THE EVOLUTIONARY STATE OF THE β CMa VARIABLE STARS

BY

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Abstract

General properties of, the latest observations of, and current theories attempting to explain the pulsations of the βCMa variable stars are reviewed. Stellar models are used to estimate the fractions of time spent in the S-bend region of the H-R diagram for the core hydrogen burning phase ($\sim$79%), the overall contraction phase ($\sim$19%), and the establishment of the shell source ($\sim$2%). A homogeneous sample of 353 early B stars within 500 pc is established. βCMa stars are found to make up $\sim$5% of that sample, a proportion consistent with the lifetime in the overall contraction phase. Observations of the remainder of the star sample for βCMa variability are needed since many of the remaining stars are listed as possible variables. Enough possible variables exist, if all or most are found to exhibit βCMa variability, to require that the core hydrogen burning phase be responsible for those pulsations.

I. The General Problems of Variable Stars.

Perhaps the most important fact about a pulsating star is that the pulsation must be driven by some process that supplies mechanical energy. This is easily evidenced by seeing what happens as a star pulsates. A pulsating star will expand past equilibrium size until the expansion is slowed and reversed by gravity. Contracting, the star will again overshoot its equilibrium size. Gas pressure builds up, contraction is slowed to a stop, and the surface is pushed outward again. Dissipative forces, such as friction, should eventually cause the pulsation to stop. Thus, some form of mechanical energy must be fed to the system to maintain the pulsation.

Another important axium is that variable stars have different modes in which it is possible for them to vibrate. Both fundamental and higher modes may be excited. In the fundamental radial mode, the amplitude of the gas's movement decreases smoothly toward the confined end of the vibration (toward the star's interior). The vibrational periods of the higher modes are shorter and the amplitudes of the gas's movement are distributedin a different way. Nodes (stationary points) are present and the amplitude is appreciable only at the free end of the vibration (at the surface of the star). More complex non-radial modes may also be excited, and which modes are excited of course depends on how and where the driving force is applied.

The way in which vibrations are started and maintained are fairly well understood for some types of variables. For example, ionization zones of Hydrogen and Helium, near the surfaces of Cepheids and RR Lyrae stars, can act as values creating a heat engine to drive pulsations (Percy, 1975).

The stars with which we are dealing, the β Cma variables, are not nearly so well understood.

II. Properties of the β CMa Variables.

The β CMa variable stars are a group of bright early class B stars. They exhibit rapid variations in radial velocity, strongly suggestive of pulsation. The light curves are sinusoidal and lag behind the radial velocity curves by 90 degrees ($\frac{1}{4}$ period). Some of the light curves show just one period, while others can be explained only by the superposition of two or more periods. The stars with the shortest periods show the smallest changes in brightness (0.03m) and in radial velocity (90km-sec^{-1}). All are slightly bluer at maximum than at minimum light (Glasby, 1969).

Observations of the narrowness of the spectral lines in the β CMa stars, until recently, seemed to indicate the absence of rotation. Until Hill's 1967 survey, all known β CMa stars had rotational velocities (v sin i) of 40 km-sec^{-1}. Non-variables of the same spectral class have rotational velocities $\sim$150 km-sec^{-1}. Projected rotational velocities (McNamara and Hansen, 1961) for eleven β CMa variables averaged 22 km-sec^{-1}. It was then thought that high rotational velocities for pulsating β CMa stars seemed to be about 50 km-sec^{-1}. New observations have since changed this premise.

Figure one is a color-luminosity diagram for the β CMa sequence of stars. Table one is a list of 21 definite and one likely β CMa stars.

Figure 1: Color-luminosity diagram for the β CMa sequence of stars. (Glasby, 1969)

