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STELLAR VARIABILITY FROM THE 2MASS CALIBRATION SCANS

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ABSTRACT

data comes from 2mass-calpswdb, have over 100 million photometric measurements, totaling light curves for 113,030 point objects. we have run supersmoother period folding, ala MACHO, on every light curve. By hand verification used to check. many are found periodic, XX binaries, YY radial pulsators. These include the best sampled light curves for an RR Lyr and Cepheid variables in the NIR, and provide an important benchmark for modeling of these stars. An additional ZZ quasi-periodic variable stars are found. we have also characterized the variability properties as functions of color, finding nearly all objects have "grey" variability, where the amplitude is independent of wavelength chosen.

Subject headings: variability, surveys, NIR

1. INTRODUCTION

Arguably the two greatest advancements in optical and infrared photometric surveys within the past two decades have been 1) the advent of 1% accurate multi-wavelength photometry for contiguous portions of the sky exceeding $\Omega \sim 10^5$ deg^2, and 2) time resolved surveys spanning days to years baselines. As both the temporal and spatial domains are explored, new astrophysical phenomena are uncovered, while the previously rare events are placed in a statistical context. Naturally, the next generation survey will exploit both of these domains simultaneously, producing deep multi-wavelength surveys with both unprecedented spatial and temporal coverage. In order to prepare for these future surveys, which will contain orders of magnitude larger numbers of variable sources, we must hone our skills using existing catalogs/databases. This will precipitate the development of new techniques, and inform the targeting, cadence, and observing strategies of the many future time domain surveys.

WISE will provide huge variability data in the mid IR for regions near the orbital poles. Many papers using NIR variability to study new physics. The VVV (VISTA variables in the Vía Láctea) survey in the bulge, DR1 just release (Saito et al. 2012)

The Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) imaged the full sky in three, simultaneously obtained, near-infrared (NIR) bands. Survey operations were conducted between 1997 and 2001, using a northern and southern telescope. Photometric calibration for 2MASS was accomplished using repeated observations of 35 selected fields, which were spaced across the sky (Nikolaev et al. 2000). An additional 5 tiles were imaged around the Large and Small Magellanic Clouds during the last year of operation. Each calibration field covered an area of approximately 8′.5 (RA) $\times 1°$ (Dec). The 35 standard calibration fields were scanned ranging between 562 and 3,692 times over the 4 year period, yielding some of the best NIR light curves yet produced. The placement of these tiles is shown in Figure 1, and they contain light curves for approximately 110,000 point source objects.

These calibration data have been used for only a handful of studies to date. Plavchan et al. (2008b) characterized many of the details in analyzing this unique dataset for time domain studies. They also mined these data for periodic objects, finding 3 new M dwarf eclipsing binaries. Plavchan et al. (2008a) studied the 131 day periodic object, 2MASS J16271848–2429059, revealing a possible three-body YSO system. Sarajedini et al. (2009) utilized the images from multiple scans of calibration tile 90067 to produce a NIR color-magnitude diagram for the open cluster M67 that probed $\gtrsim$3 magnitudes deeper than the standard 2MASS point source catalog. Becker et al. (2008) discovered and characterized a 2.6 d M dwarf binary, 2MASS J01542930+0053266. This system was located in both the 2MASS calibration tile 90004, and the "Stripe 82" region of the Sloan Digital Sky Survey (SDSS; York et al. 2000) footprint, which yielded an 8-band light curve ($ugrizJHK_s$) for the binary. Using 16 of the calibration tiles that overlapped the SDSS footprint, Davenport et al. (2012) produced some of the first constraints on the properties of M dwarf flares in red optical and NIR bandpasses.

MENTION THESE TWO? (P. Plavchan 2012 submitted) an analysis of a 92 day periodic YSO. (J. Parks 2012 submitted) a detailed study of the ρ Ophiuchus star forming region tile.

In this paper we present a census of the variable stellar objects from this 4 year NIR survey. The data and period finding methodology is outlined in §2. We describe the selection and classification of binary stars and radial pulsating objects in §3. Quasi-periodic and other large amplitude variables that were recovered are discussed in §4. We examine the general variability characteristics of point sources in the 2MASS calibration scans in §5, and concluding remarks are given in §6.

2. DATA

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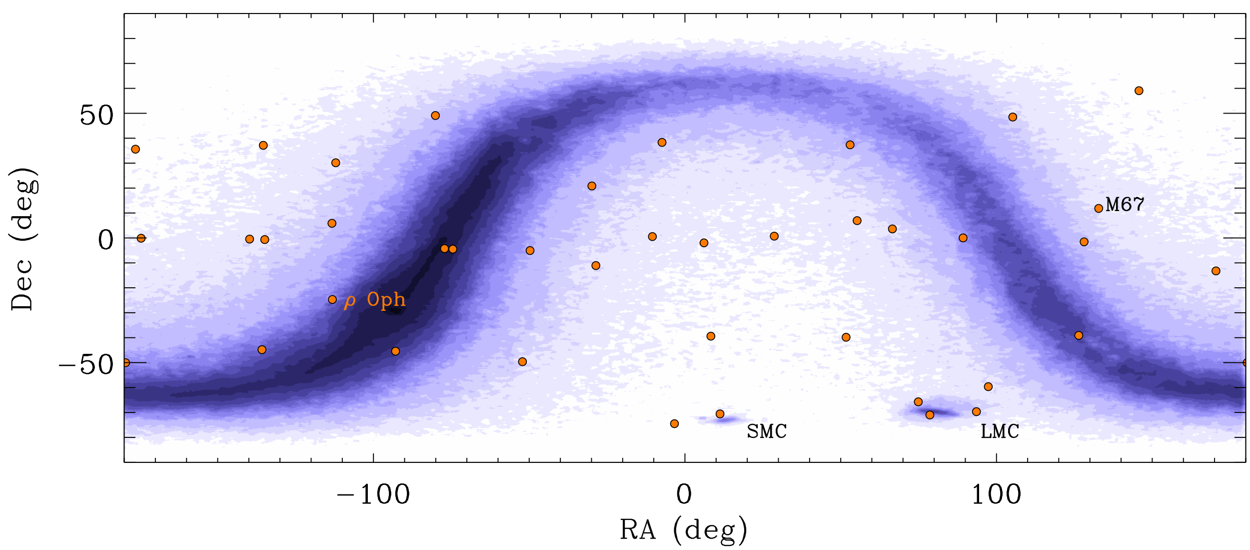

