



# **Two-Color Photometry of the Double-Mode RR Lyrae Star, NSVS-5222076**

**Dave Hurdis  
Toby Point Observatory  
Narragansett, RI**

**97<sup>th</sup> Annual Meeting of the AAVSO  
Nantucket, Massachusetts  
Saturday, October 18, 2008**

# Project Objectives

1. Replicate Michigan State Univ.'s **V**-band observations of the RRd star, NSVS-5222076.
  - a. Improve the accuracy of MSU's period determinations by combining my **V**-band observations with theirs, thus enlarging the observation time-window from 108-days to 1306-days.
2. Observe NSVS-5222076 in the **I**-band.
3. Determine the star's variation in **V** - **I** color as a function of time.
4. Upload my **V** and **I** observations to the AAVSO database.

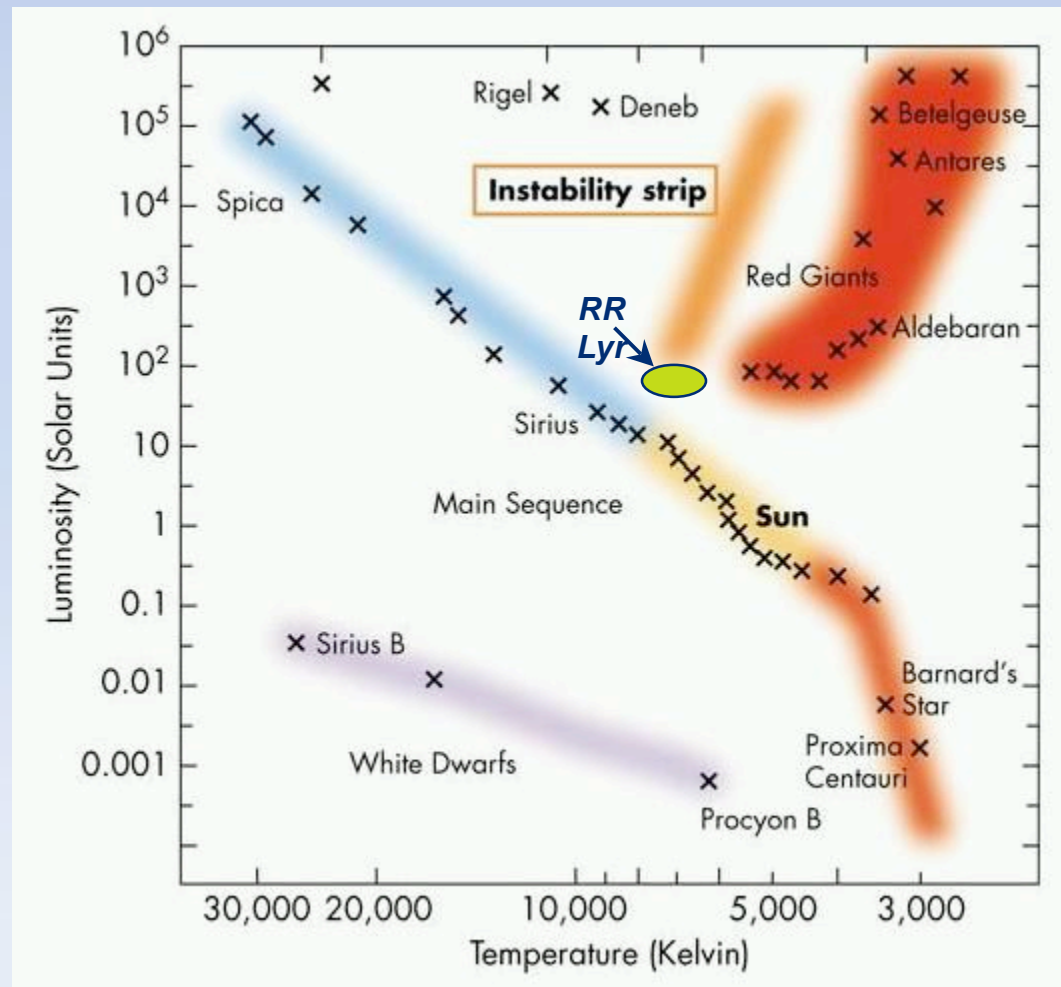
# RR Lyrae Stars

Population-II (very old)

Evolved from MS to HB via RGB

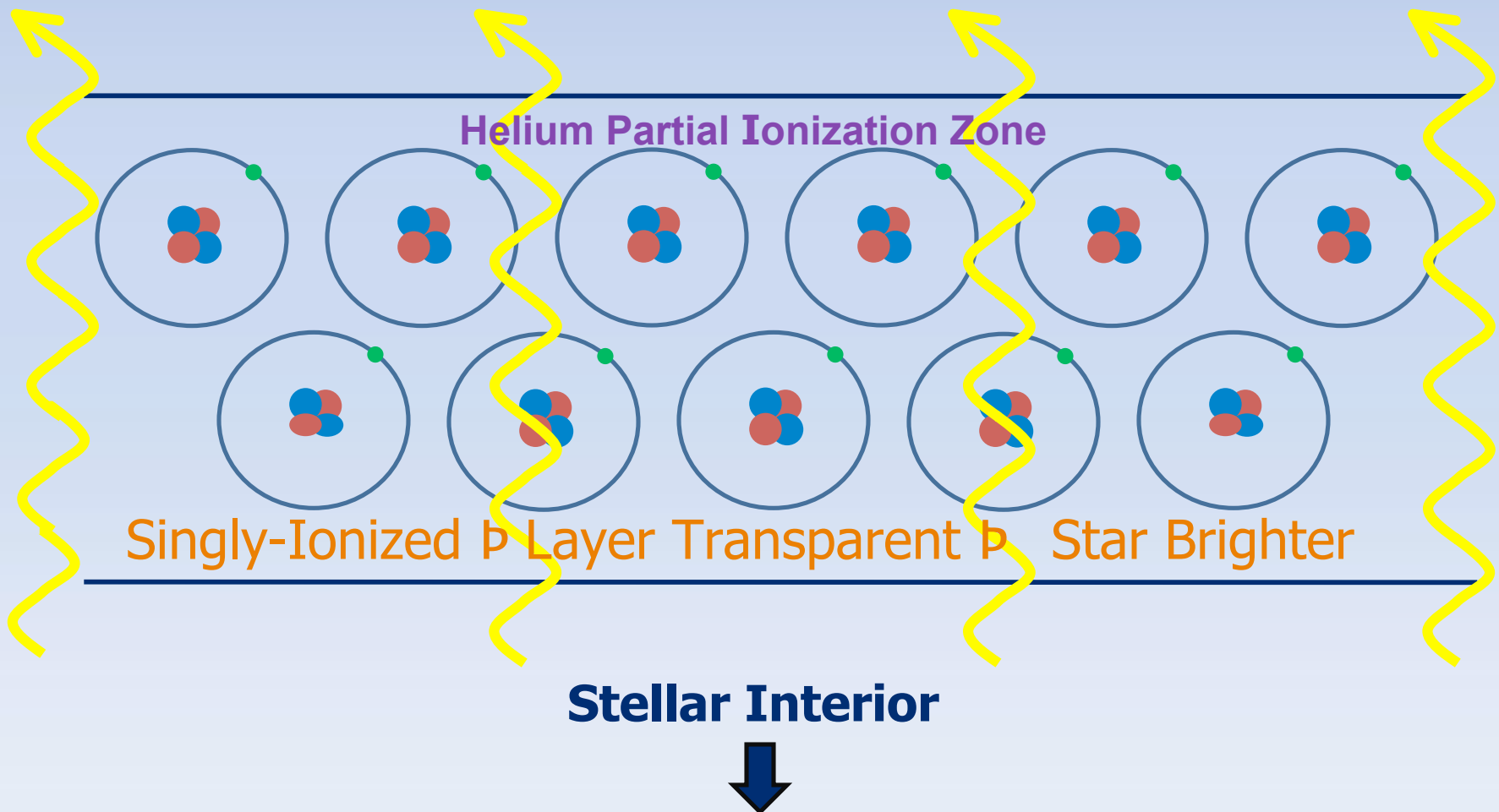
Progenitor mass  $\gg$  0.8 M

On Instability Strip



# RR Lyrae Stars

Alternating double-ionization and recombination of singly-ionized helium acts like a valve that maintains pulsation.