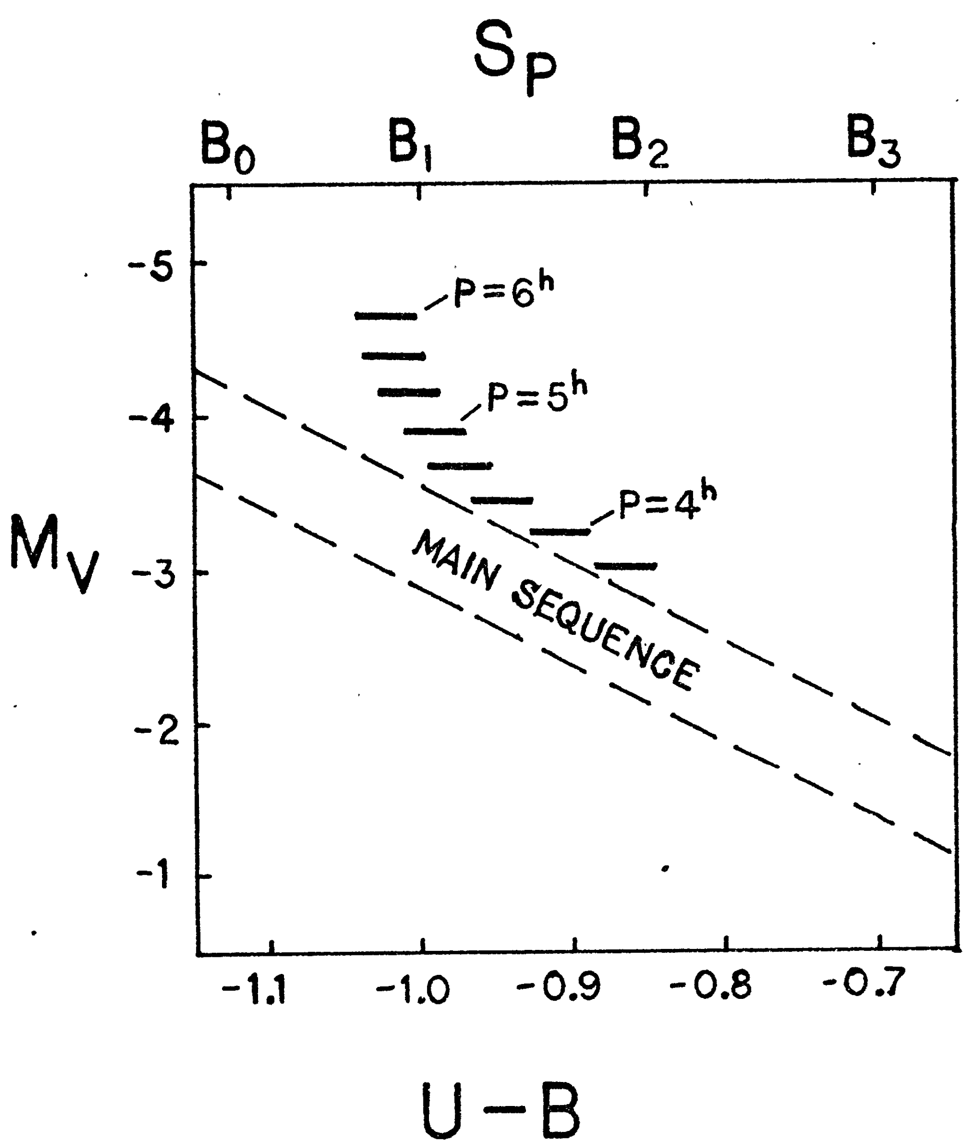


Table 1:

Definite βCMa Stars

HD	HR	STAR	α h m s	δ ° '	m_V	Sp(MK)	REF
886	39	γ PEG	0 13 14	15 11	2.83	B2 IV	1
16582	779	δ CET	2 39 29	0 20	4.07	B2 IV	1
21803	1072	KP PER	3 32 39	44 51	6.40	B2 IV	1
29248	1463	ν ERI	4 36 19	-3 21	4.12	B2 III	1
44743	2294	β CMA	6 22 42	-17 57	1.98	B1 II-III	1
46328	2387	ξ¹ CMA	6 31 51	-23 25	4.33	B1 III	1
50707	2571	15 CMA	6 53 32	-20 13	4.82	B1 III$^{@}$	1
74195	3447	O VEL	8 40 18	-52 55	3.61	B3 III$^{¢}$	2
111123	4853	β CRU	12 47 44	-59 42	1.24	B0.5 III	1
116658	5056	α VIR	13 25 11	-11 9	0.96	B1 V*	3
118716	5132	ε CEN	13 39 53	-53 28	2.30	B1 V*	4
126341	5395	τ¹ LUP	14 26 8	-45 13	4.54	B2 IV	1
129056	5469	α LUP	14 41 56	-47 24	2.30	B1.5 III	1
136298	5695	δ LUP	15 21 22	-40 39	3.21	B2 IV*	5
147165	6084	σ SCO	16 21 12	-25 35	2.93	B1 III	1
157056	6453	θ OPH	17 22 0	-25 0	3.28	B2 IV	1
158926	6527	λ SCO	17 33 36	-37 6	1.62	B1 V*	4
160578	6580	K SCO	17 42 29	-39 2	2.41	B2 IV*	5
199140	8007	BW VUL	20 54 23	28 31	6.44	B2 III$^{@}$	1
205021	8238	β CEP	21 28 39	70 33	3.18	B1 III	1
214993	8640	12 DD LAC	22 41 29	40 13	5.22	B1.5 III	1
216916	8725	16 EN LAC	22 56 24	41 36	5.60	B2 IV	1

Table 1 con't:

@ More distant than 500 pc.

