Incidence of High-Amplitude δ Scuti-Type Variable Stars

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(Received 2007 November 15; accepted 2008 January 24)

Abstract

An order-of-magnitude estimate for the incidence of high-amplitude δ Scuti-type variable stars (HADS) in the δ Scuti area of the H–R diagram was calculated. Using a model for the stellar distribution in the Milky Way, we calculated the number of stars that are expected to fall in the δ Scuti area of the H–R diagram within the magnitude range and sky coverage of the ROTSE Survey for Variables I (RSV1). The incidence of the HADS phenomenon was then obtained by comparing the number of stars calculated by the model with the actual, observed number of HADS in the RSV1. We find that ~ 0.24% of the stars that lie in the δ Scuti area of the H–R diagram within the RSV1 observational limits exhibit the HADS phenomenon. This number is much lower than the incidence of low-amplitude δ Scuti stars (LADS), ≥ 1/3, implying that the HADS phenomenon takes place in a very small fraction of stars and/or its duration is very short, compared to the LADS.

Key words: Galaxy: structure — methods: statistical — stars: Hertzsprung–Russell diagram — stars: statistics — stars: variables: delta Scuti

1. Introduction

Δ Scuti stars are pulsating variables located in the lower part of the classical Cepheid instability strip on and just above the main sequence in the Hertzsprung–Russell (H–R) diagram with spectral types roughly from A2 to F2 and periods between ~ 0.04 and ~ 0.25 d. They are astrophysically interesting variables, since their pulsations may provide important information about their astroseismological properties. While the low-amplitude Δ Scuti stars (LADS) tend to be nonradial pulsators with high rotational velocities, high-amplitude Δ Scuti stars (HADS) are mostly radial pulsators with small rotational velocities (Breger 2000; McNamara 2000a). Following Breger (HADS) are mostly radial pulsators with small rotational velocities (Breger 2000), we adopt \( \Delta m_V > 0.3 \) mag for the definition of HADS.

An immense number of scientific studies concerning Δ Scuti stars have taken place during the past few decades (see the references in Breger 2000). Rodríguez and Breger (2001) showed statistical results concerning the physical properties of 636 Δ Scuti stars discovered by individual and all-sky survey(s), but HADS are still relatively less studied variables. For example, one-third to one-half of the stars located in the lower instability strip are known to show photometrically detectable light variability due to pulsation with an amplitude limit of between 0.003 and 0.010 mag (Breger 2000), and about one-fourth of the solar-neighborhood stars in the lower instability strip are found to be variable (Poretti et al. 2003), but the incidence of the HADS phenomenon is almost unknown. HADS are particularly interesting variables, because they show relatively large-magnitude variations compared to their short periods. Information on the incidence of these variables would help us to better understand the nature and evolution of this type of pulsating star.

In the present work, we calculated the number of stars that are expected to fall in the δ Scuti area of the H–R diagram for the magnitude range and sky coverage of the ROTSE (Robotic Optical Transient Search Experiment) Survey for Variables I (RSV1: Akerlof et al. 2000) catalog. By comparing this number with the actual, observed number of HADS in the RSV1, we estimated the occurrence frequency of HADS in the δ Scuti area of the H–R diagram.

2. The ROTSE Survey for Variables I

Observations used for the present study were taken by ROTSE-I, an array of four telescopes, each with an 8′ × 8′ field of view (Akerlof et al. 2000). The ROTSE telescope was operated without any filters so that the spectral response would be primarily limited by the sensitivity of the CCD. Designed to find optical counterparts to gamma-ray bursts, it took most of its time to automatically survey the entire visible sky twice each night.

While no filters were used for the ROTSE observations, the star count model adopted in the present work involved magnitudes in conventional photometric systems. Thus, a transformation from a certain photometric system to the ROTSE magnitude was necessary. We adopted the empirical transformation from the \( B \) and \( V \) magnitudes to the ROTSE magnitude that Akerlof et al. (2000) obtained by comparing the Tycho catalog (ESA 1997) and ROTSE observations:

\[
m_{\text{ROTSE}} = 0.5 + m_V - \frac{m_B - m_V}{1.875}.
\]  

A constant of 0.5 was inserted here to compensate for the magnitude discrepancy between the Tycho and ROTSE data.
The RSV1 is the result of analyzing 5% of the available ROTSE all-sky data over a period of 3 months (1999 March 15 to June 15). It covers a Galactic latitude range of $b = 13^\circ$–$88^\circ$ and a longitude range of $l = 10^\circ$–$80^\circ$. Out of the 1781 variable stars detected (mean magnitudes between $m_{\text{ROTSE}} = 10.0$ and 15.5 mag), 91 variables, of which three are known from the General Catalog of Variable Stars (GCVS: Kholopov et al. 1998), have been classified into the $\delta$ Scuti type by the RSV1.

