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# The 2006–2008 Outburst of AG Draconis

U. Munari, A. Siviero, and P. Ochner
INAF, Astronomical Observatory of Padova, Asiago (VI), Italy

G. Wallerstein
Department of Astronomy, University of Washington, Seattle

and

F. Castellani, G. Righetti, G. Cherini, P. Valisa, and G. Cetrulo
ANS Collaboration, c/o Astronomical Observatory, Asiago (VI), Italy

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**ABSTRACT.** We describe photometric and spectroscopic observations of the major outburst that AG Dra underwent between 2006 and 2008. The outburst peaked at $U = 8.4$, $B = 9.0$, $V = 8.7$ around 2006 September 6, making it the brightest $U$-band event since the 1994 outburst. It was of the *cold* type, according to the classification of AG Dra outbursts introduced by Gonzalez-Riestra et al.. A second, fainter maximum (this time of the *hot* type) followed ~400 days after the primary one, peaking at $U = 9.1$, $B = 9.7$, $V = 9.0$ on 2007 October 7. The outburst phase ended about 600 days after the primary maximum. High resolution spectra obtained during early decline from primary maximum showed emission lines of Mg II, Si II, Ti II, and Fe II in addition to the usual lines of H, He I, and He II.

*Online material:* extended table

## 1. INTRODUCTION

AG Dra was first noted to show emission lines of H and He II by Janssen & Vyssotsky (1943), and confirmed by R. E. Wilson (1943, 1945), who also detected the underlying cool giant absorption spectrum and identified He I to be present in emission. Roman (1953) noticed the importance of the blue continuum and recorded a velocity of $-135 \pm 2.1$ km s$^{-1}$ with H, He I, and He II lines displaced by 5, 12, and 25 km s$^{-1}$, respectively, to the violet. AG Dra's variability was first recognized by Sharov (1954). These observations decisively placed AG Dra among the symbiotic stars. A spectroscopic orbit with a period of 554 days was derived by Garcia (1986), and later refined to 549 days by Fekel et al. (2000) and 550 days by Galis et al. (2004). A reflection effect with the same period modulates its optical lightcurve in quiescence (Leedjarv et al. 2004, and references therein), with an additional periodicity around 350 days ascribed to pulsation of the cool giant (Galis et al. 1999). At a Galactic latitude of 41°, AG Dra shows a mean velocity of $-148$ km s$^{-1}$, indicating membership in the Galactic halo. Its metallicity of $[\mathrm{Fe/H}] = -1.3$ confirms its kinematic assignment to the halo (Smith et al. 1996). In addition, Smith et al. (1996) found that the atmosphere of the K giant component is enhanced in elements produced by the $s$-process. This indicates that its hot companion was once an AGB star and is now a hot white dwarf or subdwarf. Prior to the 1994 outburst, observations of the 1980 event with IUE and in the optical region were described in detail by Lutz et al. (1987). Light variations during the quiet period before the 1980 outburst were described by Kaler (1987) and during the outburst by Kaler et al. (1987). In 1994 there was another outburst which was observed in the X-ray region by Greiner et al. (1997). Optical photometry was published by Skopal & Chochol (1994), Montagni et al (1996) and by Leedjarv et al. (2004) among others. A detailed discussion of the system was published by Mikolajewska et al. (1995), and a report on IUE observations from 1979 to 1996, including the 1994 outburst, was published by Gonzalez-Riestra et al. (1999). A full report on recent X-ray activity is provided by Gonzalez-Riestra et al. (2008), with AG Dra being classified among the supersoft X-ray sources with an estimated luminosity of 2600 $L_\odot$ and a radius of 0.06 $R_\odot$. High-ionization forbidden emission lines have been reported by Young et al. (2006).

