Variability Selection in PS1 3π

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PS1 3π variability studies in the MW context

searching for

i) RR Lyrae

- precision distances: streams & satellites

ii) QSO (candidates)

- as reference frame for MW astrometry
  $\Rightarrow$ absolute proper motions, study MW disk kinematics
- QSO catalog in general

PS1 3π interesting because of its size

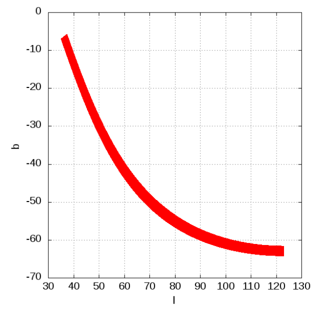
but: selecting QSOs is difficult in PS1 3π:

- SDSS: used *u-g* colors, e.g. [Bovy+2011]
  $\lightning$ PS1: no *u* band
- SDSS: also used one-band variability in S82 (300 deg^2), e.g. [Schmidt+2010]
  $\lightning$ only few 3π epochs in any one band

$\Rightarrow$ solution: model non-simultaneous multi-band variability

SDSS Sripe 82 as Testbed

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



SDSS S82: $\sim$ 60 epochs simultaneous *ugriz* photometry and has complete QSO and RR Lyrae classification

PS1 3π: $\sim$ 40 epochs non-simultaneous *grizy* photometry

$\Rightarrow$ use S82 classification in overlapping area to verify PS1 classification

Selecting Variable Objects - Approach

how to find variable objects

0) eliminate "poor" photometry

$\Downarrow$

1) identify "variable" objects via χ^2

2) multi-band variability model $\mathscr{L}(\mathbf{fitparameters}|\vec{g}\vec{r}\vec{i}\vec{z}\vec{y})$

3) follow-up classification

pre-selection by variability χ^2

As a measure for variability, we use

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

where

χ^2_{const}: presume $\bar{m}_\lambda \neq f(t)$

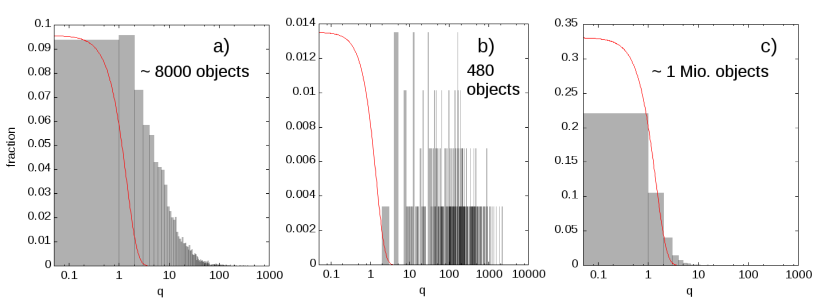
$N_{d.o.f}$ = $N - n$

n: used bands, N: number of data points in all used bands

expected:

peak at low q containing non-varying sources, tail made up by varying sources

χ^2 statistics for PS1 objects having type known from SDSS S82 (cross-matched within 1 arcsec):



a) QSOs, b) RR Lyrae, c) all other;
Gaussian distribution centered at 0, width $\sigma = 1$ overplotted

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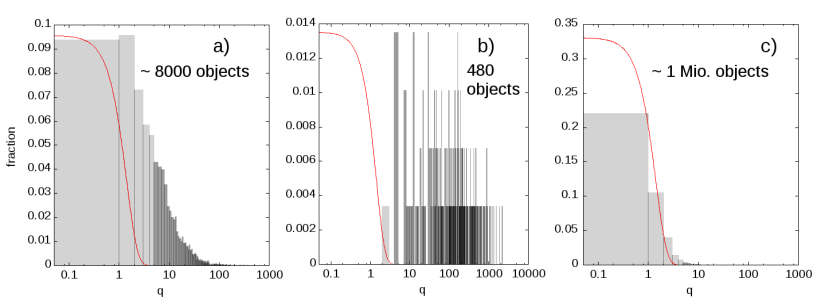


a) QSOs, b) RR Lyrae, c) all other;
Gaussian distribution centered at 0, width $\sigma = 1$ overplotted

to reduce contamination: pre-select objects by $q >$5 overall, $q >$30 in stellar locus pre-select objects by $q >$5 overall, $q >$30 in stellar locus to reduce contamination

objects of known type surviving cut:

QSOs: 30 %
RR Lyrae: 75.2 %
other: 7.9 %

reduces QSO contamination by $\times$ 400

structure-function based variability model $\mathscr{L}(\mathbf{a_r}, \gamma | grizy)$:

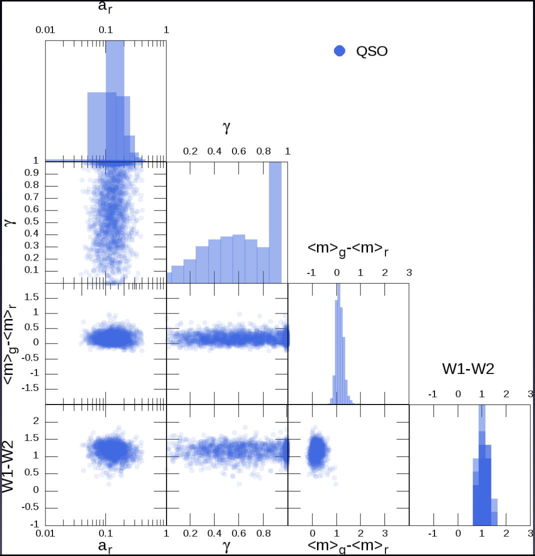
by how much has the source varied if I wait Δt?

