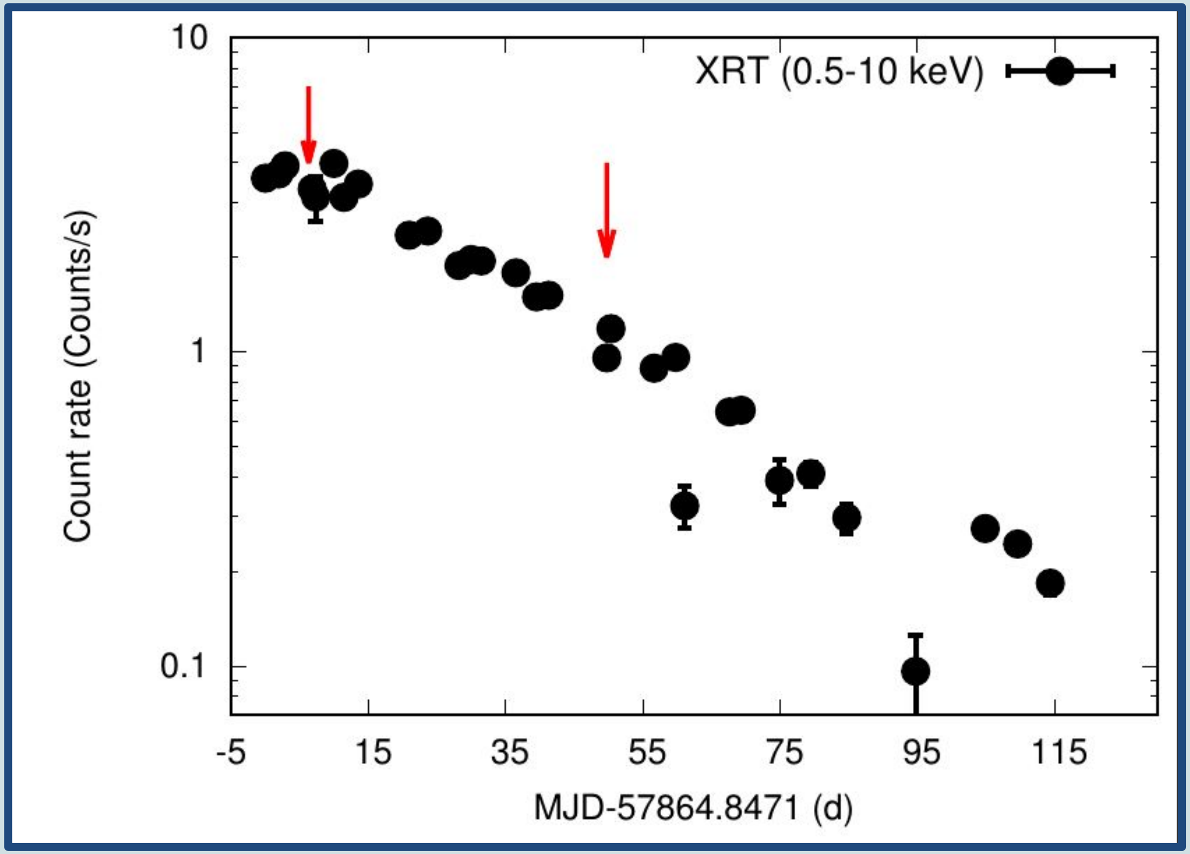


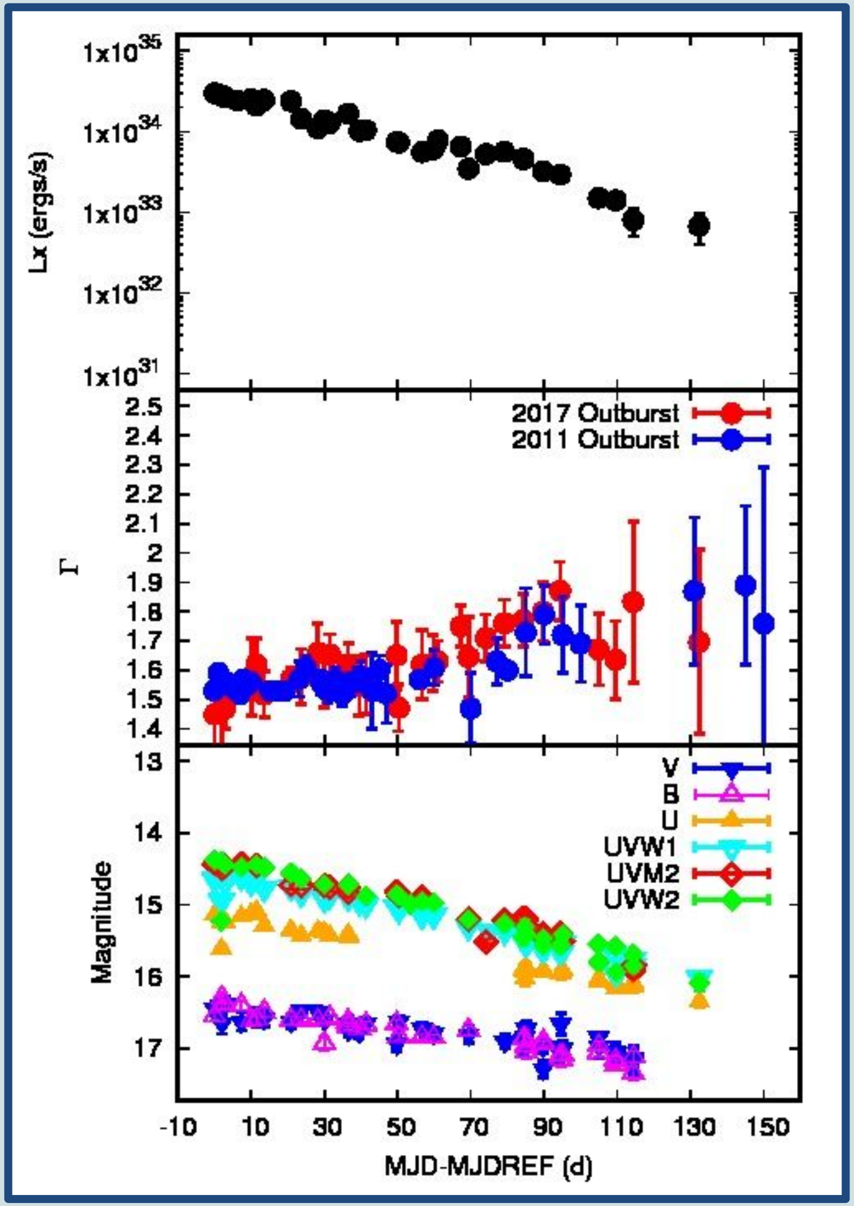
2011 Outburst of Swift J1357.2-0933 → Classified as BH VFXT



The presence on the DSS of a faint (r ~22), very red star, led Rau et al. (2011) to identify this as the quiescent donor, an ~M4 star at d ~1.5kpc.

