Finding and Classifying Variable Sources in Pan-STARRS1 3π

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Abstract

We explore, through the comparison of PS1 3π data with SDSS Stripe 82 data, how well various classes of objects, in particular QSOs and RR Lyrae can be identified on the basis of the statistical properties of their multi-color light curves.
Specifically, we describe an approach that uses, and does well with, multi-band structure functions to select QSO and RR Lyrae candidates according to their variability in PS1 3π. The results of PS1 3π variability studies in the MW context will enable us to use RR Lyrae to get precise distance estimates for finding streams and satellites. QSO candidates will be used as a reference frame for MW astrometry, to get absolute proper motions and study MW disk kinematics.
Additionally, our work will result in a value-added catalog of variable sources.

Surveys

Pan-STARRS (Panoramic Survey Telescope & Rapid Response System)
- 5 bands (grizy)
- surveyed the 3/4 of the sky visible from Hawaii (DEC > -30 deg) repeatedly ⇒ "3π" survey
- additionally: variety of deep survey fields and dedicated asteroid search time.

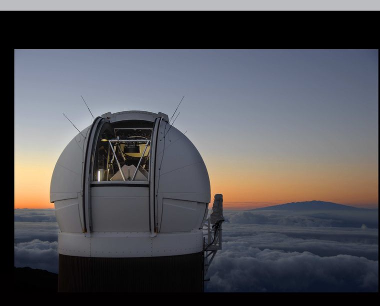
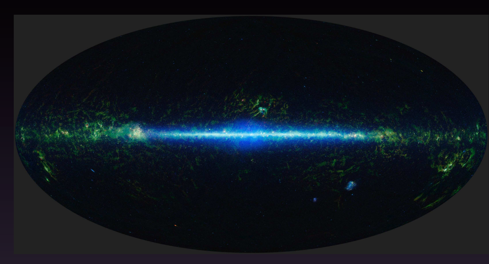
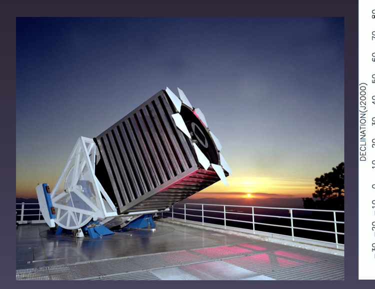
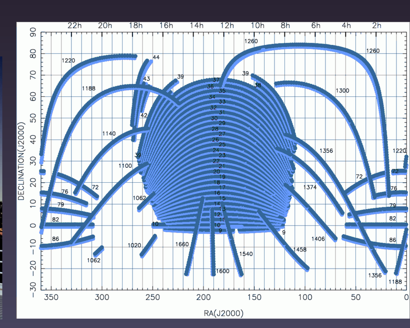


