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TITLE RADIAL AND NONRADIAL PERIODS OF DELTA SCUTI

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RADIAL AND NONRADIAL PERIODS OF DELTA SCUTI

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Five periods have been discussed by Smith (1981) for the prototype variable star δ Scuti. The main one, at 0.193772 day, has long been identified as the radial fundamental mode. The others have not been clearly understood, but the second radial overtone is probably the correct identification for the 0.116366 day period. The other three at 0.186891, 0.189435, and 0.211157 day seem to be nonradial modes because of their long periods. The first of these seems to have $\ell = 2$ and $m = -2$ as observed by Smith. Table 1 gives these observed periods. Based on the Fitch (1981) nonradial pulsation constants, the 4.48 hour (.187 day) period seems to be a p_1 mode, but as we shall see, we find that this identification is not very certain. The goal of this paper is to use our nonradial nonadiabatic computing program to predict periods in this range for a model matching the observed parameters of δ Scuti and to identify all five periods.

TABLE 1

δ SCUTI OBSERVED PERIODS

Period (day)	Period (hrs)	Identification
0.211157	5.0678	
0.193772	4.6505	Radial Fundamental Mode
0.189435	4.5464	
0.186891	4.4854	Nonradial l=2 p_1 (?)
0.116366	2.7928	Radial Second Overtone

Source: Myron A. Smith, 1981, Ap. J, 254, 242.

Figure 1 shows the Hertzsprung-Russell diagram in the region of the δ Scuti stars. This figure has been adapted from the metallic line star paper by Cox, King, and Hodson (1979). Two positions are given for δ Scuti. For a mass of 2.0 solar masses, the line of constant period of 0.194 day is drawn, and one can see that the upper right color and luminosity observations are the correct ones. Evolution theory according to Mengel, Sweigart, Demarque, and Gross (1979) gives our luminosity of 37 solar luminosities, consistent with this line of constant period and our assumed 2.0 solar masses.

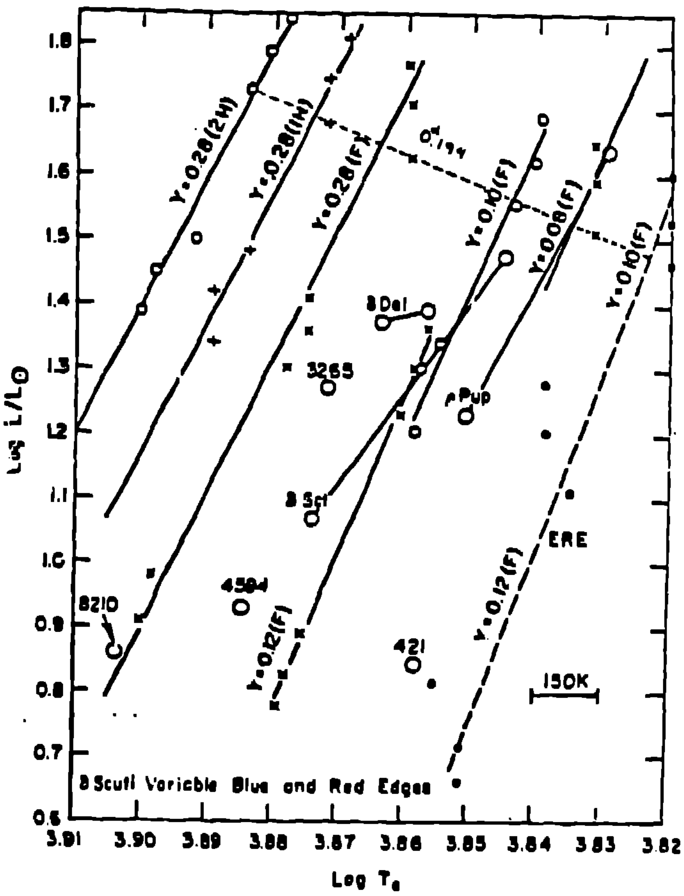

Fig. 1. The Hertzsprung-Russell diagram in the region of the δ Scuti variables. Details can be found in the Cox, King, and Hodson paper.

