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THE MSST CAMPAIGN: 4 M SPECTROSCOPY OF PG 1605+072

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Abstract. The MultiSite Spectroscopic Telescope (MSST) campaign aimed to provide a detailed view of the short-period pulsating subdwarf B star PG 1605+072. We present results from the part of the campaign undertaken on 4 m telescopes in 2002 May and June.

Key words: stars: hot subdwarfs – stars: oscillations – stars: individual (PG 1605+072)

1. INTRODUCTION

The MultiSite Spectroscopic Telescope (MSST) campaign observed the non-radially pulsating subdwarf B star PG 1605+072 in 2002 May and June (Heber et al. 2003). Spectroscopic observations were obtained on a range of 2 m and 4 m class telescopes, supported by photometry from a large number of observatories, including the Whole Earth Telescope. Other papers describing the spectroscopic results from 2 m telescopes (O'Toole et al. 2005) and the photometry (Schuh et al. 2003, Dreizler et al. 2006) are and will be published elsewhere.

Previous spectroscopic observations of PG 1605+072 with 4 m telescopes had proved the feasibility and precision of a study of velocity variations (Woolf et al. 2002), compromised only by the quantity of data obtained and issues about timing. The main focus of this part of the MSST was to maximize the length and coverage of the observations in order to obtain higher resolution in both velocity and frequency, and hence to obtain material useful for identifying oscillation modes. As a consequence of the traditional traumas of observational astronomy (time allocation, instrument failure and bad weather), out of eighteen nights originally requested, 7.5 nights were awarded and 24.3 hours of time-resolved spectroscopy was obtained, of which 19.5 hours was usable. This paper introduces the observations, and presents the frequencies derived from the radial velocity measurements.

2. OBSERVATIONS

Time-resolved spectroscopy of spectral resolution $\sim$1 Å was carried out during six nights at the Calar Alto 3.5 m telescope (Spain), the European Southern Observatory 3.5 m New Technology Telescope (Chile) and the Apache Point Observatory 3.5 m (New Mexico, U.S.A.).

Table 1. MSST 4 m observing log.

Date 2002	Obs.	Start	Finish	$t_{\rm exp}$ s	$N_{\rm obs}$
		JD−2445000			
May 14	APO	409.324	409.446	3.6	1773
May 15	APO	410.183	410.331	4.8	1727
May 18	APO	413.296	413.329	4.8	471
May 22	CA	416.908	417.146	16.5	1065
May 23	CA	417.885	418.158	16.5	1213
May 29	NTT	424.161	424.359	–	–
Total					10892

At Apache Point (APO), we used the red arm of the Dual Imaging Spectrograph where it was anticipated that velocity changes would be observable in Hα. At Calar Alto 3.5 m (CA) telescope, both arms of the TWIN spectrograph were used to obtain spectra simultaneously in the wavelength ranges 5785–6880 Å and 3850–4950 Å. At the NTT, the ESO Multi-Mode Instrument (EMMI) was used to obtain spectra in the wavelength range 6400–6700 Å. However, atmospheric conditions were so poor that none of the EMMI data have proved to be usable.

In all cases, spectra were obtained by trailing the star along the slit (Falter et al. 2003) to give two-dimensional images representing wavelength dispersion in one axis and time in the other. The time resolution is given effectively by the trail-rate along the slit divided by the projected size of the stellar disk on the detector; a higher trail rate provides better time resolution, but lower S/N per resolution element. A summary of the observations is given in Table 1. The integrated sky background is estimated using regions at each end of the slit. Arc-lamp and standard-star calibration images were obtained in order to provide wavelength calibrations and geometric correction.

The data reduction methods have been described by Falter et al. (2003). With the image trailed along the slit at a uniform rate, each two-dimensional image has to be reduced to a series of discrete spectra, with each one accurately time-stamped. The choice of extraction interval is made at this stage to optimize both the signal to noise ratio in individual spectra and the sampling rate. The reduced data products consist of a two-dimensional FITS file containing a series of wavelength calibrated time-tagged spectra for each long-slit trailed spectrum.

Spectra were read directly from the reduced FITS files and resampled onto a logarithmic wavelength scale. Velocities were determined by cross-correlating each spectrum with a template created by summing all spectra from a given series.

