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SPECTROSCOPY AND PHOTOMETRY AS A SYNERGETIC APPROACH TO THE STUDY OF STELLAR PULSATIONS

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RESUMEN

Se ilustra, mediante tres ejemplos, la importancia de la complementaridad de fotometría y espectroscopía en el estudio de fenómenos dinámicos como las pulsaciones estelares. Gracias al análisis de largas series de mediciones fotométricas, obtenemos una descripción exhaustiva de los complejos sistemas de frecuencias de dos estrellas δ Scuti multiperiodicas (FG Vir y X Cae). Observaciones espectroscópicas simultáneas nos permiten además investigar las diferentes características de los respectivos modos dominantes de pulsación: una oscilación radial en FG Vir y ondas prógradas no radiales in X Cae. El comportamiento pulsacional de esa última estrella podría tal vez estar relacionado con indicios de pérdida de masa. La probable propagación de ondas prógradas hacia la región circunestelar en presencia de pérdida de masa ha sido detectada, mediante observaciones espectroscópicas, también en la estrella Be 28 Cyg.

ABSTRACT

Through three examples, we illustrate the importance of complementarity between photometry and spectroscopy in studying dynamical processes like stellar pulsations. Analyzing large photometric time series, we get an exhaustive description of the complicated frequency patterns shown by two multiperiodic δ Scuti stars (FG Vir and X Cae). Simultaneous spectroscopic observations allow us to investigate the different characters of the respective dominant modes: a radial pulsation in FG Vir and nonradial prograde waves in X Cae. The pulsational behaviour of X Cae might be connected with some mass loss indication. Probable propagation of prograde waves to the circumstellar region in the presence of mass loss has been detected through spectroscopic observations in the Be star 28 Cyg.

Key words: **STARS: OSCILLATIONS — STARS: δ Scu — STARS: EMISSION LINE, Be — STARS: INDIVIDUAL (FG VIR, X CAE, 28 CYG)**

This morning Dr. Garrison presented a very interesting discussion about the complementarity betwe photometry and spectroscopy in studying stellar physics. The subject of the present talk is the application such a synergetic approach to understanding dynamical processes like stellar pulsations.

In this frame the term *complementarity* assumes a particular meaning. Photometry allows us to easi produce on industrial scale the large time series required for reliable frequency analyses. A photomet measurement needs less time and smaller telescopes than does a spectroscopic one. On the other han spectroscopy reveals the underlying physical phenomena more directly.

We shall try to illustrate this point by means of three examples: the cases of FG Vir, X Cae and 28 Cy The work on FG Vir and X Cae, which belong to the δ Scuti family, are currently in progress, while the Be st 28 Cyg is the object of a recent publication (Bossi et al. 1993) and also represents an improper but instructi example: we performed no photometry on this star. The spectral lines of these objects show very differe Doppler half-widths ($V \sin i \approx 15$, 70 and 210 km s^{-1} respectively): obviously our selection of this star was n a casual one.

The magnitudes of both our δ Scuti stars in the standard *UBV* system were differentially monitored at ı Silla (Chile) using the ESO 50-cm telescope. Frequency analyses of the light curves (792 ΔV measurements ared among 8 photometric nights in the case of FG Vir, 1658 ΔV values in 13 nights for X Cae) have been :rformed both by means of Vanicek's (1971) method and resorting to the CLEAN algorithm (Roberts et al.)87).

Using these techniques, we have been able to detect 7 different pulsational modes in FG Vir and 9 dependent periodicities in X Cae (also harmonics and nonlinear coupling terms have been detected). Except r three uncertain determinations due to strong aliasing phenomena, we have got reliable and accurate values all the respective frequencies.

In both cases we observe a dominant periodicity: 12.72 c/d, as reported by previous observers (López : Coca et al. 1984; González-Bedolla & Rodríguez 1990), in FG Vir, and 7.39 c/d in X Cae. The related nplitude values ($0^m.022$ and $0^m.050$ respectively) correspond to 82% and 90% of the entire detected powers.

Our spectroscopic observations of FG Vir and X Cae have been performed at La Silla using the Coudé uxiliary Telescope (CAT) and the Coudé Echelle Spectrograph (CES) equipped with a CCD detector. The lopted configuration gave a sampling of 0.0366 A/pixel (with resolutions of about 0.1 A/pixel) in the range ŀ89–4528 A. 28 Cyg was observed at Asiago (Italy) by means of a Boller & Chivens grating spectrograph ›upled to the 182-cm telescope and equipped with a Reticon detector. Sampling and resolution, in the range ›00–6750 A (which includes Hα and the He I λ6678 spectral line), were 0.45 and about 1 A/pixel respectively.

