The Astrophysical Journal, 633:460–464, 2005 November 1

DETECTION OF LONG-PERIOD VARIATIONS IN THE SUBDWARF B STAR PG 0101+039 ON THE BASIS OF PHOTOMETRY FROM THE *MOST* SATELLITE[1,2]

S. K. Randall,[3] J. M. Matthews,[4] G. Fontaine,[3] J. Rowe,[4] R. Kuschnig,[4] E. M. Green,[5] P. Brassard,[3] P. Chayer,[6] D. B. Guenther,[7] A. F. J. Moffat,[3] S. Rucinski,[8] D. Sasselov,[9] G. A. H. Walker,[4] and W. W. Weiss[10]

Received 2005 May 1; accepted 2005 July 14

ABSTRACT

We report the detection of three discrete pulsation frequencies in the long-period variable subdwarf B star PG 0101+039 on the basis of ~400 hr of *MOST* wide-band photometry. The periodicities uncovered lie at 7235, 5227, and 2650 s, respectively, and are associated with amplitudes between 0.03% and 0.06% of the mean brightness, lower than those measured in any other variable of this kind. We also find evidence for luminosity variations consistent with an ellipsoidal deformation of the subdwarf in the rotationally locked short-period binary system predicted from radial velocity measurements and evolutionary models. Our atmospheric modeling of two independent time-averaged optical spectra of PG 0101+039 yields $T_{\rm eff} \simeq 28{,}300$ K and $\log g \simeq 5.52$, making it one of the hottest long-period variable subdwarf B stars known. The fact that we nevertheless detect brightness variations in the data is in conflict with predictions from current models, which place the theoretical blue edge for observable long-period instabilities at a temperature around 4000 K cooler than that of PG 0101+039.

Subject headings: stars: interiors — stars: oscillations — subdwarfs

1. INTRODUCTION

Subdwarf B (sdB) stars are evolved extreme horizontal branch objects with atmospheric parameters in the range $20{,}000\ {\rm K} \lesssim T_{\rm eff} \lesssim 40{,}000$ K and $5.0 \lesssim \log g \lesssim 6.2$ (Saffer et al. 1994). They are composed of a helium-burning core surrounded by a hydrogen-rich shell and are characterized by masses of ~0.5 $M_\odot$. SdB progenitors are thought to have lost a significant fraction of their hydrogen envelope near the red giant tip, leaving the remaining shell too thin for them to ascend the asymptotic giant branch after helium exhaustion (Heber 1986; Dorman 1995). Instead, they evolve off and along the horizontal branch and end their lives as low-mass white dwarfs (Bergeron et al. 1994). While their precise evolutionary path and the circumstances surrounding the mass loss are not yet fully understood, it is hoped that the asteroseismology of pulsating subdwarf B stars will help constrain potential evolutionary scenarios through the determination of key parameters such as the total mass and the thickness of the hydrogen shell.

We currently know of two types of subdwarf B pulsator: the rapidly oscillating EC 14026 stars (Kilkenny et al. 1997) and the more recently discovered long-period variable PG 1716 stars (Green et al. 2003). The former excite pressure (*p*-) modes with typical periods of 100–200 s and lie at effective temperatures between 28,000 and 36,000 K, while the latter are noticeably cooler, at $22{,}000\ {\rm K} \lesssim T_{\rm eff} \lesssim 29{,}000$ K and exhibit periodicities of around 1–2 hr, corresponding to high radial order gravity (*g*-) modes. Oscillations are thought to be driven by a κ mechanism associated with a local overabundance of iron in the stellar envelope in both cases (see Charpinet et al. [1996, 1997] and Fontaine et al. [2003], respectively, for the two types of pulsator). In the case of the rapid oscillators, the periodicities observed have been recovered by predictions not only to the extent where the ranges of unstable periods coincide, but also to the point where a quantitative interpretation of the detected period spectrum has been achieved in a few instances (Brassard et al. 2001; Charpinet et al. 2003, 2005a, 2005b). These asteroseismological analyses are based on the identification of low radial order *p*-modes with degree indices $l = 0$, 1, 2, and 3 and/or 4. Because there are not enough theoretical modes with $l = 0$, 1, and 2 to account for the mode density observed, the inclusion of the latter is necessary in the asteroseismological process.

