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)

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

1. INTRODUCTION

- 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 LS, 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 s 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*[1]. The *griProject* is [EXPLAIN]... In order to reduce aliasing, extra observations needed to be made. Observation procedures are discussed in § 2 2.2. [PATHFINDER USED FOR GRI DATA...the reduction process is discussed at length Tonry in...cite]
We received the reduced image data from the ATLAS pipeline[2 3]

2.1. SNR Calculation

To calculate an appropriate sampling frequency and SNR, typical RR Lyrae star light curves from[4] with artificially introduced gaps following the Gaussian distribution. Since sampling in astronomy is always uneven, we used the Lomb-Scargle analysis (Lomb 1976 & Scargle 1982). The light curve of 210282474 is shown in Figure **??**, and Lomb-Scargle power plots with various sampling conditions are shown in Figures **??**, **??**, and **??**. We want a distinguishable and narrow peak in power plots. To determine distances from the PL relations with $\simeq 5\%$ accuracy, we need peaks with FWHM $\simeq 0.02$ days. From this condition, it looks like 15 nights with 10 observations/night is the lower limit sampling rate. The uncertainty in magnitude was taken to be 10%, and the changes, $1\% - 10\%$, in the uncertainty did not affect the period determinations significantly; we only need 10% photometry.

2.2. Data

Is it $b^{II} = +5°$ or $b = +5°$??
[NEED TO DEFINE FOV]
[VERIFY RA DEC RANGE (NOT WHAT WAS PUT INTO SIMBAD)]
[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 ($b^{II} = \pm 5°$) and spanned a range of galactic longitudes ($202° < l^{II} <$

232°). 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 $93 < RA < 119°$ and $-20° < Dec < 13°$, as shown by Figure 9. 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.

[dRA = dangle / cos(Dec)]
[EXPLAINS EXACT OBSERVATIONAL PLAN...NECESSARY?]
Observations were traced out by moving the FOV by 3° longitudinally, starting at $b^{II} = -5°$, $l^{II} = 202°$ and ending at $b^{II} = -5°$, $l^{II} = 232°$. Once observations at $b^{II} = -5°$ were complete, the FOV was shifted to $b^{II} = +5°$, $l^{II} = 232°$.

3. CONSTRUCTING STELLAR LIGHT CURVES

- how we selected stars (12+ obs, 1x1 deg^2, etc)

The selection process began

4. FAST LOMB-SCARGLE PERIODOGRAM

[INTRO TO WHAT IS PERIODOGRAM...WE CONSTRUCT PERGRAMS USING LS METHOD]

- extract variability from LS
- describe how it works and why we used LS
- major aliasing at 1 day and 0.5 day periods
- things that fall at at -50 (in Figure 2) means that those are VERY probably variable stars
- roughly _____ stars fell at -50 in Figure 2
- 315,992 stars tested for variability
- other stars (outside of 315,992) are statistically unlikely to be variable
- brief explanation of the fast LS
- period search range to avoid aliasing
- compute gri periods individually and compare each other. if period differences are less than 0.04 days, next step

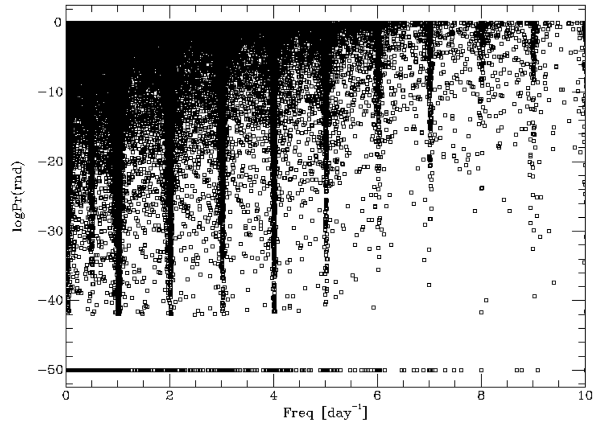


FIG. 2: *prob(f) of 80,000, most variable, stars LS was run on*

prob(f)

