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HST OBSERVATIONS OF THE DAV WHITE DWARF G 226–29

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Abstract. We observed G 226-29 for 15 hours with the HST and detected two problems in spectrograms obtained with the post-COSTAR Faint Object Spectrograph and the G160L grating. First, using the 1 arcsec entrance aperture with a triple peakup, we found a strong ($\simeq 3$ %) modulation of the total count rate on a time scale similar to the HST orbital period. Second, when comparing the observed spectrum to a spectrum of the same white dwarf obtained with IUE and to model atmospheres for DA white dwarfs, we found 25 % extra flux in the FOS spectrogram in a 75 Å region just to the blue of 1500 Å, due to a scratch in the photocathode, not corrected by the flat-field.

Key words: stars: white dwarfs – stars: variables – stars: individual: G 226-29

1. Introduction

The pulsating DA white dwarf G 226-29 (DN Dra) was observed with the 10 s exposure RAPID mode of the Faint Object Spectrograph (FOS) of the Hubble Space Telescope five times, each time for 3 hours, between September 1994 and March 1995. We used the blue detector and the G160L grating. As the star is bright and fairly hot ($V = 12.22$, $T_{\rm eff} = 12\,460$ K, Bergeron et al. 1995), the summed spectrum from each 3 h observation has a high signal-to-noise ratio (see Fig. 1).

Three pulsation modes are excited in G 226-29, all with periods near 109 seconds (Kepler et al. 1983, 1995). The purpose of the observations was to measure the amplitudes of the pulsations at ultraviolet wavelengths. From the wavelength dependence of the pulsation amplitudes we can identify the pulsation modes unambiguously and then use the results of pulsation models to determine the structure of the star (Robinson et al. 1995).

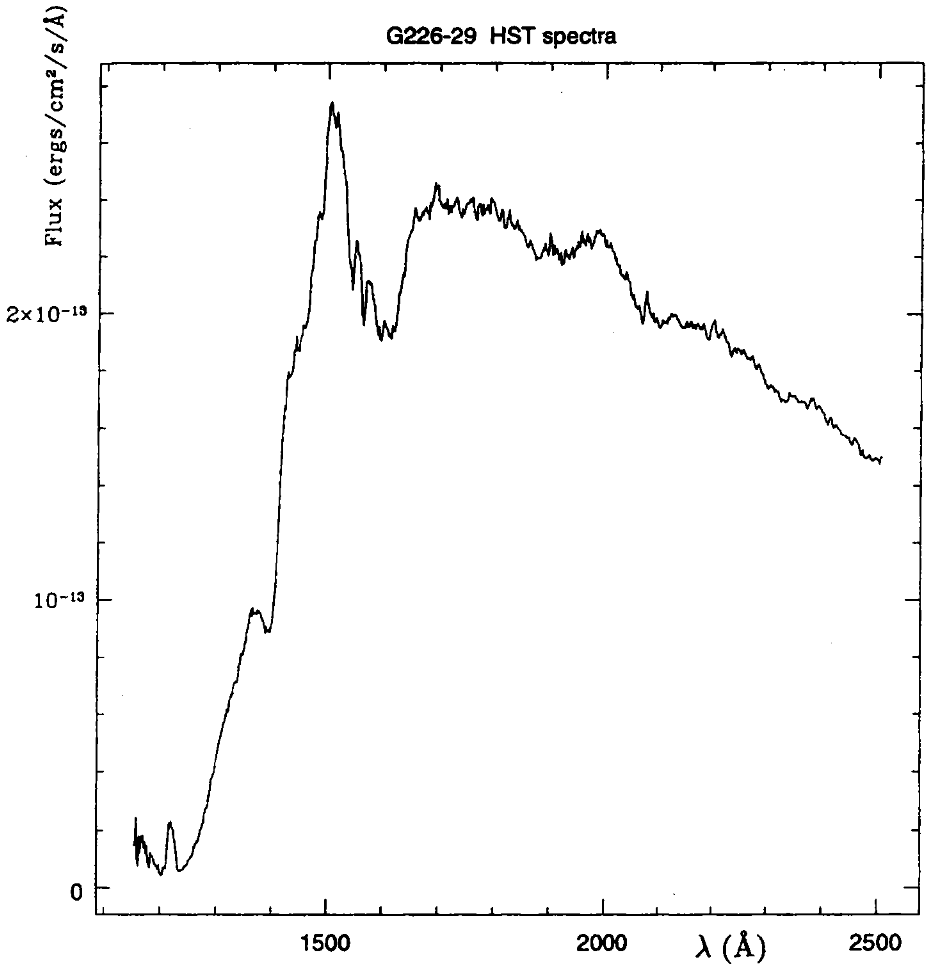

Fig. 1. FOS spectrum of the pulsating DA white dwarf G 226-29.