For the PG 1617 stars, both observational and theoretical research are still in their infancy. To date, only three long-period variables have been monitored in any detail: the class prototype PG 1716+426 (Green et al. 2003; Reed et al. 2004), PG 1627+017 (Randall et al. 2004a), and PG 1338+481 (Randall et al. 2004b). While the periodicities observed for these stars occur on a timescale similar to those predicted from models, there seem to be systematic discrepancies between the two. In particular, current models are able to excite only modes with degree indices $l \geq 3$ for all but the coolest subdwarfs (see Fig. 9 of Fontaine et al. 2003). The minimum degree index of unstable modes increases monotonically with temperature to the point where models corresponding to the very hottest PG 1716 stars can drive

---

[1] Based on data from *MOST*, a Canadian Space Agency mission operated jointly by Dynacon, Inc., the University of Toronto Institute of Aerospace Studies, and the University of British Columbia, with assistance from the University of Vienna.

[2] Observations reported here were obtained at the MMT Observatory, a joint facility of the University of Arizona and the Smithsonian Institution.

[3] Département de Physique, Université de Montréal, C.P. 6128, Succursale Centre-Ville, Montréal, QC H3C 3J7, Canada; randall@astro.umontreal.ca, fontaine@astro.umontreal.ca, brassard@astro.umontreal.ca, moffat@astro.umontreal.ca.

[4] Department of Physics and Astronomy, University of British Columbia, 6224 Agricultural Road, Vancouver, BC V6T 1Z1, Canada; matthews@astro.ubc.ca, rowe@astro.ubc.ca, kuschnig@astro.ubc.ca, walker@astro.ubc.ca.

[5] Steward Observatory, University of Arizona, Tucson, AZ 85721; bgreen@as.arizona.edu.

[6] Bloomberg Center for Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218-2695; chayer@pha.jhu.edu.

[7] Department of Astronomy and Physics, St. Mary's University, Halifax, NS B3H 3C3, Canada; guenther@ap.stmarys.ca.

[8] David Dunlap Observatory, University of Toronto, P.O. Box 360, Richmond Hill, ON L4C 4Y6, Canada; rucinski@astro.utoronto.ca.

[9] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; sasselov@cfa.harvard.edu.

[10] Institut für Astronomie, Universität Wien, Türkenschanzstrasse 17, A-1180 Wien, Austria; weiss@astro.univie.ac.at.

only modes with $l > 8$. Although this clearly indicates problems with the theoretical blue edge, these have been difficult to specify due to a lack of data. All previous observational campaigns have focused on targets of low and intermediate temperatures, where the periods detected could qualitatively be explained by excited modes of $l = 2, 3,$ and/or 4 if the star's effective temperature and surface gravity were pushed to the lower end of the spectroscopic estimates (which are less accurate for the cooler long-period variables). In order to quantify the discrepancies between modeled and experimental instabilities, we thus deem it necessary to determine the periodicities exhibited by a hotter target for which no discernible brightness variations are expected.

It is with this in mind that we choose to monitor PG 0101+039, one of the hottest subdwarf B stars known to show long-period oscillations. Also known as Feige 11, PG 0101+039 is the second subdwarf B star for which long-period variability was detected, albeit at much lower amplitudes than for the prototype (Green et al. 2003). At an apparent magnitude of $V = 12.06$, it is one of the brightest subdwarf B stars and thus an obvious exploratory target. Radial velocity measurements have found it to form part of a binary system with a relatively short orbital period of $P_{\rm orb} \sim 0.569908 \pm 0.000007$ days (Moran et al. 1999), the companion most likely being a white dwarf (Maxted et al. 2002). Interestingly, the fit of the binary period to the radial velocity data of Moran et al. (1999) was associated with an unusually large χ^2 value, indicating either systematic measurement errors or an intrinsic brightness variation of the subdwarf on a timescale of ~55 minutes. At the time, long-period variations in subdwarf B stars had not yet been discovered, and so the latter possibility was not further explored.[11]

Since previous ground-based photometric campaigns have demonstrated that the detailed frequency analysis of long-period variable subdwarf B stars will in most cases require the high duty cycle and long time coverage of space-based observations (see, e.g., Randall et al. 2004b), the photometry of PG 0101+039 was obtained with the *MOST* (*Microvariability and Oscillations of Stars*) satellite (Walker et al. 2003) in a trial run for potential future missions. *MOST* houses a 15 cm optical telescope feeding a CCD photometer through a custom broadband filter (250–700 nm), and can monitor certain stars for up to 8 weeks without interruption from its Sun-synchronous polar orbit (altitude of 820 km). It was designed to perform rapid photometry of micromagnitude precision on primary target stars brighter than $V = 6$ through Fabry lens projection of an extended pupil image of the telescope; however, its Science CCD does have an open field where slightly defocused images of secondary targets as faint as $V = 12-13$ can be obtained with a reasonable signal-to-noise ratio and time resolution of better than 1 minute. The preliminary results we present in this Paper confirm that *MOST* (and other future stellar photometry satellites such as *COROT* and *Kepler*) hold great promise for the identification and interpretation of long-period oscillations in subdwarf B stars.