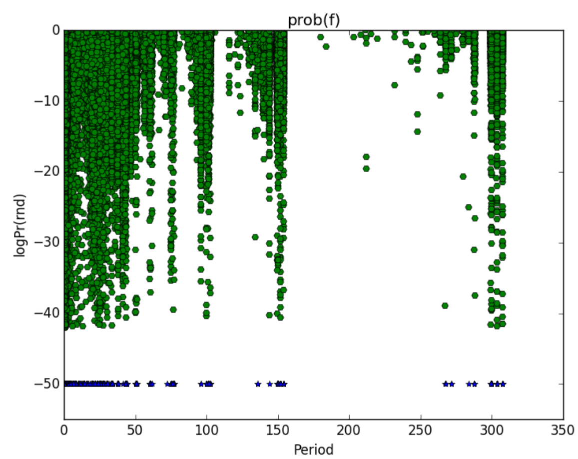
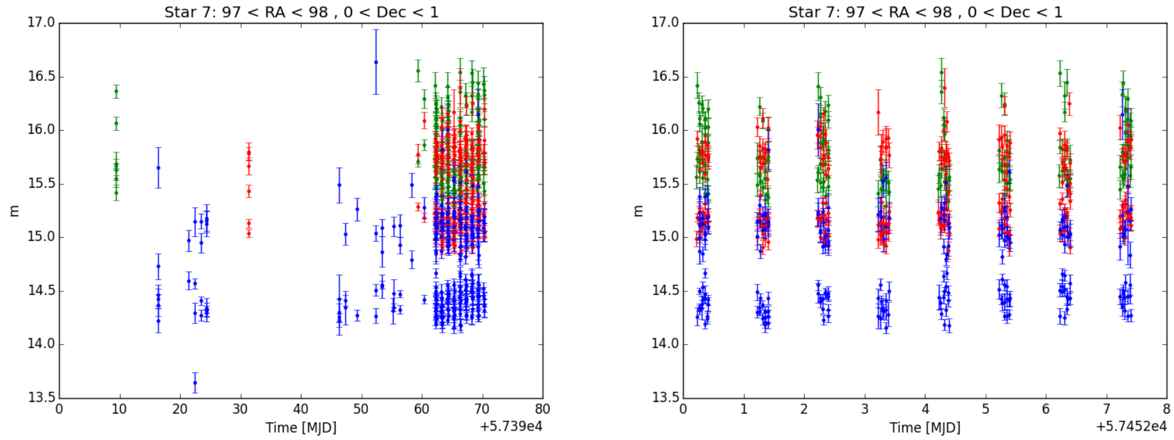


FIG. 3: *prob(f) of 80,000, most variable, stars LS was run on*

4.1. Fourier Series

- Fourier series fit to extract variable types
- compute FS and calculate χ^2/ndf. if $\chi^2/ndf < 10$, next step.
- find abs(max/min(FS)). if abs(max/min(FS)) > 0.2, then we call it's a variable stars.
- explanation of period error estimation using Fourier series.



(a) (b)