Fig. 1.— Spatial distribution of the 40 Cal-PSWDB tiles (orange circles), with titles for a few notable tiles labeled. Background contours denote increasing density from a sample of 3 million randomly drawn point sources from the 2MASS point source catalog, and trace the Galactic plane, bulge, and the Large and Small Magellanic Clouds.

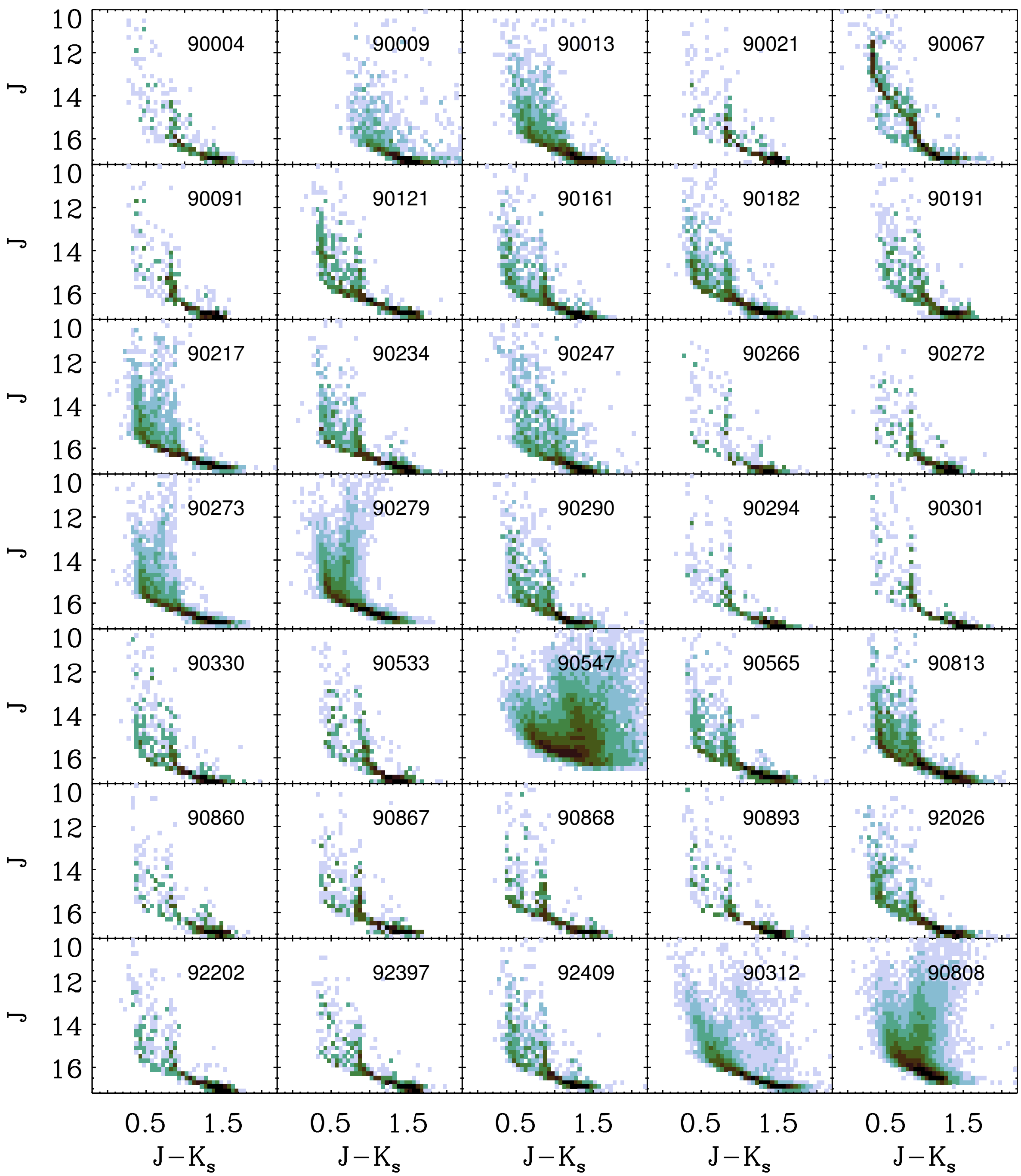

FIG. 2.— color mag diagrams for the fields

lots of testing, characterization of the Cal-PSWDB done in (Plavchan 2006; Plavchan et al. 2008b) Each night during 2MASS operations, the survey telescopes were directed at one of the calibration fields once per hour (before 1997 October 11 UT two fields were observed every 2 hours). During each visit, six consecutive scans of the field were made in alternating declination directions in ∼10 minutes of elapsed real time (a scan group). Each scan in the set of six was offset from the preceding scan by ∼5" in R.A. to avoid systematic pixel effects. The calibration fields were observed using the same freeze-frame scanning strategy used for the main survey that yielded a net 7.8 s exposure on the sky per scan. Over the course of the 2MASS survey, between 562 and 3692 independent observations were made of each of the 35 calibration fields. Table 1 presents a list of these fields and their aggregate properties.