2. OBSERVATIONS AND ANALYSIS

2.1. *Spectra and Atmospheric Model Fit*

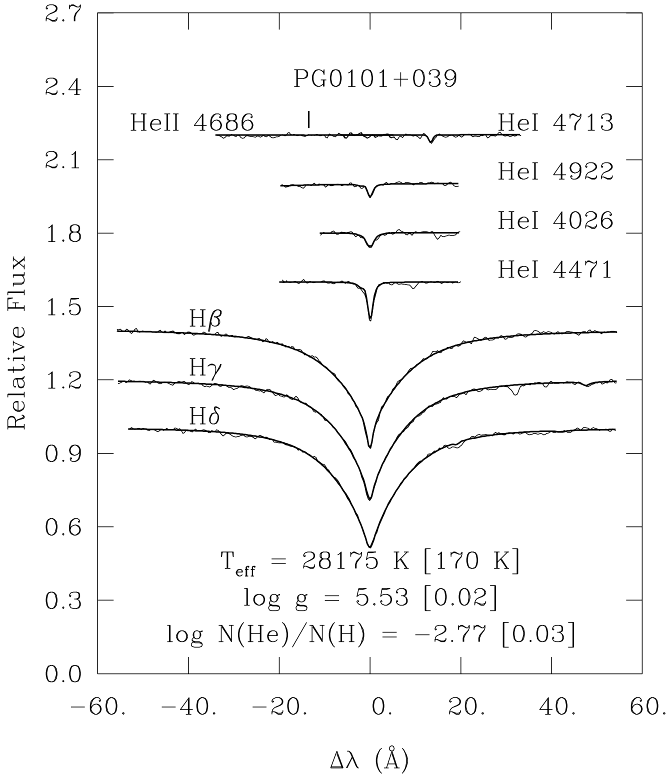

FIG. 1.—Model fit (*thick curve*) to the available hydrogen Balmer and helium lines in our MMT spectrum of PG 0101+039.

We obtained optical spectroscopy of PG 0101+039 in the course of an ongoing program designed to provide homogeneous estimates of the atmospheric parameters of a large sample of subdwarf B stars. This program is based on low-resolution (9 Å, $R \sim 500$) spectra from the 2.3 m Steward Observatory telescope at Kitt Peak and/or medium-resolution (1 Å, $R \sim 4400$) spectroscopy obtained at the MMT. For PG 0101+039, high signal-to-noise ratio (S/N ~ 200–400) time-averaged spectra from both telescopes were available, enabling two independent estimates of the atmospheric parameters on the basis of different sets of spectral lines. The model spectra are computed from non-LTE model atmospheres containing hydrogen and helium, but no metals (see E. M. Green, G. Fontaine, & P. Chayer 2005, in preparation). Figure 1 shows our best fit to the hydrogen Balmer and helium lines available from the MMT spectrum, implying atmospheric parameters of $T_{\rm eff} = 28{,}175 \pm 170$ K, $\log g = 5.53 \pm 0.02$, and $\log N({\rm He})/N({\rm H}) = -2.77 \pm 0.03$. The corresponding fit to the low-resolution spectrum gives $T_{\rm eff} = 28{,}430 \pm 170$ K, $\log g = 5.51 \pm 0.03$, and $\log N({\rm He})/N({\rm H}) = -2.70 \pm 0.08$, in agreement with the previous values within the formal errors. Test calculations with non-LTE models including metals in solar proportions suggest that the effective temperature and the surface gravity of PG 0101+039 could perhaps be reduced by ~1800 K and 0.15 dex, respectively, but not much more. It is thus evident that both the effective temperature and the surface gravity of PG 0101+039 are substantially higher than the upper limit predicted for the excitation of modes with $l \leq 8$ from our models of long-period variable subdwarf B stars (see Fig. 9 of Fontaine et al. 2003).

