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HIGH- AND LOW-DEGREE MODES IN DELTA SCUTI STARS: 1- AND 2-D FOURIER ANALYSES OF τ PEG

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PROBING THE INTERIORS OF δ SCUTI STARS

Stellar seismology of δ Scuti stars offers the best prospect for determining the interior properties of normal non-magnetic A-F stars on or near the main sequence. The discovery of rich eigenfrequency spectra in the light variations of several δ Scuti stars (e.g., θ^2 Tau: Breger *et al.* 1989; GX Peg: Michel *et al.* 1990) should make this possible for low-degree modes ($\ell \leq 4$). However, due to cancellation effects, modes of higher ℓ cannot be studied through photometry or radial velocity measurements.

The detection of rapid line-profile variations among rapidly rotating δ Scuti stars (e.g., Walker *et al.* 1987; Kennelly *et al.* 1992) has extended our sensitivity to much higher modes. These variations are consistent with moderate- to high-degree modes, where $|m| \sim \ell$. (In the simplest case, they could be pure sectorial modes with $|m| = \ell$ and pulsation amplitudes strongly confined to the stellar equator.) To use these data effectively, we need an objective way to identify the modes and their time evolution.

Therefore, we introduce here a new technique to analyse the profile variations of δ Scuti stars: **a two-dimensional Fourier transform** in both time and "Doppler space". This technique has three main advantages over conventional photometric and RV studies:

[1] Visiting Astronomer, Canada-France-Hawaii Telescope, operated by the National Research Council of Canada, the Centre National de la Recherche Scientifique de France and the University of Hawaii

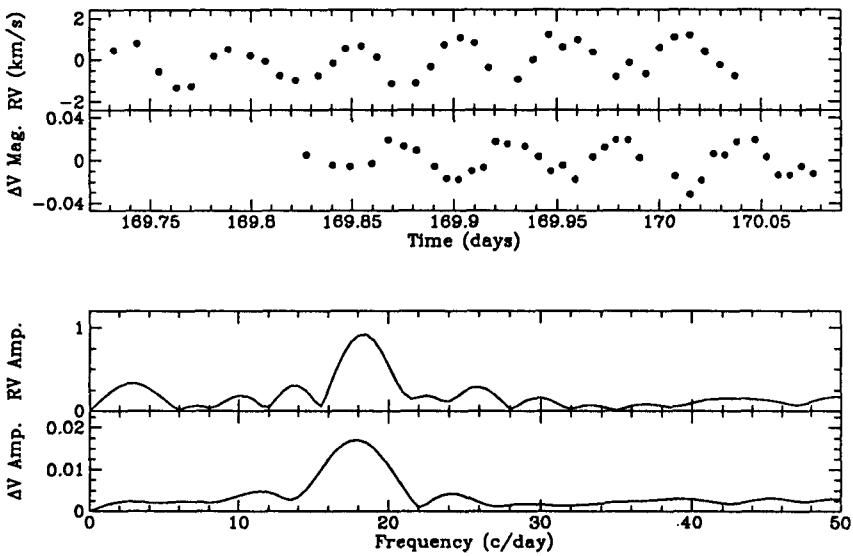
[2] Visiting Observer, 0.6-m Air Force Telescope at Mauna Kea Observatory, Institute for Astronomy, University of Hawaii

- **Direct determination of both frequency and mode of oscillation** is possible from the 2-D transform.
- **Modes of both high- and low-degree** ($0 \leq \ell \leq 16^{+}$) **can be resolved,** limited only by the instrumental resolution and the intrinsic width and rotational broadening of the line profile.
- **Complex patterns** in the profile variations are decomposed into Fourier terms, to study multi-mode beating or mode growth/decay.

THE MULTI-MODE BEHAVIOUR OF τ PEG

High-resolution high-S/N coudé spectra from CFHT and simultaneous UBV photometry from the U. Hawaii 0.6-m telescope were obtained for this rapidly rotating δ Scuti variable [$v\sin i \simeq 145$ km/s; sp. A5 V] . The spectra cover a wavelength range of 4460 - 4525 Å and span about 7 hr. RV variations were derived from these spectra by a cross-correlation technique.

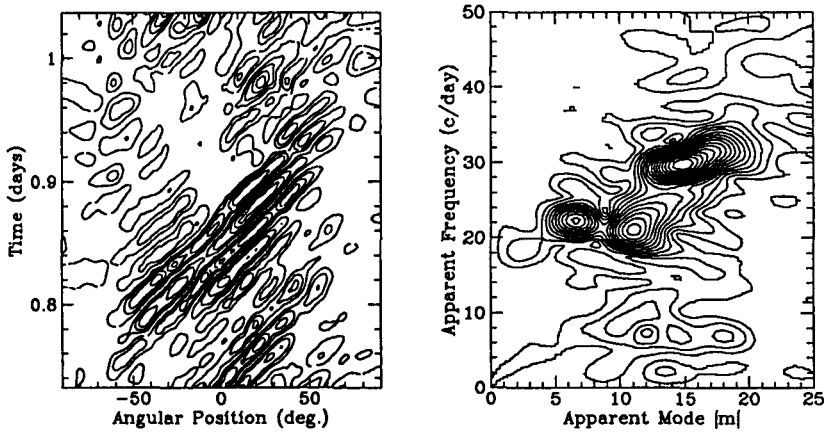
The RV and light curves are shown below, along with their respective Fourier amplitude spectra. We find a frequency near 18.5 c/d (agreeing with the published value of 18.4052 c/d (Breger 1991), given the limited frequency resolution of this data set) and a velocity-to-light amplitude ratio $K/\Delta V \simeq 53$ km s^{-1}mag^{-1} (consistent with a *non*-radial mode of low ℓ).



A contour plot of the profile variations of the unblended Fe II λ4508Å line (in which wavelength has been translated into angular position on the stellar equator) is presented in the next figure (left panel). Several "bumps" progress from blue to red through the profile, and their amplitudes appear to be modulated with time. 2-D Fourier analysis of these variations reveals a pattern of at least four peaks at frequencies between 18 and 30 c/d and

apparent $|m|$ values near 3, 6-7, 11 and 15 (right panel). (The power below 10 c/d is likely due to slow instrumental changes, etc.)

The small peak with low $|m|$ at 18.5 c/d undoubtedly corresponds to the mode causing the light and RV oscillations. Low-degree modes are more coherent across the entire profile and lead to large integrated effects despite small local amplitudes. High-degree modes of larger amplitude do not contribute significantly to RV variations.



One cannot simply translate this 2-D transform directly into mode identifications because the spectral window, temporal and spatial harmonics and possible mode interactions must first be taken into account. Note also that the "apparent frequency" includes effects of the star's rotation, while the "apparent mode" is merely a transformation assuming that $|m| = \ell$. We are currently investigating the detailed properties of the 2-D transform to obtain more definitive mode values for τ Peg.

Similar data are being analysed for two other intriguing δ Scuti variables: θ^2 Tau and 97 Tau.

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