The raw imaging data from each scan of a 2MASS calibration field were reduced using the same automated data processing system used to process the survey observation data (Cutri 2006) (Cutri et al. 2006, Section IV). The reduction process detected and extracted source positions and photometry for all objects in the images from each scan. Measurements of the standard stars in each field were used to determine the nightly photometric zero-point solutions as a function of time, and seasonal atmospheric coefficients. All source extractions from all scans were loaded into the 2MASS Calibration Point Source Working Database (Cal-PSWDB). This database contains over 191 million source extractions derived from 73,230 scans of the 35 calibration fields. Further descriptions of the Cal- PSWDB and its properties can be found in Cutri et al. (2006).

we ran the data through optics, got XX objects.

each light curve was processed with supersmsoother

objects with periods in at least 2 bands that were not obviously aliases were grabbed (about 2000 objects)

each light curve was examined by eye, about 250 were bona fide good periodic objects

3. PERIODIC VARIABLES

searched all 2000 light curves of periodic things by eye to pick out the real ones. found correct periods by hand

this is a good data set to be used for training automated light curve morphology identification routines, provides benchmark objects of many types in the NIR

Eclipsing binaries and pulsating variables can be separated and classified by fitting fourier modes to the light curves (Pojmanski 2002; Nefs et al. 2012).

To separate binaries from pulsators, we cut on:

$$b_1(\text{binary}) \geq -0.13\left(\frac{a_4}{a_2}\right) - 0.3 \tag{1}$$

and different configurations of binaries can be determined using:

$$a_4(\text{detached}) \geq \ a_2(0.5 + a_2) \tag{2}$$

$$a_4(\text{contact}) \leq a_2(0.125 + a_2) \tag{3}$$

3.1. *Binaries*

We found 100 binaries, need a histogram of their periods. We recover nearly all the binaries from Plavchan's early work (8/23 missed so far)

match to new paper by J Parks (2012)

for every binary, estimate the spectral type based on my color-locus

3.2. *Pulsators*

Infrared observations of radial pulsating stars was first performed by Wisniewski & Johnson (1968), and detailed characterization was done for Cepheid variables by McGonegal et al. (1982) and for RR Lyr variables by Longmore et al. (1985)

K-band templates first derived in Jones et al. (1996)

Sollima et al. (2008) produced JHK_s light curves for the prototypical star, RR Lyr.

4. NON-PERIODIC VARIABLES

Plavchan and student have done lots of work on this for ρ Oph field. We will only add other things that were identified by hand

5. VARIABILITY CHARACTERISTICS

plots about "color" of variability, and overall trends

6. CONCLUSIONS

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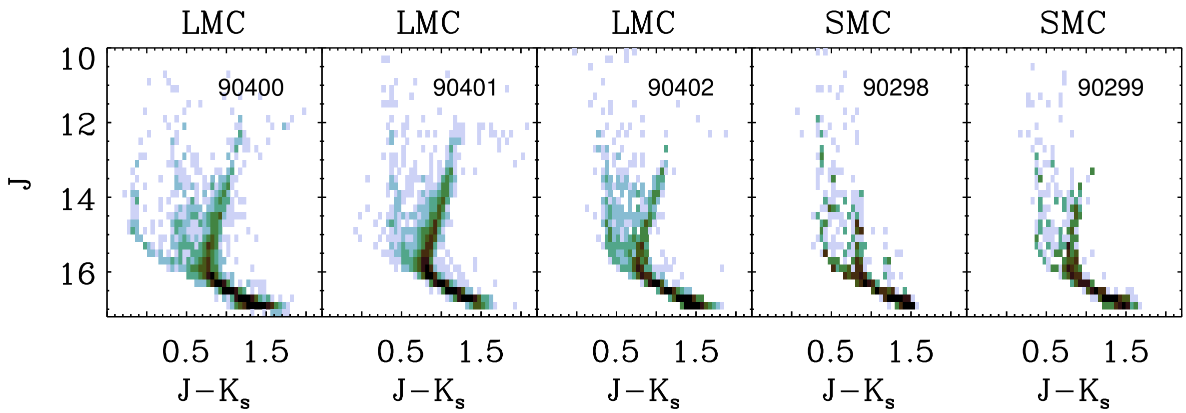

Fig. 3.— color mag diagrams for the LMC/SMC fields

TABLE 1
The catalog of binary stars, selected using Fourier modes. The full version of this catalog (146 entries) will be available online.

ObjectID (hhmmss+ddmmss)	FieldID	RA (deg)	Dec (deg)	Period (days)	$\langle J\rangle$ (mag)	$\langle H\rangle$ (mag)	$\langle K_s\rangle$ (mag)	# epochs	a_2	a_4	b_1
J015452+011053	90004	28.72067	1.18153	0.37205	13.62	12.94	12.72	2956	-0.00098	0.00166	0.01248
J015429+005327	90004	28.62207	0.89091	2.63902	15.51	14.84	14.65	2969	0.01922	-0.00187	0.01532
J162709-243408	90009	246.78799	-24.56892	4.83045	12.63	10.25	8.91	1580	0.03721	-0.00837	0.06224

TABLE 2
The catalog of radial pulsating type periodic variables, selected using Fourier modes.