2.2. *Photometry and Frequency Analysis*

MOST photometry of PG 0101+039 was obtained over 16.9 days, from 2004 September 28 to October 15, with an exposure time of 30 s and a sampling rate of once every 35 s. Observations were nearly continuous at this cadence, except for

---

[11] In retrospect, the very low amplitudes of the pulsations detected in the PG 0101+039 photometry imply radial velocity variations of less than 1 km s^{-1}, below the typical measurement errors of ~1.8 km s^{-1} reported by Moran et al. (1999). It is thus highly unlikely that the χ^2 excess reported in the radial velocity data is caused by the long-period pulsations detected.

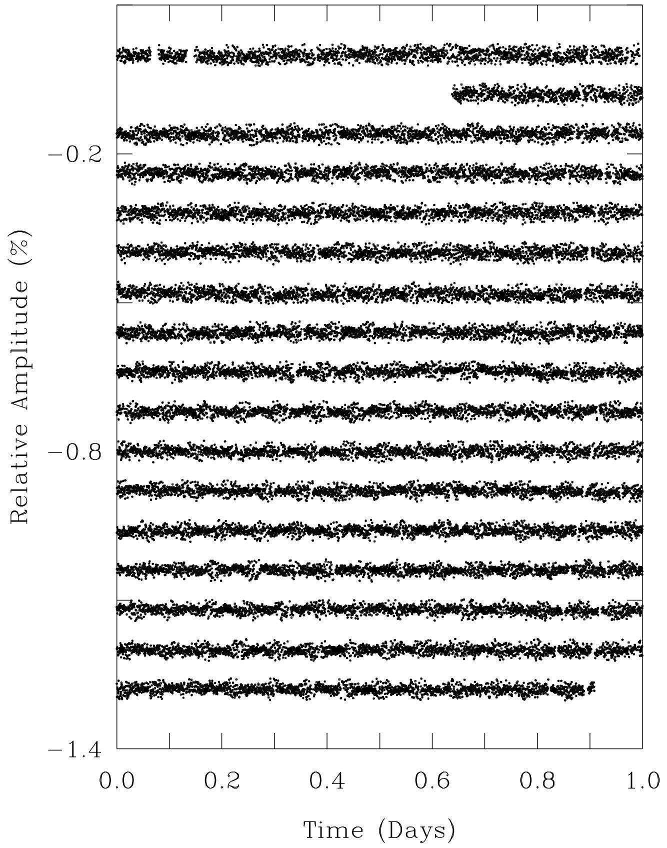

FIG. 2.—*MOST* photometry of PG 0101+039 on an absolute timescale. The top row covers the first 24 hr period of the run, and the data for subsequent days have been shifted downward arbitrarily for visualization purposes. The light curve has been corrected for outliers, general long term trends and stray light variations due to the orbit of *MOST.* The latter produces a period of elevated scatter every 101.413 minutes, which is discernible from the light curve.

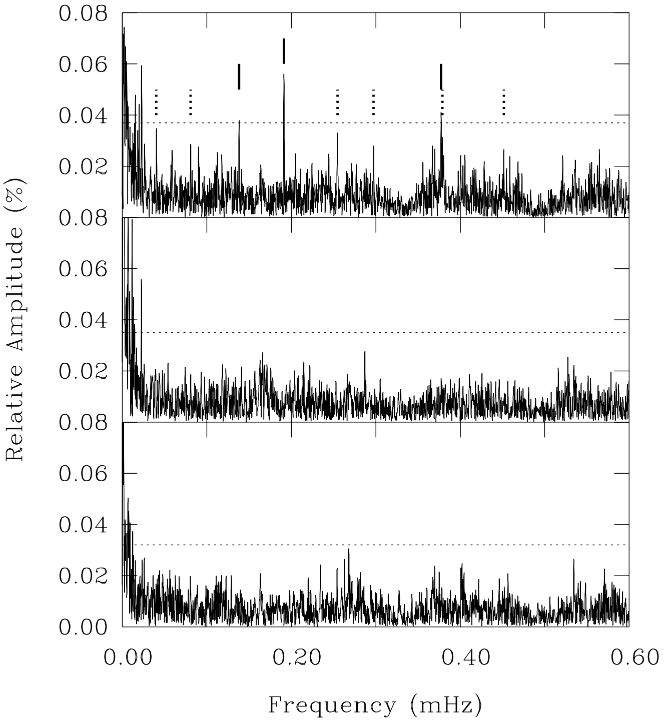

FIG. 3.—Fourier amplitude spectra of PG 0101+039 (*top*) and the two comparison stars GSC 00022-01077 (*middle*) and GSC 00022-01060 (*bottom*) in the 0–0.6 mHz bandpass. The dotted horizontal line indicates the adopted threshold of 4 times the mean noise level for each data set. In the plot for PG 0101+039 we have indicated the convincing periodicities detected (*solid vertical line segments*), as well as other potential oscillations with amplitudes above 3 times the mean noise level (*dotted vertical line segments*).

