AG CARINAE AND THE WR PHENOMENON IN LUMINOUS BLUE VARIABLES

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ABSTRACT. AG Car is a Luminous Blue Variable which recently evolved from AIe to Ofpe/WN9 in four years at about constant bolometric luminosity, while in the visual the star faded by two magnitudes. This change is probably associated with variable opacity of an unstable massive expanding envelope of a hot star. We discuss the main spectral features of the star and of its ring nebula, and the spectral variations.

1. Introduction

The galactic Luminous Blue Variable (LBV) AG Car is unique for assembling several interesting features, namely: (1) the light history typical of the Hubble-Sandage variables; (2) the peculiar emission line spectrum, and the large spectral variations; (3) the strong IR excess, and especially (4) the small ring nebula closely resembling the typical PNs. The light curve of AG Car shows irregular long term variations, with periods of minimum luminosity with $V > 8$, and rapid brightenings up to $V = 6$ (Mayall, 1969; Sharov, 1975). The star is also variable in the IR (Whitelock *et al.*, 1983). The large IR excess is attributed to f-f emission of a massive wind (Bensammar *et al.*, 1981; Lamers, 1987). A mass loss rate of $3 \cdot 10^{-5} M_{\odot} \cdot yr^{-1}$ was derived by Wolf and Stahl (1982) from the fit of the $H\beta$ scattering wings. Caputo and Viotti (1970) found that during 1949-1959 the optical spectrum varied between A1eq and B0eq.

In recent years, AG Car underwent large photometric and spectroscopic changes. Its visual magnitude gradually varied from $V = 6$ in 1981 to $V = 8$ in 1985 (Hutsemekers and Kohoutek, 1987), while there was an increase of the line excitation in the optical spectrum from Aeq in 1981 to Beq in 1983, and to Ofpe/WN9 in 1985 (Stahl, 1986; Viotti *et al.*, 1984; Wolf and Stahl, 1982). At maximum and during fading the UV spectrum was dominated by *FeII* lines which disappeared at minimum (Viotti *et al.*, 1989). The continuum slope became hotter with an increase of the far-UV flux (Viotti *et al.*, 1984). Actually, from the study of the IR-to-UV energy distribution Viotti *et al.* found that the recent large variations of AG Car occurred at almost constant bolometric magnitude of about −8.3. This 'WR-phase' of AG Car which is lasting since many years, is a useful tool to investigate the relation between LBVs and WR stars.

K. A. van der Hucht and B. Hidayat (eds.),
Wolf-Rayet Stars and Interrelations with Other Massive Stars in Galaxies, 499–504.

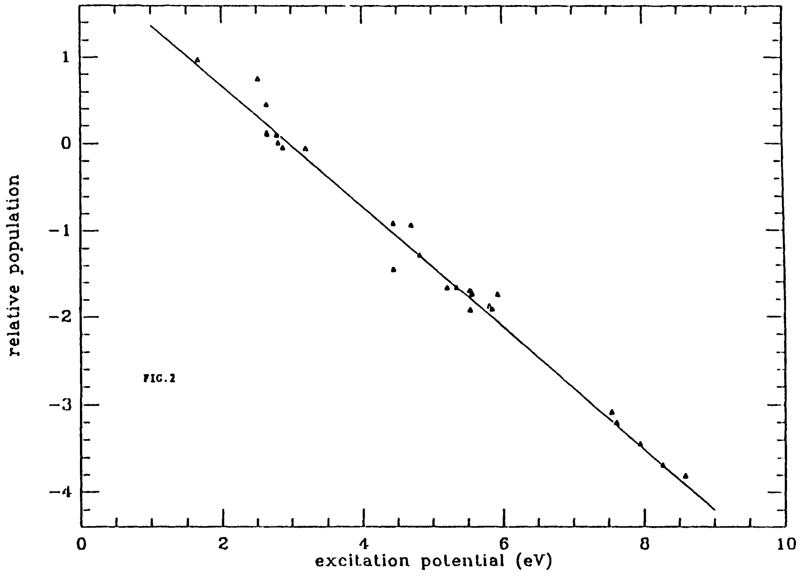

Figure 1a. The excitation of the *FeII* levels in the optical spectrum of AG Car in December 1981 ($V = 6$). The line corresponds to $T(ex) = 7200 \pm 350K$.

