The A-Star Puzzle
Proceedings IAU Symposium No. 224, 2004
J. Zverko, J. Žižňovský, S.J. Adelman, & W.W. Weiss, eds.
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DOI: 10.1017/S1743921305009890

Pulsations in pre-Main Sequence stars: The case of HD 34282

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Abstract. HD 34282 has been found to pulsate during a systematic search for short-term photometric variability in Herbig Ae/Be stars with the goal of determining the position and size of the pre-Main Sequence instability strip. Simultaneous Strömgren photometry is used in the frequency analysis, yielding two frequencies with values of $\nu_1 = 79.5$ and $\nu_2 = 71.3$ cycle d^{-1}. The main period, with a value of 18.12 min, represents the shortest period observed up to now for a δ Scuti-type pulsator. A preliminary seismic modelling, including instability predictions and rotation effects, has been attempted. Both, Main Sequence and pre-Main Sequence models predict modes in the range of 56 to 82 cycle d^{-1} (between 648 and 949 μHz), corresponding to oscillations of radial order n from 6 to 8. The mode identification is not discriminating due to the large error bars attached to the data, therefore, all possible non-radial and radial modes up to $\ell = 3$ are compatible with the observed oscillations.

Keywords. Stars: early-type, stars: emission-line Ae, stars: fundamental parameters, stars: individual: (HD 34282), stars: oscillations, stars: pre–main-sequence, δ Scuti

1. Introduction

Pre-Main Sequence (PMS) stars with masses $\geqslant 1.5$ M$_\odot$ are known as Herbig Ae/Be stars (Herbig 1960, Strom 1972). These stars raise several important questions which still need to be answered. First, their PMS nature needs to be confirmed, as their location in the Hertzsprung-Russell (HR) diagram, clearly above the Main Sequence (MS) (Strom 1972 van den Ancker *et al.* 1998), leads to the ambiguity that they could be either PMS or post-MS objects. Once their PMS nature is ascertained, the Herbig Ae/Be stars can be used to constrain the modelling of PMS evolution and to study their coupling with the circumstellar (CS) environment, involving, e.g., magnetic processes, accretion/ejection processes, and exchanges of angular momentum. The study of the pulsations of these stars represents, therefore, a unique opportunity to answer these questions. Suran *et al.* (2001) have shown that some nonradial unstable modes are extremely sensitive to the details of the internal structure, and make it possible to distinguish pre- from post-MS stars, as well as to constrain the internal rotation.

PMS stars with masses $\geqslant$1.5 $M_\odot$ are expected to cross the Instability Strip on their way to the MS, spending typically 5% to 10% of their PMS phases within it (Marconi & Palla 1998). This time is sufficiently long for a significant number of Herbig Ae stars to be present in this strip, and, therefore, to presumably exhibit δ Scuti-type pulsations.

Although photometric variability induced by variable dust obscuration or magnetic activity is rather high in these stars, the time scales for these high amplitude variations are in principle separated from those of δ Scuti-type pulsations, Keplerian rotation of the CS envelope, presumably responsible for variable dust obscuration, occurs on the time scales of months, and the star's rotation, at the origin of the variability due to surface