## 2. OBSERVATIONS

### 2.1. Photometry

Major outburst phases (characterized by several maxima, usually of declining brightness) seem to occur at roughly 13–15 yr intervals with less vigorous events taking place at random times between outbursts (Leedjarv et al. 2004). The

TABLE 1
OUR $UBV$ PHOTOMETRY OF AG DRA

| HJD | | $B$ | $B-V$ | $U-B$ | Telescope |
|---|---|---|---|---|---|
| 3548.4934 | ….. | 11.004 | 1.332 | ……. | R030 |
| 3554.4089 | ….. | 10.993 | 1.293 | ……. | R030 |
| 3847.3551 | ….. | 10.920 | 1.280 | 0.120 | R020 |
| 3931.4118 | ….. | 9.530 | 0.640 | −0.440 | R020 |
| 3934.3996 | ….. | 9.506 | …… | ……. | R010 |
| 3935.3815 | ….. | 9.447 | …… | ……. | R010 |
| 3936.3993 | ….. | 9.423 | 0.545 | ……. | R010 |
| 3937.3575 | ….. | 9.552 | 0.555 | ……. | R010 |
| 3938.3574 | ….. | 9.304 | …… | ……. | R010 |
| 3939.3915 | ….. | 9.361 | 0.500 | ……. | R010 |
| 3946.3498 | ….. | 9.230 | 0.487 | −0.610 | R020 |
| 3951.2830 | ….. | 9.182 | 0.333 | −0.540 | R010 |
| 3953.3123 | ….. | 9.147 | 0.340 | −0.691 | R010 |
| 3961.2688 | ….. | 9.097 | 0.320 | −0.674 | R010 |
| 3967.3469 | ….. | 9.060 | 0.310 | −0.600 | R010 |

NOTE.— Table 1 is published in its entirety in the electronic edition of the *PASP*. A portion is shown here for guidance regarding its form and content.

2006–2008 event here investigated began 12 yr after the onset of the 1994 major outburst phase.

$UVB$ photometry of AG Dra was independently obtained with several separate telescopes operated in Italy by ANS Collaboration, identified by their codes, with the following specifications (see Table 1 and Fig. 1): *R010*—0.13 m f/6.6 Vixen ED130SS refractor, equipped with Custom Scientific filters and a Starlight SXV-H9 CCD camera, located in Trieste; *R020*—0.40 m f/5 Newton reflector of the P. Pizzinato Observatory located in Bologna, feeding light to a HiSis 23ME CCD through Schuler filters; *R030*—0.30 m Meade RCX-400 f/8 Schmidt-Cassegrain telescope of Associazione Astrofili Valle di Cembra (Trento), with a SBIG ST-9 CCD, a Omega $B$ and a $V$ Custom Scientific filters; *R050*—0.25 m f/10 Meade LX200 telescope in Rovereto (Trento), equipped with a Apogee Alta U47 CCD camera and Optec filters; *R060*—0.40 m f/8 Ritchey-Chrétien telescope operated by Osservatorio del Monte Baldo (Verona), housing a Finger Lake Instruments ML1001E CCD camera and Schuler filters; *R100*—0.70 m f/8 Ritchey-Cretien telescope of Gruppo Astronomico La Polse di Cougnes (Udine),

