

## Lifting the Iron Curtain: Toward an Understanding of the Iron Stars XX Oph and AS 325

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**ABSTRACT.** We present new optical, near-infrared, and archival ultraviolet observations of XX Ophiuchi and AS 325, two proposed “iron” stars. These unusual stars have optical spectra dominated by emission lines arising from hydrogen, as well as ionized metals such as iron, chromium, and titanium. Both stars have been classified as “iron” stars, and a number of exotic models have been presented for their origin. Using 2 years of moderately high resolution optical spectroscopy, the first high signal-to-noise ratio *K*-band spectroscopy of these sources (which reveals stellar photospheric absorption lines), and new near-infrared interferometric observations, we confirm that both systems are composed of two stars, likely binaries, containing a hot Be star with an evolved late-type secondary. The hydrogen emission features arise in the hot wind from the Be star, while the corresponding P-Cygni absorption lines are produced from dense material in the expanding, radiation-driven wind around each system. The optical Fe II emission lines are pumped by ultraviolet Fe II absorption lines through fluorescence. Contrary to some claims in the literature, the spectral features of XX Oph and AS 325 are quite similar, evidence that they are comparable systems. We examine the variability of the spectral morphology and radial velocity motions of both sources. We also study the variability of XX Oph during a major photometric event and find that the spectral nature of the system varies during the event. A comparison of the velocity of the absorption-line components in our new spectra with those in the literature show that the structure of the stellar wind from XX Oph has changed since the system was observed in 1951.

### 1. INTRODUCTION

XX Ophiuchi was noted to be peculiar with its classification as an “iron” star at the beginning of the 20th century (Merrill 1924). Using photographic spectra, Merrill (1951) found 577 emission features between 3600 and 6500 Å, only 10 of which he did not identify. The lines consist primarily of hydrogen and ionized metals, such as Fe II, Cr II, and Ti II, with some contribution from V II, Sc II, and Ni II. While the peculiar nature of this star was emphasized, no explanation was offered for the origin of the emission in the system.

Goswami et al. (2001) obtained high-resolution spectra of XX

Oph over a year-long baseline and found that the emission lines exhibit peculiar variabilities compared to the original observations used to classify the system as an “iron” star in 1924. While no firm conclusion about the physical nature of the star was drawn, the authors suggest the structure and mass loss in XX Oph can be explained through a binary interaction. De Winter & The (1990) argue that the presence of Balmer and He I absorption indicates that the system contains a B0–B1e primary and that a near-infrared excess arises because of the presence of an M6 III secondary. These claims are backed by the presence of strong Fe II absorption against an underlying continuum in the UV (Michalitsianos et al. 1991) and the presence of TiO bands in the near-infrared (Humphreys & Gallagher 1977). Evans (1994) discovered signatures of polycyclic aromatic hydrocarbons (PAHs) in the stellar atmosphere, which suggest that an

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TABLE 1  
TABLE OF OBSERVATIONS

Object	Number of Spectra	Date	Observatory	Spectral Range (Å)
XX Oph .....	1	1984 Aug 26	<i>IUE</i> (SWP 23783)	1150–1980
HD 876423 .....	1	1985 May 23	<i>IUE</i> (SWP 26040)	1150–1980
AS 325 .....	1	1990 Mar 24	<i>IUE</i> (SWP 38427)	1150–1980
XX Oph .....	2	2003 Jun 10	Coudé	6300–9000
AS 325 .....	2	2003 Jun 10	Coudé	6300–9000
XX Oph .....	2	2003 Jul 4	Coudé	3800–5100
AS 325 .....	3	2003 Jul 4	Coudé	3800–5100
XX Oph .....	2	2003 Jul 5	Coudé	6300–9000
AS 325 .....	2	2003 Jul 5	Coudé	6300–9000
XX Oph .....	1	2003 Jul 7	Coudé	6300–9000
AS 325 .....	2	2003 Jul 7	Coudé	6300–9000
XX Oph .....	13	2003 Jul 8	Coudé	6300–9000
AS 325 .....	13	2003 Jul 8	Coudé	6300–9000
XX Oph .....	1	2003 Oct 10	UKIRT	15000–25000
AS 325 .....	1	2003 Oct 10	UKIRT	15000–25000
AS 325 .....	1	2004 May 27	Bok	3500–4500
Nearby Stars <sup>a</sup> .....	8	2004 May 27	Bok	3500–4000
Blank Sky .....	1	2004 May 28	Bok	3600–5000
Nearby Stars <sup>a</sup> .....	6	2004 May 27	Coudé	3800–5100
XX Oph .....	1	2004 Jun 25	Coudé	5200–6600
AS 325 .....	1	2004 Jun 25	Coudé	5200–6600
AS 325 .....	2	2004 Jun 26	Coudé	6300–9000
AS 325 .....	1	2004 Jun 28	Coudé	3800–5100

<sup>a</sup> Table 4 lists the neighboring stars observed during these nights individually.

inferred cool component to XX Oph is either carbon rich or oxygen rich, with an external source of PAH formation. XX Oph is a photometric variable as well. The star has historically had intermittent 1 mag drops in its optical flux, lasting several years (Prager 1940). In 2004 March, the flux of the star decreased by 1.5 mag, reaching its faintest state in 37 yr (Sobotka 2004). No clear correlation between the spectral and photometric variability has been found; XX Oph experienced a photometric minimum between 1921 and 1922, with no accompanying spectral variations (Merrill 1924).

The spectral similarities of the stars AS 325 and XX Oph were first noted by Bopp & Howell (1989). The spectra of both stars show strong hydrogen emission lines as well as emission from ionized metals; neither star has a normal stellar continuum in the optical. While XX Oph has a diverse history in the literature, AS 325 has received much less attention. It was assigned a spectral type of A7 Ia+ pec in the Stock & Wroblewski (1972) spectral survey, and type F based on strong Ca II absorption noted by Sanduleak & Stephenson (1973). Munari & Zwitter (2002) tentatively classified AS 325 as a symbiotic star or related object. The similarity of these two stars spawned the possibility that they are two examples of one type of object. Pereira et al. (2003) claim to see a rising blue continuum in AS 325 and argue that this distinct difference from XX Oph indicates the two stars are not similar.

No past study has successfully attempted to consistently interpret all of the observed properties of these two systems

across a range of wavelengths. Also, the few infrared observations of these stars have not been used to constrain any possible models of their nature. In this paper, we present new high-resolution optical spectra, high signal-to-noise ratio (S/N) near-infrared spectra, and archival *International Ultraviolet Explorer* (*IUE*) spectra of XX Oph and AS 325 and use these observations to create one cohesive picture of these peculiar systems. In § 2, we present the data used in our analysis. We discuss our findings in § 3, before concluding in § 4.

## 2. DATA

Table 1 lists all of the observations used in the analysis presented here. The details of the observations are summarized in the following sections, according to the telescope used for the measurements.

