Instabilities in accretion onto black holes

Jean Swank

Studying black holes was recognized early to be an exciting possibility of X-ray astronomy

Elihu understood the theoretical implications for the instrumentation needed to learn more about the important aspects

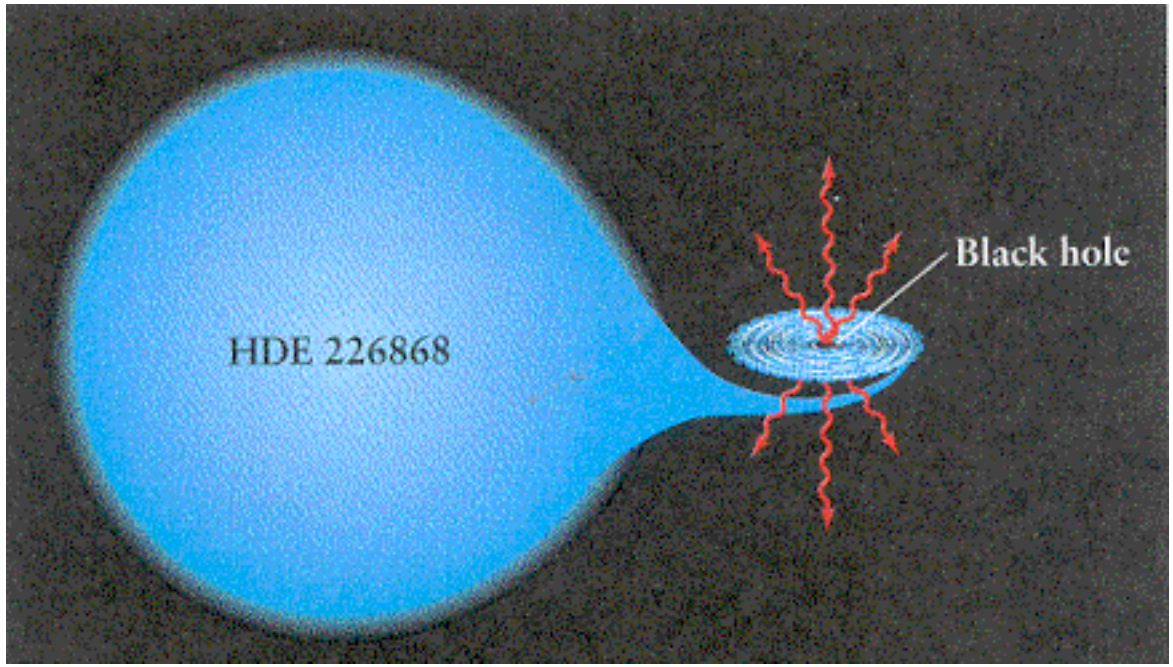
We have made progress, but still haven't reached the goal

Elihu's 1975 remarks on Cyg X-1

"We have probably been provided with an ideal laboratory for the study of the behavior of matter as it falls into an object dominated by the laws of gravitational relativity."

"Such studies will require X-ray observatories of large sensitive area, high temporal resolution and broad bandwidth, so that enough radiation is measured for characterizing each individual burst and long enough exposures to monitor this behavior for several binary periods."

