



Secular Variation of the Mode Amplitude-Ratio of the Double-Mode RR Lyrae Star NSVS 5222076

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Project Motivation

1. From 2008 observations, Hurdis (2009) estimated the mode amplitude ratio, A_0/A_1 , to be about 1.4 for both the V and Ic bands.
2. These estimates uncertain, but it was clear that the amplitude ratio was definitely less than Oaster, Smith & Kinemuchi's value of "approximately 2."
3. Estimate made difficult by having caught only four good maxima over the fourteen nights of observation. Moreover, estimate method used was inexact.
4. Clearly, more observations needed, both to verify the result, and to determine whether NSVS 5222076 is, perhaps, in the process of changing its dominant pulsation mode from fundamental to first-overtone.

Project Objectives

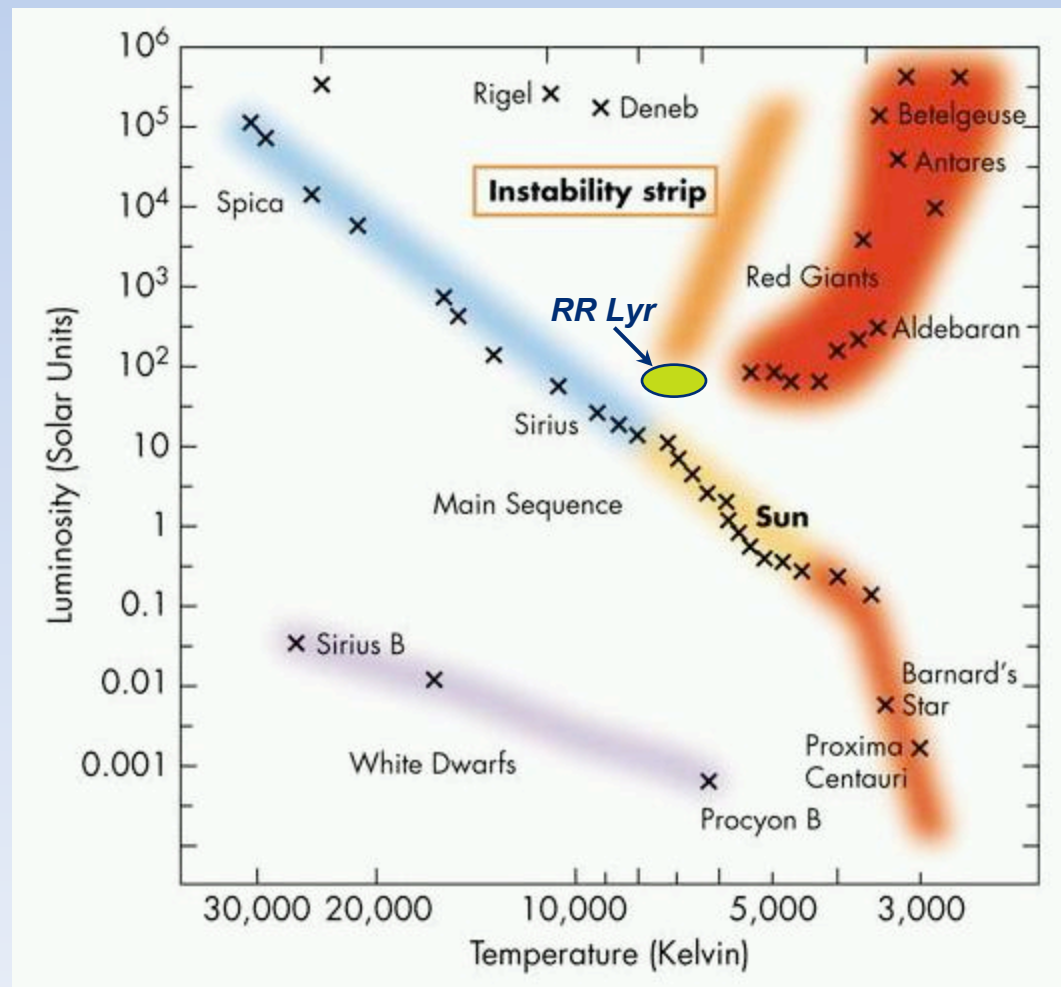
1. Time-series observations of the RRd star, NSVS-5222076 in the **V**-band and **I**-band.
2. Improve accuracy of period determination, by combining 2009 **V**-band observations with those of MSU (2005) and Hurdís (2008), thereby enlarging time-baseline.
3. Determine ratio of amplitudes, A_0/A_1 , of fundamental and first-overtone modes, for all three data sets and for both wavelength bands.

RR Lyrae Stars

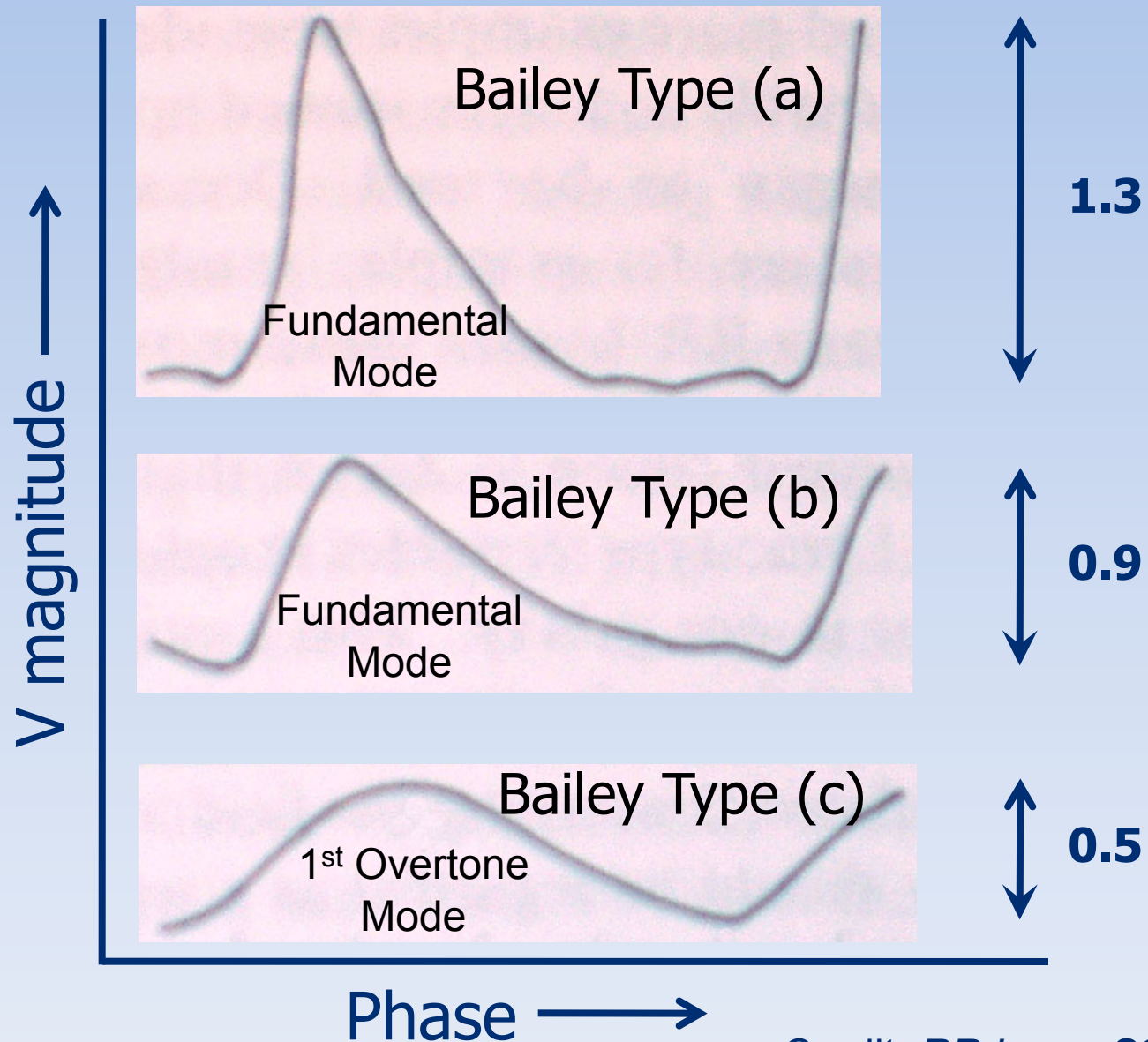
Population-II (very old) Evolved from MS to HB via RGB

Progenitor mass $\approx 0.8 M$

On Instability Strip



RR Lyrae Light Curve Shapes



Credit: *RR Lyrae Stars*,
H. Smith, Figure 1.1, pg. 3

Double-Mode RR Lyrae Stars

Bailey Type (d)

Double-mode RR Lyrae (RRd) stars pulsate in two independent modes, the fundamental and the 1st overtone.

Usually (but not always) the 1st overtone amplitude is greater than the amplitude of the fundamental, so the light curve looks sinusoidal, like that of an RRc.

NSVS 5222076

Identified by Oaster (2005) in Northern Sky Variability Survey (NSVS) data as possible new double-mode RR Lyr (RRd) star.

RRd nature confirmed by Oaster, Smith & Kinemuchi (2006).

Unusual among RRd stars in that its fundamental mode is the dominant pulsation mode, not the 1st overtone. Consequently, its light curve looks more like an RRab than an RRc.

NSVS 5222076 is a field star, conveniently located for Northern Hemisphere observers:

α (2000)= 15:46:26 δ (2000)= +44:18:47

Located in Bootes, and not far from M-3 and M-13.