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

$$V(\Delta t) \equiv \frac{1}{2} \left\langle \left(\tilde{m}_{\lambda_i}(t) - \tilde{m}_{\lambda_j}(t + \Delta t) \right)^2 \right\rangle$$
$$\stackrel{\text{model}}{\equiv} \frac{1}{2} a_i(\lambda_i) a_j(\lambda_j) \left(\frac{|\Delta t|}{1 \text{ yr}} \right)^\gamma$$

$\Rightarrow$ fit for "1-year amplitude" a_r & power-law index γ

pre-selected objects with $q > 5$ overall, $q > 30$ in stellar locus



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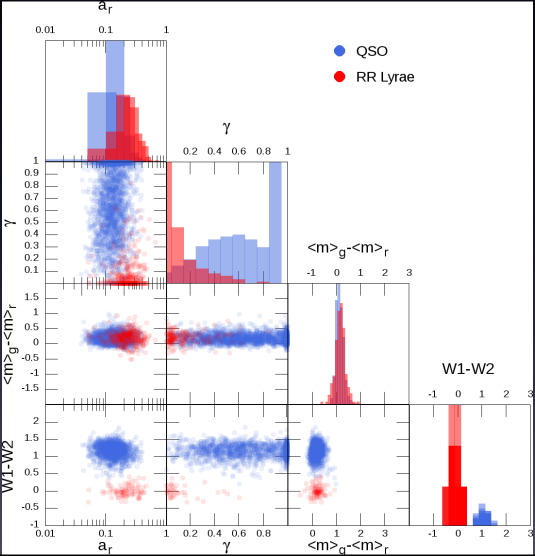

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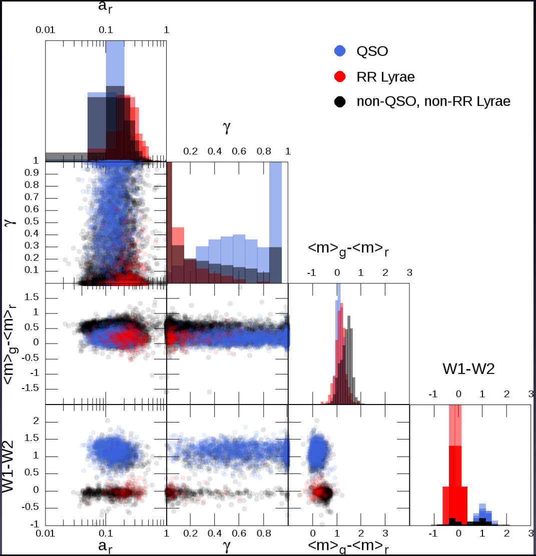
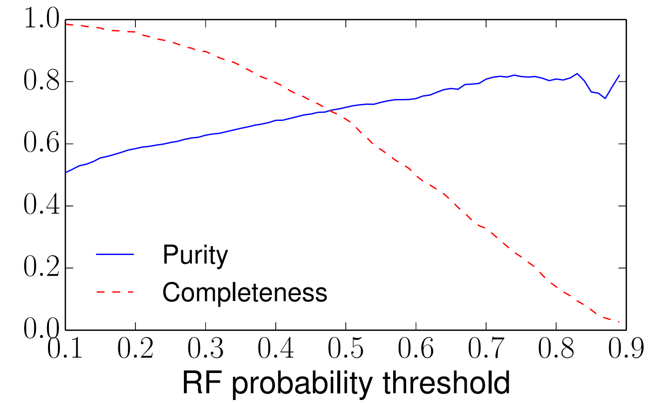


these regions in parameter space enable us to find RR Lyrae and QSO *candidates* using a classifier

e.g.

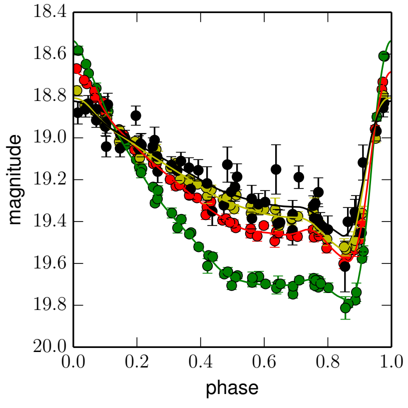
- kernel density estimator (or extreme deconvolution) + importance sampling
- Random Forest Classifier (used by Sesar et al.)

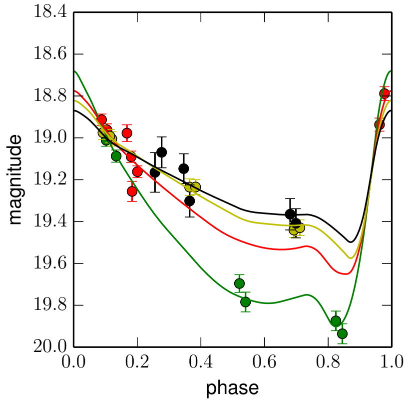
using the **Random Forrest classifier** (implemented in Python's scikit_learn package) on structure function parameters (a_r, γ, α) from MCMC, dereddened *g-r*, *r-i*, *i-z*, *z-y*



QSOs: trade-off between purity and completeness depending on the chosen RF probability cut-off value (Branimir Sesar)

RR Lyrae: periods between half a day and one day
⇒ use this fact RR Lyrae selection





left: SDSS S82, right: PS1 (Branimir Sesar)

looking for QSO for e.g. QSO catalog, astrometry
by-product: RR Lyrae candidates

- photometry (+ flags) now reliable
- developed multi-band lightcurve structure function model: PS1 $3\pi \rightarrow 40$ epochs
- identification of QSO and RR Lyrae candidates works well
- detailed classification underway