Observations of white dwarf stars can be used to study stellar and galactic evolution. The properties of individual white dwarfs define the endpoints for models of stellar evolution, while the white dwarf luminosity function provides an observational record of star formation in our Galaxy. For example, the coolest white dwarfs are remnants of stars formed in the earliest epoch of star formation, so their cooling times can tell us the age of the galactic disk in the solar neighborhood (Winget et al. 1987, Wood 1992).

A crucial step in determining the structure of a white dwarf from its pulsation periods is to identify the pulsation modes correctly. The pulsation modes are indexed with three integers (k, ℓ, m) where k represents the number of nodes in the pulsation eigenfunction along the radial direction, ℓ is the number of node lines on the stellar surface, and m gives the orientation of the lines. Pulsation modes with different indices generally have different pulsation periods. The usual procedure for identifying the mode indices is (1) calculate theoretical pulsation periods in models of white dwarfs; (2) compare the pattern of theoretical periods to the observed pattern of periods; (3) adjust the models to bring the theoretical and observed patterns into closer agreement. The problems with this procedure are clear: it does not work for white dwarfs with only a few excited pulsation modes; and, given the complexity and sophistication of the theoretical calculations and the large number of possible pulsation modes, there is ample opportunity to misidentify modes. Other methods of mode identification must be used to avoid these problems.

2. Mode identification using time-resolved UV spectroscopy

Time-resolved ultraviolet spectroscopy provides an independent method for determining pulsation indices of white dwarfs. The amplitudes of g-mode pulsations depend strongly on ℓ at wavelengths shorter than 3000 Å. Fig. 2 shows how the amplitudes depend on wavelength and ℓ for the lowest-order modes of a pulsating DA white dwarf. The amplitudes of all modes increase towards the ultraviolet but the amplitude increases more for $\ell = 2$ than for $\ell = 1$. The divergences are even greater for modes with higher ℓ.

The differences between the amplitudes of modes with different ℓ are caused by limb darkening. The brightness variations of non-radially pulsating white dwarfs are due entirely to variations in effective temperature; geometric variations are negligible (Robinson,