Field of NSVS 5222076

CHECK1:

GSC-03060-00055
V = 13.576; I = 12.810
V - I = 0.766

CHECK2:

GSC-03060-00569
V = 12.969; I = 12.313
V - I = 0.656

COMP:

GSC-03059-00534
V = 14.035; I = 13.385
V - I = 0.650

NSVS 5222076

Calibration Credit: A. Henden,
Snoita Observatory, Apr 2008

NSVS 5222076 Observations

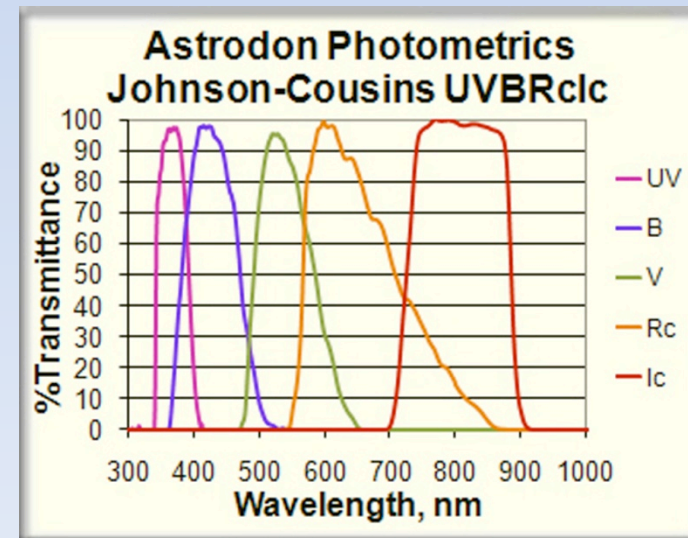
Astrokolhoz (Астроколхоз) Observatory, Cloudcroft, NM



Wright28, Celestron C11 SCT



SBIG ST-7XME CCD Camera
Pixels binned 2x2 to give 382 x 255



Astrodon, Johnson-Cousins
Interference Filter Set

NSVS 5222076 Observations

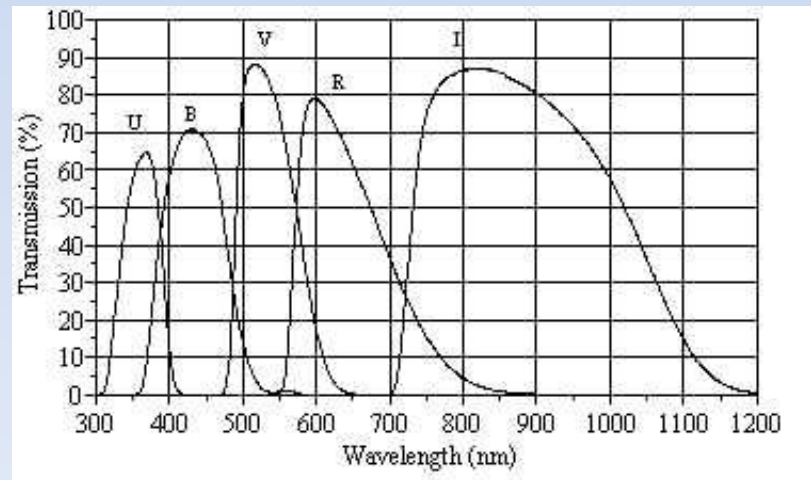
Toby Point Observatory, Narragansett, RI



Meade 40-cm LX-200 SCT



SBIG ST-8XME CCD Camera
Pixels binned 2x2 to give 765 x 510



Custom Scientific, Johnson-Cousins
(Bessel) Filter Set

Spring 2009 Observations of NSVS 5222076

1,482 **V-Band** Observations

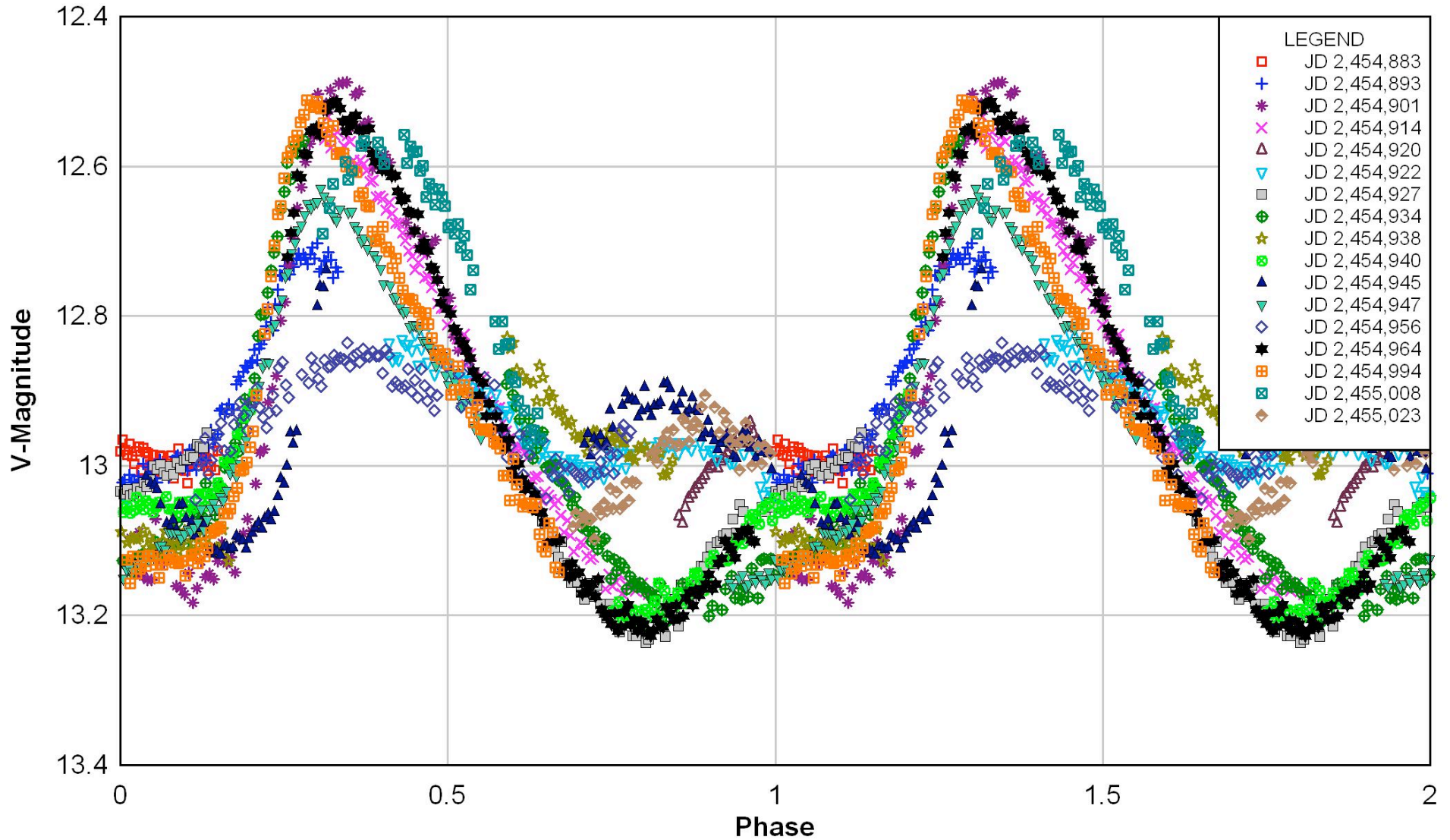
1,458 **I-Band** Observations

between JD 2,454,883 (2009 Feb 20-21)

and JD 2,455,023 (2009 Jul 10-11)