### 2.1. Kitt Peak Coudé Feed Telescope

Spectra of each of the “iron” stars, as well as a sample of neighboring stars, were obtained with the Kitt Peak National Observatory Coudé Feed Spectrograph between 2003 June 10 and 2004 June 28. Each of the “iron” stars were observed in three configurations; a “blue” setup was used to observe the 3800–5100 Å range, an intermediate “green” setting was used to study the spectrum between H $\alpha$  and H $\beta$  (4650–7000 Å), and a “red” configuration, including H $\alpha$  and the Paschen limit, covered the spectral range 6300–9000 Å. The spectral resolution

for each of these configurations was 1–2 Å, and the spectra were generally obtained as back-to-back pairs of 300 s exposures, which were combined to reject cosmic rays. A sample of stars near both XX Oph and AS 325 was observed with the blue configuration in order to search for spectral features similar to the two main stars of interest. Data reduction, including bias and overscan subtraction, flat-fielding, wavelength calibration, and flux calibration, was completed using standard packages in the Image Reduction and Analysis Facility (IRAF).

## 2.2. Bok 2.3 m Telescope

Spectra of stars located spatially near XX Oph and AS 325, a deep spectrum of the blank sky near XX Oph, and a spectrum of AS 325 were obtained with the Boller and Chivens spectrograph on the Bok 2.3 m Telescope operated by Steward Observatory. The stellar spectra span 3500–4500 Å with a spectral resolution of 2 Å, while the blank-sky spectrum covered 3350–5500 Å with 3 Å resolution. Bias subtraction, flat-fielding, wavelength calibration, and flux calibration were completed using the iSPEC package developed for IDL by J. Moustakas. iSPEC not only provides a robust calibration and extraction routine for long-slit spectra, but also maintains the error on each measurement throughout the reduction process, resulting in a fully calibrated spectrum with meaningful errors on each pixel.

## 2.3. United Kingdom Infrared Telescope

Near-infrared spectra of XX Oph and AS 325 were obtained with the UIST spectrograph on the United Kingdom Infrared Telescope (UKIRT) on 2003 October 10. UIST<sup>2</sup> is a 1–5 μm imager-spectrometer with a 1024 × 1024 InSb array and a number of grisms and slits available. Our single spectra used the *HK* grism and a long slit 0".48 wide at a plate scale of 0".12 pixel<sup>-1</sup>. This combination yielded a spectral resolution of  $R = 800\text{--}1000$  ( $\sim 330\text{ km s}^{-1}$ ) across the 1.4–2.5 μm region. The spectra were flux calibrated and telluric corrected in the normal way using spectral standard stars observed near in time and air mass to each of the program objects. At this spectral resolution, we cannot obtain meaningful velocity information, but the spectra were key to our detection of the stellar photosphere of the cool star in each system.

## 2.4. International Ultraviolet Explorer

Ultraviolet spectra of XX Oph (SWP 23783), AS 325 (SWP 38427), and a comparison star, HD 87643 (SWP 26040), were taken from the *IUE* archive through the Multimission Archive at the Space Telescope Science Institute (MAST). Each of these spectra were obtained in low-dispersion mode ( $R \sim 270$ ) with the SWP camera and span the range 1150–1980 Å. The stars were observed with a 10" × 20" aperture. Multiple observa-

tions are available in the archive for each of the stars; we present the spectra with the longest exposure times. The spectra of XX Oph and HD 87643 have been previously published, although for different purposes (Michalitsianos et al. 1991; de Freitas Pacheco et al. 1982); the spectrum of AS 325 is previously unpublished.

## 3. RESULTS AND DISCUSSION

### 3.1. Optical Emission

Representative optical spectra of XX Oph and AS 325 are shown in Figures 1 and 2, respectively. The spectrum of each star is dominated by hydrogen emission from the Balmer and Paschen series as well as ionized metal emission lines. In AS 325, the metal emission lines are weaker than those in XX Oph. These emission lines are accompanied by Balmer absorption lines blueshifted from the emission lines in classical P-Cygni profiles. XX Oph shows P-Cygni profiles in He I, while AS 325 contains absorption due to Ca II H+K and Na I, with no accompanying emission. P-Cygni profiles are visible in all of the Balmer lines except H $\alpha$ , which shows no clear absorption component. The line profile of H $\alpha$  is quite asymmetric, in agreement with past studies in the literature (Merrill 1951; Goswami et al. 2001); the blue wing of the absorption line is truncated at the position of the expected absorption component. The lack of a clear absorption component probably indicates that the H $\alpha$  line is optically thick, allowing repeated scattering to obscure the absorption component, while the higher energy Balmer lines are optically thin. Table 2 lists identifications for some of the prominent lines in each of the stars, based on the same spectra shown in Figures 1 and 2; the observed wavelengths listed in the table are based on a single observational epoch. Pereira et al. (2003) suggest that AS 325 possesses a strong blue continuum. We find no strong blue continuum in any of our AS 325 spectra, including spectra taken with different instrumental configurations that were reduced independently using different reduction software. The similarities between XX Oph and AS 325 are striking and are a strong indication that the radiative mechanisms in these two stars share common physical processes.

It should be noted that the spectral fluxes between each panel in Figures 1 and 2 show some variations. In both stars, the “green” spectra, which were taken nearly a year later than the other spectra presented, appear offset from the “red” and “blue” observations. In XX Oph, this difference agrees well with the photometric variability of the star (the “green” spectrum was obtained while the system was 1.5 mag fainter than during previous observations), an indication that the flux normalization is not largely in error. In AS 325, the flux differences can be explained by photometric variability associated with the system (although we do not have photometric observations of this star to confirm this) or they may be associated with variable seeing, transparency, and sky conditions. It should also be noted that AS 325 exhibits strong variability in its emission-line charac-

<sup>2</sup> See <http://www.jach.hawaii.edu/UKIRT/instruments/uist/uist.html>.

