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NONADIABATIC, NONRADIAL SOLAR OSCILLATIONS

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PURPOSE

Solar gravity mode (g-mode) oscillations are not easy to detect and identify because their surface amplitudes are very small. However since their largest amplitudes occur in the deep interior of the sun, their correct interpretation could be invaluable in unraveling the interior structure of the sun. Toward this end, we present some of our nonadiabatic, nonradial solar g-mode calculations, using the Lagrangian-based eigensolution program of Pesnell.

Asymptotic theory predicts that the gravity-mode period spacing (P_0) should approach a constant value as the order n increases, independent of the l-value. But how does P_0 vary with n before it reaches this constant value? We explore this question and examine our theoretical eigenperiods to see if they indeed give an asymptotic P_0 independent of l.

We also provide some g-mode growth and decay rate predictions that explain why independent observations give the same 160.01 minute pulsation mode exactly in phase over many years.

MODEL

A detailed self-consistent un-mixed current sun model was evolved by Becker using the Iben stellar evolution program. We have reconstructed this model at the solar age in our pulsation program, and to obtain a complete model we have had to increase the hydrogen content by 0.0019 and increase the luminosity by 0.2 percent over the Becker value. The reason for these changes is that we introduce into the model construction program a composition versus mass table, and the interpolated hydrogen mass fraction for each mass shell is not exactly that obtained by Becker in his evolution calculation. Table 1 presents some salient parameters of our final 1700 zone solar model.

One of our chief concerns in constructing a model was zoning. Figure 1 shows how the l=5, n=18 g-mode period changed as we varied the number of zones (and core radius). Since the period has leveled off we feel our 1700 zones, which corresponds to our smallest core radius, removes zoning effects from our g-mode results. Also, our 1700 zones gives a finer central zone structure than apparently anyone else has used.

RESULTS

Figure 2 displays our P_0 results as a function of order n and degree l. Our Lagrangian code results appear to be heading toward a constant P_0 of about 38 minutes. Unfortunately P_0 fluctuates approximately +-16% about the mean, due to our slightly non-smooth composition structure. Although the fluctuations tend to mask the point, it appears the Lagrangian approach yields an asymptotic P_0 independent of l, as expected. Table 2 shows a small sample of the g-mode growth rates we obtain. The growth rate units are better understood with an example: The reciprocal of our growth rate is the number of cycles it takes to change the mode energy by a factor of e. Thus for order 17 it takes (15845.38)/(2.36e-8) = 6.7e11 seconds = 21000 years for its energy to decrease by a factor of e. The g1, l=2 mode (at 56 minutes) is driven in this calculation by the kappa and gamma effects in the subphotosphere layers and by periodic convection luminosity blocking at the bottom of the convection zone. Deep radiative damping is dominant for modes higher than g2 at this l value.

COMMENTS

Past measurements of P_0 have been suggested to be in the range 36-41 minutes. Figure 2 shows how P_0 varies with order n as it approaches its constant asymptotic value. It is obvious that one must be at radial order 40 or above before one is relatively close to the constant asymptotic value of P_0. If one determines a P_0 from orders around 10 he may get about 32, or from around n=20 he may get about 35, or around n=30 he may get 36! This could lead to some confusion. An observer may determine P_0 from orders less than 10 (the only data he has) and fail to correct it to an asymptotic value.

The Table 2 decay rates (up to a million years) suggest that independent observers over several years can detect the same pulsation mode at exactly its predicted phase.

TABLE 1

Solar Model

Parameter	Value
Luminosity (10^{33} erg/sec)	3.6474
Mass (10^{33} gm)	1.9910
Radius (10^{10} cm)	6.9001
Surface temperature (10^3 K)	5.7264
Central temperature (10^7 K)	1.4596
Central density (gm/cm^3)	154.18
Surface X, Y, Z	.750 .230 .020
Central X, Y, Z	.421 .559 .020
Depth of convection zone	$.24R_\odot$ ($.014M_\odot$)
Temperature at bottom of convection zone (10^6 K)	1.7860
Opacities and EOS	Iben Fit

