Signals from the Abyss – searching for QPOs in AGN

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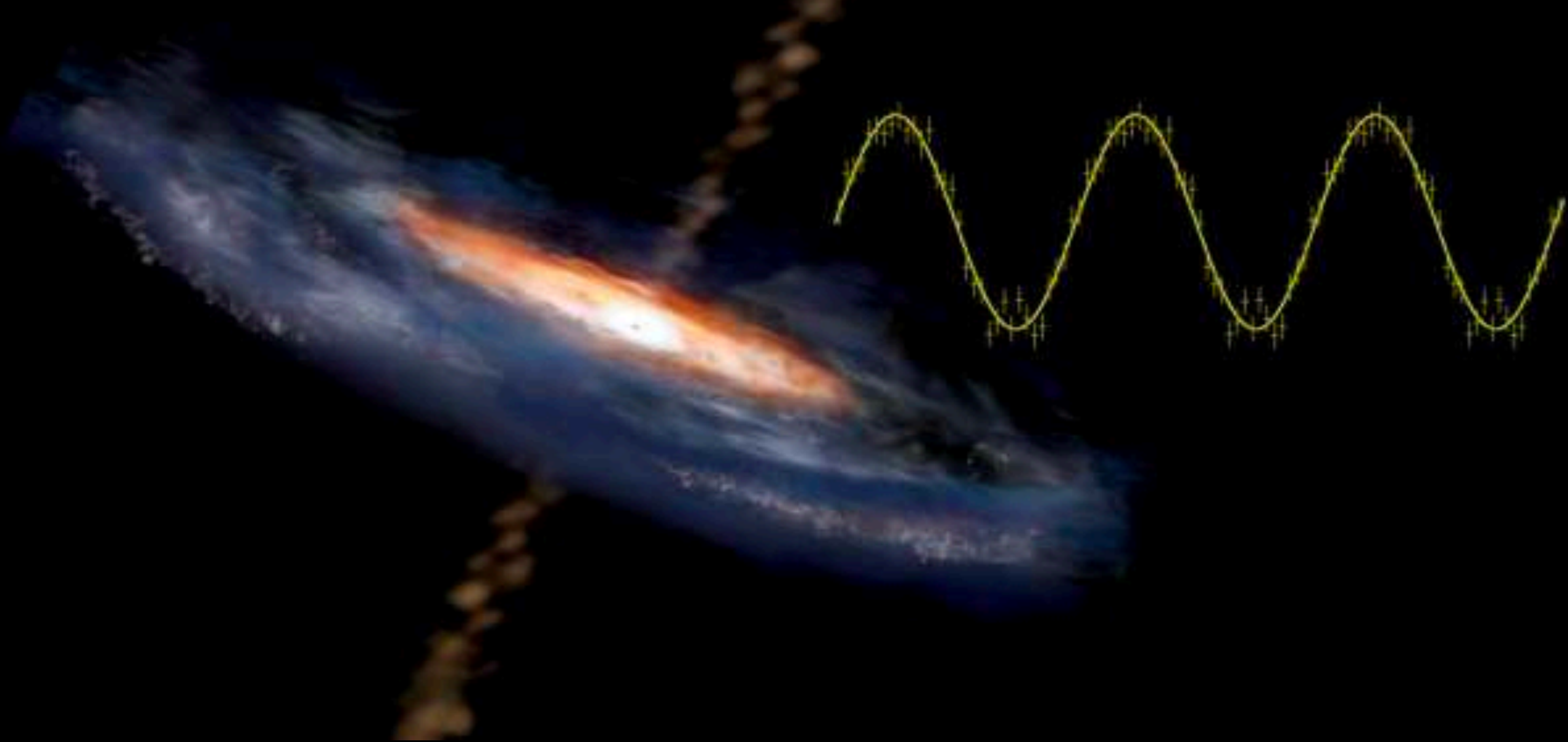