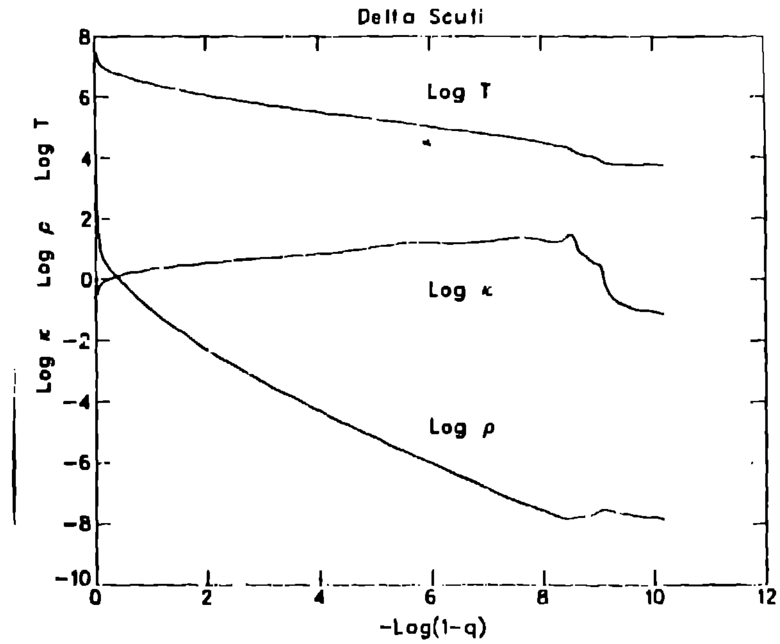

Fig. 2. The internal temperature, opacity, and density structure of the δ Scuti model is plotted versus external mass fraction.

Table 2 gives the model data including the details of the hydrogen depleted central region. Figure 2 plots this model temperature, opacity, and density structure.

TABLE 2

δ SCUTI MODEL (0.194)
195 ZONES
$M=2.0M_\odot$ $L=37.0L_\odot$ $T=7050K$ $R=4.1R_\odot$
$Y=0.18$ to $(1-q)=10^{-7}$ $X=0.973$
$Y=0.28$ to $(1-q)=0.76$ $X=0.078$
$Y=0.35$ to $(1-q)=0.84$ $X=0.050$
$Y=0.65$ to $(1-q)=0.90$ $X=0.025$
$Y=0.95$ to $(1-q)=0.93$ $X=0.014$
COXHODSONII $(Y=0.98)$ to center
$Z=0.02$ $l/H_p=1.50$ $M_{out}= 5\times10^{33}$gm
Central Ball Surface :
$M=0.026M_\odot$ $L=0.004L_\odot$ $T=27\times10^6$K $R_c=0.001R_\odot$

Table 3 lists the radial periods obtained from the linear nonadiabatic theory. The fundamental has been matched exactly, but the second overtone is a bit longer than the 0.116 day period if the identification is correct. The growth rates are larger for the larger overtones. This presents a problem because the fundamental is the dominant mode but has a very low linear theory growth rate. Further, where is the first overtone with a larger growth rate in the observations? The PdV work each cycle to cause the pulsations is plotted for these three modes in Figure 3. Driving is at the top of the convection zone, at about 18,000 K, at the bottom, at about 40,000 K and finally at about 150,000 K due to the ultimate ionization of helium.

TABLE 3

RADIAL PERIODS AND GROWTH RATES

Mode	Period (day)	Period (hrs)	η
F	0.1937	4.649	8.4×10^{-5}
1H	0.1495	3.588	8.7×10^{-4}
2H	0.1217	2.921	3.8×10^{-3}