¢ Not confirmed

* Spectral classes from Hoffeit (1964)

REFERENCES:

1 Lesh and Aizenman (1973)

2 Van Hoof (1972)

3 Dukes (1973)

4 Shobbrook (1972)

5 Shobbrook and Lamb (1972)

III. New Observations Concerning β CMa Variable Stars.

Differential photometry of 18 β CMa stars (Percy, 1970) indicates that the β CMa instability strip lies about 1.85 magnitudes above the main sequence at its upper end (B-V=-0.28) and about 1.35 magnitudes above the main sequence at its lower end (B-V=-0.23). Those 18 known β CMa stars show that the sequence ends at about M_V=-3.0 with no stars dimmer than that value.

Instability strips are also known for other types of variable stars. To become a variable, the star's evolutionary track must cross such an instability region. How long the star remains a pulsating star depends on the rate of which the star's track crosses the instability region. This rate of evolution depends on three factors: first, the mass of the star's nuclear fuel; second, the energy content of the fuel per unit mass; and third, the rate of radiation of that energy (Cox et. al., 1974).

These evolutionary changes in luminosity and effective temperature occurs far too slowly to be observed directly. However, there is a way out of this observational dilemma since β CMa stars (like Cepheids and other variables) exhibit a period-luminosity relation. Such a relation is given by Strohmeier (1972) as:

$$M_V = 0.4 - (18.1 \pm 2.3) P_0 \text{ days.}$$

Thus, a luminosity change is always accompanied by a period change. This change is slow but it can be measured because the charge accumulates over the years, leaving a phase shift in the period of the star. A search of the literature (Eagleton and Percy, 1973) has yielded values for dP/dt, for some βCMa stars, given in Table 2.

Those authors also calculated a $\dot{P}$ (dP/dt) due to evolution for a βCMa star of 16 $M_{\odot}$ with a theoretical evolutionary track. However, there is no way, at present, to determine the relative importance of various means of mass loss, magnetic effects, and other factors affecting $\dot{P}$. Observations do indicate that period changes occur, But a "simple picture of smooth evolutionary period changes is not sufficient..." to explain those observations.

The narrowness of the βCMa instability strip is one question that comes to mind since many seemingly normal stars are scattered about in the area of the strip. It is thought by some that smaller photometric errors would decrease the width of the strip, leaving in it a higher proportion of variables. Shobbrook (1974) estimates that as many as 75% of the non-variables could be eliminated from the strip by careful observations.

New βCMa stars are constantly being discovered. In 1967, (Hill, 1967) photometry of a sample of 153 early B stars in nearby galactical clusters yielded 24 new βCMa candidates. Their spectra ranged from O9.5 to B3; their luminosity classes

Table 2: Rate of change of period for some confirmed β CMa stars. (Eagleton and Percy, 1973)

STAR	MASS ($M_{\odot}$)	$\dot{P}$ (sec-cen^{-1})
δ CET	8.7	0.0
ν ERI	9.6	+0.2
β CMa	11.8	-0.4
α VIR	11.0	-1.0
σ SCO	9.8	+0.7
BW VUL	11.0	+3.5
β CEP	11.0	+1.0
12 LAC	10.5	+0.1

ranged from I to V, they had periods from three to ten hours, and projected rotational velocities from 0 to 300 km-sec^{-1}. Those having periods greater than 0.35 days did not obey a period-luminosity or a period-color radiation, while those with periods less than 0.3 days did appear to obey such relations.

Several other definite β CMa stars have been discovered since Hill's survey. Shobbrook (1973) summarized the properties of the variables he had discovered (and other previously discovered β CMa variables that he studied with the same photometric system) with the following table, Table 3. He concludes that both fast rotating and slow rotating β CMa stars exist and exhibit widely divergent behavior in light variation from star to star. The possibility of their following different period-luminosity relations could not be ruled out. An apparent β CMa star has also been found in O VEL (Van Hoof, 1972).

Much work has been done in the last few years in attempting to obtain better values for the luminosities, colors, and spectral types of the β CMa stars. Luminosities for six β CMa variables have been deduced from their membership in the Scorpio-Centaurus cluster (James and Shobbrook, 1974). The distance of α VIR has been measured interferometrically, and luminosities for the remaining variables were estimated from Hγ and Hβ line strengths.

Balona and Feast (1975) have carried out further work on the Sco-Cen association. Taking all of the stars in that

Table 3: Properties of β CMa stars obsreved by Shobbrook (Shobbrook, 1973)

PROPERTIES	NARROW LINED STARS	BROAD LINED STARS
Single Period	ξ^1 CMa	λ SCO, α VIR
Multiple Periods	β CMa, 15CMa	K SCO, ϵ CEN
Varying Period	β CMa, 15CMa	α VIR
Non-Periodic Amplitude Variations	β CMa, 15CMa	ϵ CEN, α VIR
Almost Semisoidal Light curves	β CMa	ϵ CEN, α VIR, KSCO
Non-Semisoidal Light Curves	ξ^1 CMa, 15CMa	λ SCO

association, they noted a serious discrepancy between the astrometric distance modulas, 5.78 mag., and the Hγ distance modulas, 6.46 mag. This inconsistancy is probably due to the cut-off applied to eliminate poor proper motions.