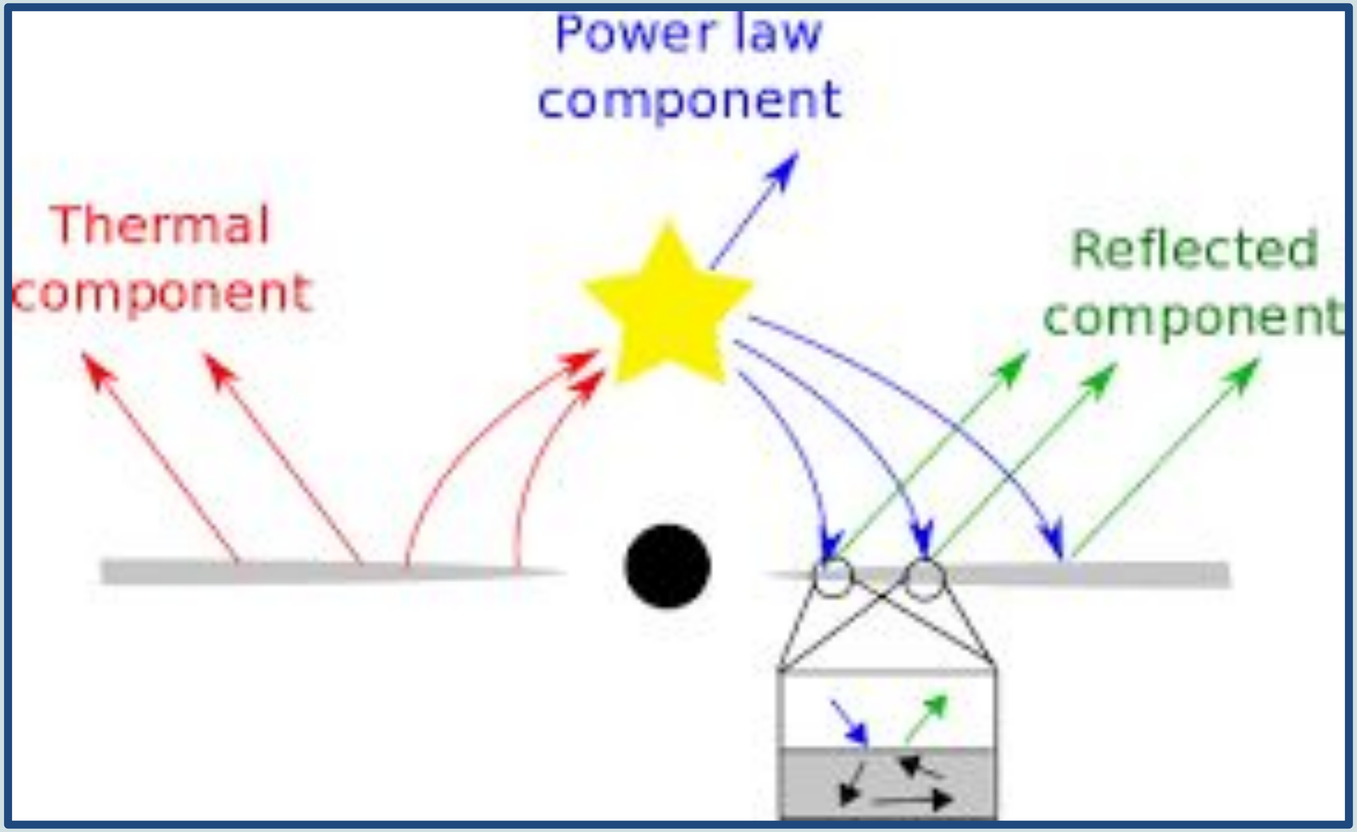
2017 Outburst





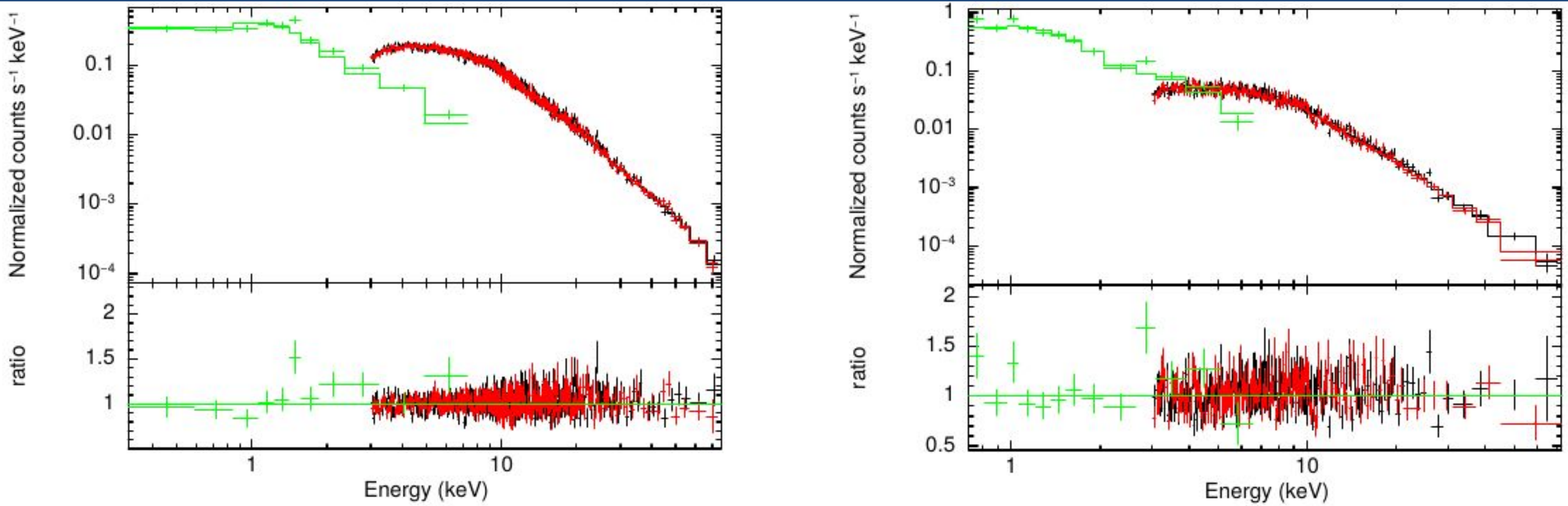
Beri et al. 2019 (MNRAS)

Multiwavelength Coordination needed to obtain deeper insights!



Abdikamalov, et al. 2019

One of the ways to investigate the putative torus model is to study the X-ray spectrum in a broadband covering high energies above 10 keV or so. The detection of any signatures of cut-off, or any reflection from the disc will be quite useful to test the torus model.



NuSTAR Obs ID	N_H (fixed)	Γ	N_{PL}^a	Flux	Reduced χ^2 (dof)
90201057002	0.012	1.663 ± 0.005	0.0235 ± 0.0003	3.50 ± 0.01	0.96 (1179)
90301005002	0.012	1.79 ± 0.01	0.0084 ± 0.0002	0.89 ± 0.04	1.01 (595)

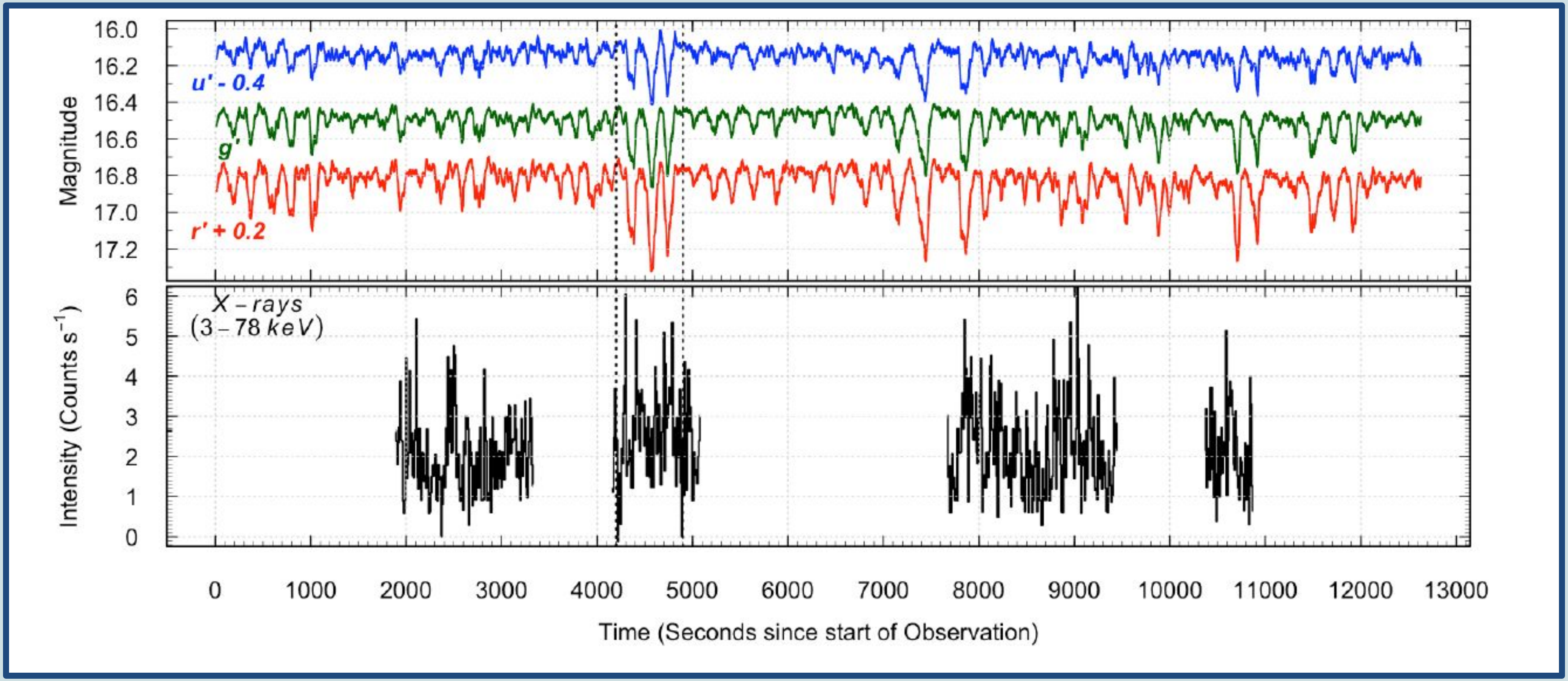
Beri et al. 2019 (MNRAS)

An absorbed disc blackbody + relxill model did not improve the spectral fit!