one major gap of about 14 hr early in the run, when the *MOST* camera was shut off due to full moonshine coming almost directly into the instrument. This implies a net duty cycle of 96.5%, and a formal frequency resolution of 0.68 μHz. The raw photometry obtained with *MOST* is subject to stray light variations caused by scattered earthshine entering the focal plane at a well-specified range of phases in the satellite's 101.413 minute (6084.7 s/0.164 mHz) orbital period. This stray light background has been subtracted, and obvious outliers as well as very long-term trends have been removed from the data during the reduction process, resulting in the light curve illustrated in Figure 2. While there seems to be some evident structure in the curve, this is mostly due to the periodic increase in point-to-point scatter associated with the orbital phases of highest stray light. The field of the *MOST* Science CCD also included two comparison stars (GSC 00022-01077 and GSC 00022-01060) of brightness similar to PG 0101+039. Given that *MOST* was not designed for wide-field CCD photometry of stars near $V = 12$ (no onboard flat-fielding calibration, for example), differential photometry of PG 0101+039 relative to these comparison stars did not improve the scatter in the light curve and was decided against. Nevertheless, the independent photometry of these additional stars was useful when trying to gauge the reliability of periodicities uncovered in the target data.

The top panel of Figure 3 shows the Fourier transform of the entire PG 0101+039 data set for the 0–0.6 mHz bandpass of interest. Beyond this, the spectrum is consistent with noise out to the Nyquist frequency of 14.3 mHz. We subjected the data to our standard prewhitening procedure (see Billères et al. [2000] for details), adopting a threshold of 4 times the noise level (indicated by the dotted horizontal line) above which peaks would be considered convincing. This value was derived from the Fourier transforms of the comparison star light curves depicted in the lower two panels of Figure 3, which exhibit peaks above the threshold only at periods longer than ~40,000 s. Since the amplitudes and periods of these peaks are similar to those of the low-frequency agglomeration of periodicities visible in the Fourier spectrum for PG 0101+039, the latter are attributed to nonstellar noise and are not considered in the remainder of this paper. In any case, it is not physically viable to find oscillations of this length in subdwarf B stars, as they would be lost to space rather than reflected at the stellar surface.[12] The remaining three convincing peaks (which are marked by solid vertical line segments) lie between 2600 and 7250 s, a range comparable to that found in other PG 1716 stars, and are associated with amplitudes between 0.03% and 0.06% of the mean brightness. Probing slightly below our imposed threshold, but staying above the often-assumed limit of 3 times the noise level, we uncover other potentially interesting periodicities (marked by dotted vertical line segments), most notably two peaks corresponding to (within 0.3%) half the binary orbital period of PG 0101+039 ($P_{\rm orb}/2 = 24{,}620$ s) and its first harmonic, respectively. Assuming the binary-synchronous stellar rotation rate expected in this type of system, these are likely caused by an ellipsoidal

---

[12] Following the theory developed by Hansen et al. (1985) for the case of white dwarfs and adapting it to our equilibrium model of PG 0101+039, we calculated that oscillations will be lost if their periods lie above the cutoff period for g-modes $P_g \sim 23{,}000/[l(l+1)]^{1/2}$ s.

deformation of the subdwarf due to the gravitational pull of its companion. A similar effect has been encountered for the short-period variable subdwarf B star KPD 1930+2752 (Billères et al. 2000), although in this case the deformation was much more extreme because of the greater proximity of the binary components.

