

PERIOD CHANGE, SEMI-CONVECTION, AND IV CYG

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Abstract

New data concerning the irregular period changes in IV Cygni are presented, and it is suggested that such changes may be related to structural changes produced by semi-convection.

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IV Cyg is a fourteenth magnitude RR Lyrae star, $P = .3343$ day, sub-type RRa (steep rising branch). A study by V. P. Tsesevich (1969) of all data through 1960 showed that the period increased by 0.003% around 1950 and then remained constant within observational uncertainty.

Images of the star appear on some 300 later plates of the Maria Mitchell Observatory. The observed time of the rapid rise in light in 1968-1970 is within 10 minutes of that predicted by Tsesevich's period. It appears, then, that the period was practically constant for 20 years. By 1974, however, the star was about 60 minutes ahead of its former schedule. In 1978, the observed time of the rise in light is 100 minutes earlier than the prediction, showing beyond a doubt that the period has become shorter again. These O-C values are good to within about 10 minutes. Analysis of the observations year by year shows that the period has been essentially constant since 1970. The change must have been rather sudden but there is no way to tell just how sudden. Perhaps the event took weeks or months. Perhaps it took a year or so. It is clear, however, that the length of time during which the period was changing was small compared with the 20-odd years during which it had been sensibly constant. The behavior of the period is summarized in Table I. The periods are good to within .0000010 day or .0003%.

TABLE I

Behavior of the Period of IV Cygni

<u>Interval</u>	<u>Period</u>	<u>Change</u>	<u>% Change</u>
Pre - 1950	0. ^d 3343287		
1950 - 1969	0.3343390	+0. ^d 0000103	+ .003%
1969 - 1978	0.3343322	-0.0000068	- .002%

The period of a pulsating variable star is sensitive to the conditions in the star's interior. Theory shows that the period depends primarily on the average density of the material within the star, therefore any redistribution of the material will result in a change in period. The change in density need not be great to cause a detectable change in period, since periods of short-period variable stars are routinely known to six or more figures. A change in the distribution of the matter will also, in theory, cause a change in average luminosity and surface temperature, but in practice these changes will be very much too small to detect. This is one reason why observations of variable stars are valuable in guiding and checking theoretical studies of stellar structure.

Observations such as those of IV Cyg demonstrate that some variable stars have episodes of sensibly constant period followed by a rather rapid change to another period. RR Gem is a particularly well-established case of this behavior, according to Szeidl (1975). Until recently, theoretical astrophysicists despaired of understanding how a gaseous star could experience occasional - as opposed to continuous - changes in density.

A typical star has large regions within which energy is transported by radiation alone, without any motion of material from one place to another. These zones are said to be in radiative equilibrium and they are stable against convection. The only changes in density within such a zone are gradual changes as the star adjusts its equilibrium to changed composition as a result of nuclear reactions.

There are also regions within which the energy is transported by convection. These are regions where radiative transfer alone would result in unstable equilibrium, with the result that the material from deeper, hotter layers moves upward to cooler regions, to be replaced by other material moving downwards. A pattern of convection currents carries the energy outward, since the upward-moving material is hotter than the downward-moving. But just as much material is moving outward as inward so there is no change in average density other than the gradual changes caused by the slowly changing composition. Thus, convective regions also contribute only to gradual period changes.

Recent theoretical work predicts that some stars, including most RR Lyrae variables, have a third type of region, in so-called neutral equilibrium, neither stable nor unstable. In these regions a process called semi-convection takes place.

An example of neutral equilibrium is a marble on a flat table. If something starts it moving it will move as far as friction allows, but will neither speed up nor return to its original position. Stable equilibrium, as in a star's radiative regions, is like a marble in a round bowl. Any change in position results in the restoration of the status quo. Unstable equilibrium, which causes convective regions, is more like a marble balanced precariously on the round bowl turned upside down. The slightest motion results in more motion.

This analogy with the zones in a star is, like all analogies, not exact, but it is suggestive. Where the equilibrium is stable there is no motion of the material. Where the equilibrium becomes unstable, motion becomes important but it leads to a steady pattern of convection currents. Neutral equilibrium permits occasional motion, initiated, perhaps, by contact with an adjacent convective region.

Let us see first how this works in a star which has a semi-convective zone but which does not happen to be pulsating. All is usually quiet in the semi-convective region, but this is a temporary situation. The lower boundary of the zone is in contact with the core of the star, in which helium is being converted to carbon and oxygen by thermonuclear reactions. Since the core is convective the material below the boundary is in motion. Occasionally, helium-depleted material being carried outward toward this boundary will overshoot and be carried into the semi-convective zone. It will be replaced by helium-richer material from above. Because of the composition difference, there will be a change in pressure locally, to which the star will promptly react by a change in structure. A result of this event will be a slight change in the average density of the star.

In a non-variable star there would be no way for us to know that this event had taken place. But suppose, now, that our star is an RR Lyrae variable. Then, in addition to occasional, random semi-convective events, there will be the usual regular pulsation. Now the slight change in average density resulting from semi-convection will be observable, since the pulsation period must change when the average density changes.

Semi-convection is being studied and applied to RR Lyrae stars by A. Sweigart and A. Renzini (1978). They find that overshooting at the convective core boundary causes periods to decrease while further upward motion of the helium-depleted material - which also will take place as a series of discrete events - causes periods to increase. The process seems promising as a way to explain complex period behavior. The work of Sweigart and Renzini does not yet allow them to predict how large the period changes will be or how often they will occur, but it does predict the average interval between changes if the size of the changes is known from observation. Their survey of observations of RR Lyrae stars in globular clusters suggests that period changes of .002% or .003% on the average have occurred about once per century. The theory, which is based on elaborate computer simulations of the evolution of RR Lyrae stars, predicts that increases or decreases of this size are to be expected rather less often, perhaps at intervals of 300 - 400 years. The agreement between theory and observation is close enough, considering the preliminary state of the theory and the short time-interval of the period analysis, to make it seem that semi-convection may indeed be the explanation of apparently abrupt period changes.

The agreement with IV Cyg is rather less close. Table I suggests that period changes can occur within 20 years. An estimate of five per century may even be an underestimate, because Tsesevich's discussion shows that a constant period before 1950 does not work as well for the relevant observations as the constant periods do for the later ones.

Perhaps the higher frequency of changes in IV Cyg compared with the globular cluster stars is due to the fact that IV Cyg, which has a shorter period, must also have a different internal structure. Sweigart and Renzini note that "it should be feasible to use the period-change observations for probing the interior structure of RR Lyrae stars." The study of RR Lyrae variables on the Maria Mitchell plates will continue and will be extended to cepheid variables.

REFERENCES

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