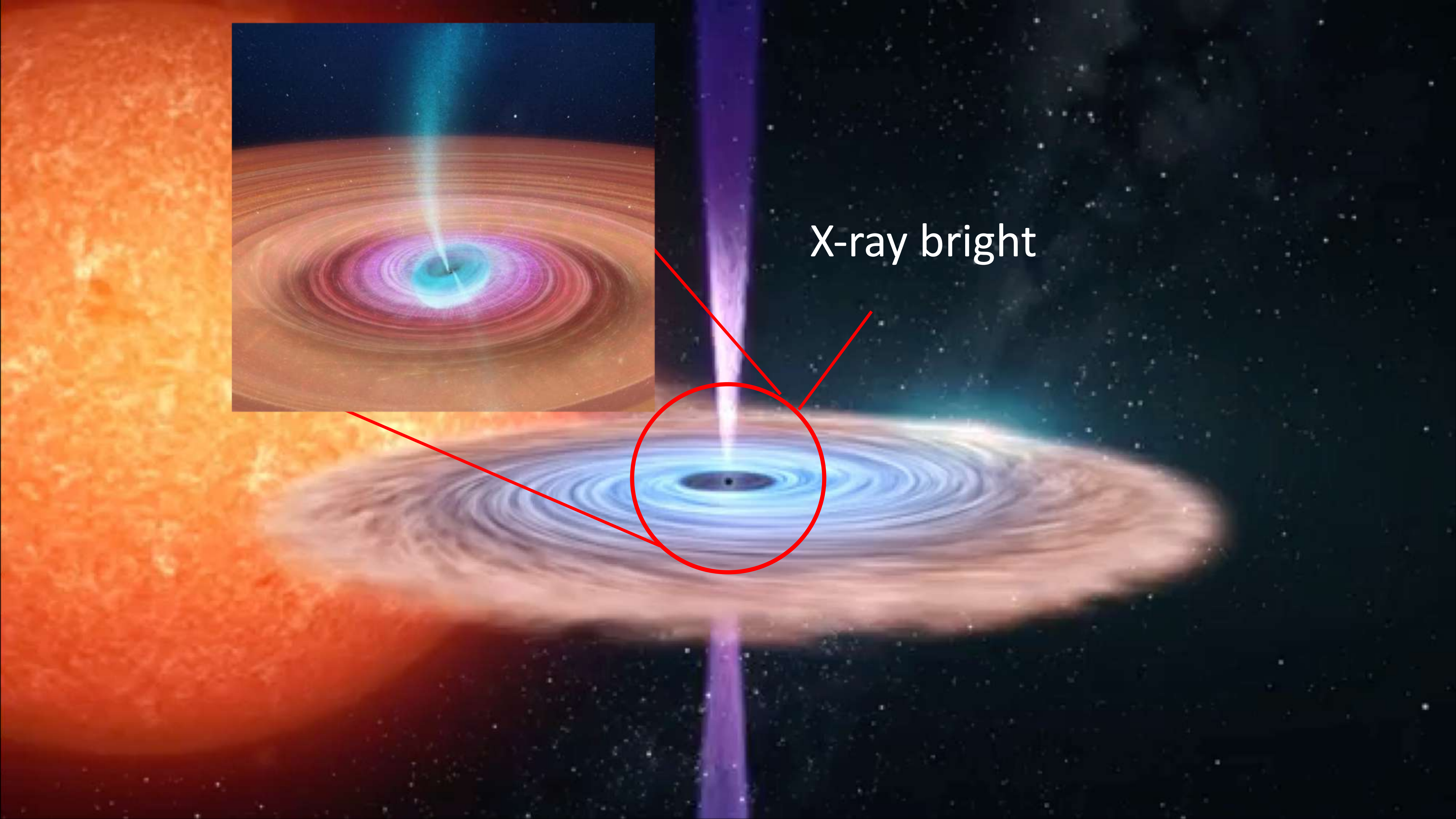
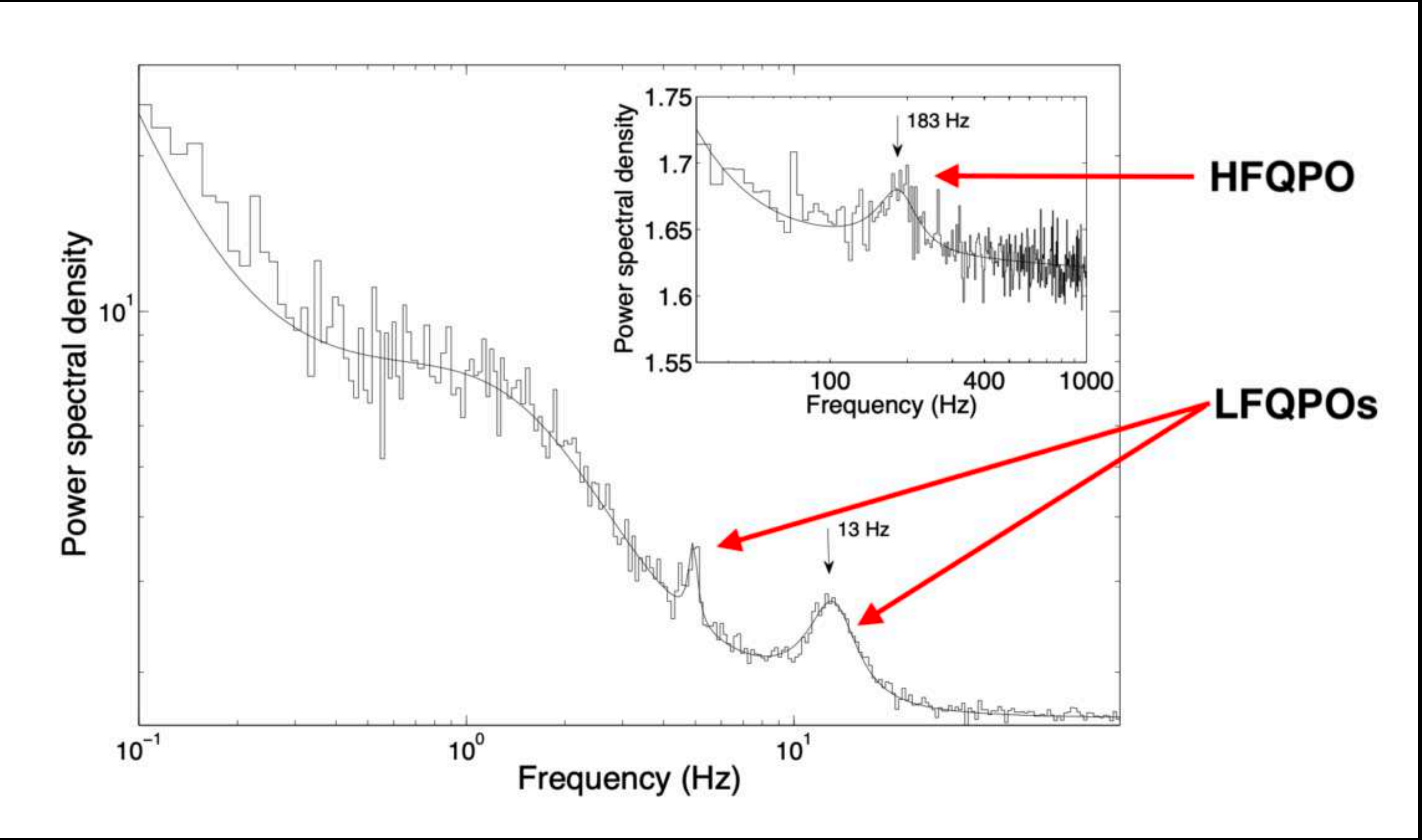
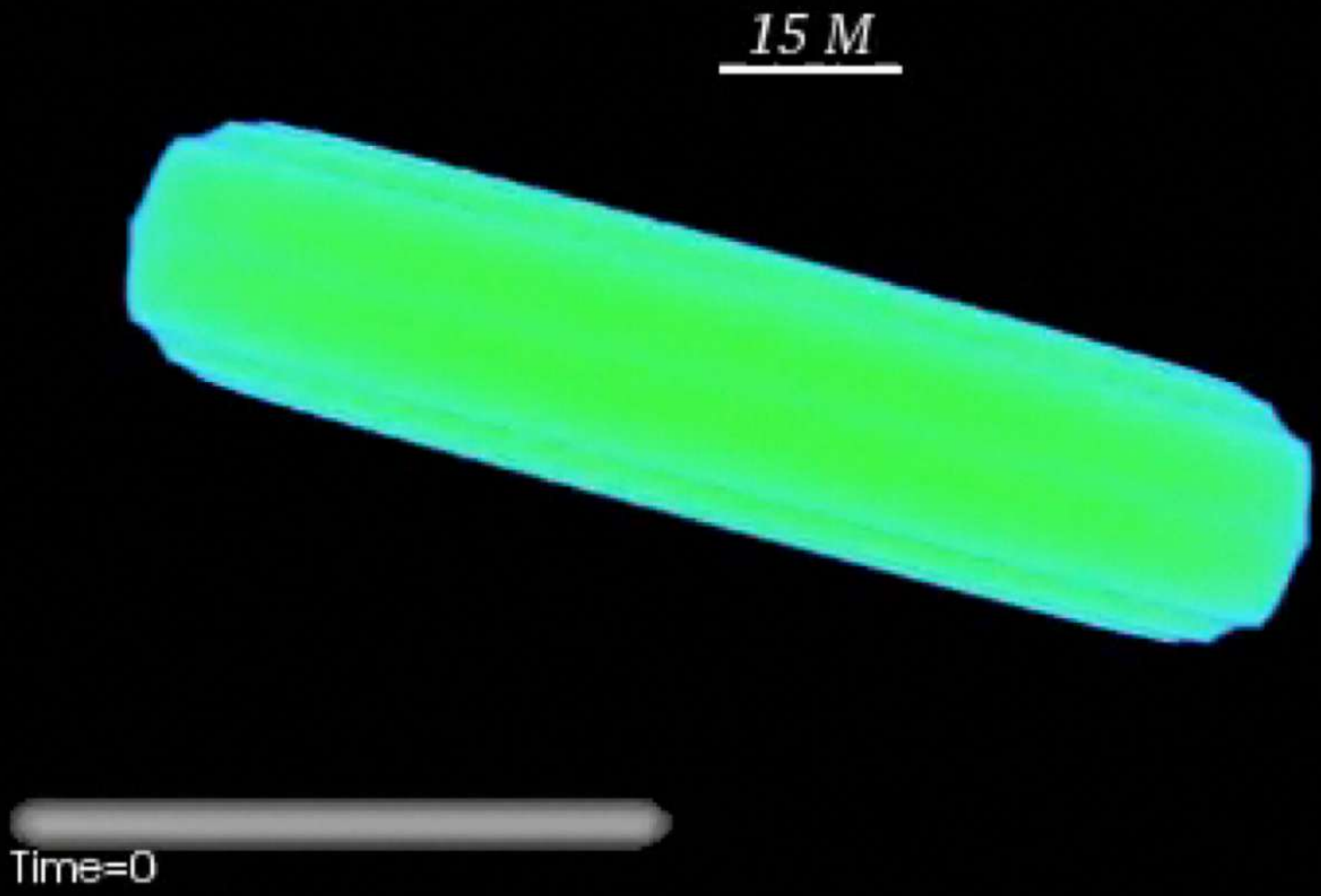



