INTERNAL CONSTITUTION AND OSCILLATION SPECTRUM OF PROCYON

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1. INTRODUCTION

In a previous paper on Procyon A, we analyzed the best available observational data (summarized here in Table 1), discussed its evolutionary status in terms of theoretical evolutionary tracks, and evaluated on the basis of these models its expected characteristic p-mode frequency spacing (Demarque and Guenther 1986). We reached the following conclusions:

(1) that the published astrometric mass of Procyon A is inconsistent with stellar models and seems too large by about 15 per cent.

(2) that evolutionary models have too high effective temperatures unless convective overshoot at the edge of the convective core, of the order of a tenth of a pressure scale height, is taken into account.

(3) that the p-mode characteristic frequency spacing for Procyon A should be in the range 25-30 μHz.

The aim of this paper is to explore theoretically the potential ability of the p-mode and g-mode non-radial oscillation spectrum to throw light on two fundamental problems raised by our first study: Procyon A's evolutionary status, and its mass-luminosity relation.

2. PROCYON A'S EVOLUTIONARY STATUS

As illustrated in Figure 1, Procyon A offers an unusual opportunity to test stellar structure theory because it could be in any of the following three evolutionary phases:

(1) core hydrogen burning,
(2) core exhaustion,
(3) hydrogen burning-shell narrowing.

Although both time-scale and luminosity arguments favor possibility (1), only observations of Procyon's p-mode and g-mode spectrum would provide a definitive test of its structure. The low-degree g-modes, in particular are remarkably sensitive to physical conditions near the center.

First turning to the p-modes, we note the dependence of the parameter D, defined in Table 2, to the structural details in the stellar core. Values of D are also listed in Table 2 for in each evolutionary phase: (1), (2) or (3). Model (1) has a small convective core. Model

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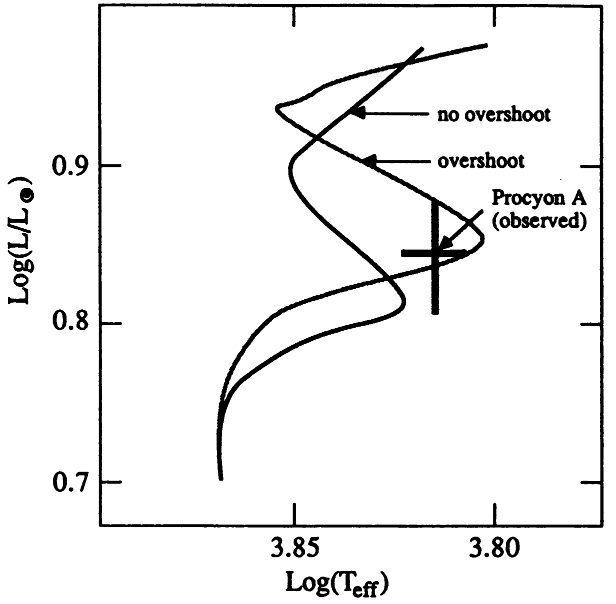
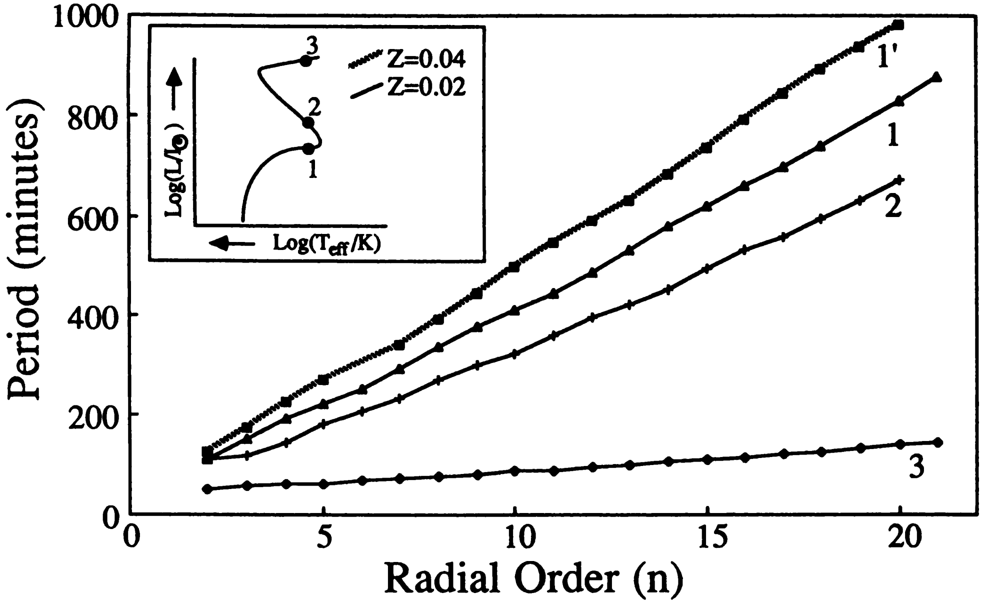
Figure 1.



(2) has a radiative core, in the process of depleting hydrogen. Model (3) has an inert helium core, exhausted of hydrogen, surrounded by a hydrogen burning shell. The sensitivity of D to central concentration has been discussed by Christensen-Dalsgaard (1984, 1986) and Ulrich (1986) for stars in phase (1) of evolution.

Figure 2 illustrates the marked sensitivity of the g-mode oscillation periods (for low degrees and radial order n $\leq$ 20) to the three phases.

Figure 2.



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3. PROCYON A'S MASS-LUMINOSITY RELATION AND METALLICITY

Doubling the interior metallicity of Procyon A, from $Z = 0.02$ to $Z = 0.04$ (twice solar), removes part of the discrepancy between the astrometric mass of $1.76 \pm 0.10\ M_0$ and the astrophysical estimate by raising the model mass to $1.58\ M_0$ [model (1') in Table 2]. Removing the discrepancy altogether would require an interior metallicity in the range of 0.05-0.06. Such high metallicities seem extreme in the context of current views on stellar abundances. However, diffusion in the outer layers can in some instances, deplete surface abundances and deceive us about the true metal content of most of the stellar interior (see also our paper on the solar interior in these Proceedings). Finally, we note that adjusting the helium abundance in the models to decrease their luminosity to the desired level is unattractive since it requires a helium abundance below observed values and below the primordial cosmological estimate.

The oscillation properties of model (1') are found in Table 2 for the p-modes, and in Figure 2 for the g-modes.

Table 1: Observational Data

Mass:	$1.76 \pm 0.10\ M_\odot$
Parallax:	$0''.287 \pm 0''.004$
$\log(L/L_\odot)$:	0.84 ± 0.03
$\log(T_{eff}/K)$:	3.810 to 3.823
Composition:	Solar ($Z=0.02$)

Table 2: P-Mode Characteristics

Model	Mass (solar)	Z	age (Gyrs)	$\Delta\nu/2$ (μHz)	$D(n=20, l=1)$† (μHz)
1	1.50	0.02	1.71	29	0.71
2	1.50	0.02	1.87	27*	0.65
3	1.50	0.02	1.98	22*	1.37
1'	1.58	0.04	1.50	29	0.61

* the characteristic frequency spacing ($\Delta\nu/2$) depends sensitively on the radius and is unaffected by the central structure. Models 1 and 1' fit most closely Procyon's radius. Models 2 and 3 have larger radii (see box in Figure 2), hence the smaller spacing.

† $D = \dfrac{\nu_{n,l} - \nu_{n-1,l+2}}{4l+6}$

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