β Cephei Pulsation Anomalies: Potential New Windows into the Instabilities and Evolution of Early B Stars

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Abstract

We have obtained *Voyager* Ultraviolet Spectrometer (UVS) measurements of well-known β Cephei stars, which now total more than 1500 hours (> 300 pulsation cycles!) and which constitute the most comprehensive coherent data set that can address fundamental pulsation properties of a significant cross-section of the group. The extended measurement sequences for individual stars, which cover many successive pulsation cycles at wavelengths where pulsation amplitudes reach a maximum, can provide more comprehensive tests of pulsation stability than any ground-based data. During 1990-91, we acquired more than 100 hours of ground-based high-resolution spectroscopic observations and UBV photometric observations, simultaneous and near-simultaneous with the UVS data set. Analysis has been initiated at NASA's Goddard Spaceflight Center (NASA/GSFC), the University of Hawaii at Hilo (UH Hilo), and the Dominion Astrophysical Observatory (DAO).

1. Description of Voyager UVS and Ground-Based Data

The two *Voyager* spacecraft have objective grating spectrometers with wavelength coverage of 500-1700 Å. Spectral resolutions of approximately 18 Å for point sources and 30 Å for diffuse sources are achieved. Instrumental sensitivity is optimized for the 800-1200 Å region. Typical limiting fluxes at 1050 Å in the far-UV are 1.0 x 10^{-12} ergs cm^{-2} sec^{-1} Å^{-1} for *Voyager 1* (5.0 x 10^{-13} for *Voyager 2*). In-flight performance of the UV spectrometers has been reviewed by Broadfoot *et al.* (1981, *Journal of Geophysical Research*, **86**, p. 8259). During 1990-91, we obtained UVS data on the stars BW Vulpeculae, β Cephei, ν Eridani, δ Ceti and 12 Lacertae.

Measurements at the DAO were made using CCD sensors on both the Cassegrain spectrograph of the 1.8-meter telescope and the coudé spectrograph of the 1.2-meter telescope. Spectral resolutions were approximately 0.3 Å and 0.1 Å respectively; time resolution was typically in the range of 2-4 minutes with a S/N exceeding 50:1. The lines of Si III, He I, Mg II, O II and C III in the wavelength range 4450-4600 Å were among those observed. For observations with the UH 2.2-meter telescope on Mauna Kea, a CCD sensor was used on the coudé spectrograph. The spectral resolution was 0.2 Å and the time resolution was 10-15 minutes with a S/N in the range 100-150. In addition, simultaneous UBV photometric

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observations were obtained on the UH 0.6-meter "Air Force" telescope during May 1991. The ground-based program has been an outstanding success, having produced almost 100 hours of simultaneous data on the stars BW Vul, β Cep, ν Eri, δ Cet and 12 Lac.

2. Scientific Objectives and Analysis

The scientific objectives which can be addressed directly with the available data are as follows: **(1)** determine the origin and significance of an "instability anomaly" present in the far-UV light curves of β Cep and ν Eri; **(2)** determine cycle-to-cycle pulsational stability from *Voyager* UVS data; **(3)** determine the role of atmospheric shock waves; investigate the relationship of shock waves to proposed pulsation mechanisms and to the range in behaviour within the group; **(4)** determine whether there exist unique relationships between pulsation amplitude and line profile variations, light and velocity curve shapes, etc.; **(5)** institute an analysis to discriminate radial from non-radial pulsation modes using temperatures derived from the *Voyager* UVS data; **(6)** continue the analysis of the long-term (decades) pulsational stability of stars such as BW Vul and assess the evolutionary significance. The more general program goals are as follows: **(a)** further define the evolutionary status of β Cephei stars; **(b)** explain the wide range in pulsation amplitude within the β Cephei group; **(c)** identify, if possible, the pulsation mechanism; **(d)** determine the significance of β Cephei instability within the context of the variability of early B stars.

Data analysis is currently in progress at NASA/GSFC, UH Hilo, and DAO. Examples of *Voyager* UVS light curves are given below. Observations have been folded into one cycle. The "instability anomaly", shown for β Cep in Fig. 2, is manifested in the form of unexplained fluctuations in intensity near the phase of maximum UV flux. In Fig. 1, UVS data for β Cep obtained during May 1991 show that the fluctuations near maximum are still present a decade later. Moreover, the magnitude of the fluctuations during 1991 appears to be comparable to that found in the 1981 data.

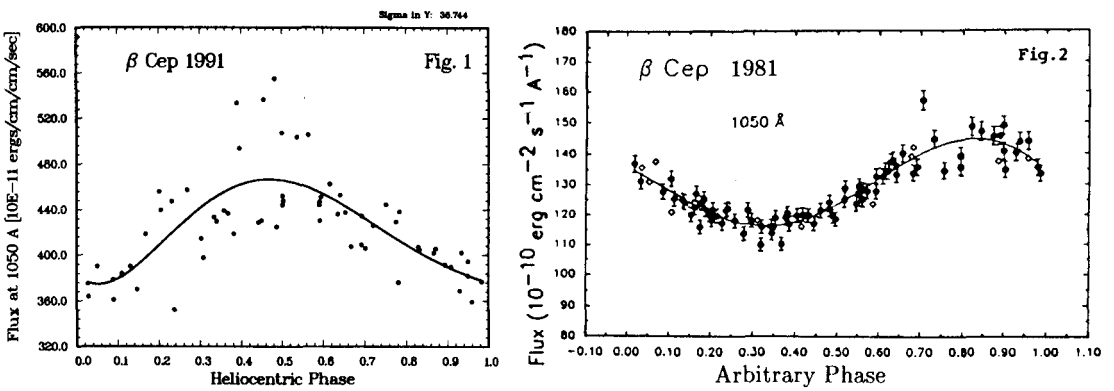

Fig. 1: *Voyager* UVS observations of β Cep (P = 4h 34m) taken over a 5-day observing period in 1991. **Fig. 2**: *Voyager* UVS observations of β Cep taken over a 26-hour observing period in 1981 (Rautenkrantz and Polidan, in prep.); note the "instability anomaly" near maximum light.

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