X-ray bright



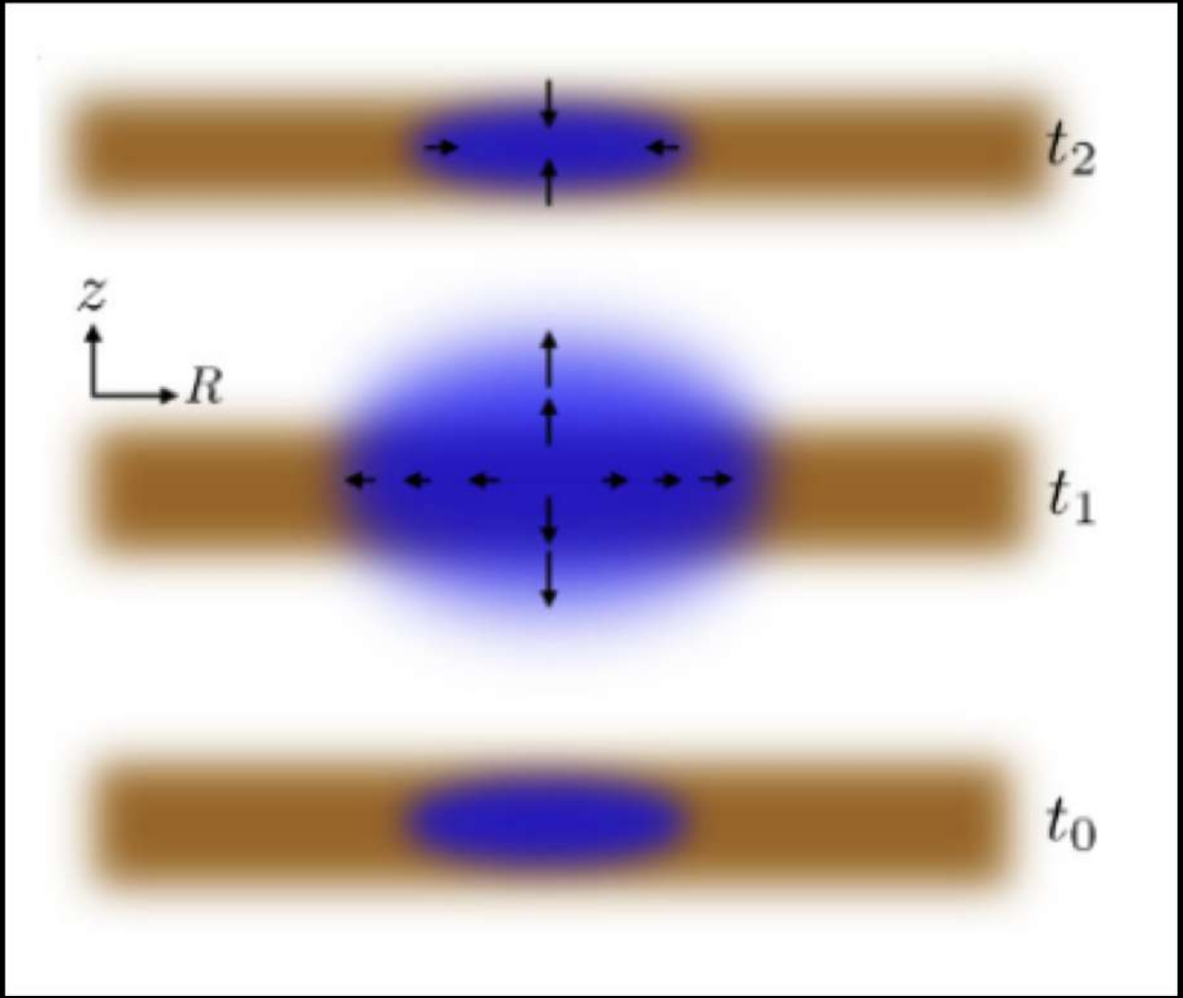
Motta et al. (2018)

Low frequency QPOs



Fragile et al. (2007)

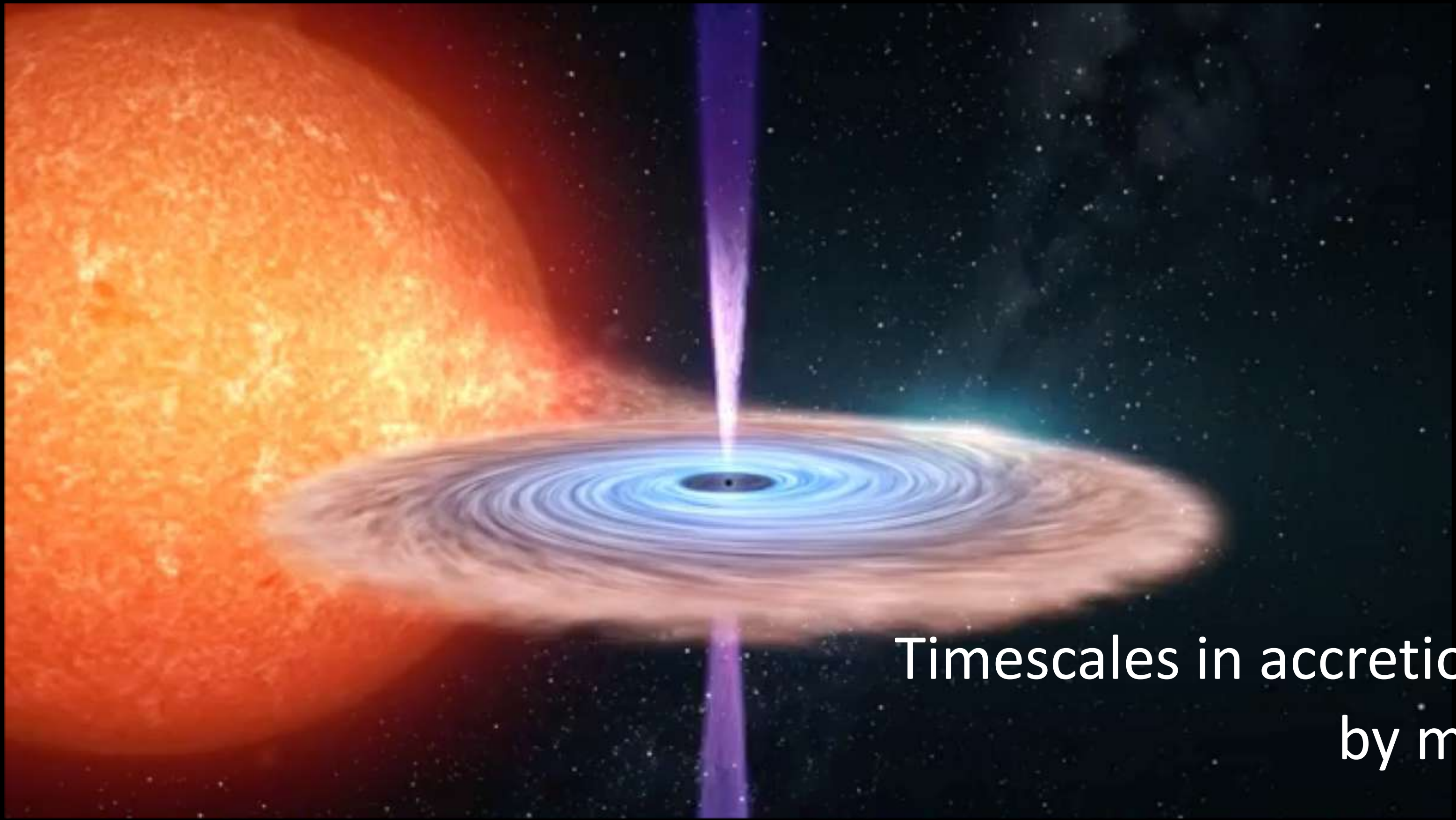
High frequency QPOs



Mishra et al. (2018)

Seen in pairs (3:2, 5:2)

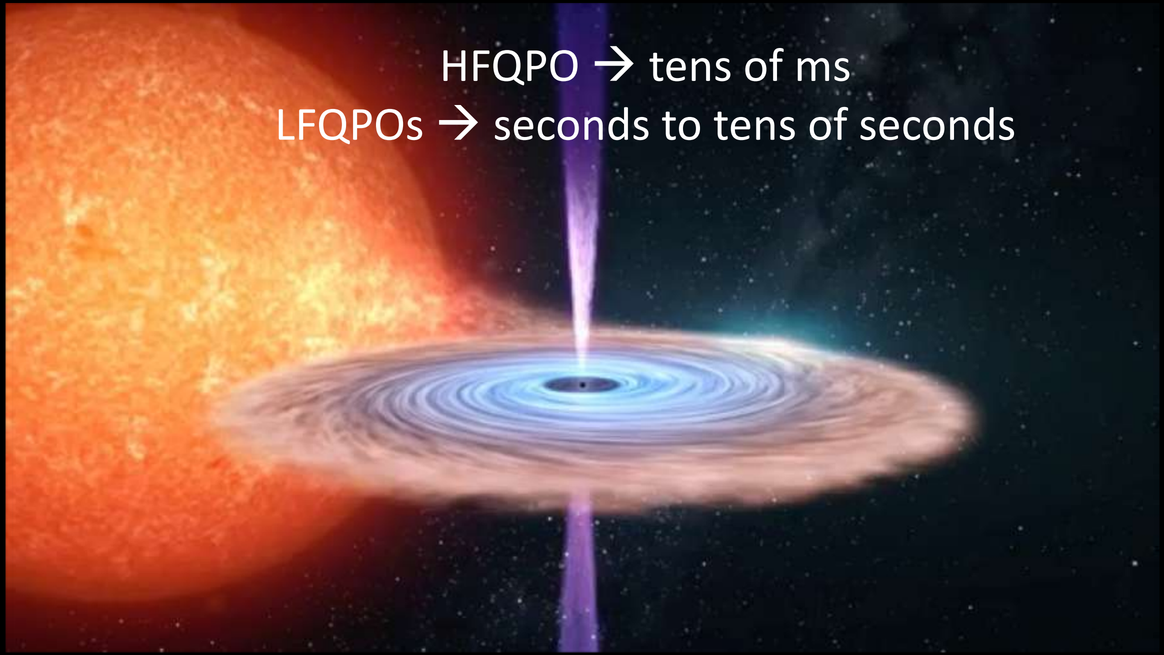
Could be due to vertical epicyclic modes and breathing mode (Blaes et al. 2006)