Parameters	a=0	a=0.8	a=0.9
	Observation 1 (Inclination: 30°)		
$kT_{\rm in}$ (keV)	$0.029^{+0.002}_{-0.029}$	$0.029^{+0.002}_{-0.029}$	$0.029^{+0.002}_{-0.029}$
Γ	1.63 ± 0.01	1.63 ± 0.01	1.63 ± 0.01
$R_{(in)} (R_g)$	80 ± 80	80 ± 80	80 ± 80
R_{refl}	<0.03	<0.02	<0.02
N^a	0.0224 ± 0.0004	0.020 ± 0.001	0.0239 ± 0.0002
$const_{FPMB}$	1.035 ± 0.006	1.035 ± 0.006	1.035 ± 0.006
$const_{XRT}$	0.78 ± 0.03	0.84 ± 0.04	0.74 ± 0.03
Reduced χ^2 (dof)	0.96 (1175)	0.96 (1175)	0.96 (1175)
	Observation 2 (Inclination: 30°)		
$kT_{\rm in}$ (keV)	-	-	-
Γ	1.75 ± 0.01	1.75 ± 0.01	1.75 ± 0.01
$R_{(in)} (R_g)$	20 ± 20	20 ± 20	20 ± 20
R_{refl}	$0.01^{+0.04}_{-0.01}$	$0.01^{+0.04}_{-0.01}$	$0.01^{+0.04}_{-0.01}$
N^a	0.000204 ± 0.000005	0.000204 ± 0.000005	0.000204 ± 0.000005
$const_{FPMB}$	1.01 ± 0.01	1.01 ± 0.01	1.01 ± 0.01
$const_{XRT}$	0.83 ± 0.04	0.83 ± 0.04	0.83 ± 0.04
Reduced χ^2 (dof)	1.01 (593)	1.01 (593)	1.01 (593)

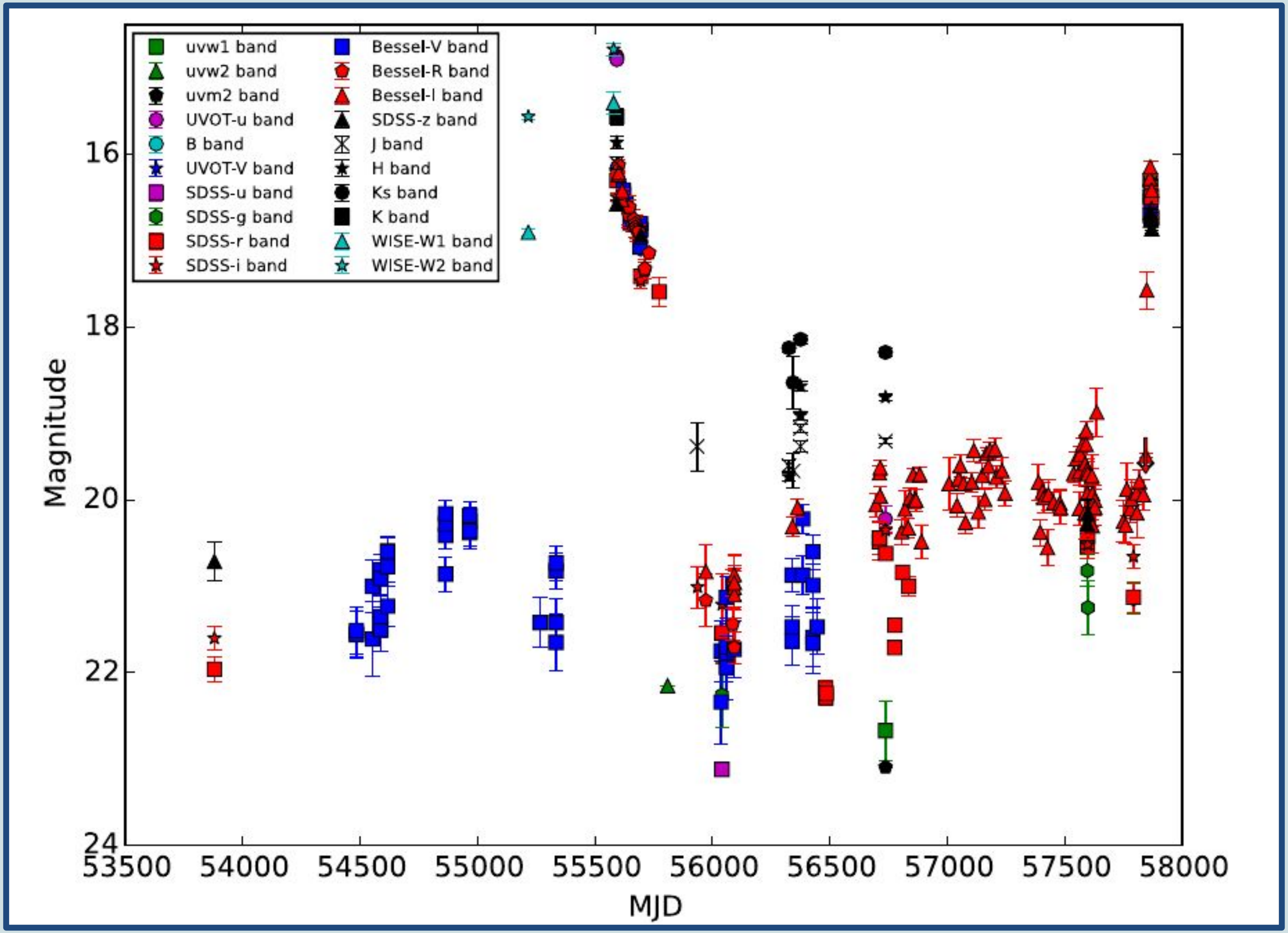
Note: a $\rightarrow$ Normalization (N) is in units of photons cm^{-2} s^{-1} keV^{-1} at 1 keV.

ULTRACAM +NuSTAR light curves!



