AN EVOLVING TRIO OF HYBRID STARS: C 111

NASA Grant NAG5-12478

Annual Report No. 3

For the period 1 September 2004 through 31 August 2005

Principal Investigator

Dr. Andrea K. Dupree

August 2005

Prepared for

National Aeronautics and Space Administration

Washington, D.C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
is a member of the
Harvard-Smithsonian Center for Astrophysics

The NASA Technical Officer for this Grant is George Sonneborn, Code 681.0 NASA/GSFC.

Program Title: An Evolving Trio of Hybrid Stars: FUSE GI Program C 111
Annual Report: 09/01/2004-08/31/2005
PI: A. K. Dupree, Smithsonian Astrophysical Observatory
SAO: P5262-12-01
NASA: NAG5-12478

1 Scientific Activity

Hybrid stars are a class of cool, luminous single stars originally identified based on the appearance of their ultraviolet *IUE* spectra. C IV emission is present (signifying temperatures of at least 10^5 K), and asymmetric emission cores of Mg II are found, accompanied by absorption features at low and high velocities, indicating a massive stellar wind and circumstellar material. Many members of this class have been identified and X-rays have been detected from most hybrids. They represent the critical evolutionary state between coronal-like objects and the Alpha Ori-like objects and assume a pivotal role in the definition of coronal evolution, atmospheric heating processes, and mechanisms to drive winds of cool stars.

The last of our observations was obtained and transmitted to us in the spring of 2004. We have reviewed the spectra and all of the stars show the highest temperature species of O VI, although only the two brightest contain the fluoresced species of Fe II, thought to arise in an extended atmosphere. We have also obtained He I 10830Å spectra for these targets, which is important because this line forms a superb diagnostic of atmospheric dynamics in the low chromosphere. A REU student (Columbia University undergraduate) has been analysing these spectra this summer.

The *FUSE* data are being reduced using the new reduction pipeline produced by Van Dixon and we are helping to Beta test the new version. For all the spectra, semi-empirical modeling of the atmospheres will be carried out with state of the art codes. Photospheres for the giants can be constructed with Kurucz models. Semi-empirical outer atmospheres will be built using the *PANDORA* code (Avrett 1996, IAU Symp 176, p. 503). An arbitrary abundance distribution is specified. *PANDORA* solves the complete non-LTE radiative transfer equation, including the effects of expansion and spherical geometry on the line source function and the emergent profiles. Radiative losses are modeled as well as the observed optical and ultraviolet line profiles and fluxes. HST/GHRS spectra are available for γ Dra; high and low resolution spectra from IUE for μ UMa and ι Aur. We also have optical and infrared spectra for these stars at both the Helium lines (λ10830) and Ca II H and K. We expect to find asymmetric resonance lines of C III (λ977) that can be modeled in order to determine the velocity field and the mass flux.

In a complementary analysis, archival FUSE spectra were used to demonstrate the presence of a hot wind from the T Tauri star, TW Hya (Dupree et al., 2005, ApJ, 625, L131). These results are in harmony with the published survey of luminous cool stars carried out with *FUSE* (Dupree et al. 2005, ApJ, 622, 629).

TW Hya was a GI *FUSE* target, a classical T Tauri star that is currently believed to be undergoing accretion, and one that is most fortuituously is observed almost 'face-on' so that the polar regions are viewed. Spectroscopy of the infrared He I (λ10830) line with KECK/NIRSPEC and IRTF/CSHELL and of the ultraviolet C III (λ977) and O VI(λ1032) emission with *FUSE* reveals that the classical T Tauri star TW Hydrae exhibits P Cygni profiles, line asymmetries, and absorption indicative of a continuous, fast ($\sim$400 km/s), hot ($\sim$300,000 K) accelerating outflow with a mass loss rate $\sim 10^{-11}$–10^{-12} $M_{\odot}$ yr^{-1} or larger. Spectra of T Tauri N from *FUSE* appear consistent with such a wind. The source of the emission and outflow seems restricted to the stars themselves. Although the mass accretion rate is an order of magnitude less for TW Hya than for T Tau, the outflow reaches higher velocities at chromospheric temperatures in TW Hya. Winds from young stellar objects may be substantially hotter and faster than previously thought.

