A 1 Hour Quasi-Period
in the
Seyfert Galaxy 3C 273

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Abstract

Quasi-periodic signals (QPOs) have yielded important constraints on the masses of black holes in galactic X-ray binaries, and here we extend this to active galactic nuclei (AGN). We analyze 19 observations of 10 AGN obtained with the *XMM-Newton* EPIC PN camera, employing a wavelet transform. We detect a statistically significant 3.1 ks quasi-period in the quasar 3C 273. If this period represents an orbital timescale originating near a last stable orbit of 3 R_S, it implies a black hole mass of 6.8 x 10^6 $M_\odot$. A central black hole mass of 7.6 x 10^7 $M_\odot$ is implied for a maximally rotating black hole with a last stable orbit of 0.6 R_S. Both of these estimates are substantially lower than previous reverberation mapping results which place the black hole mass of 3C 273 at 2.35 x 10^8 $M_\odot$. Assuming that the reverberation mapping mass is correct, the X-ray quasi-period must be caused by a higher order oscillatory mode of the disk.

1. Introduction

Quasi-periods are thought to originate in the inner accretion disk of a black hole or neutron star in an X-ray binary (XRB) system (van der Klis 2000). Consequently, QPOs have been used in galactic XRBs to introduce important constraints on the masses of the central black holes of these systems. This reasoning can be extended to supermassive black holes since AGN and XRBs are similar: previous work has revealed similarities in the X-ray light curves of both, and there is evidence that similar physical processes may be underlying the variability in both AGN and XRBs (McHardy et al. 2004).

While this semblance between AGN and XRBs seems promising, no claim of an X-ray quasi-period in an AGN has been found to be statistically robust. This has led to questions of whether existing X-ray observations of AGN are even sensitive enough to detect QPOs (Vaughan & Uttley 2005). Here we show that current observations are suitable and that a robust quasi-period in an AGN has been found.

2. Observations

Instrument: *XMM-Newton* EPIC PN camera (0.3-10 keV)
Selection Criteria: bright AGN with continuous observations exceeding 30 ks

Object	Observation ID	Start Date	Length (ks)	<Counts>*
3C 273	126700301	2000-06-13	66	140
3C 273	126700801	2000-06-17	60.6	120
3C 273	136550101	2003-01-05	88.6	160
3C 273	159960101	2003-07-07	58	230
IRAS 13349+2438	096010101	2000-06-20	44.6	10
M 81	111800101	2001-04-22	130	20
MCG-6-30-15	029740701	2001-08-02	127	70
MCG-6-30-15	029740801	2001-08-04	125	120
MKN 421	099280101	2000-05-25	32.5	740
MKN 421	099280301	2000-11-13	46.6	1060
MKN 766	109141301	2001-05-20	128.5	90
NGC 3516	107460601	2001-04-10	129	20
NGC 3516	107460701	2001-11-09	128	12
NGC 4151	112310101	2000-12-21	30	20
NGC 4151	112830201	2000-12-22	57	25
NGC 5548	089960301	2001-07-09	93.4	75
NGC 5548	089960401	2001-07-12	37	90
PKS 2155-304	124930201	2000-05-31	59	280
PKS 2155-304	124930301	2001-11-30	44.6	380

