Supplemental Material for J110057

October 23, 2017

Further Observational Details

Selection in SDSS-III BOSS of J110057

SDSS J110057.71-005304.5 was first detected by the ROSAT and appears in the All-Sky Survey Bright Source Catalogue [RASS-BSC; 3, 22]. J110057 was then imaged by the Sloan Digital Sky Survey and satisfied a number of spectroscopic targeting flags[1] making it an SDSS quasar target. A spectrum was obtain on MJD 51908 (Plate 277, Fiber 212) and the spectrum of a $z = 0.378$ quasar was catalogued in the SDSS Early Data Release [19]. The physical properties of J110057, derived from the MJD 51908 spectrum and using the methods in Shen et al. [20], are given in Table 1.

The second epoch spectrum is from the SDSS-III Baryon Oscillation Spectroscopic Survey [BOSS; 4] and shows the dramatic downturn at $\lesssim$4300Å . SDSS-III BOSS actively vetoed *against* low-z QSOs [18], and it was due to J110057 being selected as an ancillary target via a White Dwarf program [9, 10] that a second spectral epoch was serendipitously obtained. Since J110057 was not a BOSS QSO target, it is not subject to the "blue offset" present for BOSS QSO targets [13].

A third epoch spectrum was obtained from the Palomar 5m telescope using the DBSP instrument. Two exposures of 600s+300s were taken in good conditions. Features to note include the continuum straddling Mg II being blue in the 2017 spectrum, as it was for the SDSS spectrum in 2000, as opposed to red, as it was for the BOSS spectrum in 2010.

J110057 is in the DECaLS DR3, where there are 8, 3 and 9 exposures in the g, r and z-band respectively. The g- and r-band observations have fairly limited time spans, ($56707 \leq g_{\mathrm{MJD}} \leq 56727$ and $56367 \leq r_{\mathrm{MJD}} \leq 56367$) and are separated by roughly a year. The z-band observations span almost 3 years ($56383 \leq z_{\mathrm{MJD}} \leq 57398$). The DESI imaging brick name is 1651m010.

Selection in NEOWISE-R of J110057

WISE W1 and W2 lightcurves for $\sim$200,000 SDSS spectroscopic quasars were extracted from Data Release 3 (DR3) of the Dark Energy Camera Legacy Survey (DECaLS). These light curves span from the beginning

[1] SERENDIP_BLUE, ROSAT_D, ROSAT_C, ROSAT_B, QSO_SKIRT, ROSAT_A, see Stoughton et al. [21] and Richards et al. [17] for flag descriptions.

Quantity	Value
SDSS name	J110057.71-005304.5
R.A. / deg	165.240463
Declination / deg	-0.884586
redshift, z	0.3778±0.0003
$M_i(z=2)$ / mag	-24.48
log ($L_{\mathrm{bol}}/\mathrm{ergs}^{-1}$)	45.78±0.02
log ($M_{\mathrm{BH}}/M_{\odot}$)	8.83±0.14
Eddington ratio	0.070

Table 1: Physical properties of J110057 using the methods from Shen et al. [20].

of the WISE mission (2010 January) through the first-year of NEOWISER operations (2014 December). The W1/W2 light curves are obtained by performing forced photometry at the locations of DECam-detected optical sources [12, 14, 15]. This forced photometry is performed on time-resolved unWISE coadds [12], each of which represents a stack with depth of coverage $\sim$12 exposures. A given sky location is observed by WISE for $\sim$1 day once every six months, which means that the forced photometry light curves typically have four coadd epochs available. Coadd epochs of a given object are separated by a minimum of six months and a maximum of four years. The coaddition removes the possibility of probing variability on $\lesssim$1 day time scales, but it allows us to push $\approx$1.4 magnitudes deeper than individual exposures while removing virtually all single-exposure artifacts (e.g. cosmic rays and satellites).

Approximately $\sim$30,000 **NPR NOTE:: This number seems low to me; NPR to double check; can also triple check with Aaron** of the SDSS/BOSS quasars with such W1/W2 light-curves available are "IR-bright", in the sense that they are above both the W1 and W2 single exposure thresholds and therefore detected at very high significance in our coadds. For this ensemble of objects, the typical variation in each quasar's measured (W1-W2) color is 0.06 magnitudes, which includes statistical and systematic errors expected to contribute variations at the few hundredths of a mag level. The typical measured single-band scatter is 0.07 magnitudes in each of W1 and W2.