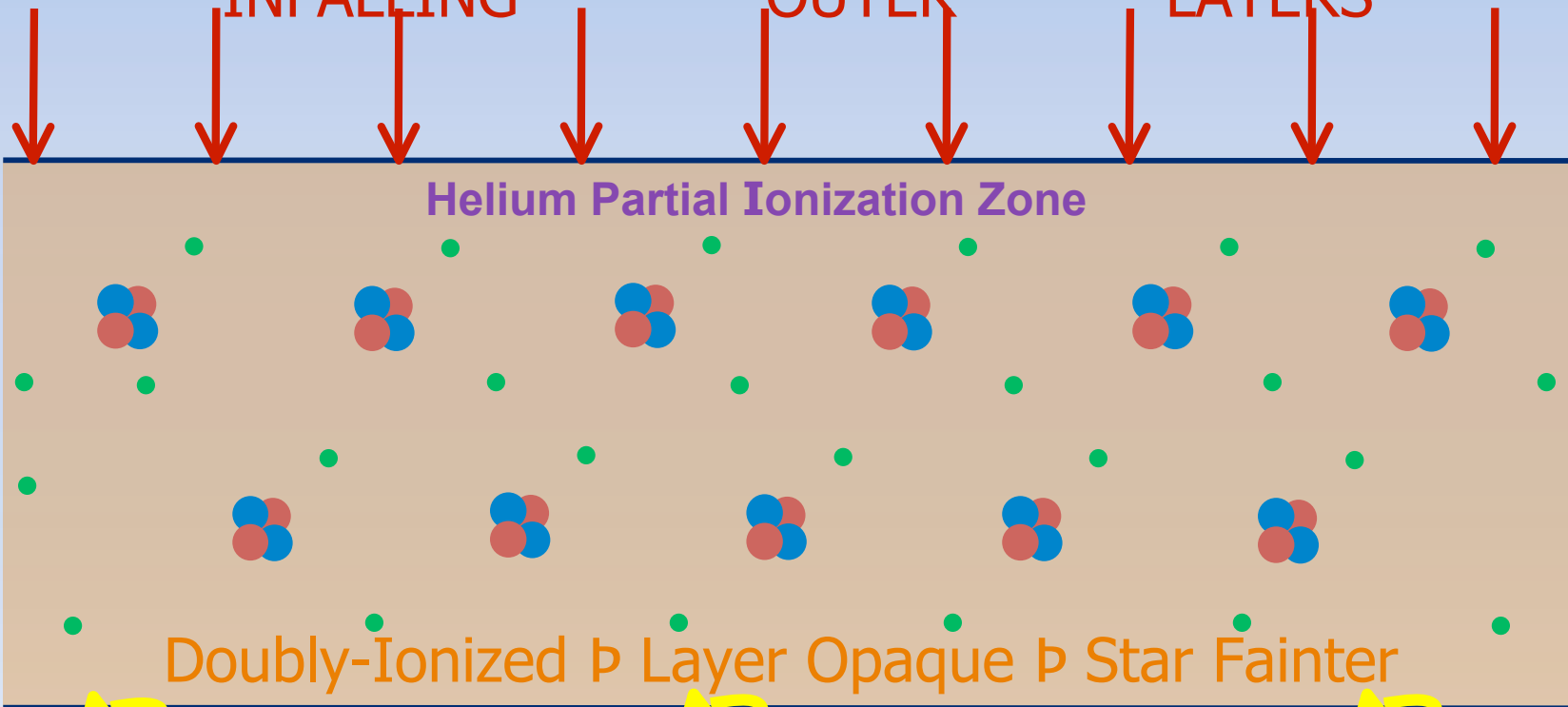
# RR Lyrae Stars

Alternating double-ionization and recombination of singly-ionized helium acts like a valve that maintains pulsation.

INFALLING

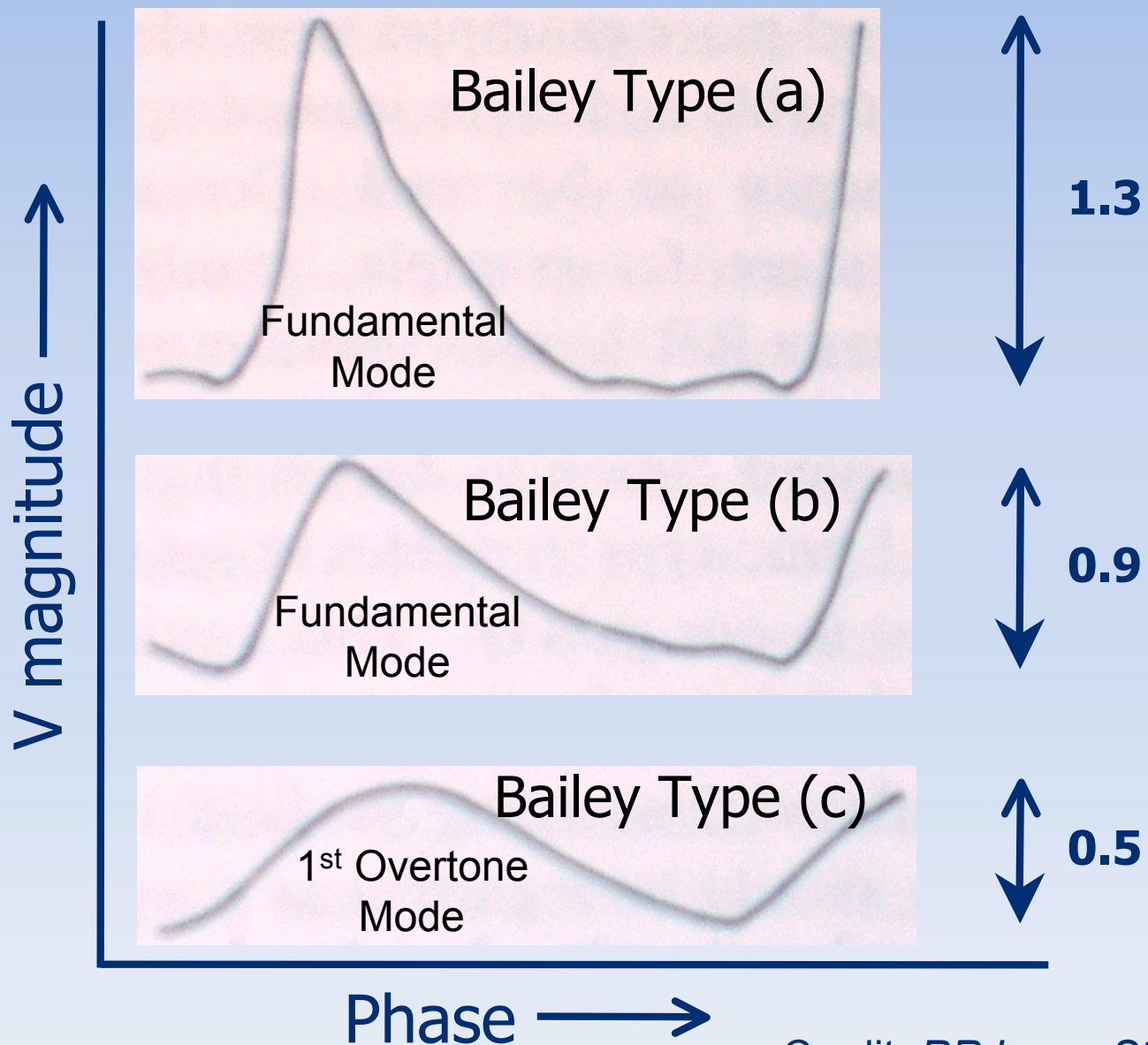
OUTER

LAYERS



Stellar Interior

# RR Lyrae Light Curve Shapes



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

# Double-Mode RR Lyrae Stars and Why They Are Important

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

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

After maximum expansion, the star's layers free-fall inward. This is a special case of orbital motion (along a straight line), so the falling gas must obey Kepler's Third Law:

$$P^2 / R^3 = 4\pi^2 / GM \quad \text{where: } P \text{ is pulsation period}$$

R = star radius and  
M = star mass

or  $P^2 \propto R^3 / M$

So, two independent periods provide two equations to independently determine the two unknowns, R and M.

# NSVS 5222076

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

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

Unusual among RRd stars in that its fundamental mode is the dominant pulsation mode, not the 1<sup>st</sup> 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:

a (2000)= 15:46:26      d (2000)= +44:18:47

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



# Field of NSVS 5222076

## CHECK:

GSC-03060-00055

$V = 13.576$ ;  $I = 12.810$

$V - I = 0.766$



## COMP:

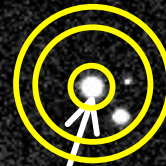
GSC-03059-00534

$V = 14.035$ ;  $I = 13.385$

$V - I = 0.650$



$(V - I)_{\text{Sun}} = 0.88$



NSVS 5222076

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

# NSVS 5222076 Discovery Observations

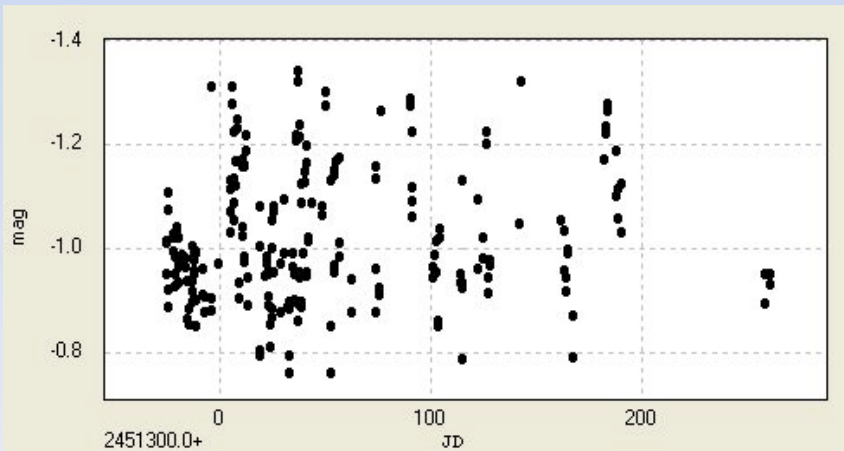


## ROTSE-I

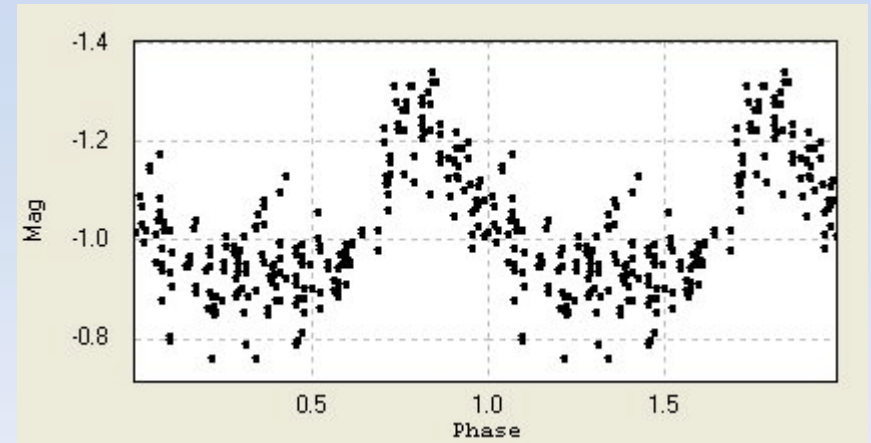
Four 200-mm f/1.8 Canon telephoto lenses, each with an **unfiltered** 2048 x 2048 CCD camera. Credit: Univ. of Michigan.

## Northern Sky Variability Survey (NSVS)

ROTSE-I data were used by Oaster (2005) for the discovery of NSVS-5222076. 218 observations over a 285-day window between Apr 99 and Jan 00.



ROTSE-I data: noisy and unfiltered.  
Obtained from: <http://skydot.lanl.gov/nsvs/nsvs.php>



Phase diagram for,  $P_0 = 0.49405$  days

# NSVS 5222076 MSU Observations

Oaster, L., Smith, H. A., and Kinemuchi, K., *A Double-Mode RR Lyrae Star with a Strong Fundamental-Mode Component*, *PASP*, 118: 405-409, 2006 March.



**Lindsay Oaster**,  
recently at McMaster  
Univ.



**Horace A. Smith**,  
Michigan State Univ.



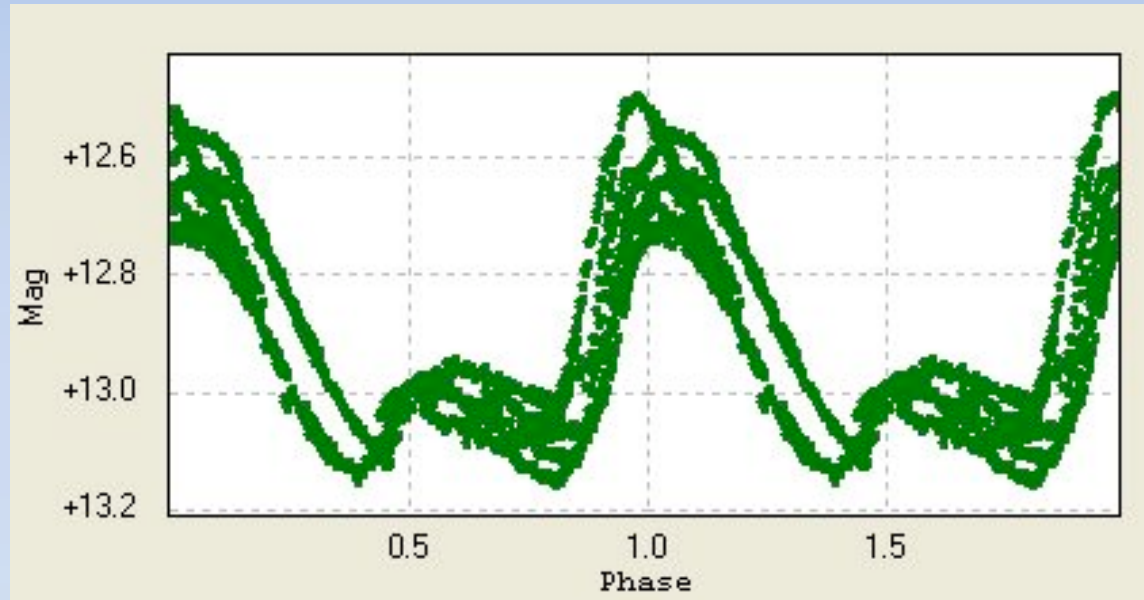
**Karen Kinemuchi**,  
Univ. of Florida



60-cm telescope  
Apogee Ap47p CCD camera  
(1024 x 1024)  
MSU Campus Observatory

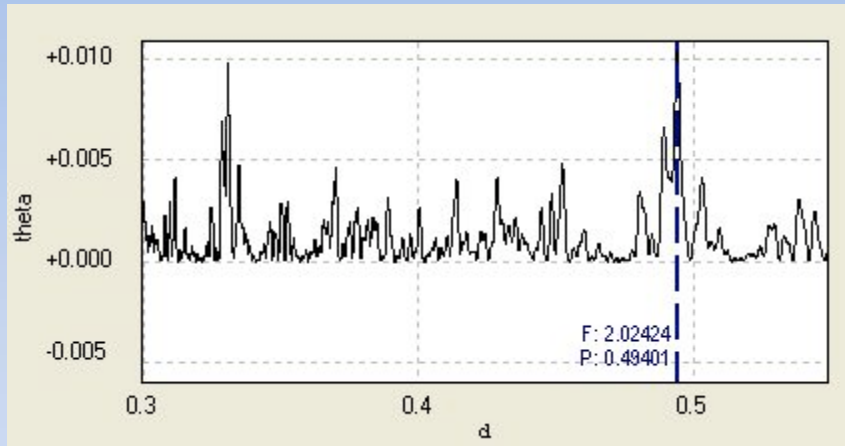


# NSVS 5222076 MSU Observations

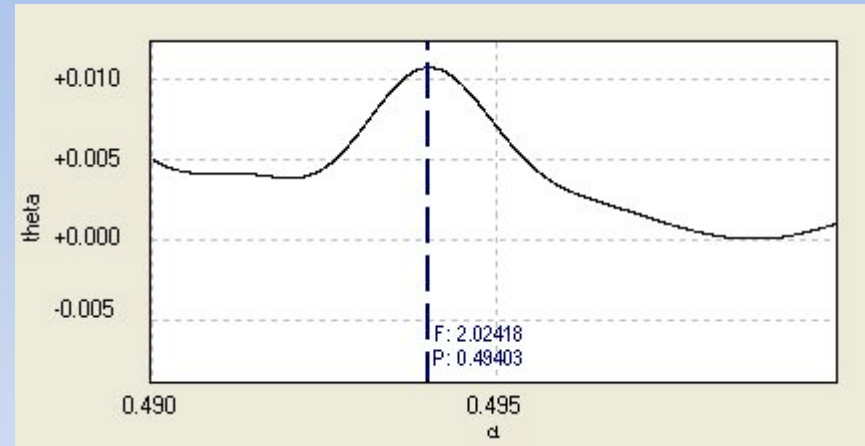


Phase diagram for,  $P_0 = 0.4940$  days  
1570 observations from 16 nights over  
a 108-day window (Feb – Jun 2005)

# NSVS 522076 MSU Observations

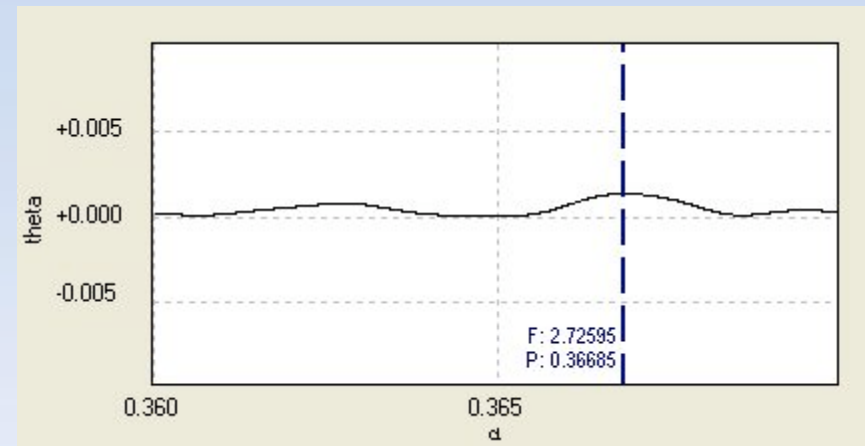


Initial period analysis is dominated by the fundamental and its harmonics.