The first recognized black hole Cygnus X-1

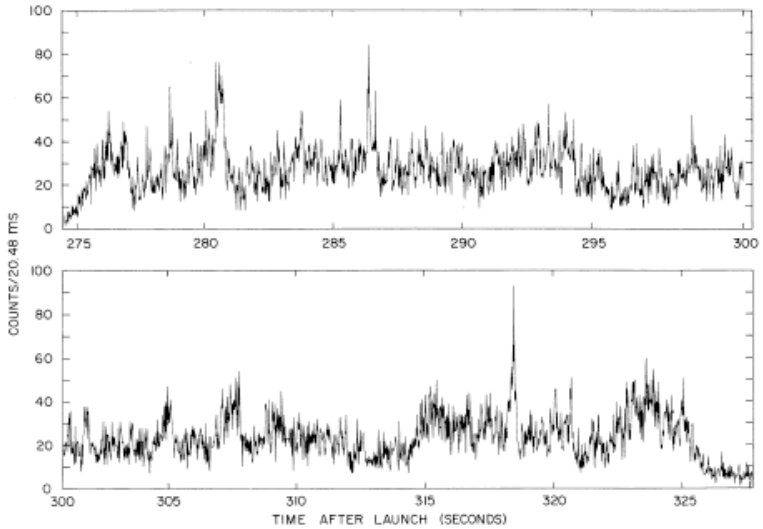


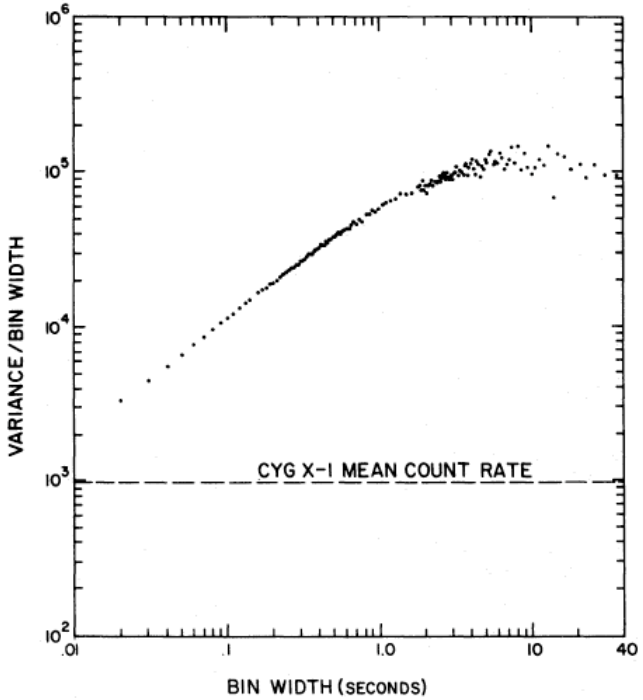
Cyg X-1 was discovered in a rocket flight in 1965. It was reported to be unusually variable in *Uhuru* observations

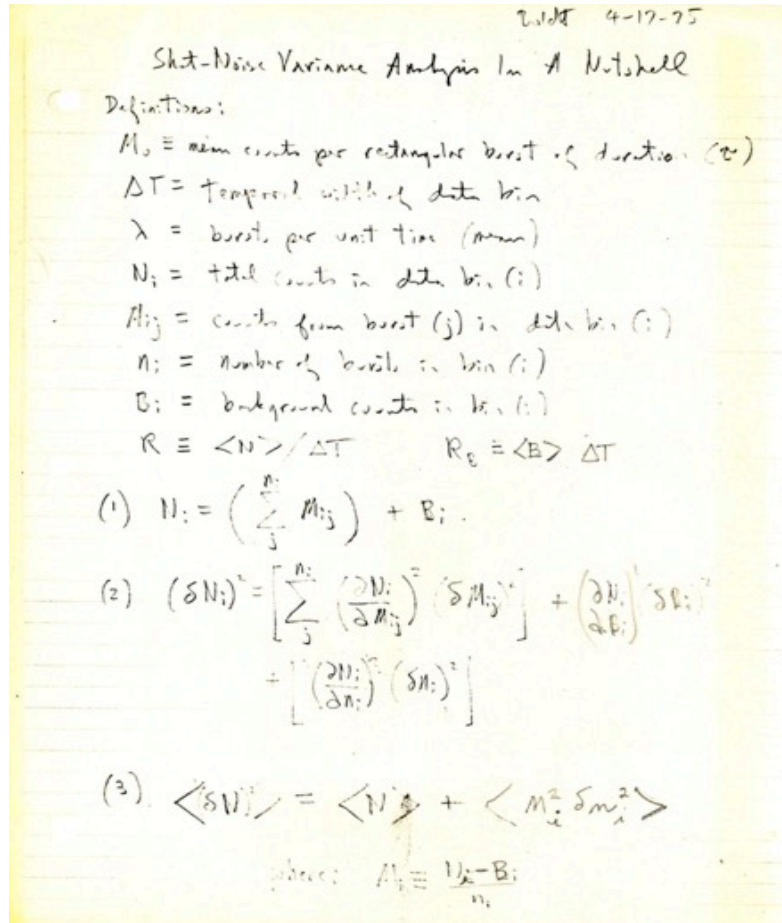
Theorists (Shakura and Sunyaev) said in 1973 that accretion onto black holes might be very variable – with millisecond time scales

Goddard's X-ray group observed it with rocket flights in 1973 and 1974.

