First Test of the New Spectrophotometer Devoted to Stellar Seismology

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Solar seismology (or helioseismology) was born in 1975. Since that recent date it provided the first unambiguous information regarding the internal structure of the sun.

The resulting recrudescence of astronomers' interest for solar physics coincides, and this is not by chance, with the one due to uncertain and controversial results obtained in measuring the neutrino flux and the solar oblateness. It could be necessary to question either some aspects of elementary particle physics or the theory of stellar evolution. The consequences of this last possibility over all astrophysics explain why the importance of solar seismology has quickly become much broader than the frame of solar or even stellar physics.

Since 1975, our group has specialized in this solar programme. Radial and low-degree solar pulsations are detected by means of the Doppler shift measured with a sodium optical resonance spectrophotometer. The sun is observed in integrated light, "like a star". A major step has been crossed by using this instrument at the Geographic South Pole. Down there, it was possible to obtain continuous data over more than five days. This made possible the identification of over 80 solar acoustic eigen modes (Grec et al., 1983). Their Doppler amplitudes are from 2 to 25 cm s^{-1} and their periods in the five-minute range corresponding to relatively high order overtones (12–34) of radial and low degree ($l \leq 3$) modes. Typically the frequency distribution of power (obtained by Fourier analysis) displays a discrete pattern of almost equidistant peaks around 3 millihertz. They are separated by 68 microhertz and correspond to successive overtones of alternately even and odd degree modes. (See Grec et al., 1983.)

The small but significant discrepancy between these measured frequencies and the corresponding ones calculated with various solar models (Rhodes and Ulrich, 1983) has urged solar astronomers to get more information in order to probe more accurately the deeper layers of the sun's interior. At the same time, and taking into account the fact that the sun was observed "as a star" it was decided to start the same kind of observation on other stars, in order to broaden the field of comparison between observation and theoretical calculations.

Measuring Doppler shift fluctuations of a few cm/s on a star is a highly difficult task. For evident reasons of flux difference, we could not use the same instrument for observing the sun and for observing stars. Consequently, a new specialized spectrophotometer was designed and built in our laboratory (Fossat et al., 1982). Optimized in photon efficiency, its principle is to measure Doppler shift fluctuations through changes of the monochromatic intensity in a wing of the Na D1 sodium absorption line in the stellar spectrum. The monochromatic filter is an optical resonance sodium cell between two crossed polarizers. In a permanent axial magnetic field, both the absorption of a circular polarization and the rotation of the linear polarization are acting and result in the transmission of a 0.08 Å bandwidth centred on the laboratory wavelength of Na D1. It is then shifted on the adequate portion of the stellar line wing by using the combined effects of the stellar radial velocity and the orbital motion of the earth.

Such a filter has altogether an absolute spectral stability (the sodium atoms themselves decide of the transmission wavelength) and a very high transmission.

Typically the slope of the D1 sodium line wing is of the order of 10^{-4} (in relative value) per m s^{-1}. The relative fluctuation of intensity measured through the filter will then be of about $2\,10^{-5}$ for an 20 cm s^{-1} amplitude oscillation. Provided the time series are long enough for separating the successive peaks in the Fourier analysis, the photon noise will be beaten down to this level if the total number of integrated photons is about $1/(2.10^{-5})^2 = 2.5\ 10^9$.

A counting rate of a few 10^4 per second can do the job if a few nights of integration can be obtained. Extrapolating our personal experience with the sun indicated that such a value could be obtained by using the largest available telescopes to observe the brightest stars.

It was decided to test the new instrument on α Centauri, because of the very close similarity of this star with the sun. Seven nights were granted for this programme at the ESO 3.6 m telescope in June 1982. Unfortunately the first five nights remained totally cloudy. The sixth night, we had to stop after just over two hours of recording due to high wind speed. The last one provided 7 hours of data, unfortunately through a non-photometric sky, its transparency fluctuating by 3 to 5%.

The counting rate obtained during this observation was 6×10^3 per second, including about 900 of dark current (photomultiplier dark current and depolarized light from the continuum). Only one night with cirrus clouds was not enough for detecting the stellar oscillations. The detailed analysis (Decanini, 1983) leads to a noise of a few m s^{-1} per point of the Fourier spectrum.

For the continuation of this observing programme we have the following remarks:

– The photon noise estimation made here above is very straightforward. It assumes, for example, that the stellar oscillations have the same amplitude as the solar oscillations, and that they manifest in our filter only through a Doppler shift of the line. Evidently, the amplitude will depend on the star. There are theoretical arguments, namely the balance of energy between convection and oscillations, which indicates that stars somewhat hotter and older than the sun would oscillate with 5 to 10 times more amplitude. (Christensen-Dalsgaard and Frandsen, 1983.) On the other hand, our filter can detect monochromatic changes of intensity in the line wing due not only to Doppler shift (local temperature, sodium ionization . . .)

– The weather will almost necessarily be better than it was during this first test.

– The counting rate can be improved first by broadening the filter bandwidth (100 mÅ, instead of 80, can be obtained with a few more degrees in the sodium cell temperature and a stronger permanent magnet) and mostly by using both D1 and D2 sodium lines.

Just when finishing to write this note, we are coming back from a second observing run granted at the 3.6 m telescope in May 1983. Two and a half very good nights have been efficiently used, with a photon-counting rate of over $3\ 10^{+4}$ per second. The Fourier analysis of this signal remains to be done and will appear in one of the next issues of the *Messenger*. Certainly, oscillations similar to the solar five-minute p-modes are detectable.