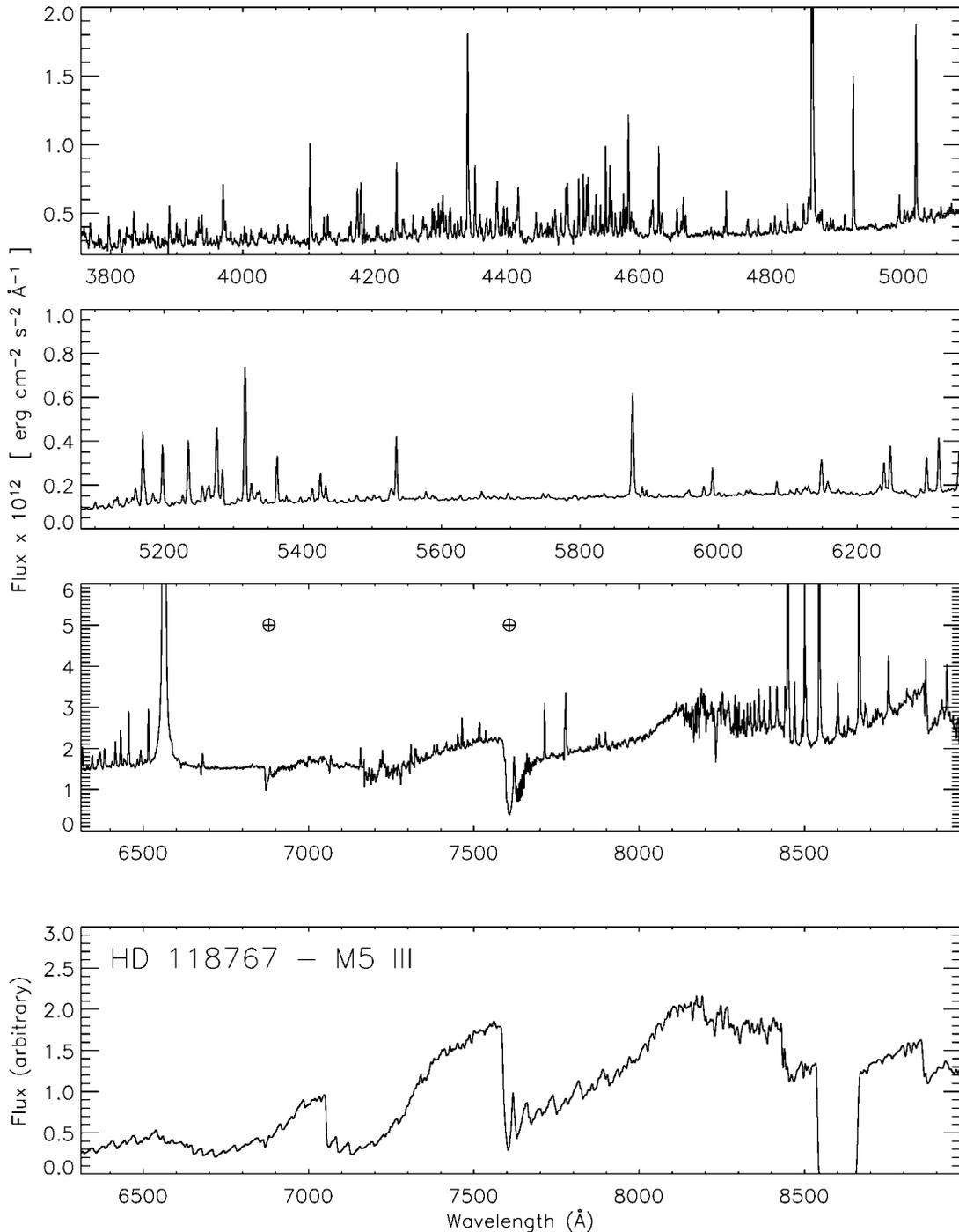


FIG. 1.—Optical spectrum of the star XX Ophiuchi and a comparison star of similar spectral type. The strong absorption bands located in the red spectrum (and marked with the  $\oplus$  symbol) are telluric bands in the Earth's atmosphere and not inherent to the source. It should be noted that the spectra were taken at different epochs. While the red and blue spectra were taken on 2003 July 5 and 2003 July 4, respectively, the green spectrum was taken on 2004 June 25. The bottom panel shows an M5 III star, similar to our infrared determined M5 II classification, from the UVES high-resolution library of stars, which has been convolved to our resolution. The complex emission structure in the optical makes a direct comparison of the two spectra difficult, but there is a correspondence between the red continuum shape of the comparison star and that of XX Oph. The sharp feature near 8600 Å in the comparison spectrum is a region of missing data, not a true feature.

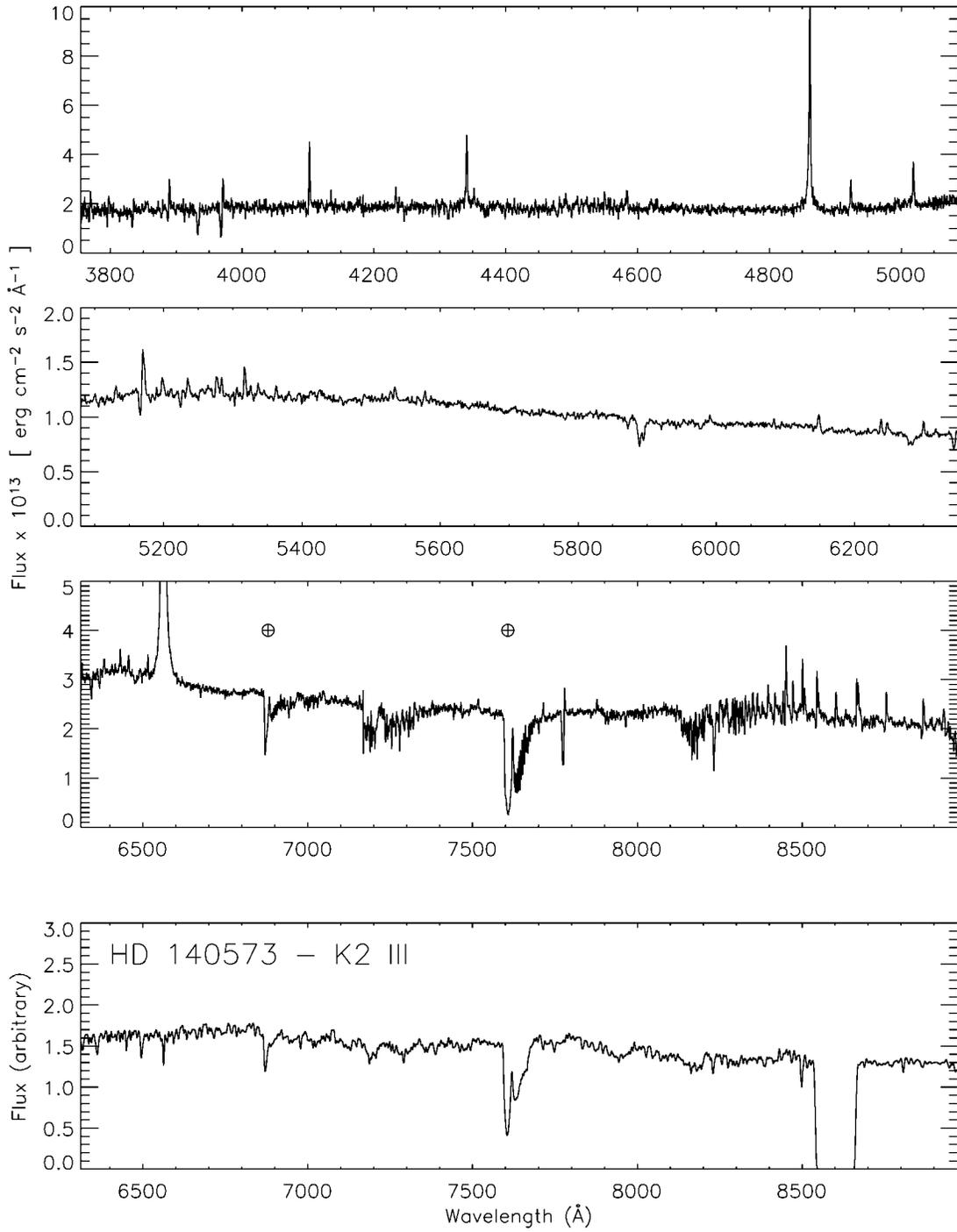


FIG. 2.—Same as Fig. 1, but for the star AS 325 and a comparison K2 III star.