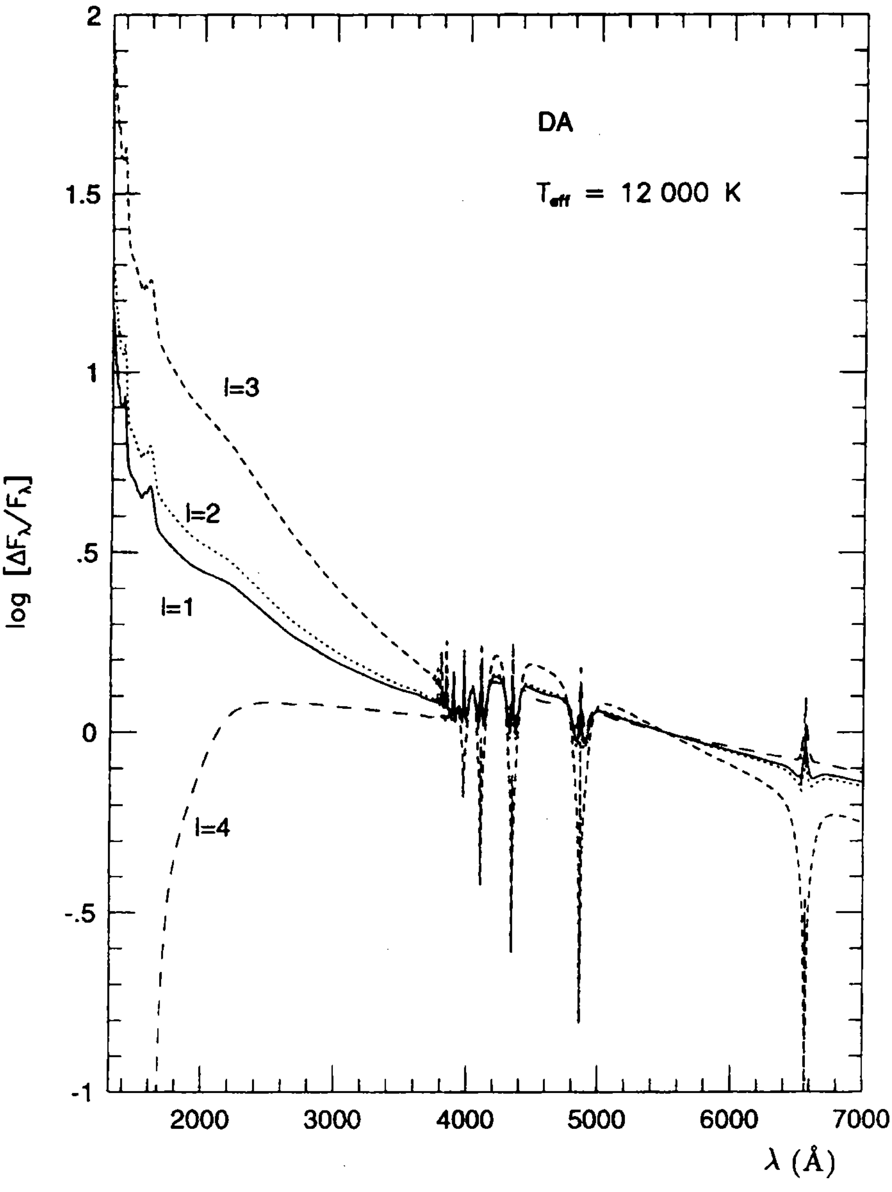

Fig. 2. The amplitudes of the $\ell = 1$ to $\ell = 4$ pulsation modes in a pulsating DA white dwarf as a function of wavelength. The atmospheres were calculated from the most recent version of the model atmosphere code by Koester et al. (1979). The amplitudes have been normalized to 1.0 at 5500 Å.

Kepler & Nather 1982). The pulsations divide the stellar surface into zones of higher and lower effective temperature described by spherical harmonics; modes of higher ℓ have more zones than those of lower ℓ. From a distance, we can measure only the integrated surface brightness, which includes the effects of limb darkening, so modes of higher ℓ are washed out by the cancelation of different zones. At ultraviolet wavelengths, the effects of limb darkening increase, decreasing the contribution of zones near the limb. Consequently, modes of higher ℓ are cancelled less effectively in the UV and their amplitudes increase more steeply at short wavelengths than those of low ℓ. Theoretical calculations of the amplitudes require good model atmospheres but are entirely independent of the details of pulsation theory and white dwarf structure calculations.

Robinson et al. (1995) used this method to determine ℓ for the pulsating DA white dwarf G 117-B15A. They measured the amplitude of its 215 s pulsation in the ultraviolet with the HST high-speed photometer and identified it as an $\ell = 1$ mode. Equipped with the correct value of ℓ, they found that the mass of the surface hydrogen layer in G 117-B15A was between 1.0×10^{-6} and 8×10^{-5} $M_\odot$, which is too thick to be consistent with models invoking thin hydrogen layers to explain the spectral evolution of white dwarfs. They also found $T_{\rm eff} = 12\ 375 \pm 125$ K, substantially lower than the accepted temperature at that time but close to the presently accepted temperature (Koester et al. 1994, Bergeron et al. 1995).

3. Data set problems

We detected two problems in the FOS data sets. First, we found a ~ 3 % modulation of the total count rate on a time scale similar to the HST orbital period (see Fig. 3). This modulation is probably caused by a combination of factors. We used a 1 arcsec entrance aperture and a triple peakup to center the star in the aperture. The triple peakup yields a centering accuracy of only ± 0.2 arcsec which, when coupled with the 0.8 arcsec PSF of the image, produces a light loss at the aperture of at least a few percent. As the position of the star image in the aperture wanders during the HST orbit, the amount of light lost at the aperture varies, modulating of the detected flux.