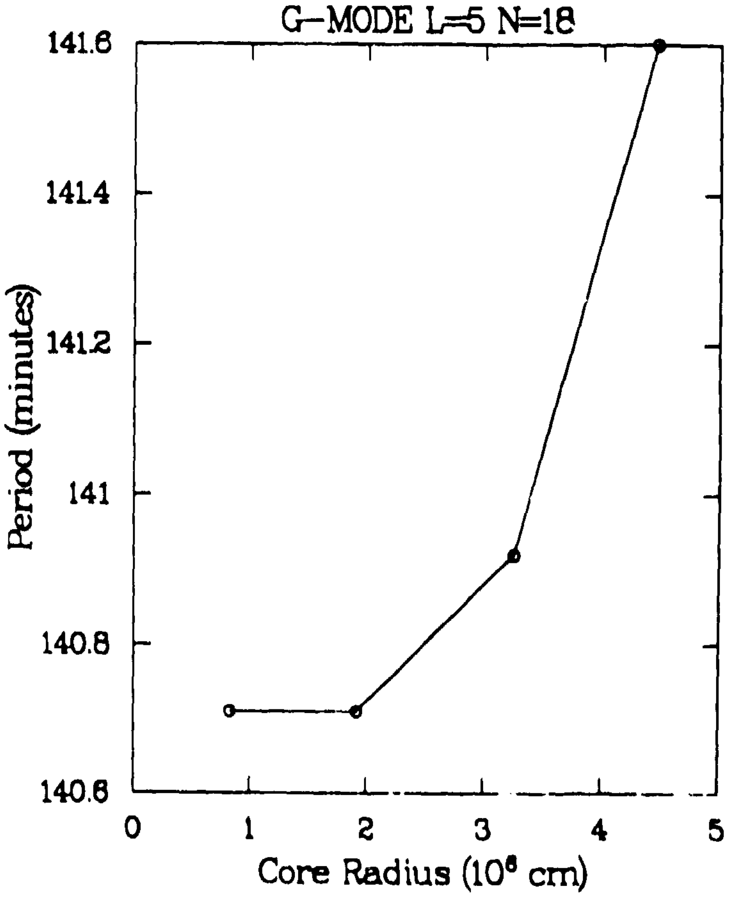

Figure 1: The period for the $l=5$, $n=18$ g-mode decreases and levels off as the number of modeling zones increases from 1000 to 1200 to 1400 to 1700 zones.

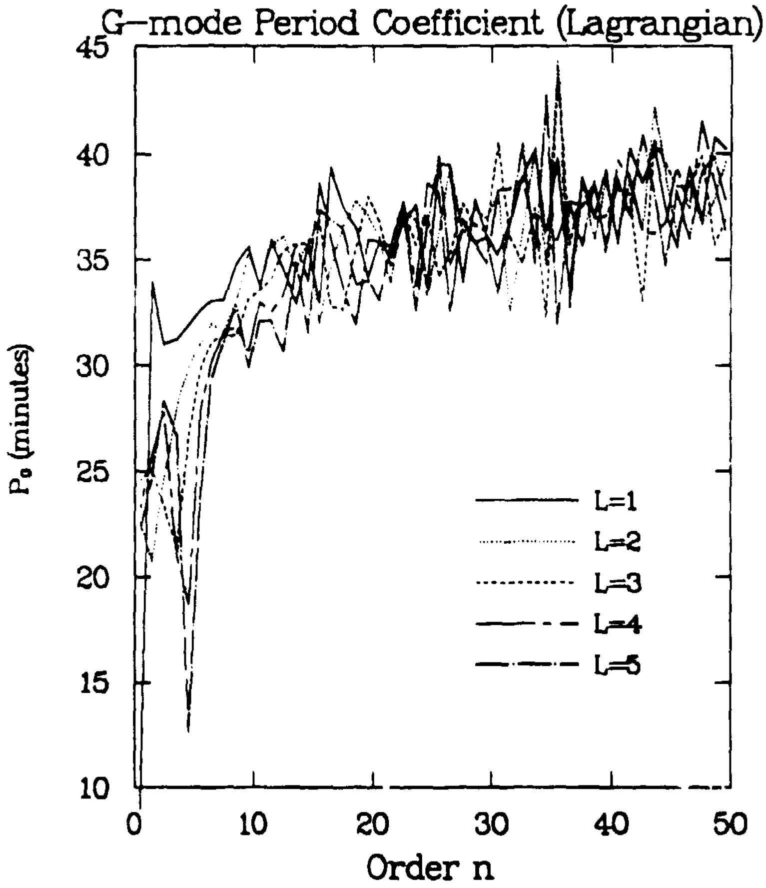

Figure2: The gravity mode period coefficient (Po) as a function of degree (L) and order (n). Po for any point is computed from SQRT(L(L+1))*(P(L,n+1)-P(L,n)) and is plotted at n+1/2.

TABLE 2

Growth Rates For L=2

Order	Non-Adiabatic Period (seconds)	Predicted Growth Rate (e/cycle)
17	15845.38	-2.36E-08
13	12486.69	-1.14E-08
8	8231.49	-3.33E-09
7	7457.66	-2.43E-09
6	6675.15	-1.73E-09
5	5915.57	-1.18E-09
4	5181.65	-7.26E-10
3	4495.54	-3.31E-10
1	3385.21	4.86E-10