Photo Credit: http://www.ifa.hawaii.edu/info/press-releases/PS1/PS1.jpg

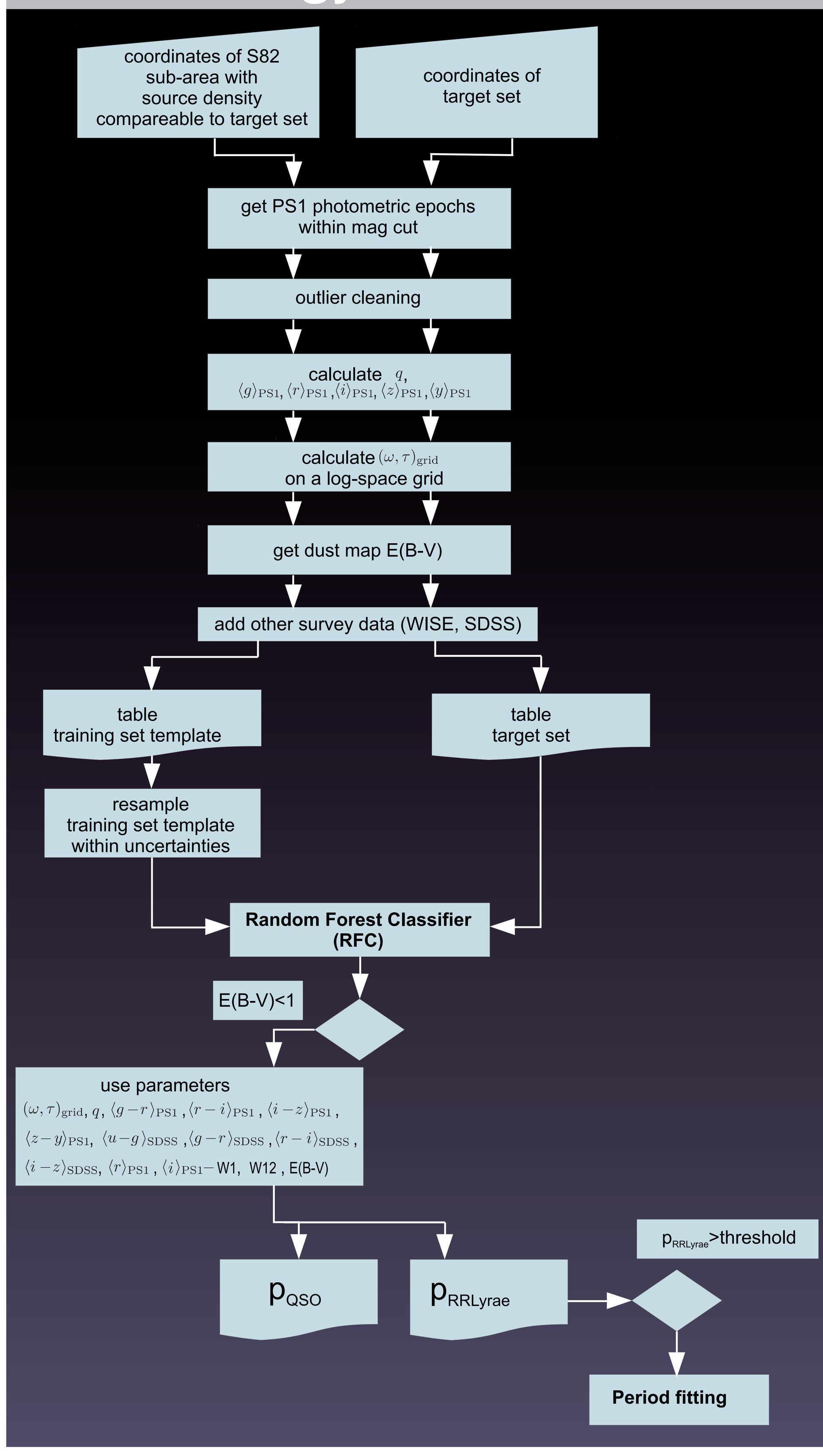
WISE (Wide-field Infrared Survey Explorer)
- all-sky survey in 3.4, 4.6, 12 and 22 μm wavelength range bands
- resolution of 6" (12" at 22 μm)
- infrared catalog will help search for the origins of planets, stars, and galaxies



WISE: artist's impression
A full-sky view with infrared wavelengths rendered in visible light.
Photo credit: NASA/VAFB http://photojournal.jpl.nasa.gov/catalog/PIA17254

SDSS (The Sloan Digital Sky Survey)
- original SDSS observing plan (2000 to 2008): the SDSS Legacy Survey
  ⇒ ugriz of ~ 7,500 square degrees of the North Galactic Cap, three stripes in the South Galactic Cap of 740 square degrees in total
- Stripe 82: scanned multiple times to enable a deep co-addition of the data and to enable discovery of variable objects.
- The Sloan Digital Sky Survey is continuing through the Third Sloan Digital Sky Survey (SDSS-III)



The SDSS telescope
Photo credit: www.sdss3.org
Sky coverage equatorial: Full Footprint with Stripe Labels in equatorial coordinates