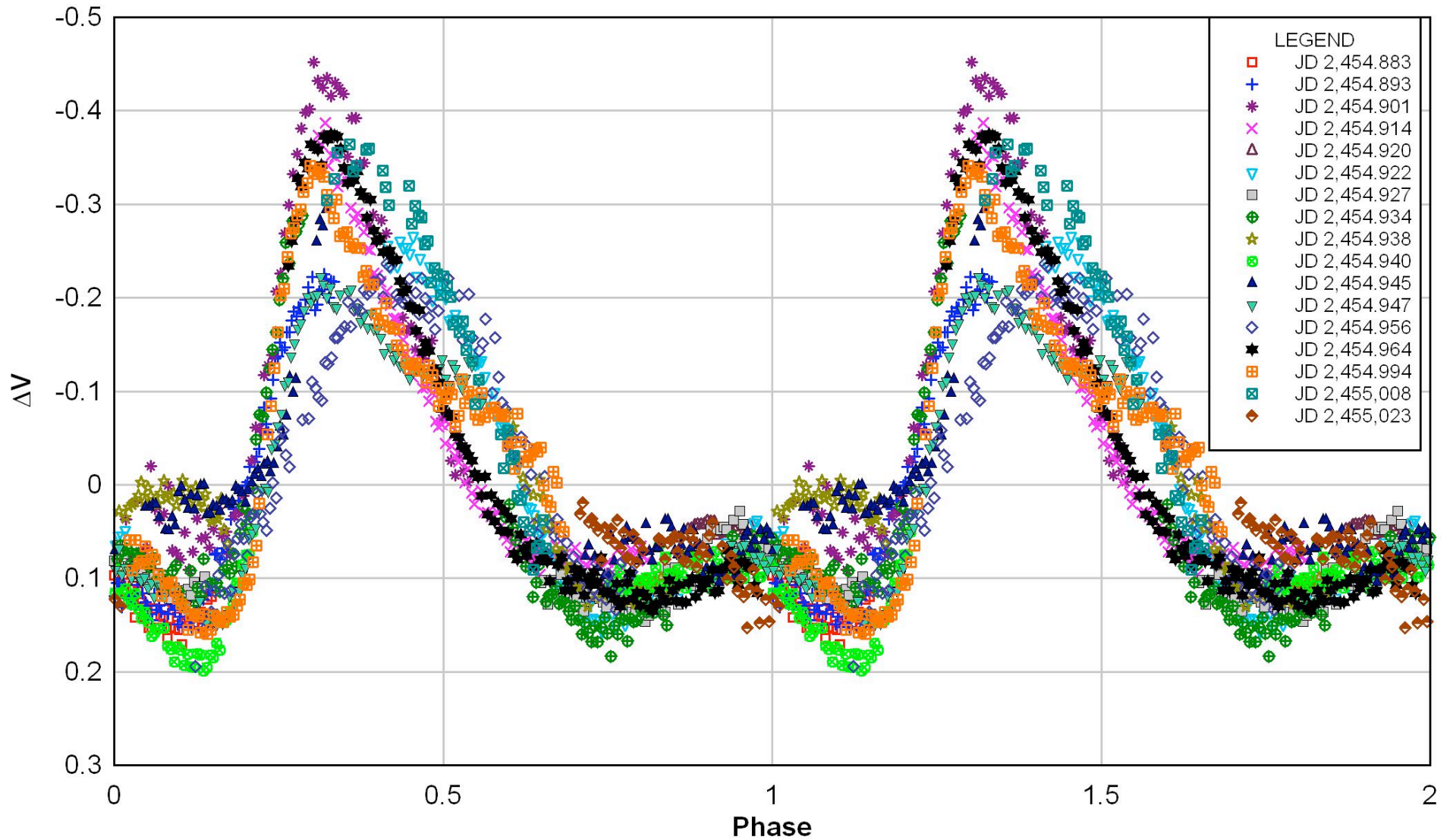
PHASE PLOT, V-FILTER

NSVS 5222076, Phase Plot, V-Filter, Data of Hurdis & Krajci 2009



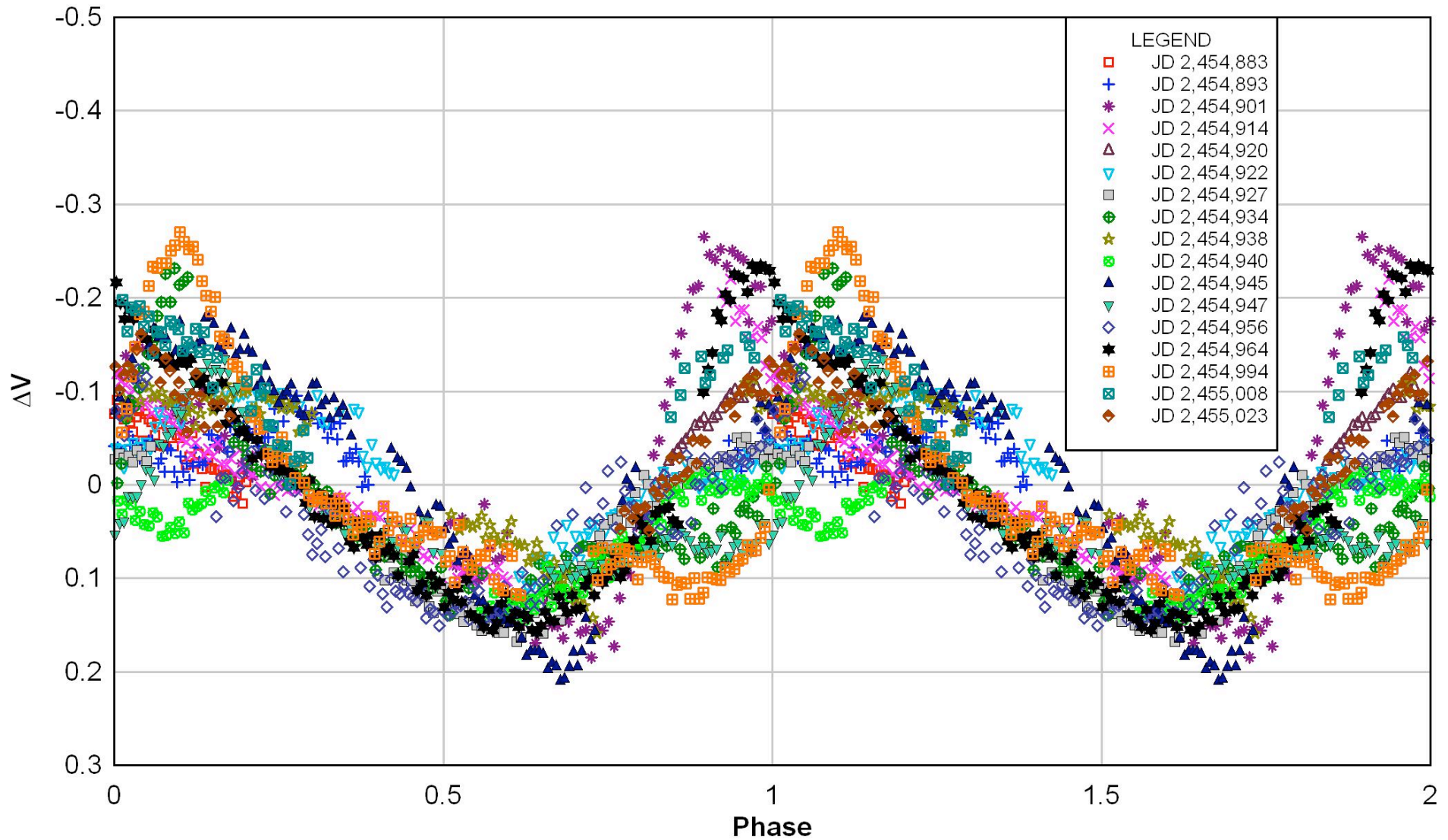
FUNDAMENTAL MODE, f_0 , V-FILTER

NSVS 5222076, f_0 Phase Plot, V-Filter, Data of Hurdis & Krajci 2009



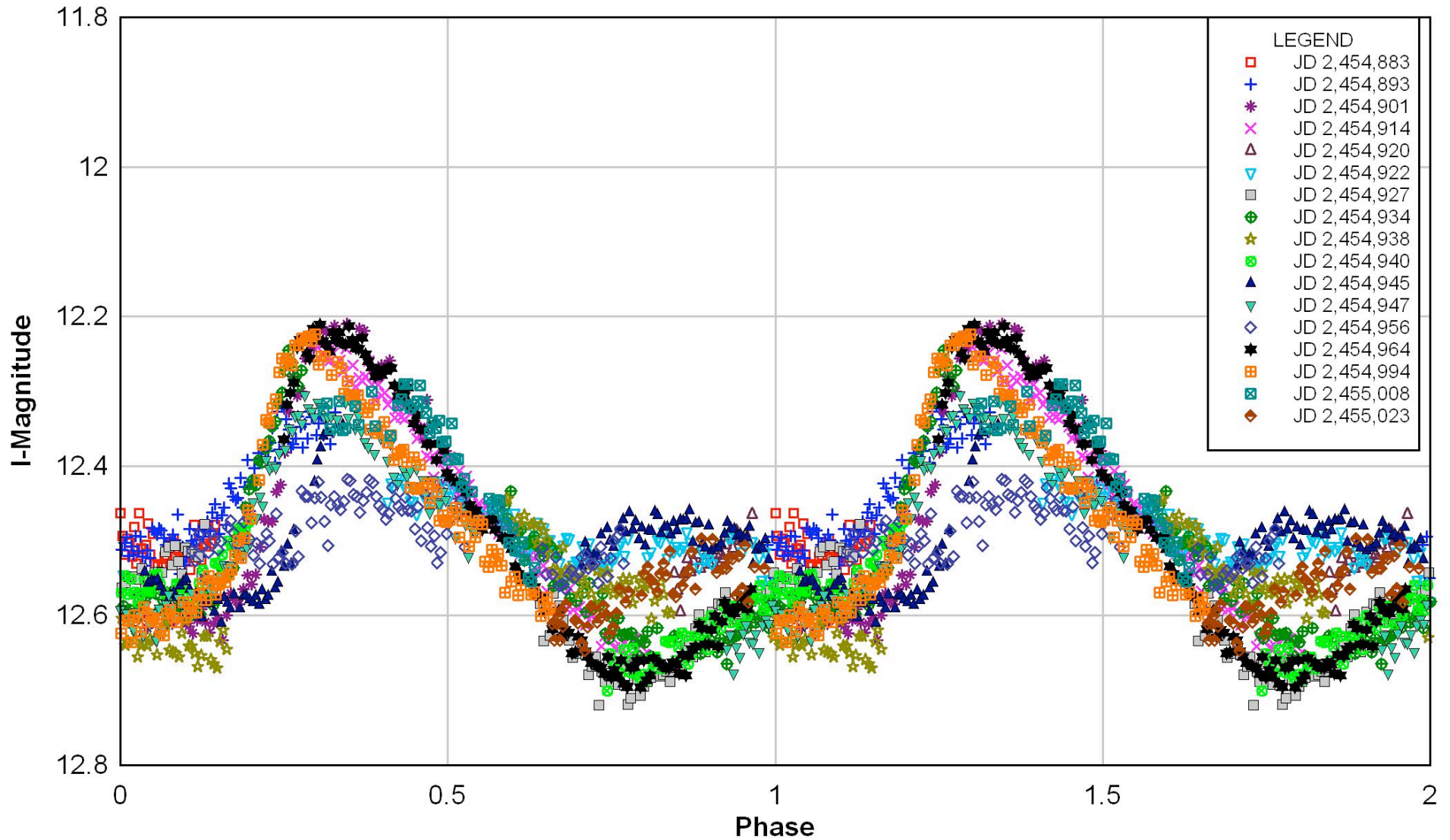
1ST OVERTONE MODE, f_1 , V-FILTER

NSVS 5222076, f_1 Phase Plot, V-Filter, Data of Hurdis & Krajci 2009



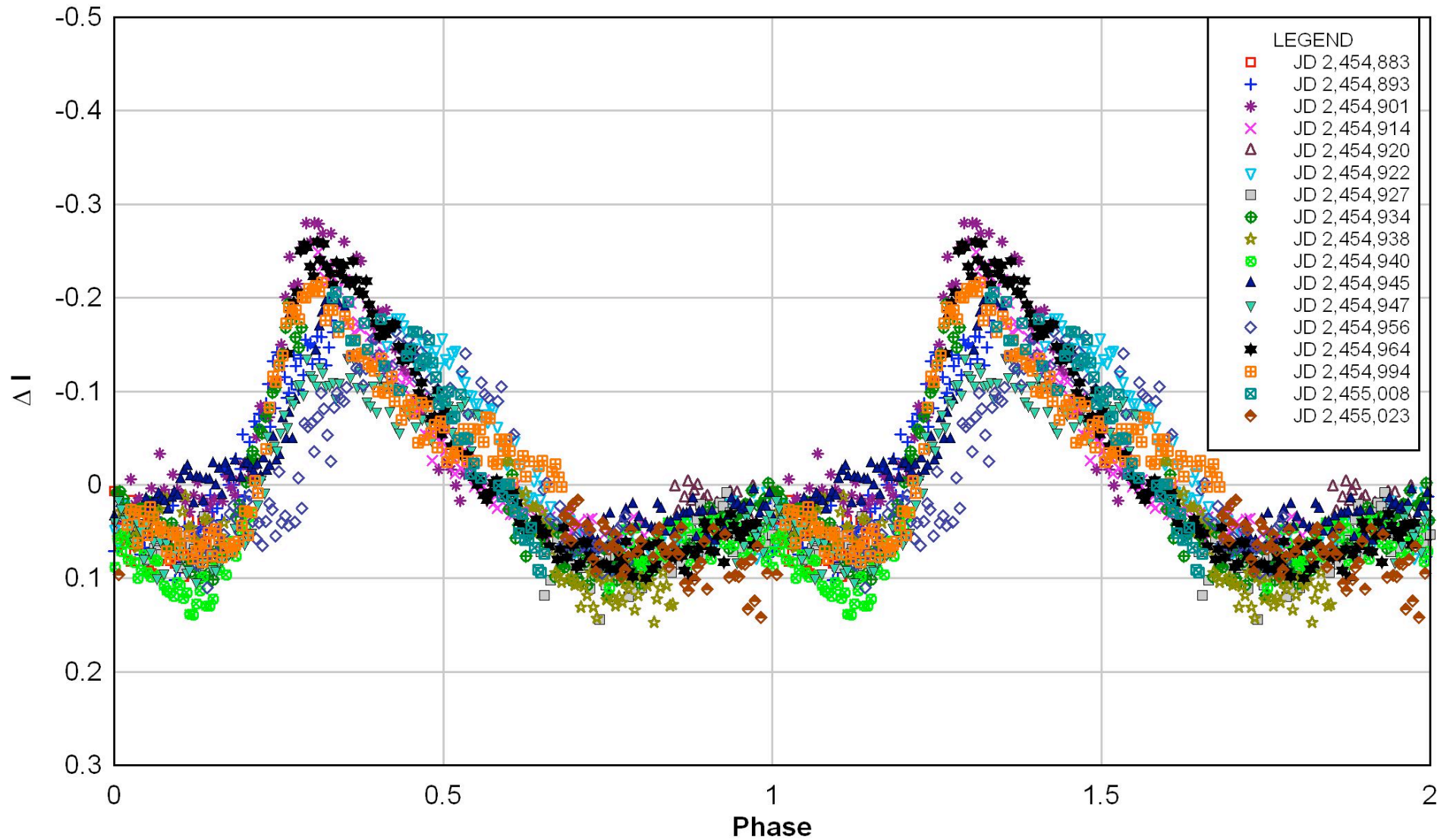
PHASE PLOT, I-FILTER