Second, when comparing the observed spectrum to the spectrum of G 226-29 obtained with IUE and to model atmospheres for DA white dwarfs (Koester et al. 1994), we found a spurious "bump" in the FOS spectrum in a 75 Å region just to the blue of 1500 Å. The bump is not subtle; it rises 25 % above the surrounding continuum (see Fig. 4).

The excess is caused by a scratch on the cathode of the FOS blue detector, in a region used only for the G160L grating, for which the pipeline flat field does not correct properly. The scratch is at an angle with respect to the diode array so that the wavelength of the bump in the spectrum changes as the position of the spectrum on the cathode changes. The pipeline flat field was obtained with a 0.04 arcsec centering accuracy in the 4.3 arcsec aperture and is not correct for any other aperture or position. Fig. 4 also shows a smaller bump around 2000 Å. Starting July 95, there is a new flat in the HST pipeline (F6515441Y.R1H) which should be used to recalibrate all post-COSTAR observations with the G160L. After recalibrating our data, there was no significant change. The central 1 arcsec aperture, where the scratch is at maximum, is not recommended for any future observations. One should use the upper pair 1 arcsec aperture, and a 4 stage peakup which requires 53 min to center the object with an accuracy of 0.04 arcsec, if $S/N > 30$ is required.

4. Discussion

To identify the pulsation modes in a white dwarf we need to know only the fractional amplitudes of the pulsations as a function of wavelength. Since the fractional amplitudes are immune to multiplicative errors in the calibration of the spectrograms and since both of the problems we have found are multiplicative, our project was successful. Our analysis to date shows that all three modes are indeed $\ell = 1$ pulsations.

These calibration problems will however hinder our ability to use these extremely high signal-to-noise ratio spectra to measure the temperature and gravity of the star because the spurious bump occurs in the far wing of the Lyα line, the region of the spectra most sensitive to temperature and gravity (Koester et al. 1994).

These two problems should not be present after Cycle 7, scheduled for February 1997, when STIS replaces FOS, because STIS is an area detector. But to measure the UV amplitudes, it is necessary to measure the pulsation amplitudes throughout the entire ultraviolet spectrum to guarantee correct mode identification. FOS can observe the entire ultraviolet spectrum from 1150 Å to 2500 Å at once, whereas STIS will have to observe the spectrum in two sets