We undertook a search for extreme outliers relative to these trends. Specifically, we selected objects with the following characteristics:

- Monotonic variation in both W1 and W2.
- W1 versus W2 flux correlation coefficient $>$0.9.
- >0.5 mag peak-to-peak variation in either W1 or W2.

This yielded a sample of 248 sources. 31 of these are assumed to be blazars due to the presence of FIRST radio counterparts. Another 22 are outside of the FIRST footprint, leaving 195 quasars in our IR-variable sample.

A link to the key properties of our sample can be found here: `qso_pages_v01` and the links to the catalogs are given here: `dr3_wise_lc_sample.fits.gz` and here: `dr3_wise_lc_sample.fits.gz`. The first catalog has 248 rows, which are the selected highly IR-variable sample of objects. The second catalog is the full 200 622 quasar sample quasars that have "good" WISE light curves available in DECaLS DR3. In each file, there are 3 extensions: the first extention are the WISE light curve summary metrics; the second extension the DECaLS DR3 data for each object, and the third extenion, the SDSS data for each object. A full characterization of the typical mid-IR quasar variability will be presented separately.

Additional Multiwavelength data

Checking the data archives we found there was no source within 30 arcsec in the VLA FIRST, i.e., at 21 cm radio frequencies. None of the *Hubble Space Telescope*, the *Spitzer Space Telescope* or the *Kepler* Mission has observed J110057. It is also not in the HSC DR1 footprint. There is the detection in ROSAT (which tirggers using the 2nd all-sky survey (2RXS; Boller et al. 2016, A&A, 588, 103) as 2RXS J110058.1-005259 with 27.00 counts (count error 6.14) and a count rate = 0.06$\pm$0.01. The NED gives J110057 as $1.27 \pm 0.28 \times^{-12}$ erg/cm^2/s in the 0.1-2.4 keV range (unabsorbed flux). J110057 is not in either *Chandra* or *XMM-Newton*.

Further Model Details

Our model consists of three main parts: *(i)* an event that causes an initial change of torques at the ISCO; *(ii)* the propagation of an cooling front in the accretion disk outward from the central engine and an associated increase in the number density of scatterers and *(iii)* a propagation in towards the central black hole of a heating front (leading to a 'recovery' in the observed spectra).

For out data and observations of J11057, we have to remain agnostic to the events that initially causes the initial change of torques at the ISCO. A change in magnetic field being the cause of non-zero torques is well studied, see e.g., Agol & Krolik [2], Gammie [5], Krolik [11], Reynolds & Armitage [16]. Notably,

Description		quantity
Orbital	$t_{\rm orb}$	$6 \text{ days} \left(\frac{R}{50r_g}\right)^{3/2} \left(\frac{r_g}{c}\right)$
Thermal	$t_{\rm thermal}$	$6 \text{ months} \left(\frac{\alpha}{0.03}\right)^{-1} \left(\frac{R}{50r_g}\right)^{3/2} \left(\frac{r_g}{c}\right)$
Front propagation	$t_{\rm front}$	$11\text{yr} \left(\frac{h/R}{0.05}\right)^{-1} \left(\frac{\alpha}{0.03}\right)^{-1} \left(\frac{R}{50r_g}\right)^{3/2} \left(\frac{r_g}{c}\right)$
Cloud-crushing	$t_{\rm cc}$	$100 \text{ yr} \left(\frac{\rho_{\rm cloud}/\rho_{\rm medium}}{10^6}\right)^{1/2} \left(\frac{R}{4\times10^{10}\text{km}}\right) \left(\frac{V_{\rm rel}}{10^4 \text{ km/s}}\right)^{-1}$
viscous	t_ν	$230\text{yr} \left(\frac{h/R}{0.05}\right)^{-2} \left(\frac{\alpha}{0.03}\right)^{-1} \left(\frac{R}{50r_g}\right)^{3/2} \left(\frac{r_g}{c}\right)$

Table 2: Here, α is the viscosity of the disk; $\rho_{\rm cloud}$ is ; $\rho_{\rm medium}$ is ; R is the radius of the accretion disk; r_g is the Gravitational radius; $V_{\rm rel}$ is .