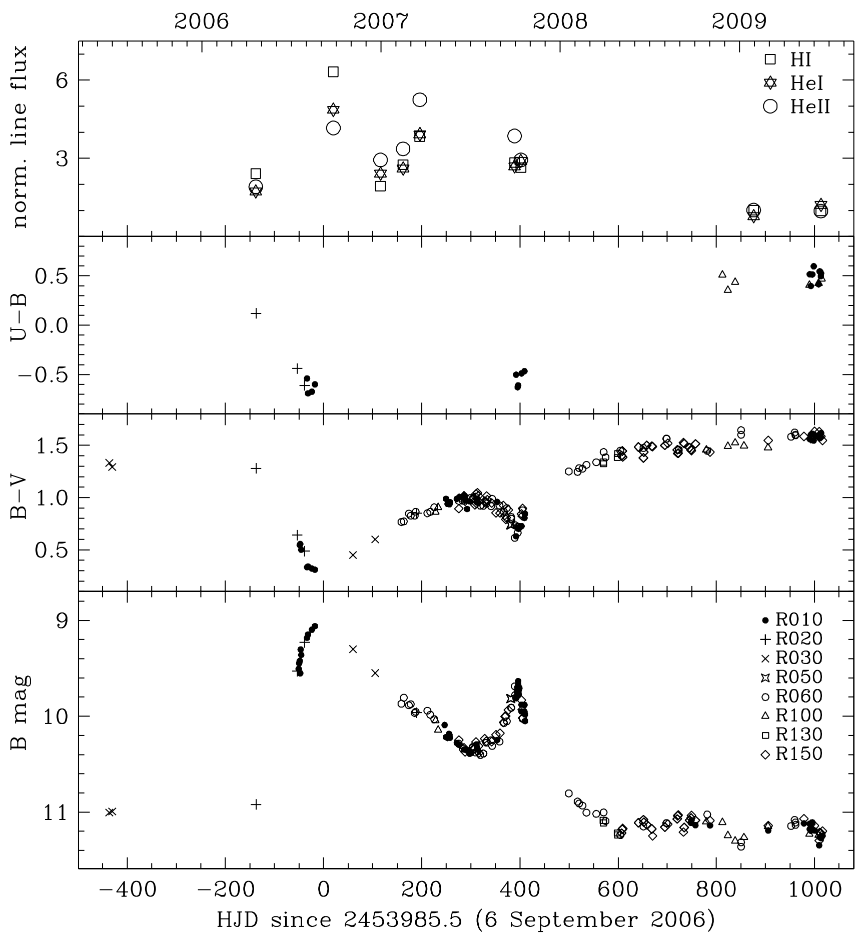


FIG. 1.—The $UBV$ light curve of the 2006–2008 outburst of AG Dra from our observations in Table 1. Key in bottom panel identifies the telescopes described in § 2.1. The top panel presents the variation in intensity of hydrogen, He I, and He II emission lines with respect to their values in quiescence ($\Delta t = +876$ and $+1013$ days).

TABLE 2
JOURNAL OF LOW-RESOLUTION SPECTROSCOPIC OBSERVATIONS

| Date | UT | $\Delta t$ (days) | $B$ (mag) | Exposure time (s) | Grating | Dispersion (Å pixel$^{-1}$) | Range (Å) | Telescope |
|---|---|---|---|---|---|---|---|---|
| 2006 Apr 21 ....... | 21:25 | −138 | 10.92 | 3000 | 300 | 2.3 | 3500–7600 | 1.22 m |
| 2006 Sep 27 ....... | 21:43 | +21 | 9.02 | 60 | gr4 | 4.2 | 3600–7600 | 1.82 m |
| 2006 Dec 31 ....... | 18:47 | +116 | 9.36 | 1800 | 600 | 1.8 | 3900–7400 | 0.60 m |
| 2007 Feb 15 ....... | 21:45 | +162 | 9.83 | 1800 | 600 | 1.8 | 3900–7400 | 0.60 m |
| 2007 Mar 22 ...... | 01:10 | +196 | 9.95 | 420 | gr4 | 4.2 | 3500–7600 | 1.82 m |
| 2007 Sep 30 ....... | 20:39 | +389 | 9.69 | 1800 | 600 | 1.8 | 3900–7400 | 0.60 m |
| 2007 Oct 13 ....... | 18:32 | +402 | 9.88 | 1800 | 600 | 1.8 | 3900–7400 | 0.60 m |
| 2009 Jan 29 ....... | 19:03 | +876 | 11.30 | 2700 | 600 | 1.8 | 4000–7600 | 0.60 m |
| 2009 Jun 15 ....... | 21:54 | +1013 | 11.20 | 1200 | 300 | 2.3 | 3400–7500 | 1.22 m |

which has an Apogee ALTA U9000 CCD Camera and Schuler filters; *R130*—0.50 m f/6 Ritchey-Cretien telescope operated by Associazione Ternana Astrofili in Stroncone (Terni), equipped with an Sbig STL1001E CCD Camera and Optec filters; *R150*—0.20 m C8 Celestron telescope in Granarolo (Bologna), with a Starlight SXV-H9 CCD Camera and Custom Scientific filters.

All photometric measurements were accurately fluxed and color corrected using the local photometric sequence calibrated by Henden & Munari (2006) around AG Dra. They are presented in Table 1 and Figure 1. The Poissonian component of the total error budget was less than 0.005 mag for all the data. The rms of the local standard stars around the color equations was 0.021 mag on average.

### 2.2. Low-Resolution Spectroscopy

Low-resolution, absolutely fluxed spectra of AG Dra were obtained on several occasions during the development of the 2006–2008 outburst. They are summarized in the journal of observations in Table 2. We used (i) the B&C spectrograph of INAF Astronomical Observatory of Padova attached to the 1.22 m telescope operated in Asiago by the Department of Astronomy of the University of Padova; (ii) the 0.6 m telescope of Osservatorio Astronomico G. Schiaparelli in Varese (Italy), equipped with a grating spectrograph; and (iii) the AFOSC imager + spectrograph mounted on the 1.82 m telescope operated in Asiago by the INAF Astronomical Observatory of Padova.