Refined period analysis:  
 $P_0 = 0.4940 \pm \cancel{0.0001}$  days  
 **$\pm 0.0011$**

Upon prewhitening (i.e., removal of the fundamental and its harmonics) the 1<sup>st</sup> overtone period,  $P_1$ , emerges:



1<sup>st</sup> overtone,  $P_1 = 0.3669 \pm \cancel{0.0002}$  days  
 **$\pm 0.0008$**

# NSVS 5222076 Observations

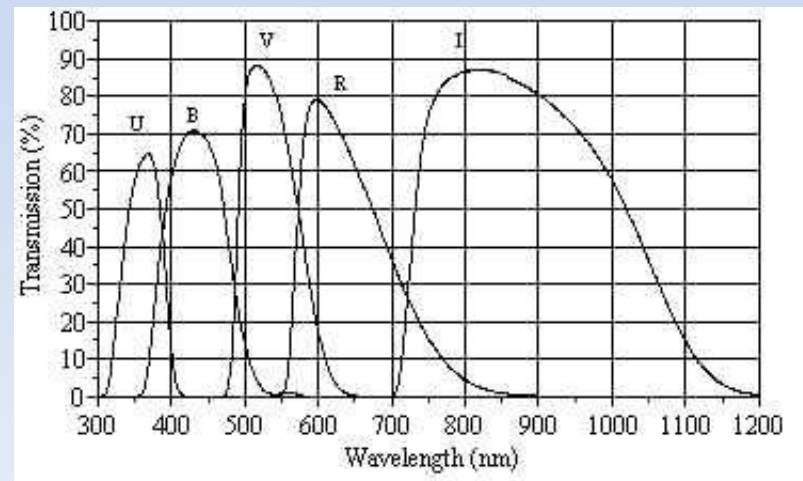
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Meade 40-cm LX-200 SCT



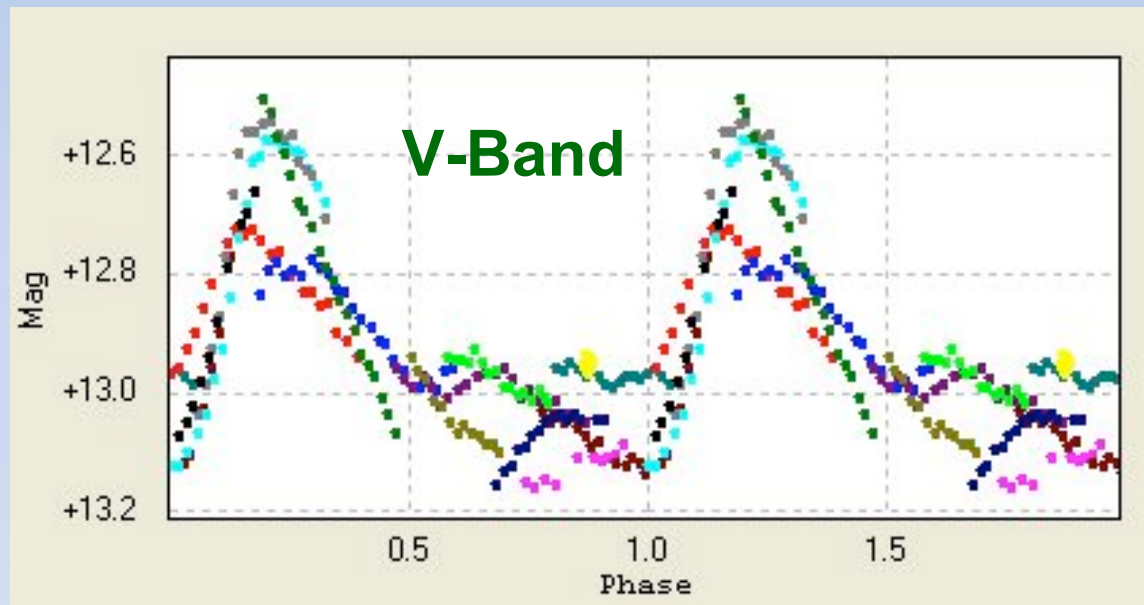
SBIG ST-8XME CCD Camera  
Pixels binned 2x2 to give 765 x 510



Custom Scientific Johnson-Cousins  
(Bessel) Filter Set

# NSVS 5222076 V-Band Observations

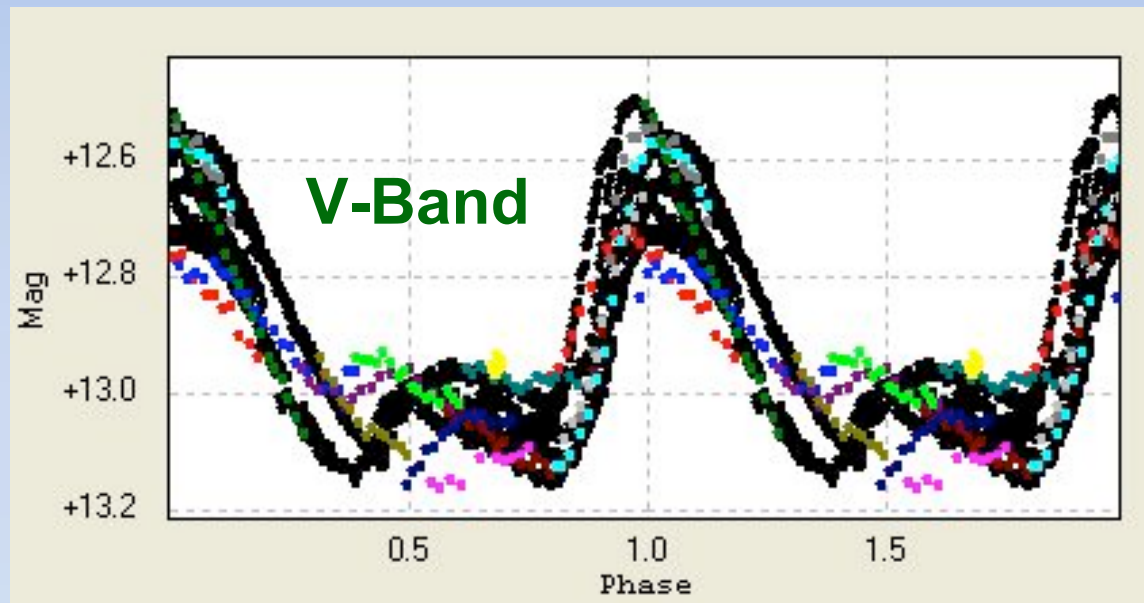
Toby Point Observatory, Narragansett, RI



Phase diagram for,  $P_0 = 0.4941$  days.  
235 stacks from 1109 **V-band** observations from 14 nights  
over an 89-day window (Jun – Sep 2008)

# NSVS 5222076 Observations

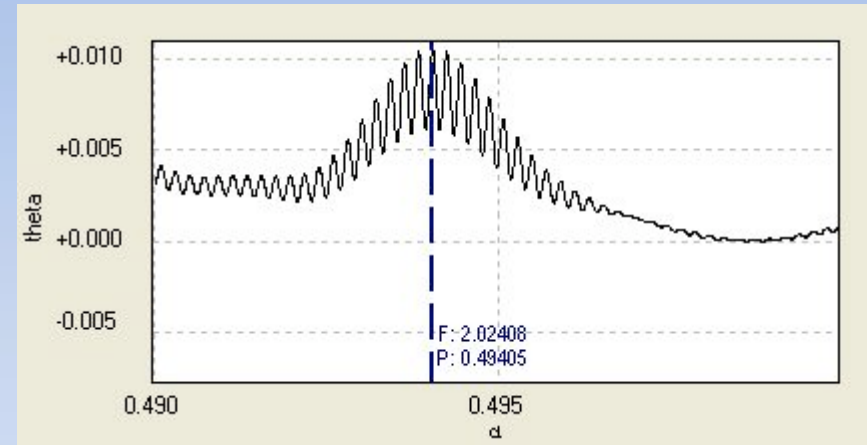
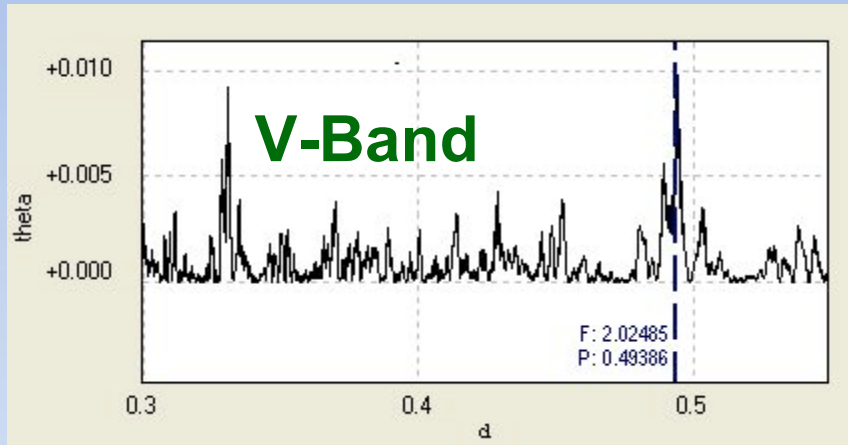
MSU **V-data** combined with TPO **V-data**