ObjectID (hhmmss+ddmmss)	FieldID	RA (deg)	Dec (deg)	Period (days)	$\langle J\rangle$ (mag)	$\langle H\rangle$ (mag)	$\langle K_s\rangle$ (mag)	# epochs	a_2	a_4	b_1
J120137-494808	90217	180.40575	-49.80240	0.08777	15.22	15.03	14.95	1685	0.03441	-0.14304	0.06262
J183913+492837	90182	279.80688	49.47710	0.37473	15.96	15.68	15.43	1682	0.01161	-0.14297	0.02263
J174818-452629	90279	267.07571	-45.44157	0.41014	14.93	14.68	14.60	977	0.00012	-0.00248	-0.00028
J162725-250621	90009	246.85564	-25.10589	0.48514	15.46	14.98	14.82	1579	-0.00560	0.02069	0.00883
J220009+211502	92409	330.04028	21.25065	0.51424	14.60	14.35	14.29	41	-0.00234	-0.02196	0.00994
J190144-042605	90808	285.43744	-4.43475	0.52396	15.61	15.14	14.97	1879	-0.00112	-0.02633	0.00154
J174835-452347	90279	267.14786	-45.39640	0.54504	15.63	15.35	15.22	972	0.02224	-0.16258	0.03681
J015450+001501	90004	28.70900	0.25038	0.63698	14.27	14.01	13.98	2972	0.02093	-0.11219	0.05638
J085107+115302	90067	132.78021	11.88394	0.67940	11.19	10.80	10.69	3692	0.03375	-0.15717	0.04523
J082535-392008	90312	126.39848	-39.33574	3.07471	12.57	11.66	11.28	3501	0.00012	-0.06949	0.04578
J174811-455323	90279	267.04904	-45.88993	6.45956	14.02	13.40	13.27	968	0.03683	-0.14425	0.06046

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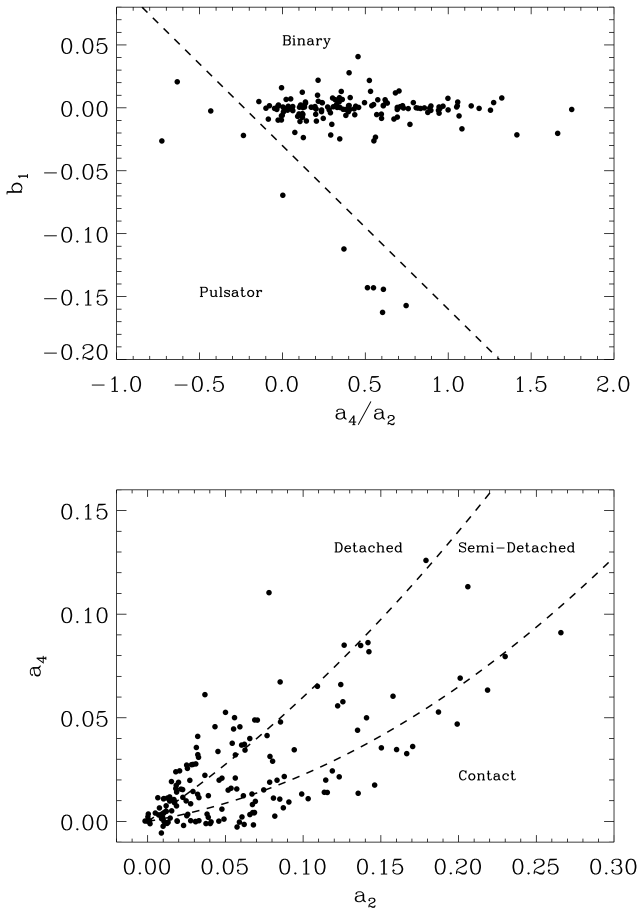

FIG. 4.— Fourier modes used to select between eclipsing binaries and pulsators (top) and different classes of eclipsing binaries (bottom).

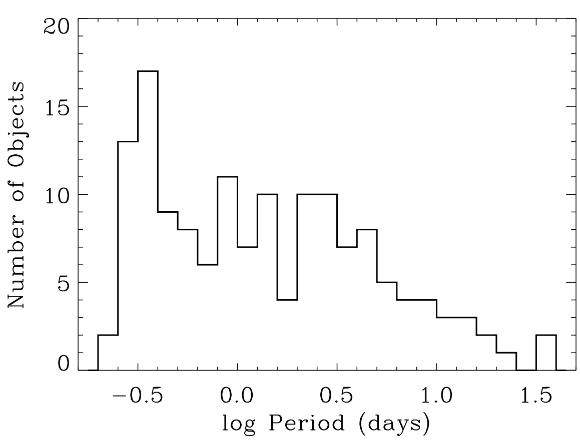

FIG. 5.— Histogram of objects selected as binaries.

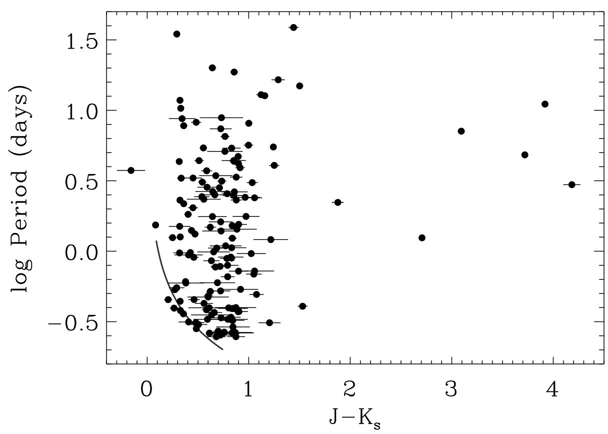

FIG. 6.— Period versus median colors for objects selected as binaries. The photometry was not corrected for reddening. The power law short period contact binary limit from Deb & Singh (2011) is shown for comparison (solid grey line).