However, some of the $\delta$ Scuti stars have light curves (or, periods and amplitudes) similar to those of W Ursae Majoris (W UMa) type eclipsing binaries, which are often misclassified as $\delta$ Scuti-type pulsating stars, particularly when the number of observing epochs are not enough, or less-rigorous criteria are used in automated classifications. Poretti (2001) and Morgan (2003) showed that Fourier decomposition can be an effective way to identify some pulsating stars, such as HADS, RRc, and RRab stars.

Jin et al. (2003, 2004) conducted follow-up observations for 49 $\delta$ Scuti stars in the RSV1 catalog, whose Fourier parameters show $\delta$ Scuti signatures, and found that only 6 of them (see table 1) are bona fide $\delta$ Scuti stars, and that most of the rest are W UMa stars (note that all of the 6 bona fide $\delta$ Scuti stars are HADS). Judging from the Fourier parameters of the remaining 43 stars, it is quite unlikely that there are additional bona fide HADS in the RSV1 catalog. We thus conclude that the number of HADS in the RSV1 survey is $\lesssim 6$; this number will be compared in section 5 with the number of $\delta$ Scuti candidates in the magnitude and spatial coverage of the RSV1 in order to determine the incidence of the $\delta$ Scuti phenomenon.

We chose the RSV1 survey for this comparison, because its $\delta$ Scuti content has been thoroughly studied, and the number of bona fide HADS in the survey is reliably given.

### 3. Observational Completeness

Since the discovery of variable stars is not the primary goal of the ROTSE-I experiment, the RSV1 catalog may not be complete. Indeed, the number of available epochs during the three-month period for each star ranges from only 40 to 110. However, Akerlof et al. (2000) found that more than 80% of the RR Lyrae and $\delta$ Scuti stars of the GCVS in the RSV1 survey area with $m_V$ between 10 and 13 mag are recovered in the RSV1 catalog.

We conducted a similar test with the All Sky Automated Survey (ASAS: Pojmanski 2002) data that overlap the RSV1 catalog in both magnitude range and sky coverage. The latest catalog of the ASAS (ASAS-3 Catalog of Variables Stars) contains almost 8000 periodic pulsators and over 10000 eclipsing binaries located in the southern hemisphere below the declination $+28^\circ$ with $m_V < 14$ mag. Inspections between RSV1 variables and ASAS $\delta$ Scuti stars with $\Delta m_V > 0.3$ mag and periods of less than 0.3 d led to 20 ASAS $\delta$ Scuti stars in the RSV1 area. Out of the 20, 11 stars were detected as variables by the RSV1, resulting in a recovery fraction of 55%.

We conclude that the detection efficiency of the HADS in the RSV1 survey is at least $\sim 50\%$ for $m_V < 14$ mag.

### 4. The Star Count Model of the Milky Way

A detailed model by Wainscoat et al. (1992) for the point source sky that comprises geometrically and physically...
Fig. 1. Luminosity functions in ROTSE magnitude from the model (thin lines) and the NSVS data (thick lines) toward 12 circular regions of a 1° radius within the spatial coverage of the RSVI. The histograms are shown for the magnitude range of the NSVS, $10 \leq m_{\text{ROTSE}} \leq 15.5$. 
realistic representations of the Galactic disk, bulge, stellar halo, spiral arms, molecular ring, and the extragalactic sky is used to calculate the number of stars that fall in the δ Scuti area of the H–R diagram, i.e., stars with a luminosity class of V and a spectral type between A6 and F0. In this model, galactic components are represented by 87 types of the Galactic source, each fully characterized by scale heights, space densities, and absolute magnitudes at $BVHK$, 12 μ, and 25 μ.

Out of the 87 source types considered in the star count model, two correspond to the HADS: A2–5 V and F0–5 V. Considering the number of stars within 100 pc from the Sun as a function of spectral type, we apply weights of 0.16 and 0.13, respectively, to the forementioned source types. We use the numbers of stars within 100 pc from the Sun for determining the weights because the adopted star count model gives the number density of each source type as a function of distance and direction from the Sun relative to the number density in the solar neighborhood.