Using the Hγ luminosity calibrations of Balona and Crampton (1974), they derive a Zero-Age Main Sequence (ZAMS), apply the Hγ calibration to the βCMa variables, and, plotting those stars on an H-R diagram, find that most fall in the S-bend region for stars with z=0.06 (fraction of heavy elements). See Figure 2, a graph of these results.

Lesh and Aizenman (1973) have found simlar results. Presenting spectral types on the MR system for 17 bright βCMa variables, seven bright suspected variables, and 23 fainter suspected variables, they found that the variables occupy a very restricted region in their observational H-R diagram. In the theoretical H-R diagram this "instability strip" is shown to coincide with the region traversed three times by a star in the course of its post main sequence evolution: once in the core hydrogen-burning phase, once in the secondary contraction phase, and once in the shell hydrogen burning phase. Here one might hastily assume that the normal B stars in this region are in the core hydrogen burning phase and that the βCMa variables are in one of the two later stages of evolution. However, many theorists disagree with this assumption. Figure 3 shows some theoretical evolutionary tracks in the S-bend region along with some observational and theoretical main sequences.

Figure 2: H-R diagram of βCMa Variables (Lesh and Aizenman, 1973)

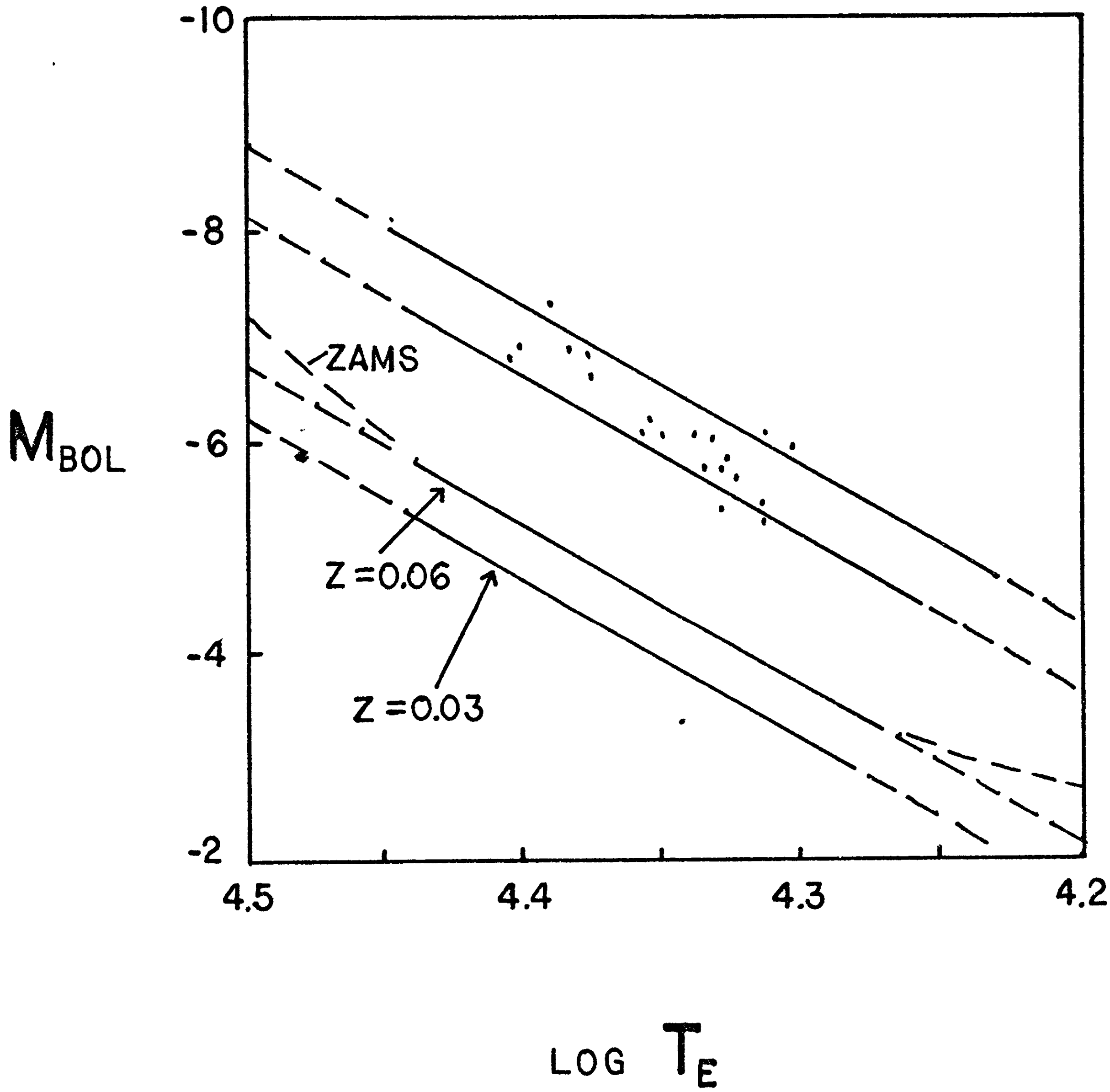
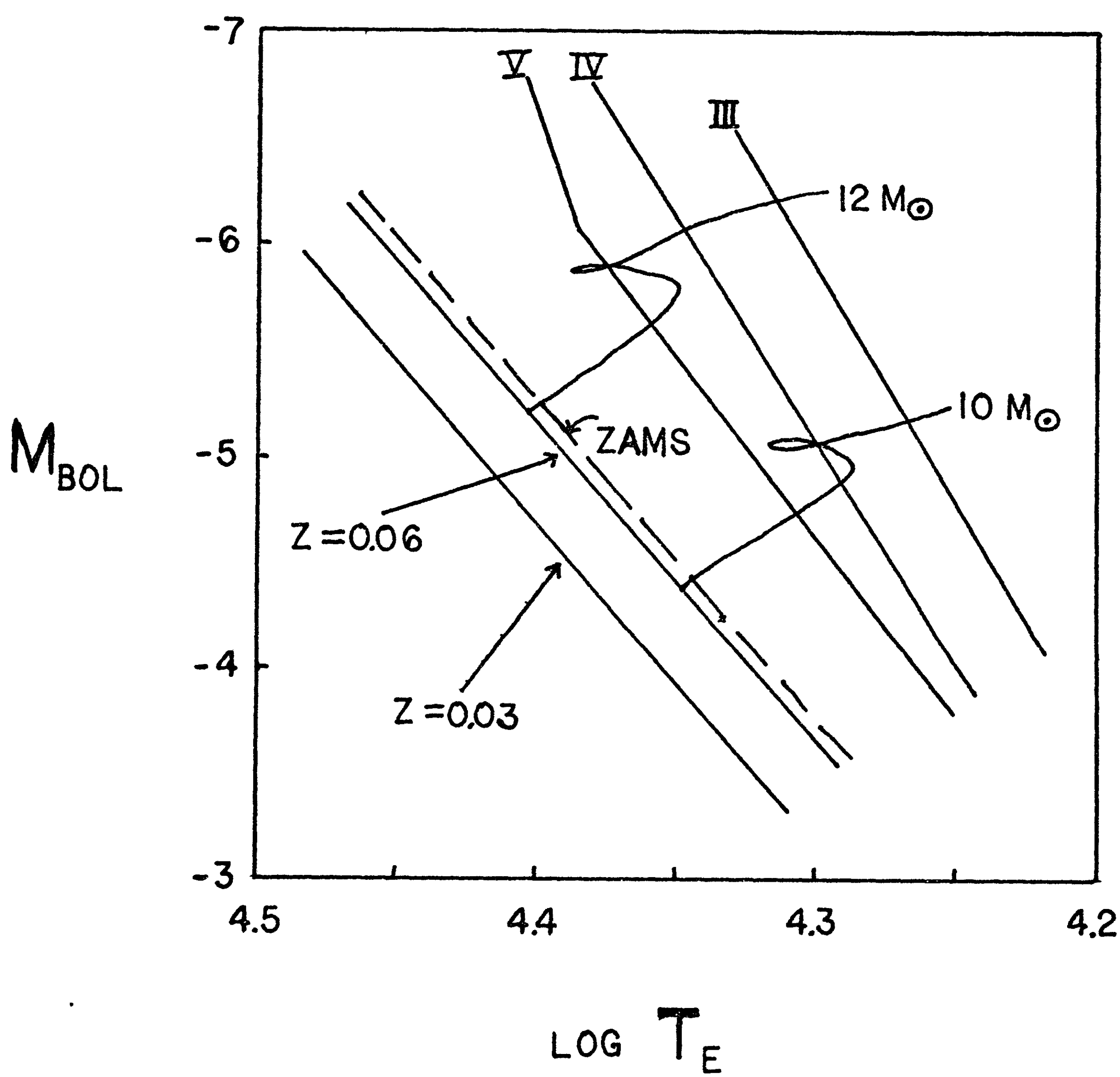


Figure 3: This diagram (Lesh and Aizenman, 1973) shows the observational and theoretical main sequence for class B stars, emphasizing how the normal stars and theoretical S-bend regions overlap.