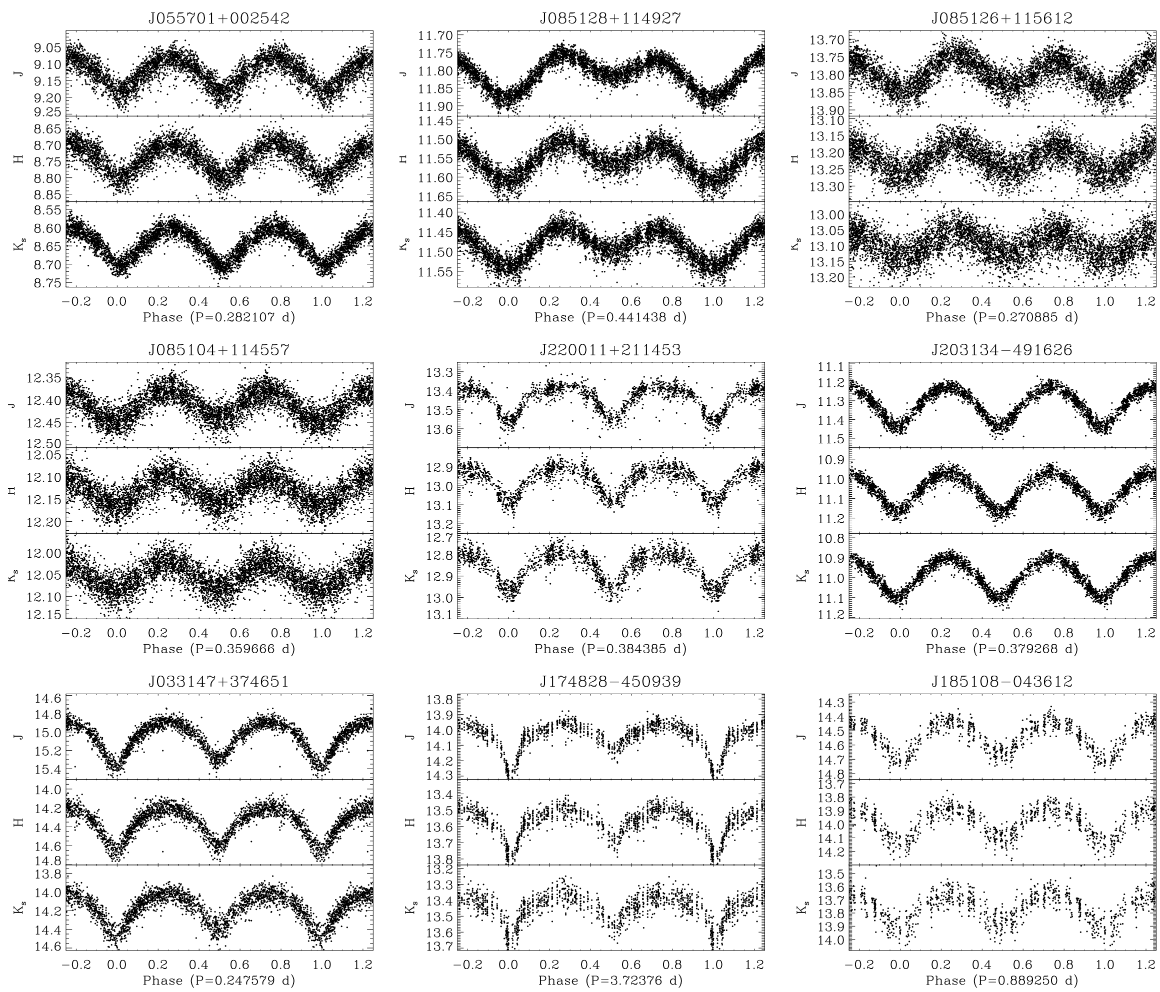

FIG. 7.— detached binaries

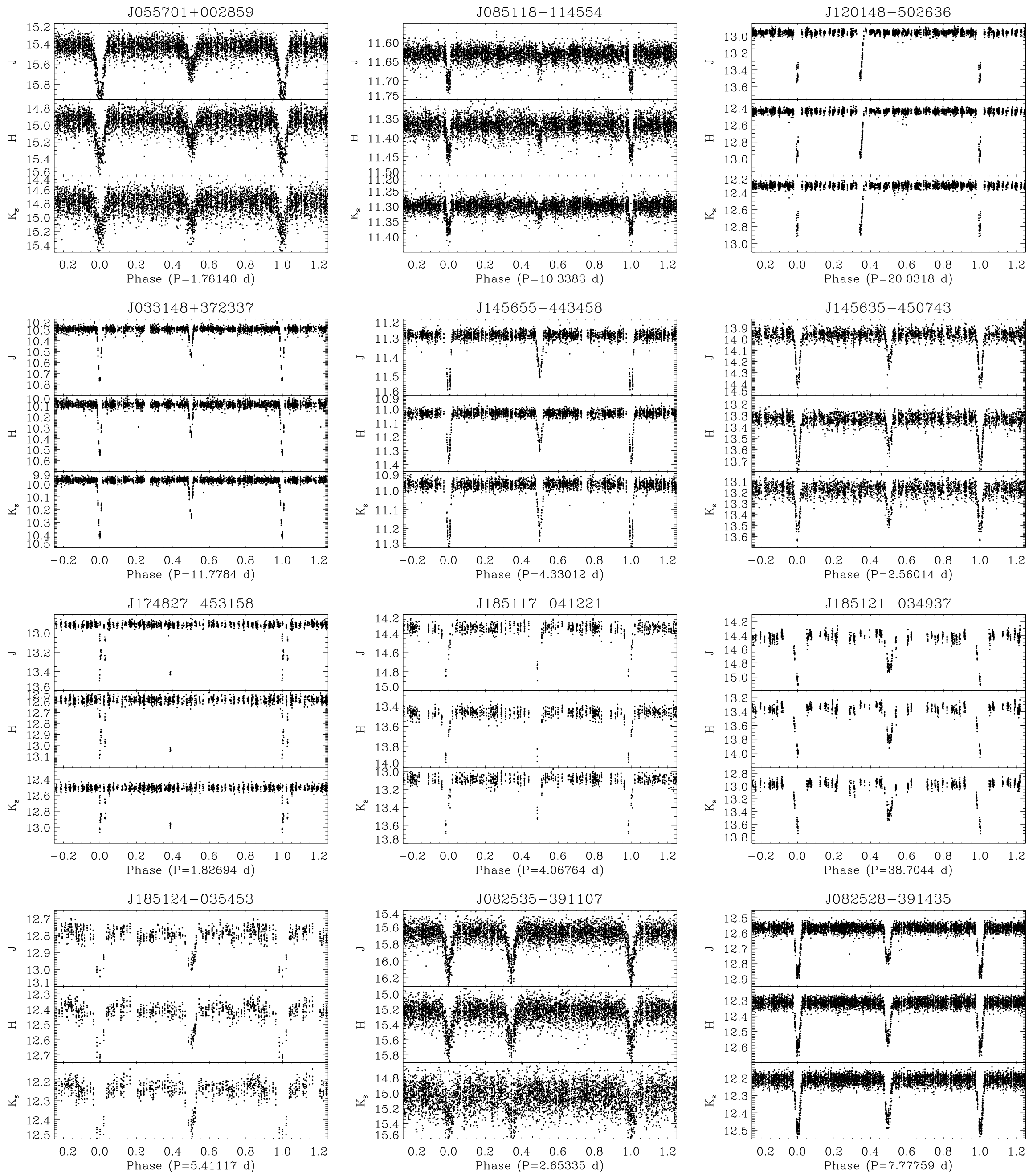

FIG. 8.— detached binaries

TABLE 3
THE CATALOG OF QUASI-PERIODIC VARIABLES. (THIS TEX FILE NEEDS TO BE REVISED TO ONLY INCLUDE THE ACTUALLY INTERESTING OBJECTS, MOST ARE ALREADY SHOWN)

ObjectID (hhmmss+ddmmss)	FieldID	RA (deg)	Dec (deg)	$\langle J \rangle$ (mag)	$\langle H \rangle$ (mag)	$\langle K_s \rangle$ (mag)	# epochs	σ_J (mag)	σ_H (mag)	σ_K (mag)
J162659-243556	90009	246.74608	-24.59911	16.40	13.45	11.86	1543	0.01401	0.00569	0.00182
