THE ONSET OF PULSATION IN RED GIANTS

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Abstract

The Hipparcos astrometric and photometric database has many applications for undergraduate research projects. As one example, we have investigated the onset of variability in red giants by noting the excess scatter (above and beyond the instrumental scatter) in the Hipparcos photometric measurements of 7600 giants with +1.35 < (V–I) < +1.70. Microvariability (0.00 < ΔV < 0.01) sets in gradually for (V–I) > +1.46 ±0.01 and variability (ΔV > 0.01) increases rapidly for (V–I) > +1.55. These are, however, reddened colors, but the small contamination by distant reddened supergiants may be offset by the contamination by reddened earlier-type giants. According to three recent effective temperature scales, these two (V–I) colors correspond to 4085 K and 3905 K, respectively, with an internal uncertainty of ±10 K.

1. Introduction

As red giants expand and cool, they become unstable to pulsation. Stebbins and Huffer (1930) tested the variability of about 200 M giants and about 200 B-K giants. They found that giants earlier than M0 showed a constant average scatter in magnitude which was equal to the expected observational scatter of 0.012 magnitude. Subsequent surveys by Eggen, the AAVSO Photoelectric Photometry Program, and others (see review by Percy 1997) confirmed that, starting at M0III, the incidence and amplitude of variability increased rapidly with spectral type. This is particularly conspicuous in the V band, because it contains TiO bands whose strength is very sensitive to the temperature variations which occur during pulsation.

Although all of these surveys, plus the survey of K giants by Percy (1993), suggested that K giants are not appreciably variable, there is evidence to the contrary. Edmonds and Gilliland (1996), using the Hubble Space Telescope (HST), found microvariability in K giants in the globular cluster 47 Tuc. However, these may be Population II K giants which have relatively blue colors and early spectral types, but temperatures similar to those of Population I M giants. There are also three important surveys of photometric microvariability of red giants. Grenon (1993) analyzed the microvariability of stars in the Geneva photometry. There is incipient microvariability (amplitude less than 0.01) at spectral type K4III (their figure 3) or T_{eff} = 4200 K (their figure 7), and incipient macrovariability (amplitude greater than 0.01) at spectral type M0III or T_{eff} = 3700 K according to the temperature scale that they used. Jorissen *et al.* (1997) analyzed photometry from the ESO Long-Term Photometry of Variable Stars project. Their results depend critically on the exact interpretation of the distribution of the points in a photometric scatter versus (b–y) color plot, but it appears that microvariability sets in at (b–y) = 0.80 and macrovariability sets in at (b–y) = 1.10. These correspond to spectral types K4III and M0III. Finally, Eyer and Grenon (1997) have analyzed the Hipparcos photometry of giants of known spectral type; it appears from their diagrams that microvariability sets in at spectral type K4III, and macrovariability at K9III.

Because of the availability of new effective temperature scales for cool giant stars (Bell and Houdashelt 1998; Bessell *et al.* 1998; Perrin *et al.* 1998), based on model atmospheres and/or angular diameters, and of new pulsation models with an improved treatment of the coupling between pulsation and convection (Xiong *et al.* 1998), we have made another analysis of the photometric scatter of several thousand red giants in the Hippparcos database (ESA 1997). The project was done as a second-year research project by one of us (MG), so the approach was exploratory and simple. In particular, our approach neglects the interstellar reddening of the stars in the sample, because we chose the stars on the basis of observed (V–I).

2. Method

We considered all stars in the Hipparcos database with (V–I) in the range +1.35 to +1.70, and with parallax less than 15 milli-arcseconds (mas). This amounted to about 7600 stars. The sample was contaminated by some reddened early-type supergiants, but they constituted less than 1.5 per cent of the sample, and we believe that our method of analysis is insensitive to them. We also found a small number of large-amplitude red variables which appear to be evolved Population II giants with cooler temperatures, but with (V–I) in the sample range. Again, we do not believe that they affect our analysis. They stood out because of their unusually large amplitudes.

For each interval of 0.01 in (V–I), we determined the *median* scatter given in the Hipparcos database. The median value is less affected by extreme values than the mean. The results are shown in Figure 1.