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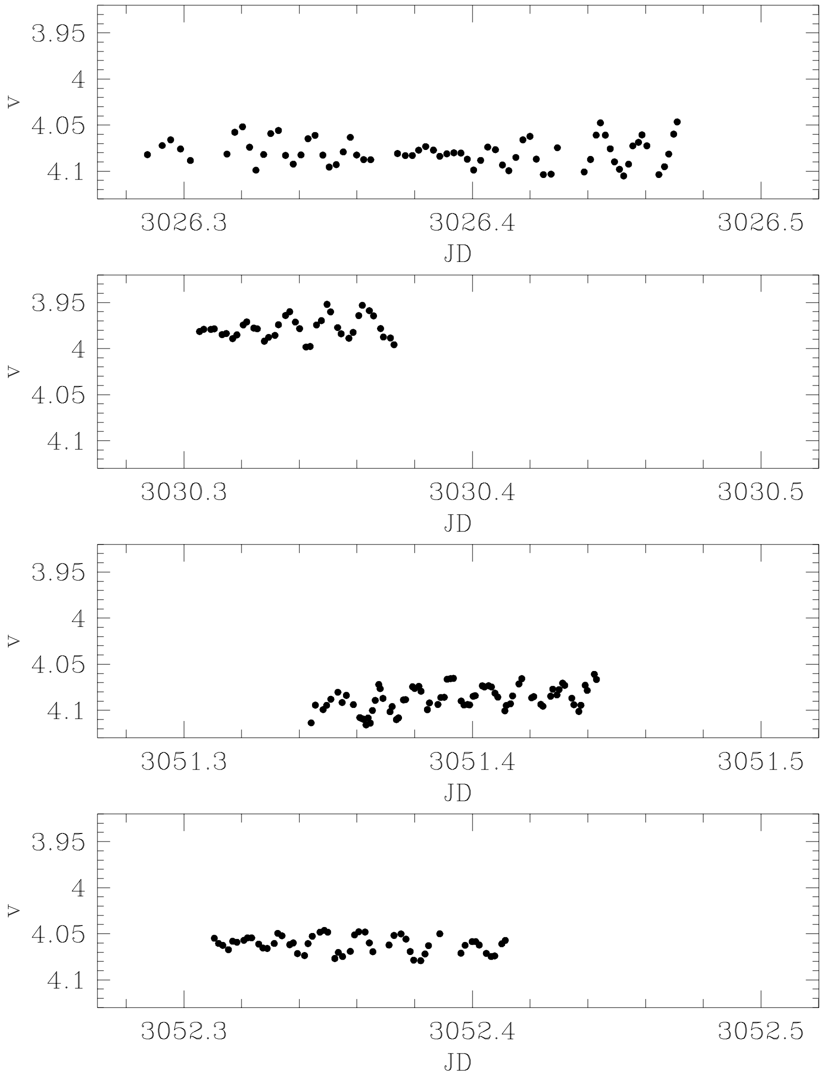

Figure 1. v light curves of the δ Sct PMS star HD 34282 during four nights in January and February 2004 (JD+2450000.00).

activity, is typically of the order of one to several days, while p-modes in these stars are found with periods of minutes to hours.

The observations secured so far of the pulsational variability in Herbig Ae stars are insufficient to verify the existence, the width and the location of the instability strip in the HR diagram. It is therefore very important to start a systematic photometric survey of a large number of Herbig Ae stars, to study the observational characteristics of the PMS instability strip, and to compare them with theoretical predictions (Marconi & Palla 1998).

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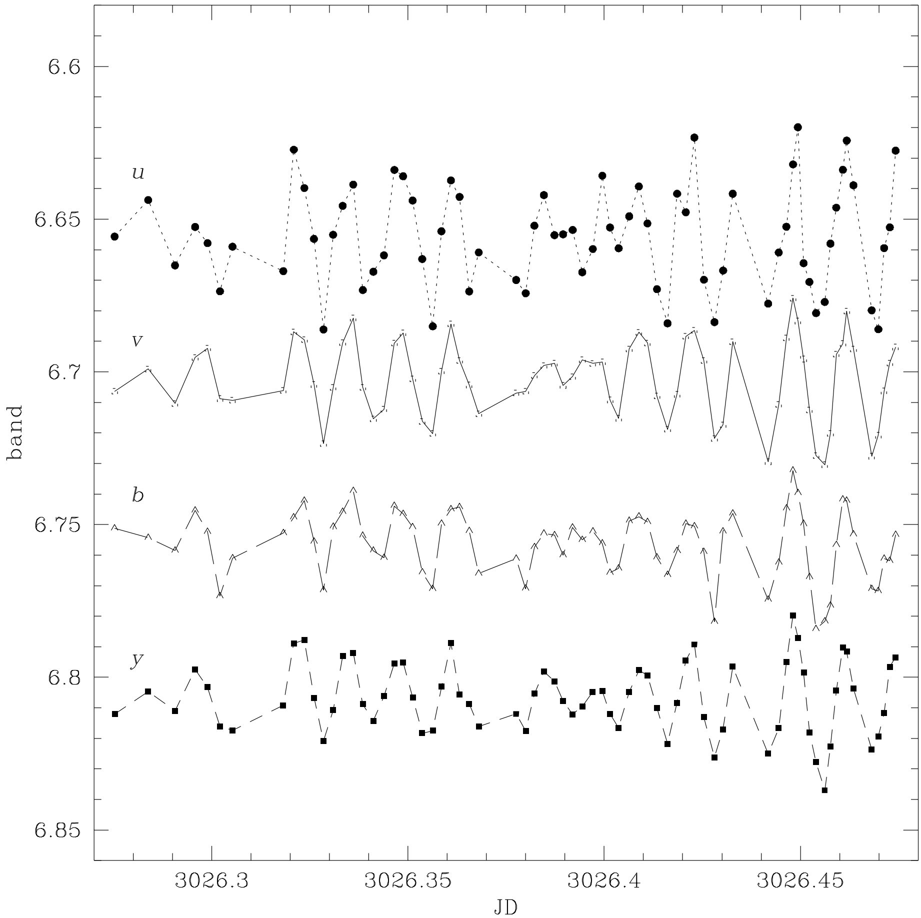

