COMBINED SATELLITE AND GROUND-BASED OBSERVATIONS OF THE QUIESCENT, HIGH LATITUDE SYMBIOTIC VARIABLE AG DRACONIS = BD+67°922

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ABSTRACT. Satellite observations, from Einstein, IUE, and IRAS, have been combined with ground-based observations to derive the quiescent energy distribution of the symbiotic star AG Draconis. A detailed comparison is made between the combined observations and various steady-state composite models, including blackbody accretion disks.

1. INTRODUCTION

1.1. AG Draconis at Quiescence

The high latitude ($b = +41^{\circ}$) symbiotic variable AG Draconis was in relative quiescence from 1955 until late 1980 when it began its latest series of outbursts. Preceding the first in the latest series of outbursts in November 1980, both X-ray and ultraviolet observations were obtained with the Einstein and IUE satellites, respectively. We have combined these data with extant ground-based optical, infrared and radio measurements in order to derive the quiescent continuum energy distribution from 41 A to 0.7 cm. The uncertainty in combining such disparate data is minimized by the relative stability of AG Dra during its extended period of quiescence. The interpretation of the energy distribution is also facilitated by the relatively low reddening ($E(B-V) \leq 0.06$ mag) inferred from the 2175 A interstellar feature.

We present comparisons of the quiescent data to various composite models, both with and without steady-state accretion disks. By successfully deconvolving the quiescent distribution, we seek to identify the individual components which may lead to the eruptive behavior.

2. OBSERVATIONS

2.1. X-ray Detection

The single quiescent X-ray observation obtained with the Einstein satellite has been discussed by Anderson, Cassinelli, and Sanders (1981). A

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X-ray luminosity of L_X = 3-5 x 10^{32} ergs/sec was deduced, assuming that $N_H \gtrsim 3 \times 10^{20}$ cm^{-3}. A temperature of T = 2-16 x 10^5 K was inferred for the X-ray emitting region.

2.2. Ultraviolet Spectrophotometry

Low resolution ultraviolet spectra were obtained prior to 1980 using the IUE satellite, revealing a strong emission line spectrum superposed on a continuum increasing to the shortest wavelengths. Both permitted and intercombination lines of HeII, CIV, NIV], and OIII] are evident. Mean continuum fluxes were derived by averaging the data in selected line-free regions.

2.3. Optical Spectrophotometry

Optical data for AG Dra in quiescence was obtained by Blair et al. (1983) spanning the interval 3500 - 7500 A with a resolution of about 10 A. A large Balmer jump appears in emission, as well as the strong Balmer and Helium emission lines. Unfortunately, there is a 300 A gap between the IUE LWR spectrum at 3200 A to the optical data beginning at 3500 A.

2.4. Infrared Measurements

Ground-based infrared photometry of AG Dra in quiescence was obtained by Swings and Allen (1972) and Allen (1979). Following the 1980 outburst, both ground-based IR data and IRAS measurements were taken. The post-outburst infrared photometry of Taranov and Yudin (1983) reveals that AG Dra has not varied significantly in the infrared, where its flux distribution is dominated by the late type secondary ($\Delta m = \pm 0.25$ mag at 2.3μ). Thus, while the IRAS data represent post-outburst values, we nonetheless assume that the 12, 25, 60 and 100μ fluxes are representative of the quiescent levels. AG Dra is identified with IRAS16013+6656 in the IRAS Point Source Catalog (PSC); only the 12μ measurement is a firm detection. The remaining fluxes are upper limits (Fig. 1).

2.5 Radio Upper Limits

AG Draconis has only been detected as a weak radio source: Cohen and Ghigo (1980) set an upper limit of 7.8 Jy at 43.1 GHz from their radio molecular maser line survey. More recently, Seaquist, Taylor and Button (1984) determined an upper limit of 0.41 mJy at 4.89 GHz.

The combined continuum fluxes are shown in Figure 1. No reddening correction has been applied, as the inferred interstellar reddening is small. The IRAS measurements have been color corrected for an assumed blackbody temperature of T = 3600K, the adopted temperature of the secondary, following Young et al. (1985). The fluxes are calculated using an assumed distance of d = 700 pc, and are displayed on a logarithmic λf_λ scale for convenience.

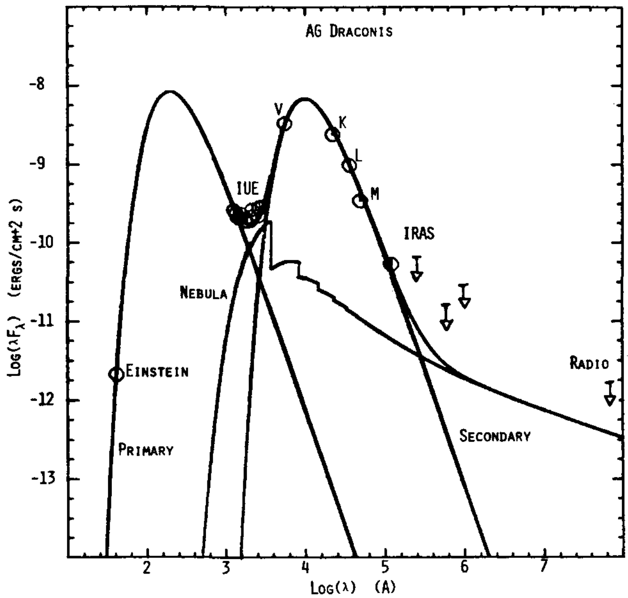

Figure 1. Quiescent continuum observations of AG Draconis. Open symbols represent data; arrows indicate upper limits. No reddening correction has been made and fluxes are calculated for a distance of d = 700 pc. Solid lines represent model fit. See text for discussion.