The weights of 0.16 and 0.13 are obtained as follows. The source types neighboring to A2–5 V and F0–5 V in the Wainscoat et al. (1992) model are B8–A0 V and F8 V. Thus we assume that the A2–5 V type actually covers spectral types A2 V through A7 V and a half of A1 V while the F0–5 V type covers A8 V through F6 V. Table 2 gives the numbers of stars with spectral types between A1 V and F6 V within 100 pc from the Sun in the Hipparcos catalog (ESA 1997). We find from this table that the fraction of A6 through A7 to A1 through A7 (with a half weight for A1) is 0.16, while that of A8 through F0 to A8 through F6 is 0.13.

5. Model-Data Comparison

The applicability of the adopted star-count model to the RSV1 data was tested by comparing the stellar luminosity functions (LFs) predicted by the model with the observed LFs from the ROTSE survey, toward several positions within the spatial coverage of the RSV1. In this case, we used the Northern Sky Variability Survey (NSVS: Wozniak et al. 2004) data set, which is a collection of all (including the nonvariable objects) photometric data from the ROTSE-I survey.

Figure 1 shows a comparison of the LFs from the model and the NSVS data toward 12 positions within the spatial coverage of the RSV1. The LFs are shown for the magnitude range of the NSVS, $10 \leq m_{\text{ROTSE}} \leq 15.5$. The incompleteness of the NSVS generally increases sharply near 15 mag, but it starts at brighter magnitudes in the field of $|b| < 20°$ due to significant stellar blending (Wozniak et al. 2004). These phenomena are clear in figure 1, and we limited our calculation to the magnitude range of $10 \leq m_{\text{ROTSE}} \leq 14$ and a Galactic latitude range of $|b| > 20°$. Apart from the discrepancy due to the incompleteness, figure 1 shows that there is a general agreement between the model and the data at $|b| > 20°$, and demonstrates that the adopted star count model can be reliably used for estimating the number of stars in the δ Scuti region of the H–R diagram.

We find that for the magnitude range of $10 \leq m_{\text{ROTSE}} \leq 14$ and the spatial coverage of the RSV1 with a constraint $|b| > 20°$, the star count model yields a total of 280210 stars, while it yields 3270 HADS candidate stars, i.e., stars with spectral types from A6 V to F0 V. As discussed in section 2, there appears to be 6 bona fide HADS in the RSV1 catalog, but only 4 of them satisfy $|b| > 20°$ and $m_{\text{ROTSE}} \leq 14$ mag (see table 1). Since the detection efficiency of the HADS in the RSV1 survey is estimated to be $\sim 50\%$ (see section 3), the incidence of the HADS phenomenon in the δ Scuti region of the H–R diagram becomes $4/0.5/3270 \equiv 0.24\%$. Considering only the Poisson noises, the relative uncertainty involved with our estimate for the incidence is $\sim 50\%$. This uncertainty is rather large, but our calculation certainly gives an order-of-magnitude estimate for the incidence.

Our estimate for the incidence of the HADS, 0.24%, is much lower than that of the LADS, $\sim 1/3$, implying that the HADS phenomenon takes place in a very small fraction of stars and/or its duration is very short, compared to the LADS. Since the relations between HADS and LADS in terms of their origins and natures are still uncertain, our estimate for the incidence of HADS in the δ Scuti region of the H–R diagram will be useful in revealing their relations to the LADS.

We are grateful to M. Breger, C. Akerlof, P. R. Wozniak, Seung-Lee Kim, G. Pojmanski, and B. Paczyński for their valuable discussions and help. We thank the anonymous referee for his/her helpful comments, which greatly improved our manuscript. This publication makes use of data from the Northern Sky Variability Survey created jointly by the Los Alamos National Laboratory and University of Michigan. The NSVS was funded by the Department of Energy, the National Aeronautics and Space Administration, and the National Science Foundation. This work was supported by the research fund from Kyung Hee University.

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1. While the effective temperatures of both LADS and HADS range from ~7000 K to ~8500 K, which roughly corresponds to a spectral range of A2 through F2, HADS have a narrower temperature range, ~7200 K through ~8000 K (McNamara 2000b), which roughly corresponds to a spectral range of A6 through F0.
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