Figure 2. *u*, *v*, *b* and *y* light curves of HD 34282 on the first night of observations.

2. The observing program

The observations secured for HD 34282 form part of a survey undertaken at the Sierra Nevada Observatory (OSN), Spain, within the framework of a collaboration between the Observatoire de Paris and the Instituto de Astrofísica de Andalucía to investigate the observational characteristics of the PMS instability strip. We have used the 0.9-m telescope of the OSN, managed by the IAA, to obtain $uvby\beta$ photometry. The whole dataset was reduced and calibrated to the respective standard systems by using software developed by our group. These data has been utilised to determine $T_{\rm eff}$, $\log g$ and [Fe/H] of HD 34282.

3. HD 34282 (V1366 Ori)

HD 34282 (= V1366 Ori) has been classified in the spectral range between A0 and A3 by several authors (Gray & Corbally 1998, Mora *et al.* 2001, Merín *et al.* 2004). This is a very interesting object as: 1) the star has strong IR excess (Sylvester *et al.* 1996, Malfait *et al.* 1998, Merín *et al.* 2004), 2) it is a relatively nearby star, according to Hipparcos measurements $d = 160^{+60}_{-40}$ pc (van den Ancker *et al.* 1998), and 3) observations with the IRAM 30-m antenna revealed a double-peak profile in the $J = 2 \rightarrow 1$ transition of

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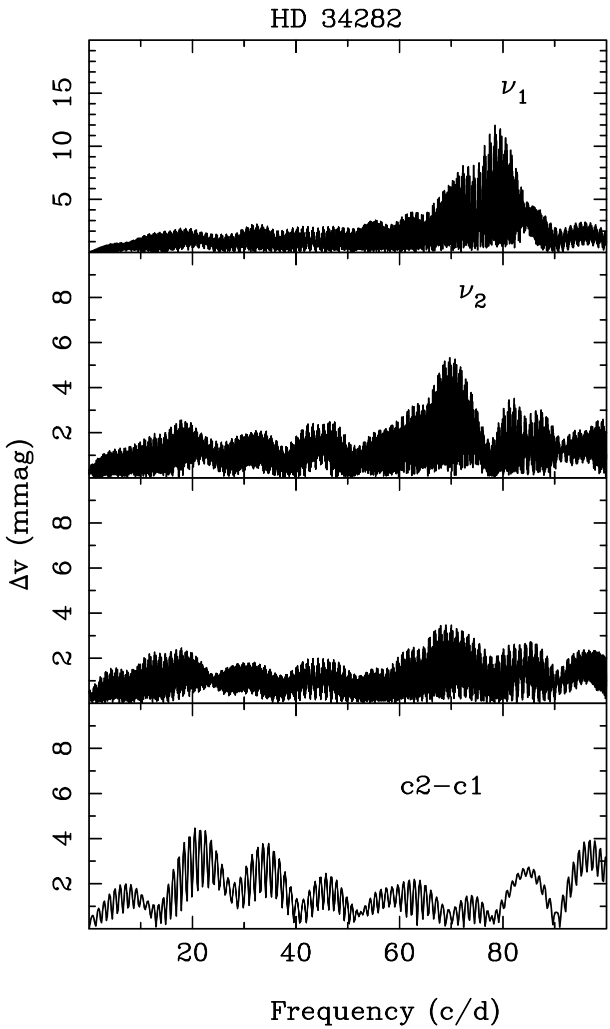