3. QUIESCENT MODELS

The recent radial velocity results of Garcia (1986) convincingly verify the binary nature of AG Dra. Thus, as the foundation for a quiescent model, we derive parameters for the primary and secondary components and additionally treat the complications of possible mass exchange by considering the contributions from a circumsystem nebula and a steady-state accretion disk.

3.1 Primary

From the X-ray and IUE data, we require a primary with $L = 174 L_{\odot}$ and $T = 191{,}000$ K. We treat the primary as a blackbody and fit its energy distribution to the X-ray datum assuming it is entirely thermal in nature (Fig. 1).

3.2 Secondary

An excellent fit to the observed distribution from 6000A to 12 microns is achieved with a secondary component having $L = 144 L_{\odot}$ and $T = 3600$ K. The secondary is identified as a K5 giant, which in quiescence does not appear to fill its Roche lobe. Thus, any mass exchange at quiescence is postulated to be the result of stellar winds from one or both stars.

3.3 Non-stellar Components

3.3.1 Circumsystem Nebula. The rich emission line spectrum and the strong Balmer jump in emission clearly point to the existence of a substantial amount of material associated with the underlying binary. The combined IUE and optical spectrophotometry are seen in Figure 2, revealing details not evident in the continuum distribution (Fig. 1).

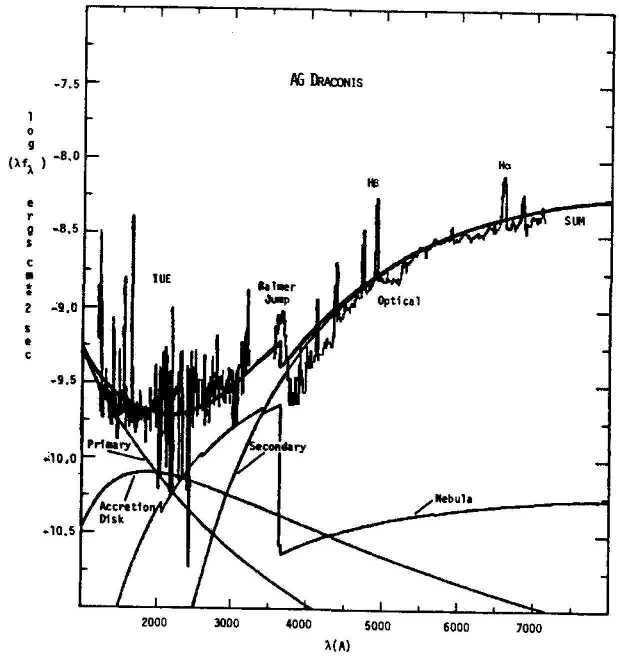

Figure 2. Combined ultraviolet and optical spectrophotometry of AG Dra. A gap of about 300 A exists between the IUE and optical data. Note the strong emission lines and the large Balmer jump in emission. Model components are labelled and overall fit is shown.

The nebular contribution is shown in Figures 1 and 2, for values of T_e = 20000 K, log n_e = 8 cm^{-3} and an emission measure , log EM = 58 cm^{-3}. Such a nebular component correctly reproduces the observed Hβ flux but underestimates the Balmer jump by at least a factor of two. This discrepancy implies a possible calibration error in the data (at the extreme shortward edge of the calibration curve) or that there is an additional source of Balmer emission.

3.3.2 Steady-state Accretion Disk. Although the secondary star appears to underfill the Roche lobe at quiescence, the existence of a wind-fed low luminosity accretion disk cannot be ruled out. Kenyon and Webbink (1984) have published a variety of combined nebula-disk models for symbiotics; in Figure 2, we show the contribution from a "blackbody" disk, characterized by an accretion rate of log(dM/dt) = -8 $M_\odot$/yr, around a primary star of $0.7M_{\odot}$. Such a disk may contribute significantly to the soft X-ray emission, which would arise from the disk boundary layer. As well, a disk naturally provides a means to account for eruptive behavior due to changes in the disk structure or the mass tranfer rate. Whether an increase in the mass transfer rate can come from enhancements in the stellar wind or is due to the onset of mass exchange through inner Lagrangian overflow has not been established yet for the symbiotics. Clearly, time-dependent accretion disk models must be explored (Duschl 1986).

4. CONCLUSIONS

A detailed binary model has been constructed which can satisfactorily reproduce the quiescent continuum energy distribution of the lightly reddened symbiotic star AG Draconis. Consisting of a white-dwarf-like primary and a K5 giant secondary, the system is embedded in a dense, warm circumsystem nebulosity. Furthermore, the primary may be surrounded by a low luminosity, wind fed accretion disk at quiescence. The lack of any significant variability in the infrared over the last eruptive period clearly indicates the eruptions are associated with the primary or the accretion disk, as suggested originally by Viotti et al. (1984).

Additional observations in the X-ray and radio regions are required to resolve the outstanding questions concerning the exact nature of the primary and the amount of free-free emission. Recent EXOSAT observations have been obtained by Piro et al. 1985, yielding an X-ray flux of $F_x \approx 3.4 \times 10^{-13}$ ergs/cm^2 s in the 0.2-1.0 keV range, nearly an order of magnitude smaller than the flux reported by Anderson, Cassinelli, and Sanders (1981), indicating significant changes in the nature of the X-ray emitting region. Our model also predicts that the extreme ultraviolet (EUV) observations planned in the near future will detect AG Dra as a strong source.

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