IV. Theories Proposed for the β CMa Stars.

With the stage of evolution of the β CMa stars still somewhat uncertain we are also left with the two problems with which we started; the mechanism and modality of the pulsations. Many possible explanations have been put forward by many different authors, and the only general consensus is that the radial modes cannot be excited directly. Aizenman and Cox (1975b) do suggest, however, that the non-radial modes that are excited might couple to the radial fundamental and harmonic modes; the modes that we are most likely observing.

Aizenman and Cox (1975a) investigated possible non-adiabatic effects and concluded that the phase shifts between the pressure and density variations brought about by those small non-adiabatic effects cannot be neglected in a star that is in thermal imbalance. The other larger effects are dynamical in nature and can be descibed by the analogy of a slowly varying spring constant in a simple mechanical system.

Adiabatic non-radial oscillations have also been investigated. Harper and Rose (1970) give their results of calculations using Parkers forth order linear differential equation that describes the adiabatic non-radial pulsations of a compressable self-gravitating gas sphere. They computed a sequence of 10 $M_{\odot}$ models from the main sequence to the stage of hydrogen exhaustion in the core. For several of those models they calculated the fundamental radial mode and the Kelvin mode to see if the period of the variability and the possible resonance between the two modes fitted the observations. They found that when their model had evolved off the main sequence about one magnitude, the pulsation period was about 4 hours and the periods of the two modes were close enough to be in resonance. They concluded that the observed double periodicity of some β CMa stars could be due to resonance between the lowest radial mode and the Kelvin mode.

As a follow up to this work, Dupree (1974a) calculated models for 8, 10, and 12 $M_\odot$ stars. But periods found in these calculations agree quite well with those observed for the stars β CMa, 12 LAC, and KP PER. ν ERI fits the model less well while σ SCO and 16 LAC, both definite binaries that show large orbital motion, do not fit the computations. This is not likely due to the effects of the binary companion.

The four stars for which the models fit well can be represented by models in the late core hydrogen-burning stage, but not lose to the gravitational contraction stage. The modes that seem to be involved are the radial fundamental modes and the non-radial fundamental modes.

Using nonlinear methods, Dupree (1974b) concludes that in slowly rotating β CMa stars two modes will be present, and that those modes will interact even if they are not precisely degenerate.

Percy (1970) has examined models of stars 10 $M_\odot$ in the terminal stage of hydrogen burning and found that there should be a semi-convective zone present. For stars brighter than M_V=-3.0 the zone should be large enough to overcome stabilizing processes and allow pulsation. He suggests that this hypothesis be studied using a non-linear treatment of convection, in the presence of rotation.

Osaki (1974) presents a model with a rapidly spinning core in the late stages of hydrogen-burning in the core. He thinks that oscillatory large scale convective motion of the core having a frequency coinciding with the eigen-frequency of a non-radial oscillation of the whole star may excite such a non-radial oscillation of the whole star. Large amplitudes are found only in the convective core and at the surface of the star. The mode most likely to be excited is a sectoral mode, which is a wave traveling around the equator in the same direction as the rotation.

Differential rotation of the core and the surface is obviously indicated but the possible presence of angular momentum transport makes estimation of the velocity of rotation at the surface a very difficult matter. Thus this model cannot be tested observationally.

Strothers and Simon (1969) attempt to explain β CMa stars that are members of binary systems. They set forth two possible mechanisms for the variability. In both cases the β CMa component has accreted a He rich envelope from the companion star and is still burning hydrogen in the core.

The first mechanism, the μ mechanism, is the "reversal of the gradient of near molecular weight". Here heavy surface material compresses the envelope while the central density remains almost unchanged. Their models indicate that this mechanism will operate in inhomogeneous stars of 6 to 95 $M_{\odot}$.

If the He in the envelope mixes rapidly with the rest of the star, a higher degree of homogenity results and radiation pressure will be increased. Pulsational instability will develop in this "β mechanism" for stars of 12 to 60 $M_{\odot}$.

In trying to sum up the theoretical situation Iben (1974) states that the solution probably lies in the fact that the βCMa stars lie right in the overall contraction phase rather than in the core hydrogen-burning phase. There should be a huge convective shell and, taking into account time depardent convection, "it could be that fluctuations of convective motions act as the continual perturbation that drives the pulsation".

Thus, among the theorists, disagreement prevails with regard to the mechanism, modality, and evolutionary state responsible for the variability of the βCMa stars.