TABLE 2  
 PROMINENT SPECTRAL LINES IN XX Oph AND AS 325

$\lambda_{\text{lab}}$ (Å) (1)	SPECIES (2)	LINE TYPE (3)	$\lambda_{\text{obs}}$		$\lambda_{\text{lab}}$ (Å) (1)	SPECIES (2)	LINE TYPE (3)	$\lambda_{\text{obs}}$	
			XX Oph (4)	AS 325 (5)				XX Oph (4)	AS 325 (5)
3771.74	H	A	3768.30	3768.80	4385.39	Fe II	E	4384.57	...
3771.74	H	E	3770.39	3770.44	4391.03	Ti II	E	4390.48	...
3786.32	Ti II	E	3785.49	...	4395.03	Ti II	E	4394.58	...
3799.02	H	A	3795.52	3795.63	4399.77	Ti II	E	4399.47	...
3799.02	H	E	3798.23	3799.71	4411.07	Ti II	E	4410.51	...
3814.12	Fe II	E	3813.37	...	4413.78	Fe II	E	4413.14	...
3819.60	He I	A	3817.67	...	4416.83	Fe II	E	4416.39	...
3819.60	He I	E	3819.83	...	4432.45	Fe II	E	4431.78	4432.72
3824.93	Fe II	E	3824.18	...	4443.79	Ti II	E	4443.46	...
3827.08	Fe II	E	3826.64	...	4457.94	Fe II	E	4457.74	...
3833.70	He I	A	3833.28	...	4464.45	Ti II	E	4463.97	4464.48
3833.70	He I	E	3834.21	...	4468.51	Fe II	E	4468.18	...
3836.52	H	E	3838.20	3836.82	4468.51	Ti II	E	4468.61	...
3888.60	He I	A	3886.98	...	4472.93	Fe II	E	4472.49	4472.63
3888.60	He I	E	3888.10	...	4489.18	Fe II	E	4488.70	4488.56
3890.20	H	E	3888.90	3889.64	4491.40	Fe II	E	4490.90	4491.15
3900.55	Ti II	E	3900.12	...	4501.27	Ti II	E	4500.76	...
3906.03	Fe II	E	3905.23	...	4515.34	Fe II	E	4514.89	4514.98
3914.50	Fe II	E	3913.92	3914.33	4520.22	Fe II	E	4519.72	4520.00
3933.66	Ca II	A	...	3932.64	4522.63	Fe II	E	4522.22	4522.65
3938.97	Fe II	E	3938.24	...	4529.47	Ti II	E	4528.71	4529.13
3968.47	Ca I	A	...	3967.62	4533.97	Ti II	E	4533.68	4534.23
3971.24	H	A	3967.07	3968.73	4534.17	Fe II	E	4533.70	4534.69
3971.24	H	E	3970.06	3970.62	4539.60	Cr II	E	4539.01	4539.88
3974.17	Fe II	E	3973.90	...	4541.52	Fe II	E	4541.20	...
3987.60	Ti II	E	3987.21	...	4549.47	Fe II	E	4549.07	4549.58
4025.13	Ti II	E	4024.82	...	4549.62	Ti II	E	4549.61	4549.94
4054.08	Cr II	E	4053.74	...	4555.89	Fe II	E	4555.44	4555.76
4102.94	H	A	4099.79	4100.37	4558.65	Cr II	E	4558.18	4558.57
4102.94	H	E	4101.71	4102.14	4563.76	Ti II	E	4563.35	4563.77
4122.67	Fe II	E	4122.43	...	4571.97	Ti II	E	4571.40	...
4124.79	Fe II	E	4124.59	...	4576.34	Fe II	E	4575.93	4576.03
4128.75	Fe II	E	4128.15	...	4583.84	Fe II	E	4583.31	4583.83
4161.54	Ti II	E	4161.03	4161.51	4588.20	Cr II	E	4587.85	4588.09
4173.46	Fe II	E	4173.15	...	4589.90	Cr II	E	4589.44	...
4178.86	Fe II	E	4178.48	4178.88	4589.96	Ti II	E	4589.39	...
4233.17	Fe II	E	4232.77	4232.97	4592.05	Cr II	E	4591.58	...
4251.44	Fe II	E	4250.60	...	4616.63	Cr II	E	4616.19	...
4258.15	Fe II	E	4257.73	4257.88	4618.80	Cr II	E	4618.25	...
4273.33	Fe II	E	4272.73	...	4620.52	Fe II	E	4620.03	4620.68
4287.39	Fe II	E	4287.01	...	4629.34	Fe II	E	4628.85	4629.04
4287.87	Ti II	E	4287.71	...	4634.07	Cr II	E	4633.94	...
4290.22	Ti II	E	4289.70	4290.13	4635.32	Fe II	E	4635.30	4634.21
4294.10	Ti II	E	4293.68	4294.01	4639.67	Fe II	E	4639.04	...
4296.57	Fe II	E	4296.02	...	4656.98	Fe II	E	4656.47	...
4300.05	Ti II	E	4299.33	4299.76	4657.21	Ti II	E	4656.47	...
4303.18	Fe II	E	4302.56	4303.12	4666.76	Fe II	E	4666.27	...
4305.89	Fe II	E	4305.15	...	4670.18	Fe II	E	4669.62	...
4307.86	Ti II	E	4307.21	4307.65	4697.60	Cr II	E	4697.03	...
4320.96	Ti II	E	4320.21	4320.98	4708.67	Ti II	E	4708.29	...
4330.69	Ti II	E	4329.96	...	4713.16	He I	A	4711.33	...
4341.74	H	A	4337.95	4338.75	4713.16	He I	E	4712.91	...
4341.74	H	E	4340.14	4340.59	4720.15	Fe II	E	4719.22	...
4346.85	Fe II	E	4346.06	...	4728.07	Fe II	E	4727.57	4727.87
4351.77	Fe II	E	4351.22	4351.56	4731.45	Fe II	E	4731.02	...
4359.33	Fe II	E	4358.63	...	4745.48	Fe II	E	4745.00	...

4367.66	.....	Ti II	E	4367.05	...	4772.06	.....	Fe II	E	4771.35	...
4369.41	.....	Fe II	E	4368.75	...	4774.72	.....	Fe II	E	4774.01	...
4374.81	.....	Ti II	E	4374.10	4375.50	4779.98	.....	Ti II	E	4779.44	...

teristics, possibly associated with an increased mass-loss rate (see § 3.7), which could, in turn, result in a drop in the continuum level seen in the spectra. While the reason for the flux discrepancies may be astrophysical or observational, none of the results presented here are dependent on the absolute normalization of the spectra, and thus it does not affect our analysis.

The metal emission lines, hydrogen emission lines, and Balmer absorption lines all occur at different velocities in the spectra of the two stars. Table 3 quantifies the velocities for each species in both systems. The velocities of each of the strong features of a given species are averaged to construct the ensemble velocity of that species. The reported values are the average velocities measured from data spanning several nights of observations; typical dispersion around the mean was  $80 \text{ km s}^{-1}$ , giving an estimate of the average error in our velocity determinations. As noted by the referee, averaging velocities measured on lines of very different strengths may lead to a biased estimate of the average velocity, as less opaque lines may be formed in different layers of the wind compared to more optically thick ones. To minimize this effect, we only use the four strongest Balmer lines as an estimate of the hydrogen emission-line velocity. For the metal species, which also exhibit lines of various strengths, we only use the brightest 20% of the lines to determine the average velocity. The velocity structure for both systems is similar; the absorption lines are the most blueshifted, with the hydrogen emission lines, metal lines, and Ca II and O I lines being shifted progressively less to the blue.

### 3.2. Environment

Figure 3 illustrates the environment of each star from the Wisconsin H $\alpha$  Mapper (WHAM; Haffner et al. 2003). Both of these stars appear to reside in regions of enhanced hydrogen emission in our Galaxy. The WHAM kinematic data show the H $\alpha$  emission toward XX Oph (AS 325) occurs at  $2.4 \pm 11.8$  ( $17.5 \pm 27.02$ )  $\text{km s}^{-1}$ . While the velocities of the interstellar gas are inconsistent with the Balmer emission-line velocities measured in the two “iron” stars, the velocities of the metals are consistent within the measurement errors. It is possible that the emission signatures in these two stars are not localized near the stars, but instead originate in extended regions along our line of sight to them (i.e., arising from a phenomena associated with the ISM alone). In order to probe this possibility, we obtained spectra of several similarly bright stars in the vicinity of the two “iron” stars of interest. Table 4 lists the properties of the stars chosen for these observations. None of these stars shows any sign of the emission features noted in the spectra of XX Oph and AS 325.