J162722-244807	90009	246.84578	-24.80195	10.92	9.83	9.34	1581	-0.00000	-0.00000	0.00046
J162718-245453	90009	246.82655	-24.91494	11.42	10.54	9.95	1567	0.07128	0.04564	0.02912

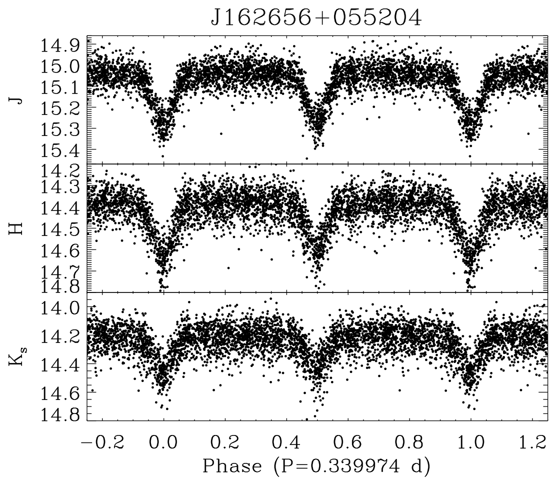

FIG. 9.— detached binaries

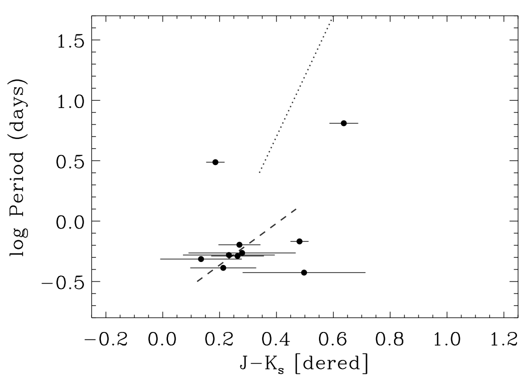

FIG. 10.— 17 radial pulsator variables. dashed line is theoretical prediction from Catelan et al. (2004) with Z=0.001 (no discernible dependence on Z) dotted line is for cepheids, from ...

