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# The Newly-Discovered $\gamma$ Doradus Variables

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**Abstract.** In this contribution we describe a new class of pulsating stars, the prototype of which is the bright, early F-type dwarf, $\gamma$ Doradus. These stars typically have between 1 and 5 periods ranging from 0.4 to 3 d with photometric amplitudes up to $0\overset{m}{.}1$ in Johnson $V$. The mechanism for these observed variations is high-order, low-degree, nonradial, gravity-mode pulsation. A recent theoretical development describing a proposed driving mechanism for these new variables is discussed.

## 1. Introduction

Cousins & Warren (1963) discovered that the bright F0V star $\gamma$ Doradus was variable over a range of several hundredths of a magnitude with two principal periods close to 0.8 d. $\gamma$ Doradus has an absolute magnitude similar to that of a $\delta$ Scuti star, but is somewhat cooler, and thus for many years it was deemed a "variable without a cause". Over the past decade, more than 150 variable stars with spectral types and luminosity classes similar to $\gamma$ Doradus have been discovered that exhibit variability on a time scale that is an order of magnitude slower than $\delta$ Scuti stars. Mantegazza, Poretti, & Zerbi (1994), Krisciunas (1994), and Hall (1995) suggested that these objects may constitute a new class of variable stars. Breger & Beichbuchner (1996) investigated whether any known $\delta$ Scuti stars also showed $\gamma$ Doradus-type behavior and found no clear cut examples of stars that show both "fast" and "slow" variability; Fig. 1 of their paper nicely illustrates the locations of the two kinds of variables in the color–magnitude

diagram. However, not all of their $\gamma$ Doradus stars are regarded as *bona fide* members of the group.

On the basis of extensive photometry, radial velocities, and line-profile variations, it has been proven that many of these objects are indeed pulsating variable stars (see, e.g., Krisciunas et al. 1995; Balona et al. 1996; Hatzes 1998; Kaye 1998; Kaye et al. 1999a, 1999b; Zerbi et al. 1999). Given the nature of the observed variability in these stars, the cause must be high-order ($n$), low-degree ($\ell$), nonradial g modes. We argue that since this small (but growing) group of objects all have similar physical characteristics and show broad-band light and line-profile variations resulting from the same physical mechanism, they form a new class of variable stars. In this paper, we indicate the cohesiveness of this group and its differences from other variable star classes. Finally, we provide a set of criteria by which new candidates may be judged.

## 2. General Characteristics of the Class

Our list of *bona fide* $\gamma$ Doradus stars is complete to September 1999 and all objects of this class have extensive enough photometric and/or spectroscopic datasets to rule out other variability mechanisms. A complete, commented, up-to-date list of all proposed candidates for this group, as well as their observational history, is kept by Handler and Krisciunas at the World Wide Web site: `http://www.astro.univie.ac.at/~gerald/gdor.html`. The basic physical properties of these stars (e.g., Strömgren colors, mass, radius, [M/H], $v \sin i$, etc.) can be found at the same location.

The truly intriguing characteristic of $\gamma$ Doradus stars is that they are variable; considering the part of the Hertzsprung–Russell diagram in which they lie, previous pulsational models say they should not be. The outer convection zones of these stars are too shallow to generate and sustain a large magnetic dynamo, thus making starspots improbable. Most of the $\gamma$ Doradus stars are multi-periodic; the average period is close to 0.8 d. The observed variations are not necessarily stable, and may be highly dynamic (Kaye & Zerbi 1997). Typical amplitudes cluster around 4 percent ($= 0\overset{\mathrm{m}}{.}04$) in Johnson $V$, and may vary during the course of an observing season by as much as a factor of four. For the best-studied stars (e.g., $\gamma$ Doradus itself, 9 Aurigae, and HR 8330), line-profile variations with periods equal to the photometric periods have been confirmed (Balona et al. 1996; Kaye 1998; Kaye et al. 1999b). No high-frequency signals have been detected in either the photometry or the spectroscopy, indicating a lack of the p-mode pulsation common in $\delta$ Scuti stars.

## 3. Defining a New Class

We argue that the $\gamma$ Dor stars form a homogeneous set based on their physical characteristics and their mechanism for variability, and thus form the basis for a new class of variable stars.

In following with the informal discussions at the "Astrophysical Applications of Stellar Pulsation" conference (Stobie & Whitelock 1995) held in 1995 at Cape Town, South Africa and in recent papers in the literature (see e.g., Krisciunas et al. 1993; Balona et al. 1996; Zerbi et al. 1997; Poretti et al. 1997;

Kaye 1998; Kaye et al. 1999a, 1999b), we propose that this type of variable star henceforth be known and recognized by the name $\gamma$ *Doradus variable stars.* The extent of the $\gamma$ Doradus phenomenon, as it is currently known, consists of variable stars with an implied range in spectral type A7–F5 and in luminosity class IV–V; their variations are consistent with the model of high-order ($n$), low-degree ($\ell$), nonradial, gravity mode oscillations. Although it is conceivable that variations such as those of the stars in this class may occur outside of this region, it is likely that other mechanisms of variability would then dominate, and thus this combination of spectral type, luminosity class, and (most importantly) variability mechanism, forms a suitable definition.

From an observational point of view, the g-mode oscillations seen in $\gamma$ Doradus variables are characterized by periods between 0.4 and 3 d and peak-to-peak amplitudes $\lesssim 0\overset{\mathrm{m}}{.}1$ in Johnson $V$. The presence of multiple periods and/or amplitude modulation is common among these stars, but is not included in the formal definition presented here. Spectroscopic variations are also observed, and these manifest themselves both as low-amplitude radial velocity variations (that cannot be attributed to duplicity effects) and as photospheric line-profile variations.

## 4. Concluding Perspective

$\gamma$ Doradus stars constitute a new class of variable stars because they all have about the same mass, temperature, luminosity, and the same mechanism of variability. They are clearly not a sub-class of any of the other A/F-type variable or peculiar stars in this part of the HR diagram, and may offer additional insight into stellar physics when they are better understood. Modeling by Guzik et al. (2000) is beginning to shed light on the theoretically required interior structure and on the specific physics driving the observed variability, and these preliminary models indicate that a mechanism dependent upon a convection/pulsation interaction called "convective flux modulation" (see also Guzik et al. 2000). Even though this represents significant progress in the field of $\gamma$ Doradus variables, much observational and theoretical work lies ahead.

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## Discussion

*Douglas Gough*: Following on from Joergen Christensen-Dalsgaard's comment, because there are just a few g modes of high amplitude and low frequency, one could in principle use the frequency modulation of the stochastically excited p modes, which we are sure must exist, to study the structure of the g-mode oscillations directly. This would add a very exciting new aspect to asteroseismology.

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