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Improving the DRW fit parameters for S82 quasars with increased baseline combining SDSS, CRTS and PS1 data

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ABSTRACT
Aim: Improve on DRW parameters reported in MacLeod et al. (2011) by an increase of the QSO light curve baseline. We compare the tools used to fitting for τ and SF_∞ to those of Kozłowski, Szymon (2017).

1 MOTIVATION

MacLeod et al. (2011) successfully derived many QSO parameters for the DRW model based on fits to SDSS light curves in S82. Encouraged by conclusions of Kozłowski, Szymon (2017), we expand baselines of quasar light curves utilizing data from CRTS and PS1. We show improvement in the accuracy of parameter fit (Hernitschek+2016 sought to improve on parameters, but had insufficient baseline using solely PS1).

2 METHODS

We first confirm the scaling relations by Kozłowski, Szymon (2017) by testing the retrieval of simulated light curve parameters with Celerite . In addition to reproducing his Fig.2 we also plot the fractional bias due to insufficient length of the light curve baseline. We confirm that longer baseline should significantly improve time scale constraints. Light curve error distribution and sampling are less important, i.e. it would improve the accuracy of fit more to have a larger baseline than denser sampling.

Then we explore the combined SDSS-PTF-CRTS-PS1 Quasar dataset in the Stripe82 footprint (Fig. 2).

2.1 Data

We start with the SDSS DR7 QSO (**?**) near-simultaneous ugriz SDSS photometry [1]. We also used the CRTS DR2 (Drak et al 2009) light curves obtained for these objects by B.Sesar using a positional query. With the SDSS ra,dec, we obtained the PTF DR1 (Rau et al. 2009) r-band light curves. We use PanSTARRS DR2 (Chambers et al. 2011, Flewelling et al. 2018) grizy light curves for DR7 QSO from C. MacLeod. We make an outer join of all catalogs, flagging from which survey came which data point, as well as photometric filter.

[1] http://www.astro.washington.edu/users/ivezic/macleod/qso_dr7/Southern.html

2.2 Photometric offsets

To effectively combine all photometric information from various telescopes and imaging filters we re-derived the necessary photometric offsets. We used as our sample blue SDSS S82 stars (-1<g-i<1), limited to this range in color because it closely matches the natural distribution for quasars (see Fig. 1)

We find photometric offsets as follows :

$$m - s = f(x) \tag{1}$$

where m is the mean magnitude for a target survey (eg. PS1{g,r,i,z,y}, or PTF{g,R}), s is the synthetic SDSS magnitude in a given band, and x is the median SDSS color (eg. $g-i$). (For instance, **??** derived all offsets against x = SDSS$(g-r)$, $m = PS1\{g,r,i,z,y\}$, and s = SDSS(r)

The issue of interstellar extinction : due to dust present between us and the standard stars (or background quasars), the observed light will appear slightly redder because dust preferentially scatters blue light away. This depends on the location of the source on the sky and is related to the dust inhomogeneities in the Milky Way.

However, in deriving bandpass to bandpass transformation all that matters is the flux received at the Top of the Atmosphere (TOA), for which all photometry is corrected at the pipeline processing level (both for SDSS, PTF, PS1, and CRTS). In other words, all that matters is that any SED at TOA will have slightly different magnitude (hence colors) depending on whether we observe it with SDSS(r), PS1(r), or PTF(R). Therefore, to derive photometric offsets (which are time-independent), we use Sloan colors not corrected for extincton (and likewise, PS1, PTF, etc.) .

In that way we form a 'master bandpass', consisting of SDSS bands, and PS1, PTF, CRTS equivalents. Since all SDSS bands are observed nearly simultaneously, we choose SDSS(r) as the 'master band', and we transform photometry from all 'nearby' bandpasses in other surveys (PTF gR, PS1 gri, CRTS V) - PS1 u,z,y are too distant from SDSS r. To separate in color space the stellar locus we use SDSS(g-i) color because it has a larger wavelength baseline than SDSS(g-r) color. For each 'master band' light curve we