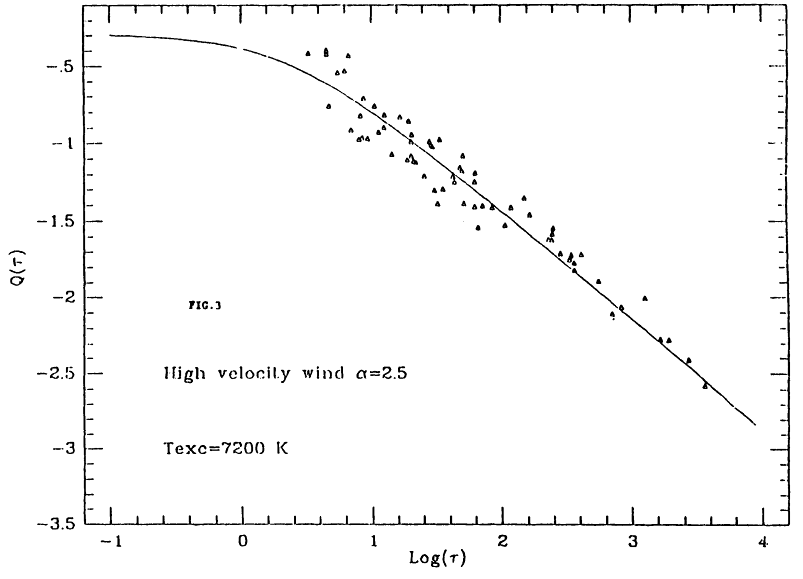

Figure 1b. The Self Absorption Curve for *FeII* in AG Car. The line points are fitted with a theoretical high velocity accelerated wind model.

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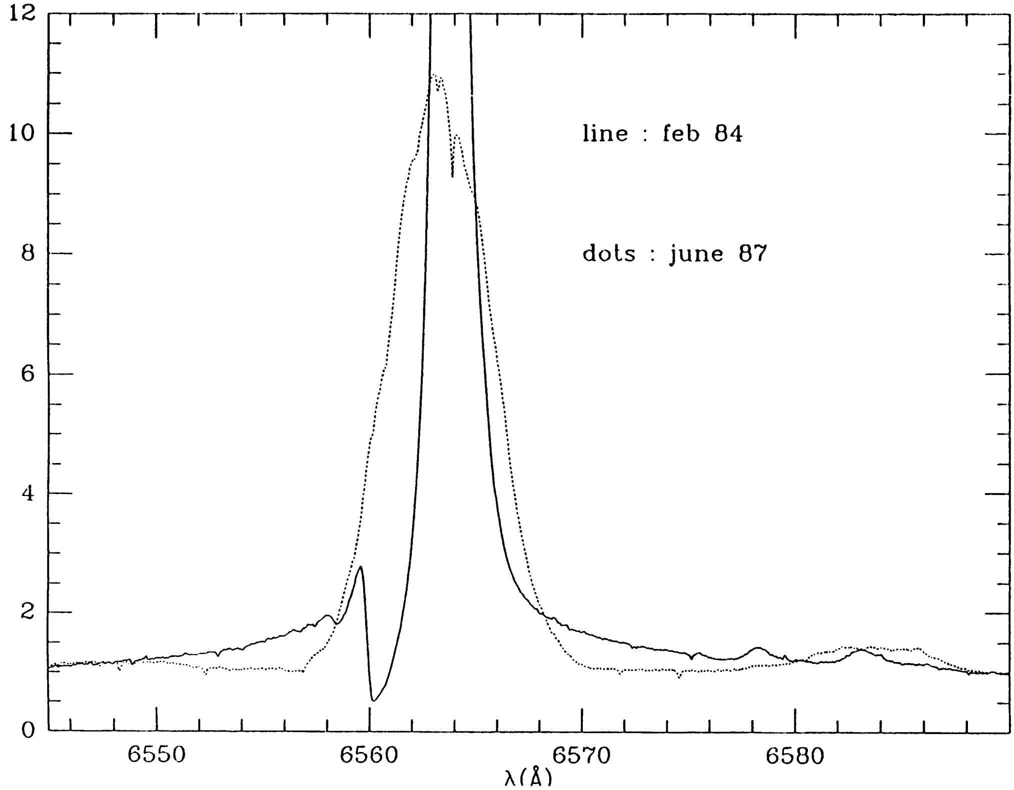

Figure 2. The high resolution profile of *H* in February 1984 and in June 1987 when AG Car was in the Be and Of/WN9 phases (ESO, CAT-CES).