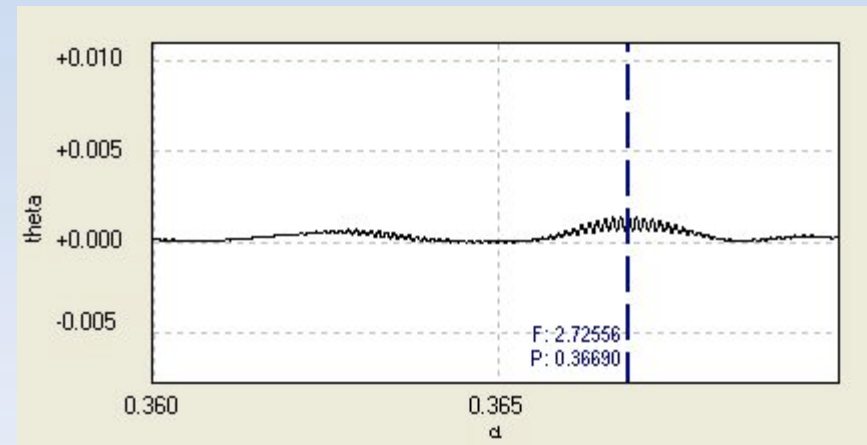
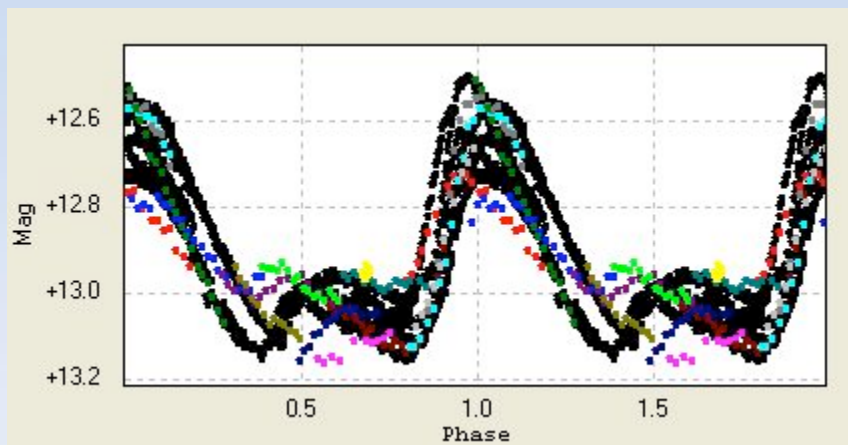
Phase diagram for,  $P_0 = 0.49405$  days.  
1570 MSU observations plus 235 TPO stacks  
from 29 nights over a 1306-day window (Feb 05 – Sep 08)



# MSU Combined with TPO V-data



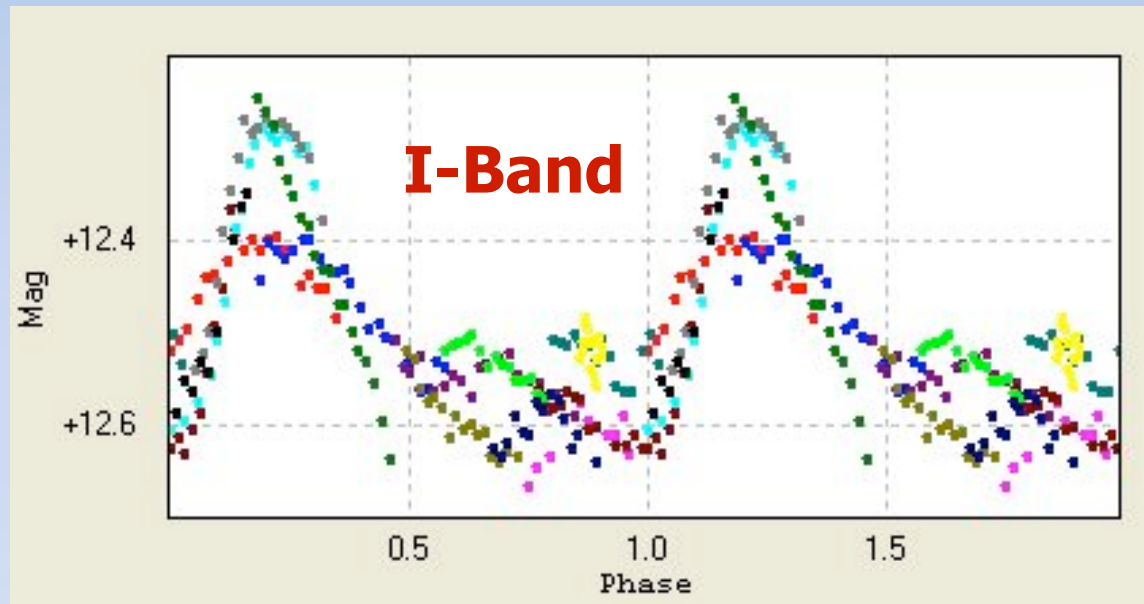
Refined period analysis:  
 $P_0 = 0.49405 \pm 0.00007$  days



1<sup>st</sup> overtone,  $P_1 = 0.36690 \pm 0.00003$  days

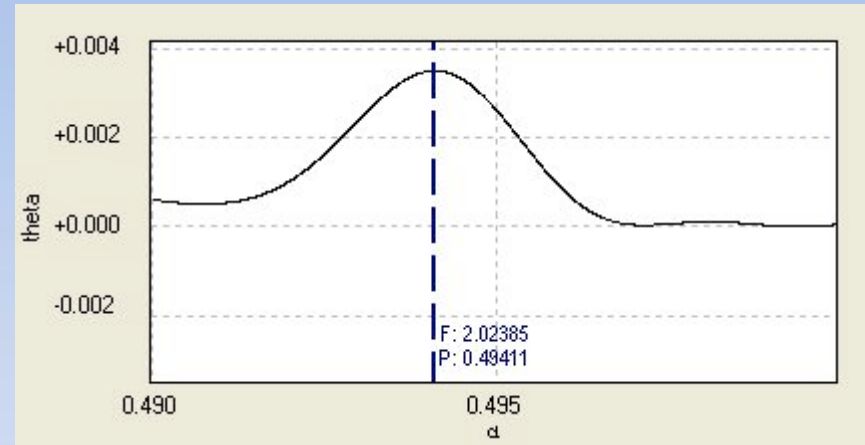
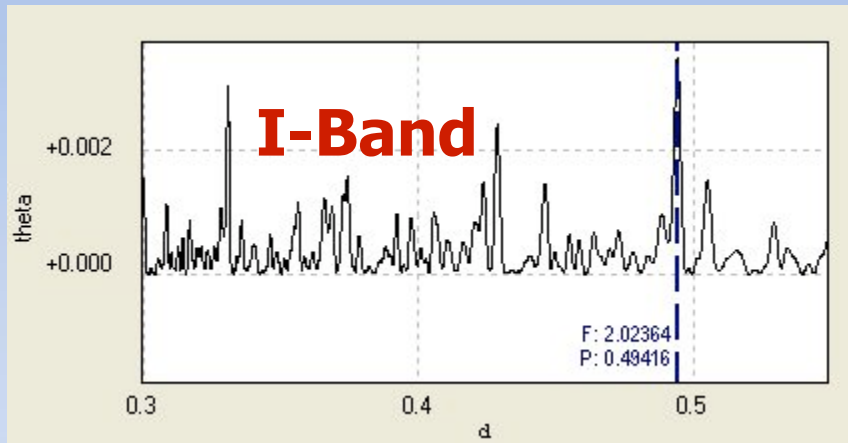
# NSVS 5222076 **I-Band** Observations

Toby Point Observatory, Narragansett, RI

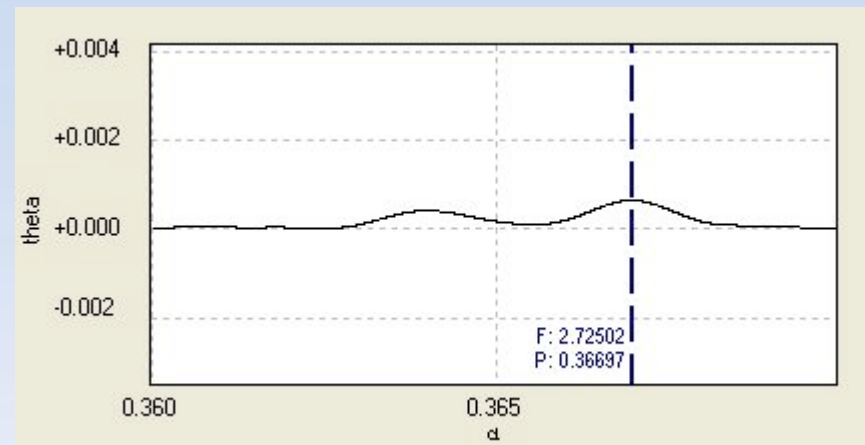
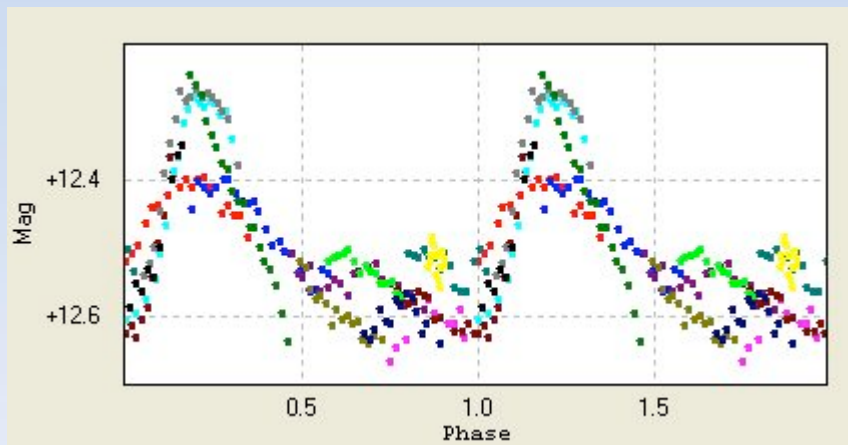


