

Evaluating the Pan-STARRS Variability Parameter

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By Thursday (4/18) we need: well thought out section titles and plots that show all the points we wanna make

remake prob(f) plot with all 300,000 stars (not only 80,000)

FLS analysis on ATLAS Pathfinder Telescope data, verified PS variability criteria

1. INTRODUCTION

Hello DH¹

- why we care
- what made us care about this project
- NO structure / distance stuff (maybe put it in looking forward section at end)
- talk about PS catalog
- variability surveys (discuss other attempts to measure variables across the sky)
- why are variables interesting
- why do we want to find variables and care about where they are located
- Summary: we ran FLS, analyzed stars, why did we do it all
- Mention what will be discussed: “in section 2 we describe the observations we used...”

2. ATLAS PATHFINDER 1 OBSERVATIONS

- we used data from ATLAS
- supplemented with ATLAS data [REF TONRY] (possibly make this a subsection)
- what was the weather like during observations
- PSF FWHM variations (only include if we discuss crowding)
- ‘we recieved the reduced image data from the ATLAS pipeline; which gave us RA, Dec, mag, etc...’
- http://fallingstar.com/how_atlas_works.php

[VERIFY CORRECT CITATIONS:

Initially, determination of variability was going to be achieved using data collected by the *griProject*². The *griProject* is [EXPLAIN]...

In order to reduce aliasing, extra observations needed to be made. Observation procedures are discussed in § 2.2.1. [PATHFINDER USED FOR GRI DATA...the reduction process is discussed at length Tonry in...cite]

We received the reduced image data from the ATLAS pipeline³⁴

2.1. Data Collection

[NEED TO CITE TONRY FOR OUR OBSERVATIONS]

[MENTION THAT OUR OBS NECESSARY TO REDUCE ALIASING]

Using the Pathfinder telescope, observations were made at two galactic latitudes ($b^{II} = \pm 5^\circ$) and spanned a range of galactic longitudes ($202^\circ < l^{II} < 232^\circ$). Observations discussed here indicated the center of each FOV. Exposures were collected for 20 s and separated by 3° longitudinally. For implementation by the Pathfinder telescope, a conversion to RA and Dec was made; giving a range of $93 < RA < 119^\circ$ and $-20^\circ < Dec < 13^\circ$, as shown by Figure 4. To account for the 0.05° gap between the detectors, a 0.1° offset in RA was implemented on every other night. Spanning 20 nights, 10 observations a night were collected on 3/8/16-3/27/16. Luckily, all of these nights had weather perfectly attuned for observations. Half a night of observations were lost on 3/19/26, due to a crash of the server controlling the telescope.

Observations were traced out by moving the FOV by 3° longitudinally, starting at $b^{II} = -5^\circ$, $l^{II} = 202^\circ$ and ending at $b^{II} = -5^\circ$, $l^{II} = 232^\circ$. Once observations at $b^{II} = -5^\circ$ were complete, the FOV was shifted to $b^{II} = +5^\circ$, $l^{II} = 232^\circ$.

2.2. Object Cuts

Threw away stars with magnitude error of 0.
 After isolating ‘good’ observations we threw away any stars with less than 12 observations: could have fallen on the edge of each 1 deg^2 FOV, fallen on portion of detector with bad PSF, etc
 needed 12 observations to reduce / eliminate aliasing
 of all 1.5 billion stars in our FOV we scanned the most variable ($\log Pr(rnd) \leq 45$)
 - located: `cd/home/rrlyrae/logprob_low_deg45take2`
 - 1558 stars
 new grouping list that DH wanted (after removing aliased regions)
 - located: `cd/home/rrlyrae/alias_mgrps`
 - 776 stars

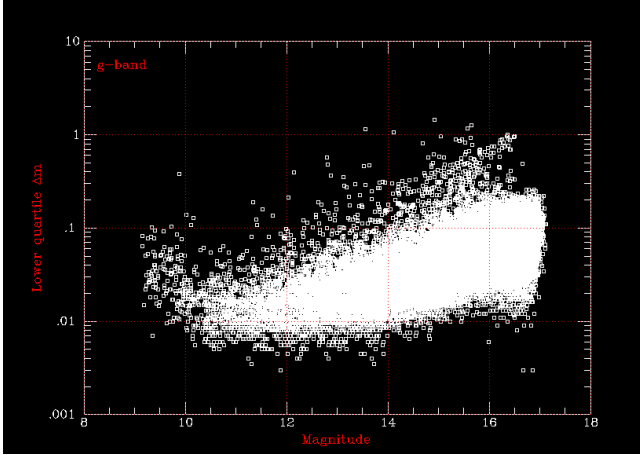


FIG. 1: Lower quartile variance as a function of magnitude.