NSVS 5222076, Phase Plot, I-Filter, Data of Hurdis & Krajci 2009



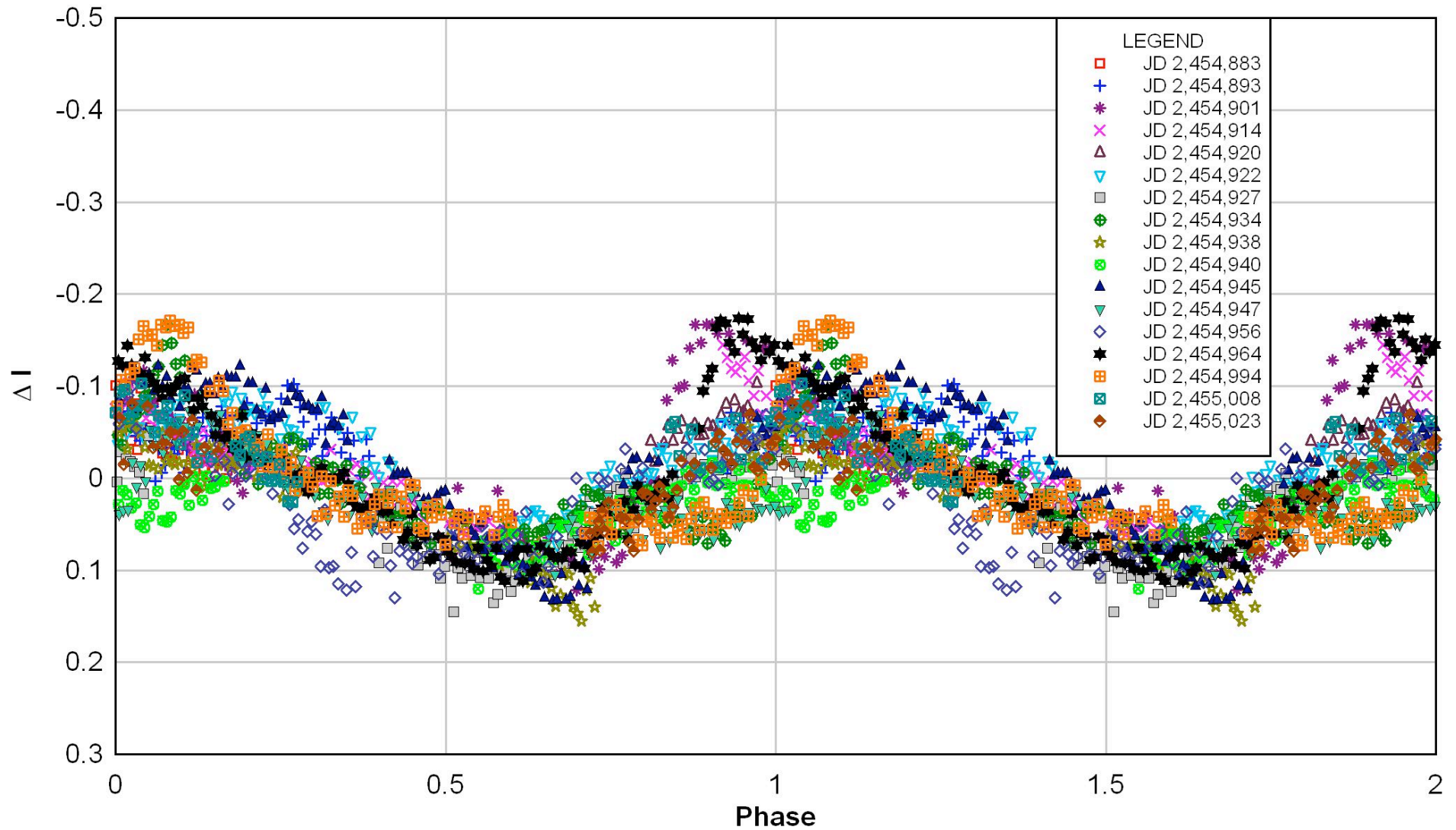
FUNDAMENTAL MODE, f_0 , I-FILTER

NSVS 5222076, f_0 Phase Plot, I-Filter, Data of Hurdis & Krajci 2009



1ST OVERTONE MODE, f_1 , I-FILTER

NSVS 5222076, f_1 Phase Plot, I-Filter, Data of Hurdis & Krajci 2009



IMPROVED PERIOD DETERMINATION

We combined our 2009 V-band observations with those of MSU (2005) and Hurdis (2008), thereby creating a combined time baseline of 1,609-days. We have determined the pulsation periods to be as follows:

Fundamental Period, $P_0 = 0.494050 \pm 0.000037$ day

1st Overtone Period, $P_1 = 0.366894 \pm 0.000010$ day

Least-Squares Fit of 2009 V-Band Light Curve with PERIOD04

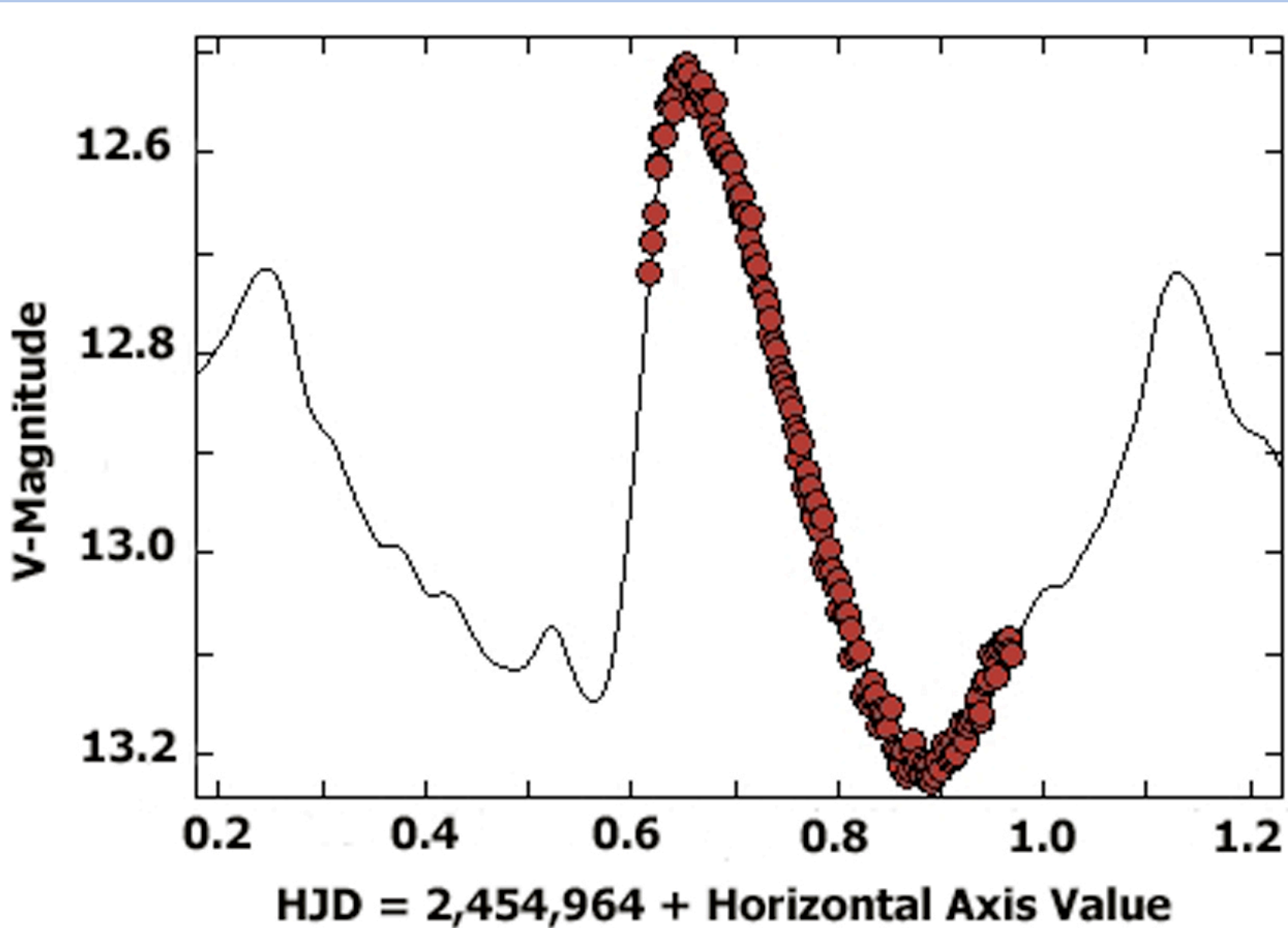
PERIOD04 fit to 2009 V-band data.

Frequency (cycles/day)	Amplitude (mag)
2.02409 ($=f_0$)	0.165
2.72558 ($=f_1$)	0.112
$2f_0$	0.070
$f_0 + f_1$	0.032
$f_1 - f_0$	0.031
$3f_0$	0.029
$2f_0 + f_1$	0.028
$4f_0$	0.023
$5f_0$	0.015
$2f_1$	0.015
$4f_0 + f_1$	0.011
$3f_0 + f_1$	0.011
$6f_0$	0.005

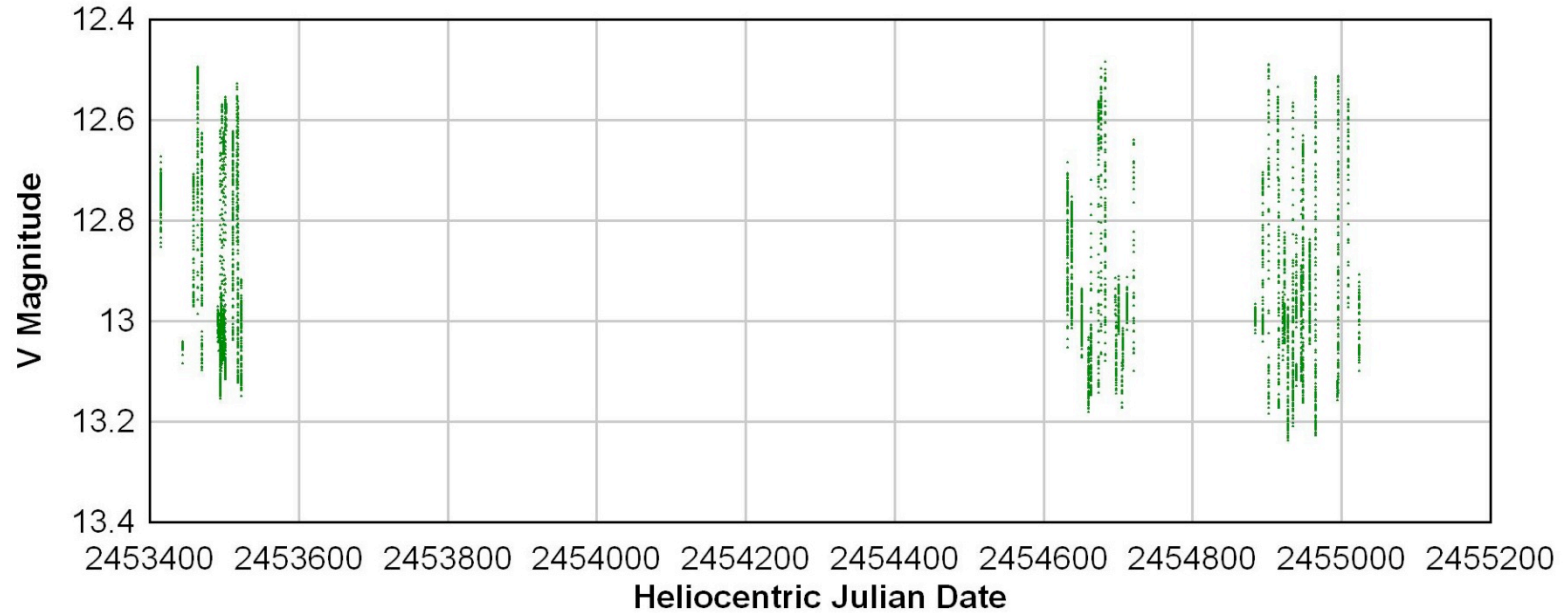
PERIOD04 fit to 2009 I-band data.

Frequency (cycles/day)	Amplitude (mag)
2.02409 ($=f_0$)	0.107
2.72558 ($=f_1$)	0.070
$2f_0$	0.051
$3f_0$	0.018
$2f_0 + f_1$	0.017
$f_0 + f_1$	0.016
$f_1 - f_0$	0.015
$4f_0$	0.012
$2f_1$	0.012
$3f_0 + f_1$	0.008
$4f_0 + f_1$	0.007
$3f_1$	0.007
$4f_1$	0.006
$6f_0$	0.005

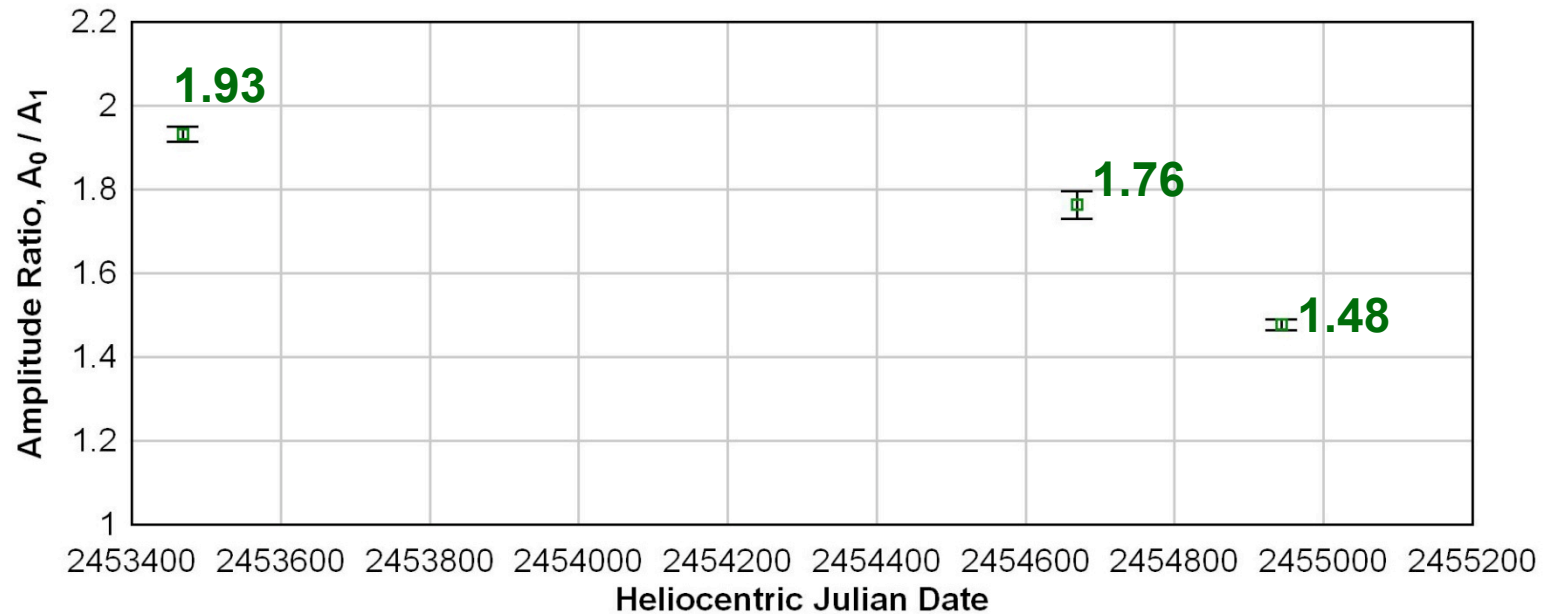
Least-Squares Fit of 2009 V-Band Light Curve with PERIOD04