Phase diagram for,  $P_0 = 0.4941$  days.  
231 stacks from 1051 **I-band** observations from 14 nights  
over an 89-day window (Jun – Sep 2008)

# NSVS 5222076 I-Band Observations



Refined period analysis:  
 $P_0 = 0.4941 \pm 0.0011$  days



1<sup>st</sup> overtone,  $P_1 = 0.3670 \pm 0.0005$  days

# Determination of **V-I** Colors

Why high signal-to-noise ratio photometry is essential for determining **V-I** colors accurately:

$$V = 13.10 \pm 0.03$$

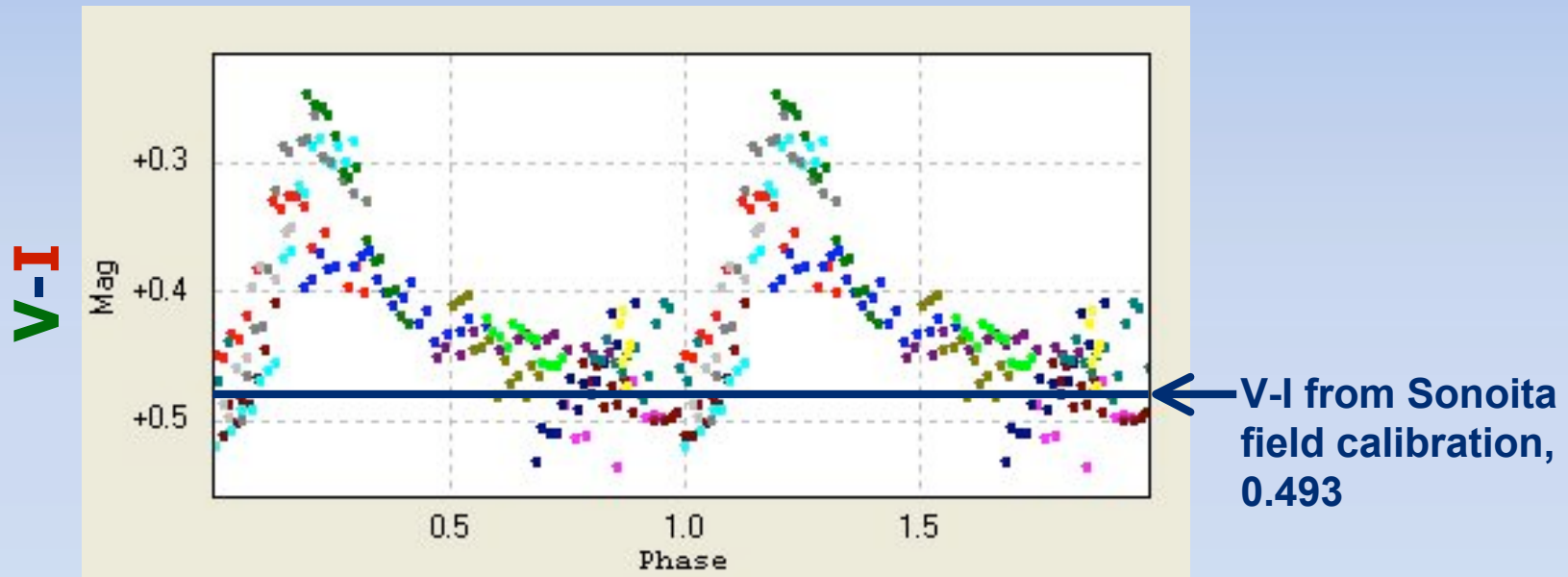
$$I = 12.60 \pm 0.03$$

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$$V - I = 0.50 \pm 0.06$$

# NSVS 5222076 V-I Colors

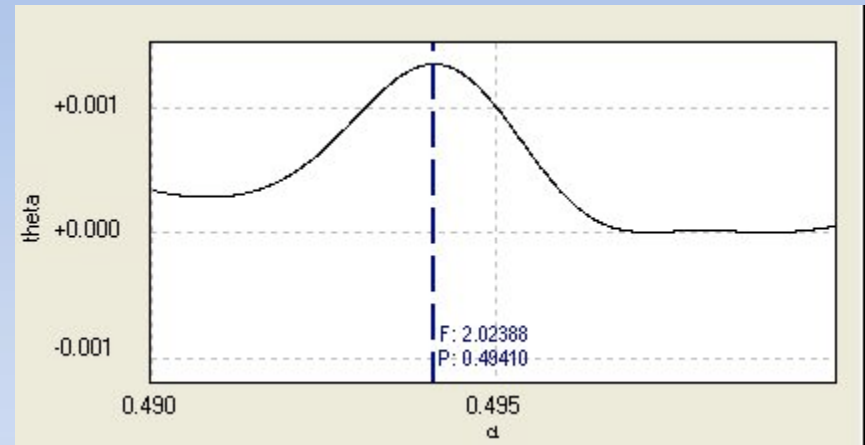
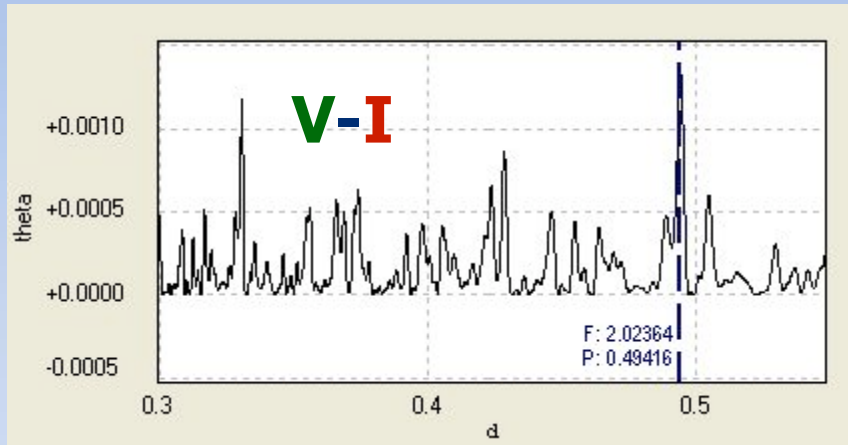
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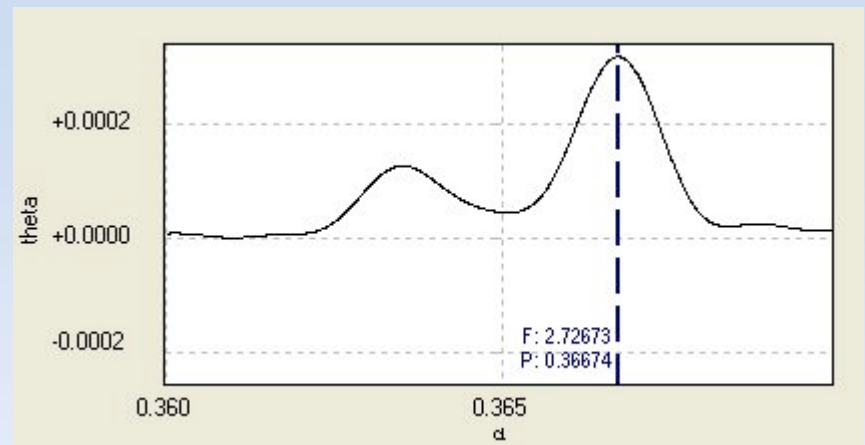
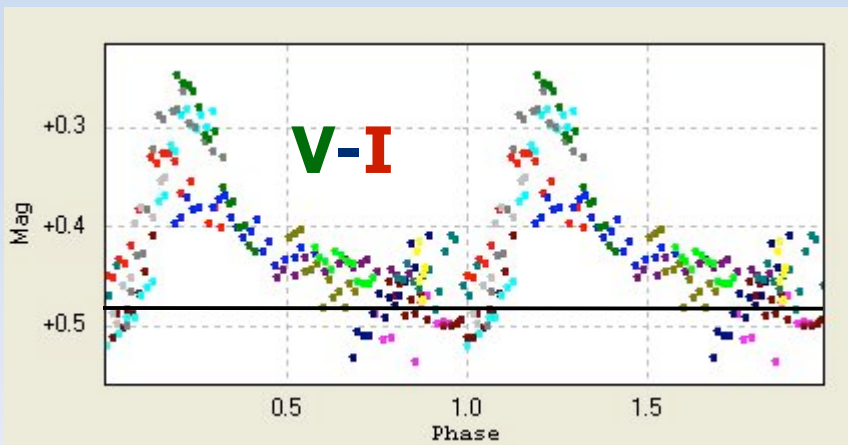
Phase diagram for,  $P_0 = 0.4941$  days.

