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Cepheid period changes as tests of stellar evolution

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Abstract. The observed rates of period change in Cepheids are in general agreement with predictions from published stellar evolutionary models, but display a greater spread of values than expected, a feature that should allow us to probe the internal physical properties of Cepheids in more detail.

Key words. Stars: Cepheids – Stars: evolution

1. Introduction

Cepheids are F and G supergiants that are post-hydrogen-burning products of main-sequence B stars of $3-20\ M_{\odot}$ on their way to becoming, or on their way from a prior stage as, red supergiants associated with core and shell helium-burning. Traversal of the Cepheid instability strip in the H-R diagram occurs at nearly constant luminosity, whereas lines of constant radius are inclined. The mean radii of Cepheids therefore slowly increase or decrease according to the sense in which they traverse the instability strip: increasing radii for evolution towards lower surface temperatures, and decreasing radii for evolution towards higher surface temperatures.

The gradual changes in mean radii $\langle R \rangle$ of Cepheids give rise to gradual changes in their periods of pulsation P: longer P as $\langle R \rangle$ increases (evolution from left to right in the H-R diagram), and shorter P as $\langle R \rangle$ decreases (evolution from right to left in the H-R diagram). Such changes are observed as parabolic trends in O–C diagrams when the data cover time spans of $50-100$ yr or more. Such information exists for over 200 Cepheids.

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2. Comparing Observations with Model Predictions

It is not necessary to test individual stellar evolutionary models for their pulsation properties. Rate of period change in Cepheids can be predicted from the same models using the period-density relation, namely:

$$P\rho^{\frac{1}{2}} = Q = \frac{PM^{\frac{1}{2}}}{(\frac{4}{3}\pi)^{\frac{1}{2}} R^{\frac{3}{2}}} \ ,$$

where P is pulsation period, ρ is mean density, M is stellar mass, R is stellar radius, and Q, the pulsation constant, has a slight period dependence of $Q \propto P^{\frac{1}{8}}$ according to Turner & Burke (2002).

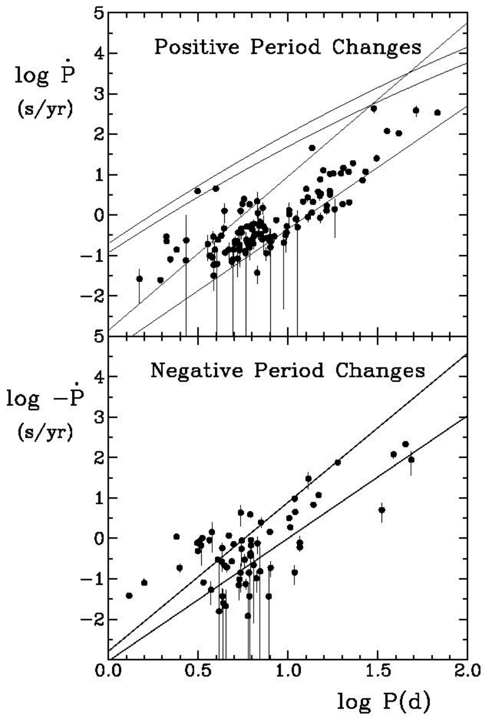

Fig. 1. Comparison of observed rates of period change in Cepheids, plotted as solid circles along with their derived uncertainties, with the range of values predicted by published stellar evolutionary models (solid lines). The upper portion of the diagram corresponds to Cepheids in first crossings (top) and third crossings (bottom) of the instability strip, while the lower portion of the diagram corresponds to Cepheids in second crossings.

With the last dependence included, a time derivative gives:

$$\frac{\dot{P}}{P} = \frac{6}{7}\frac{\dot{L}}{L} - \frac{24}{7}\frac{\dot{T}}{T} \quad .$$

The above formula predicts specific rates of period change in classical Cepheids from stellar evolutionary tracks. Figure 1 illustrates the observed rates of period change for over 200 Cepheids relative to the range of values predicted by a variety of published stellar evolutionary tracks, namely those of Maeder & Meynet (1988), Alibert et al. (1999), Lejeune & Schaerer (2001), and Claret (2004). How do the observed rates of period change in Cepheids compare with predictions?

The main features of Figure 1 can be summarized as follows: (i) the observed rates of period change in Cepheids are of the same order of magnitude as the predicted rates, with exact agreement for the few Cepheids likely to be in the first crossing of the instability strip; (ii) the observed rates exhibit a greater spread for Cepheids in second and third crossings of the instability strip and do not coincide with any one set of published model predictions; (iii) the observed spread for $P \leq 10^{d}$ implies the possible existence of Cepheids in what may be fourth and fifth crossings of the instability strip (large $\dot{P}$ at a given period). In summary, the general agreement between observations and predictions is good, but the observed rates of period change in Cepheids display greater variations than predicted by existing stellar evolutionary models.

3. Conclusions

As recognized roughly fifty years ago by both Parenago and Struve (1959), the dominant factor responsible for period changes in Cepheid variables is evolution. And, as noted by Struve, “It appears that studies of period change are by far the most sensitive test available to the astronomer for detecting minute alterations in the physical characteristics of a star.”

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