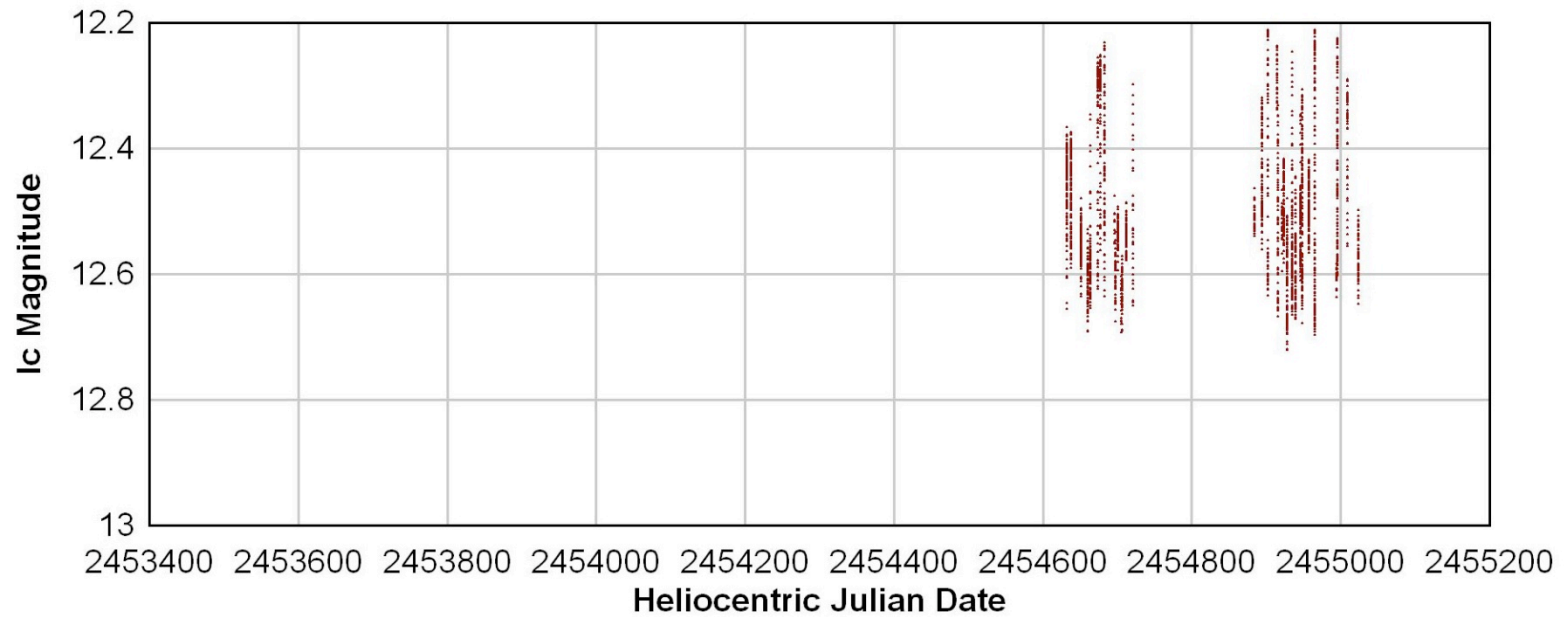
Combined Data Sets: Mich. St. 05, Hurdis 08, Hurdis & Krajci 09, V-Filter



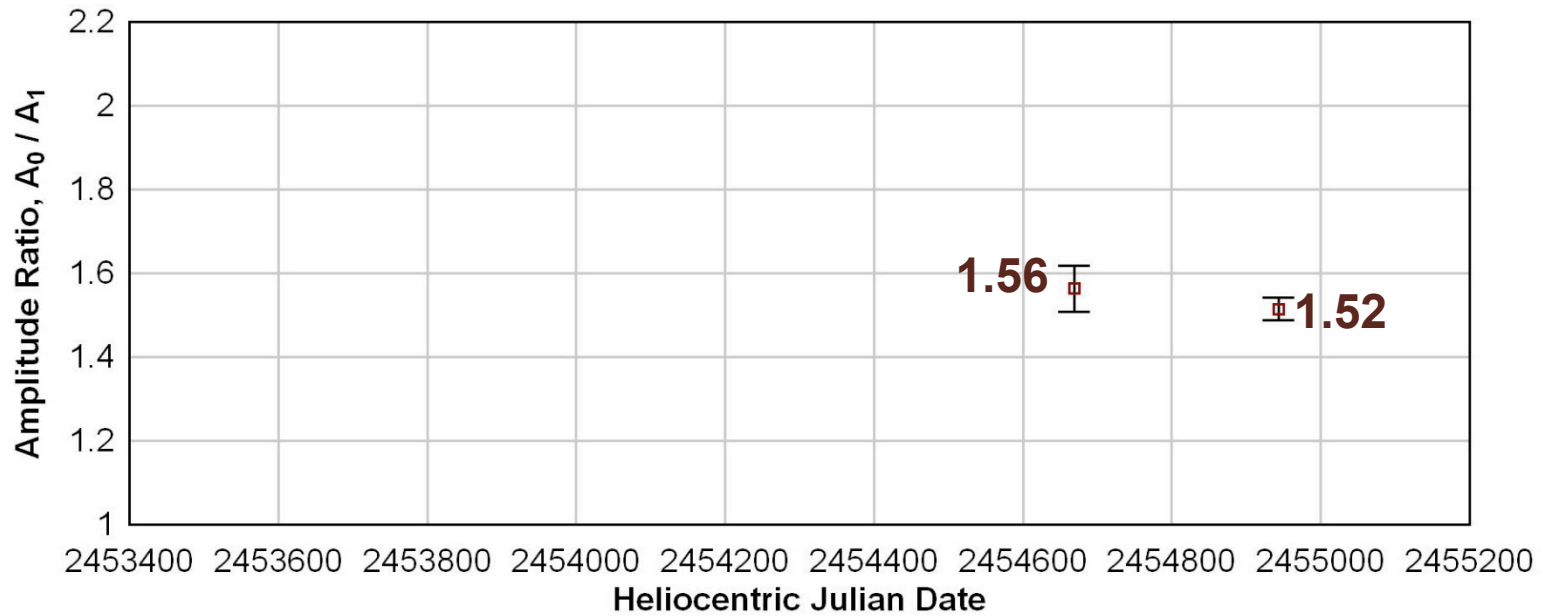
Time Variation of Amplitude Ratio, A_0 / A_1 , V-Filter



Combined Data Sets: Hurdis 08, Hurdis & Krajci 09, I-Filter



Time Variation of Amplitude Ratio, A_0 / A_1 , I-Filter



Mode Switching of Double-Mode RR Lyrae Stars

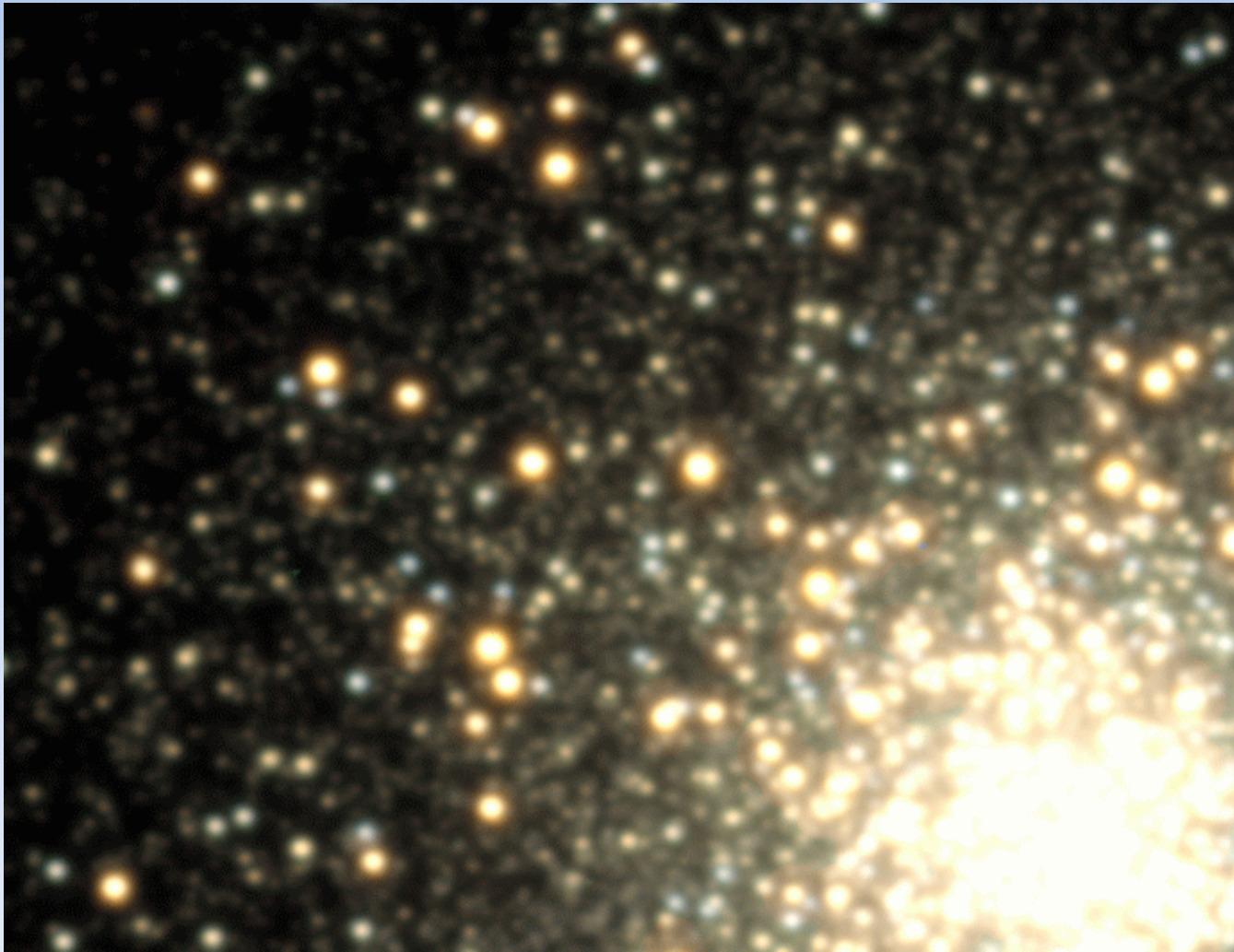
In the globular cluster, M3, a few RRd stars have been observed to undergo changes in the relative strengths of the two pulsation modes.