201 **V-I colors** from 14 nights of stacked **V-band** and **I-band** images taken over an 89-day window (Jun – Sep 2008)

# NSVS 5222076 V-I Colors



Refined period analysis:  
 $P_0 = 0.4941 \pm 0.0012$  days



1<sup>st</sup> overtone,  $P_1 = 0.3667 \pm 0.0005$  days

# SUMMARY

## 1. Michigan State **V**-band observations successfully replicated.

### a. Estimated period errors improved by factors of 15 and 27.

#### MSU Data Alone

$$P_0 = 0.4940 \pm 0.0011 \text{ days}$$

$$P_1 = 0.3669 \pm 0.0008 \text{ days}$$

$$P_1 / P_0 = 0.743$$

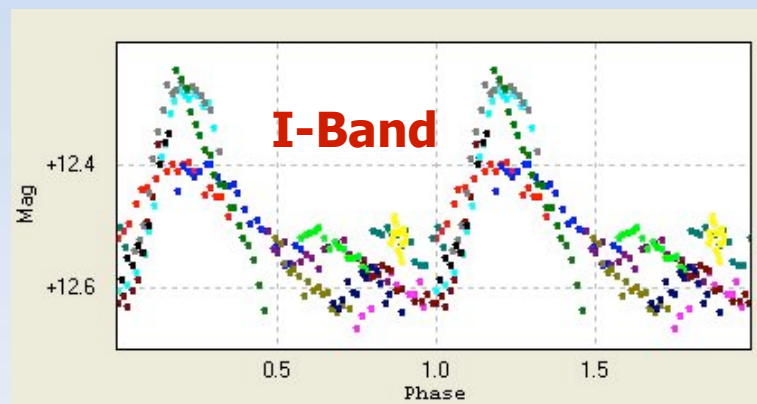
#### MSU plus TPO Data

$$P_0 = 0.49405 \pm 0.00007 \text{ days}$$

$$P_1 = 0.36690 \pm 0.00003 \text{ days}$$

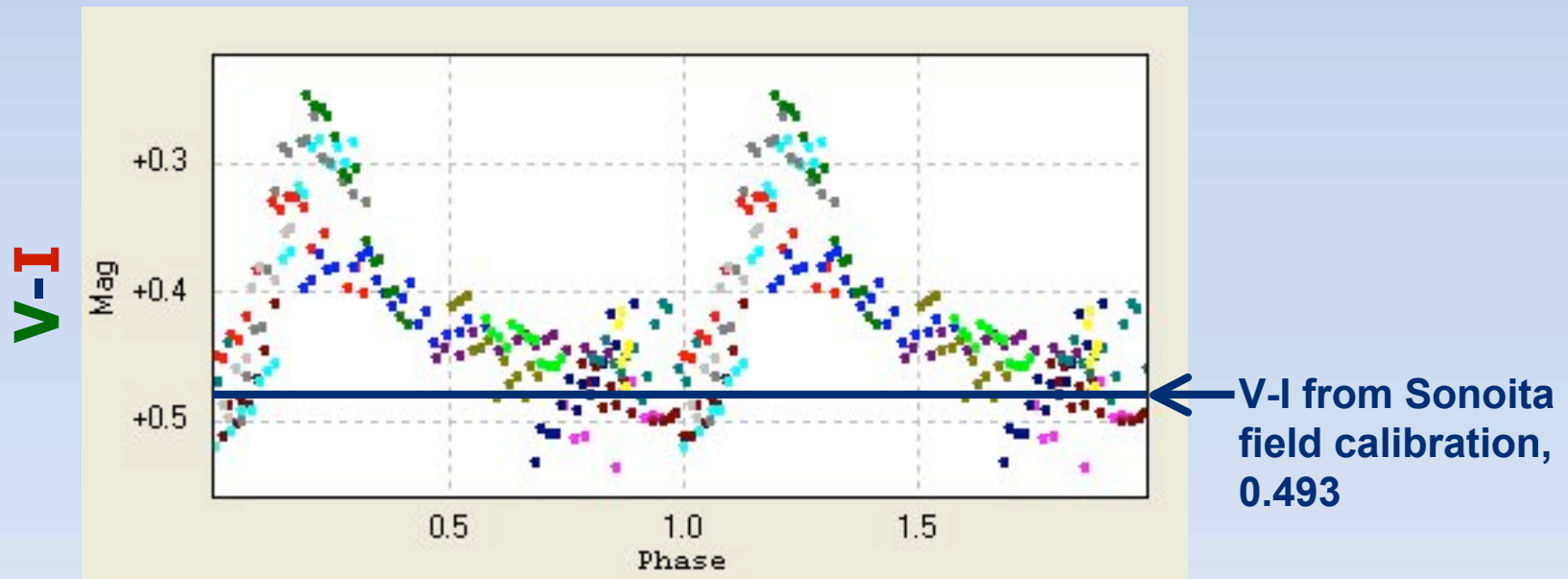
$$P_1 / P_0 = 0.7426$$

## 2. **I**-band observations and photometry were carried out.



# SUMMARY

3. **V – I** color variation of NSVS-5222076 has been estimated.





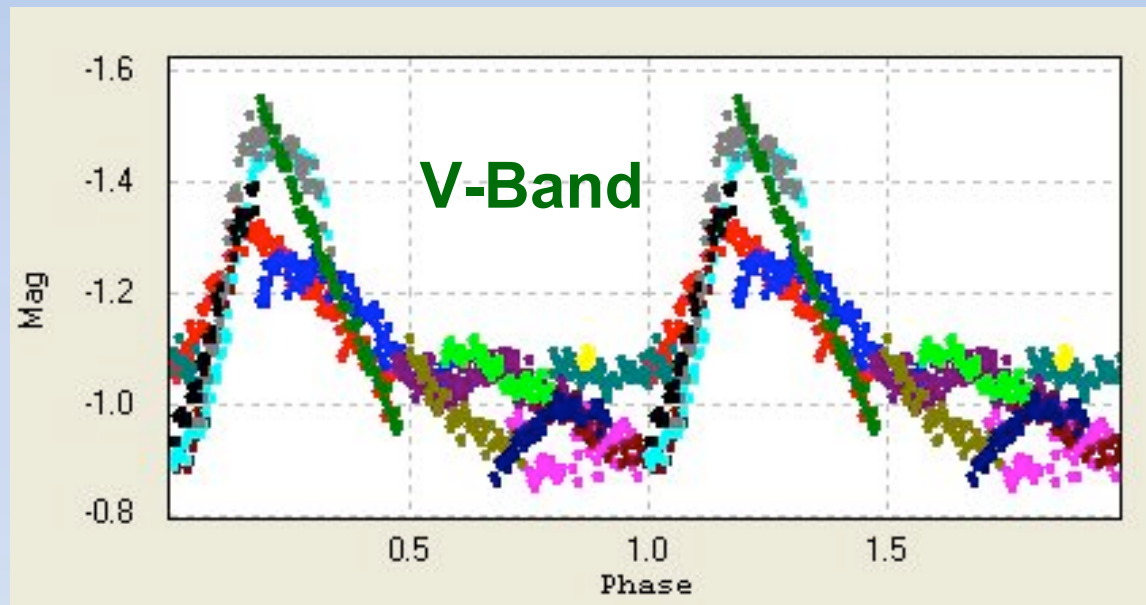
**QUESTIONS?**

**BACK-UP SLIDES**

# NSVS 5222076 V-Band Observations

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Delta Mag = Magnitude - 14.035

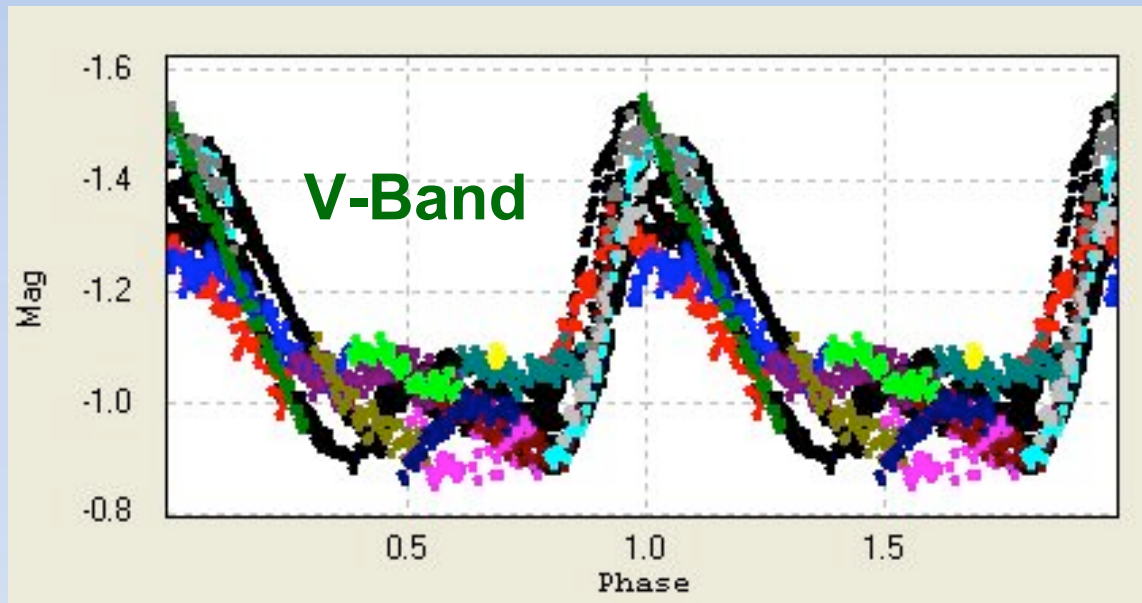


Phase diagram for,  $P_0 = 0.4942$  days.  
1110 **V-band** observations from 14 nights  
over an 89-day window (Jun - Sep 2008)

