A new interpretation of optical and infrared variability in Quasars

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Changing-look quasars are a class of recently identified objects in which the strong UV continuum and broad optical hydrogen emission lines associated with unobscured quasars either appear or disappear on timescales of months to years [1, 2, 3, 4]. The physical processes responsible for this behaviour are still debated, but changes in the black hole accretion rate or accretion disk structure appear more likely than changes in obscuration [5, 6]. Here we report on three epochs of spectroscopy of SDSS J110057.70-005304.5, a quasar at a redshift of $z = 0.378$, whose UV continuum and broad hydrogen emission lines have dramatically faded over the past ≈20 years. The change in this quasar was initially seen in the infrared, and an archival spectrum from 2010 shows an intermediate phase of the transition during which the flux below rest-frame 340nm has collapsed. This is unique compared to previously published examples of changing-look quasars, and is best explained by dramatic changes in the innermost regions of the accretion disk. The optical continuum has been rising again since mid-2016, leading to a prediction of a rise in hydrogen emission line flux in the next few months. If our model is confirmed, the physics of 'changing look' quasars are governed by processes at the innermost stable circular orbit (ISCO) around the black hole, and the structure of the innermost disk. The easily identifiably and monitored Changing Look Quasars would then provide a new probe of the strong gravity regime.

The "Changing-Look" quasar phenomenon, where the dramatic disappearance, or appearance, of prominent broad optical emission lines is seen on month-to-year timescales, is now widely observed, [1, 2, 3, 4, 7, 8] yet poorly understood. Changes in obscuration are generally disfavoured [5, 6], and it is clear that the CLQs are a key laboratory into understanding accretion physics and the nature of the AGN broad line region (BLR).

For the AGN accretion disk, the famous $\alpha-$disk model [9] for a optically thick, geometrically thin disk ($h/R \ll 1$, where h is the vertical scale height of the disk) is known to have serious short-comings e.g. [10, 11, 12]. For example, AGN seem to be cooler than they ought to be [e.g., 12] with the SEDs of AGN showing a universal near-UV shape, reaching a maximum in νS_ν around 1100Å. Such a peak suggests a characteristic temperature of T∼30 000K, wheres for a thermal model, the characteristic temperature should be roughly T∼100 000K. Moreover, constraints from microlensing observations for the size of the optical emission region [e.g., 13, 14, 15, 16] suggestion this region is larger than the one predicted by the standard Shakura-Sunyaev disk.

CLQs have traditionally been discovered by looking for large, $|\Delta m| > 1$ magnitude changes in the optical light curves (e.g. in the g-band). However, we have taken advantage of the ongoing Near-Earth Object WISE Reactivation mission [NEOWISE-R; 17, 18, 19], as well as the Dark Energy Camera Legacy Survey (DECaLS[1]) in order to discover new CLQs. Our team is the first to extend this selection to the infrared using NEOWISE-R mission data. Indeed, we have found a sample of SDSS quasars that show dramatic decreases in their IR flux over the course of a few years. These changes are on timescales too short to be considered due to changes in obscuration, so a new explanation is

[1] `legacysurvey.org/decamls/`

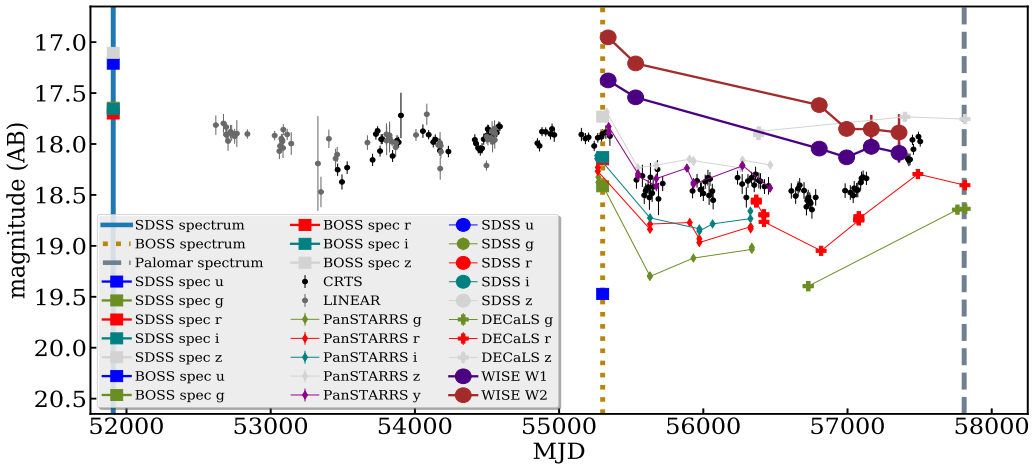

Figure 1 The light curve of J110057. SDSS, DECaLS and PanSTARRS give the optical photometery. The WISE IR light curves are shown and their dramatic decrease led to the identification of J110057. The three spectral epochs are shown by the vertical lines.

needed.