### 2.3. Echelle Spectroscopy

A high-resolution spectrum of AG Dra (resolving power 35,000) was obtained on 2006 October 3 with the Echelle spectrograph of the 3.5 m telescope of the Apache Point Observatory. The middle UT was 08:04 and the total exposure time was 2500 s. The spectral coverage extends from 3900 to 10,000 Å, and the S/N ≥100 almost everywhere. At the time of this observation ($\Delta t = +26$ days past maximum), AG Dra was still very close to maximum brightness.

TABLE 3
THE INTEGRATED ABSOLUTE FLUX (IN UNITS OF $10^{-13}$ erg cm$^{-2}$ s$^{-1}$) OF EMISSION LINES ON OUR LOW-RESOLUTION SPECTRA OF AG DRA, IDENTIFIED BY THEIR $\Delta t$ (DAYS) WITH RESPECT TO PRIMARY MAXIMUM (SEE TABLE 1)

| $\lambda$ (Å) | Line | $\Delta t = -138^d$ | +21 | +116 | +162 | +196 | +389 | +402 | +876 | +1013 |
|---|---|---|---|---|---|---|---|---|---|---|
| 7088 ........ | O VI [a] | 30 | 0 | 14 | 27 | 46 | 31 | 44 | 15 | 11 |
| 7065 ........ | He I | 23 | 48 | 34 | 34 | 48 | 33 | 33 | 7 | 16 |
| 6825 ........ | O VI [a] | 67 | 0 | 41 | 55 | 100 | 65 | 63 | 37 | 38 |
| 6678 ........ | He I | 20 | 54 | 25 | 27 | 42 | 28 | 34 | 11 | 14 |
| 6563 ........ | H$\alpha$ | 1070 | 1700 | 925 | 1010 | 1500 | 994 | 1030 | 358 | 438 |
| 5876 ........ | He I | 23 | 84 | 32 | 37 | 58 | 40 | 43 | 11 | 15 |
| 5017 ........ | He I | 5 | 54 | 20 | 15 | 25 | 21 | 17 | 2 | 1 |
| 4922 ........ | He I | 6 | 42 | 13 | 12 | 18 | 12 | 10 | 2 | 3 |
| 4861 ........ | H$\beta$ | 162 | 484 | 115 | 183 | 245 | 187 | 182 | 61 | 64 |
| 4686 ........ | He II | 81 | 177 | 125 | 143 | 223 | 164 | 125 | 43 | 42 |
| 4471 ........ | He I | 4 | 21 | 6 | 10 | 15 | 7 | 7 | 3 | 7 |
| 4340 ........ | H$\gamma$ | 57 | 202 | 47 | 81 | 111 | 88 | 71 | 33 | 24 |
| 4101 ........ | H$\delta$ | 30 | 120 | 26 | 33 | 58 | 41 | 59 | 15 | 13 |

[a] Raman-scattered bands.