In four such cases (M3-V79, V166, V200, and V251) switching from one mode being dominant to the other has been observed.

These changes can occur rapidly, over the span of a single year. Such stars are believed to be undergoing rapid evolutionary changes.

V79 exhibited an abrupt change in its fundamental period in 1897, and switched in 1992 from being a single-mode (fundamental) pulsator to a double-mode pulsator with dominant first-overtone (Clement & Goranskij, 1999).

GLOBULAR CLUSTER, M3



**Animated GIF credit:
J. Hartman & K. Stanek**

Mode Switching of Double-Mode RR Lyrae Stars

“Blazhko-like” amplitude modulation has also been observed in V79 (Goranskij & Barsukova, 2007).

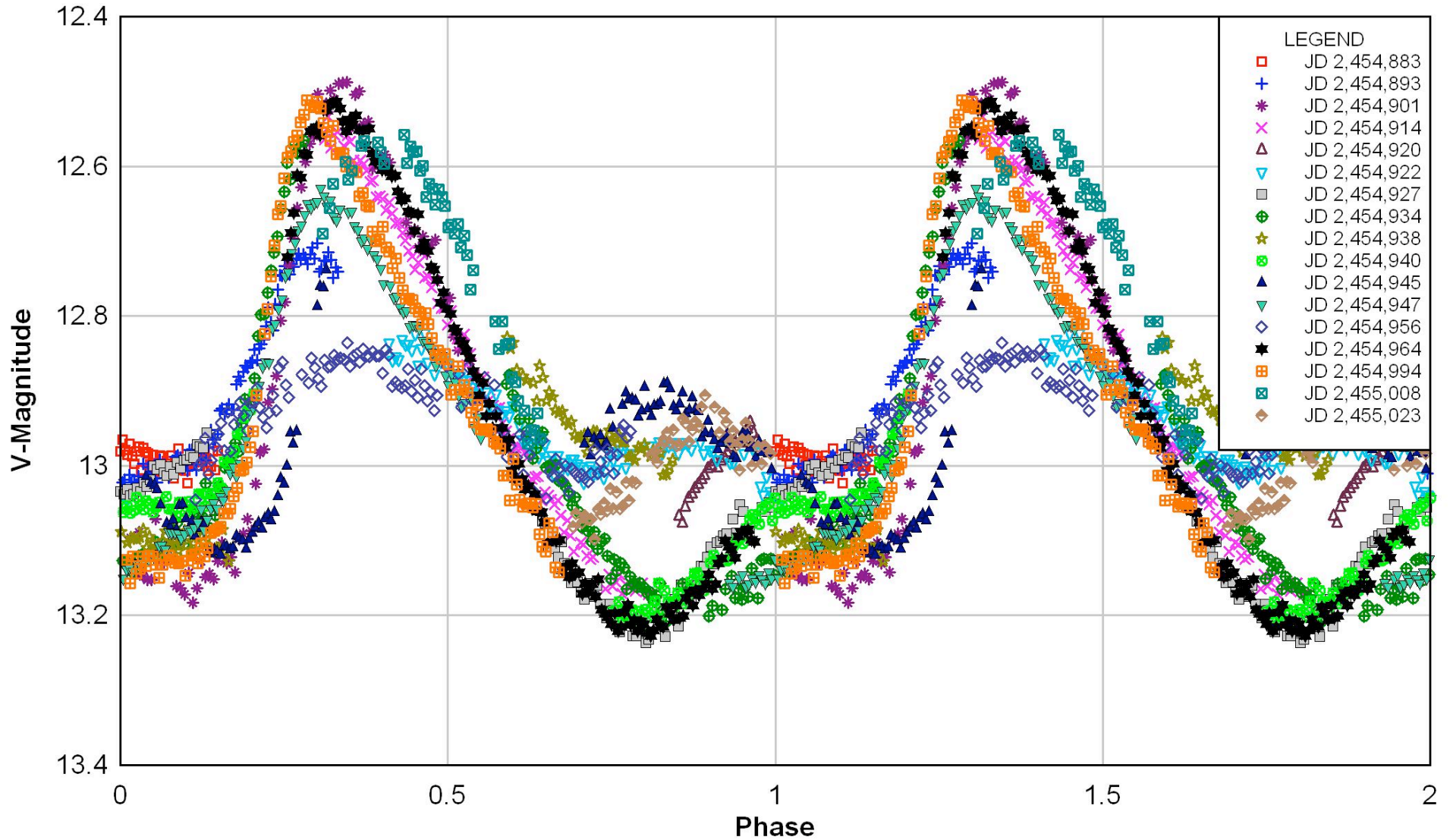
Recent PERIOD04 analysis of combined 2008 and 2009 data sets for NSVS 5222076 by Matt Templeton showed evidence of “Blazhko-like” amplitude modulation.

The “Blazhko-like” amplitude modulation in NSVS 5222076 is non-periodic.

Could this behavior be further evidence of pulsation instability in NSVS 5222076, prior to an impending mode switch?