Methodology



S82 as a Testbed

use SDSS S82 to explore variability issues in PS1 3π data

SDSS S82:
~60 epochs simultaneous ugriz photometry,
complete QSO and RR Lyrae classification

PS1 3π:
~40 epochs non-simultaneous grizy photometry

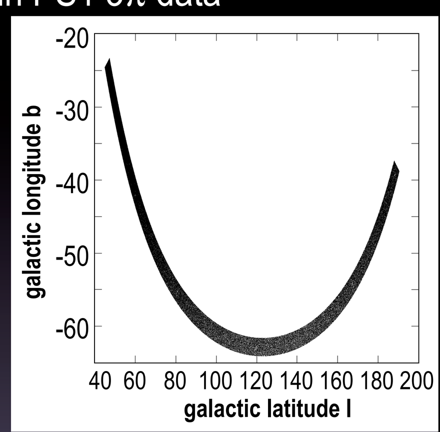


Fig. 1: SDSS S82 sky coverage

⇒ use S82 classification in overlapping area to calibrate and verify PS1 classification

pre-select by χ^2

As a measure for variability, we use

$$q = \frac{\chi^2_{\rm const} - N_{d.o.f}}{\sqrt{2\,N_{d.o.f}}}$$

where

$\chi^2_{\rm const}$: presume $\bar{m}_\lambda \neq f(t)$
n: used bands
N: # of data points in all bands
$N_{d.o.f} = N - n$

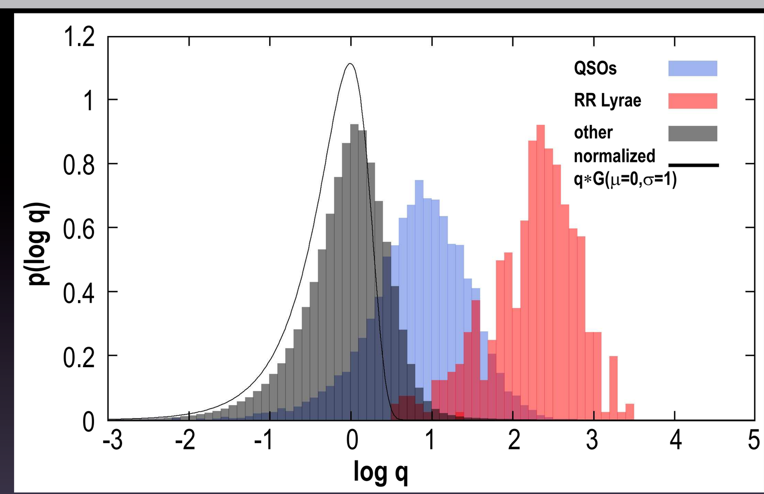


Fig. 2: distribution of q for SDSS S82 objects

structure function based variability model

by how much has the source varied if we wait Δt?

$$\tilde{m}_\lambda(t) = m_\lambda(t) - \bar{m}_\lambda$$

$$V(\Delta t) \equiv \frac{1}{2}\left\langle \left(\tilde{m}_{\lambda_i}(t) - \tilde{m}_{\lambda_j}(t+\Delta t)\right)^2 \right\rangle$$

$$\overset{\rm model}{\equiv} \omega_i(b_i)\omega_j(b_j)\exp\left[-\frac{|\Delta t|}{\tau}\right]$$