3. MODELING THE VARIATIONS OF PG 0101+039

The three convincing pulsational periods (f_1 to f_3) and the signature of the ellipsoidal variation and its first harmonic (e_1 and e_2) are listed in Table 1 in order of descending amplitude. While the amplitudes and phases of the oscillations are associated with formal errors due to the least-square fitting process to the light curve, the frequencies are derived directly from the Fourier transform, which provides no formal error estimates. The accuracy of the frequencies extracted should, however, be of the order of 1/10 of the resolution, i.e., about 0.1 μHz. Considering the periodicities arising from the ellipsoidal deformation of the subdwarf (e_1 and e_2) then yields a photometrically determined binary period of $P_{\rm orb} = 0.571 \pm 0.001$ days, marginally longer than that found from spectroscopy, but still in accordance with it. While this strongly supports the assumed notion of a binary-synchronous rotation rate, the data show no convincing evidence for rotational splitting of the harmonic pulsation frequencies. Lifting the m-fold degeneracy of a mode with indices k and l by breaking spherical symmetry should result in a frequency multiplet whose components are separated by

$$\Delta f = \frac{1 - C_{kl}}{P_{\rm rot}}, \tag{1}$$

where $P_{\rm rot}$ is the rotation period and

$$C_{kl} \sim \frac{1}{l(l+1)} \tag{2}$$

in the limit where $k \gg 1$ (see below for a justification of this assumption for PG 1716 stars). Apart from a peak at 2724 s (0.3671 mHz), which potentially constitutes the $m = -1$ component of the oscillation at 2650 s (f_2) and would imply an $l = 1$ mode, we find no indication of such splittings, which is probably due to their low amplitudes compared to the noise level. While this is disappointing from the point of view of constraining the modes' degree indices using the frequency spacing of a given multiplet, it does mean that the pulsation frequencies detected constitute independent harmonic oscillations and can be directly compared to the theoretical period spectrum.

We construct a model representative of PG 0101+039 with an effective temperature $T_{\rm eff} = 28{,}400$ K, a surface gravity $\log g = 5.53$, a total mass $M_*/M_\odot = 0.48$, and the transition between the helium core and the hydrogen-rich envelope located at a logarithmic depth $\log q(H) = -2.70$. Based on the same numerical tools employed by Charpinet et al. (1997; see also Fontaine et al. 1998; Charpinet et al. 2001; Fontaine et al. 2003) for the construction of their "second-generation" models, it features an opacity profile that largely depends on the nonuniform distribution of iron as a function of depth, computed by considering the competitive action of gravitational settling and radiative levitation on traces of iron in a pure hydrogen background. It is the precise shape of the resulting opacity profile that determines whether or not the κ mechanism can operate effectively and thus generate the energy needed to drive oscillations. Since nonadiabatic calculations do not predict unstable modes with degree indices $l \leq 8$ in our model, we focus on the theoretical period spectrum obtained from adiabatic oscillation computations. Figure 4 compares the periods detected in the light curve of PG 0101+039 to those calculated in the range 2000–8000 s on the basis of modes with degree indices $l = 1$–4. The predicted oscillations correspond to g-modes with high radial orders of $k \sim 10$–55. Although the precise values of the computed periods may vary with the atmospheric parameters of the model, the qualitative picture does not change noticeably within the spectroscopic uncertainties. It is immediately obvious that the observed periods are vastly outnumbered by those computed in the same range, even if only more readily visible modes with $l = 1$ and 2 are considered. The question is whether this is due to the observational constraints placed by the noise level of the data and could be overcome by more sensitive observations, or whether the excitation mechanism simply does not generate enough energy to drive all the modes in the period range. Even if a combination of the two is true, it is clear that unique mode identification in this star represents a major challenge and will require both additional observed periodicities and independent constraints on their degree indices, be it on the basis of multicolor photometry (see, e.g., Randall et al. 2005), time-series spectroscopy (see, e.g., O'Toole

TABLE 1

Oscillations Detected in the Light Curve of PG 0101+039

Parameter	Frequency (mHz)	Period (s)	Amplitude (%)	Phase (rad)
f_1	0.1913	5227	0.054 ± 0.006	3917 ± 88
f_2	0.3774	2650	0.041 ± 0.006	707 ± 62
f_3	0.1382	7235	0.038 ± 0.006	4882 ± 182
e_1	0.0405	24687	0.034 ± 0.006	10019 ± 665
e_2	0.0810	12344	0.029 ± 0.006	1209 ± 405