Timescales in accretion flows tend to scale by mass:

$T_{viscous}$ = some factors x GM/c^3
$T_{thermal}$ = some factors x GM/c^3
$T_{dynamical}$ = some factors x GM/c^3

Scaling from BHBs to AGN

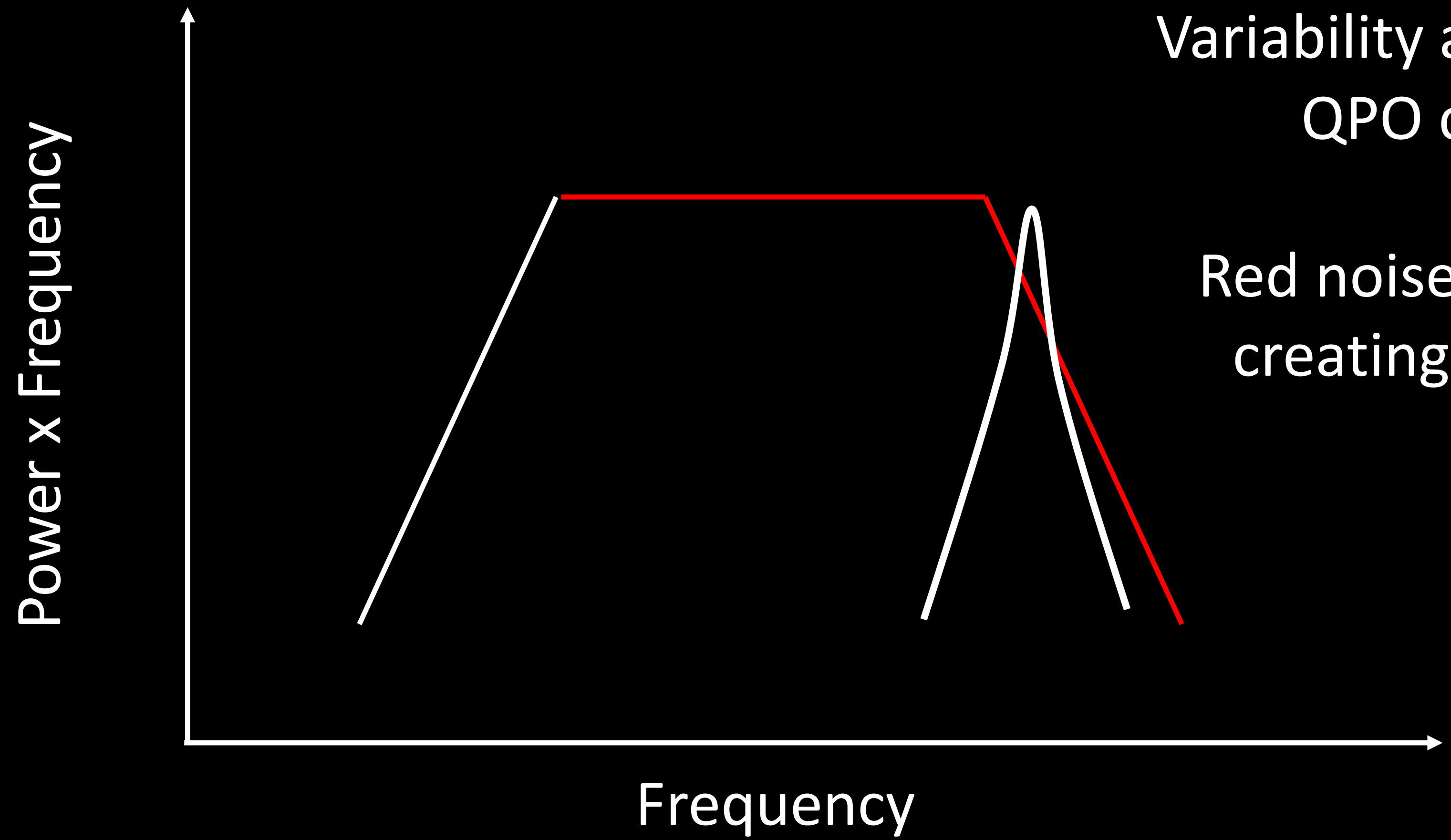


Flux $\propto M/D^2$

AGN are 1000s+ of times further away but the mass is $1\text{x}10^5$ times bigger or more

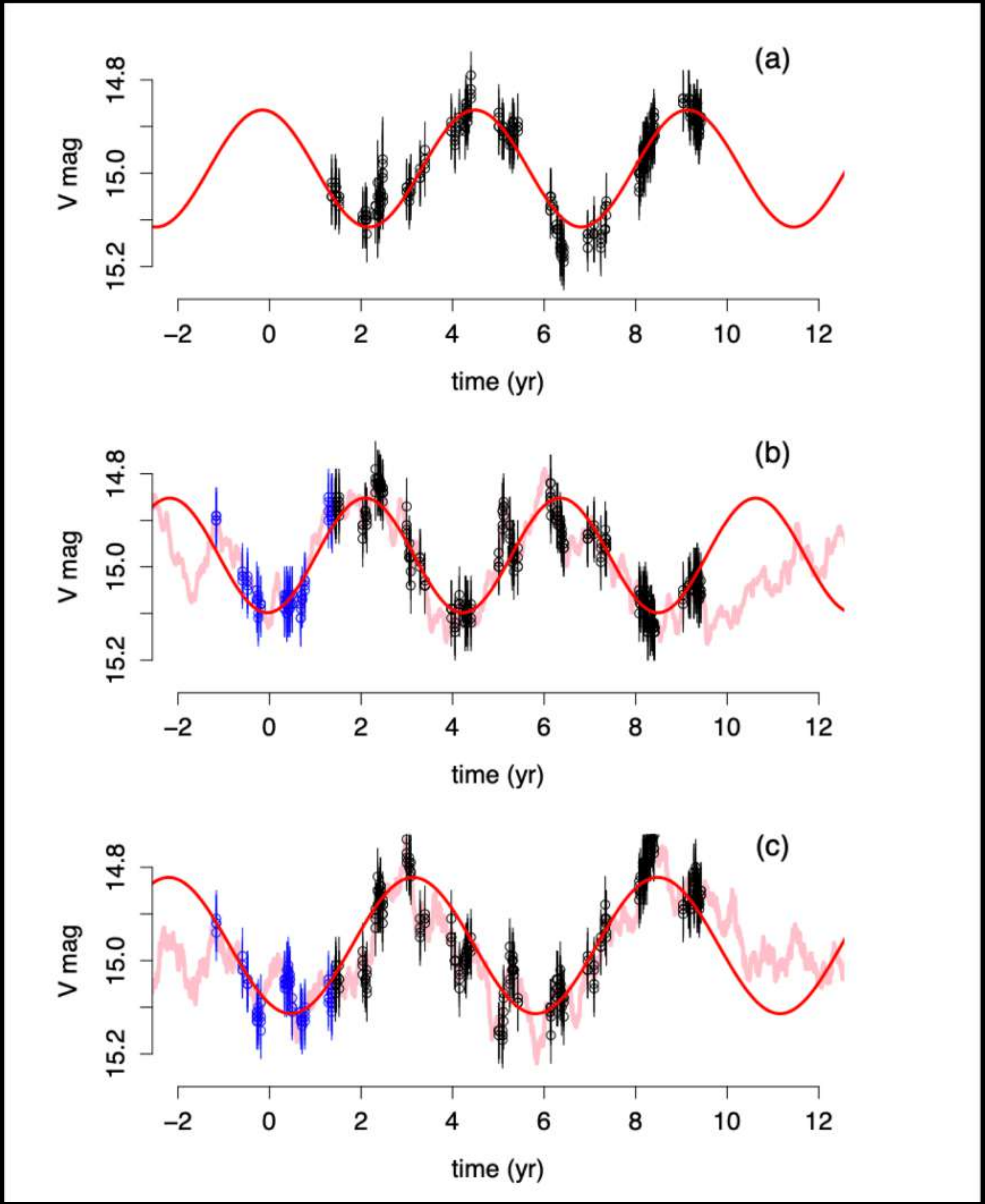
As QPO is slowed down (1/M) we get more photons/phase bin