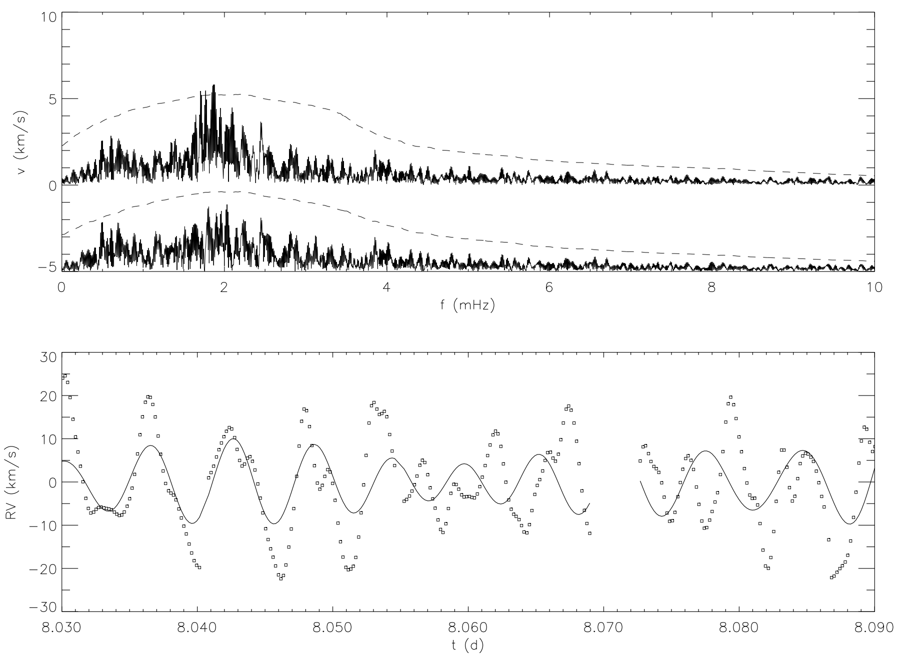

Fig. 1. Best solution for the CA blue spectroscopy. Top: the velocity amplitude spectrum (v) before (above) and after (below) subtraction of the four highest peaks. The dashed line shows the 4σ level in each case. Bottom: part of the radial velocity curve with the best four-frequency solution (solid) from Table 2. Times are in JD–2452410.

Problems with the wavelength calibrations, evident from substantial offsets for individual frames, were corrected by demanding the mean velocity for each frame to be 0 $\mathrm{km\,s^{-1}}$.

3. FREQUENCY ANALYSIS

Velocity amplitude spectra for each dataset (CA blue, CA red, APO red and APO+CA red) were calculated using a simple Fourier transform. The limited overall coverage restricts the frequency information that can be extracted. All datasets show an excess of power in the range 1.5–2.5 mHz. Despite apparent similarities in the velocity curves, the amplitude spectra obtained from each arm of the TWIN spectrograph differ considerably from one another. A careful comparison was carried out to look for systematic correlations.

Table 2. MSST 4 m frequencies and amplitudes.

$F_{\rm b}$ mHz	$V_{\rm b}$ km/s	P s	$F_{\rm r}$ mHz	$V_{\rm r}$ km/s	$F_{\rm 2m}$ mHz	$V_{\rm 2m}$ km/s
1.705	6.0	586				
1.756	5.4	569	1.767	8.5		
1.867	7.2	536	1.867	6.5	1.891	2.3
2.095	5.4	477			2.076	15.4

We have formally analyzed only the two CA datasets, which have a formal temporal resolution $(2/T)$ of 18 mHz. A detection threshold was defined by a local