V. The Evolutionary State of the β CMa Variables.

Again, observations require that the β CMa stars be in one (or perhaps more) of three evolutionary states: core hydrogen-burning, secondary contraction, or shell hydrogen-burning. A natural assumption here is that the presence of variability is directly dependent on the evolutionary state; i.e.- β CMa stars should be in evidence in only one of the three states. Thus we ask, which evolutionary state is responsible for the pulsations, and can we determine this state observationally?

One such observational test would be to determine the proportion of β CMa stars in a statistically complete sample of early B stars; a number that one could compare directly to the proportion of its lifetime that an early B star should spend in each of the three evolutionary phases. To establish the lifetime expected for each phase we can select stellar models appropriate to the early B stars/ β CMa stars. To select these models we need to know the mass range of stars exhibiting β CMa variability.

We note that all confirmed β CMa variable stars are found in the range of spectral classes B0.5 to B2 and luminosity classes III to V. The most luminous star is classified B0.5III and the least luminous star, B2IV. This corresponds to a range in absolute visual magitude of -4.74 to -3.54 and a mass range of approximately 25 to 15 $M_{\odot}$ (Allen, 1973). β CMA candidates (Hill, 1967) are reported with spectral classes as late as B3V. This corresponds to $M_V = -2.30$ and a mass of approximately 10 $M_\odot$. Thus the models that we choose should correspond to stars in the mass range between 10 and 25 $M_\odot$.

Three stellar models spanning this mass range were selected from the vast literature on the subject. A 20 $M_\odot$ model (Barbaro et. al., 1973), a 15 $M_\odot$ model and a 9 $M_\odot$ model (Iben, 1972). These models all provided figures for the time spent in each evolutionary state and, most importantly, were similar in the initial compositions assumed for the model stars. The models of both authors used X=0.7 while Barbaro et. al. used Z=0.044 and Iben used Z=0.06. The several models calculated by Barbaro et. al. showed that the value of Z had very little effect on the resulting models.

None of the models provided calculations of the time spent in the S-bend region during core hydrogen-burning. One could, however, estimate the proportion of the total core hydrogen-burning phase spent in the S-bend region using a 10 $M_\odot$ model (Lesh and Aizenman, 1973b) which provided several ages along the core hydrogen-burning track. The estimate thus adopted was 10% of the total core hydrogen-burning time. Thus the time spent in the S-bend region during core hydrogen-burning is defined as 1/10 of the total core hydrogen-burning time.

The figures for time spent in overall contraction are of course entirely within the S-bend region; and the times required for establishment of the shell source are, in any event, far too short to account for the observed number of variables.

Roughly, the fractions of time spent in the S-bend region during each phase are as follows: core hydrogen-burning in S-bend region, approximately 79%; overall contraction, approximately 19%; and establishment of the shell source, approximately 2%. The results of the models and calculations of the time spent in the three evolutionary states are summarized in Table 4.

Next, one must determine the proportion of β CMa stars in a statistically complete sample of B stars. Percy (1974) has made a small attempt at this. He found that of the 42 B1-B2 stars within 200 pc. of the sun, at least 8, or 14%, are β CMa variables. However, lack of information about the variability of B1-B2 stars in the region may cause the figure to be too low, and the area having an abnormally high proportion of giants (the presence of the Sco-Cen open cluster) may cause the figure to be too high.

A more complete sample (Lesh and Aizenman, 1973b) should extend to 500 pc. Such a sample includes a number of open clusters and associations (Allen, 1973) including the Sco-Cen cluster, the II PER association, the I Ori association, and the Perseus cluster, plus a large number of field stars.

I found a total of 238 stars (spectral classes B0 to B3,

Table 4: Lifetime in the evolutionary states of the S-bend region for 20, 15, and 9 $M_\odot$ models.

MODEL	UNITS	CORE H-burning	CORE S-bend	SECONDARY CONTRACTION	SHELL estab.	TOTAL in S-bend
20 $M_\odot$ *	10^6y	7.726	0.7726	0.178	0.022	0.9726
	%	——	79.437	18.301	2.262	——
15 $M_\odot$ @	10^6y	10.1	1.01	0.227	0.00755	1.2445
	%	——	81.154	18.240	0.607	——
9 $M_\odot$ ¢	10^6y	21.14	2.114	0.6053	0.09113	2.8104
	%	——	75.22	21.538	3.243	——
Average % of total time in each region:			79%	19%	2%	

REFERENCES:

* Barbaro et. al., 1973

@ Iben, 1972

¢ Iben, 1972

luminosity classes II to V) between -20 and -90 declination (Hoffeit, 1964). Fifty-nine of these stars did not have luminosity classes. Of the 179 remaining stars, 130 (using spectroscopic parallaxes (Allen, 1973) assuming negligable interstellar absorption) were within 500 pc. of the sun. This was 73% of the stars with luminosity classes. If the same percentage of stars without luminosity classes are within 500 pc., then we would expect 43 of these stars to be within the required distance. Thus between -20 and -90 we find approximately 173 (B0 to B3, II to V) stars within 500 pc. of the sun. North of -20 dec. we find 224 early B stars within 500 pc. of the sun (Lesh, 1968). This is a total of approximately 396 stars. Bright Star Catalogue Numbers are listed in Table 5.