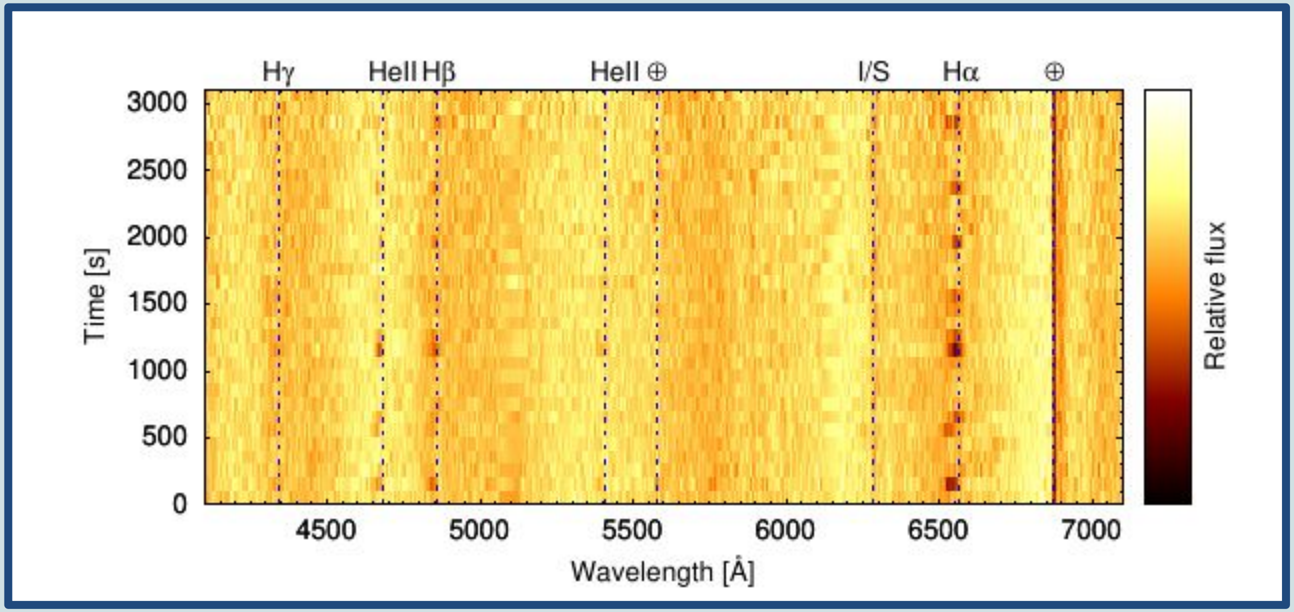
Paice et al. 2019

OIR light curves of Swift J1357.2–0933 from 2006 to 2017



Russell et al. 2018

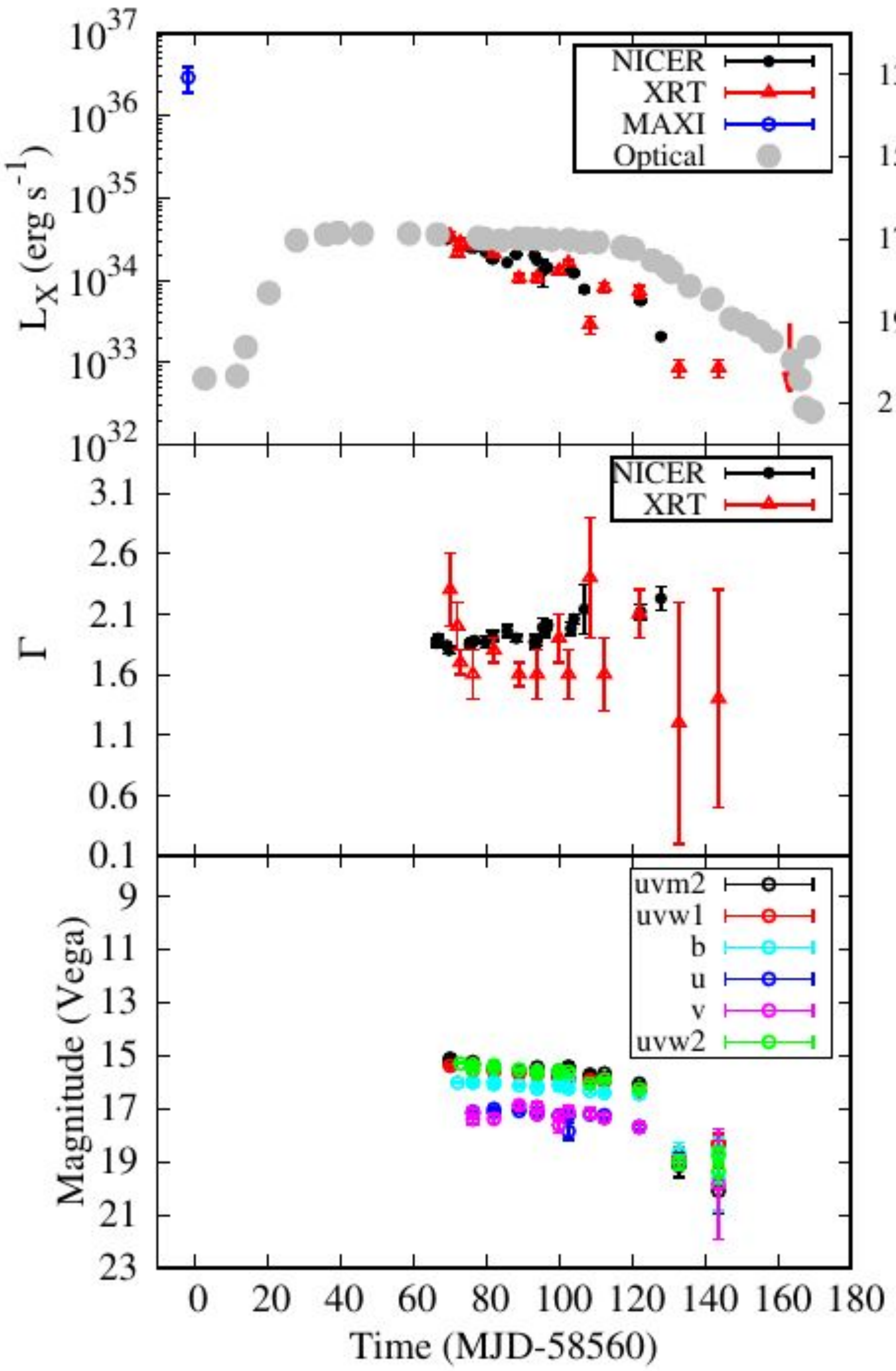
Hot, dense HeII outflows during the 2017 outburst

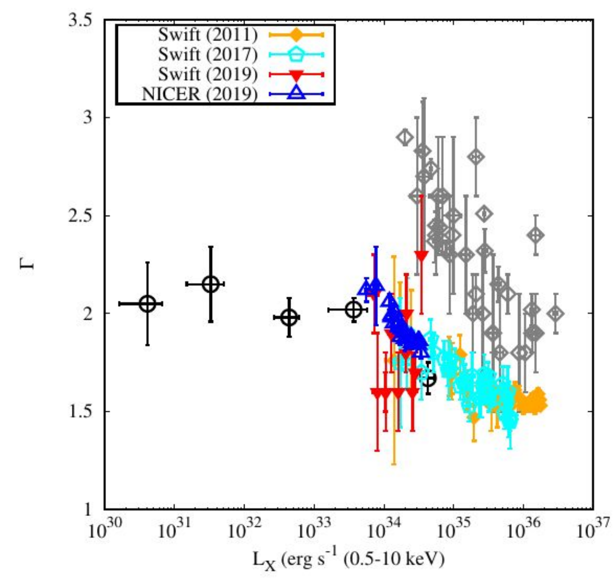


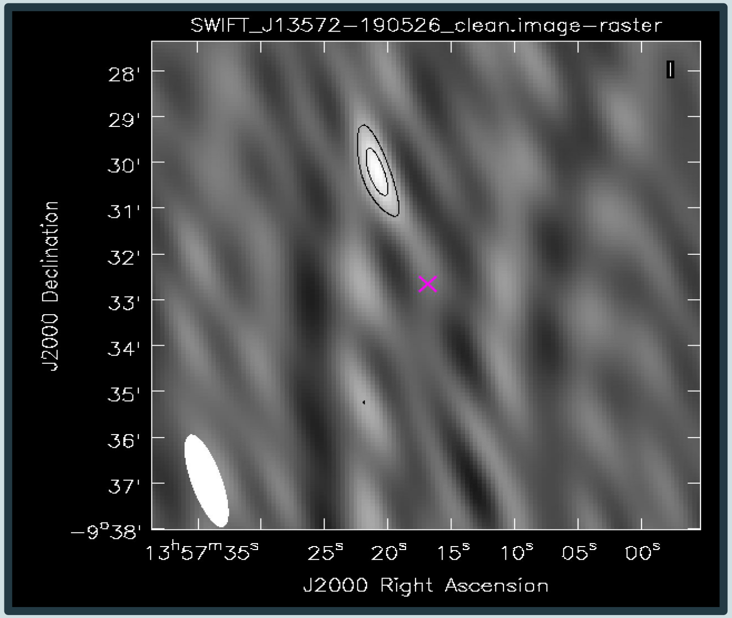
The outburst amplitude - Porb relation to extend the possible distance range out to **≥6.3kpc**, thereby increasing all the luminosity estimates by ~ ×40 to at least LX ~ 4 × 10^36 erg s^-1 and hence **it is not a VFXT!**