FIG. 1: *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.*

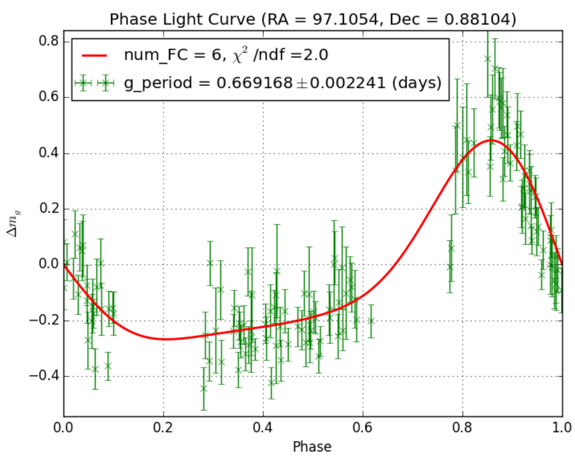


FIG. 4: *Type ab*

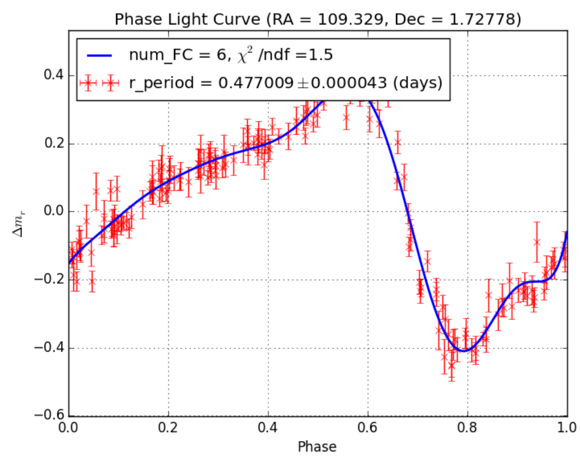


FIG. 6: *Type ?*

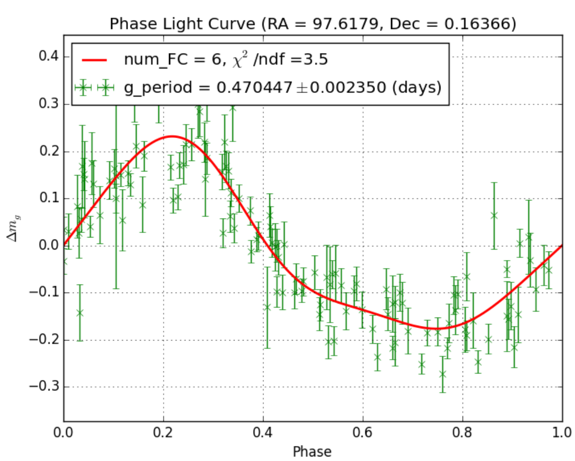


FIG. 5: *Type c*

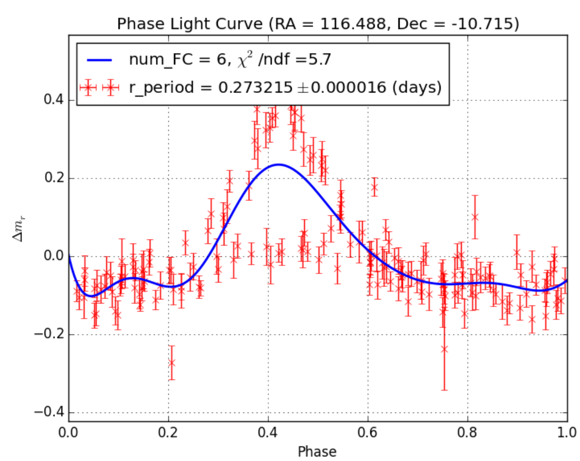


FIG. 7: *Blazhko Effect (period doubling)*

5. RESULTS

- compare with PS[5]
- density/distribution of variables in sky
- (what LS gave us for our catalog)
- put a table with 5 stars, to show off part of catalog

Figure 8 shows no correlation between the HPS criteria and verified RR Lyraes. Of the 1.5 Billion stars identified in our FOV, 320,000 were checked for variability using
[DESCRIBE LOWER QUARTILE METHOD]

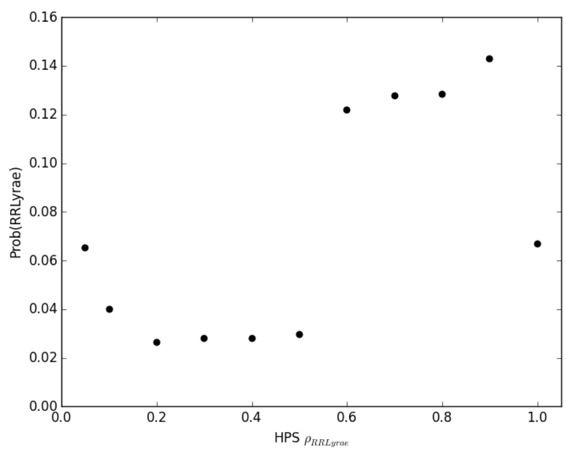


FIG. 8: *Evaluation of HPS RR Lyrae criteria.*

5.1. Simbad Completeness

- Pull established RR list from Simbad
- Pull other variable data from simbad, too
- Compare list of observed RR to catalogs
- Is anyone actually reading this outline, this bullet point serves no purpose
- Wow, its sad how little Jeff did since class began (especially after JT gave him the code to do it a month ago) - 6 obs x 4 nights = January-April work period haha
- Establish completeness with Simbad

[FIX SIMBAD CITATION]
In order to evaluate the completeness of our results, comparisons needed to be made to other variable star catalogs. Simbad[6] provided a list of variable stars within our FOV. Pulsating sources encompasses all variable objects.

