Using Gaussian Processes to classify and characterize quasar light curves

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Background

A better understanding of how well the Damped Random Walk (DRW) model can be used to model quasar variability is crucial for using the DRW best-fit parameters to characterize and classify quasars. It is a relatively recent field : Kelly et al. (2009) showed that the DRW parameters can be linked to the physics of the accretion disk. Since Kozłowski et al. (2010) proposed the DRW model for quasar selection, MacLeod et al. (2010) moved the field of quasar variability studies from a handful of objects to a proper statistical study fitting over 9 000 quasars in SDSS Stripe 82. As bias in retrieved parameters decreases with light curve length, we test employing combined data from SDSS, CRTS, PS1, PTF to improve the accuracy of retrieved parameters. We also consider different ways of probing the non-Gaussian likelihood, such as expectation value and Maximum A-Posteriori (MAP) estimate.

Kernel approach

Gaussian Process consists of a mean function and a covariance function (autocorrelation, "kernel"). Many existing light curve fitting tools use this approach, still drawing inspiration from a seminal paper by Rybicki&Press (1995). include eg. JAVELIN (Zu et al. 2011), George (Ambikasaran et al. 2015), Celerite (Foreman-Mackey et al. 2017). In particular, Celerite promises a very fast $\mathcal{O}(N)$ approach for covariances that consist of a combination of exponentials. For the Ornstein–Uhlenbeck process, or Damped Random Walk, the kernel is

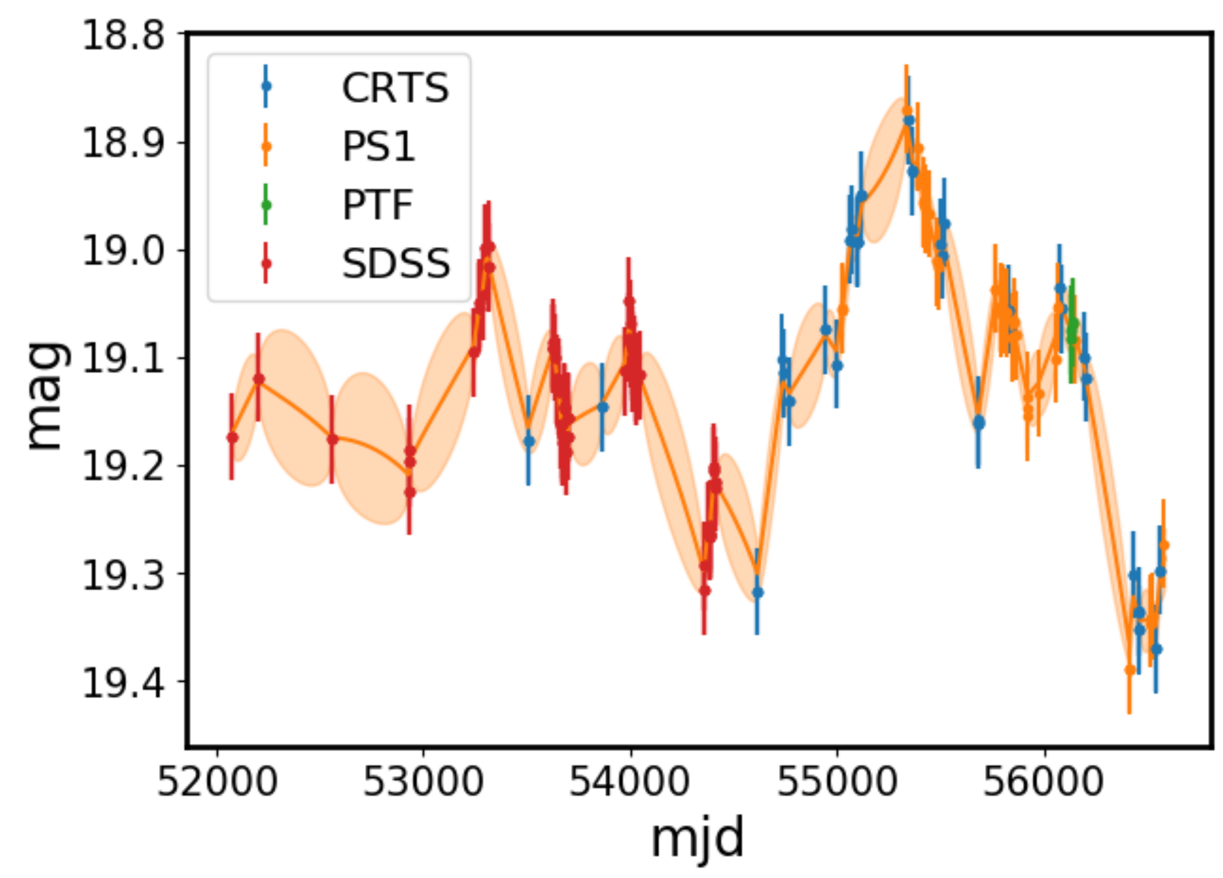
$$k(\Delta t) = \sigma^2 e^{-\Delta t/\tau}$$