Charles et al. 2019

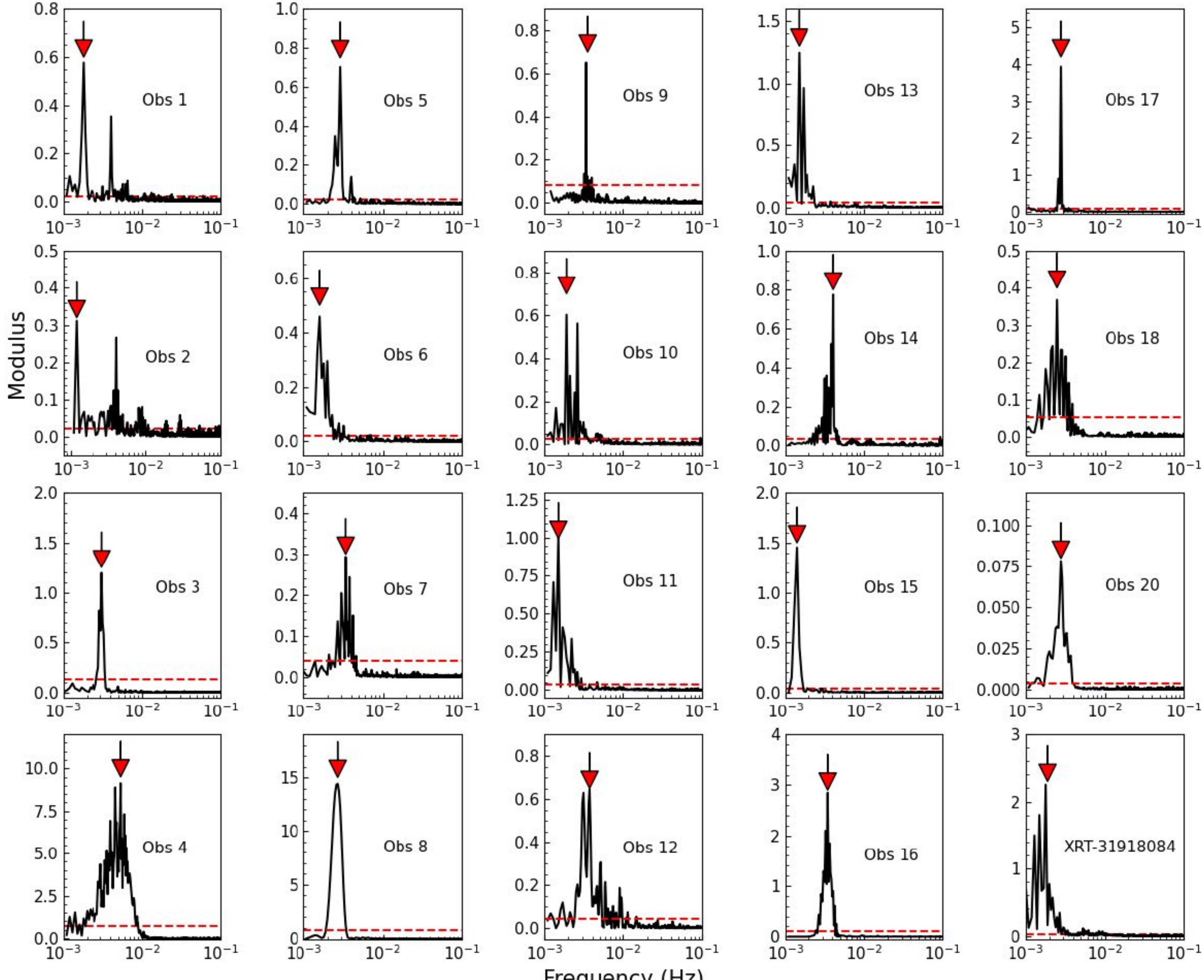
2019 Outburst



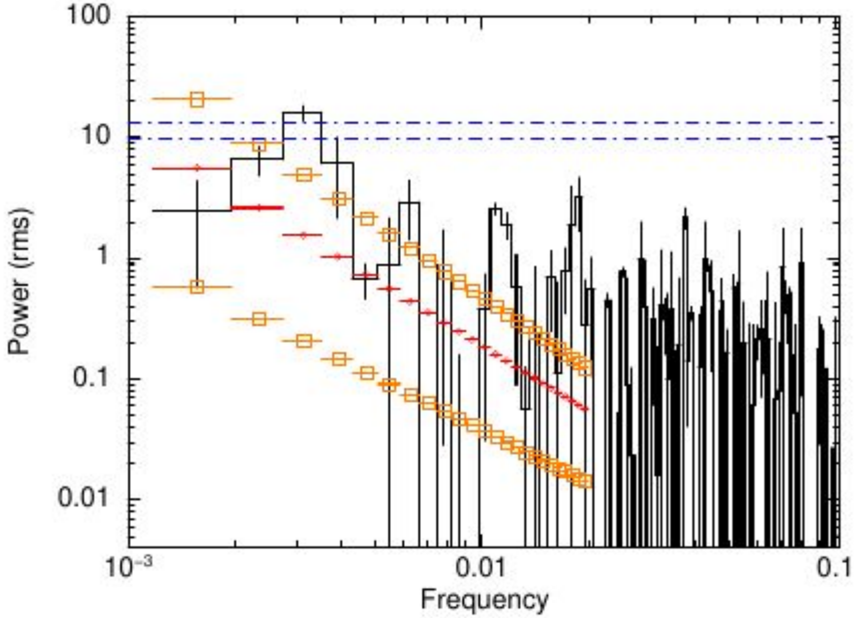


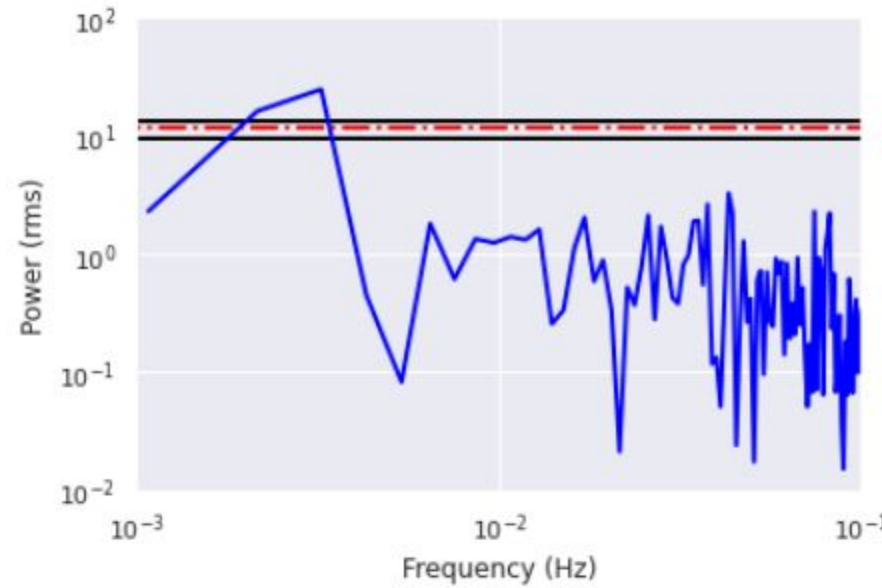


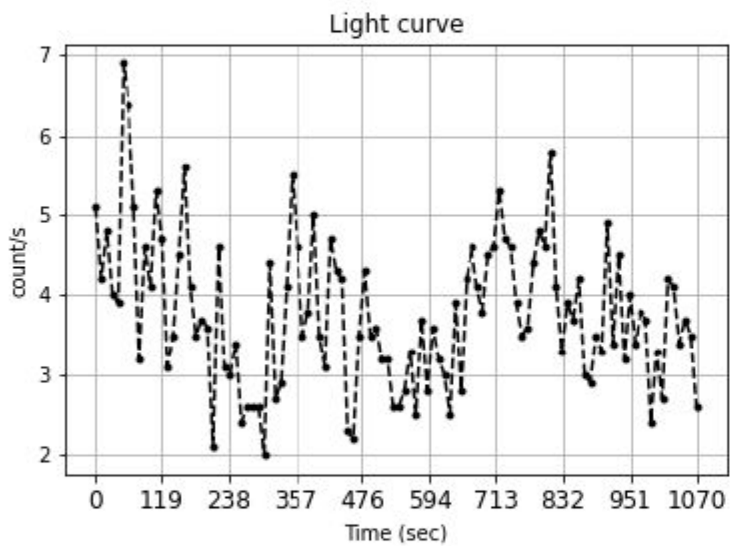
Beri et al. 2023 (MNRAS)