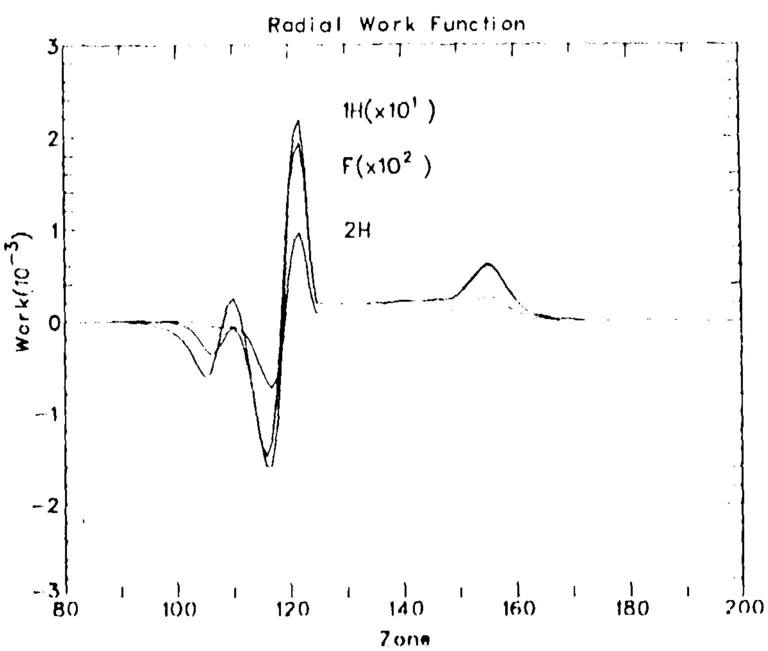

Fig. 3. The PdV work per pulsation cycle is plotted versus zone number for the 3 lowest radial modes. The three driving regions are at 18,000 K, 40,000 K, and 150,000 K. All damping has been completed at depths interior to 500,000 K.

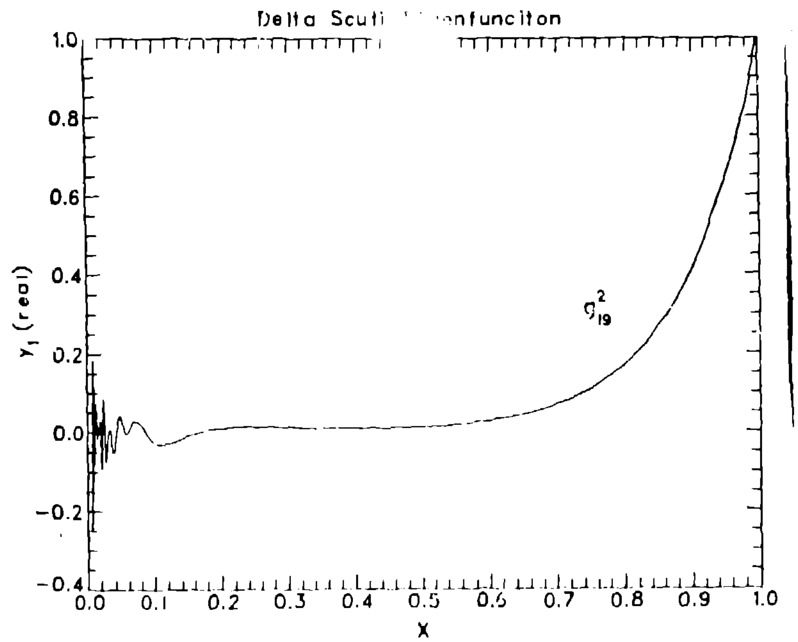

Fig. 4. The $y_1 = \delta r/r$ eigenvector is plotted versus radius fraction $x = r/R_*$.

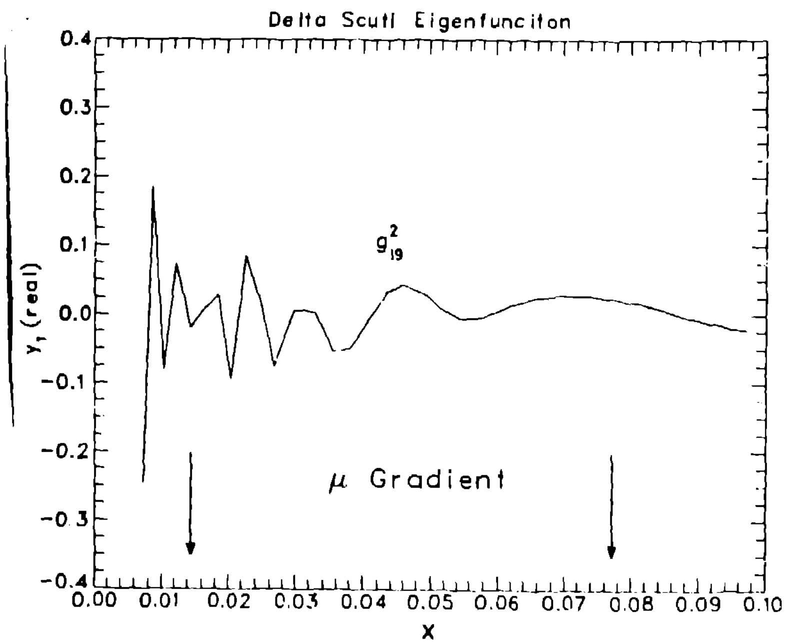

Fig. 5. The nonradial y_1 eigenvector is plotted versus zone number. Small oscillations occur in the μ gradient region outside of the hydrogen exhausted core.

