The Be Phenomenon in Early-Type Stars, IAU Colloquium 175
ASP Conference Series, Vol. 214, 2000
M. A. Smith, H. F. Henrichs, and J. Fabregat, eds.

Multi-frequency Variations in the Be star ζ Ophiuchi

A.D. de Souza Jr., E. Janot-Pacheco, N.V. Leister

Instituto Astronômico e Geofísico, Universidade de São Paulo, C.P. 3386, 01060-970, São Paulo, SP, Brasil

S. Jankov

Astronomska Opservatorija Beograd, Volgina 7, 11050 Beograd, Yugoslavia

A.M. Hubert, M. Floquet

Dasgal, UMR 8633 DU CNRS, Observaroire de Meudon, 92195 Meudon, France

Abstract. In this work we have adopted the non radial pulsation (NRP) model in order to explain the rapid spectroscopic time variations observed in the Be star ζ Ophiuchi. Time series analysis were performed with CLEAN and Sequential CLEANEST techniques. We have also applied a different version of the Local CLEANEST that is optimized for multi-periodic signals observed in monosite campaigns. The frequencies of 7.19 and 11.89 cycles/day have been identified. These frequencies were found in previous papers about the star.

1. Application of CLEAN and Sequential CLEANEST (SC)

The CLEAN algorithm (Roberts et al. 1987) was applied to each of the 450 residual time series formed by subtracting the global mean spectrum of the observing run from each individual spectrum, and following the procedure of Gies & Kullavanijaya (1988). The gain was set at 0.8 and the number of iterations was limited to 10. The code was developed in C by Emilio (1997).

Figure 1 shows the results of CLEAN applied to a set of 135 high resolution ($R \simeq 60{,}000$) spectra (He I λ667.8 nm line) obtained in 1996 between May 30 to June 2 at the Brazilian Laboratório Nacional de Astrofísica observatory with a 1.60m B&C telescope using the coudé spectrograph (observations were reduced with IRAF[1]). The results from SC (Foster 1995) are similar to CLEAN's since both methods find the periodicities in a sequential way.

[1]IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for research in Astronomy (AURA), Inc., under cooperative agreement with the National Science Foundation.