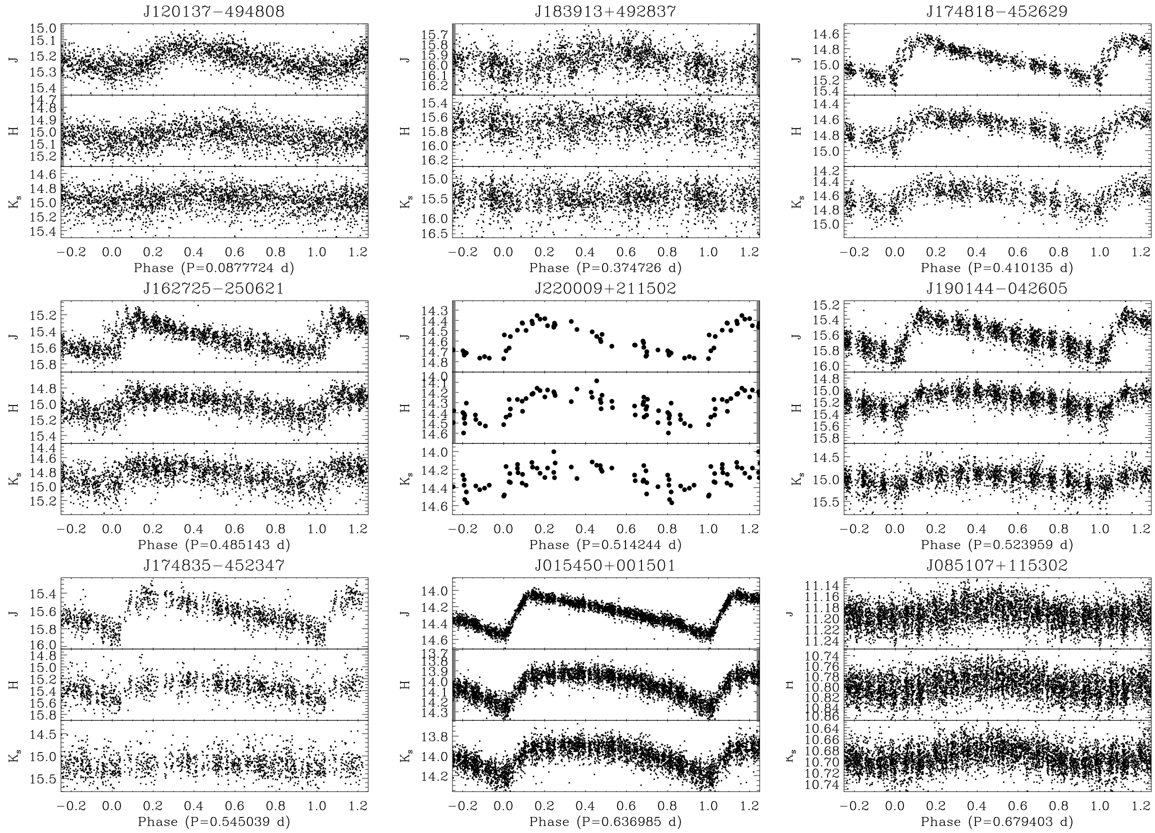

FIG. 11.— pulsators with periods less than 2 days (RR Lyr type)

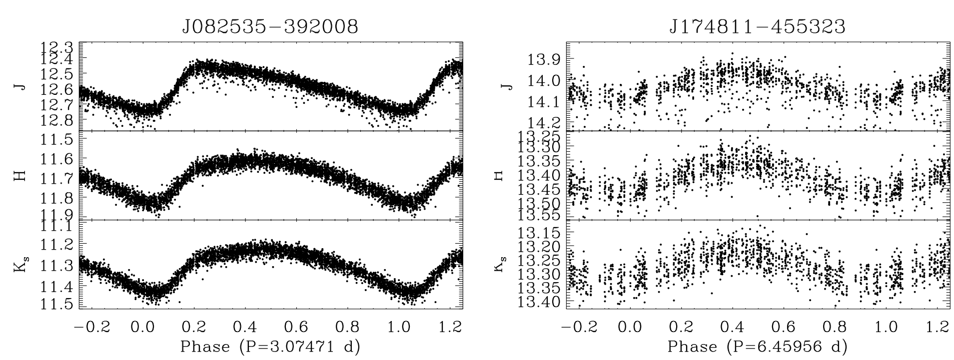

FIG. 12.— Pulsators (cepheids) with periods longer than 2 days

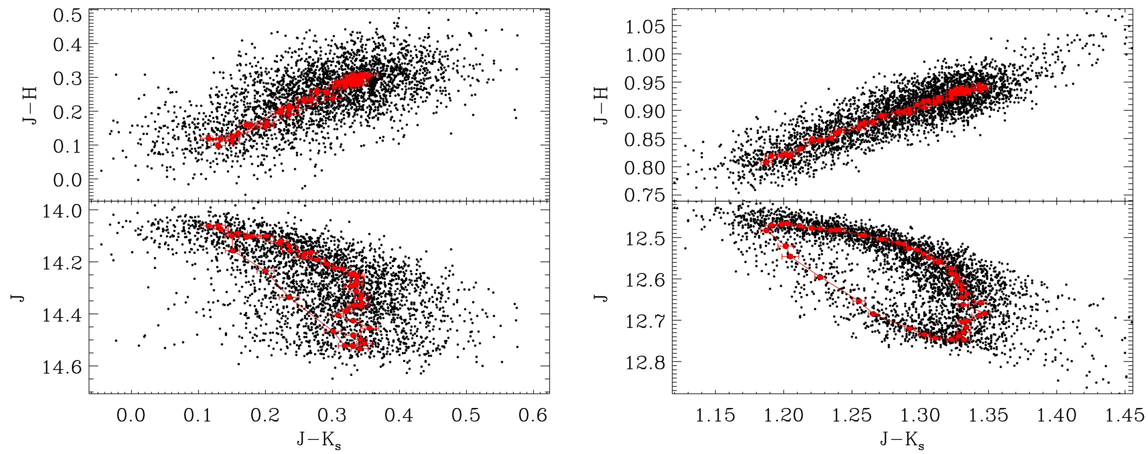

FIG. 13.— The color–magnitude evolution as a function of pulsation phase for the best sampled RR Lyr (top) and Cepheid (bottom) stars in our sample.