A warning: all accreting systems vary stochastically



Variability at same freq as QPO candidate

Red noise *very* good at creating fake signals

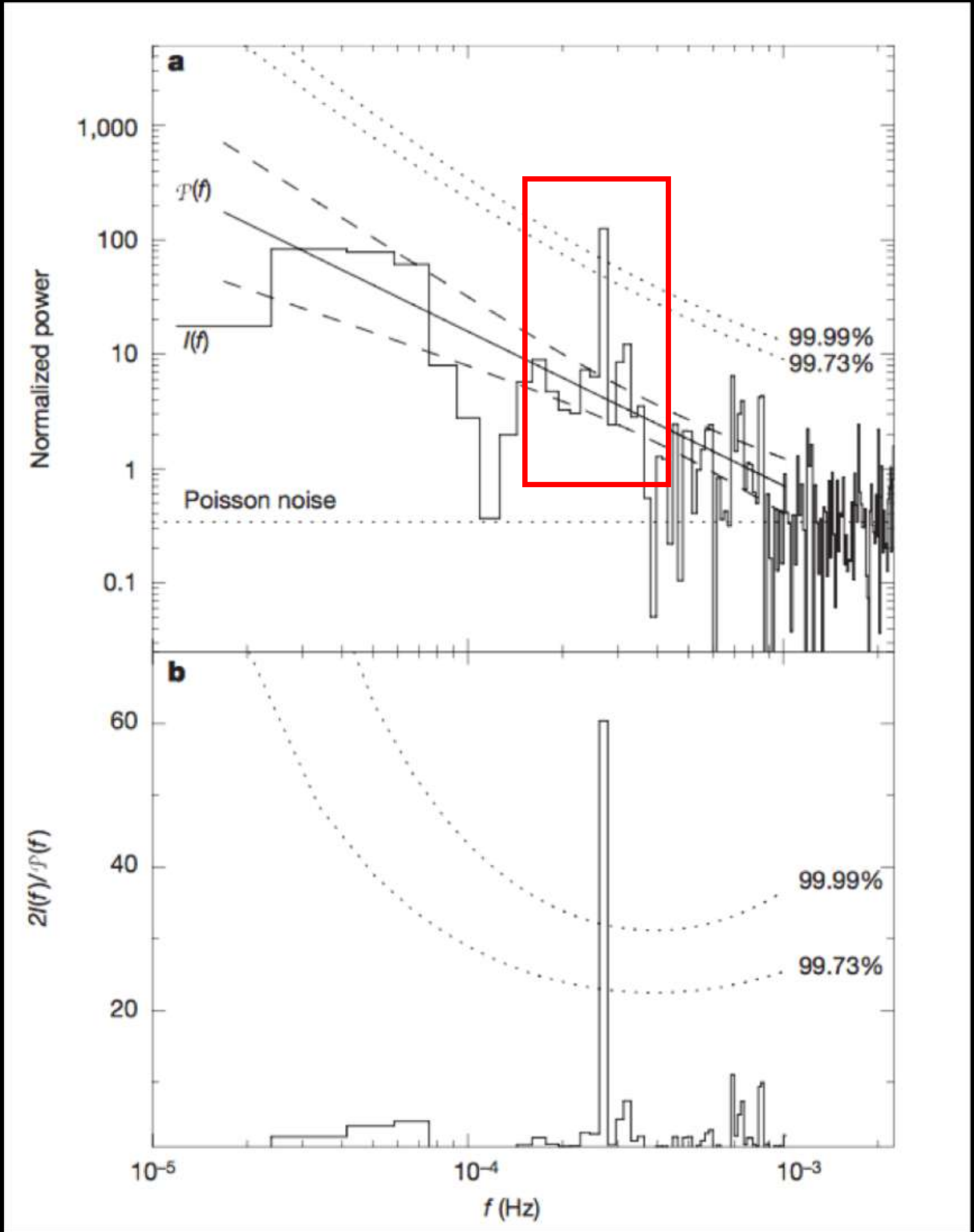


Vaughan et al. (2016)

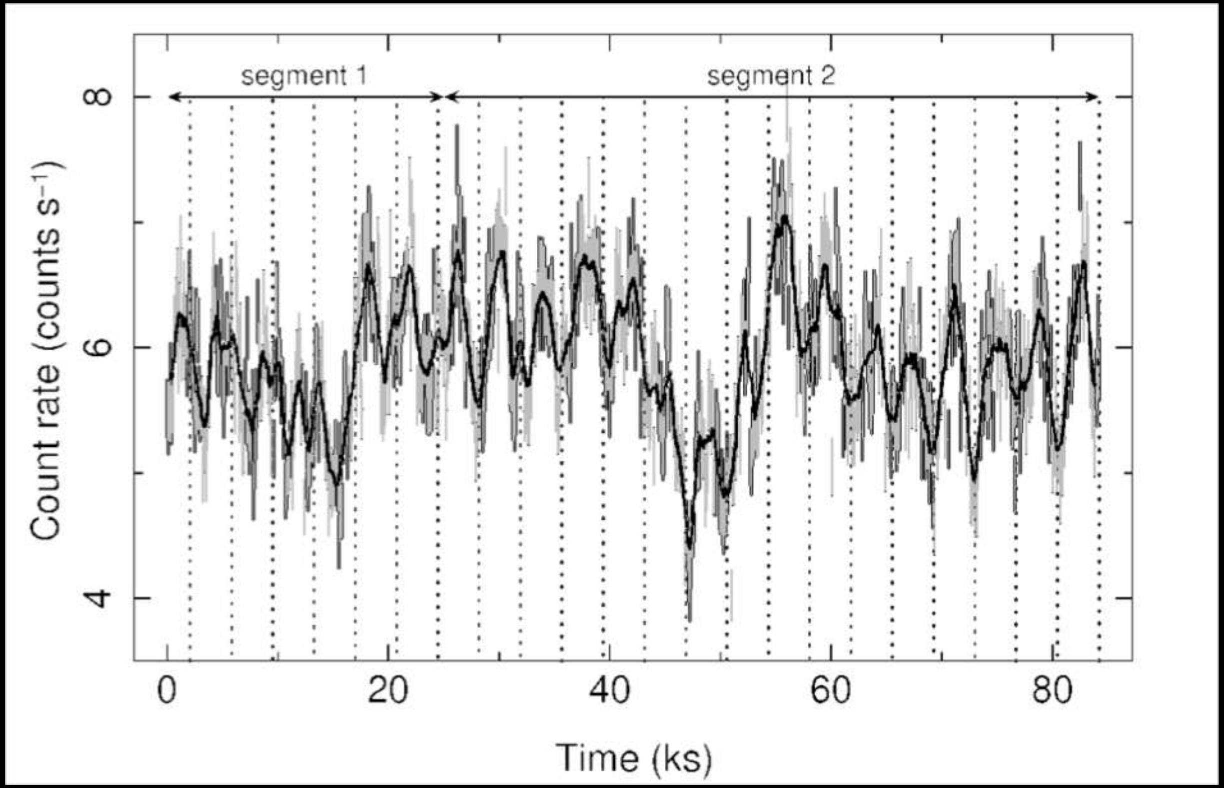
Particularly dangerous for low frequency, low cadence observing of AGN (e.g. attempts to locate bSMBHs)

<u>Need more than 5 cycles to make any realistic claim</u>

<u>Make sure you always simulate the null hypothesis to establish your FAP (Vaughan 2005)</u>