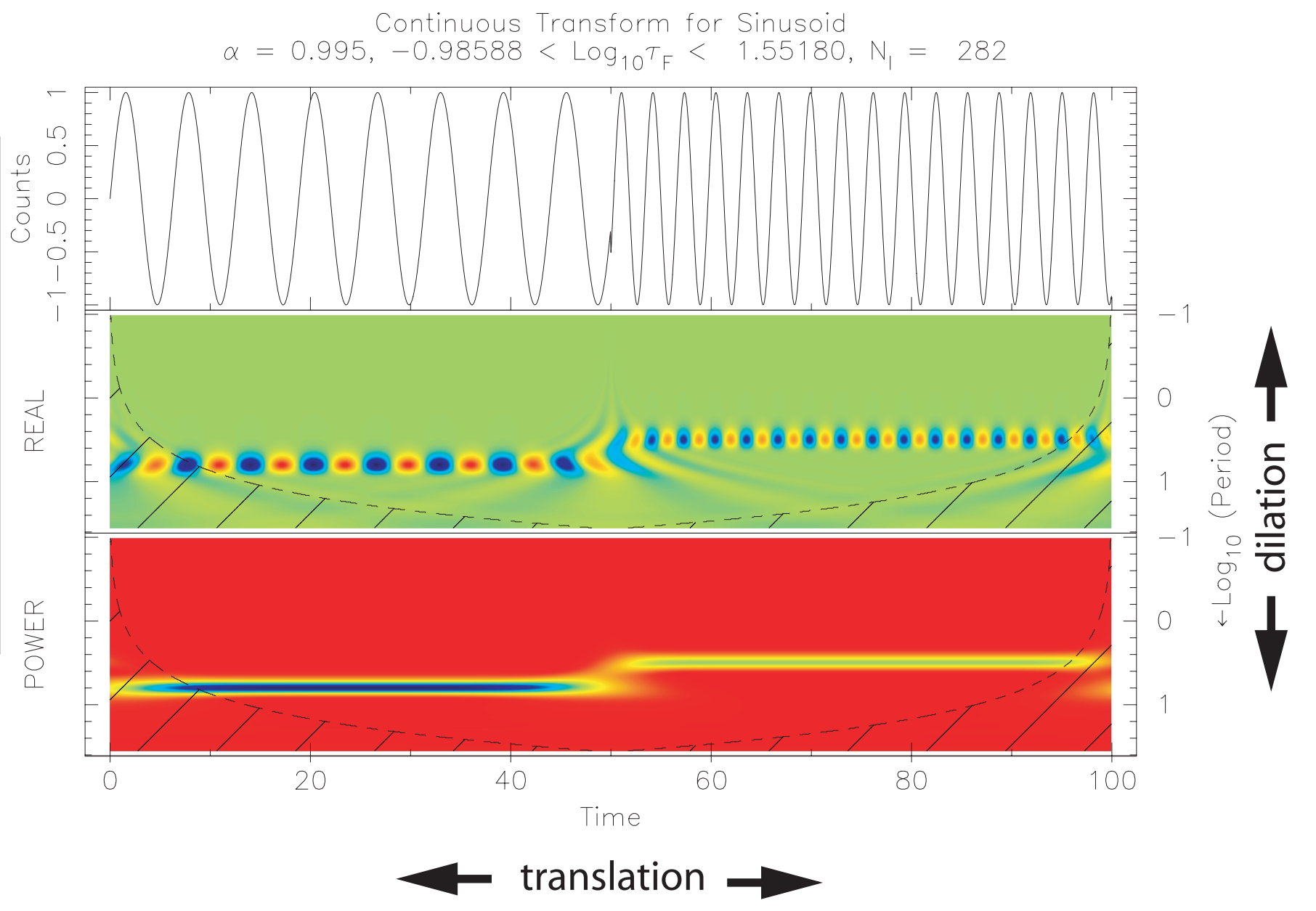
* Events are grouped into 5s bins.