“Shot noise”







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Shot-Noise Variance Analysis In A Nutshell

Definitions:

$M_0 \equiv$ mean counts per rectangular burst of duration (τ)

$\Delta T =$ temporal width of data bin

$\lambda =$ bursts per unit time (mean)

$N_i =$ total counts in data bin (i)

$M_{ij} =$ counts from burst (j) in data bin (i)

$n_i =$ number of bursts in bin (i)

$B_i =$ background counts in bin (i)

$R \equiv \langle N \rangle / \Delta T \qquad R_B \equiv \langle B \rangle \Delta T$

(1) $N_i = \left(\sum_j^{n_i} M_{ij} \right) + B_i$

(2) $(\delta N_i)^2 = \left[\sum_j^{n_i} \left(\frac{\partial N_i}{\partial M_{ij}} \right)^2 (\delta M_{ij})^2 \right] + \left(\frac{\partial N_i}{\partial B_i} \right)^2 (\delta B_i)^2 + \left[\left(\frac{\partial N_i}{\partial n_i} \right)^2 (\delta n_i)^2 \right]$

(3) $\langle (\delta N_i)^2 \rangle = \langle N_i \rangle + \langle M_i^2 \, \delta n_i^2 \rangle$

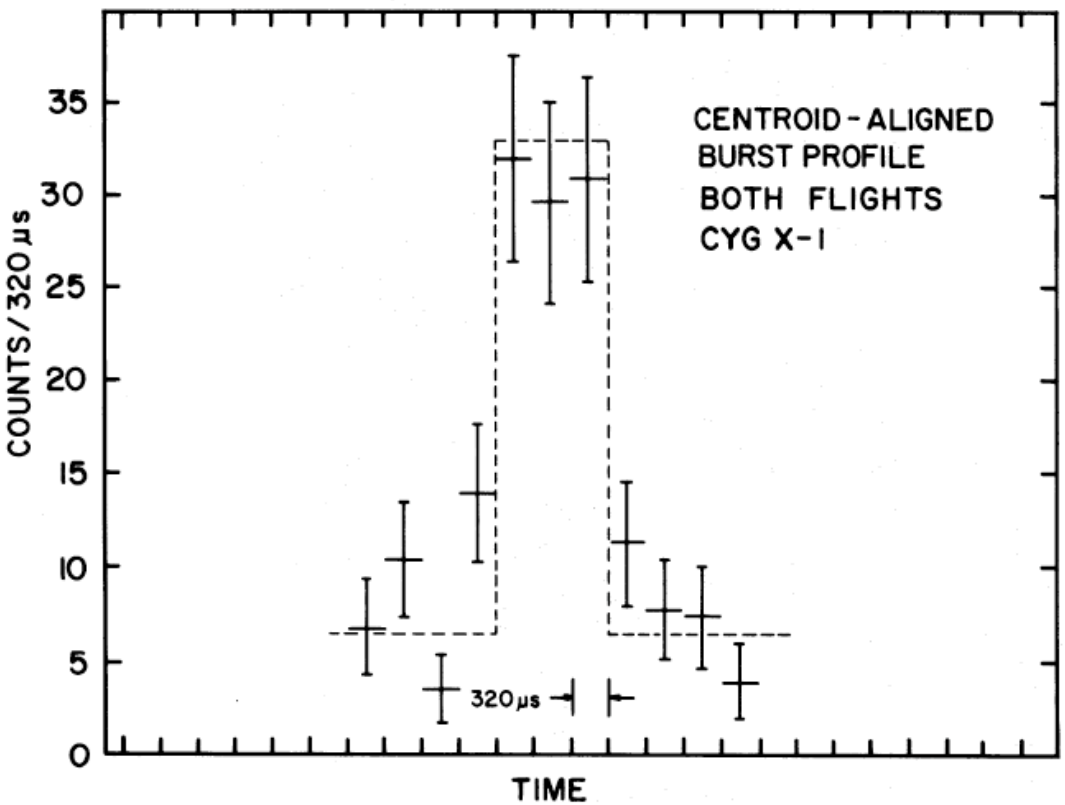
where: $M_i \equiv \frac{N_i - B_i}{n_i}$

$(\text{Var } N)/\Delta T = \text{Rate } (1 + fm\Delta T/\tau) \qquad \Delta T < \tau$

$= \text{Rate } (1 + fm) \qquad \Delta T > \tau$

Millisecond bursts

Order of 10 counts in 1 msec. 12 such bursts, on tops of flares. Application of Poisson statistics with respect to local averages indicated these were unlikely to be random fluctuations.