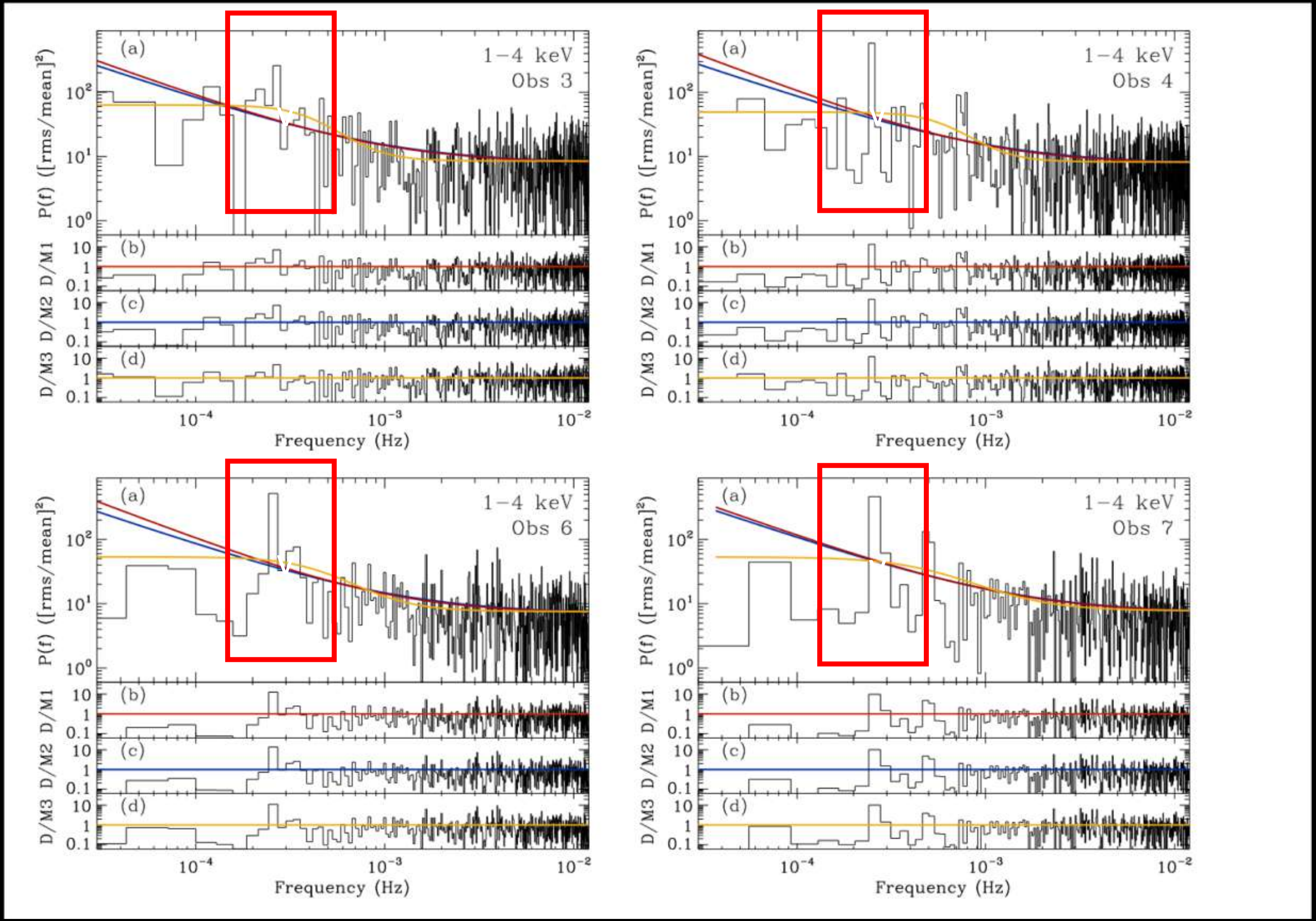


High frequency QPOs offer more cycles so a greater chance of being proven genuine



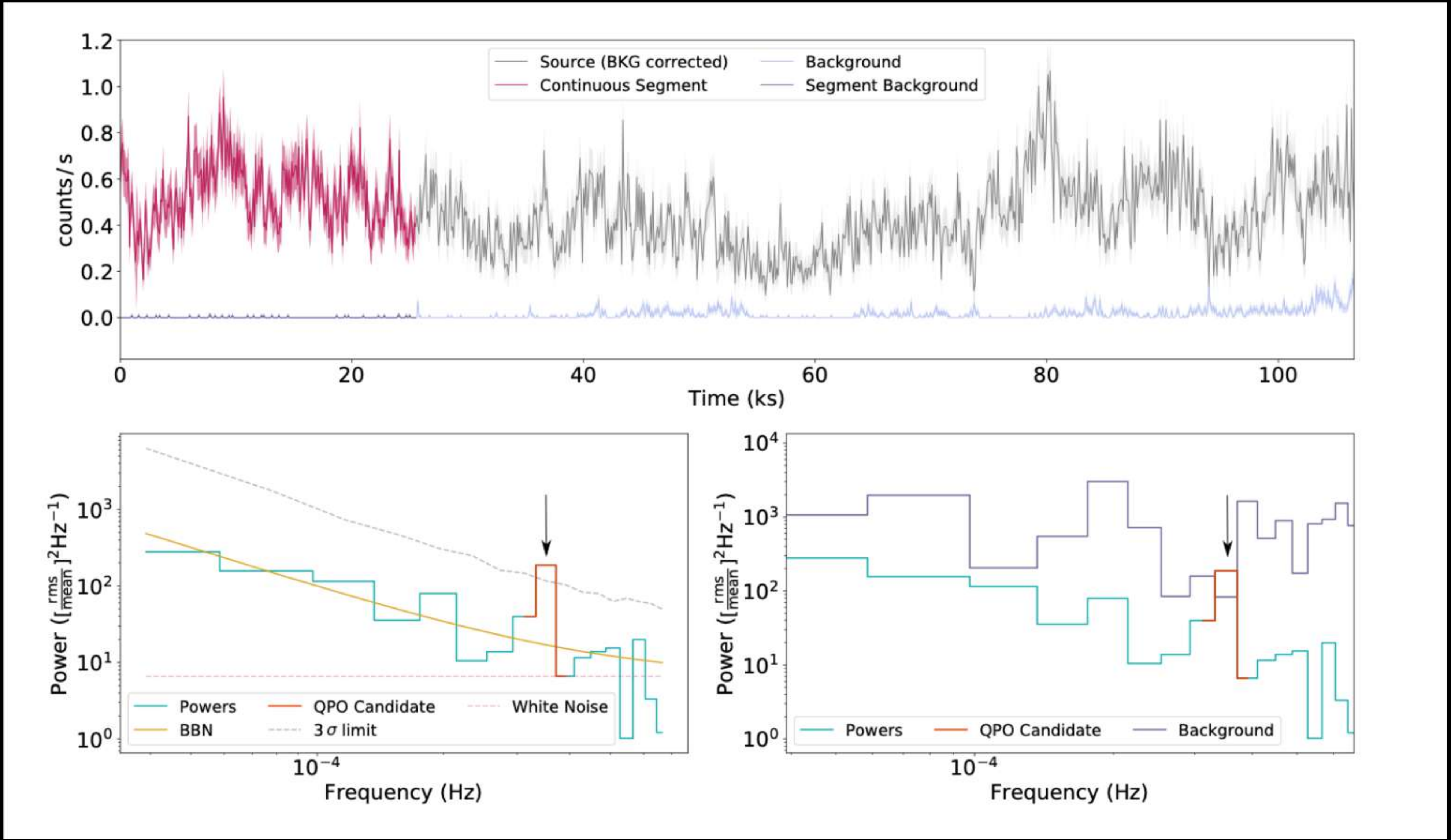
Gierlinski et al. (2008)

Confirmed in follow-up observations when *energy resolved*



Alston et al. (2014)

New searches using energy dependence



Ashton & Middleton (2021)

Obs ID	Duration (ks)	Peak Significance (GS)	Peak Energy (keV)	QPO candidate Frequency (Hz)	Frequency Error (Hz)	FRMS Value	Q
RE J1034+396, $M_{\rm BH} \sim 6.17$ [a b]							
0506440101	28.94	1.0000	0.7 - 1.0	2.34×10^{-4}	3.91×10^{-5}	0.071	5.98
0655310201	41.60	1.0000	1.2 - 2.4	2.34×10^{-4}	3.91×10^{-5}	0.123	5.98
0675440101	23.92	1.0000	0.7 - 3.4	2.34×10^{-4}	7.81×10^{-5}	0.097	3.00
0675440201	28.82	1.0000	0.9 - 6.2	2.73×10^{-4}	3.91×10^{-5}	0.112	5.98
IRAS 13224-3809, $M_{\rm BH} \sim 6.00$ [c]							
† 0780561301	125.29	0.9991	6.0 - 10.0	7.81×10^{-5}	9.77×10^{-6}	0.201	8.00
0780561301	125.29	0.9980	2.2 - 6.4	2.83×10^{-4}	9.77×10^{-6}	0.121	29.0
† 0780561401	82.92	1.0000	4.0 - 5.8	7.81×10^{-5}	1.95×10^{-5}	0.279	4.00
0780561401	82.92	0.9997	3.2 - 9.8	4.69×10^{-4}	1.95×10^{-5}	0.136	24.1
0780561701	113.20	0.9995	3.2 - 3.8	$\boxed{9.77 \times 10^{-5}}$	9.77×10^{-6}	0.209	10.0
* 0792180201	128.63	0.9979	4.0 - 5.6	1.66×10^{-4}	9.77×10^{-6}	0.294	17.0
† 0792180301	53.26	0.9994	4.8 - 9.6	$\boxed{9.77 \times 10^{-5}}$	1.95×10^{-5}	0.304	5.01
0792180501	93.83	0.9992	0.9 - 1.6	1.02×10^{-3}	1.95×10^{-5}	0.059	52.3
0792180601	105.02	0.9984	6.6 - 8.6	$\boxed{9.77 \times 10^{-5}}$	9.77×10^{-6}	0.246	10.0
1H 0707-495, $M_{\rm BH} \sim 6.3$ [c]							
0653510301	95.19	0.9984	4.8 - 6.2	$\boxed{1.95 \times 10^{-4}}$	1.95×10^{-5}	0.255	10.0
0653510501	94.72	0.9997	4.0 - 5.4	$\boxed{1.95 \times 10^{-4}}$	1.95×10^{-5}	0.225	10.0
* 0653510601	105.85	0.9975	5.6 - 8.2	1.27×10^{-4}	9.77×10^{-6}	0.224	13.0
PG1244+026, $M_{\rm BH} \sim 6.24$ [d]							
0675320101	71.81	0.9993	3.0 - 5.8	2.15×10^{-4}	1.95×10^{-5}	0.074	11.0
NGC 4051, $M_{\rm BH} \sim 6.24$ [e]							
0109141401	25.77	0.9997	5.0 - 6.0	3.52×10^{-4}	3.91×10^{-5}	0.095	9.00
† 0606321801	39.83	0.9998	3.4 - 4.0	1.56×10^{-4}	3.91×10^{-5}	0.180	3.99
ARK 564, $M_{\rm BH} \sim 6.41$ [f]							
† 0006810101	4.95	1.0	3.0 - 5.4	1.88×10^{-3}	3.13×10^{-4}	0.134	6.00
0670130501	17.18	0.9987	2.0 - 3.8	8.59×10^{-4}	7.81×10^{-5}	0.073	11.0
0670130701	44.71	1.0	2.6 - 2.8	2.73×10^{-4}	3.91×10^{-5}	0.163	6.98
0670130801	51.65	0.9998	3.0 - 3.4	2.54×10^{-4}	1.95×10^{-5}	0.072	13.0
MRK 766, $M_{\rm BH} \sim 6.63$ [g]							
*† 0304030301	38.35	0.9976	3.0 - 4.6	4.69×10^{-4}	3.91×10^{-5}	0.055	12.0