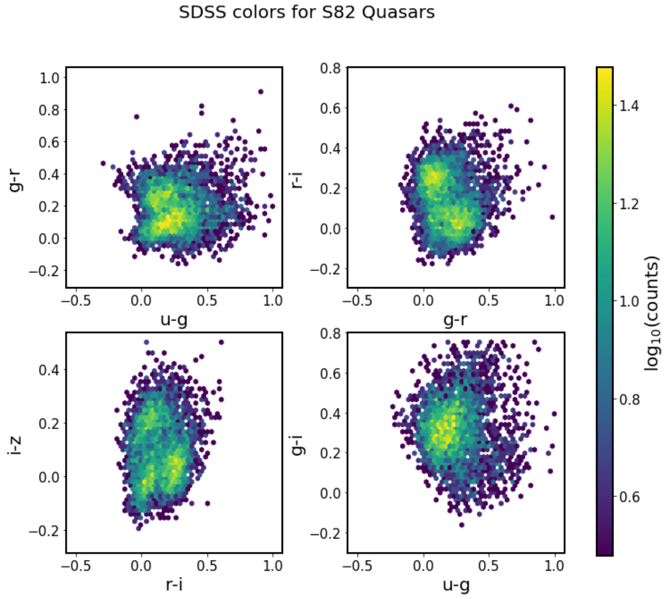

Figure 1. Color - color diagrams for 6444 SDSS S82 quasars with PTF, PS1 and CRTS photometry. The convention is to always define a 'color' by subtracting the redder filter from the bluer filter. That way any color has negative values for intrinsically bluer objects - emitting more in the blue part of the spectrum (eg. QSO, RR Lyr), and positive values for redder objects (eg. M stars). Thus using the SDSS base of 'u g r i z' colors, we form u-g, g-r, r-i, i-z colors, as well as g-i, which skips the r filter. Another convention is to plot the bluer color on x-axis (eg. u-g) vs redder color (eg. g-r) on y axis (see **??**). Thus from the upper-left panel to bottom-right panel we cycle through color pairs showing that quasars occupy a distinct locus in each color combination. To calculate photometric offsets between SDSS and PS1, PTF, CRTS, we employ standard stars with colors based on the region occupied by quasars in the u-g vs g-i color space.

keep track which points originated from SDSS(r), PTF(gR), PS1(gri), or CRTS(V).

2.3 Simulated light curves

We made a controlled experiment of long (20 tau) , well-sampled (dt=5 days) light curves, with 400 points each . We used different priors (Jeff1, Jeff2, p1, p2, flat), and found that sigma, tau from MAP (maximum a posteriori estimate) with Jeff1 is most consistent with Chelsea's code. We further investigated the logL evaluated on a grid of sigma,tau, and conclude that the non-Gaussian shape of the log-likelihood cauese the MAP to be biased, and the expectation value of marginalized posterior distribution is less biased (at 1% level) . We find that the expectation value based sigma, tau are less biased, and for a very coarse grid 25x25 elements, the value of input parameters is still recovered at the 1% level (we expect the overall distribution to be biased on the 1% level, so this is sufficient accuracy).

We first check whether there is an improvement of fit for simulated DRW sampled at observed cadence - we plot τ_{out} vs τ_{in} for SDSS sampling, PS1+SDSS sampling, PS1+CRTS+SDSS sampling, PS1+CRTS+PTF+SDSS sampling. This helps establish,

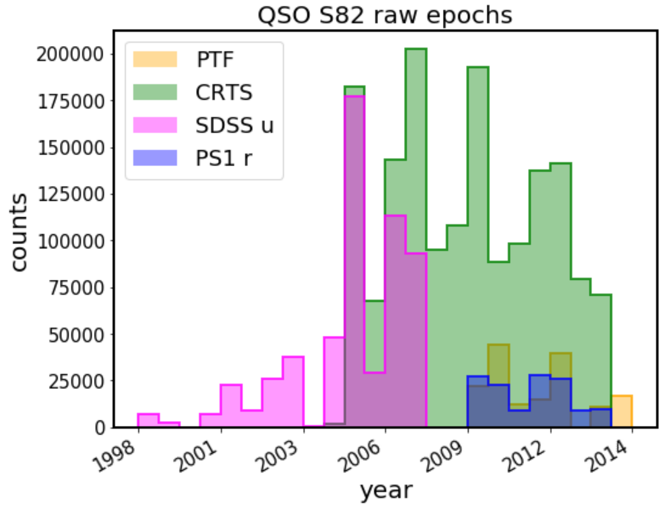

Figure 2. Count of raw photometric measurements for Quasars in Stripe 82 from four surveys . Note that both CRTS and OTF significantly increase the original baseline of SDSS measurements.

based on simulated data (where we know the truth), whether we should expect much improvement in fit accuracy when using real data.

We then perform fits using observed points selecting photometry only from a subset of surveys : τ_{PS1}, $\tau_{(PS1+SDSS)}$, τ_{SDSS}. We also check whether we get a better fit behavior using only bright quasars with $\tau_{\langle mag \rangle <19}$.

Using the best combination of survey data, we revisit MacLeod et al. (2011) correlations of retrieved characteristic quasar timescale τ and variability amplitude σ with black hole mass, luminosity, etc.

REFERENCES

Kozłowski, Szymon 2017, A&A, 597, A128
MacLeod C. L., et al., 2011, The Astrophysical Journal, 728, 26

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