Elihu had the concept that an enhanced density could persist for seconds and that rotation around the black hole, with relativistic beaming, could give rise to these bursts with a recurrence time of about 14 milliseconds, that appeared in a few seconds of data.

If that were the case, the mass and the angular momentum of the BH followed….

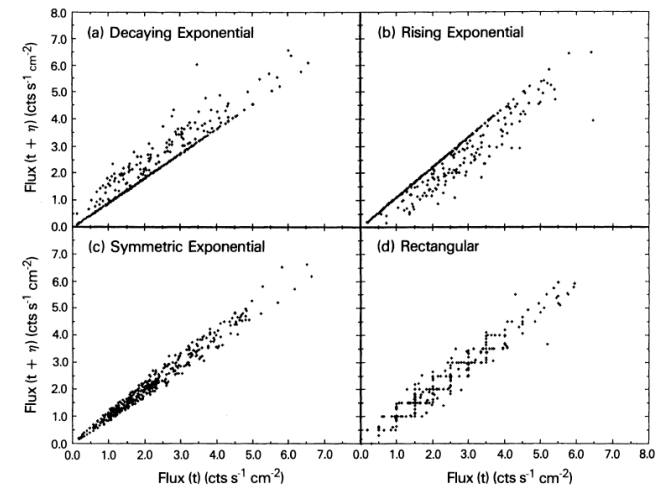
Missions studying Cyg X-1 Timing

Mission	Cm2	Count/s	Millisec resol.	Tot sec expos	Publications (partial list!)
Uhuru 1971	840	250	192	800	Terrell Weisskopf, Kahn & Sutherland
Rocket 1973	1360	1500	0.32	50	Rothschild, Boldt, Holt & Serlemitsos
Rocket 1974	1360	1500	0.16	180	Rothschild, Boldt, Holt & Serlemitsos
EXOSAT 1983	1790	740	20	4070	Belloni & Hasinger; Lochner, Swank & Szymkowiak;
HEAO A2 1977	1318	760	80	2743	Lochner, Swank & Szymkowiak
HEAO A1 1977	1650	1000	0.01	270	Meekins, Wood, Hedler, Byram, Yentis, Chubb & Friedman
Ginga 1987	4000	4700	31	16220	Negoro, Kitamoto, Takeuchi & Mineshige
RXTE 1996	6500	5000	0.122	11464	Focke, Wai & Swank; Gerlinski & Zdziarski

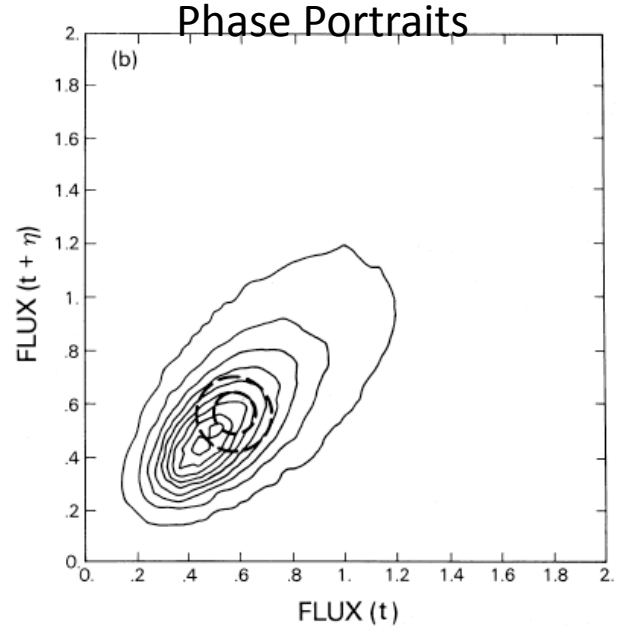
Better shot models - J Lochner

Measures:

Variance with bin size Δt	rate λ
Autocorrelation function	tau (0.1-1 s)
Skewness (3rd moment)	
Power spectrum	$S(f) \approx 1/f$
Phase portrait	**Flux(t+η) vs Flux(t)**



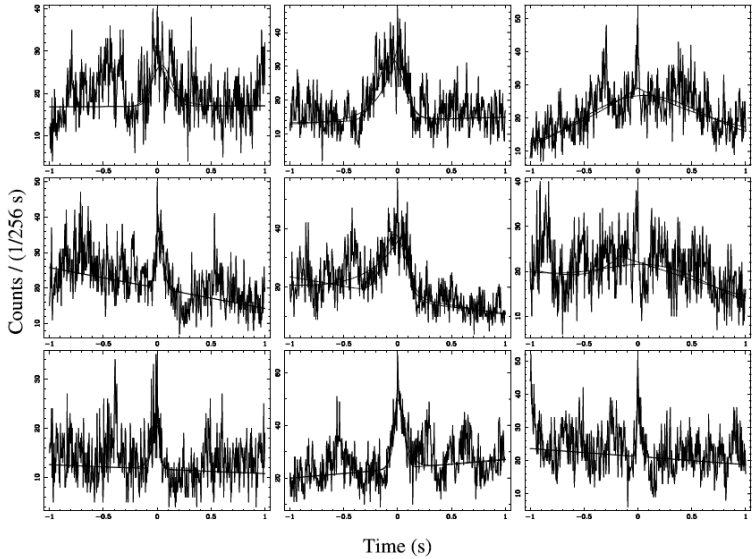
Phase Portraits

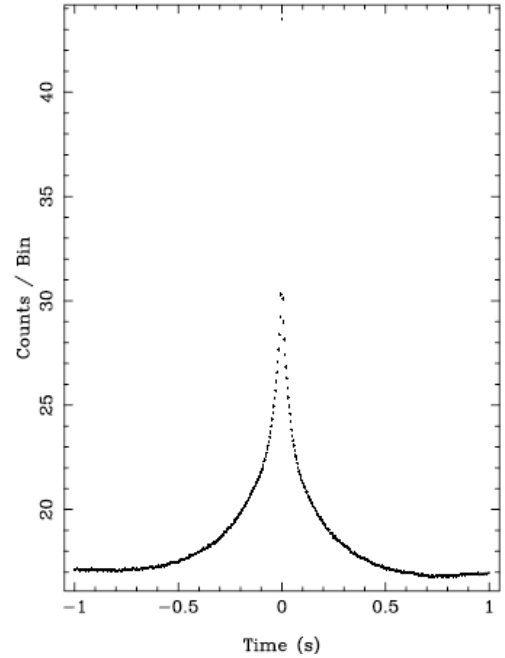


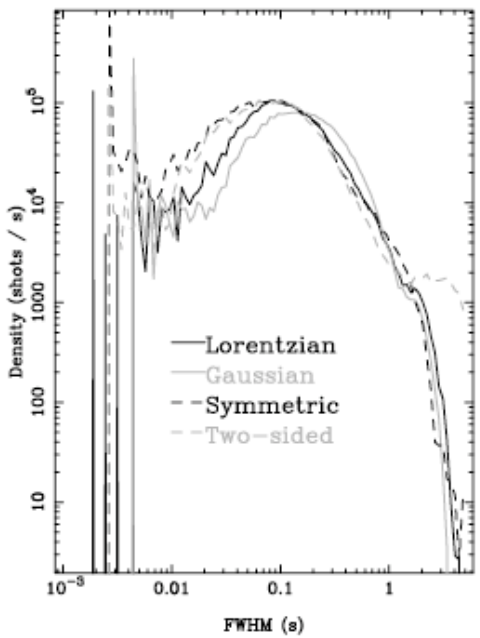
Models: $I(t) = \mathrm{Sum}_k\, F(t-t_k)$

