# Searching for Pulsating Stars in the Field of Intermediate-Age Open Cluster NGC 2126

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# Overview

# Introduction

**Stellar clusters** provide a sample of stars having the same age, distance and initial composition. Allow us to determine their physical properties using theoretical isochrone fitting. (e.g. Tapia et al., 2010; Glushkova et al., 2013).

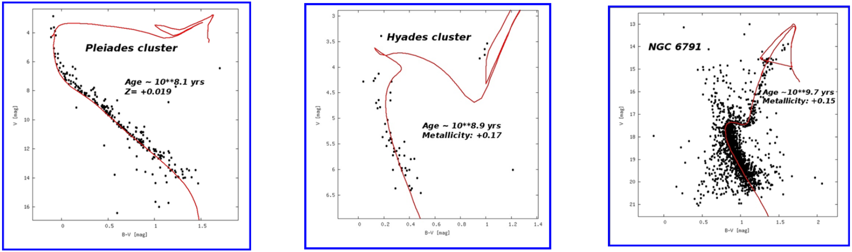


Figure 1: The CMD of three open clusters with the theoretical isochrone fitting (Credit: WEBDA database)

# Introduction

**Concept:**

"Stellar clusters represent snapshots of the process of stellar evolution. They are frozen in time from a human perspective."

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- **Cluster + pulsating stars**: set of constraints on the solution (i.e. pulsation models), stringent tests of stellar structure and evolution.
- This combination provides a set of constrain which allow to find more accurate solutions and to study the characteristics of stars and clusters together.

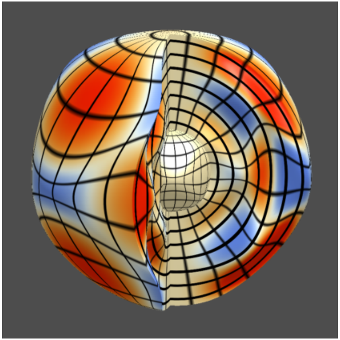

Figure 2: Model of a pulsating star (Credit: University of Wisconsin)

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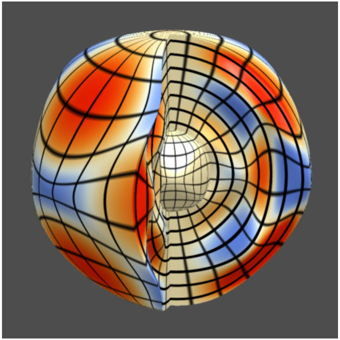

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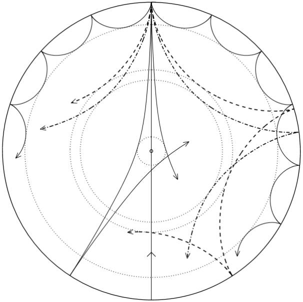

Figure 3: Low $l$-degree modes are penetrating close to core of the star (Cunha et al., 2007).

astero ⇒ star
seismos ⇒ oscillations
logos ⇒ discourse

The analysis of stellar oscillations enables the study of the stellar interior because different modes penetrate into different depths inside the star.

$$Y_l^m(\theta,\phi) = (-1)^m \sqrt{\frac{2l+1}{4\pi}\frac{(l-m)!}{(l+m)!}} P_l^m(\cos\theta)\exp(im\phi) \tag{1}$$

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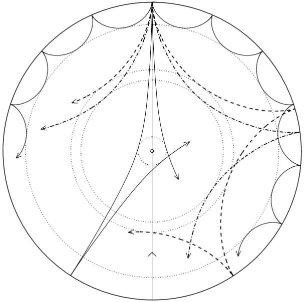

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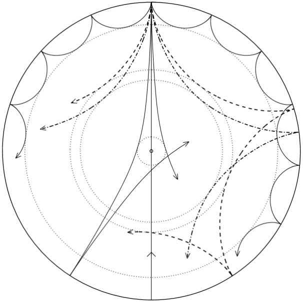

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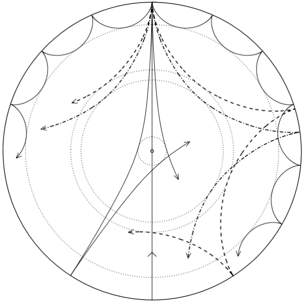

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# Pulsating Stars across the H-R diagram

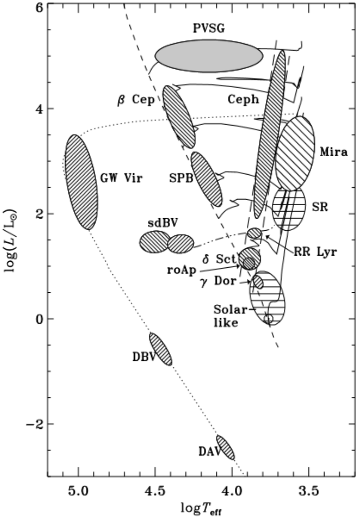


Figure 4: Pulsating stars across the HR diagram (Aerts et al., 2010).