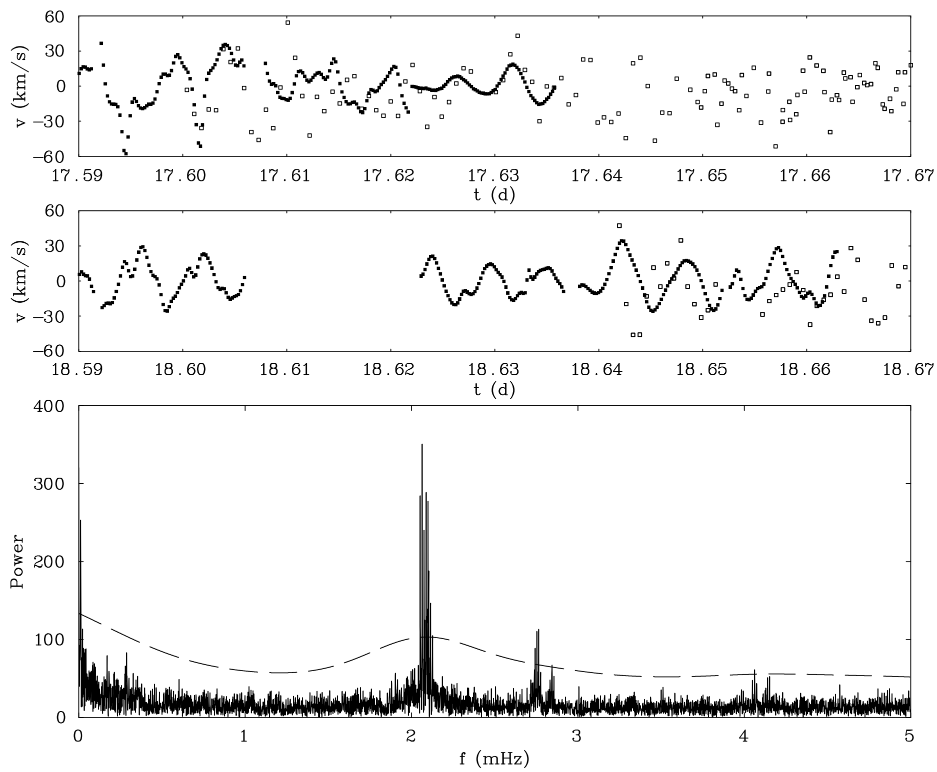

Fig. 2. Top: comparison of 4 m spectroscopy (CA blue: solid symbols) with concurrent radial velocities from the MSST 2 m campaign (open symbols). Times are in JD–2452410. Bottom: power spectrum of 2 m radial velocities for three nights (JD 2452416.61–2452418.98). The dashed line represents the 4σ level.

σ. Any peak above 4σ was deemed real, a sinusoid was fitted and its frequency and amplitude recorded. The data was prewhitened by the fit and the procedure repeated until no peaks exceeded the 4σ level. The solutions are given in Table 2 for the blue (F_{b}) and red (F_{r}) arms, and also compared to the MSST 2 m ($F_{2\mathrm{m}}$) results.

These solutions are unsatisfactory. As we know from the 2 m data, there are unresolved frequencies present which suggest that substantial errors should be attached to the amplitudes given in Table 1. It is notable that the signal at 2.076 mHz detected in the 2 m campaign (O'Toole et al. 2005) has a much lower amplitude in the CA data. It is apparent that neither signal at 1.71 and 1.76 mHz was detected in the MSST 2 m campaign (O'Toole et al., 2005). While, given the frequency resolution of our data, the signal at 1.76 mHz may coincide with one at 1.744 mHz in the light curve of Kilkenny et al. (1999). There are sufficient discrepancies between the 2 m and 4 m results to raise a number of questions.

Following the conference at which these first results were presented, we re-analyzed a short section of the 2 m data spanning just three nights (JD 2452416.61–2452418.98) centered on the two nights of the CA observations (O'Toole et al. 2005). Figure 2 shows both 2 m and 4 m data in the regions of overlap where it will be seen that the level of correlation is not high. It is also clear that the principal signal at 2.076 mHz is present in the 2 m data over these three nights, while it is not seen in the 4 m data. At the very least it would appear that we have oversampled the trailed CA spectra. Reconciling and understanding the remaining discrepancies will require further work.

While O'Toole et al. (2005) note that the 2.076 mHz peak had a much reduced amplitude in early velocity studies (O'Toole et al. 2003; Woolf et al. 2002; O'Toole et al. 2002) compared with contemporary photometric studies (Kilkenny et al. 1999; Koen et al. 1998), it had a larger velocity amplitude in the study by Falter et al. (2003). Although the mode amplitude may be variable over long time scales, we have so far failed to confirm any such variability on a short time scale.

In conclusion, MSST 4 m data should provide a high-time and spectral resolution snapshot of the radial-velocity behavior of PG 1605+072 over short intervals during the more extended 2 m campaign. Further analysis of the combined data from 2 m, 4 m and photometry campaigns remains to be completed.

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