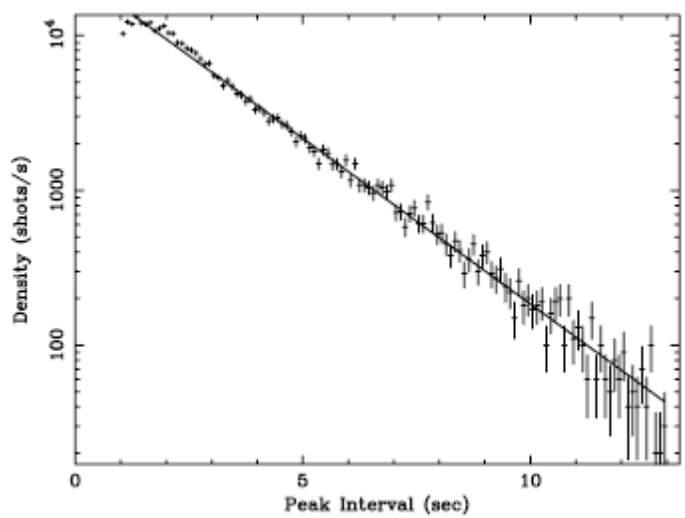
Rectangular	Terrell, Boldt
Exponential	Lochner
Symmetric exponential	Lochner
Distribution of tau and height	Lochner