The absence of emission-line features in neighboring stars may simply indicate that stars chosen for comparison are all

projected in front of the origin of the peculiar emission. If the emission features we find in both XX Oph and AS 325 arise in an extended nebular region, a deep spectrum of nearby blank sky would reveal emission features similar to those seen in each of the “iron” stars. A 1200 s exposure of the sky near XX Oph obtained at the Bok 2.3 m Telescope on Kitt Peak revealed no emission due to metal lines. This indicates that the cause of the unusual spectra of AS 325 and XX Oph is intrinsic to the two systems and does not simply arise from unrelated phenomena along our line of sight to the stars.

### 3.3. Spectral Types

The optical spectra of both XX Oph and AS 325 are quite complex and do not resemble typical spectra, making any precise determination of the spectral type of the underlying stars difficult. Observations at other wavelengths, however, can help explain the nature of these peculiar systems. It has been noted previously that the far-ultraviolet spectrum of XX Oph shows strong absorption due to Fe II (Michalitsianos et al. 1991). The presence of strong ultraviolet flux from XX Oph indicates that it must have a hot component, suggested to be a Be star in other analyses (Lockwood et al. 1975; de Winter & The 1990). In the optical, the high reddening ( $A_V = 1.6\text{--}4.0$ , depending on the analysis; Evans et al. 1993; Lockwood et al. 1975) obscures the blue continuum, hiding the star. Figure 4 shows the ultraviolet spectra of XX Oph, AS 325, and HD 87643, a Be star (de Freitas Pacheco et al. 1982), taken from the *IUE* archive. The three spectra look quite similar—all have strong signs of absorption due to Fe II and Al III, with weaker absorption from Fe III. The similarity between the three spectra indicates that the stars are likely quite similar; XX Oph and AS 325 *both* likely have Be components.

Our near-infrared *K*-band spectra of these two stars are shown in Figure 5, while Figure 6 shows the CO region of both stars in greater detail. While a detailed analysis of the infrared features of these stars will be presented in a later paper (including near-infrared integral field spectroscopy from 1.2 to  $5 \mu\text{m}$  of the two stars and a previously unpublished *Infrared Space Observatory* spectrum), these *K*-band spectra reveal the underlying stellar properties of the red stars in the systems and deserve mention here. The spectra are dominated by emission lines from the Brackett series and Paschen  $\alpha$  in their blue regions. Redward of  $2.2 \mu\text{m}$ , the stellar photosphere finally reveals itself, showing absorption due to  $^{12}\text{CO}$ , Na I, Ca I, and  $^{13}\text{CO}$ , a signature of evolved late-type stars. We compare our *K*-band spectra with the stellar atlas of Wallace & Hinkle (1997) to determine the approximate spectral type of the cool component in each system. While the spectra in this catalog do not cover all spectral types and luminosity classes, a fair evaluation

TABLE 2 (Continued)

$\lambda_{\text{lab}}$ (Å)	SPECIES	LINE TYPE	$\lambda_{\text{obs}}$		$\lambda_{\text{lab}}$ (Å)	SPECIES	LINE TYPE	$\lambda_{\text{obs}}$	
			XX Oph	AS 325				XX Oph	AS 325
(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
4798.27	Fe II	E	4797.95	4798.57	5425.26	Fe II	E	5425.28	5425.90
4798.52	Ti II	E	4798.00	...	5433.13	Fe II	E	5433.19	...
4805.08	Ti II	E	4804.51	...	5465.93	Fe II	E	5466.59	...
4812.34	Cr II	E	4811.75	...	5477.24	Fe II	E	5477.48	5477.01
4814.53	Fe II	E	4813.74	...	5493.83	Fe II	E	5492.85	...
4824.13	Cr II	E	4823.76	...	5502.07	Cr II	E	5502.39	...
4833.20	Fe II	E	4832.57	...	5527.61	Fe II	E	5527.41	5527.99
4836.23	Cr II	E	4835.60	...	5534.85	Fe II	E	5535.03	5534.66
4840.00	Fe II	E	4839.06	...	5544.76	Fe II	E	5544.14	...
4848.23	Cr II	E	4847.87	...	5586.90	Fe II	E	5587.08	5586.71
4856.19	Cr II	E	4855.54	...	5627.25	Fe II	E	5627.22	5628.60
4862.74	H	A	4858.39	4859.50	5746.97	Fe II	E	5746.79	...
4862.74	H	E	4861.09	4861.27	5813.68	Fe II	E	5813.31	...
4874.01	Ti II	E	4873.45	4873.55	5823.15	Fe II	E	5822.79	...
4874.48	Fe II	E	4874.21	...	5835.45	Fe II	E	5835.25	5834.91
4876.47	Cr II	E	4875.93	...	5875.60	He I	E	5875.61	...
4884.61	Cr II	E	4883.75	...	5889.95	Na I	A	...	5888.68
4889.62	Fe II	E	4889.01	...	5895.92	Na I	A	...	5894.50
4893.82	Fe II	E	4893.29	...	5902.82	Fe II	E	5902.56	...
4911.19	Ti II	E	4910.59	...	5991.38	Fe II	E	5991.34	5990.44
4923.93	Fe II	E	4923.33	4923.53	6084.11	Fe II	E	6084.14	6083.42
4950.74	Fe II	E	4950.25	...	6113.32	Fe II	E	6112.85	6112.99
4990.50	Fe II	E	4990.19	...	6129.70	Fe II	E	6129.40	6129.43
4993.36	Fe II	E	4992.89	4993.40	6147.73	Fe II	E	6148.05	6148.03
5000.74	Fe II	E	5000.66	...	6149.26	Fe II	E	6148.60	...
5005.51	Fe II	E	5005.31	5005.09	6158.19	O I	E	6157.72	...
5018.44	Fe II	E	5018.02	5018.23	6239.95	Fe II	E	6238.61	6238.14
5072.28	Ti II	E	5071.87	...	6247.56	Fe II	E	6247.76	6246.98
5072.39	Fe II	E	5071.88	...	6300.30	O I	E	6300.29	6299.79
5100.66	Fe II	E	5100.22	5100.36	6317.80	Fe II	E	6317.69	...
5107.94	Fe II	E	5107.37	...	6331.97	Fe II	E	6332.07	...
5111.63	Fe II	E	5110.94	5112.35	6369.46	Fe II	E	6369.51	...
5129.15	Ti II	E	5128.82	...	6383.72	Fe II	E	6384.22	6382.95
5132.67	Fe II	E	5132.36	5130.79	6416.92	Fe II	E	6416.90	6416.74
5136.80	Fe II	E	5136.80	...	6432.68	Fe II	E	6432.55	6432.25
5154.07	Ti II	E	5154.19	...	6456.38	Fe II	E	6456.36	6455.90
5158.00	Fe II	E	5158.51	...	6482.31	Fe II	E	6482.48	...
5169.03	Fe II	E	5168.92	5169.66	6516.08	Fe II	E	6516.17	...
5172.47	Fe II	E	5172.28	...	6564.71	H	E	6563.01	6563.99
5184.79	Fe II	E	5183.60	...	6678.15	He I	A	6673.13	...
5188.68	Ti II	E	5188.39	...	6678.15	He I	E	6678.23	...
5197.58	Fe II	E	5197.63	5197.63	6746.53	Fe II	E	6749.99	...
5226.54	Ti II	E	5226.56	...	6873.84	Fe II	E	6872.53	...
5227.49	Fe II	E	5227.91	5227.10	6896.17	Fe II	E	6895.17	...
5234.62	Fe II	E	5234.43	5234.45	6922.88	Fe II	E	6921.49	...
5247.95	Fe II	E	5247.40	...	7011.23	Fe II	E	7009.25	...
5264.18	Fe II	E	5264.30	5263.80	7065.71	He I	A	7064.85	...
5276.00	Fe II	E	5275.94	5276.17	7065.71	He I	E	7065.61	...
5284.11	Fe II	E	5283.51	5284.21	7155.16	Fe II	E	7154.82	7154.63
5306.18	Fe II	E	5306.15	5305.87	7214.72	Ti II	E	7214.17	7214.17
5316.23	Fe II	E	5316.33	5316.53	7222.39	Fe II	E	7222.11	7221.19
5325.55	Fe II	E	5325.56	5325.31	7307.97	Fe II	E	7308.98	7309.21
5333.65	Fe II	E	5333.81	5331.96	7388.18	Fe II	E	7388.74	...
5336.77	Ti II	E	5337.19	...	7452.54	Fe II	E	7450.66	7453.12
5376.45	Fe II	E	5376.32	...	7462.38	Fe II	E	7463.68	7464.26
5381.02	Ti II	E	5380.97	...	7479.69	Fe II	E	7480.93	...
5395.86	Fe II	E	5395.91	5395.29	7515.83	Fe II	E	7516.49	7516.74
5402.06	Fe II	E	5402.05	5401.98	7711.72	Fe II	E	7713.17	7714.40
5414.07	Fe II	E	5414.00	5413.45	7775.39	O I	E	7776.86	7778.58