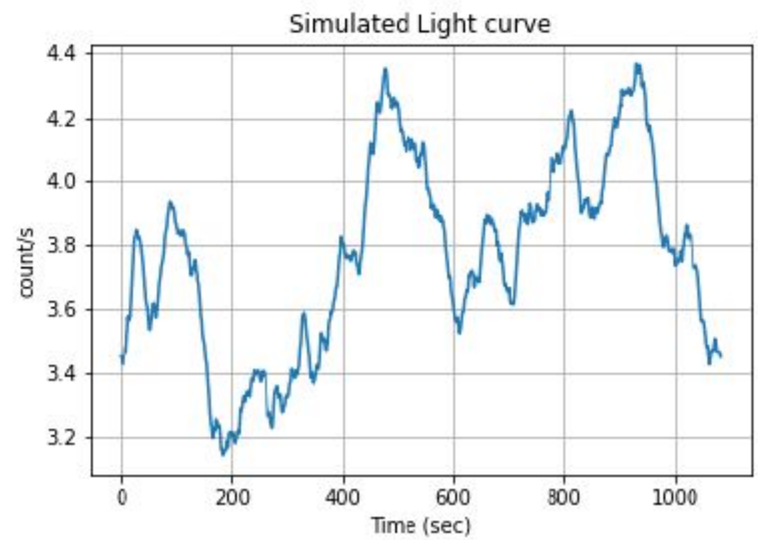


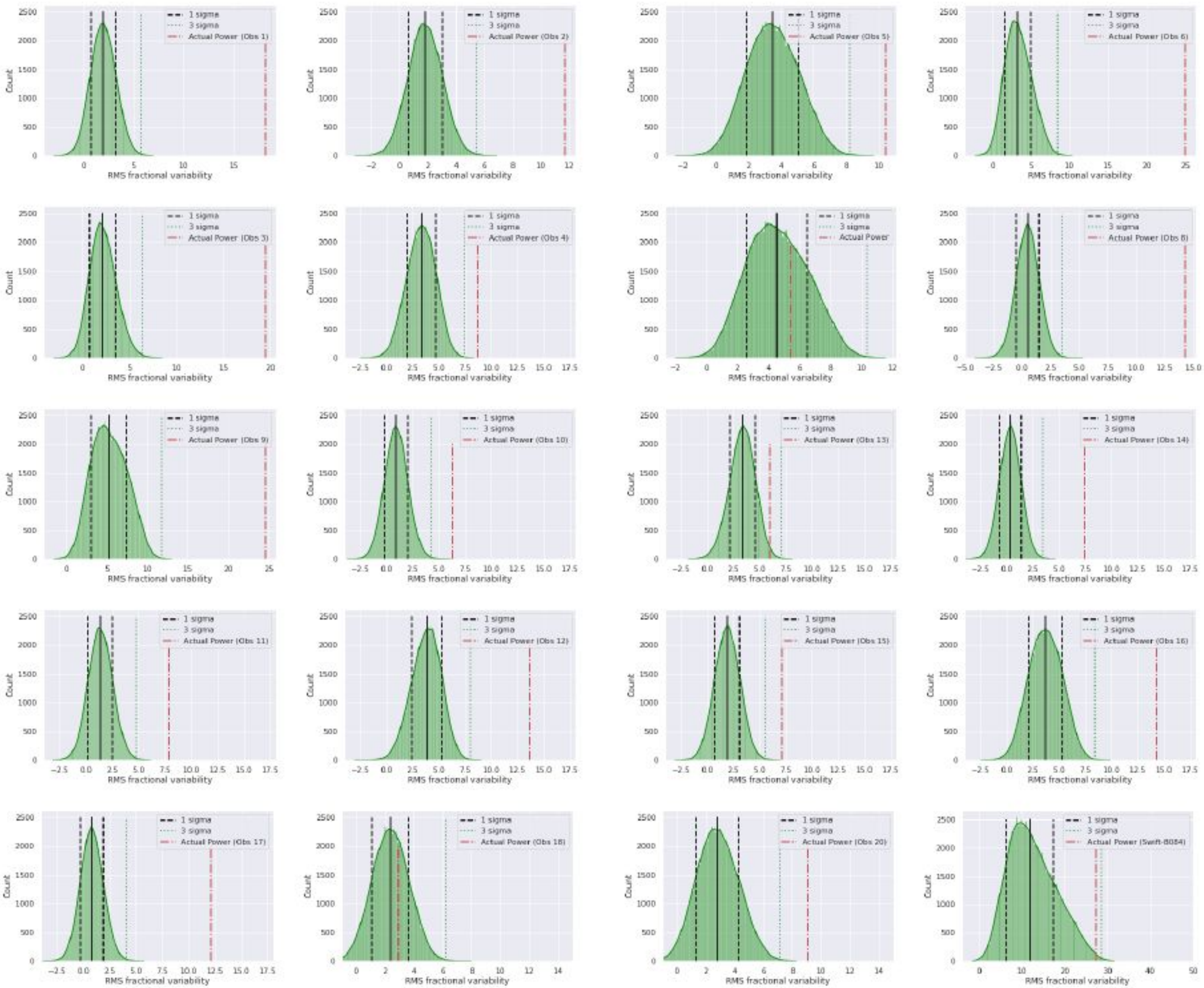
Obs 1
Obs 5
Obs 9
Obs 13
Obs 17
Obs 2
Obs 6
Obs 10
Obs 14
Obs 18
Obs 3
Obs 7
Obs 11
Obs 15
Obs 20
Obs 4
Obs 8
Obs 12
Obs 16
XRT-31918084
Modulus
Frequency (Hz)


Power (rms)
100
10
1
0.1
0.01
10^{-3}
0.01
0.1
Frequency


Power (rms)
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
Frequency (Hz)