Resolving individual shots – W Focke

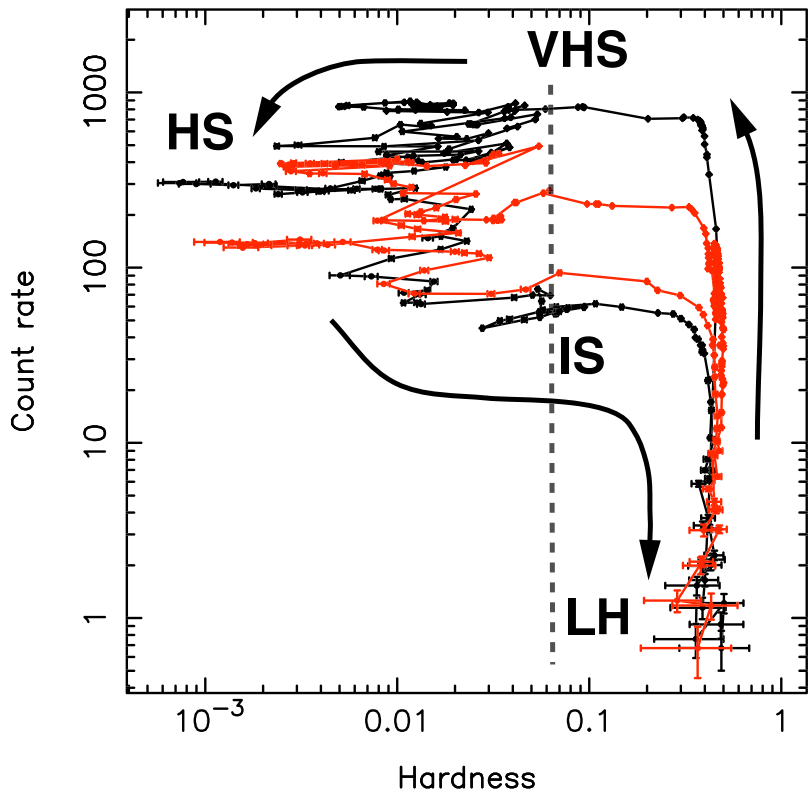


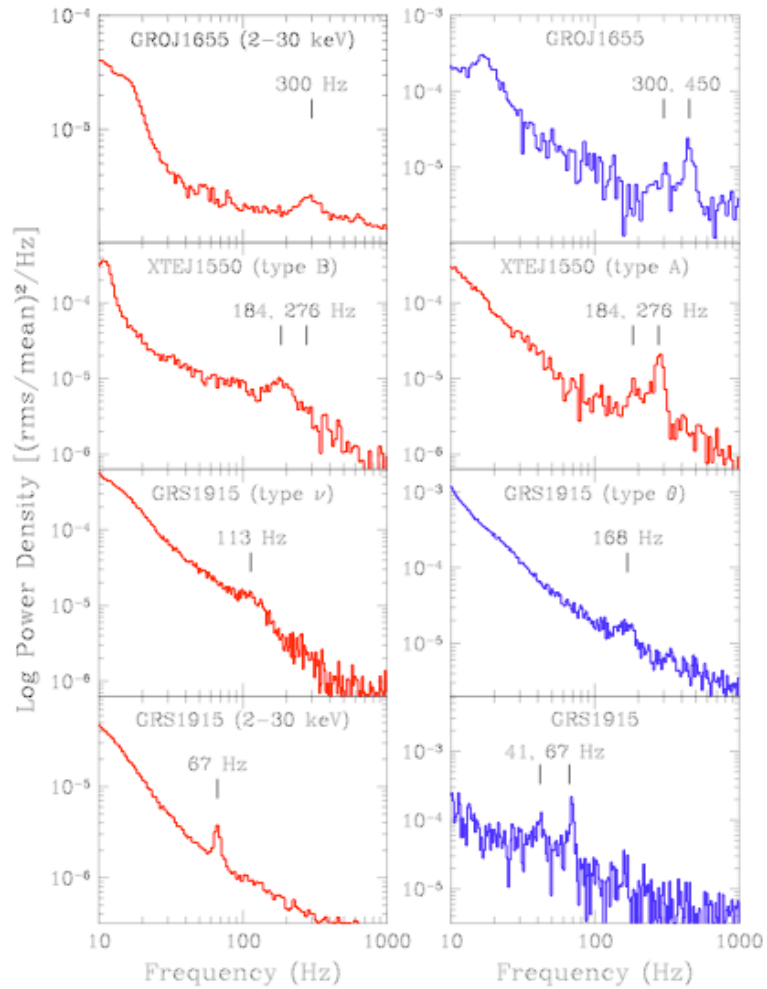




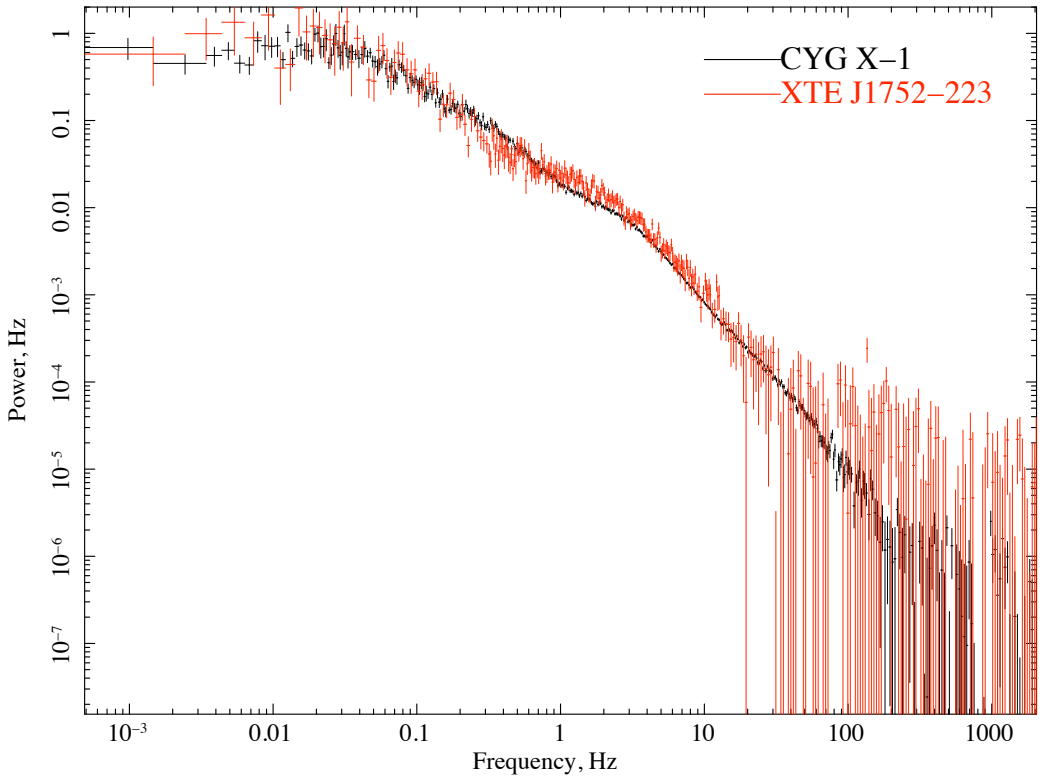


The context of black hole states





A new Cygnus X-1



N Shaposhnikov

Another source – another opportunity to see details that will help understand

- How are the shots formed?
- Are there shorter times scale bursts?

If we had 10 times the area these would be clear!