# Distribution of the Variable Stars in Open Clusters

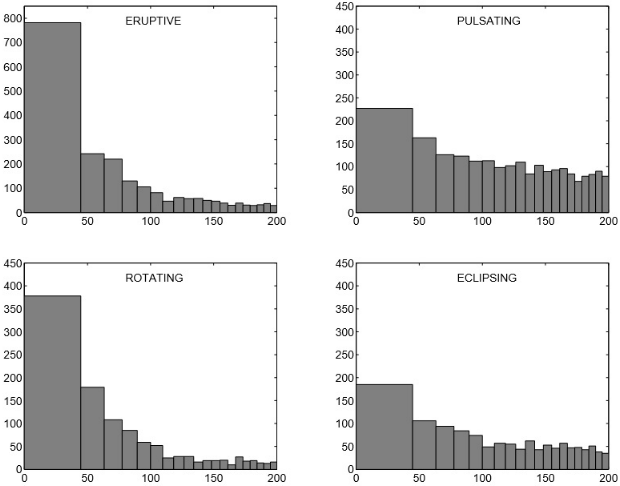


Figure 5: Distribution of the variable stars according to their distance from the centre (in cluster radii) in open clusters smaller than 60 arcmin in diameter (Zejda et al., 2012).

# Why NGC 2126?

- Open clusters with an age of 0.3-1 Gyr and a distance of 1-2 kpc are suitable for studying short-period pulsating stars, especially $\delta$ Scuti type stars (Frandsen and Arentoft, 1998).
- Faint open clusters aren't well investigated for the $\delta$ Scuti type pulsating stars.
- Gaspar et al. (2003) discovered multiperiodic $\delta$ Scuti pulsating stars, binary stars and one eclipsing binary with a pulsating component which was suspected to have a resonance of orbital to pulsations period makes this cluster interesting for a more detailed study about accurate resonances.

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# Observations

Figure 6: The 1-m telescope at Mount Lemmon Optical Astronomy Observatory, Arizona (LOAO)

# Observations

Figure 7: The 2.4-m telescope at Thai National Observatory (TNO)

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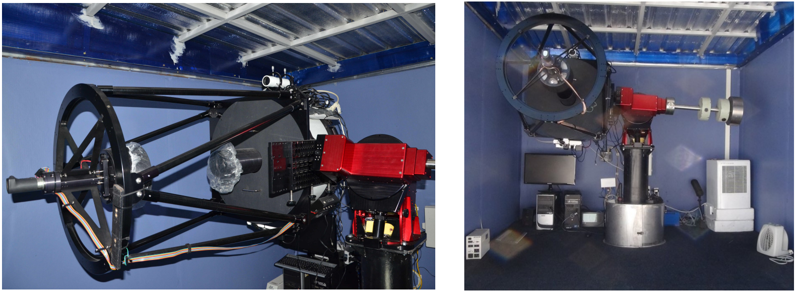

Figure 8: The 0.5-m telescope at Thai National Observatory (TNO)

# Observations and Data Reduction

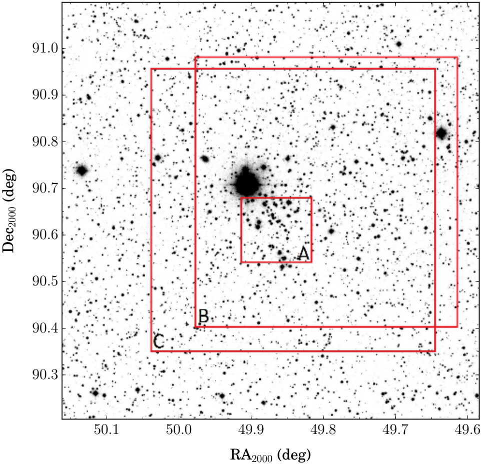


Figure 9: Digitized sky survey image of NGC 2126.