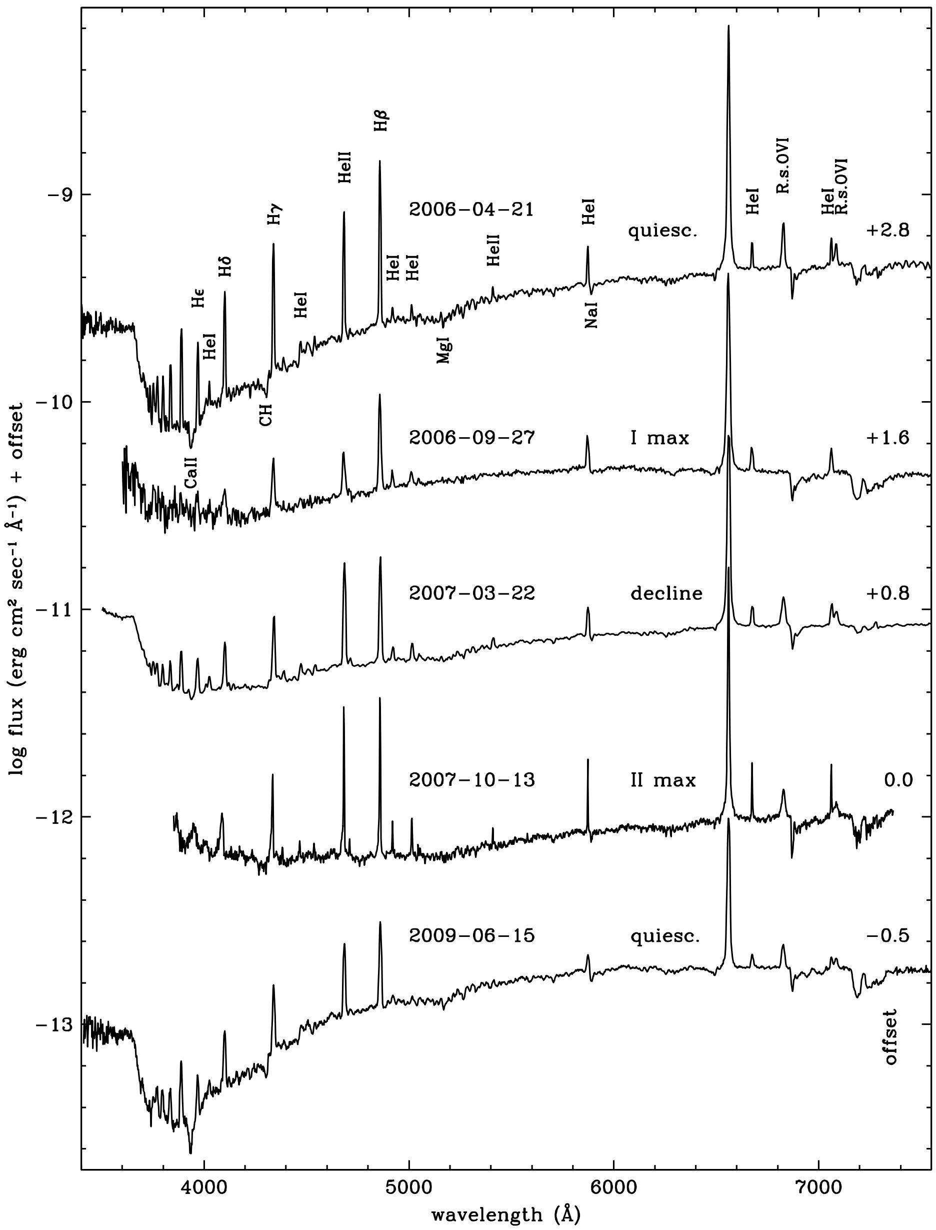


FIG. 2.—The spectroscopic evolution of the 2006–2008 outburst of AG Dra from our low-resolution, absolutely fluxed spectra. The spectra are offset for clarity by the quantity given at the far right.

## 3. OUTBURST EVOLUTION

The 2006–2008 outburst begun around 2006 mid-June and peaked at $U = 8.4$, $B = 9.0$, $V = 8.7$ around 2006 September, making it the brightest $U$-band event since the 1994 outburst that reached $U = 7.6$ mag. The rise time of 2.5 months is the same as for the 1994 event that originated a chain of at least other five maxima of decreasing brightness (Tomova & Tomov 1999; Leedjarv et al. 2004). A second, fainter maximum followed ~400 days after the primary one, peaking at $U = 9.1$, $B = 9.7$, $V = 9.0$ on 2007 October 7. Following the second maximum, AG Draconis resumed the decline toward quiescence, which was reached ~600 days after the primary maximum (cf. Fig. 1).

The outbursts of symbiotic stars are characterized by disappearance of high-ionization emission lines and emergence of a hot absorption spectrum, similar to an A/F supergiant, that overwhelms the cool star spectrum at blue optical wavelengths (Ciatti 1982). The A/F supergiant absorption spectrum is caused by the expansion of the pseudophotosphere around the outbursting white dwarf, that drives a drop in temperature and a shift to optical wavelengths of the emission peak.