3. Data Analysis & Results

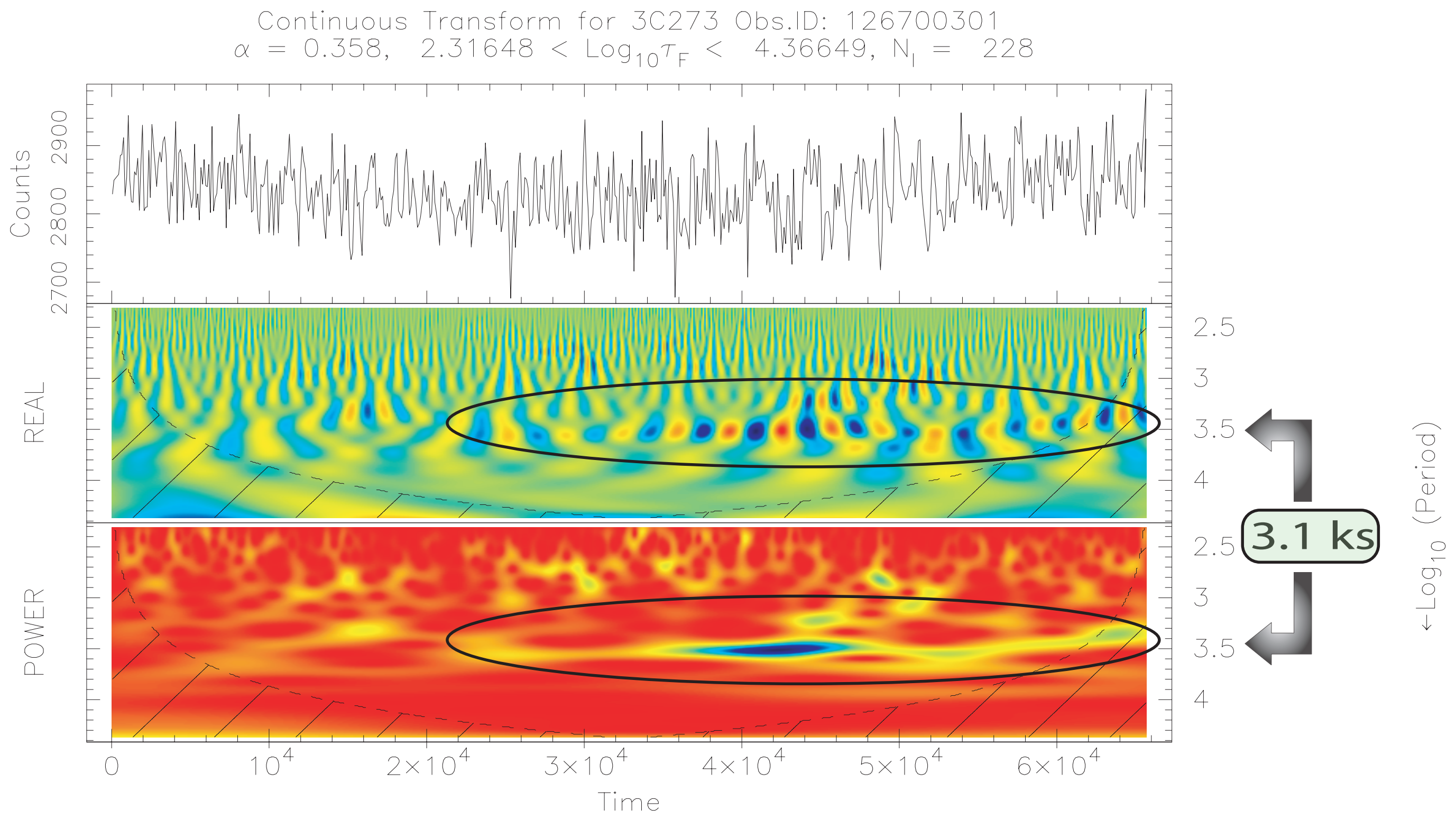
3.1 Wavelet Analysis & Results

The wavelet transform (WT) convolves a dilated and translated mother wavelet with the signal. It maps the power of a particular frequency at different times in translation-dilation space, giving an expansion of the signal in both time and frequency. Hence, the WT not only tells you which frequencies exist in the signal, but also *when* they exist, allowing us to see whether a timescale varies in time.