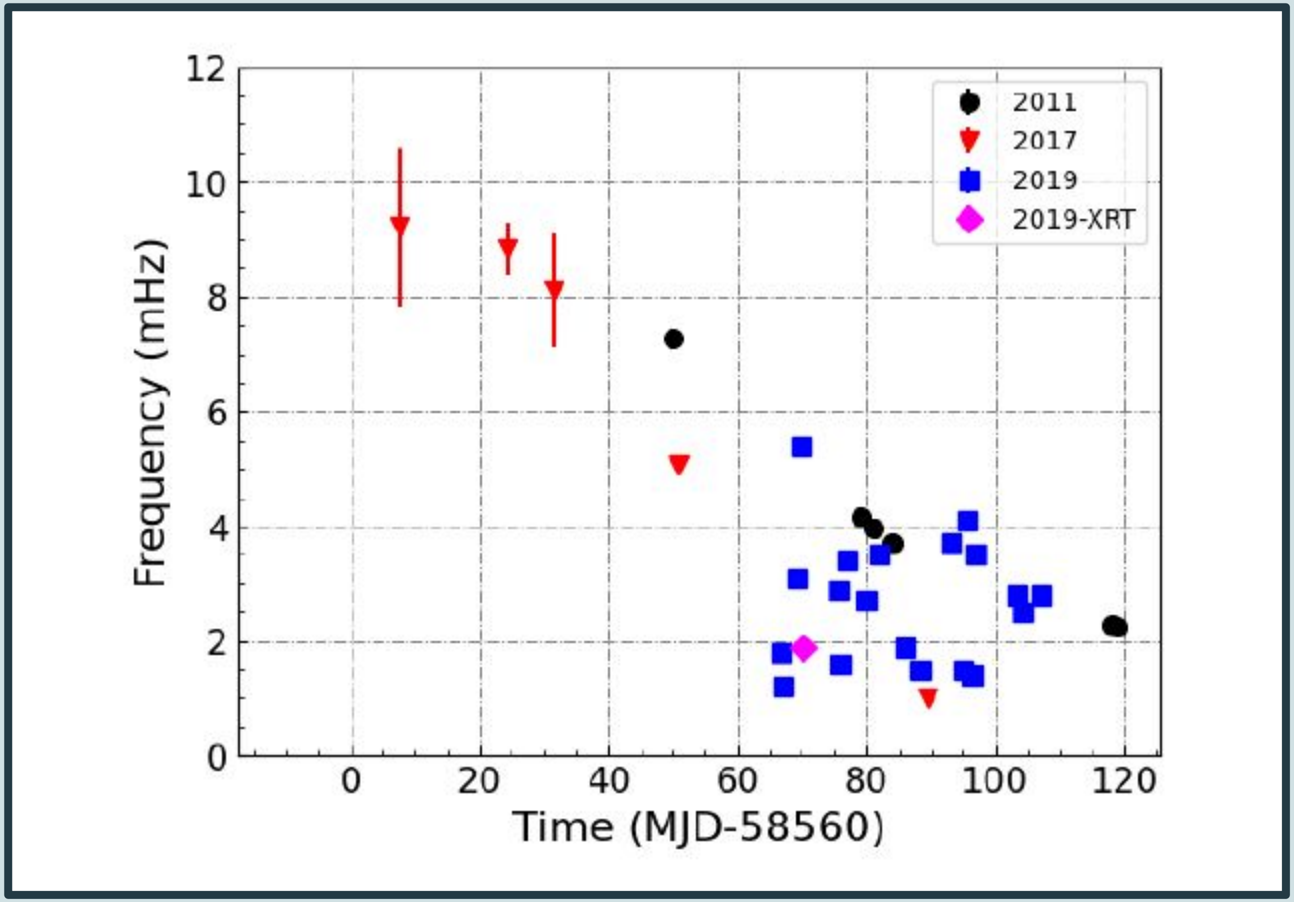

Light curve
count/s
7
6
5
4
3
2
0 119 238 357 476 594 713 832 951 1070
Time (sec)


Simulated Light curve
count/s
4.4
4.2
4.0
3.8
3.6
3.4
3.2
0 200 400 600 800 1000
Time (sec)



1 sigma
3 sigma
Actual Power (Obs 1)
Actual Power (Obs 2)
Actual Power (Obs 5)
Actual Power (Obs 6)
Actual Power (Obs 3)
Actual Power (Obs 4)
Actual Power
Actual Power (Obs 8)
Actual Power (Obs 9)
Actual Power (Obs 10)
Actual Power (Obs 13)
Actual Power (Obs 14)
Actual Power (Obs 11)
Actual Power (Obs 12)
Actual Power (Obs 15)
Actual Power (Obs 16)
Actual Power (Obs 17)
Actual Power (Obs 18)
Actual Power (Obs 20)
Actual Power (Swift-B084)
Count
RMS fractional variability

Observation	Frequency (mHz)	Significance (σ)
Obs 1	1.8±0.1	12
Obs 2	1.2±0.1	8
Obs 3	3.1±0.1	12
Obs 4	5.4±0.1	3.9
Obs 5	2.9±0.1	4.4
Obs 6	1.6±0.1	12
Obs 7	3.4±0.1	0.45
Obs 8	2.7±0.1	14
Obs 9	3.5±0.1	12
Obs 10	1.9±0.1	5
Obs 11	1.5±0.1	6
Obs 12	3.7±0.1	7
Obs 13	1.5±0.1	2.1
Obs 14	4.1±0.1	7
Obs 15	1.4±0.1	4.3
Obs 16	3.5±0.1	6.7
Obs 17	2.8±0.1	10
Obs 18	2.5±0.1	0.4
Obs 20	2.8±0.1	4.3
XRT-31918084	1.8±0.1	2.7



Beri et al. 2023 (MNRAS)

X-ray QPOs in the millihertz frequency range have been detected for the **first time during the outburst of J1357.**

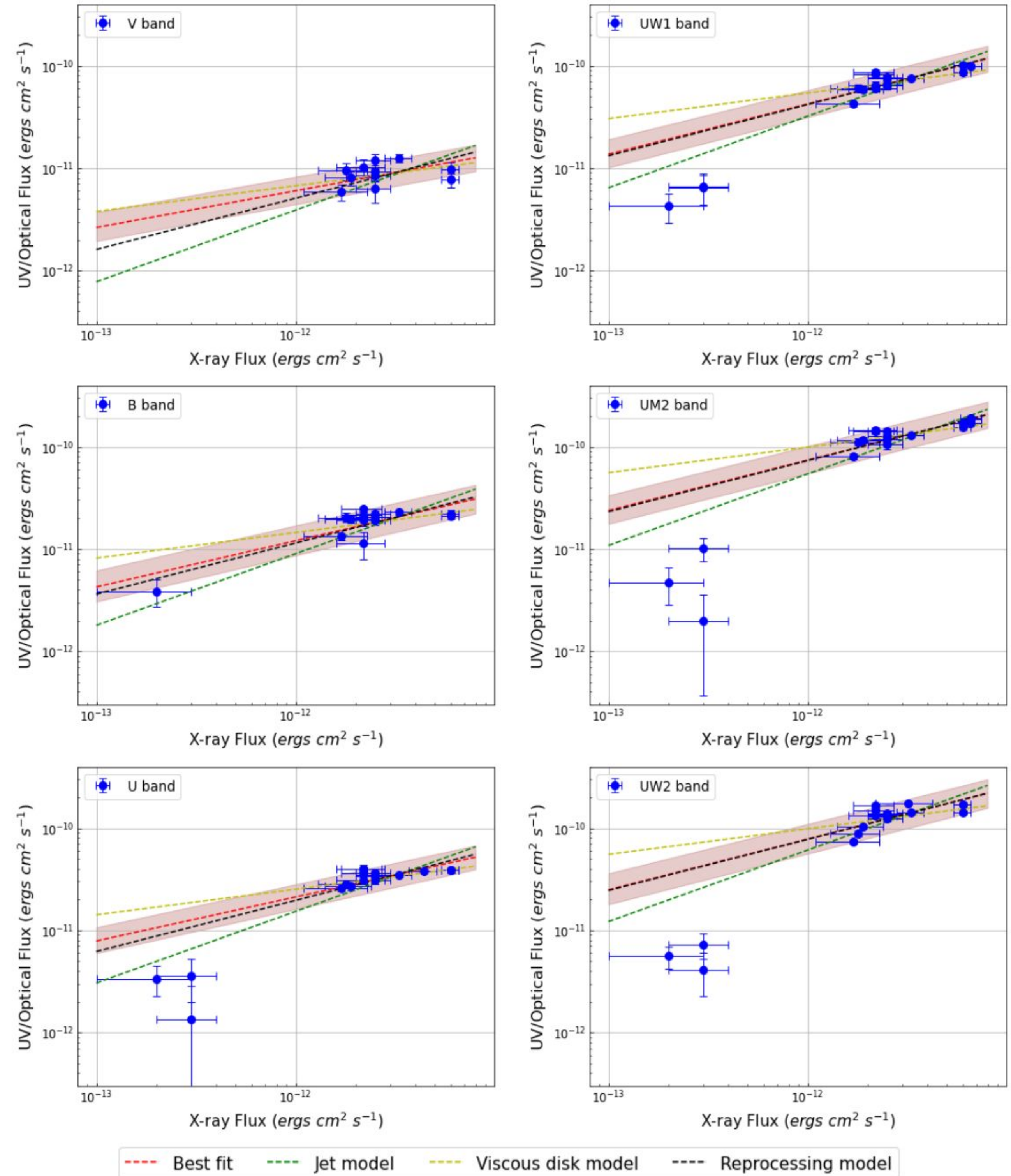
Origin of X-ray QPO not clear?