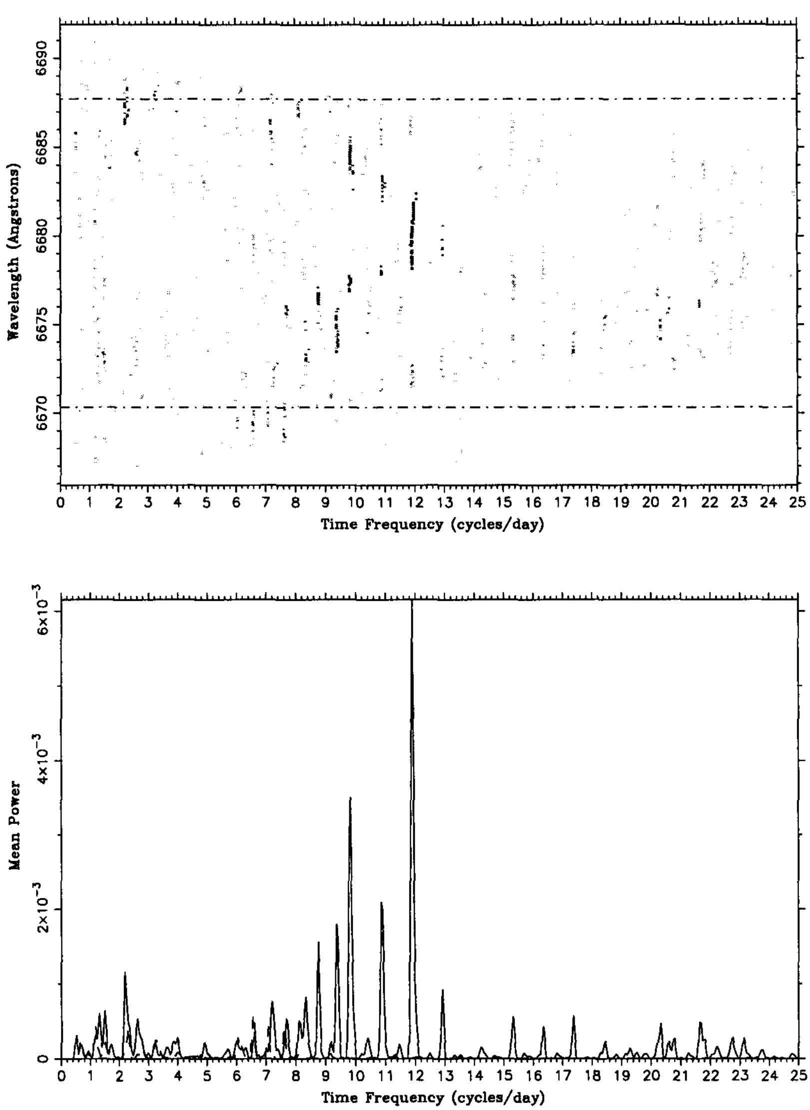

Figure 1. Application of CLEAN on the spectral data of 1996. *Upper:* Global CLEANed periodogram at each position across the line profile. The limits of the He I 6678Å line are indicated. *Lower:* Corresponding periodogram averaged across the wavelength axis inside (solid curve) and outside (dashed curve) the line; it is clear that the periodic variations are present mainly inside the line. The strongest peak is located around 11.9 c/d. There are also peaks around 8.9/9.9/10.9/12.9 c/d which are probably just 1 day aliases of the 11.9 c/d. Furthermore, since CLEAN find the frequencies in a sequential way, the aliases do not occur together at any wavelength. CLEAN has also identified some very weak signal around 1.2, 2.2, 7.2, 8.3 and 9.3 c/d.