We can also obtain a useful bit of information about the pulsational behaviour of our δ Scuti stars by a mple phasing of our spectrograms (22 in one night for FG Vir and 100 in 4 nights for X Cae) with the respective ›minant periodicities detected through photometric means. For clarity, Figure 1 shows the resulting patterns r a single spectral line (Ti II λ4501). Also at first glance the flux diagrams represented in the figure appear very fferent: FG Vir seems to show a simple periodic line translation, whereas X Cae presents more complicated :ofile variations.

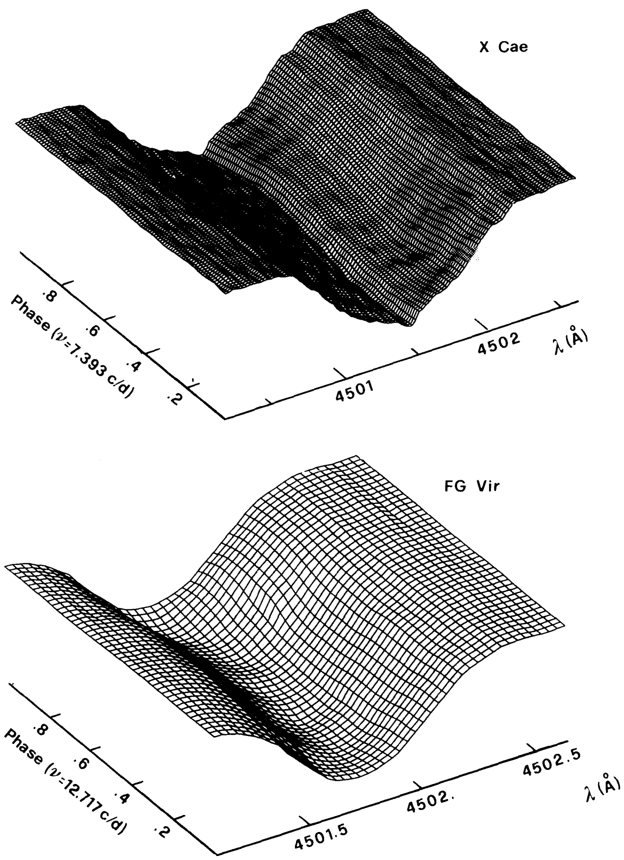


Fig. 1. Ti II λ4501 line profiles as functions of the dominant pulsational periodicities: 12.72 c/d in FG ir (bottom) and 7.39 c/d for X Cae (top).

Obviously, this remark does not exhaust our analysis. In the case of FG Vir, which is a very slow rotator we can get more information using the method suggested by Balona (1986) and based on the variation analysi of the line profile moments:

$$M_n = \int_{-\infty}^{\infty} \lambda^n (1 - f(\lambda)) d\lambda \quad ,$$

where $f(\lambda)$ is the normalized flux (M_0 is the equivalent width, M_1/M_0 the radial velocity, M_2/M_0 a kind c moment of inertia, etc.). In our case, only M_1 seems to vary with the frequency of 12.72 c/d, suggesting th radial character of the dominant mode.

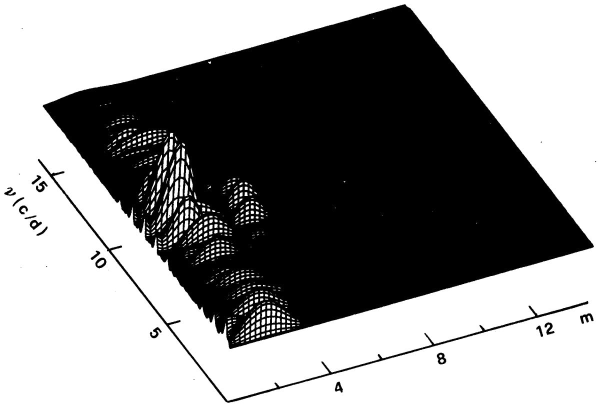


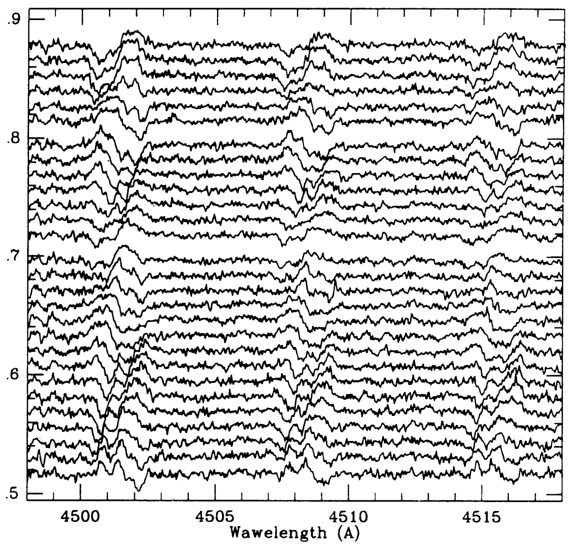
Fig. 2. 2-dimensional power spectrum of the Ti II $\lambda4501$ line profile variations in X Cae.