⇒ fit for "1-year amplitude" ω_r & time scale τ

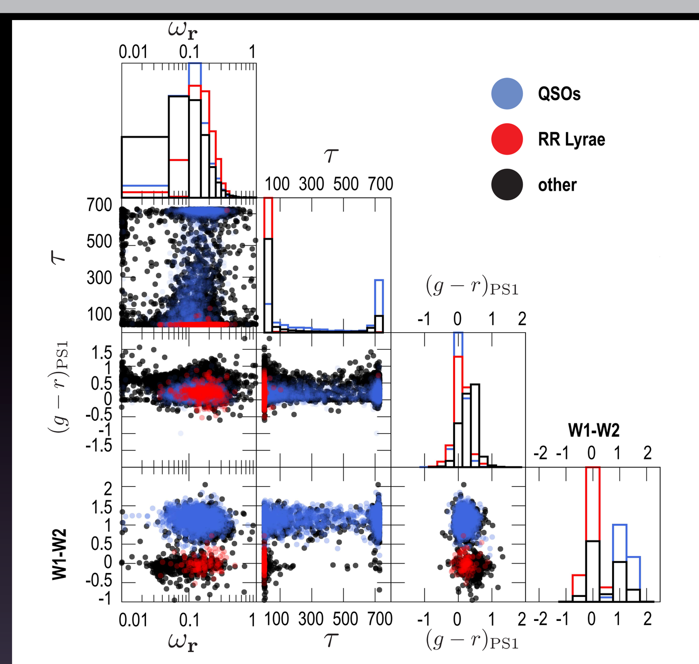


Fig. 3: triangle plot of posterior parameter for 2380 QSOs, 362 RR Lyrae, 1097 other objects within S82 overlapping area. The structure function parameter (ω_r, τ) are fitted to PS1 light curves using MCMC.
The object type is cross-matched to SDSS S82 within 1 arcsec.

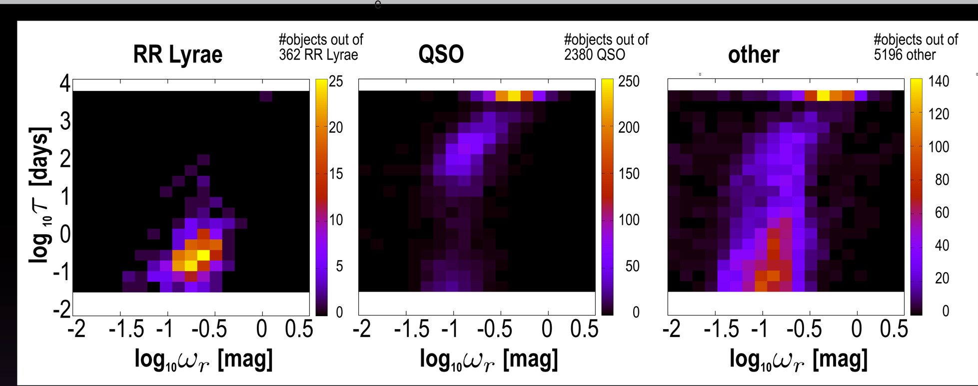


Fig. 4: density map: approximation of structure function parameter on a grid

For reasons of computation time, we tested how well approximation on a grid compares to MCMC. For a classifier, using a grid is a useful approximation, as compare Fig. 4 to Fig. 3.
In Fig. 4, the best fit structure function parameter $(\omega_r, \tau)_{\rm grid}$ for 2380 QSO, 362 RR Lyrae and 5196 other, respectively, are estimated on a logarithmic grid.
The color scale indicates the number of objects whose best-fit structure function parameter are falling in the respective grid point.

Preliminary Results

completeness/purity RR Lyrae, QSOs using the **Random Forest Classifier** (implemented in Python's scikit_learn package)