Of those approximately 396 stars, 19 (about 5%) are confirmed β CMa variables. This proportion of variables is compatiable with the expected lifetime of the overall contraction phase of evolution. One must be wary of this result, however; since far from all of the stars in the sample have been observed for β CMa variability. A total of 67 (about 20%) of the stars in the sample with reasonable distance estimates were listed in the Bright Star Catalogue as being of questionable variable status. Thus many variable candidates are evident in the sample. Table 6 lists those "VAR?" stars and constitutes a list of top priority stars to be observed for β CMa variability. It is noted that several confirmed β CMa

Table 5: Early B stars within 500 pc. (Hoffeit, 1964).

HR

38	1333	1848	1934	2373	3194	4234
39	1423	1851	1946	2387	3213	4537
153	1443	1852	1950	2475	3239	4573
155	1463	1855	1952	2494	3294	4590
179	1497	1858	1961	2501	3322	4603
264	1508	1861	1962	2510	3326	4721
302	1552	1864	1993	2538	3343	4656
496	1567	1868	2031	2544	3356	4679
533	1622	1871	2052	2577	3359	4730
542	1640	1873	2106	2596	3415	4743
779	1641	1875	2142	2614	3447	4798
801	1659	1876	2149	2618	3468	4844
938	1679	1886	2159	2648	3498	4848
985	1731	1887	2161	2702	3562	4853
987	1748	1890	2199	2745	3582	4898
1072	1756	1891	2205	2749	3593	4942
1074	1764	1892	2213	2770	3642	5056
1123	1765	1897	2232	2787	3659	5131
1131	1781	1898	2249	2790	3663	5190
1153	1783	1900	2266	2800	3734	5191
1163	1788	1903	2273	2817	3886	5193
1174	1790	1906	2282	2825	3941	5231
1191	1798	1911	2284	2911	3943	5248
1215	1803	1913	2288	2921	3952	5249
1220	1810	1918	2292	3055	3990	5267
1239	1811	1923	2294	3084	4064	5285
1253	1820	1924	2325	3117	4074	5316
1260	1833	1928	2344	3135	4196	5336
1273	1840	1931	2356	3159	4204	5354
1320	1842	1932	2370	3168	4222	5375

Table 5: (con't)

HR

5378	6027	6946	7790	8606
5395	6028	6960	7807	8640
5425	6084	7029	7844	8651
5440	6112	7074	7862	8725
5469	6115	7081	7899	8733
5471	6118	7084	7929	8758
5551	6141	7100	7940	8768
5571	6143	7121	7996	8777
5576	6165	7173	8029	8800
5595	6175	7200	8047	8803
5626	6247	7210	8053	8808
5651	6252	7249	8146	8926
5684	6353	7258	8171	9005
5695	6431	7279	8215	9011
5708	6453	7298	8238	9071
5730	6462	7318	8260	
5776	6510	7347	8301	
5812	6527	7403	8335	
5885	6580	7471	8341	
5902	6588	7474	8356	
5904	6601	7516	8375	
5907	6622	7554	8384	
5928	6684	7565	8385	
5942	6712	7591	8427	
5944	6787	7623	8439	
5948	6819	7647	8520	
5953	6873	7688	8539	
5984	6875	7700	8549	
5985	6897	7708	8553	
5987	6924	7739	8579	
5993	6941	7777	8603	

Table 6: Possible variables (VAR? stars) (Hoffeit, 1964).

HR		
8758	2817	542
8603	2749	179
8260	2745	155
8146	2648	153
7790	2596	
7777	2288	
7591	2142	
7279	1952	
7200	1923	
7074	1918	
6712	1911	
6684	1906	
6588	1900	
6453	1897	
5985	1892	
5984	1886	
5944	1861	
6595	1811	
5440	1803	
5354	1790	
5248	1679	
5191	1641	
5190	1552	
4798	1333	
4656	1273	
4621	1220	
4603	1215	
4573	1174	
3659	1163	
3642	985	
3498	938	
	[illegible]	
	[illegible]	
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	[illegible]	

variables (i.e.- β CMa and σ LUP) are listed as "VAR?" stars.

The conclusion that the overall contraction phase is responsible for the variability will remain in doubt until many more of the sample stars can be classed as either normal or β CMa stars. Such observations are direly needed.

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