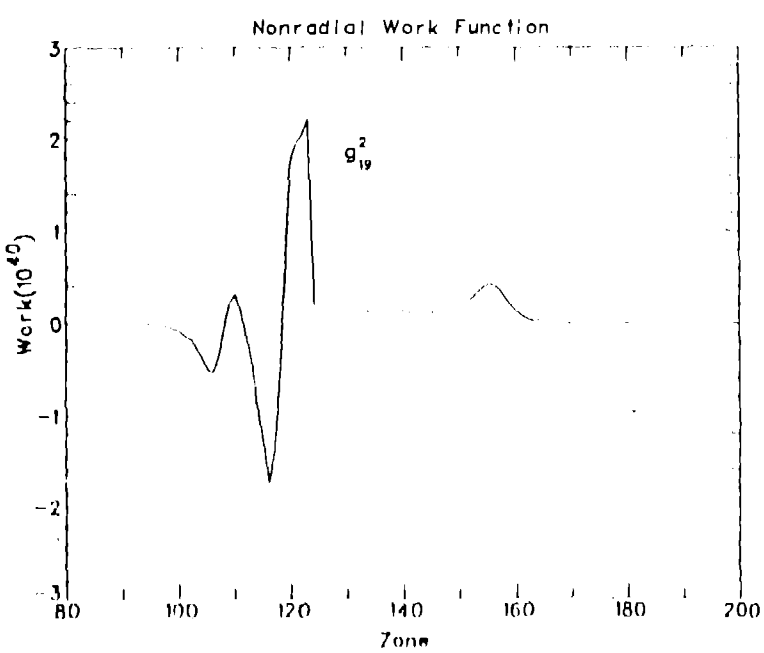

Fig. 6. The nonradial mode driving is plotted against zone number. These driving and camping regions are exactly the same as for the radial case.

A 195 zone model has been used in the nonradial nonadiabatic linear theory program to calculate periods and growth rates for modes of order $\ell = 2$. Considerable care was needed to see that the equation of state derivatives were accurately calculated. The many oscillations in the isothermal core result in a large g order. Table 4 lists periods in the range of the observed δ Scuti periods. Growth rates are positive, indicating that at least at small amplitude these modes should appear.

TABLE 4

δ SCUTI MODEL

Mode	Π (hrs)	η	KE
g_{20}	4.71	2.53×10^{-5}	1.29×10^{48}
g_{19}	4.52	4.05×10^{-5}	3.95×10^{45}
g_{18}	3.98	1.31×10^{-4}	1.21×10^{45}
g_{17}	3.73	1.09×10^{-4}	2.28×10^{45}
g_{16}	3.32	6.57×10^{-4}	2.22×10^{44}
g_{14}	2.85	1.29×10^{-6}	1.47×10^{47}
g_{13}	2.54	6.95×10^{-3}	4.28×10^{43}

The eigenvector, y_1 for g_{19}, is given in Figure 4. A closeup is given in Figure 5. This is the radial motion variations which is normalized to unity at the surface. The imaginary part of this eigenvector is small indicating that the motion is closely in phase at all depths. The μ gradient region tends to trap eigenvector oscillations, and this can be seen interior to $x = 0.08$.

In Figure 6 we give the PdV work each cycle to promote the driving of the pulsations. The regions are again the ionization of hydrogen and helium, just as for the radial mode case.

The list of observed periods in Table 1 does not seem to match the theoretical list in Table 4. Furthermore, the behavior of the eigenvectors in the deep interior, and especially in the isothermal core, makes interpretation of the theoretical results difficult. At present the identification of the observed periods in δ Scuti does not seem possible and much further work is needed.

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