In this article we present the $z = 0.378$ quasar SDSS J110057.70-005304.5 (hereafter J110057) that we have spectral observations showing a transition in the blue-continuum slope traditionally associated with the blackbody object with broad hydrogen emission lines, into a to become a regular galaxy. We present a model that invokes changes at the innermost stable circular orbit (ISCO) to be the triggering event for the change in the accretion disk, which along along with the changes in the BELs, explains a major change to the disk interior to $150R_g$ as well as the IR light curves. Critically, our model makes predictions to the future behvaiour of J110057.

1 Results

We started by matching the SDSS-III BOSS Data Release 12 Quasar catalog [DR12Q; 20] to the NEOWISE-R IR data (WISE W1 at 3.4μm, WISE W2 at 4.6μm). We found ≈200 objects with fading light IR light curves; these objects were identified by a factor of 2 or more change in the observed WISE W1 and W2 bands (see the Supplemental Material for the NEOWISER detailed selection). Scanning these 200 objects we also examined the change in optical colour using the SDSS and DECaLS imaging surveys looking for changes suggestive of CLQs. From this inspection, a priority list of ≈ 70 quasar targets was derived and we obtained new optical spectroscopy from the Palomar 5m telescope. J110057 was one of these 70 objects, but critically, had spectra from both SDSS and BOSS and was thus a top priority target.

Figure 1 gives the light curve of J110057. Along with WISE IR data, optical data from the SDSS, the Catalina Real-time Transient Survey [CRTS; 21, 22], LINEAR [23] and PanSTARRS [24, 25, 26, 27] is available. Figure 2

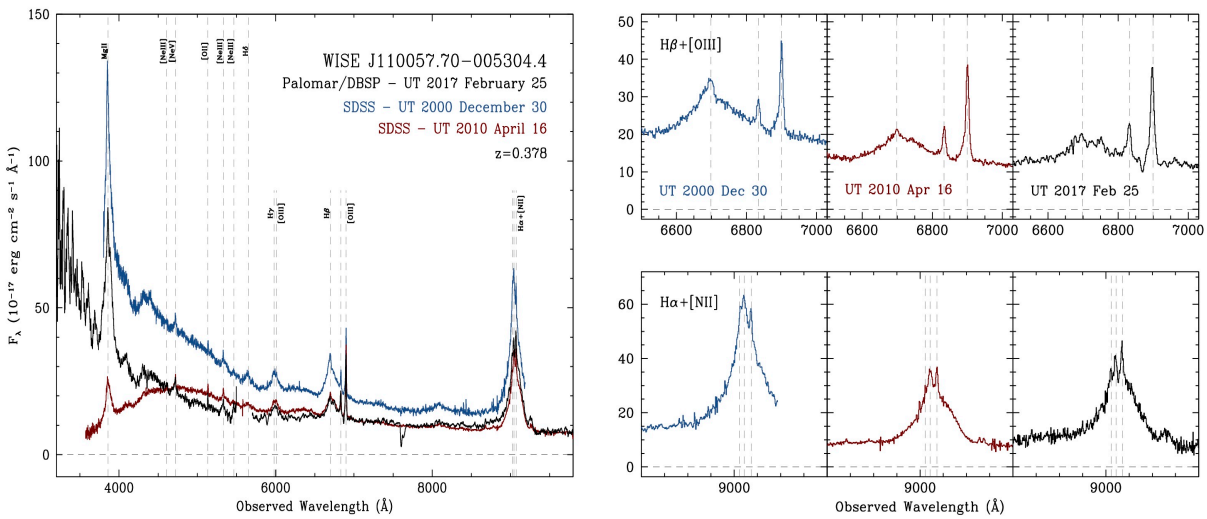

Figure 2 Optical spectra of J110057 obtained on MJD 51908 (blue; SDSS), 55302, (red; BOSS) and 57809 (black; Palomar/DBSP). *Left::* The full optical spectra; *Right (top)::* Zoom in on the Hβ-[O III] complex; *Right (bottom)::* Zoom in on the Hα-N II complex.

shows the three optical spectra of J110057. Figure 2 shows the optical spectra for J110057 from the SDSS, the BOSS and Palomar observations taken on MJD 51908, 55302, and 57809. The MJD 51908 SDSS spectrum is of a typical blue quasar, the blue continuum then collapses. The Supplemental Material gives further observation details, the summary of which, outside an achival ROSAT detection, there is no further multiwavelength, multi-epoch data.

2 Discussion

Using [28] as our starting point, our preliminary model [29] of emission from a multicolor disk implies changes in the region from the ISCO to ∼few tens-100 $R_{\rm g}$ are required to suppress flux into the observed g-band. In particular, we suggest a physical collapse of the disk scale height due to a cooling front propagating outward from the ISCO.