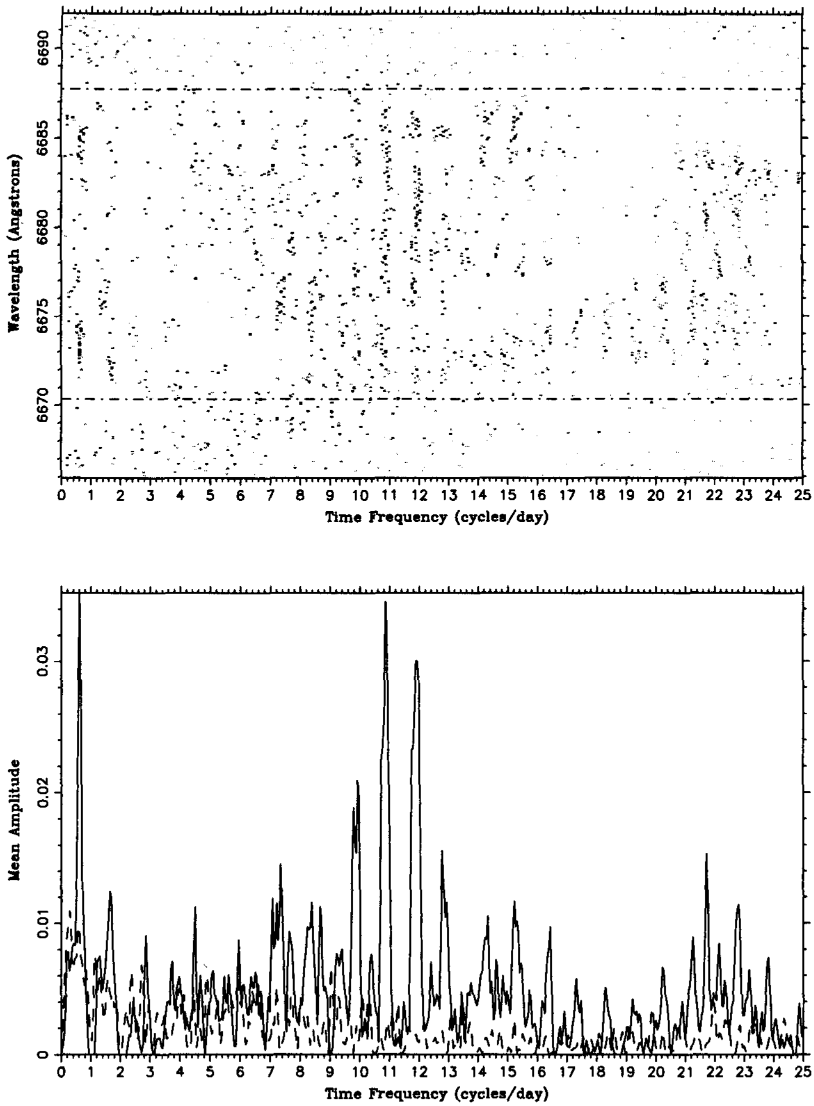

Figure 2. Same as Figure 1 but for the application of LCPSF on the spectral data of 1996. For our data a good compromise between the calculation time and the quality of the results is obtained for $n = 40$, $p = 4$ and $b = 9$. The peaks at 0.6 and 1.6 c/d are probably just artifacts, since they completely disappear when we analyse the time series formed by subtracting the nightly mean profiles from each spectrum of the corresponding nights. The LCPSF seems to increase the relative importance of the low amplitude signals when compared to SC and CLEAN. In addition, the periodic signals were identified over a larger range inside the line as we can see particularly for the frequencies 9.9, 10.9 and 11.9 c/d.

2. Application of a different version of Local CLEANEST

In general, CLEAN and SC find the correct periodicity in data sets, but as it was nicely described by Foster (1995), these algorithms can be fooled by complex window functions. In order to solve this problem Foster (1995) proposes another procedure: the Local CLEANEST (LC). However, this procedure would require an excessive computer time for real monosite multiperiodic data. Thus, in order to reduce the computer time while keeping the LC ability in dealing with the alias problem, we have introduced a pre-selection frequency step before applying the LC. We may divide this variation of the LC in the following steps:

1) select all possible n peaks in the DCDFT (Ferraz-Mello 1981).

2) calculate the model functions for all possible combinations of this n frequencies taken p by p ($p << n$) without any kind of frequency refinement.

3) order the groups of p frequencies according to the quality of the model functions (measured by the power level according to Foster 1995) and choose the $b < n$ first frequencies from this ordered list.

4) scan around the values of these b frequencies in order to find the local maximum of the power level.

We performed some simulations with this different version of LC in order to test the algorithm sensibility to different choices of n, p, b, and the step and number of points to perform the scan. The best values of these parameters depend on the kind of multiperiodicity and window function of the data set. Figure 2 is an example of the application of LC with the pre-selection of frequencies (LCPSF) to our spectra.

3. Summary and Conclusions

The LCPSF seems to be more sensitive than CLEAN and SC to identify multiperiodic signals. If our periodic analysis were only performed with SC and/or CLEAN there would probably be too much doubt whether or not there is a frequency other than 11.9 c/d (or one of its aliases). We would neglect the signal at 7.2 c/d which is a frequency found in several previous works (Reid et al. 1993, Kambe et al. 1997, among others). However, it is clear from Figure 2 that LCPSF was not able to eliminate all the spurious frequencies from the power spectrum. Scanning over more points around the central frequencies can diminish the problem, but this increases rapidly the computer time.

References

Emilio, M. 1997, MsC. Thesis, Astronômico e Geofísico, Univ. de São Paulo

Ferraz-Mello, S. 1981 AJ 86, 619

Foster, G. 1995, AJ 109, 1889

Gies, D.R., Kullavanijaya, A. 1988, ApJ 326, 813

Kambe, E., Hirata, R., Ando, H. et al. 1997, ApJ 481, 406

Reid, A.H.N., Bolton, C.T., Crowe, R.A. et al. 1993, ApJ 417, 320

Roberts, D.H., Lehar, J., Dreher, J.W. 1987, AJ 93, 968