Now our spectrophotometer will also have to be used on stars of different types. Following the theoretical arguments already mentioned, the best candidate will be Procyon. In any case we are now on the verge of seeing the birth of seismological investigation of non-variable stars.

References

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Detection of Highly Ionized N and O in the Infrared Spectrum of Nova Muscae 1983?

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This bright nova was discovered in January 1983 by Liller (1983, IAU Circular No. 3764), just before our scheduled infrared observing runs at the ESO 3.6 m and 1 m telescopes during which we were able to both monitor it photometrically between 1.2 μm and 10 μm and obtain low resolution 1.4-4.2 μm spectra. A detailed description and analysis of these data will be contained in an extensive paper combining ultraviolet, optical and infrared observations, which is now being prepared mostly by J. Krautter. As, to our knowledge, no previous infrared spectra of novae between 1 μm and 2 μm have been published, we would like to make use of this short article to report the discovery of a strong but broad emission feature at 1.56 μm which we can best explain at the moment as an unresolved group of recombination lines to He II, OV and NV – species normally associated with UV rather than IR spectroscopy.

The 1.45 μm – 1.8 μm spectrum shown in fig. 1 was obtained on Feb. 10 using the InSb CVF spectrophotometer at the ESO 1 m telescope. As expected, it contains the strong hydrogen recombination lines BR_ζ (10-4, 1.736 μm) and BR_η (11-4, 1.681 μm) plus a broad emission region resulting from unresolved hydrogen lines between $Br_{12\text{-}4}$ and the series limit. (Other bracket lines are present in the longer wavelength spectra, e.g., BR_γ (2.17 μ) and Br_α (4.05 μm) and their intensity ratios imply that at this stage the optical depth of the gas to hydrogen lines was intermediate between the optically thin and optically thick limits. Ratios of He II recombination lines on the other hand suggest that the gas was optically thick at the He II transitions. Taken together, these results are consistent with a very steep gas density distribution, as would be expected shortly after the nova outburst.)

The new discovery in fig. 1 is the strong feature at 1.56 μm which, as can be seen by comparison with the hydrogen lines, is broader than the instrumental resolution even though the latter was only R ~ 65. Features of this type, arising in a variety of astronomical objects, are usually attributed to emission bands of molecules in grain mantles. In the present case, however, the nearest known molecular feature is one at 1.53 μm observed in cool, C-rich Mira stars (Goebel et al., 1981, *Astrophysical Journal,* **246,** 455). If the 1.56 μm feature does arise in grain mantles therefore, the molecules responsible have not yet been found in other astronomical situations. The alternative explanation offered here is that this "broad" 1.56 μm feature consists of closely spaced emission lines. In fact, as shown in fig. 2, the feature can be adequately fit with just two lines, whose most probable centre wavelengths are 1.575 μm and 1.557 μm. The former can be identified with He II (13-7, 1.573 μm) and the second with XV (10-9, 1.554 μm) where, because the latter transition is quasi hydrogenic, the element X cannot be uniquely identified on the basis of the infrared spectrum alone. Given the strength of the emission, however, it would appear reasonable on abundance arguments to assume that C, N or O are responsible. Of these, C is essentially excluded by the extremely high (392 eV) ionization potential of CV. Also, the C IV infrared recombination lines,

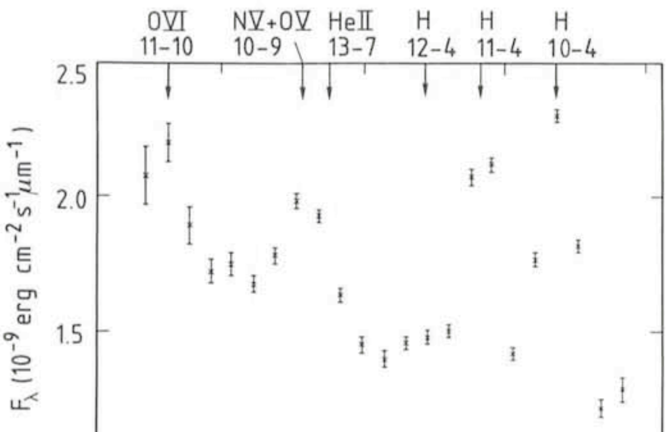

Fig. 1: *1.42–1.80 μm spectrum of Nova Muscae 1983. The intensity scale is in units of 10^{-9} erg cm^{-2} s^{-1} μm^{-1} and identified lines are indicated on the top of the spectrum.*

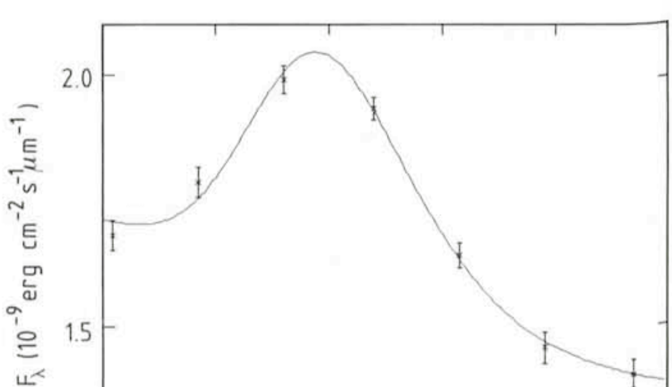

Fig. 2: *The 1.56 μm broad feature fitted with two Gaussian lines having the instrumental half-width of 0.017 μm. The best fit (minimum χ^2) parameters are λ_o = 1.557, I = 1.3 (± 0.1)·10^{-11} erg cm^{-2} s^{-1} and λ_o = 1.575, I = 3.6 (± 1.1)·10^{-12} erg cm^{-2} s^{-1} for the two lines.*