[OF THESE WE MATCHED...RR LYRAE...REF FIGURE]

[review what he did, but heres a summary:]
[48 simbad objects overlay our FOV]
[33 have an entry in lsum.dat]
[Of 15 that overlap w/o lsum entry]
[14 are defective]
[at least one filter has less than 10 detections]
[=¿ it's a survey problem, not an LC problem]
[P(rand) for the 33 that do occur in lsum]
[27/33 show up as high probability variables]

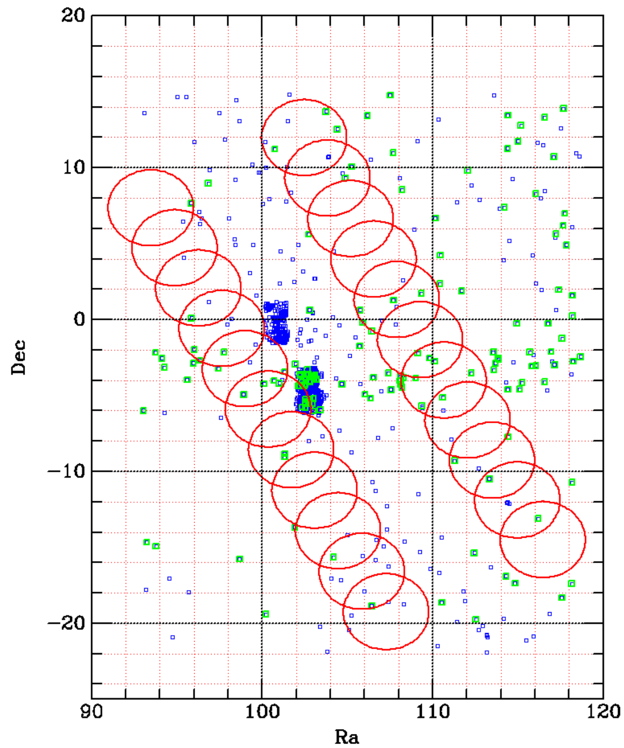


FIG. 9: *Observation path with Simbad pulsators in blue and RR Lyrae in green.*

6. 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

HPS $\rho_{RRLyrae}$	HPS_{total}	$HPS_{matched}$	RR	var (notRR)	$Not - Variable_{matched}$	$notvar_{notmatched}$(outside mask)	Prob(var)	Prob(RR
0.0-0.05	5029	138	9	37	92	4891	$46/138 = 0.33$	$9/138 = 0$
0.05-0.1	124	25	1	11	13	99	12/25	1/25
0.1-0.2	154	38	1	18	19	116	19/38	1/38
0.2-0.3	116	36	1	14	21	80	15/36	1/36
0.3-0.4	82	36	1	21	14	46	22/36	1/36
0.4-0.5	85	34	1	19	14	51	20/34	1/34
0.5-0.6	90	41	5	17	19	49	19/41	5/41
0.6-0.7	89	47	6	22	19	42	28/47	6/47
0.7-0.8	64	39	5	23	11	25	28/39	5/39
0.8-0.9	46	28	4	19	5	18	23/28	4/28
0.9-1.0	21	15	1	8	6	6	9/15	1/15
0.0-1.0	5900	477	35	209	233	5423		

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

7. SUMMARY AND CONCLUSIONS

[TALK ABOUT IT]

ACKNOWLEDGMENTS

We would like to thank John Tonry, Conor McPartland, Marielle Dela Cruz, and Jeff Kleyner.

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