We have also made very preliminary studies of the light curves and power spectra of a small sample of the stars—one in each (V–I) bin. The stars were chosen to each have a total range of 0.05 magnitude. The power spectra were calculated with the date-compensated discrete Fourier transform of Ferraz-Mello (1981), implemented in a computer program kindly made available by Dr. E.P. Belserene.

3. Results

Figure 1 shows the median scatter in the photometric data, as a function of raw (V–I) color. (The spreadsheet which was used unfortunately rounds off the averages to ±0.0005.) The scatter remains constant up to about (V–I) = +1.48. Between (V–I) about +1.45 and +1.55, the scatter increases slightly from about 0.0145 to 0.0150. Assuming that the "extra" scatter is intrinsic, it gives an intrinsic $\sigma = 0.004$ at (V–I) = +1.55. This corresponds to a full amplitude of about 0.01 magnitude, if the variability has the equivalent of a sine-curve distribution. Beyond (V–I), about +1.55, the scatter increases more quickly.

The attempts to study the light curves and power spectra of the stars were generally not successful, because of the small number of observations and the large gaps between them. The data generally include groups of several observations taken within a short interval of time. Such data are not well suited for the determination of periods of 5 to 50 days (the typical time scales in stars such as these), in stars which are semiregular at best. We also found that there are sometimes unusual distributions of the times of measurements. In the case of γ Ret, for instance, we discovered that the separations of the groups of observations were clustered between 20 and 30 days. This can create a type of aliasing effect in the power spectrum.

Two of the 15 stars—Hipparcos 336 and 8526—showed small variations on a time scale of about 400 days. Such long-term variations are common in small-amplitude pulsating red giants; their cause is unclear, since their time scale is one to two orders of magnitude longer than the radial pulsational time scales.

None of the power spectra showed significant peaks, though there was a tendency for power to occur in the period range of 3 to 20 days. This is consistent with the periods found in other early M giants (see, for instance, Jorissen *et al.* 1997), though the variations tend to be semiregular at best. Another student, Branko Miskov, also found a lack of clear periodicity in a sample of red giants with slightly larger scatter.