The case of X Cae is easier to deal with; the Doppler spreading makes the spectra of fast rotators similar t one-dimensional maps of the stellar surfaces. So, we only have to examine a two-dimensional power spectrui of the line profile variations to get the identification of the sectorial number m. In X Cae, a first estimate (this power spectrum, obtained through a simple numerical integration of the Fourier transform, allows us, as preliminary result, to separate the effects of pulsations at 7.39 and 7.46 c/d (which are distinguishable withoı difficulty in the light curve) in spite of the insufficient frequency resolution provided by the spectroscopic tin series. As shown in Figure 2, these periodicities seem to correspond to nonradial pulsations with $m = 2$ an $m = 4$ respectively.

In Figure 3 we show the evolution of the perturbations (i.e., deviations of each spectrogram from a mea spectrum) in some lines in our spectral range for one of the observational nights: apparently they travel froı the blue edge to the red one of each line. This means that we are observing prograde waves. This fact could t connected with the mass loss mechanism proposed by Osaki (1986) if we interpret the absorption nuclei whic are visible in the spectral lines of this star (see again Figure 1) as produced by the presence of circumstell matter rather than by binarity.

Another possible example of effectiveness of Osaki's mechanism might be 28 Cyg. Through the analys of a series of 110 spectrograms obtained in 7 nights, we could detect different frequencies in this Be star. . bimodal nonradial pulsation producing mass loss and also propagating in the circumstellar region according t the outline shown in Figure 4 (the actually observed frequencies are combinations of the physical ones define in the corotating frame with a rotational frequency which depends on the distance from the star), seems to t the most probable explanation of this activity (for a thorough discussion see Bossi et al. 1993).

Unfortunately our frequency analysis was not quite exhaustive: the available data gave us some indicatic that additional periodicities might be present, even if they were difficult to determine without ambiguit Moreover, our exiguous time base did not allow us to get evidence in discriminating between quasi-period variations and genuine periodicities. In this sense, 28 Cyg represents an instructive counterexample of oı synergetic approach.



'ig. 3. Perturbations travelling from the blue edge ɔ the red edge of the spectral lines in X Cae.

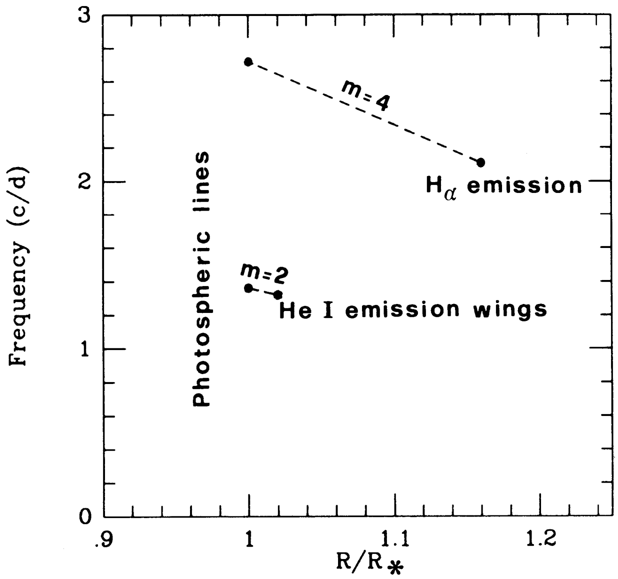


Fig. 4. Frequencies detected in 28 Cyg and probable corresponding pulsating layers.

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DISCUSSION

/Iichel: 28 Cygni, one of the stars in your work is a Be star. How confident are you about explaining its ariability as pulsation? i.e., how to avoid explaining this by just stellar rotation?

Bossi: The possibility of an ad hoc spot distribution carried around by the stellar rotation cannot be ruled out, ut it would require a very peculiar symmetrical spot configuration in the equatorial zone of the stellar surface.

Jonzález-Bedolla: Is the behavior of 28 Cygni similar to *o* And?

Bossi: Maybe, *o* And is another well-known Be star whose variability seems to ɾ ɔw a dominant periodicity r pseudo-periodicity. Photometric observations performed at San Pedro Mártir last September by Sareyan, ılvarez and myself appear consistent with this picture. I also performed spectroscopic observations of this bject, but the material, consisting of a series of about 50 spectrograms, has not yet been reduced.

Costero: To what degree of confidence are the several oscillation modes established?

Bossi: The light curves of FG Vir and X Cae consist of about 800 and 1600 measurements respectively nd present very high signal-to-noise ratios. Moreover, we performed frequency analysis through two different ıethods independently. Therefore, I can believe them with very high degree of confidence, except for the above uoted uncertainties due to strong aliasing phenomena.

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