Optical/UV-X-ray correlation

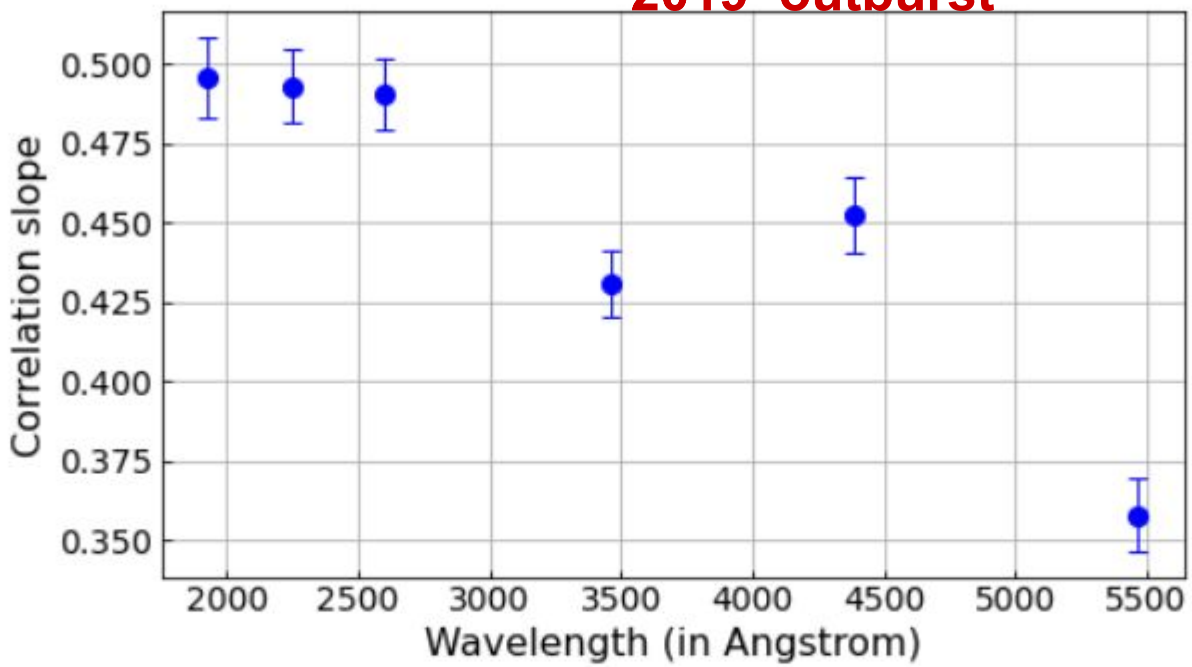
A fruitful method to understand the origin of the emission at low frequencies (optical and UV) is to study its correlation with the X-ray emission using simultaneous observations.

Sample	X-ray reprocessing model			Jet model			Viscous disc model	
	Model	$\mid \beta_{\rm data}$-$\beta_{\rm model} \mid$	$\frac{n_{\rm data}}{n_{\rm model}}$ *	Model	$\mid \beta_{\rm data}$-$\beta_{\rm model} \mid$	$\frac{n_{\rm data}}{n_{\rm model}}$	Model	$\mid \beta_{\rm data}$-$\beta_{\rm model} \mid$
BHs: $L_{\nu,\rm OPT}$	$nL_{\rm X}^{0.5}a$	0.05±0.03	9.3±0.4	$L_{\rm X}^{0.7}$	0.11±0.02	1.05±0.07	$L_{\rm X}^{0.25}$	0.34±0.02
BHs: $L_{\nu,\rm NIR}$	$(\frac{\nu_{NIR}}{\nu_{OPT}})^{\alpha}nL_{\rm X}^{0.5}a$	0.06±0.03	15.5–81.3†	$L_{\rm X}^{0.7}$	0.09±0.04	1.78±0.16	$L_{\rm X}^{0.17}$	0.44±0.04
NSs: $L_{\nu,\rm OPT}$	$nL_{\rm X}^{0.5}a$	0.09±0.02	1.0*	$L_{\rm X}^{1.4}$	0.81±0.03	6.03±1.94	$L_{\rm X}^{0.50}$	0.09±0.03
NSs: $L_{\nu,\rm NIR}$	$(\frac{\nu_{NIR}}{\nu_{OPT}})^{\alpha}nL_{\rm X}^{0.5}a$	0.05±0.03	3.2–16.6†	$L_{\rm X}^{1.4}$	0.09±0.41	9.55±3.08	$L_{\rm X}^{0.30}$	1.19±0.41

Russell et al. 2006


V band
UW1 band
B band
UM2 band
U band
UW2 band
UV/Optical Flux (ergs cm² s⁻¹)
X-ray Flux (ergs cm² s⁻¹)
Best fit
Jet model
Viscous disk model
Reprocessing model

2019 outburst



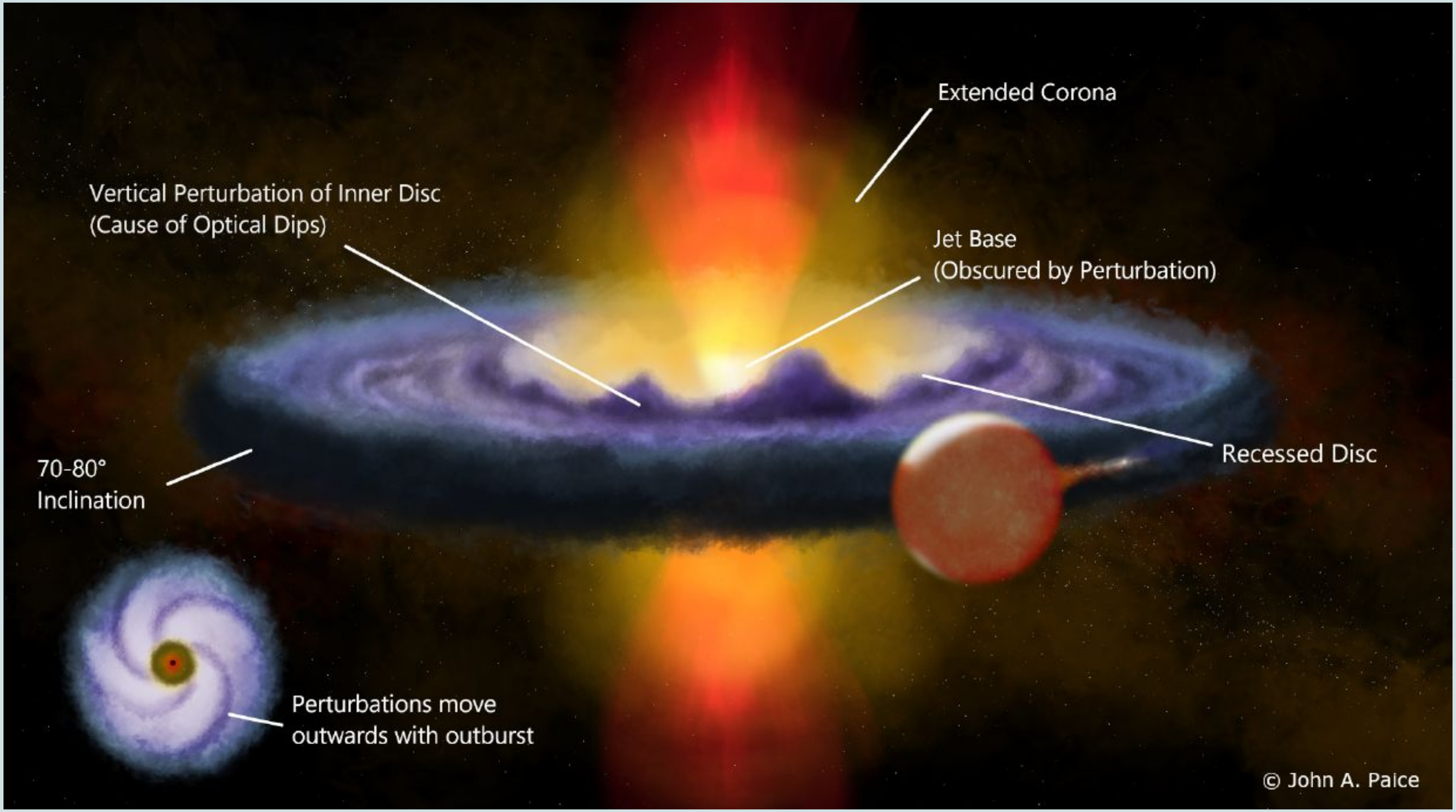
2017 outburst

UVOT Band	Wavelength	β (fit values)
v	5402	0.17 ± 0.02
b	4329	0.17 ± 0.03
u	3501	0.24 ± 0.02
uvw1	2634	0.27 ± 0.03
uvm2	2231	0.30 ± 0.03
uvw2	2030	0.35 ± 0.05

2019 outburst

Filter (wavelength)	Best fit slopes (β)
V (5468)	0.36 ± 0.01
B (4392)	0.45 ± 0.01
U (3465)	0.43 ± 0.01
UVW1 (2600)	0.49 ± 0.01
UVM2 (2246)	0.49 ± 0.01
UVW2 (1928)	0.49 ± 0.01

Beri et al. 2023 (MNRAS)



Swift J1357.2-0933 remains a puzzling source with many questions yet to answer!

Thank you! :)