In order to exploit the lower quartile variance, shown in Figure ??, a factor of $0.2m$ was added to account for Poisson error. The higher a star deviates from the average value, the more likely it is variable.

3. CONSTRUCTING STELLAR LIGHT CURVES

- how we selected stars (12+ obs, $1 \times 1 \text{ deg}^2$, etc)

The selection process began

4. EVALUATING THE HPS VARIABILITY PARAMETER

- put a table with 5 stars, to show off part of catalog

A paper, *Finding, Characterizing and Classifying Variable Sources in Multi-Epoch Sky Surveys: QSOs and RR Lyrae in PS1 3π Data*⁵ (HPS), quantifies the likelihood that a star is an RR Lyrae. Using their variability statistic, $\rho_{RRLyrae}$, density and distribution of RR Lyrae and other variable candidates were determined. Table I evaluates the validity of HPS’s variability criteria.

Figure 3 shows no correlation between the HPS criteria and candidates verified to be RR Lyrae stars. Of the 1.5 Billion stars identified in our FOV, we isolated the 320,000 most variable, as described in § 2.2.2.

[DESCRIBE $\log Pr(rnd)$...how some vars might have slipped past, but only]
 [CITE WHERE IT SAYS RRLYRAE HAVE 0.5 ; PERIOD ; 1.2 [DAYS]]

A grouping and matching algorithm, written by J. Tonry², made it possible to isolate and group stars from various nights of observations. Implementation of $\log Pr(rnd)$ allowed for complete confirmation of RR Lyrae candidates. Only stars with different variable classifications, those having lower amplitude variations, would have been able to go undetected. Masking out regions of high aliasing reduced the need to run a more rigorous analysis, due to the statistically improbability of these sources being variable. A total of 5,658 stars fell within the masked region, shown in Figure ??. FLS and FSS analysis identified 1,239 variable stars in our FOV. A defining characteristic of RR Lyrae is their variability periods, falling between 0.5 and 1.2 days. Using this restriction 279 stars were confirmed to be RR Lyrae. Variability classification was confirmed by visually inspecting the light curves of all 279 RR Lyrae and the remaining 960 unclassified variable stars. Following this procedure gives us 100% purity.

Using the same matching algorithm² made comparing observations with other variable catalogs possible. To evaluate the HPS RR Lyrae criteria, our observations were matched to stars flagged as potential RR Lyrae candidates by HPS. Shown in Table I and Figure 3, there is no correlation between HPS criteria and verified RR Lyrae stars.

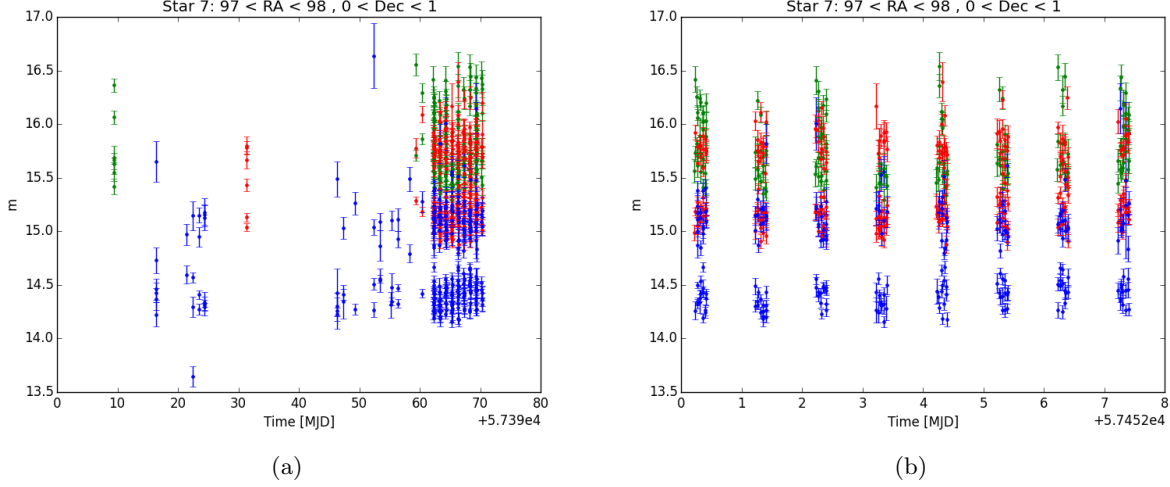


FIG. 2: *Light Curve of a variable star. Panel ‘(a)’ shows a light curve constructed using all collected and ATLAS data. Panel ‘(b)’ is a restricted selection of ‘(a)’, not showing any observations made by ATLAS.*