# NSVS 5222076 Observations

MSU V-data combined with TPO V-data

Delta Mag = Magnitude - 14.035

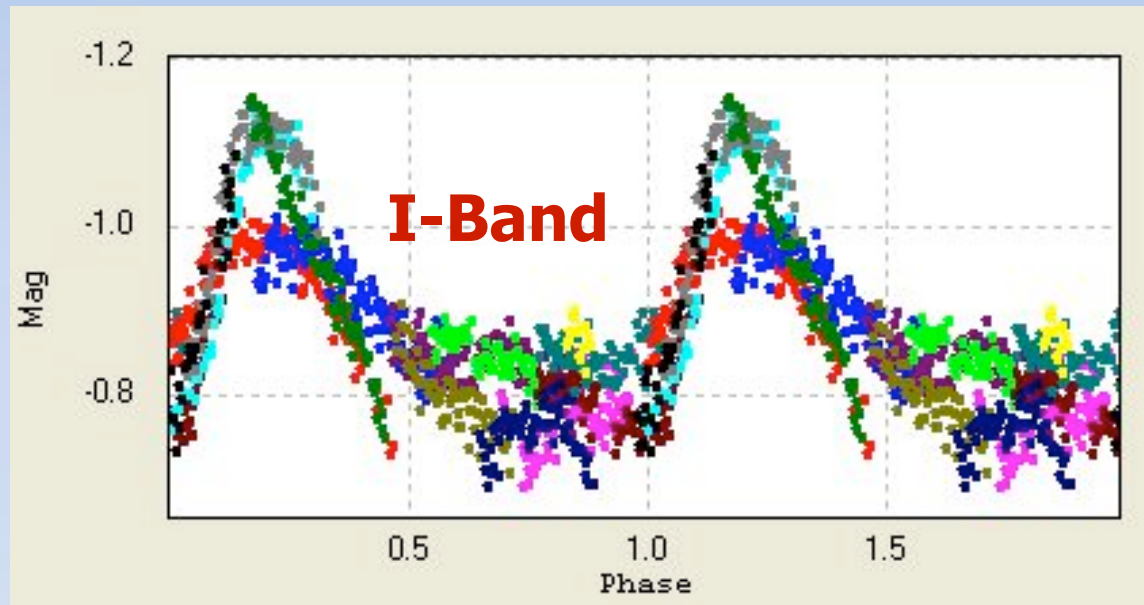


Phase diagram for,  $P_0 = 0.49405$  days.  
1570 MSU observations plus 1110 TPO observations  
from 29 nights over a 1306-day window (Feb 05 - Sep 08)

# NSVS 5222076 **I-Band** Observations

Toby Point Observatory, Narragansett, RI

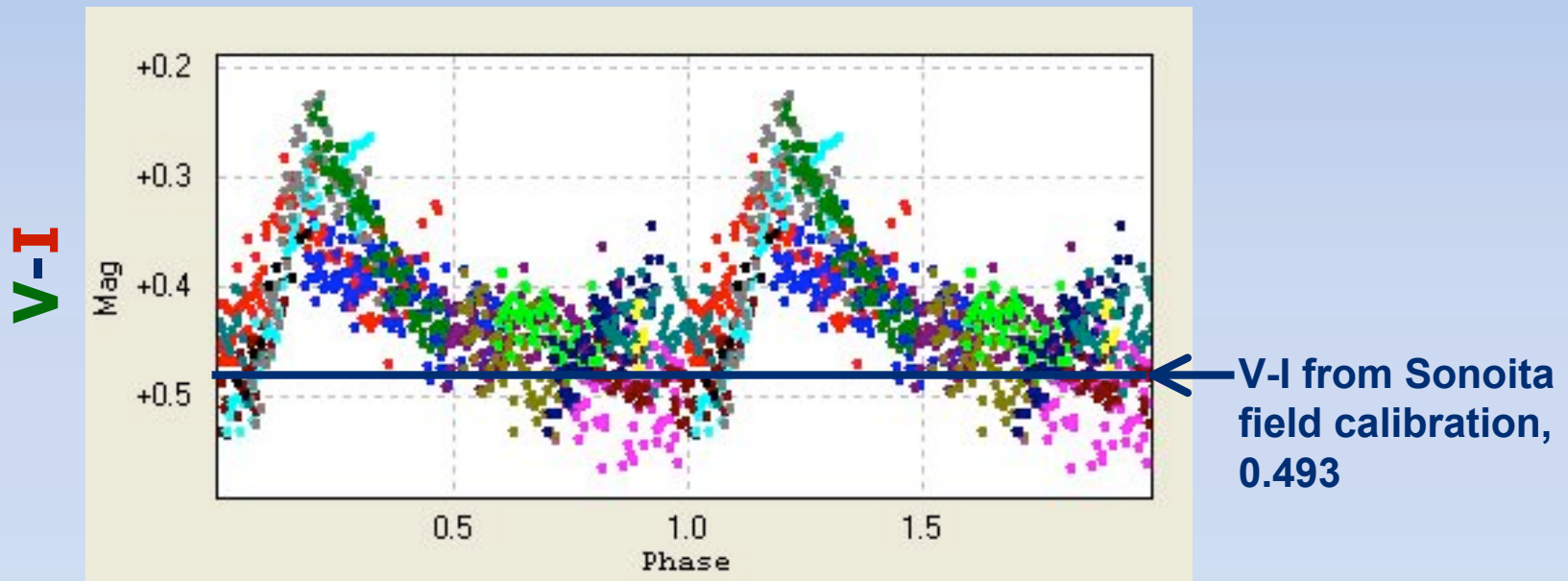
Delta Mag = Magnitude - 13.385



Phase diagram for,  $P_0 = 0.4942$  days.  
1062 **I-band** observations from 14 nights  
over an 89-day window (Jun - Sep 2008)

# NSVS 5222076 **V-I** Colors

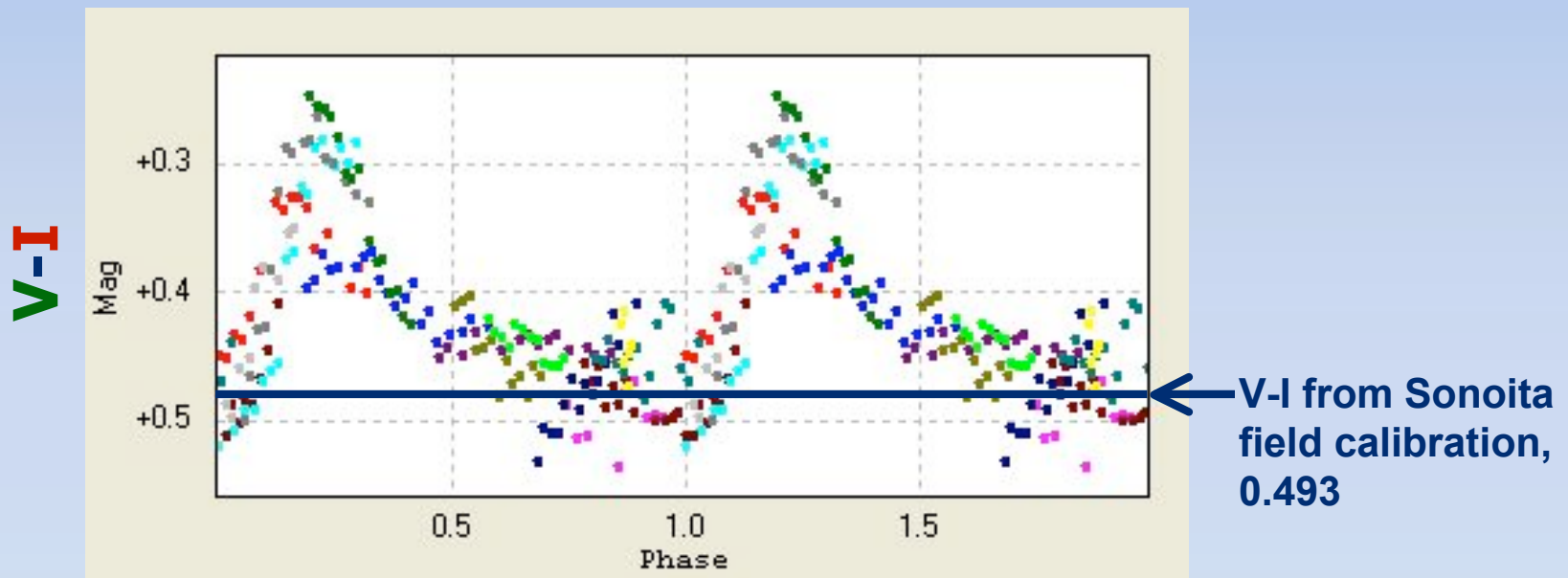
Toby Point Observatory, Narragansett, RI



Phase diagram for,  $P_0 = 0.4940$  days.  
969 **V-I colors** from 14 nights of **V-band** and **I-band** images  
taken over an 89-day window (Jun – Sep 2008)

# NSVS 5222076 **V-I** Colors

Toby Point Observatory, Narragansett, RI



Phase diagram for,  $P_0 = 0.4941$  days.  
201 **V-I colors** from 14 nights of stacked **V-band** and **I-band** images taken over an 89-day window (Jun – Sep 2008)