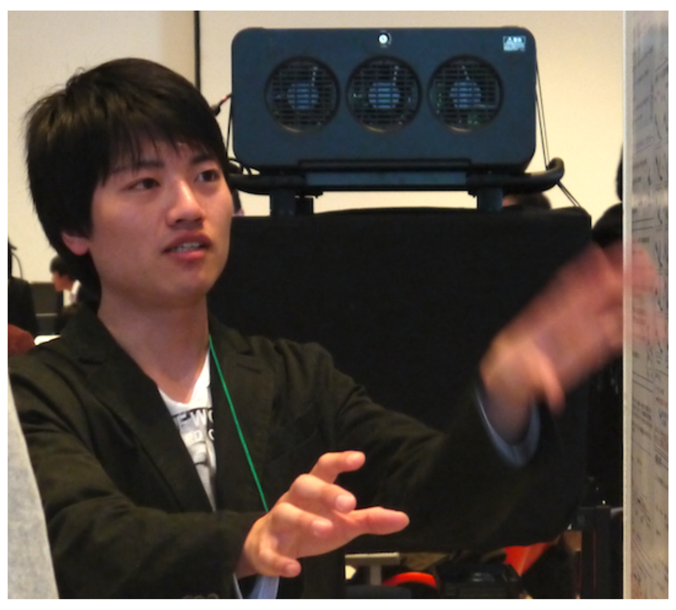

The nature in broadband photometry of long secondary periods in AGB stars

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Abstract

About 30-50% of luminous red giant variables show additional long period variations other than their pulsations. This is called long secondary period (LSP). In several oxygen-rich stars showing LSPs, J-K_s color barely changes or even becomes bluer when a star dims (Takayama et al. 2015). The origin of the LSP is unknown. We analyzed the long-term optical near-infrared light variations of a large number of red giant variables with LSP in the Small Magellanic Cloud (SMC) using data from OGLE (Optical Gravitational Lensing Experiment) and long-term JHK_s observations. A sample of 36 oxygen rich stars and 25 carbon stars, which showed well-periodicity, were obtained. By a fit with a first-order Fourier series, we derived the $VIJHK_s$ light amplitudes in every stars. In most amplitude-amplitude diagrams except ΔI vs ΔK_s, the oxygen-rich stars and the carbon stars showed distinctions in the inclinations of the slopes. This suggest that the temperature, density and pressure of the gas of the stellar atmosphere may change during the LSP cycle. Therefore transit in an eclipsing binary, which has been discussed as the possible explanation of LSP, would be ruled out. The slope of the oxygen-rich stars on (ΔJ, ΔK_s) diagram was slightly steeper than 1. In the oxygen-rich stars, the phase lags between the J band and K_s band light curves were small, and the median value was about -0.04. This implied that the bluing in J-K_s color as Takayama et al. found would be caused due to not the phase lag between J and K_s light curves but the larger K_s amplitudes than J's.

1, What is the LSP?

Sequences A', A and B on PL diagram (Fig. 1)・・・ "OSARGs", radial and non-radial pulsation (e.g. Takayama et al. 2013)

C' and C ・・・ "Mira/SR", radial fundamental (C) and first (C') overtone modes (e.g. Ita et al. 2004)

E ・・・ "eclipse/ellipsoidal variability", close binary (Wood et al. 1999)

D ・・・ "long secondary period", the origin is unknown (e.g. Wood et al. 1999, Takayama et al. 2015)

Why has it been unsolved?

Pulsation model ・・・ The radial pulsation is ruled out because LSP generally 4 times longer than the period of radial fundamental mode in red giants. The g^+ mode is also done because of the thick convection envelope in a red giant (Wood et al. 1999).

Eclipsing binary ・・・ Such longer periods can be easily explained by orbital periods. The typical companion mass expected from the radial velocity variations is about $0.09M_{\odot}$. It is, however, too small to agree with binary population (i.e. brown dwarf desert) (Wood et al. 2004).

Dust formation ・・・ Some LSP stars showed a mid-IR excess which implied dust clouds around a star. But no dust composition which can explain the light amplitudes and color variations in optical and near-IR band have been found (Takayama et al. 2015).

Rotating spotted star ・・・Spot model showed that the observed light amplitudes can be explained by assuming a large spot but it can not explain the amplitude of the variations in most broadband colors (e.g. I-J) (Takayama et al. 2015).

We didn't still reach a step to understand whether a star intrinsically varies during the LSP cycle.