TABLE 4
RADIAL VELOCITIES OF AG DRA LINES ON THE APO ECHELLE SPECTRUM OF 2006 OCTOBER 3

| Features | $V_r$ (km s$^{-1}$) | $\delta V_r$ (km s$^{-1}$) | Number of lines |
|---|---|---|---|
| $H_{Balmer}$ ...... | −115.4 | 2.9 | 5 |
| $H_{Paschen}$ ..... | −135.8 | 0.9 | 15 |
| He I ........ | −139.9 | 2.2 | 14 |
| He II ....... | −163.0 | 10.0 | 3 |
| [O III] ...... | −147 | ... | 1 |
| Fe II ........ | −148.5 | 3.5 | 14 |
| Mg II ....... | −144.0 | 1.0 | 2 |
| Si II ........ | −146.5 | 1.0 | 2 |
| Ti II ........ | −147.0 | 3.0 | 3 |

The outbursts experienced by AG Dra are of a different type, with the high ionization emission lines remaining present through the whole event (e.g., Viotti et al. 2005). The color evolution of the 2006–2008 outburst of AG Dra is consistent with a reinforced nebular continuum overwhelming the continuum of the cool giant. The emission lines increased their absolute flux by about 5 times, on average, with respect to quiescence (see Table 3 and top panel of Fig. 1), an amount similar to the increase in the $B$-band brightness. A similar enhancement of the emission measure of the nebular continuum was also recorded during previous outbursts (Tomova and Tomov 1999), as it occurred for the integrated flux of the emission lines (Tomov and Tomova 2002).

The disappearance of the symbiotic bands at 6825 and 7088 Å (Raman scattering by neutral hydrogen of the O VI 1032, 1038 Å doublet) at the time of primary maximum (cf. Fig. 2) could either indicate a decrease of the photospheric temperature (supported by the reduced He II/H$\beta$ emission ratio) or a decrease in the column density of scattering neutral hydrogen (supported by the much larger ionized fraction of the circumstellar hydrogen).

González-Riestra et al. (1999) identified two different types of outburst behavior affecting AG Dra: the *hot* type, during which the He II/H$\beta$ flux ratio keeps close to 1 and the O VI Raman-scattered bands remain strong, and the *cool* type, with He II/H$\beta$ reducing to 0.5 or less and the O VI Raman-scattered bands disappearing. During the 2006–2008 outburst, AG Dra went through both behaviors, the primary maximum being of the cool type and the second maximum of the hot type (cf. Fig. 2).

The high resolution spectrum of 2006 October 3 gives $-153.9 \pm 0.3$ km s$^{-1}$ as the velocity of the cool giant from measurement of 26 sharp absorption lines, mostly of Fe I. Our radial velocities of the emission lines are shown in Table 4. H I is represented by 4 Balmer lines and 15 Paschen lines. The latter show $V = -135.7 \pm 3.6$ km s$^{-1}$, while the Balmer lines yield $-115.3 \pm 2.9$ km s$^{-1}$. The discrepancy is probably due to the distortion of the Balmer line profiles by absorption from the metastable 2s level which may be overpopulated at low densities. Lines of He I show a velocity of $-139.8 \pm 2.2$ km s$^{-1}$. All the He I triplets have P Cygni profiles with absorption $-203.4 \pm 3.9$ km s$^{-1}$. Two singlets show P Cygni absorption with a velocity of $-189.7$ km s$^{-1}$ and a third singlet shows very weak absorption with a discrepant velocity. Two He II lines show a velocity of $-169$ km s$^{-1}$. Forbidden lines are very weak. Both [O III] lines at 5007 and 4363 Å seem to be present but with discrepant velocities, while the 4959 line is absent. The [S II] line at 4068 Å is strong, while its companion at 4076 Å is absent. No [Fe II] lines could be identified, though permitted lines of Mg II, Si II, Ti II, and Fe II are present.

A high-resolution spectrum by Viotti et al. (2003) during quiescence showed H and He I emission and 3 narrow absorption components of the Na D lines spanning from $-125$ to $-35$ km s$^{-1}$. We confirm their component at $-35$ km s$^{-1}$ with equivalent widths for D1 and D2 of 63 and 93 mÅ. It appears to be of interstellar origin. In fact, the equivalent width corresponds to a reddening of $E(B-V) = 0.027$ when the calibration by Munari & Zwitter (1997) is applied, and the Burstein & Heiles (1982) maps report $E(B-V) = 0.03$ for the AG Dra direction. Our other two components at $+12$ and $-157$ km s$^{-1}$ are probably due to circumstellar gas, as holds for some of the components of Viotti et al. (2003), and are associated with mass loss and gas streams.

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