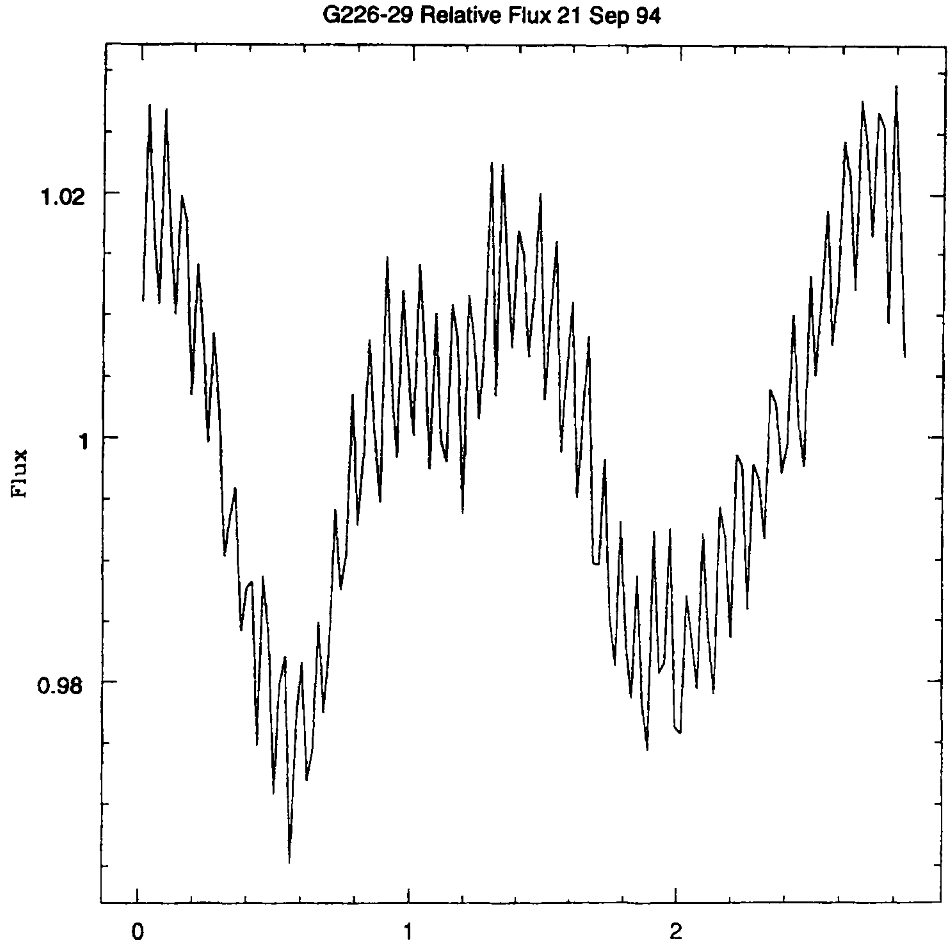

Fig. 3. Light loss with the 1.0 arcsec aperture. In this figure we plot the count rate summed through all wavelengths, divided by the average, versus time. The rapid variation on a time scale of 100 s is caused by the pulsations of the star.

of observations obtained at different times. If there are variations in the amplitude of the pulsation modes, that will introduce serious uncertainties if the pulsation amplitudes at different wavelengths are measured at different times. Furthermore, the necessity to observe a star twice with STIS will nullify any advantage gained from its putative factor of ~ 2 better sensitivity.

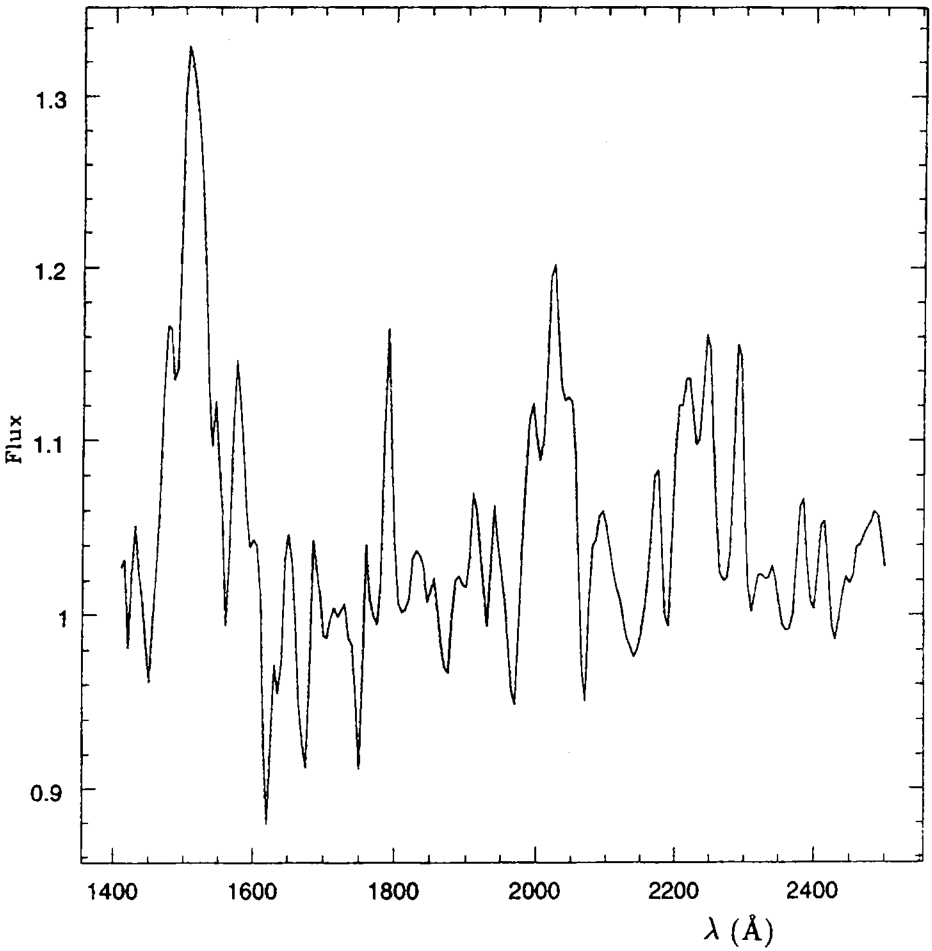

Fig. 4. Ratio of the HST spectrum of G 226-29 to the IUE spectrum.

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