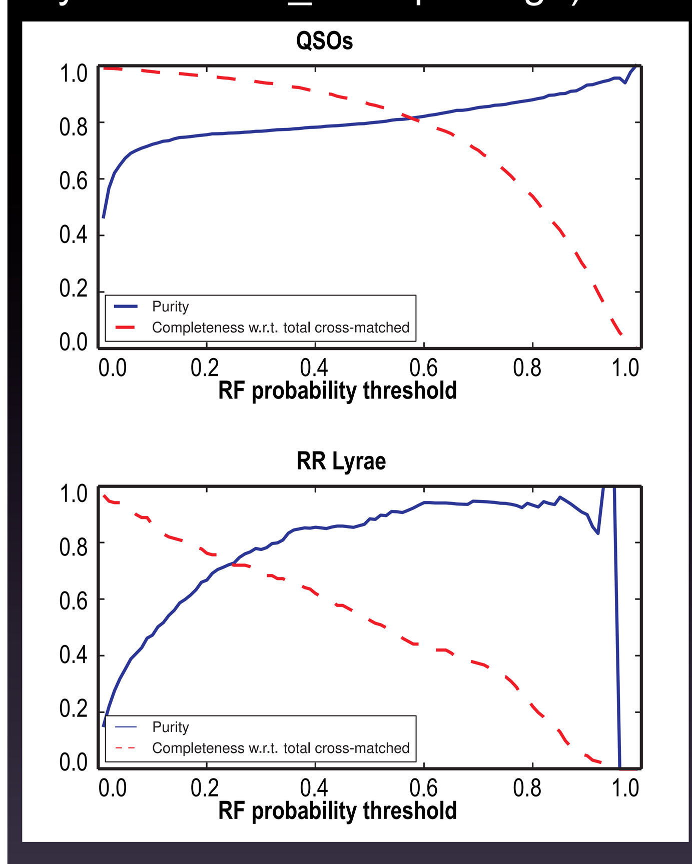
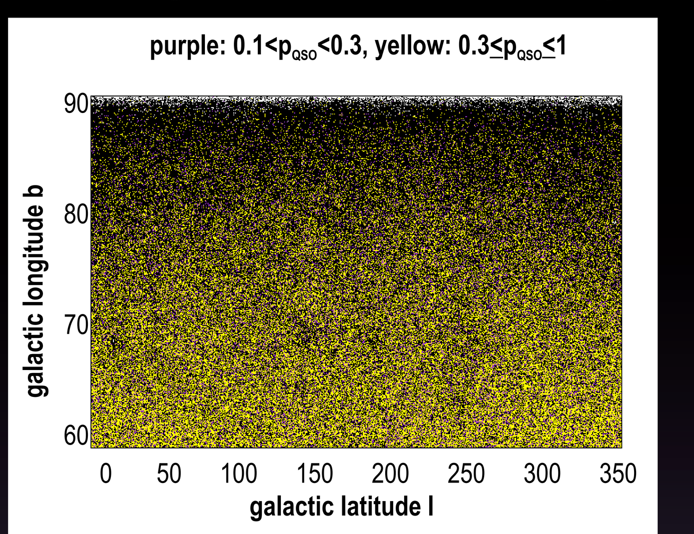
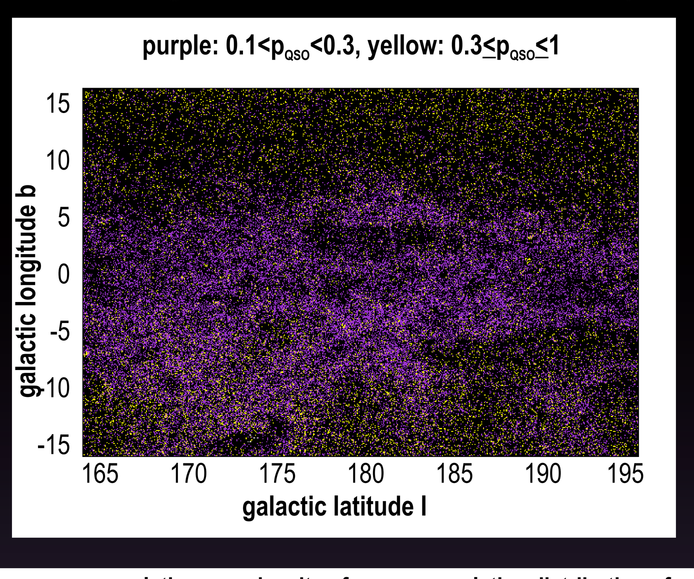