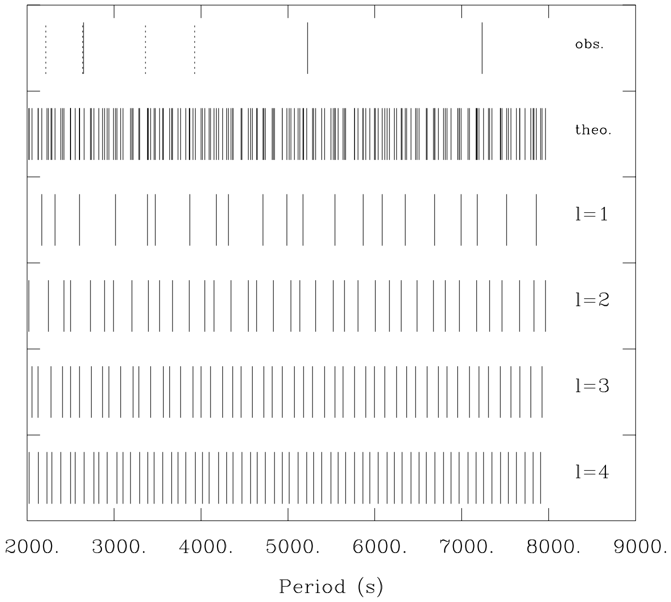

Fig. 4.—Theoretical pulsation spectrum of a model representative of PG 0101+039, with $T_{\rm eff} = 28{,}400$ K, $\log g = 5.53$, $M_*/M_\odot = 0.48$, and $\log q({\rm H}) = -2.70$. All pulsation modes with $l = 1$, 2, 3, and 4 in the 2000–8000 s interval are indicated. Modes with different degree indices l are illustrated both separately and as part of the total theoretical spectrum. This is to be compared to the values of the stellar pulsation modes listed in Table 1 (*solid line segments*) and the other potential oscillations indicated in Fig. 3 (*dotted line segments*).

et al. 2003), or the interpretation of rotational splitting (see, e.g., Charpinet et al. 2005a).

4. CONCLUSION

The analysis of ∼400 hr of *MOST* photometry for the long-period variable subdwarf B star PG 0101+039 uncovered three convincing stellar oscillations with periods in the 2650–7250 s range, as well as evidence for an ellipsoidal deformation of the subdwarf due to the gravitational pull of its binary companion. While the latter implies a binary-synchronous rotation rate, as was to be expected from evolutionary scenarios, we were not able to detect the corresponding rotational splitting. The amplitudes of the pulsations extracted all lie below 0.06% of the star's mean brightness, significantly lower than those reported for the other three (cooler) PG 1716 stars monitored to date. According to current nonadiabatic theory, this observed trend of oscillation amplitudes decreasing with the effective temperature of the target can be explained by the fact that hotter models excite modes with a successively higher minimum degree index l, and the brightness variations integrated over the visible disk thus diminish. Our models also recover the tendency for hotter PG 1716 stars to excite shorter periods than their cooler counterparts, albeit on a relative rather than an absolute scale. In particular, the theoretical range of instability consistently underestimates the range of periods observed for a given target.

The most serious shortcoming of our models is probably their inability to excite modes with "acceptable" degree indices (i.e., $l \leq 4$) over a substantial part of the atmospheric parameter range where real PG 1716 stars are found. The very fact that we detected long-period variations in a subdwarf B star as hot as PG 0101+039 is in conflict with predictions. According to theory, a model with the appropriate atmospheric parameters is able to excite only modes with degree indices $l \geq 9$, which we must concede would most likely not be observable even in the best of circumstances. Unlike for previous targets, where periods with $l \leq 3$ or 4 could be inferred by pushing the stars' atmospheric parameters to the lower end of the uncertainty on their estimates, the accuracy and high values of our spectroscopic determination of $\log g$ and $T_{\rm eff}$ for PG 0101+039 do not allow this. It is thus beyond doubt that our current PG 1716 models are subject to a real blue-edge problem, and will have to be refined if the oscillations detected in the light curve of PG 0101+039 are to be explained. One particularly promising idea that we are now investigating in Montréal is to include helium in the iron levitation calculations, which are currently effected assuming a pure hydrogen background. While preliminary computations indicate that this will influence the iron abundance profile and potentially have an impact on the opacity-driving mechanism, it is not certain whether the instability strip will shift in the right direction. This can only be answered by detailed modeling, a discussion of which is beyond the scope of this paper and will be presented elsewhere.

Beyond the implications for the study of long-period variable subdwarf B stars, the data obtained for PG 0101+039 have demonstrated that *MOST* can detect oscillations with ∼0.5 mmag amplitudes in a 12 mag star from observations lasting just over 2 weeks. Considering that the satellite was primarily designed to monitor targets brighter than 6 mag, this is a considerable achievement and should constitute an incentive for future *MOST* missions dedicated to subdwarf B stars. In particular, it would be extremely interesting to monitor a slightly cooler PG 1716 star with higher amplitude oscillations for the full 8 weeks that *MOST* can focus on a single target without interruption. It is almost certain that the resulting data would surpass anything obtainable from ground-based photometry as far as coverage and frequency resolution are concerned. Indeed, long-period variable subdwarf B stars make ideal targets for space-based observations, as the data gaps and atmospheric brightness variations inherent to time-series photometry obtained at ground level often prevent the unambiguous identification of pulsation frequencies. As the only orbiting space telescope currently dedicated to asteroseismology, *MOST* may well hold the key to exploiting the period spectrum exhibited by these stars.