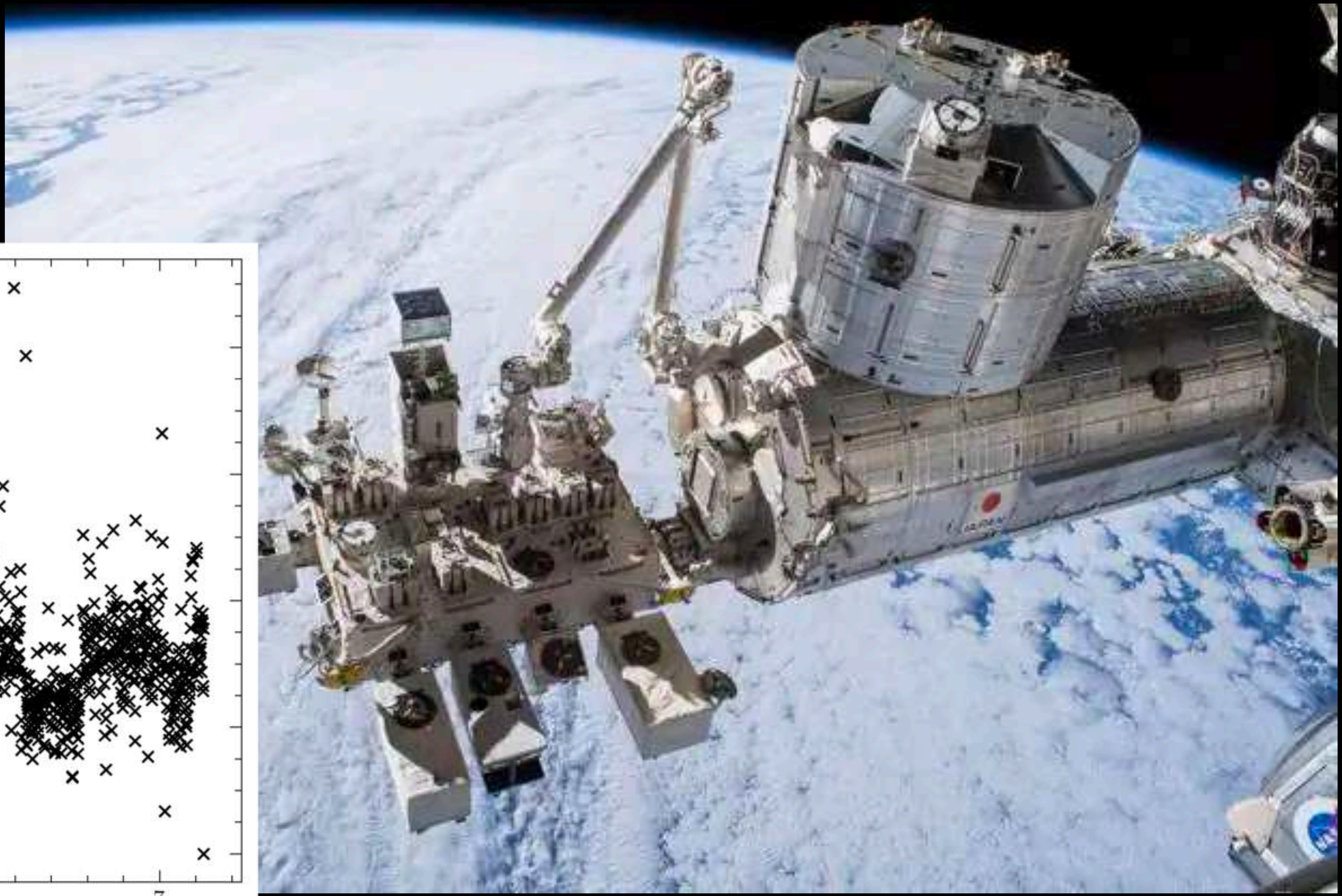
Key result:
Some <u>repeating</u> signals

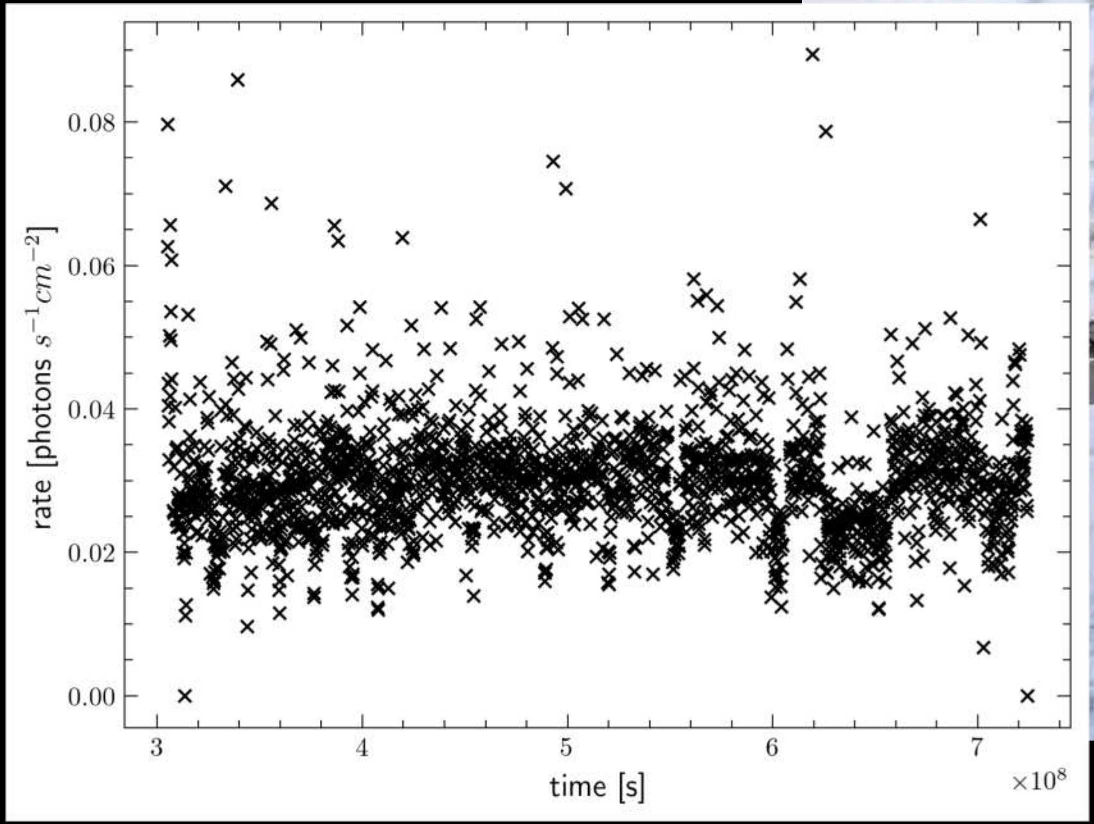
Some of the strongest signals appear associated with reflection dominated component