Fig. 6: trade-off between purity and completeness depending on the chosen RFC probability cut-off value

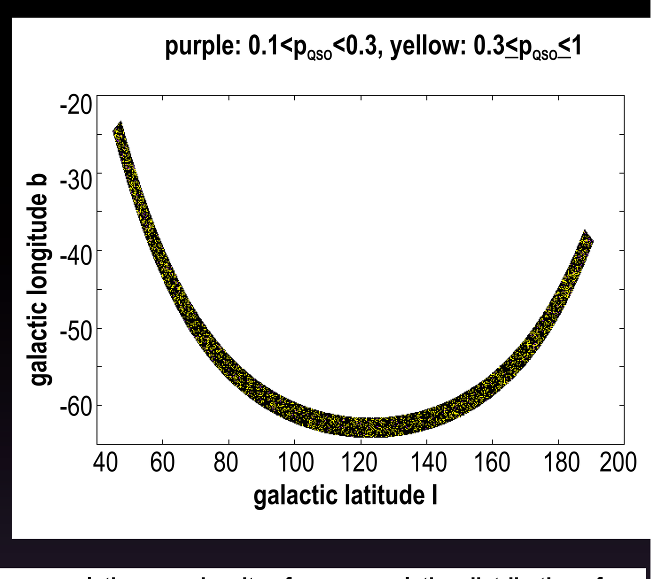
0<l<360, 60<b<90
around Galactic north pole
2763 deg², 5,098,975 classified objects

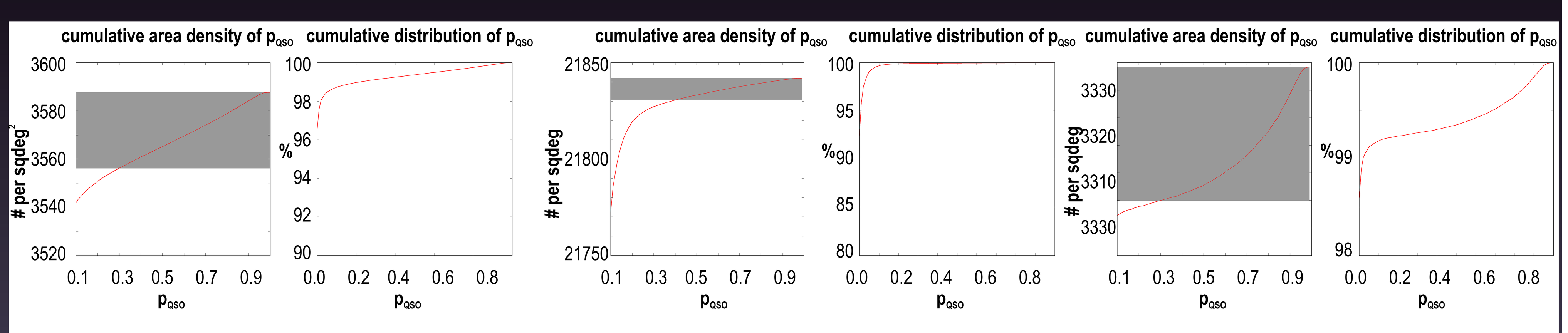


165<l<195, -15<b<15
around Galactic anticentre
890 deg², 14,476,355 classified objects



S82, 270 deg²
1,664,181 objects,
classified half of them





comparing the cumulative source density, expect:
- contaminants increase for higher source density ⇒ increase of # low p_{QSO}
- ~ const. area density for true QSOs ⇒ const. area density for objects with high p_{QSO}

Conclusion

developed multi-band lightcurve structure function model

identification of QSO and RR Lyrae candidates based on multi-color photometry and PS1 variability works well:

- QSO: in S82, 85% purity, 85% completeness for p_{QSO}>0.5
- RR Lyrae: including period fitting (Branimir Sesar), we get feasible lists of candidates: right period in 85% of S82 RR Lyrae