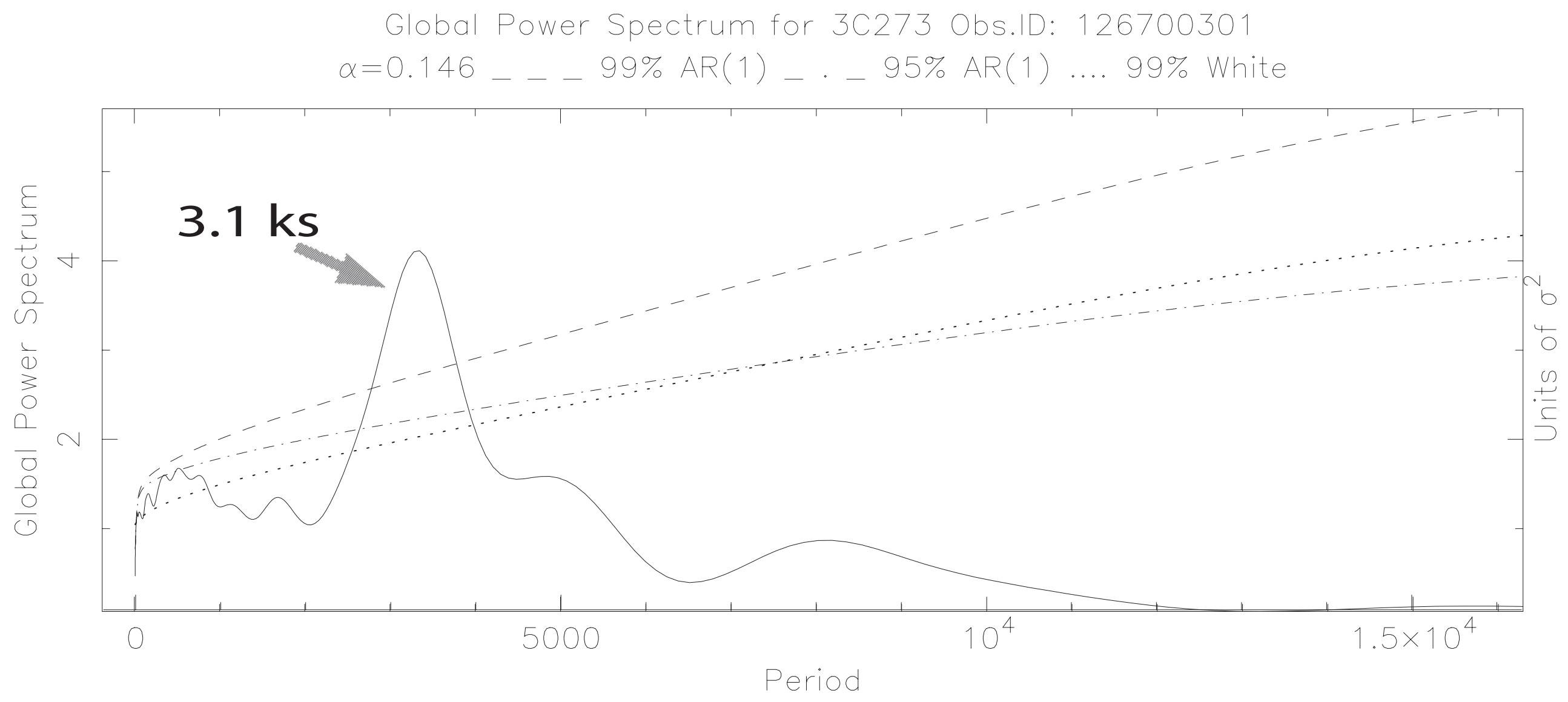
To demonstrate the point mentioned above, we apply the WT to a sinusoid of constant amplitude which varies in frequency (top panel). The real plot of the WT as well as its power plot (middle panel and bottom panel, respectively), detect the two different frequencies in the signal, as well as when each frequency is present.



A quasi-periodicity at 3.1 ks is detected in one observation of 3C 273. The WT result for this observation is shown below with the quasi-period highlighted in the real and power plots. Although strong in this observation, no periodicity appears in any of the three other observations of this object.