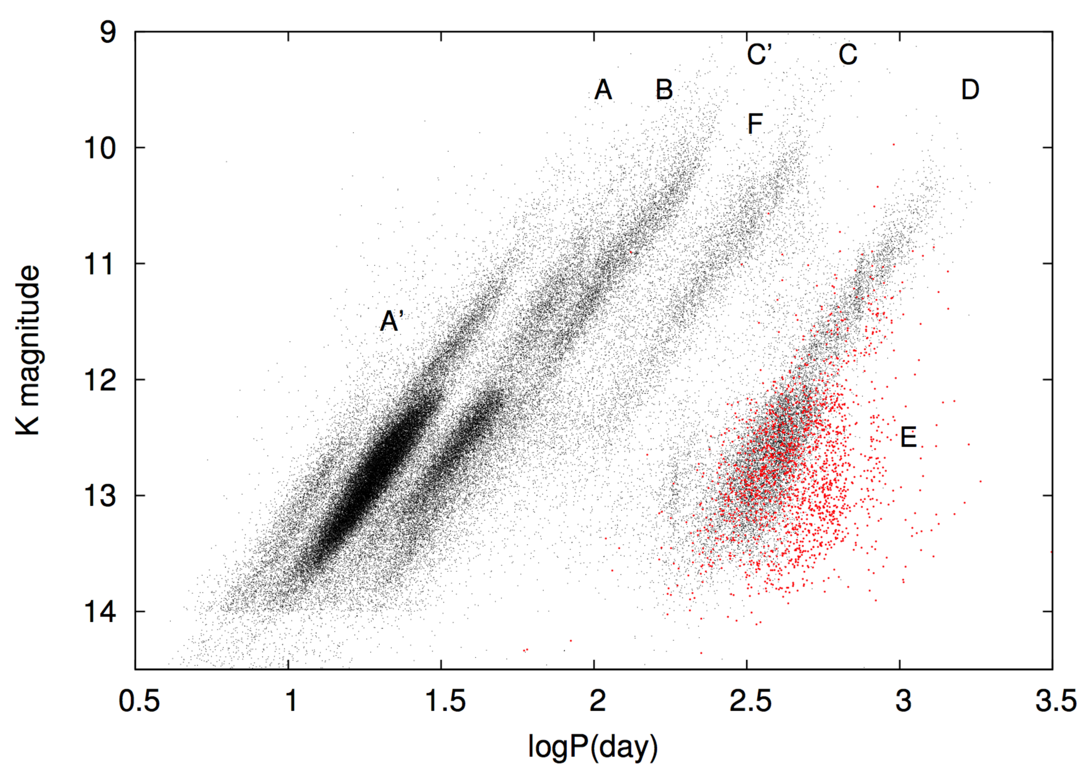

Fig. 1 Period-Luminosity relations in the red giant variables obtained by OGLE in the LMC.

2, Database

*OGLE V&I bands observations in the SMC ・・・ 1997-2009 (Soszynski et al. 2011)

*JHK_s observations with IRSF/SIRIUS camera in the SMC ・・・ 2001-2009 (Ita et al. in prep)

*List of the LSP stars in the SMC ・・・ Soszynski et al. 2011

->Period analysis using a first order Fourier series for a fit to the observed light curves. A sample of 36 oxygen-rich stars and 25 carbon stars, which show a better periodicity in each of I, J and K_s light curve, were obtained.