FUSE spectra reveal a profile of C III (λ977) in TW Hya exhibiting P Cygni structure with a clear absorption trough recovering near -325 km s^{-1} and extending to higher outflow velocities than the He I line. As expected a self-absorbed line in a differentially expanding atmosphere, appears asymmetric with a steeper slope occurring on the negative velocity side than on the positive velocity side of the profile. A similar shape is found in the O VI line, although no diminution of absorption creating an emission 'bump' is detected. Since cool stars lack a local continuum in this part of the far uv spectrum, the line intensity drops to near zero, exactly what is observed in C III and O VI. The similarity of the profile shapes in TW Hya suggests that the wind at the C III level (80,000K) continues to

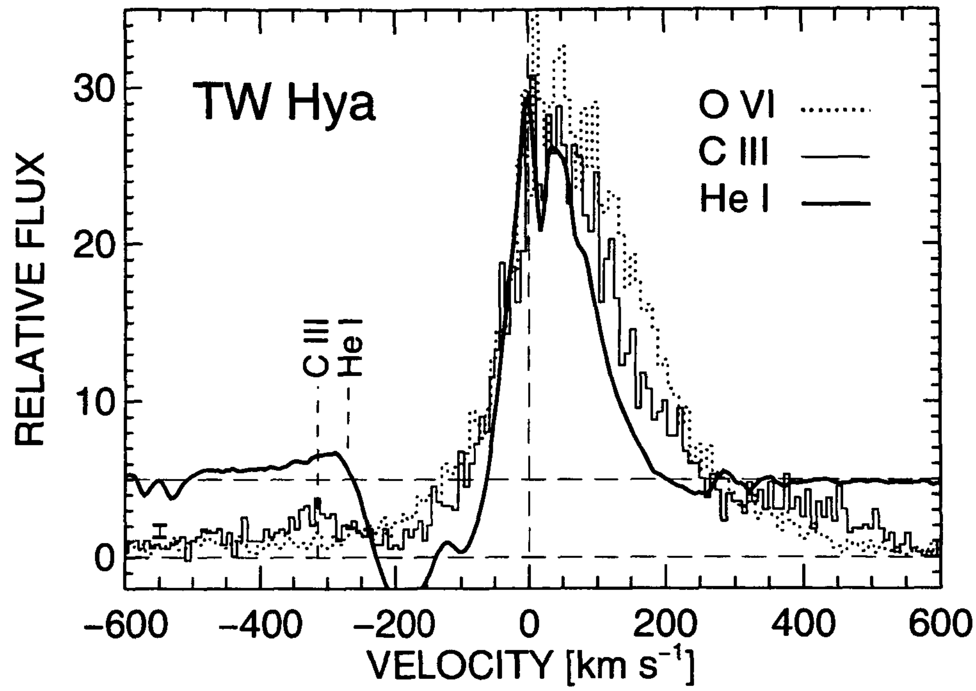

Figure 1: He I λ10830, C III λ977, and O VI λ1032 transitions in TW Hya. The notch in the TW Hya spectrum of He I at -100 km s^{-1} is found also at times in H-α profiles. Extraction of the spectra taken during the *FUSE* night, demonstrates that the low level emission near C III centered at -320 km s^{-1} and $+400$ km s^{-1} is associated with the star, and is not contaminated by airglow emission. The emission feature at -320 km s^{-1} in the C III profile has a 6σ significance in one bin sampled twice per resolution element. Emission present at $+400$ km s^{-1} in the C III profile, might originate from the star itself (although a full extent of the line to ±500 km s^{-1} may be excessive) or it could be due to O I (λ978.624) that is fluoresced by the stellar C III line, and arising in the expanding wind with an outflow of $\sim$100 km s^{-1}. A similar feature is identified in the *FUSE* spectrum of the cool supergiant β Dra (Dupree *et al.* 2005).

higher temperatures of 3×10^5K indicated by the presence of O VI asymmetry, assuming a collisionally ionized plasma. The C IV and N V profiles of TW Hya (as reported in Herczeg *et al.* 2002, ApJ, 572, 310) also show the same asymmetry as O VI, typical of wind absorption.

Publications Using FUSE Spectra During this Reporting Period

A Hot Wind from the Classical T Tauri Stars: TW Hydrae and T Tauri, A. K. Dupree, N. S. Brickhouse, G. H. Smith, & J. Strader, 2005, ApJ, 625, L131.

A Far-Ultraviolet Spectroscopic Survey of Luminous Cool Stars, A. K. Dupree, A. Lobel, P. R. Young, T. B. Ake, J. L. Linsky, & S. Redfield, 2005, ApJ, 622, 629.

Inferring Coronal Structure from X-Ray Light Curves and Doppler Shifts: A Chandra Study of AB Doradus, G. A. J. Hussain, N. S. Brickhouse, A. K. Dupree, et al., 2005, ApJ, 621, 999.

An Assessment of the Fe XVIII and Fe XIX Line Ratios from the Chandra Grating Observations of Capella, P. Desai, N. S. Brickhouse, J. J. Drake, A. K. Dupree et al., 2005, ApJ, 625, L59.

Far Ultraviolet Spectroscopic Explorer Observations of the Symbiotic Star AG Draconis, P. R. Young, A. K. Dupree, B. R. Espey, S. J. Kenyon, & T. B. Ake, 2005, ApJ, 618, 891.