and corresponds to the Structure Function :

$$\mathrm{SF}^2(\Delta t) = 2\sigma^2(1 - e^{-|\Delta t/\tau|})$$

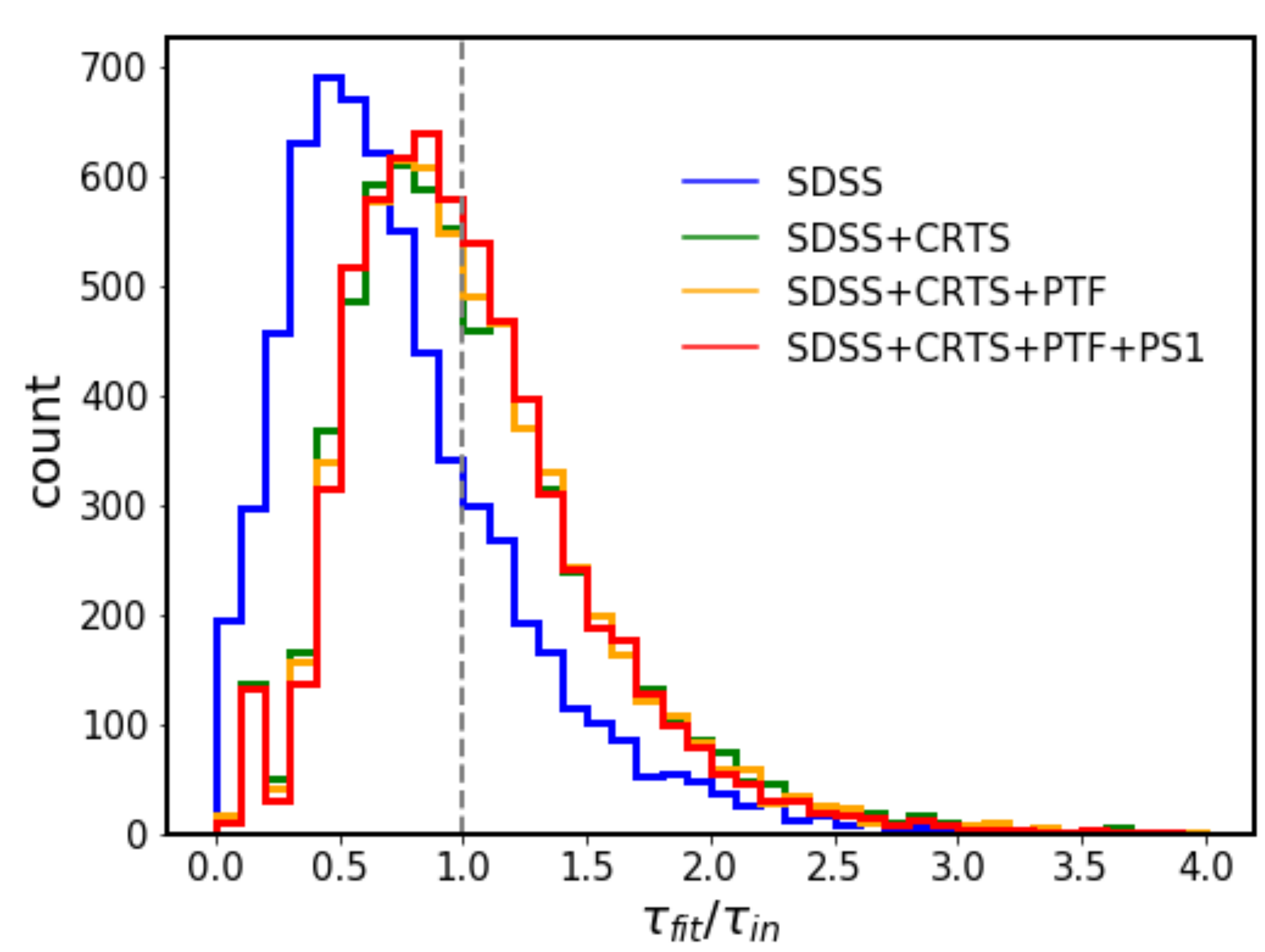
(used to study the ensemble behavior by eg. Suberlak et al. 2017, Kozłowski 2016)

Combined datasets



This simulated light curve, sampled at cadences corresponding to various surveys, illustrates that we can significantly extend quasar light curves by combining different catalogs. Here we use PanSTARRS DR2 (Chambers et al. 2011, Flewelling et al. 2018), CRTS DR2 (Drake et al. 2009), and PTF (Rau et al. 2009). Starting from the SDSS DR7 near-simultaneous ugriz photometry for Stripe 82 quasars (Schneider et al. 2008), we cross-match the catalogs, and find a common photometric solution using the blue S82 standard stars ($-1 < g - i < 1$), thus verifying offsets calculated by Ofek et al. 2011 (PTF) and Tonry et al. 2012 (PS1).