3, Result and discussion

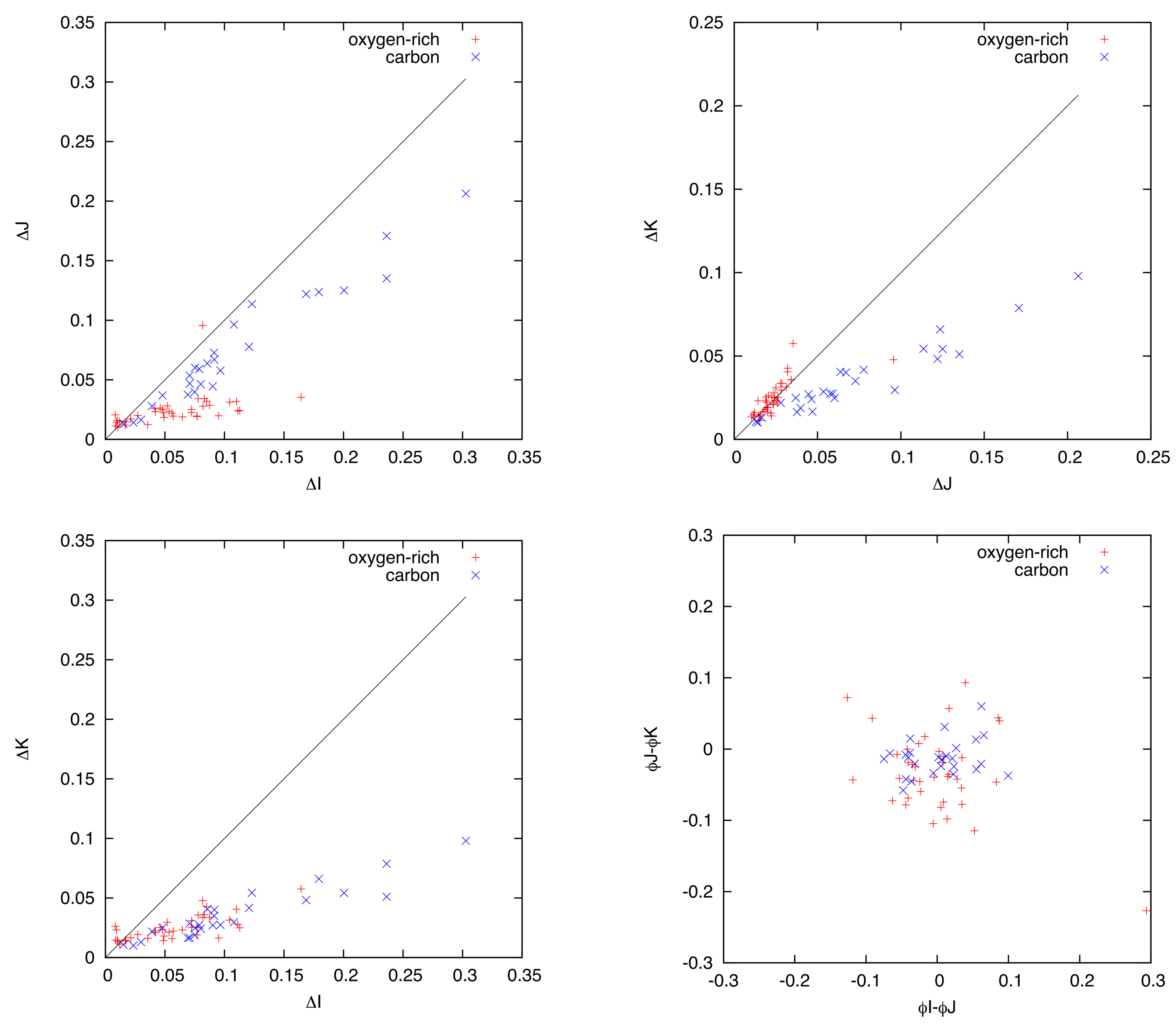

Fig. 2 ***Upper two panels and bottom left panel*** : Amplitude-amplitude diagrams. The red pluses show a sample of the oxygen-rich stars while the blue crosses are the carbon stars. The black solid lines on each panel show the line of y=x. ***Bottom right panel*** : Phase lags between two light curves among $IJHK_s$ bands. *The symbols are same as above.*

By combining data from OGLE and the long-term near-IR observations, we investigated the distributions of the light amplitudes in each spectral type of the stars (i.e. oxygen-rich stars and carbon stars). The upper two panels and the bottom left panel in Figure. 2 show the amplitude-amplitude diagrams. To determine the amplitudes, a first-order Fourier series was used for a fit to the folded light curves with the period of the I band light curves

$$m(\Phi)=m_0+\alpha\sin[2\pi\Phi+\pi\beta] \quad (-1 \le \beta \le 1), \qquad \text{-(1)}$$

$$\Phi_{obs}=(t_{obs}-2450000)/P - [(t_{obs}-2450000)/P]. \qquad \text{-(2)}$$

Phase of 0 in the folded light curves was determined at HJD2,450,000. The (ΔI, ΔK_s) diagram shows that the amplitudes in the oxygen-rich stars and the carbon stars grow up with similar slopes. While in the (ΔI, ΔJ) and (ΔJ, ΔK_s) diagrams one can see the difference of the inclination of the slopes between the two spectral types and ΔK_s in the oxygen-rich stars are even slightly larger than ΔJ. As Derekas et al. (2006) found, eclipsing binaries like sequence E are expected similar light amplitudes between different wavelength, and it should be same in both oxygen-rich star and carbon star. However the photometric nature of LSPs depends on the spectral types (i.e. surface chemical compositions) of the stars. This implies that the temperature, density and pressure of the gas of the stellar atmosphere would change with the LSP, and transit in an eclipsing binary can be ruled out from the explanation of the origin of the LSPs. One of possible eclipsing binary models which may be able to explain the distinction between oxygen-rich stars and carbon stars is a binary system with a red giant having temperature gradient on the stellar surface such as hot and cool regions.

The bottom right panel of Figure. 2 shows the differences of the initial phases (β) in two different light curves. Note β was determined by Eq. (1) with period derived from the I band light curves. In both the oxygen-rich and carbon stars, the values of both $|\Phi I-\Phi J|$ and $|\Phi J-\Phi K|$ are smaller than about 0.1. The median value of the $\Phi J-\Phi K$ in the oxygen-rich stars is -0.039. Takayama et al. (2015) found that in the oxygen-rich stars J-K_s color barely changes or even becomes bluer when a star dims. Our result implied that the bluing in J-K_s color would be caused due to not the phase lag between J and K_s light curves but the larger ΔK_s values than ΔJ. The possible interpretation of such larger K_s amplitudes is broadband absorption near 1.9μm by H_2O molecules in the stellar atmosphere as mentioned by Takayama et al. (2015). This also indicates a possibility that a star intrinsically varies with the LSP.

Reference

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