2. The optical spectrum of AG Carinae

The optical spectrum of AG Car near maximum shows strong emissions of *H* and *FeII* with P Cygni profiles. We have analyzed the *FeII* emissions in the December 1981 spectrum using the Self Absorption Curve method (SAC) described by Friedjung and Muratorio (1987). Figure 1a shows the population of the *FeII* levels. A remarkable result is the fact that the level population follows a Boltzmann-type law from 1.6 to 8.6 eV, in spite of the fact that the lines are formed outside LTE. The corresponding mean excitation temperature is $7200 \pm 350K$. In Figure 1b the SAC of the *FeII* lines is fitted with a SAC model of an accelarated wind ($\alpha = 2.5$) with a wind velocity larger than the random volocity. It is also suggested that the *FeII* region is confined to a limited zone around the star.

During the fading phase of AG Car large profile variation was noted (Bandiera *et al.*, 1989). In February 1984 $H\alpha$ displayed a strong emission peak with a P Cygni absorption at about $-150\ km{\cdot}s^{-1}$ extending to $-180\ km{\cdot}s^{-1}$ (Figure 2). Broad scattering wings were present. At minimum the line was present with a broad (FWHM = 250 $km{\cdot}s^{-1}$) emission and no wings. Note the weak *CII* emissions in 1984, and the broad [*NII*] emission in 1987 (see Stahl, 1986). Broad wings were also present at maximum in the other Balmer lines and in the strongest $FeII$ emissions. These wings can be explained by electron scattering with $T_e = 9500 - 15000K$ and $\tau = 1.0$ for the Balmer lines, and $T_e = 7000K$ and $\tau = 0.5$ for the $FeII$ 5018Å line. This difference could be explained by line formation at different envelope depth. The fit of the $H\beta$ wings in February 1983 suggests $T_e = 19000K$ and $\tau = 1.8$.

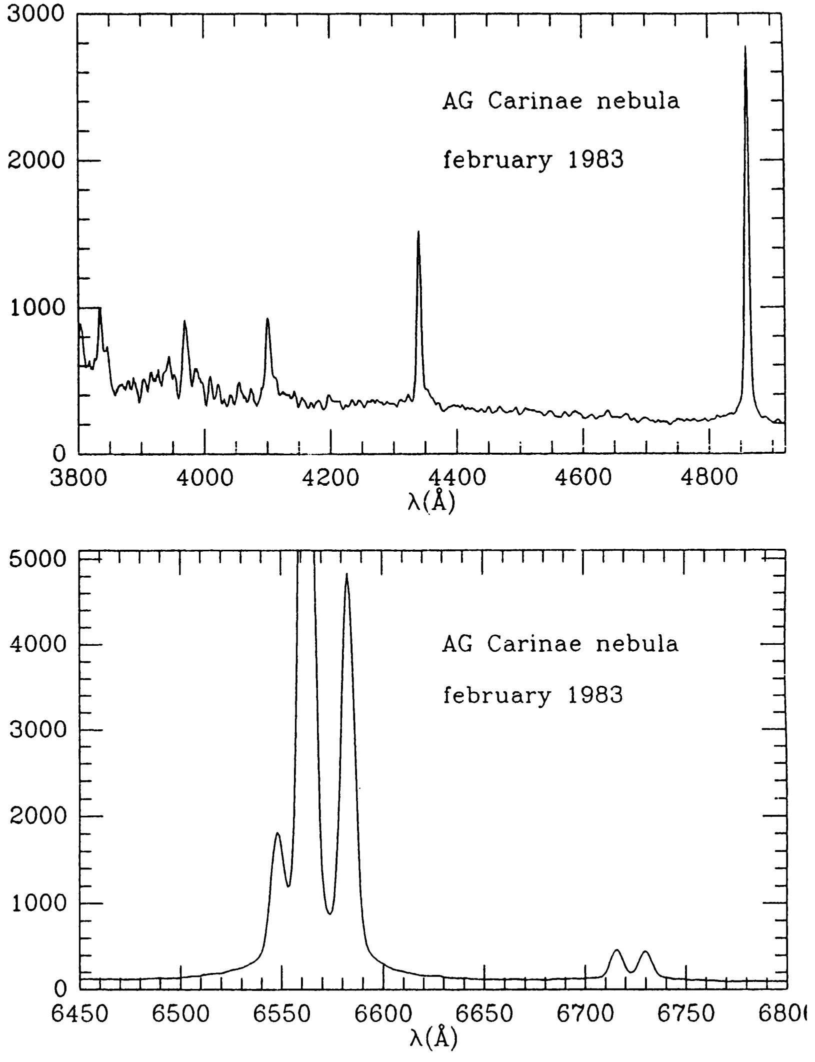

Figure 3. The low resolution optical spectrum of the AG Car nebula in February 1983 (ESO, 1.52 m telescope).