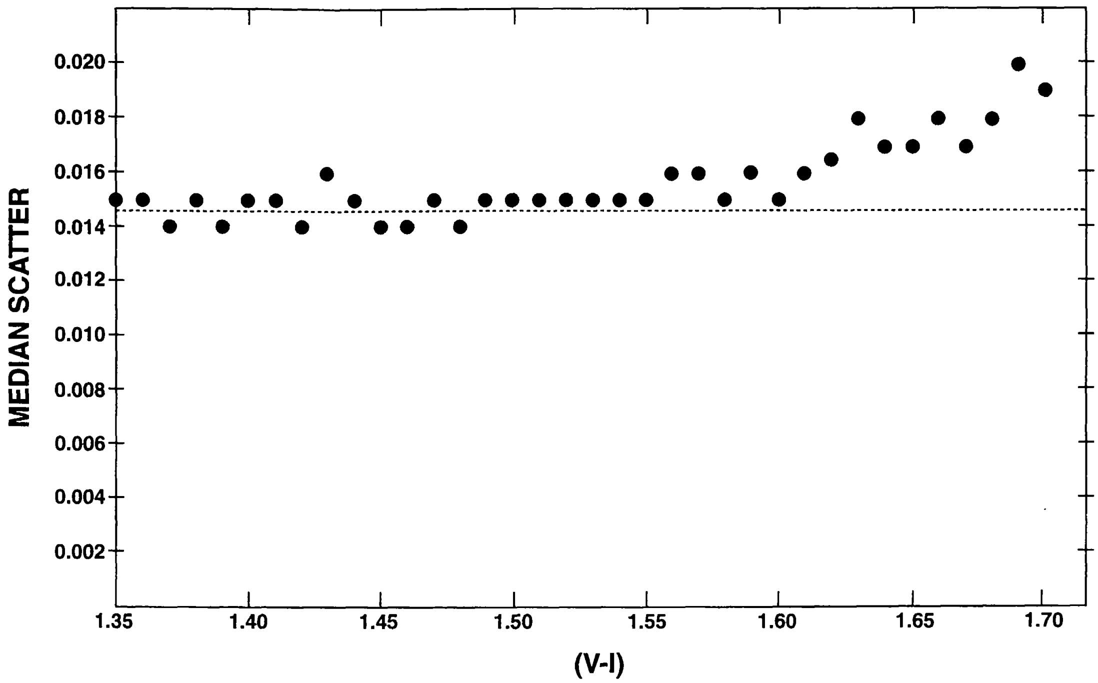

Figure 1. The mean photometric scatter for 7600 (mostly) red giants, as a function of unreddened (V-I) color. The instrumental scatter is 0.0145. Microvariability sets in at (V-I) = +1.46, and variability sets in at about +1.55.

4. Discussion

The macrovariability which sets in at M0III is usually ascribed to radial pulsation, since there are associated radial velocity variations. The rapid increase in amplitude in Figure 1, beyond M0III, is not entirely due to the effect of TiO bands, because the Hipparcos photometric system includes most of the visual portion of the spectrum, including the B, V, and much of the R band.

The (V–I) colors in the Hipparcos catalogue are affected by reddening. The median distance of the red giants in the sample is about 500 pc. The typical reddening in (B–V) for stars chosen by apparent magnitude is about 0.25 per kpc (Allen 1963), and the reddening in (V–I) is about 1.65 times higher, or 0.4 per kpc, or 0.2 per 0.5 kpc. Many stable, earlier-type giants will be reddened by several tenths of a magnitude into the (V–I) range chosen, thus “diluting” the incidence of variability. A few distant, earlier-type supergiants may be reddened into the (V–I) range chosen, but they constitute less than two per cent of the sample.

We have applied the three new temperature scales (Bell and Houdashelt 1998; Bessell *et al.* 1998; and Perrin *et al.* 1998) to the apparent (V–I) mentioned above; they give very consistent results for the onset of microvariability (4090K, 4070K, 4095K, respectively), and for the onset of macrovariability (3880K, 3920K, 3910K, respectively); we adopt the mean values of 4085K and 3905K, with an internal uncertainty of ±10K.

5. Education considerations

The Hipparcos and Tycho databases are a rich source of material for projects at the graduate, undergraduate, and even high school level (Percy 1997). The basic data have been made available in a CD-ROM package called *Celestia 2000*. In addition to the necessary software to search the database, it includes basic data for all stars in the catalogues; for the variable stars, it includes the descriptors (periodic, unsolved, etc.), the variability data, and in some cases, the light curve. It does not include the individual measurements—the epoch photometry.

The analysis of the individual measurements of variable stars is a useful tool for developing and integrating a wide variety of skills in science, math, and computing, and this has resulted in a major AAVSO education project called *Hands-On Astrophysics: Variable Stars in Math, Science, and Computer Education.* The software which has been developed as part of this project can be used to analyze any set of variable star measurements, including the Hipparcos and Tycho epoch photometry.

The use of the epoch photometry for student projects is not entirely straightforward, however, because the photometry is only available on the full six-CD-ROM version of the database and this version requires a C compiler. ESA has developed an interactive tool (along the lines of their Catalogue Search Facility on the Hipparcos web site) for the Hipparcos epoch photometry. This tool allows one to access the data, and display the light curve. It extends the sample folded light curves given on the Hipparcos education web page. The Tycho Annex A epoch photometry is not available on-line. The address of the Hipparcos web site is (http://astro.estec.esa.nl/Hipparcos/hipparcos.html); Hipparcos data are also available from the Stellar Data Centre in Strasbourg, and other astrophysical data centers.

The distribution of the measurements is not always suitable for projects. There are groups of several measurements over a period of a day or two. These are very useful for studying the short-term and long-term variability of Be stars, for instance, but not for stars in which the typical time scale is more than a few days.

Nevertheless, there is a multitude of projects in which students in high school and university could experience the excitement of using real data to make new discoveries about variable stars.

6. Acknowledgements

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