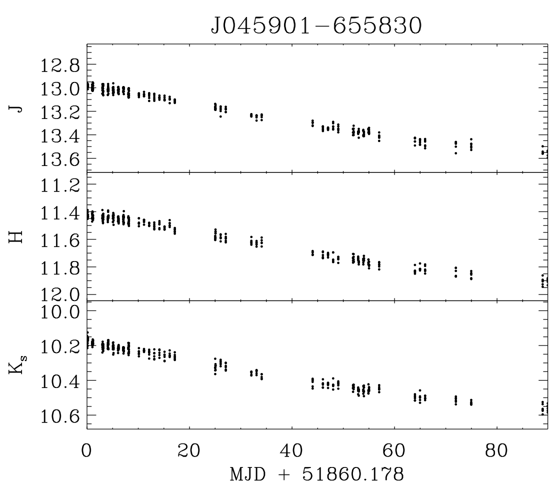

FIG. 14.— LMC, 377 epochs over 90 days, looks kinda like nova of some sort, no other known observations (that i've found)

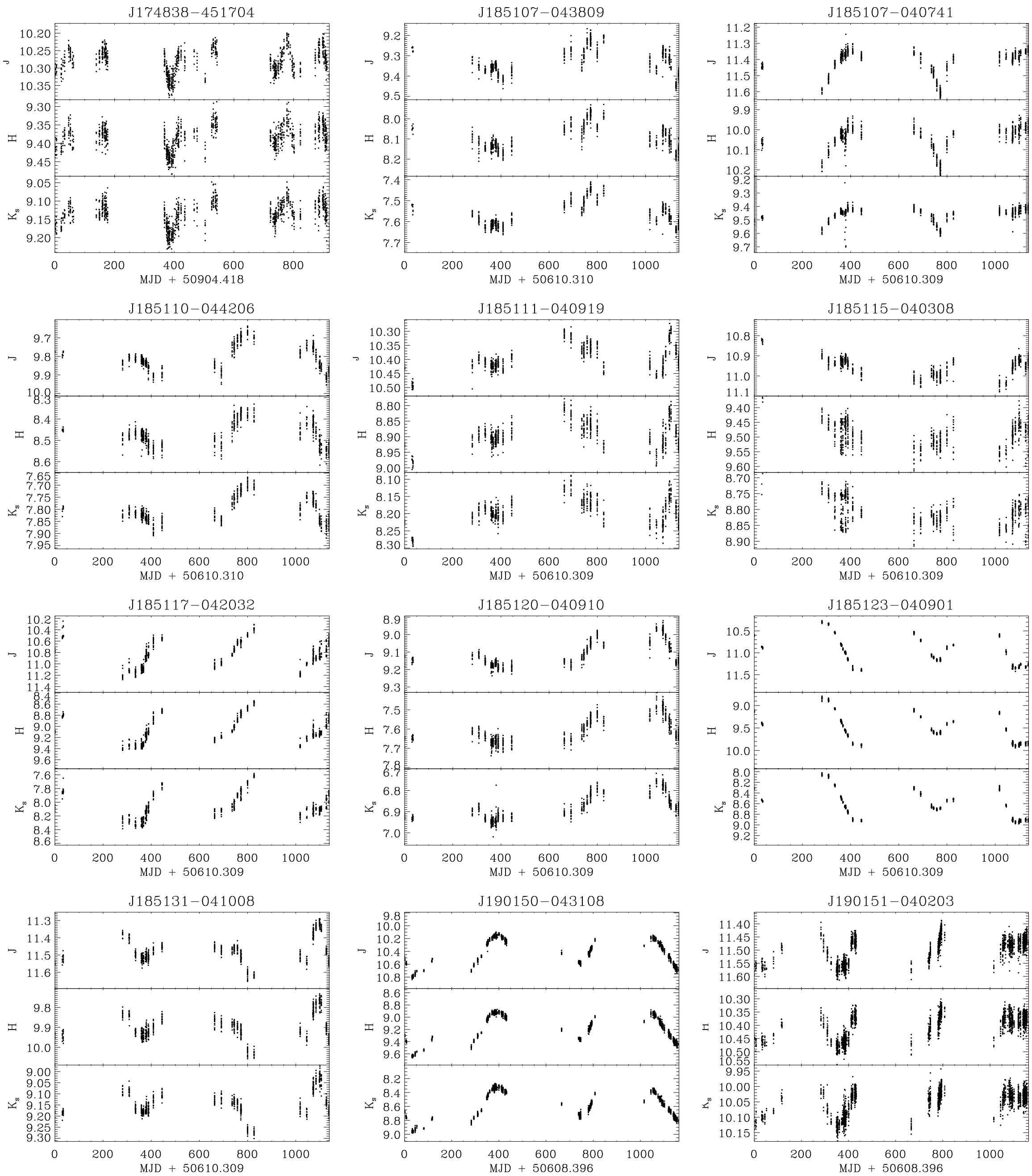

FIG. 15.— some long quasi-periodic variable objects. a couple look like DY Per's maybe? Nothing quite like RCB