| HPS $\rho_{RRLyrae}$ | HPS_{total} | $HPS_{matched}$ | RR Lyrae | Not RR Lyrae | Prob(RR) |
|----------------------|---------------|-----------------|----------|--------------|----------|
| 0.0-0.05 | 5029 | 138 | 46 | 92 | 0.33 |
| 0.05-0.1 | 124 | 25 | 12 | 13 | 0.48 |
| 0.1-0.2 | 154 | 38 | 19 | 19 | 0.50 |
| 0.2-0.3 | 116 | 36 | 15 | 21 | 0.42 |
| 0.3-0.4 | 82 | 36 | 22 | 14 | 0.61 |
| 0.4-0.5 | 85 | 34 | 20 | 14 | 0.59 |
| 0.5-0.6 | 90 | 41 | 22 | 19 | 0.54 |
| 0.6-0.7 | 89 | 47 | 28 | 19 | 0.60 |
| 0.7-0.8 | 64 | 39 | 28 | 11 | 0.72 |
| 0.8-0.9 | 46 | 28 | 23 | 5 | 0.82 |
| 0.9-1.0 | 21 | 15 | 9 | 6 | 0.60 |
| 0.0-1.0 | 5900 | 477 | 244 | 233 | 0.51 |

TABLE I: A comparison of verified observations and HPS RR Lyrae candidates.

4.1. Simbad Completeness

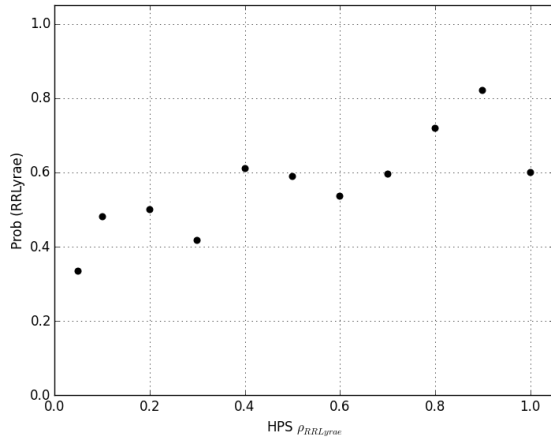


FIG. 3: *Evaluation of HPS RR Lyrae criteria.*

[FIX SIMBAD CITATION]

In order to evaluate the completeness of our results, comparisons needed to be made to other variable star catalogs. Simbad⁶ provided a list of variable stars within our FOV. Pulsating sources encompasses all variable objects. With 48 objects overlapping our FOV, shown in Figure 4, we achieved a completeness of 98%.

[possible put two light curves in as examples of objects that overlap our field]

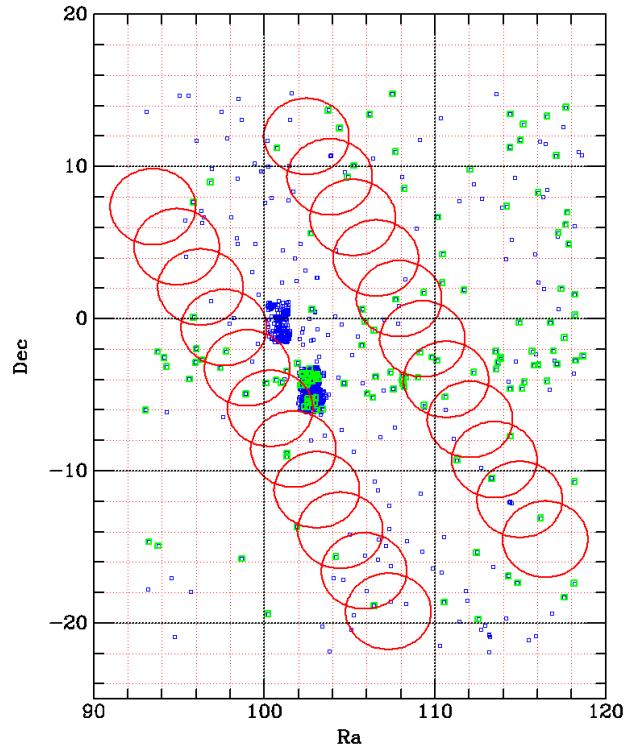


FIG. 4: Observation path shown in red, with Simbad pulsators in blue and RR Lyrae in green.

5. DISCUSSION

- Evaluation of PS criteria
- what went wrong
- what could have gone better
- future outlook
- we could map spiral arms using x y and z

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² J. L. Tonry, personal communication (2016).

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⁴ J. L. Tonry, C. W. Stubbs, K. R. Lykke, P. Dhertty, I. S. Shivvers, W. S. Burgett, K. C. Chambers, K. W. Hodapp, N. Kaiser, R.-P. Kudritzki, et al., *The Astrophysical Journal* **750**, 99 (2012), URL <http://stacks.iop.org/0004-637X/750/i=2/a=99>.

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