For J110057 we apply our model as follows. We start with an inflated disk, with non-zero torque at the ISCO, and $h/R \sim 0.2$ inside of $R \sim 100R_{\rm g}$. This is the initial state in circa 2000 (≈ MJD 51900). Around 2007, there is a switch to a zero torque at ISCO state. A cooling front is set-up, which propagates out from the ISCO at the timescale, $t_{\rm front}$. Regions behind the front emit flux at $\sim 0.1L$ of what they did prior to the passage of the front (**NPR comment;: due to drop in T? T** $\downarrow \times 1.78 \Rightarrow L \downarrow \times 10$), and the temperature decrease leads the height to drop by a factor of 2. (**NPR comment: just due to less kinetic energy??**). $L_{\rm ion}$ starts decreasing due to the drop in ionizing photons, which in turn causes the Balmer lines to also decrease in flux.

If the inner accretion disk is usually inflated [e.g.,see 28, 30, 31], such a cooling front will naturally produce: 1) a collapse in the scale height of the disk; 2) a decrease in flux moving from UV to longer optical wavelengths; 3) a temporarily thicker scattering atmosphere, further decreasing flux at short wavelengths. This model implies changes

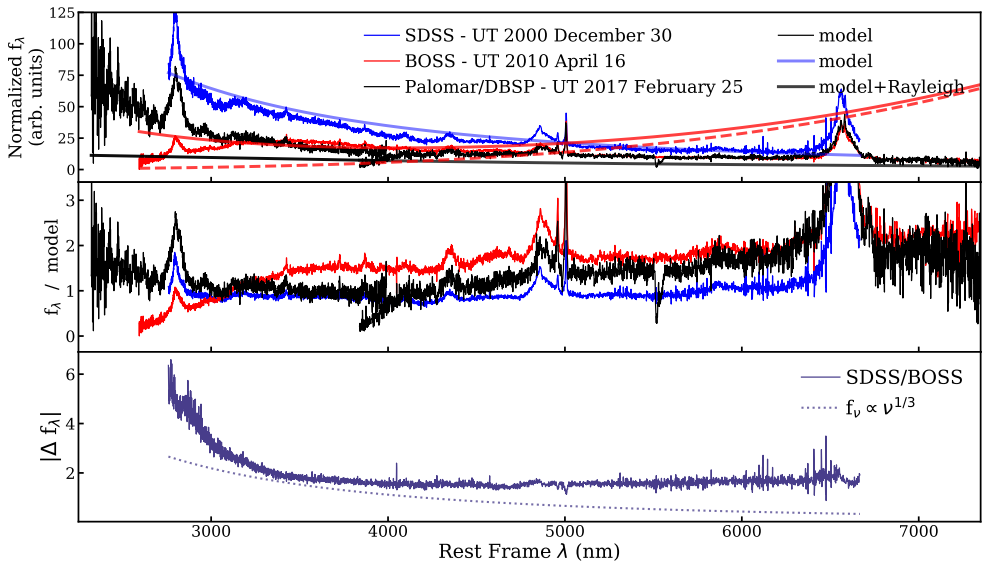

Figure 3 The three observed spectra of J110057, with our model being overplotted at each spectral epoch. For clarity, the bottom panel shows the spectra with the model divided through.

to the optical emission moving from shorter to longer wavelengths (as the radius of the cooling front increases), on months-to-years-long timescales. It also predicts a longer time to recover the original flux (compared to the initial collapse, as a front will move more slowly in a thinner disk (see Fig. 2). A decrease in the UV flux would also be expected to cause a decrease in IR flux, as the heating of the IR-emitting dusty torus is reduced; however, there should also be a delay due to light travel time.

Since the disk starts puffed-up, the cooling front time is not long, and by 2010 (MJD 55300), the front has reached $R \sim 50R_g$. During that time, the collapsing disk height increases the number density of scatterers, which in turn causes Rayleigh scattering producing the blue downturn in the 2010 spectrum. The cooling front keeps going, until it hits the part of the disk where it is normally thin, around $R = 100R_g$, arriving around 2012. This sets up another (heating) front, which will travel *back in* towards the SMBH, and re-inflate the disk. This 'returning' front travels more slowly because the disk is thinner. It also means the return to normal will be asymmetric in time, as observed, and the g-band bottoms out first because that is coming from $R \sim 100R_g$.

Using **(author?)** [29] and **(author?)** [28], Figure 3 shows a model for a $M_{\rm BH} = 3 \times 10^8 M_\odot$, radiative efficiency of $\varepsilon = 0.1$, accretion rate in units of Eddington accretion, $\dot{M} = 0.032$, inner and outer disk radii in units of r_g of SMBH of radius$_{\rm in}$=6.0, radius$_{\rm out}$=1.0×10^4. The resulting model spectra can be seen in Figure 3. We expect the front to return to the ISCO in about 2018. That means the H lines will come back a few months later, but the WISE IR flux shouldn't come back until about 2021.

[32] observed a similar event to J110057, with SDSS J231742.60 +000535.1. However, their object provided

an ambiguous case, as the IR brightness of their source did not decline. However this is consistent with our model, as their cooling event is relatively brief. We discuss J231742 and the **(author?)** [32] result further in the Supplemental Material.

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