Ashton & Middleton (2021)

Searching for LFQPOs (days to months)

Hard to do in the X-rays but not impossible



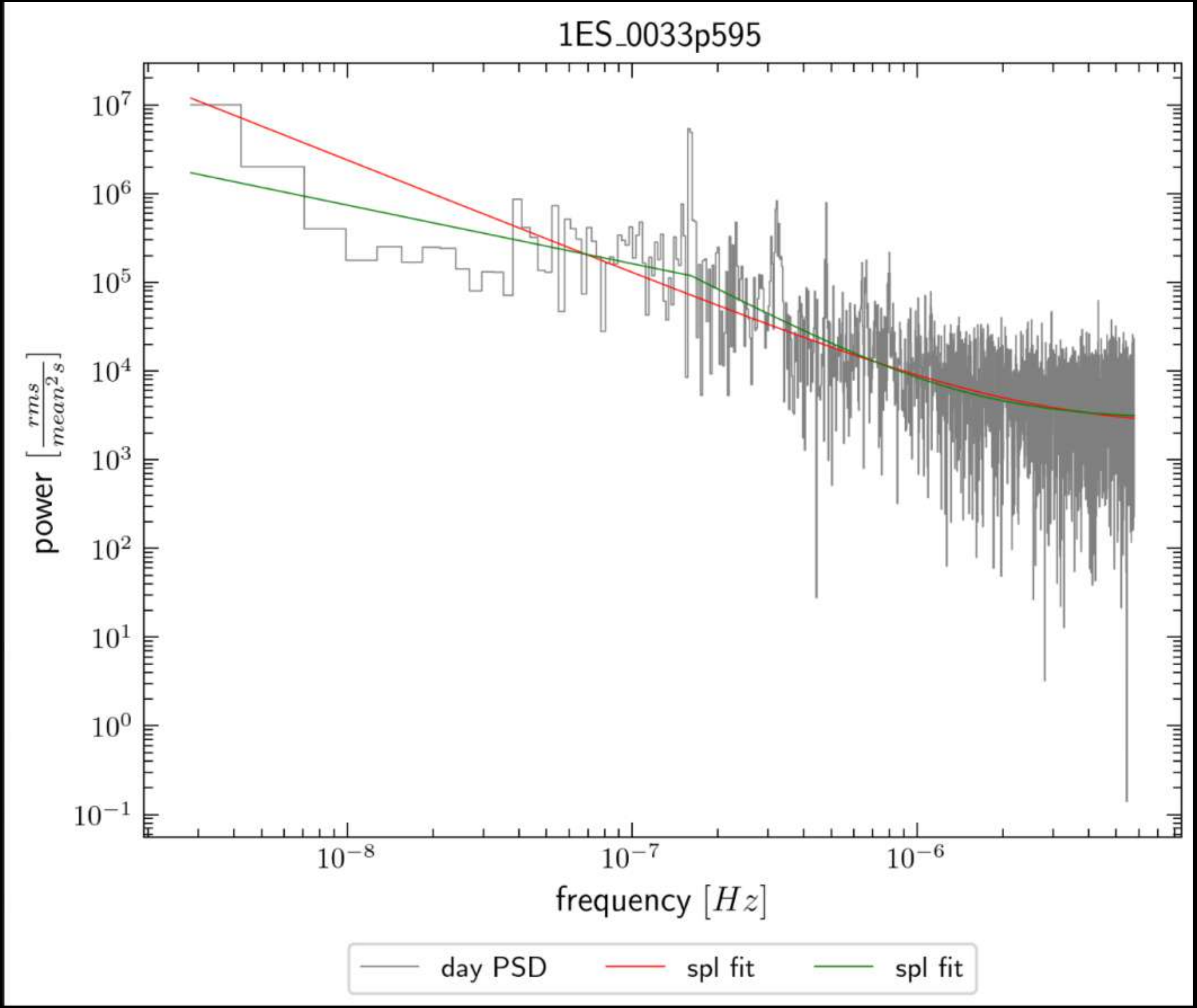


Searching for LFQPOs (days to months)

Code is similar to PSRESP (Uttley et al. 2002) which simulates and resamples based on observations

Allows for model uncertainty with MCMC

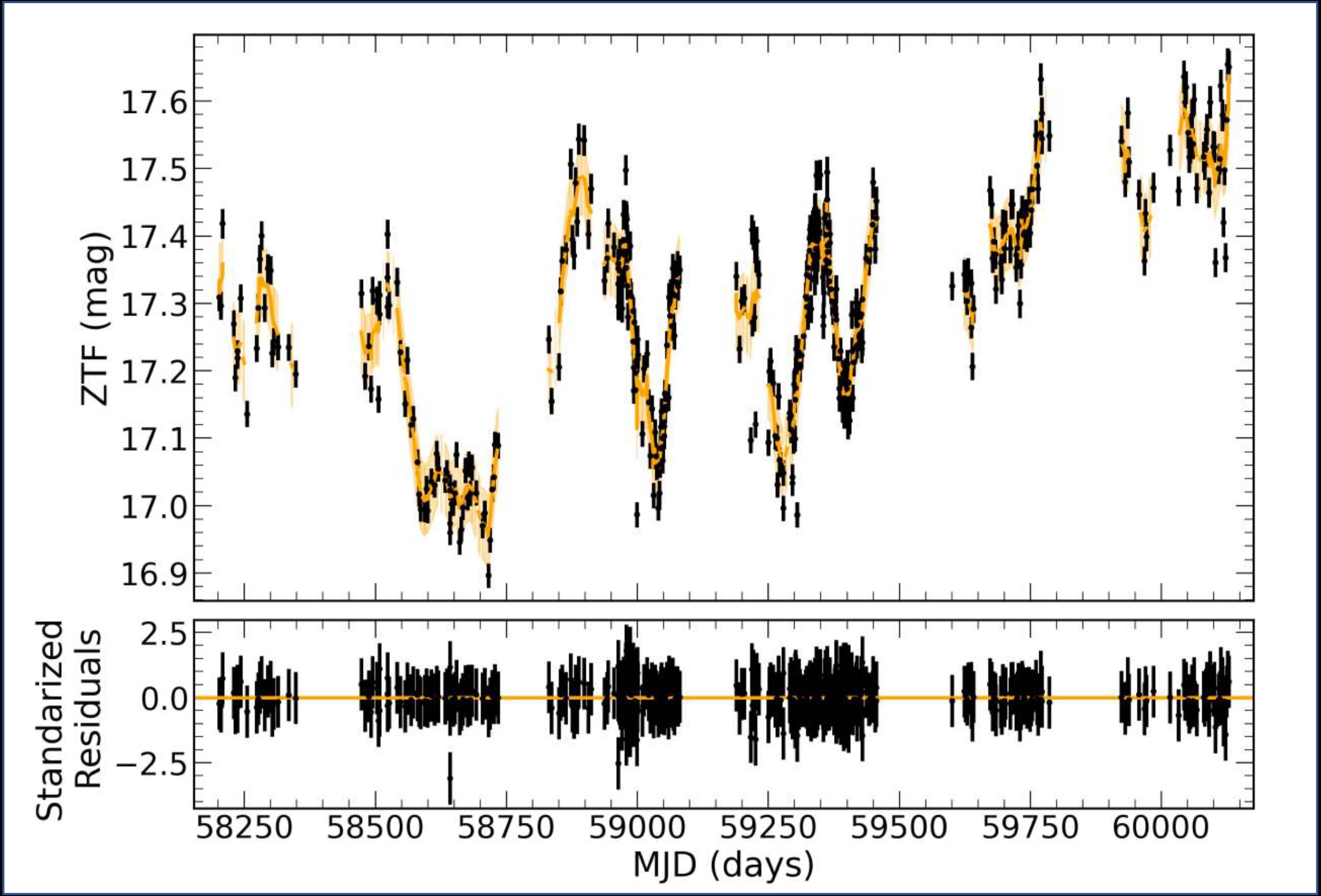
Compares models with AIC



Ward & Middleton (in prep)

Searching for LFQPOs (days to months)

GP code **with FAP** now built (Gurpide & Middleton in prep) and is being deployed on MAXI and ZTF data. Hoping to extend beyond Cellerite models in very near future



Are there *any* LFQPOs in AGN? If not, why not?

How are HFQPOs in AGN generated? Do they behave like BHB QPOs?

What do we hope to learn from QPOs and QPO searches

How does the noise in AGN (PSD) respond to accretion rate and mass?

How do characteristic freqs change with energy band?