Figure 3. Fourier analysis of the Strömgren *v* data. The Fourier transform of the differential photometry of the comparison stars (C2−C1) is given in the bottom panel.

the CO molecule, characteristic of a large rotating disk, further supported by Plateau de Bure interferometer observations (Piétu *et al.* 2003). Other characteristics of this star are:

- Disk outer radii from $R_{\rm out} = 700$ to 835 AU (Merín *et al.* 2004, Piétu *et al.* 2003)
- Mass of the disk from $M_{\rm disk} = 0.11$ to $0.70\,M_{\odot}$ (Piétu *et al.* 2003, Merín *et al.* 2004)
- $V = 9.873$, $(b-y) = 0.126$, $m_1 = 0.174$, $c_1 = 1.001$, $\beta = 2.918$ (this study)
- Distance determinations from 326 pc (from our photometry) to 547 pc (Sylvester *et al.* 1996), Hipparcos distance $d = 160$ pc (van den Ancker *et al.* 1998)
- $T_{\rm eff} = 8760$ K, $\log g = 4.4$ (from our photometry)
- $T_{\rm eff} = 8625 \pm 200$ K, $\log g = 4.2 \pm 0.2$, [Fe/H]=-0.8 ± 0.1 (from high-resolution spectroscopy, Merín *et al.* 2004)

Our data for HD 34282 show photometric variations at two time scales, from day to day and within a day, as seen in Fig. 1. A blow-up of the data taken on the first night where these intraday variations are clearly visible, is shown in Fig. 2. The plot presents,

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from top to bottom, the u, v, b and y light curves, showing that the amplitude of the modulation decreases from the ultraviolet to the yellow.

4. Results and conclusions

A systematic search for short-term photometric variability has been undertaken for all known Herbig Ae stars with the goal of detecting their intrinsic variability and of precisely locating them in the HR diagram, to constrain the position and size of the observed PMS instability strip. The work presented here for HD 34282 is one result of this search.

HD 34282 was found to pulsate at at least two frequencies. This is an important result in itself since it adds to the short list of PMS stars known to belong to the δ Scuti pulsators. Furthermore, the highest of its frequencies yields a period of only 18 min, which is the shortest found so far for this type of stars. Moreover, the largest amplitude of the light curves in the Strömgren system is observed for u. This behaviour is explained as pulsation in a high radial order in stars near the blue edge of the classical instability strip.

The central star of HD 34282 is theoretically expected to pulsate whether it is a normal MS or a PMS star in the same position in the HR diagram. Furthermore, the highest of the observed frequencies only becomes unstable for models of low metallicity, pointing thus towards the same conclusion as that from spectroscopic measurements, that is, that the star is metal-poor.

5. Future work

More observations better distributed in time are needed to allow the detection of more periods and more precise phases and amplitudes, so permitting a better understanding of this object. This will give us a possibility of modelling the physical conditions of the deep interior of a PMS star.

For this purpose a multi-site observational campaign for November 2004 is being co-ordinated.

Acknowledgements

PJA acknowledges financial support at the Instituto de Astrofísica de Andalucía-CSIC by an I3P contract (I3P-PC2001-1) funded by the European Social Fund. MJG wants to thank the French PNPS (Programme National de Physique Stellaire) for financial support. Spanish CICYT (Comisión Interministerial de Ciencia Y Tecnología) is acknowledged for providing funds for the project with reference number SP2001-4528-PE.

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