This work was supported in part by the Natural Sciences and Engineering Research Council of Canada and by the Fonds de recherche sur la nature et les technologies (Québec). G. F. also acknowledges the contribution of the Canada Research Chair Program. R. K.'s contributions are funded by the Canadian Space Agency.

REFERENCES

Bergeron, P., Wesemael, F., Beauchamp, A., Wood, M. A., Lamontagne, R., Fontaine, G., & Liebert, J. 1994, ApJ, 432, 305

Billères, M., Fontaine, G., Brassard, P., Charpinet, S., Liebert, J., & Saffer, R. A. 2000, ApJ, 530, 441

Brassard, P., Fontaine, G., Billères, M., Charpinet, S., Liebert, J., & Saffer, R. A. 2001, ApJ, 563, 1013

Charpinet, S., Fontaine, G., & Brassard, P. 2001, PASP, 113, 775

———. 2003, in White Dwarfs, ed. D. de Martino, R. Silvotti, J.-E. Solheim, & R. Kalytis. (NATO ASI Ser. B, 105; Dordrecht: Kluwer), 69

Charpinet, S., Fontaine, G., Brassard, P., Billères, M., Green, E. M., & Chayer, P. 2005a, A&A, in press

Charpinet, S., Fontaine, G., Brassard, P., Chayer, P., Rogers, F. J., Iglesias, C. A., & Dorman, B. 1997, ApJ, 483, L123

Charpinet, S., Fontaine, G., Brassard, P., & Dorman, B. 1996, ApJ, 471, L103

Charpinet, S., Fontaine, G., Brassard, P., Green, E. M., & Chayer, P. 2005b, A&A, 437, 575

Dorman, B. 1995, in Proc. 32nd Liège Astrophys. Colloq., Stellar Evolution: What Should be Done?, ed. A. Noels, et al. (Liège: Inst. d'Astrophys.), 291

Fontaine, G., Brassard, P., Charpinet, S., Green, E. M., Chayer, P., Billères, M., & Randall, S. K. 2003, ApJ, 597, 518

Fontaine, G., Charpinet, S., Brassard, P., Chayer, P., Rogers, F. J., Iglesias, C. A., & Dorman, B. 1998, in IAU Symp. 185, New Eyes to See Inside the Sun and Stars, ed. F.-L. Deubner, J. Christensen-Dalsgaard, & D. Kurtz (Dordrecht: Kluwer), 367

Green, E. M., et al. 2003, ApJ, 583, L31

Hansen, C. J., Winget, D. E., & Kawaler, S. 1985, ApJ, 297, 544

Heber, U. 1986, A&A, 155, 33

Kilkenny, D., Koen, C., O'Donoghue, D., & Stobie, R. S. 1997, MNRAS, 285, 640

Maxted, P. F. L., Marsh, T. R., Heber, U., Morales-Rueda, L., North, R. C., & Lawson, W. A. 2002, MNRAS, 333, 231

Moran, C., Maxted, P., Marsh, T. R., Saffer, R. A., & Livio, M. 1999, MNRAS, 304, 535

O'Toole, S. J., Jorgensen, M. S., Kjeldsen, H., Bedding, T. R., Dall, T. H., & Heber, U. 2003, MNRAS, 340, 856

Randall, S., et al. 2004a, Ap&SS, 291, 465

Randall, S. K., Fontaine, G., Brassard, P., & Bergeron, P. 2005, ApJS, in press

Randall, S. K., Fontaine, G., Green, E. M., Brassard, P., & Terndrup, D. M. 2004b, Proc. SOHO 14/GONG 2004 Workshop (ESA SP-559), Helio- and Asteroseismology: Towards a Golden Future (Noordwijk: ESA Publications Division), 119

Reed, M.D., et al. 2004, ApJ, 607, 445

Saffer, R., Bergeron, P., Koester, D., & Liebert, J. 1994, ApJ, 432, 351

Walker, G. A. H., et al. 2003, PASP, 115, 1023