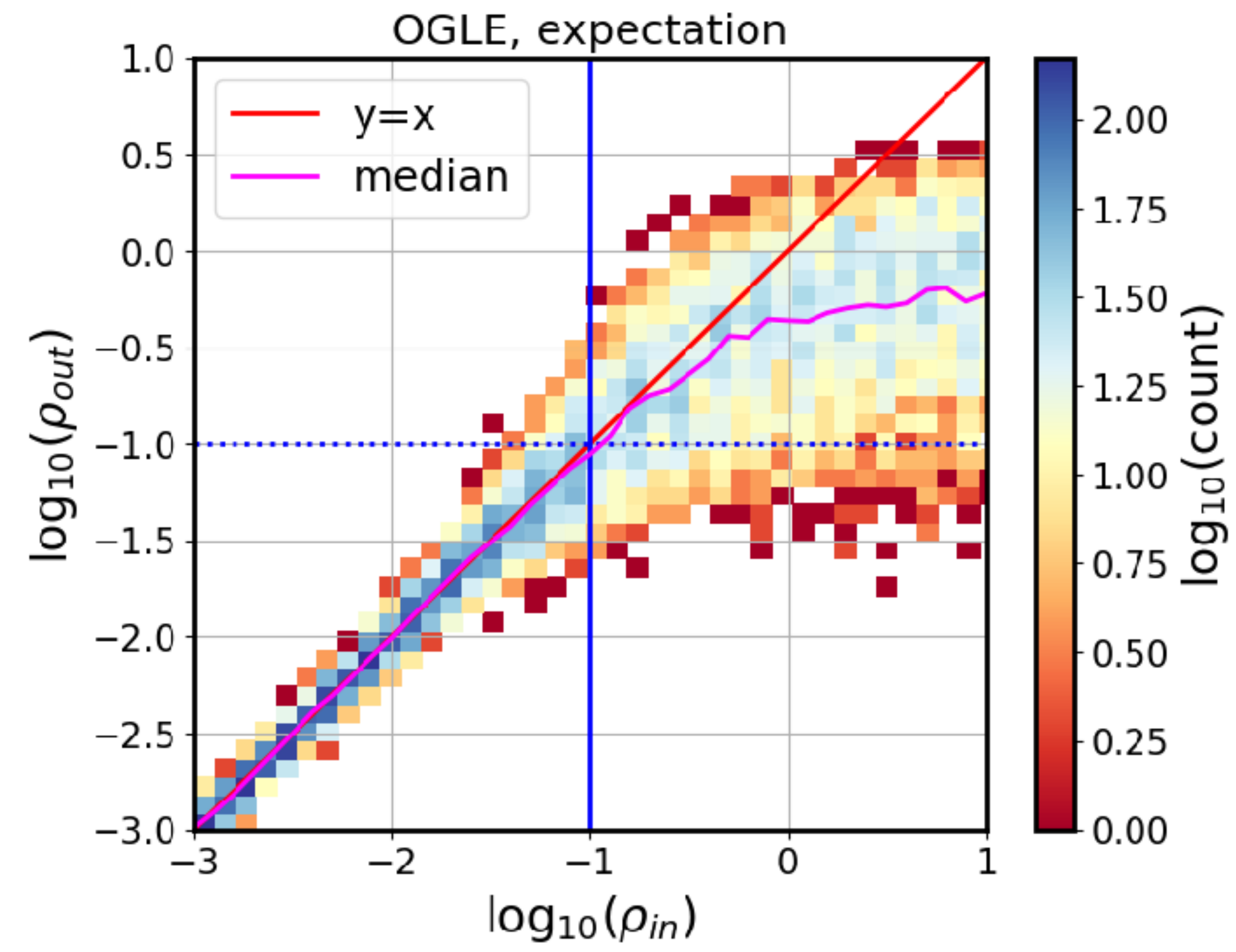
Combined results

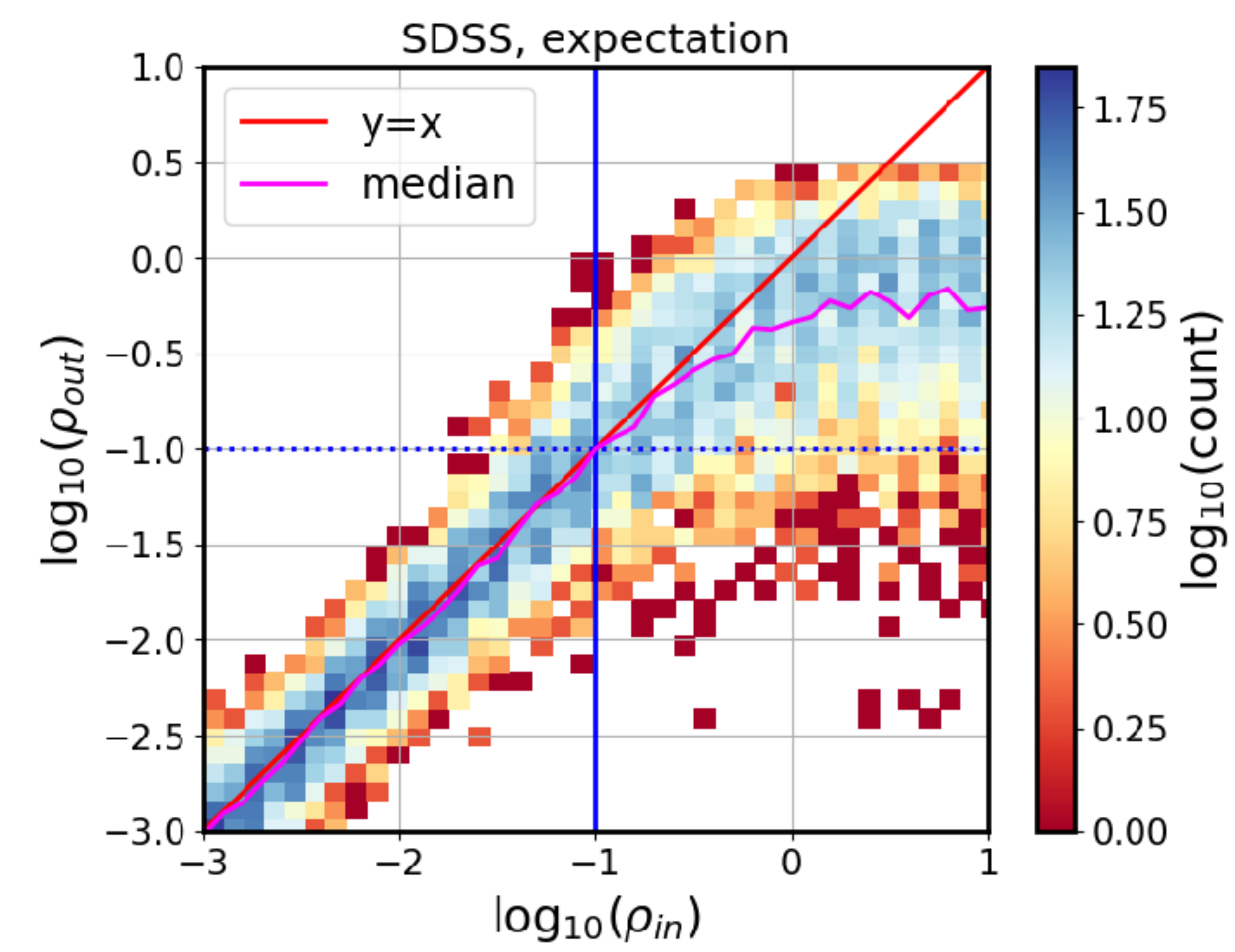


To verify the improvement in retrieved DRW parameters we simulated DRW light curves with input timescale τ = 575 days, amplitude 0.2 mag, corresponding to the median of S82 quasars as found by MacLeod et al. 2011. The median baseline of 6444 quasars with data from all four surveys is 9.8 times larger than this timescale, i.e. already in the unbiased regime $-1.05 < \log_{10}(575\,\mathrm{d}/t_{exp}) < -0.8$

We find that adding more epochs corresponding to CRTS, PTF, PS1, decreases the bias, with biggest improvement thanks to the CRTS data, which corresponds to the largest increase in the baseline.

Simulated light curves





We confirm Kozłowski (2017) scaling relations by testing the retrieval of input timescales for simulated DRW light curves, sampled at SDSS (N=60 epochs) or OGLE (N=445) cadence. Using fixed light curve length of 8 years, we simulated 100 different timescales τ, parametrizing the ratio of the timescale to baseline as $\rho = \tau/t_{exp}$. We find that a longer light curve baseline can decrease the bias in retrieved input timescale τ, which implies that adding new data to quasar light curves can help improve the results of MacLeod et al. (2011). We find that the bias increases as the timescale becomes longer than 10% of the baseline. Using the expectation value of the marginalized log posterior rather than the MAP estimate decreases the bias, thanks to the non-Gaussian shape of the likelihood.

Future work includes revisiting relations studied by MacLeod et al. (2011) and Hernitschek et al. (2016), correlating the DRW parameters with the spectroscopic information about the quasars (such as black hole mass, luminosity - see Kelly et al. 2013).