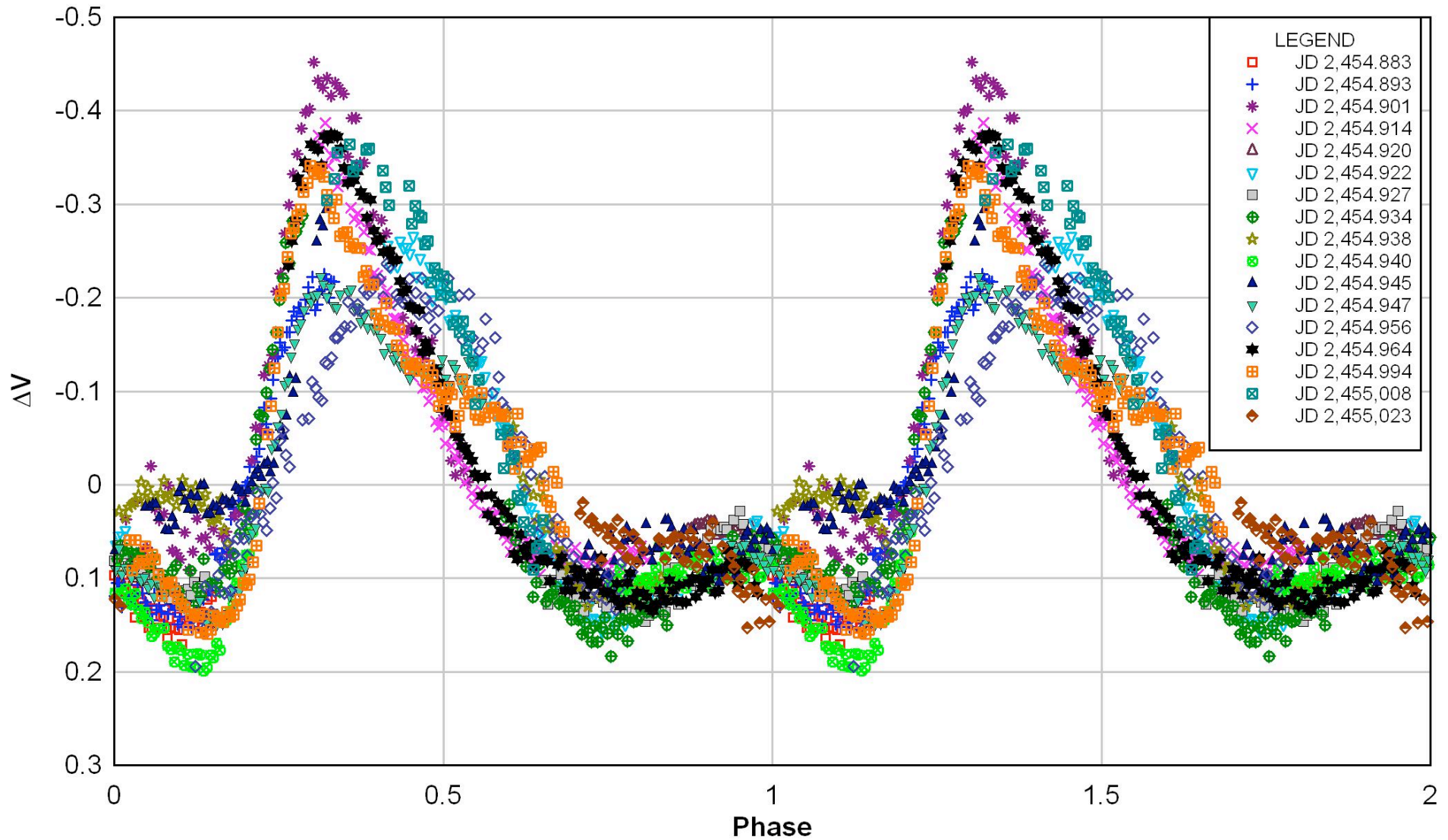
PHASE PLOT, V-FILTER

NSVS 5222076, Phase Plot, V-Filter, Data of Hurdis & Krajci 2009



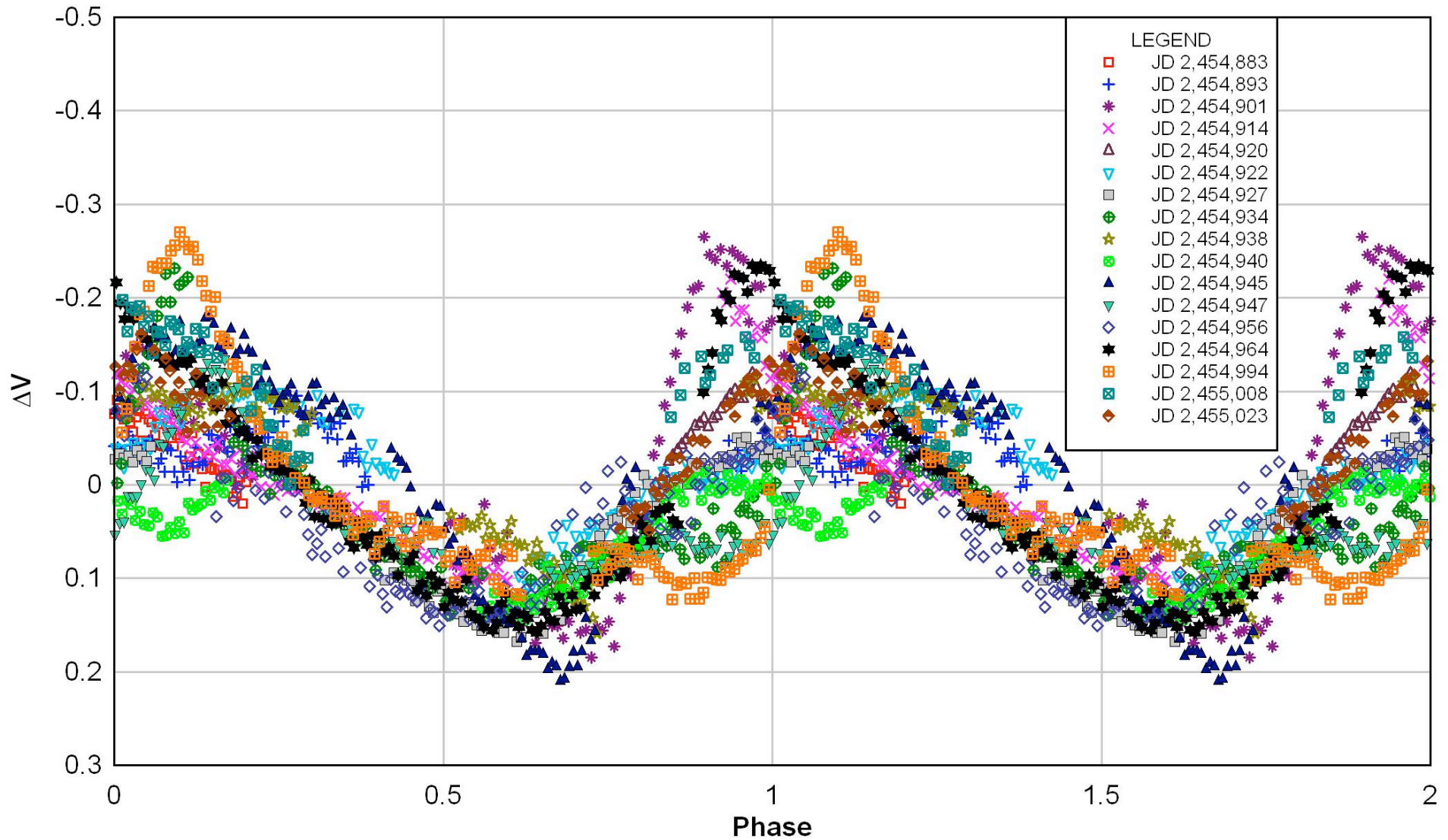
FUNDAMENTAL MODE, f_0 , V-FILTER

NSVS 5222076, f_0 Phase Plot, V-Filter, Data of Hurdis & Krajci 2009



1ST OVERTONE MODE, f_1 , V-FILTER

NSVS 5222076, f_1 Phase Plot, V-Filter, Data of Hurdis & Krajci 2009



SUMMARY

1. The fundamental and 1st-overtone periods of NSVS 5222076 have been determined, with improved accuracy. They are

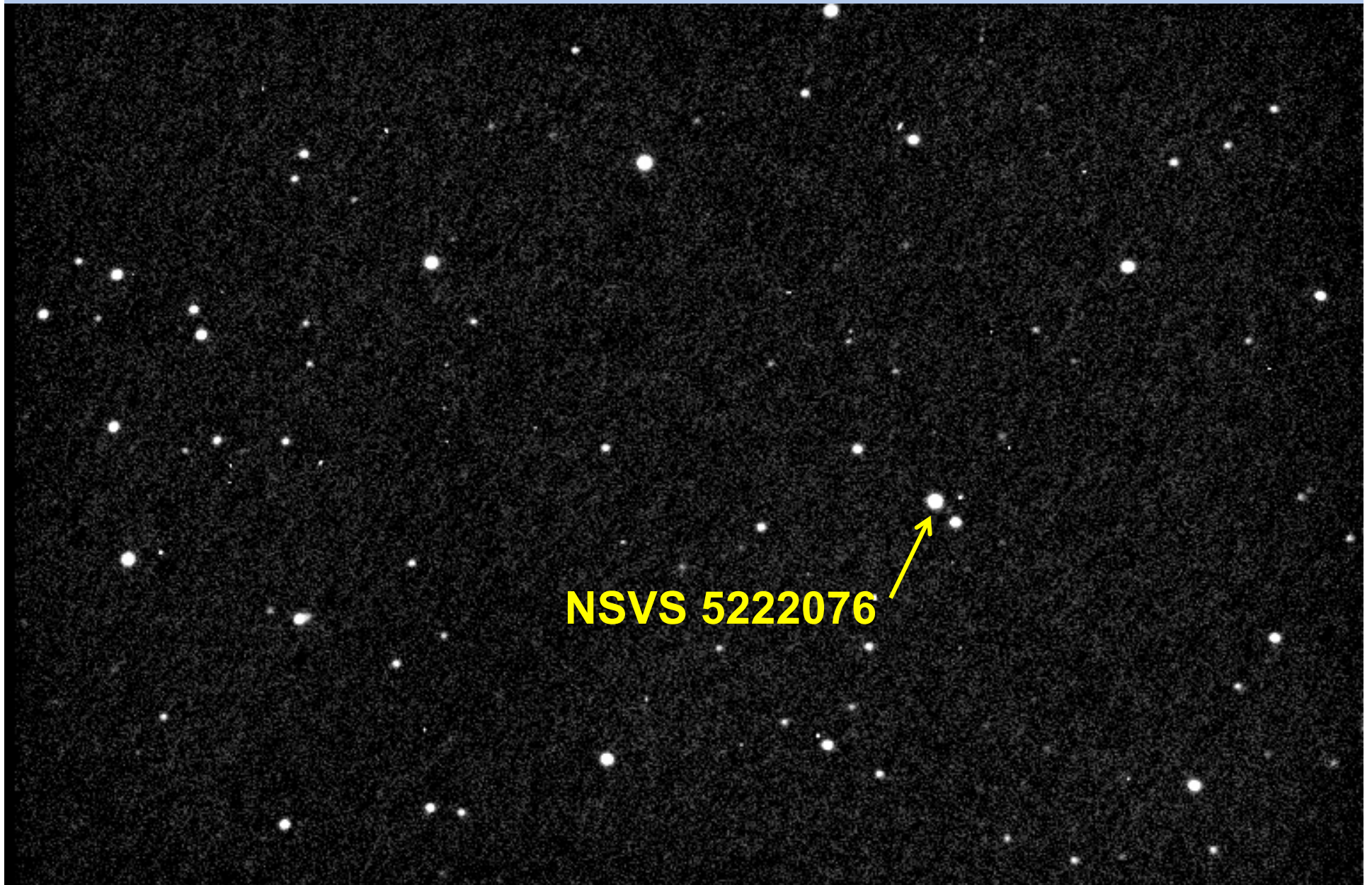
$$P_0 = 0.494050 \pm 0.000037 \text{ day}$$

$$P_1 = 0.366894 \pm 0.000010 \text{ day}$$

2. In the **V**-band, the amplitude ratio, A_0/A_1 , of the fundamental and 1st-overtone modes is found to have declined from 1.93 in 2005 to 1.76 in 2008 to 1.48 in 2009.
3. In the **I**-band, A_0/A_1 was 1.56 in 2008 and 1.52 in 2009.
4. Continued monitoring of NSVS 5222076 is needed to catch the anticipated impending mode switch.

Field of NSVS 5222076

NSVS 5222076



QUESTIONS?