MNRAS 000, 1–2 (2015) Preprint 19 February 2016 Compiled using MNRAS LATEX style file v3.0

SDSS Stripe 82 : quasar variability from forced photometry

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Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

1 INTRODUCTION

2 DATA ANALYSIS

We use data from all SDSS runs up to an including run 7202 (Data Release 7), including all 6 SDSS camera columns.

All epochs (individual images) were background-subtracted, and then scaled from the Digital Unit counts to fluxes by comparing standard objects against the Ivezic+2007 catalog (similar to Jiang+2014).

The data were coadded, and all objects detected in the i-band coadds were assigned a deepSourceId (== objectId). For star-galaxy separation, the entire clump was considered as one parent source (with single ParentSourceId). For an object which is a parent (eg. a galaxy), ParentSourceId is null. This amounts to 40 milion i-band detections down to 3σ. 8 million of those are brighter than 23^{rd} mag. Thus the total number of photometric measurements is : (40 million i-band detections) x (80 epochs) x (5 filters) = 16 billion measurements, including (8 million i-band detections i < 23) x (80 epochs) x (5 filters) = 3 billion measurements brighter than 23^{rd} mag.

Forced photometry was performed in u,g,r,i,z on the individual epoch images (NOT difference imaging), in locations specified by i-band coadds. (DIFFERENCE imaging is when photometry is done on coadd - individual-epoch-image) . Therefore in some cases the flux reported for a given aperture is negative, because after background subtraction noise oscillates around 0, and when it is scaled up, it can have negative values. [stored in rawDataFPSplit] The background in the optical bands is bright, and if we assume that the measured number of bacground counts oscillates around the value B_0, then the measured background count B is distributed as a Gaussian of width σ_B : $B - B_0$ $N(0, \sigma_B$. The noise is Poissonian, i.e. depends on the number of counts, and since for optical mesaurements the number of counts is large, $\sigma_B = \sqrt{B}$. On a 4kx4k CCD, with 16 Mpix, 5σ (corresponding to 1 false detection in a million), we would expect about 16 false detections. Now considering the distribution of the probability (likelihood) of flux measurement $L(F|data)$, for bright sources it is a very narrow Gaussian centered on the measured F_S, width σ_F on the level of $1-2\% \approx 0.01-0.02$ mag. However, for faint sources the probability, centered around the F_S, is much wider, so that there is a nonzero probability of negative flux measurement. A Bayesian way to address this issue is to impose the prior $p(F)$, since we understand that physically flux cannot be negative, so that the posterior probability $p(F|data) \propto L(F|data)p(F)$. A simple flat prior, being 0 for $F < 0$ and 1 otherwise, would not affect the measured F_S for bright sources, but for faint sources it would move the distribution (posterior) to be above zero flux. This would be the upper limit on the flux of that source. Therefore we decided to apply the Bayesian prior in case where $\langle F_L \rangle < k\sigma >$, with $k = 2$ (2σ corresponds to 2% probability of $F_L < 0$).

To test our method we generate fiducial lightcurves (DRW / sinusoidal / ...), with a uniform sampling ($N = 100 - 1000$). Based on the generated flux (F_{true}) we define 5σ level as the robust 25-th percentile (or median) of the F_{true} distribution : $\sigma_F = (1/5)F_{25\%}$. Thus we defined F_{obs} as $F_{true} + F_{noise}$, with the Gaussian noise $F_{noise} = \sigma_F\, N(0, 1)$. For each F_{obs} we consider a normalized Gaussian $N(\mu = 0, \sigma = 1)$, where $x^* = \langle F_L \rangle/\sigma_F = F_{obs}/\sigma_F$, is a position from which we calculate the area $A = \int_{x^*}^{\infty} F_L$, defining by xB a point where the $\int_{x_B}^{\infty} F_L = 0.05A$. Then the upper limit on our measurement is $F^{upper}_{faint} = (x_B + x^*)\,\sigma_F$

The average brightness of an object in a given filter can be found in two ways. The median of the forced photometry values (over all epochs, including the negative fluxes) will better reflect the actual brightness of a variable source. This may mean that the median is negative, i.e. the median flux is negative. Since the magnitude is undefined for negative fluxes, we then revert to the lightcurve, and for each exposure with negative flux we find the zero point magnitude (m_1) - the magnitude for a source with a flux of 1 count per sec, different for each exposure. The zero point magnitude for each exposure with negative flux is calculated from the Flux of 0 magnitude source, F_0, as $m_1 = 2.5 \log_{10} F_0$. For that object the new median magnitude in that filter will be the upper limit.

Colors can be calculated in two ways: using the median of forced photometry over all epochs (object detected in coadded i-band has photometry in all epochs), or the median over single-epoch detections (only when an object was above the detection threshold for a single epoch). Thus the median over all detections will be biased (especially for faint sources) towards higher brightness. On the other hand, the median over all epochs will be more representative of the true brightness of an object in a given filter. If a median brightness is negative, we use zero point magnitudes and in such cases median over all epochs will be an upper limit on

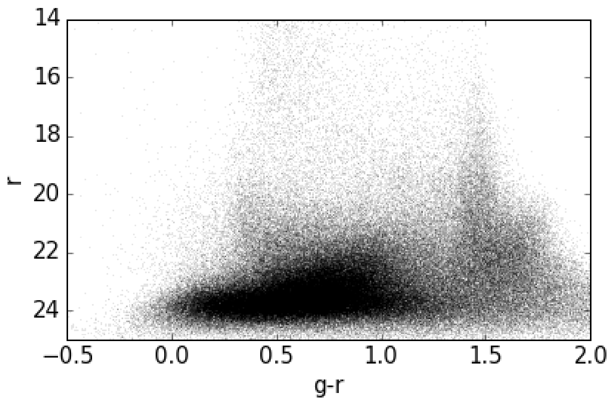

Figure 1. A color-magnitude plot, analogous to Figure 2 from Ivezić+2003 . We use only 200 000 sources, corrected for galactic extinction, plotting the median photometry over all epochs only for sources where median flux is not negative.

brightness, but still less biased than median over all detections. Therefore we choose to use median over all epochs to calculate colors (see Fig. 3 for an example).

Since the reported fluxes are not extinction-corrected, we use a table of E(B-V) in a direction of a given source to correct for the galactic extinction. We use the formula $x_{corr} = x_{obs} + A_x * E(B-V)$, where x is u,g,r,i,z , and A_x is 5.155, 3.793, 2.751, 2.086, 1.479 for each filter respectively [SOURCE?]

3 RESULTS

4 CONCLUSIONS

ACKNOWLEDGEMENTS

Funding for the SDSS and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the U.S. Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society, and the Higher Education Funding Council for England. The SDSS Web Site is http://www.sdss.org/.

The SDSS is managed by the Astrophysical Research Consortium for the Participating Institutions. The Participating Institutions are the American Museum of Natural History, Astrophysical Institute Potsdam, University of Basel, University of Cambridge, Case Western Reserve University, University of Chicago, Drexel University, Fermilab, the Institute for Advanced Study, the Japan Participation Group, Johns Hopkins University, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.

This paper has been typeset from a TEX/LATEX file prepared by the author.