TABLE 2 (Continued)

$\lambda_{\text{lab}}$ (Å) (1)	SPECIES (2)	LINE TYPE (3)	$\lambda_{\text{obs}}$		$\lambda_{\text{lab}}$ (Å) (1)	SPECIES (2)	LINE TYPE (3)	$\lambda_{\text{obs}}$	
			XX Oph (4)	AS 325 (5)				XX Oph (4)	AS 325 (5)
7775.40	O I	E	7776.74	7778.67	8498.02	Ca II	E	8500.33	8500.87
8316.61	H	E	8316.29	8317.66	8504.88	H	E	8504.96	8506.40
8325.77	H	E	8326.44	8327.41	8542.09	Ca II	E	8544.25	8544.76
8336.13	H	E	8335.81	8337.72	8547.79	H	E	8548.12	8549.47
8347.91	H	E	8347.99	8349.06	8600.82	H	E	8600.79	8602.33
8361.36	H	E	8361.20	8362.57	8662.14	Ca II	E	8664.47	8664.96
8376.84	H	E	8376.86	8378.18	8667.46	H	E	8667.82	8669.21
8394.76	H	E	8394.92	8396.22	8752.94	H	E	8753.31	8754.47
8415.69	H	E	8415.76	8416.99	8865.28	H	E	8866.04	8866.78
8440.34	H	E	8440.27	8441.31	8912.07	Ca II	E	8915.07	...
8446.80	O I	E	8448.85	8449.98	8927.36	Ca II	E	8930.02	8929.42
8469.64	H	E	8469.88	8471.41	8931.48	Fe II	E	8930.21	8931.53

NOTE.—Lab wavelengths listed in cols. (1) and (6) were found in the NIST Atomic Spectra Database (see [http://physics.nist.gov/cgi-bin/AtData/main\\_asd](http://physics.nist.gov/cgi-bin/AtData/main_asd)). The types are grouped by emission lines (E) and absorption lines (A).

of the spectral type of each star can be made. We find the  $K$ -band spectrum of XX Oph is well described by an M5 II star, in close agreement with past studies, which have suggested an M6 III secondary (Lockwood et al. 1975; Humphreys & Gallagher 1977). AS 325 is a close match to that of HR 7806, a K2.5 III star. Figure 6 shows the CO region of both stars and the best-fit spectrum for comparison. The bottom panels of Figures 1 and 2 show stars with a spectral type similar to that determined from our infrared spectra taken from the Ultraviolet and Visual Echelle Spectrograph (UVES) library of high-resolution field star spectra (Bagnulo et al. 2003) and convolved to our resolution. In both stars, the emission lines and the presence of the hot component contaminate the optical spectrum, making a direct comparison difficult, but there is good correspondence between the continuum shape of the comparison star spectra and that of the “iron” stars.

Under the assumption that our infrared spectral classifications are correct, we can use the  $K$ -band magnitude of XX

Oph from Kamath & Ashok (1999) and AS 325 from the Two Micron All Sky Survey (2MASS) to determine the distance to the systems. We find that XX Oph (AS 325) is located at approximately 912 pc (1100 pc) if the cool component has the same properties as RV Hya (HR 7806), a known M5 II (K2.5 III) star with a robust parallax. This distance to XX Oph is within the  $1\sigma$  error of that determined from a *Hipparcos* parallax,  $546^{+805}_{-205}$  pc.

### 3.4. Stellar Radius

We measured the angular size of XX Oph using the Palomar Testbed Interferometer (Colavita et al. 1999) in both  $H$  and  $K$  bands on five separate nights in 2003 using the northwest baseline (85 m). The visibility data were calibrated using the standard method by Boden et al. (1998), utilizing three unresolved stars as calibrators: HD 161868 ( $0.73 \pm 0.10$  mas), HDC 158352 ( $0.60 \pm 0.10$  mas), and HD 173417 ( $0.60 \pm 0.10$  mas). The visibility data were then fitted using the uniform disk (UD) model, such that

$$V^2 = \left[ \frac{2J_1(\pi B\theta/\lambda)}{\pi B\theta/\lambda} \right]^2, \quad (1)$$

where  $B$  is the projected baseline (m),  $\lambda$  is the wavelength of observation (m),  $\theta$  is the UD angular size (rad), and  $J_1$  is the first-order Bessel function.