Afshordi & Paczyński [1] argue that a thick disk at the ISCO should produce a substantial torque, while a thin one will not. Regardless of the initial trigger, we suggest some event causes a change in the torque conditions at the ISCO. As such, we build on the non-zero torque model from Zimmerman et al. [23].

For the second part and stage of our model, we need to explain the observed light-curves and optical spectra. J110057 changes from $\approx$17.9mag to $\approx$18.5mag in the observed g-band over $\lesssim$100 days (in the observed frame). This translates to a Johnson V-band flux density change from 0.262 mJy to 0.151 mJy. However, given the redshift of $z = 0.378$, the observed V-band 380-750nm corresponds to 276-544nm in the rest frame ($-6.56 < \log(\lambda) < -6.26$) or near-UV to red in the quasar frame. The source flux density drops to 58% of the original flux in $\sim$3 months.

Simply changing the boundary condition at $R_{\rm in}$ from non-zero torque to zero torque (e.g. collapsing a puffed-up disk inner edge, or, as mentioned above, the magnetic fields) leads to the difference in the SEDs (**NPR NOTE:: Figures 6 and 7 in our notes**. At $\log\lambda = 6.56$, the flux for $R_{in} = 9r_g$ (dark blue in both) drops by ~ 0.2 dex from ~ 38.0 to ~ 37.8 or from 10.0 to 6×10^{37} ergs), or to 60% of the initial flux density, consistent with the values above.

However, in the restframe spectrum, the 300 nm flux seems to drop by a factor of $\sim$5 (given the uncertainty in the normalization). The flux at λ <350 nm is dropping relative to the optical flux. In order to make the multi-color blackbody spectrum do this, we would need dim large regions of the inner disk simultaneously. For example, if the entire inner disk at $R \leq 50r_g$ changed state and became dimmer on thermal timescales at each annulus, we can reproduce both the change at short wavelengths and the observed V-band change.

Gardner & Done [6] present observational evidence (see their figure 7 cartoon) for an interior puffy structure while Jiang et al. [8] examine in detail the effects of the boundâĂŞbound transitions in iron and the his iron opacity "bump", on the thermal stability and vertical structure of radiation-pressure-dominated accretion disks, relevant in UV emitting regions of the accretion disk flow.

Relevant Timescales

There are several relevant timescales associated with J110057 and our model explaining the observations. These are given in Table 2, where we parameterize the relevant disk timescales at $R \sim 50r_g$ as:

Comparison with Guo et al. 2016

Figure 1 of Guo et al. (2016) shows a UV collapse (green curve) in their source (J23+) at a very similar wavelength to that in the 2010 spectrum of our source (J110057), and with turnover in both around $\sim$350 nm. The collapse in J23 happens in 23 days [Figure 2 of 7] and this object was observed with SDSS back on MJD 52177 (normal) and then 23 days later on MJD 52200. There is a drop of 1.2mag in the u-band and 0.5mag in g-band, with r, i, z are all consistent with the earlier observation. J23 is observed with SDSS again about a year later and (u, g, r, i, z) are all back consistent with 'normal'. More importantly, XMM-Newton spectra straddle this time period. The XMM-Newton spectra are from June 3 and Nov. 28 2001. Both spectra are consistent with *no neutral absorption in the rest-frame*. So the sightline is clear on both of those dates (i.e. the Nov. spectrum is 45 days after the UV catastrophe). Guo et al. [7] also find that the IR does not significantly change and that the broad lines are consistent with being constant over time.

Guo et al. [7] discuss two scenarios to explain this behaviour: 1) inner accretion disk change and 2) eclipse by an optically thick cloud. They make the point that in principle both models could explain the observation. In scenario 1) they suggest that turning off the disk at $< 60rg = 30rSch$ would explain this (in the same manner as we discuss for J11057) but they find this implausible since "quasars are not observed to flicker like this typically". Guo et al. [7] then spend more time on scenario 2). So, based on the initial optical spectrum (23 days before the u-band dip) and the Nov. X-ray spectrum (45 days after the u-band dip) they say that the dip lasts < 65 days.

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