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3. The ring nebula

There are many examples of circumstellar nebulae associated with LBVs and WR stars, and AG Car is the most conspicuous one. From the study of its UV brightness Viotti *et al.* (1988) concluded that scattering by dust particles should be the main source of the UV radiation. The presence of cool dust in the nebula was confirmed by the Kuiper Airborne observations of McGregor *et al.* (1988). We have observed the optical spectrum of a bright part of the nebula 15″ to NE) in February 1983, and found a rather low excitation spectrum with strong Balmer lines, and weak emissions of HeI, $[NII]$, $[SII]$, and $FeII$ (Figure 3). The Balmer decrement, when compared with case B emission, suggests a colour excess of $E(B-V) = 0.60$. The spectrum is similar to that observed one year later (when the star was 0.6 *mag* fainter) by Mila Mitra and Dufour (1990). They found N/O and N/S ratios higher than in nearby HII regions. Recent coronographic observations of Paresce and Nota (1989) revealed the presence of bipolar and helical structures in the nebula, possibly associated with asymmetric mass ejection from the central object.

4. Conclusions

Table 1 summarizes the main data on AG Car. AG Car well probably is an evolved massive star with a hot core surrounded by an extended envelope produced by its large mass outflow. At the maximum the expanding envelope is opaque to the UV photons from the core, so that the emerging spectrum is that of a P Cygni Ae or Be star with an effective temperature around $10000K$. After 1981 the envelope was gradually ionized and became more transparent, so that the effective radius decreased by about a factor ten, while the effective temperature increased to more than $30000K$. The star now displays WR features but with a low expansion velocity close to the wind velocity at maximum. The origin of this evolution of AG Car is still uncertain. The unstable structure of the envelope probably has a crucial role, but we cannot anticipate how long the present high temperature phase will last. The asymmetry of the mass outflow and the bipolar structure of the nebula could suggest the presence of a binary system, which is however difficult to support observationally. The dust in the nebula should have been produced some thousand years ago, possibly during an 'η' Car phase of the star. As suggested by Viotti (1987) a consistent increase of the mass loss rate could produce a drastic cooling of the envelope, or of some parts of it, even below dust condensation temperature and give rise to dust formation. In this regard, it would be important to investigate the chemical anomalies of the star and of its nebula which are similar to those of η Car itself.

Table 1. Basic data on AG Car (period 1981 to 1987)

Visual magnitude	6 to 8	Hutsemekers and Kuhoutek, 1987
Spectral type	1981 AOIeq	Wolf and Stahl, 1982
	1983 B Ieq	Viotti *et al.*, 1984
	1985 Ofpe/WN9	Stahl, 1986
$E(B-V)$	0.60 ±0.05	Viotti *et al.*, 1984
distance	2500 *pc*	Bensammar *et al.*, 1981
$M(bol)$	-8.3 ±0.3	Viotti *et al.*, 1984
mass loss	$3 \cdot 10 - 5 M_{\odot} y^{-1}$	Wolf and Stahl, 1982

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DISCUSSION

Barlow: A comment about the $HeI5876$ profile you showed. You interpreted the edge 250 $km{\cdot}s^{-1}$ as a terminal velocity. It is now being argued that in the UV the edge velocities are influenced mainly by shocks and turbulences in the wind, and it is a deep black absorption edge that really gives the terminal velocity. By analogy, one might argue that it is the deepest point in that absorption profile which corresponds to terminal velocity, and it is about just over 200 $km{\cdot}s^{-1}$ which is very similar to what the $[FeII]$ lines give at other epoches.

Niemela: How did you determine that AG Car is member of Car OB2?
Baratta: There are at least two reasons to believe that AG Car belongs to the Key-Hole Nebula complex. First, because this complex includes many peculiar luminous stars (in particular η Car), and AG Car is a nearby peculiar luminous star. In addition, the radial velocity of the interstellar lines is nearly the same. The recent suggestion of a larger distance of 6 kpc (instead of 2.5 kpc), is essentially based on the theoretical (and questionable) need of a higher luminosity for this LBV star.