- The CCD frame processing was performed using the standard routines of CCDPROC in the IRAF package (Stetson, 1987) and we measured differential magnitude of the stars.
- For the photometric calibrations, we observed standard stars in the open cluster M 67 (Landolt, 1973).

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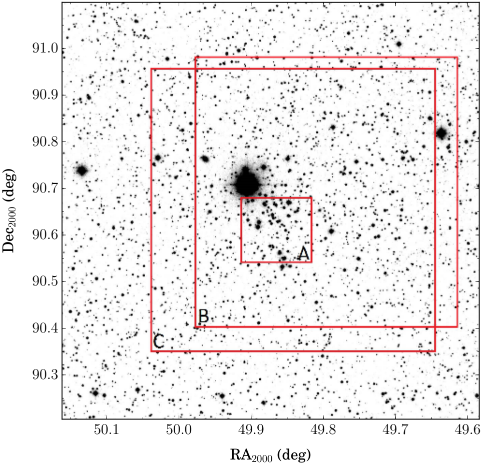


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# Data analysis: CMD

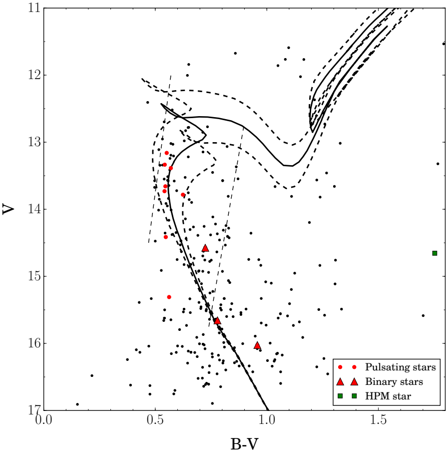


Figure 10: Color-magnitude diagram of the open cluster NGC 2126

- We fitted the theoretical isochrone to the data using the Padova isochrones library (Girardi et al., 2002).
- The best fit to the data by adopting: Z=0.019 (metallicity), $\log(t) = 9.1 \pm 0.1$
- A reddening of $E(B-V) = 0.27 \pm 0.01$ mag
- Distance modulus: $(m-M) = 10.80 \pm 0.05$ mag

# Period Analysis

- We performed a Discrete Fourier Transform (DFT) period analysis for all stars in the observed field of view showing any variability
- We used the algorithm Period04 (Lenz and Breger, 2005) in order to study the pulsation properties of the stars.
- In this procedure, we selected only peaks with signal-to-noise ratio (S/N) larger than 4 (Breger, 1993).
- From these period analyses, we distinguished in total eleven variable stars: three eclipsing binaries and eight pulsating variable stars. Two of them are new $\delta$ type pulsating stars according to their light variation behaviors and their position in the color-magnitude diagram (CMD).

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# New Pulsating Star: $\delta$ Scuti N1

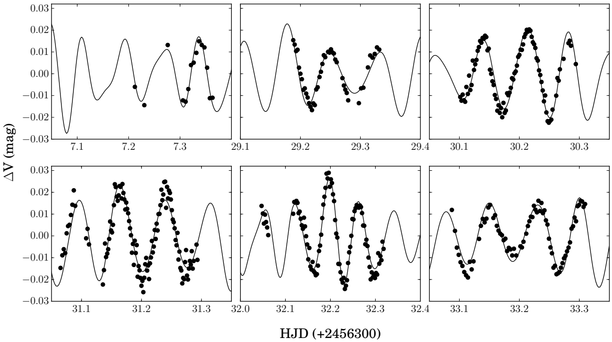


Table 1: Results of the nine-frequency fit to the $V$ light curve new variable star N1.

| $f_i$ | frequency(f) (c/d) | $\sigma_f$ (c/d) | amplitude(A) (mag) | $\sigma_A$ (mag) | phase($\phi$) (rad) | $\sigma_\phi$ (rad) | S/N |
|---|---|---|---|---|---|---|---|
| $f_1$ | 13.597445 | 0.000002 | 0.0156 | 0.0002 | 0.562 | 0.002 | 35.31 |
| $f_2$ | 17.173266 | 0.000008 | 0.0036 | 0.0002 | 0.714 | 0.010 | 8.24 |
| $f_3$ | 4.009167 | 0.000013 | 0.0024 | 0.0002 | 0.450 | 0.015 | 4.54 |
| : | : | : | : | : | : | : | : |
| $f_9$ | 21.827054 | 0.000018 | 0.0017 | 0.0002 | 0.881 | 0.021 | 4.74 |