The mean angular diameter in the  $H$  band is  $1.83 \pm 0.06$  mas, and in the  $K$  band is  $1.94 \pm 0.06$  mas. Assuming a nominal 20% error in the distance of 912 pc, the stellar radii in the two bands are  $179 \pm 36$  and  $190 \pm 38 R_{\odot}$ , respectively. To estimate the bolometric flux from the cool component in XX Oph, the component for which we measure the diameter, we fit available photometry spanning the wavelength range

TABLE 3  
VELOCITIES FOR SEVERAL SPECIES IN XX OPH  
AND AS 325

Species	XX Oph (km s <sup>-1</sup> )	AS 325 (km s <sup>-1</sup> )
H (Balmer) emission	-94	-65
H (Balmer) absorption	-280	-227
He I emission	0	...
He I absorption	-110	...
O I emission	31	84
Ca II emission	85	90
Ca II H+K absorption	...	-77
Ti II emission	-28	-2
Cr II emission	-31	2
Fe II emission	-21	-8
Na I absorption	...	-68

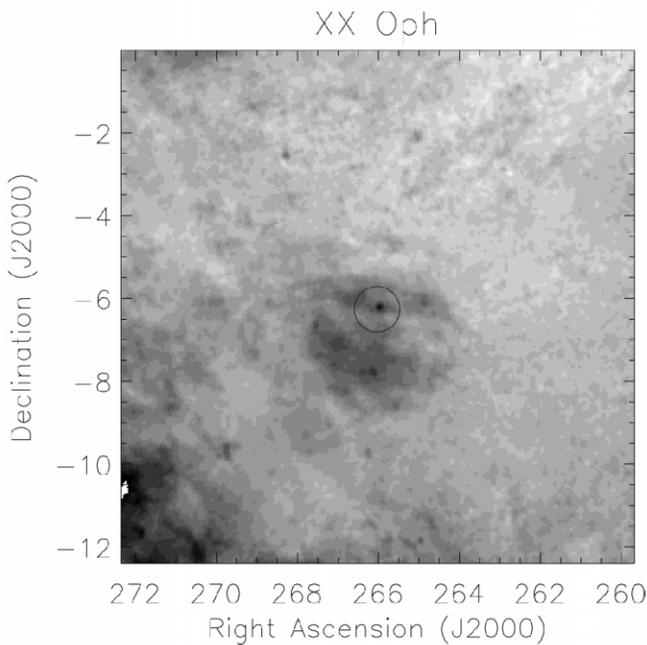
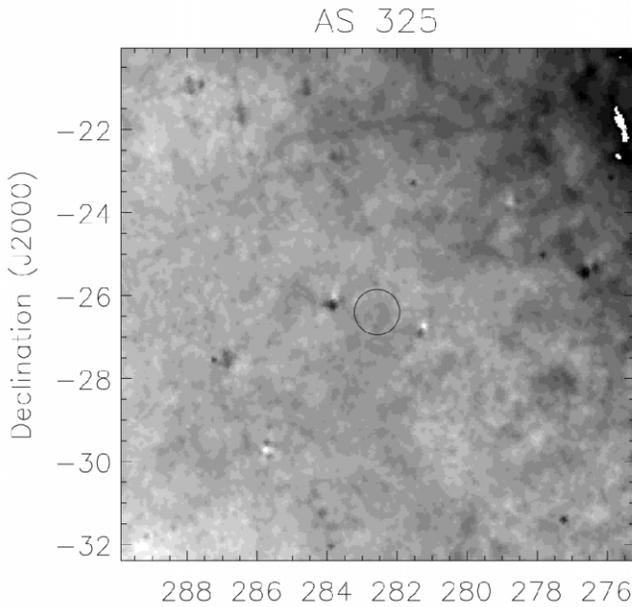


FIG. 3.—Environment of both “iron” stars from the Wisconsin H $\alpha$  Mapper. The bottom panel shows the H $\alpha$  emission near XX Oph, while the top panel illustrates the emission near AS 325. Both stars (marked by the circles) are located in regions of significant H $\alpha$  emission. Note that XX Oph is located particularly near a localized enhancement, while AS 325 is not visible in this short WHAM exposure.

TABLE 4  
OBSERVED COMPARISON STARS

Star	R.A. (J2000.0)	Decl. (J2000.0)	$m_v^a$ (mag)	Observatory
BD -07°4467	17 36 54.58	-07 41 52.4	9.3	Coudé
BD -07°4473	17 38 53.24	-07 44 24.2	9.5	Coudé
BD -07°4476	17 40 04.47	-07 06 21.5	9.3	Coudé
NSV 9567	17 43 08.01	-06 20 25.0	8.83	Bok
BD -06°4636	17 43 29.85	-06 08 01.7	9.8	Bok
BD -05°4487	17 43 45.23	-06 03 59.9	9.5	Bok
BD -06°4642	17 44 26.54	-06 24 22.2	9.8	Bok
BD -07°4494	17 44 39.40	-07 48 47.4	9.4	Bok
BD -07°4504	17 48 11.49	-07 05 24.1	9.5	Coudé
PPM 734398	18 46 19.77	-27 54 57.7	9.5	Coudé
CPD -27°6538	18 50 21.15	-26 55 25.0	9.5	Bok
CD -27°13276	18 50 44.23	-27 00 31.6	9.90	Bok
CD -26°13591	18 54 53.66	-26 20 46.4	9.5	Bok
V4061 Sgr	18 56 27.7	-27 30 22	9.22	Coudé

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

<sup>a</sup> All magnitudes were taken from the SIMBAD Astronomical Database.

5550 Å–5  $\mu$ m (Allen 1973; Swings & Allen 1972; Gezari et al. 1993; Lockwood et al. 1975) with a blackbody spectrum; we find  $F_{bol} = 10.2 \pm 1.5 \times 10^{-8}$  ergs cm<sup>-2</sup> s<sup>-1</sup>. We calculate the effective temperature using

$$T_{eff} = 2341 (F_{bol}/\phi^2)^{1/4}, \quad (2)$$

where  $F_{bol}$  is the bolometric flux in units of 10<sup>-8</sup> ergs cm<sup>-2</sup> s<sup>-1</sup> and  $\phi$  is the measured angular diameter in mas. This calculation yields effective temperatures in the *H* and *K* bands of  $3092 \pm 126$  and  $3001 \pm 118$  K, respectively. The derived ra-

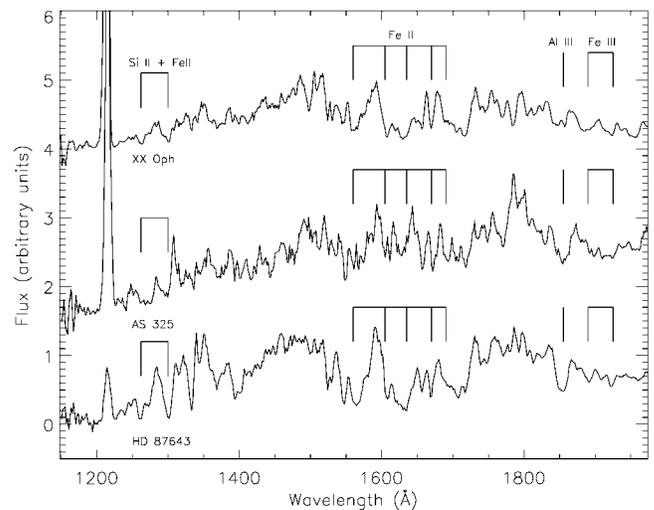


FIG. 4.—Archival far-ultraviolet spectra of XX Oph, AS 325, and the Be star HD 87643 from *IUE*. The three spectra are quite similar—all show deep absorption from Al III, a sign of a strong wind, as well as absorption from ionized iron. The optical Fe II emission is likely pumped by these iron absorption lines through fluorescence.