The global power spectrum sums the wavelet power spectra at all times. The 3.1 ks detection exceeds expected levels of white and red noise (dotted lines). The structure function (Section 3.2) shows that white nosie is the dominant noise process in this observation.



3.2 Structure Function Analysis & Results

The global power spectrum illustrates that the 3.1 ks detection surpasses expected levels for white or red noise. However, we want to know which of these noise processes dominates our signal. To do this, we create a structure function (SF), a technique which calculates the mean deviation of data points. Here we use the first order structure function as set forth by Simonetti et. al 1985.

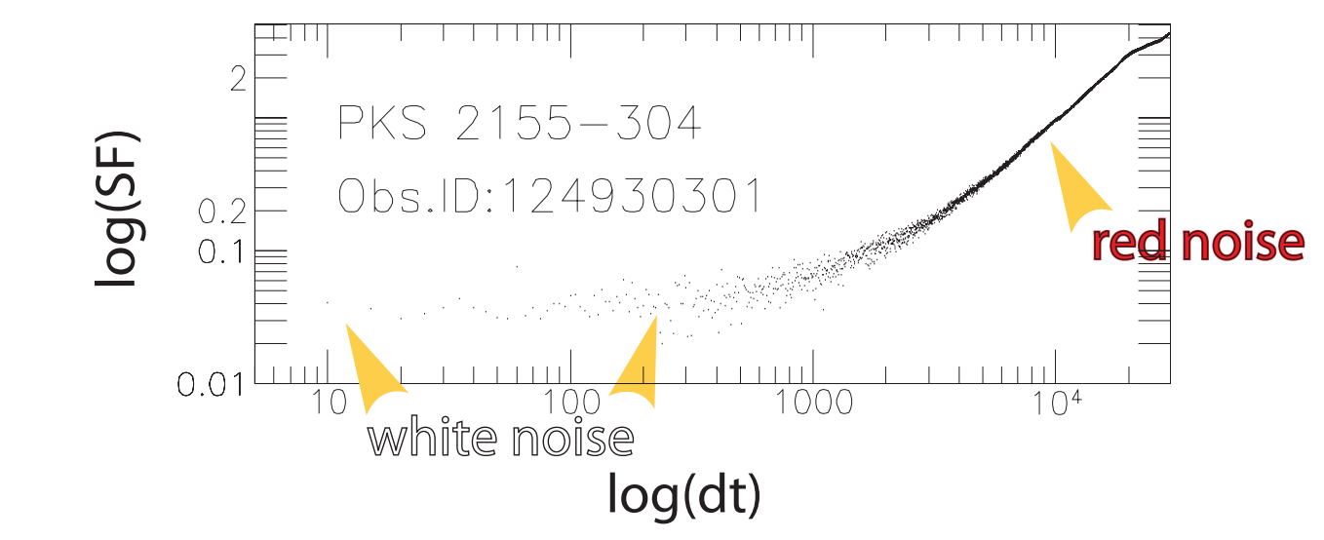
$$SF = <[F(t) - F(t + dt)]^2>$$

structure function

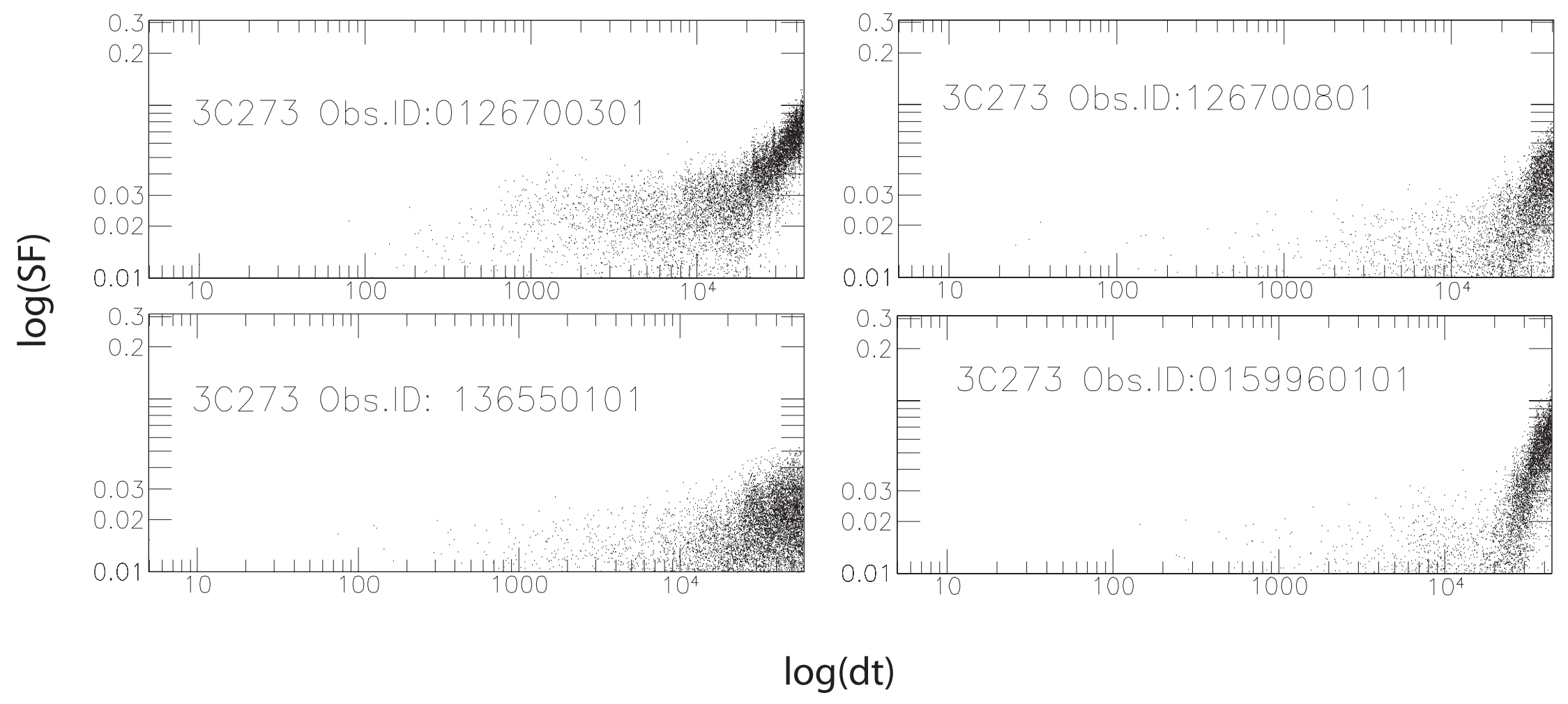
flux at time t

flux at time t+dt

After plotting the log of the SF versus the log of dt, the slopes of the power-law portions of the structure function curve can tell us the noise process underlying the signal. Here is a typical example...



Below are the SFs for all four observations of 3C 273. The observation with the 3.1 ks quasi-period (upper left) is dominated by white noise around 3000s. This observation also has the greatest excess of white noise compared to the other three observations.



4. Discussion

Previous reverberation mapping results place the mass of the black hole in 3C 273 at 2.35 x 10^8 $M_\odot$ (Kaspi et al. 2000) pointing to an orbital period of ~100 ks for a last stable orbit of 3 R_S and a period of ~9 ks for 0.6 R_S. The 3.1 ks quasi-period is only about 30% of these orbital timescales and therefore this X-ray quasi-period must be caused by another phenomenon, namely oscillations in the accretion disk. We suggest that oscillations with modes higher than two are occuring in the accretion disk of 3C 273, producing the detected 3.1 ks quasi-period. Previous work has implied that this is possible (Rubio-Herrera & Lee 2005).

References

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