# New Pulsating Stars: $\delta$ Scuti N2

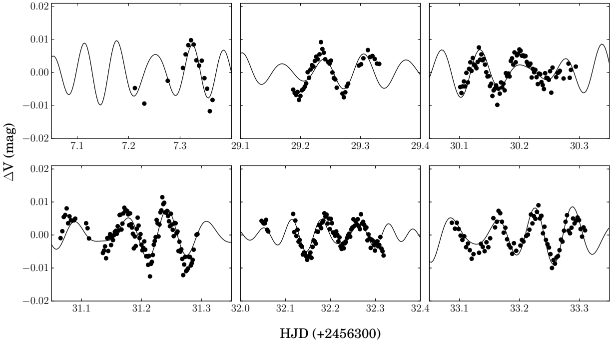


Table 2: Results of the six-frequency fit to the $V$ light curve new variable star N2.

| $f_i$ | frequency(f) (c/d) | $\sigma_f$ (c/d) | amplitude(A) (mag) | $\sigma_A$ (mag) | phase($\phi$) (rad) | $\sigma_\phi$ (rad) | S/N |
|---|---|---|---|---|---|---|---|
| $f_1$ | 14.552467 | 0.000006 | 0.0037 | 0.0002 | 0.174 | 0.006 | 13.64 |
| $f_2$ | 15.284740 | 0.000010 | 0.0021 | 0.0002 | 0.647 | 0.011 | 7.77 |
| $f_3$ | 19.073477 | 0.000014 | 0.0014 | 0.0002 | 0.586 | 0.017 | 5.76 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| $f_6$ | 14.086533 | 0.000016 | 0.0012 | 0.0002 | 0.933 | 0.019 | 4.44 |

# Results

Table 3: Summary of 11 new and known variable stars in NGC 2126

| ID | Name | RA | Dec | V | B-V | Type |
|---|---|---|---|---|---|---|
| V1 | V546 Aur | 06:01:44.15 | +49:56:30.4 | 13.76 | 0.68 | $\gamma$Dor |
| V2 | V547 Aur | 06:01:57.42 | +49:58:55.0 | 14.26 | 0.68 | $\gamma$Dor |
| V3 | V548 Aur | 06:02:05.27 | +49:49:11.4 | 15.15 | 0.72 | $\delta$Sct |
| V4 | V549Aur | 06:02:21.33 | +49:52:37.2 | 15.75 | 1.01 | EA |
| V5 | V550 Aur | 06:02:26.43 | +49:51:56.6 | 12.81 | 0.67 | $\delta$Sct |
| V6 | V551 Aur | 06:02:38.27 | +49:53:04.7 | 14.27 | 0.84 | EA |
| ZV1 | - | 06:02:33.07 | +49:42:47.7 | 13.05 | 0.70 | $\delta$Sct |
| ZV2 | - | 06:02:21.77 | +49:52:23.6 | 13.33 | 0.67 | Hybrid |
| ZV3 | - | 06:02:20.11 | +49:48:23.7 | 15.40 | 0.84 | EA |
| N1 | - | 06:02:38.74 | +49:52:45.1 | 13.34 | 0.54 | $\delta$Sct |
| N2 | - | 06:02:27.46 | +49:50:27.5 | 13.73 | 0.54 | $\delta$Sct |

# Conclusions

- We have estimated important physical parameters of the cluster with standard photometric methods.

- We have detected eleven variable stars in a field of the cluster. Eight are pulsating stars, three are eclipsing binaries, one of them is eclipsing binary with a pulsating component.

Table 4: The summary of variable stars in the open cluster NGC 2126

| Variable Type | Number of star | ID |
|---|---|---|
| Short period variables | 6 | V3, V5, ZV1, ZV2, N1, N2 |
| Long period variables | 2 | V1, V2 |
| Algol type binary (EA) | 2 | ZV3, V3 |
| Eclipsing with pulsating star | 1 | V6 |
| Total | 11 | - |

- Spectroscopic data for all variable stars are needed to study more detail about individual stars.

# Acknowledgments


- D. Mkrtichian, P. Lampens and S. Komonjinda.
- Department of Physics and Materials Science, Chiang Mai University (CMU)
- Development and Promotion of Science and Technology Talents Project (DPST).
- The Royal Observatory of Belgium (ROB)
- The National Astronomical Research Institute of Thailand (NARIT)
- The International Astronomical Union (IAU)

# Thank you