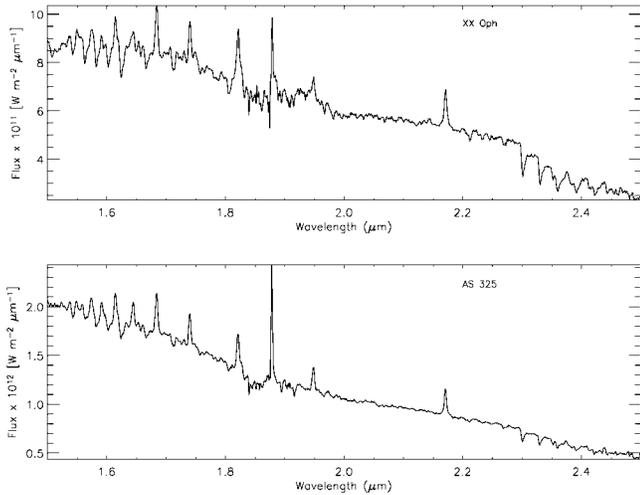


FIG. 5.—Near-infrared spectra of XX Oph and AS 325 obtained on 2003 October 10. The spectral structure of the stars changes across this wavelength range; in the blue, the spectra are dominated by emission lines, while the red end of the spectra is dominated by absorption signatures from the photosphere of the cool star in each system.

dus and effective temperature of XX Oph are consistent with that of a late-type (M6–M8) luminosity class II star (van Belle et al. 1999), in good agreement with the spectral type we determine from our  $K$ -band spectra. It should be noted that the spectral energy distribution of XX Oph is composed of both a hot and cool component, and thus any determination of the bolometric flux from one of the two stars may be contaminated by the presence of the second component. Here we use the bolometric flux only for an estimate of the effective temperature, and not for any in-depth analyses.

### 3.5. Binarity

In order to place limits on the possible binary nature of these two systems, we examined the hydrogen emission-line velocities on both long and short timescales using a combination of the strong  $H\alpha$  line and several of the strongest Paschen lines present in the spectra. Since the hydrogen emission lines arise from the wind from the hot Be star component, these emission lines can be used as a proxy to trace the kinematics of the hot star and its radial velocity motion. Since these emission lines are not tied directly to the stellar photosphere but instead originate from the hot wind of the star, these emission lines are only an indirect tracer of the stellar kinematics. On the longest timescales (months to years), there is no sign of coherent velocity changes in the two systems. While the time sampling of our measurements is not systematic, it is still clear that there is no long-term gross radial velocity motion. On 2003 July 8, several observations of each star were obtained covering the red portion of the spectrum to look for short-term variations in the velocities of the emission lines. Spectra of XX Oph and AS 325 were obtained as alternate pairs of 300 s exposures for

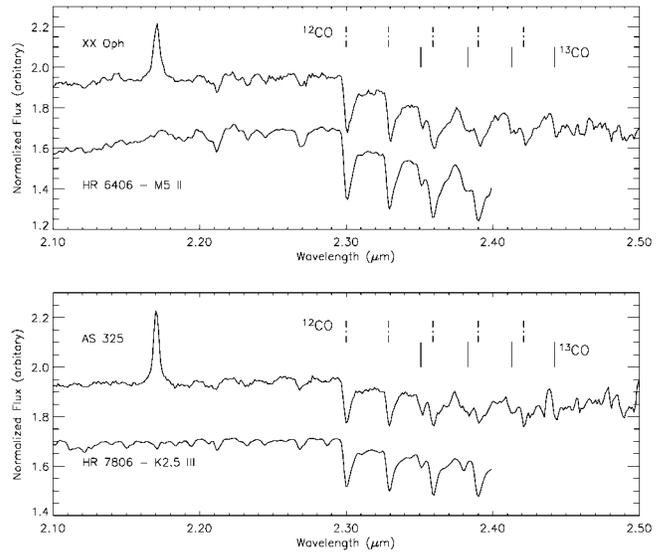


FIG. 6.—CO region of both stars in detail. For comparison, we show a spectral standard that fits the data well. We find that the spectrum of XX Oph is well matched by an M5 II star, in close agreement with past analysis in the literature. AS 325 resembles a K2.5 III star. The two spectra in each panel are offset for clarity.

over 3 hr. The velocities of multiple hydrogen emission lines were found to show no measurable variation during the 3 hr period. Given our resolution of approximately  $2 \text{ \AA}$  at  $6500 \text{ \AA}$ , corresponding to  $92 \text{ km s}^{-1}$ , we can centroid  $H\alpha$ , which is observed at a S/N greater than 100, to a level of approximately  $10 \text{ km s}^{-1}$  (the ability to centroid scales as the resolution over the square root of the S/N in the line). Allowing for an additional  $20 \text{ km s}^{-1}$  uncertainty induced by the asymmetric shape of the  $H\alpha$  line and possible wavelength calibration error, we place upper limits of  $25 \text{ km s}^{-1}$  on the maximum allowed radial velocity that could be induced by a binary companion. The lack of any gross radial velocity motions on short timescales rules out the presence of a massive, previously unknown close component not directly inferred from the spectra. In order to place more stringent constraints on the long-term radial motions of the stars, time-resolved  $K$ -band echelle spectroscopy, possible with current instrumentation at UKIRT, is needed.

### 3.6. Origin of Spectral Features

The ultraviolet spectra observed by *IUE* are compelling evidence that both stars have a strongly reddened hot component. The optical and ultraviolet spectral features likely arise in a strong, radiation-driven wind around each system. Both of the stars have wide and strong Al III absorption in the ultraviolet, probably formed in this wind. For comparison, HD 87643 (see Fig. 4), which shows an ultraviolet spectrum very similar to that of the two “iron” stars studied here, has a mass-loss rate of  $7 \times 10^{-7} M_{\odot} \text{ yr}^{-1}$  (de Freitas Pacheco et al. 1982). It is interesting to note that the velocity of the Al III absorption line

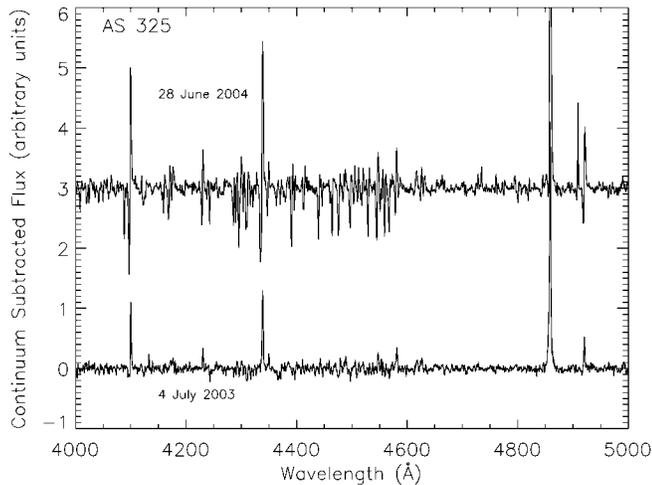


FIG. 7.—Spectral variability of the star AS 325 over a 1 yr baseline. The bottom spectrum is AS 325 on 2003 July 4, while the upper spectrum (offset vertically for clarity) shows AS 325 on 2004 June 28. The differences are striking. The P-Cygni profiles in the Balmer lines, which are present but weak in the earlier spectrum, become quite strong by the upper spectrum. The Fe II lines show strong P-Cygni profiles in the top spectrum as well. This evolution is interpreted as indicating density changes in the Be star wind.

in XX Oph (AS 325) of  $-240 \text{ km s}^{-1}$  ( $-80 \text{ km s}^{-1}$ ) agrees reasonably well with the Balmer absorption velocity of  $-280 \text{ km s}^{-1}$  ( $-227 \text{ km s}^{-1}$ ), although the spectral resolution of *IUE* ( $\sim 1000 \text{ km s}^{-1}$ ) makes interpretation of this similarity difficult. Dense material in the expanding wind provides the P-Cygni absorption that is observed in the optically thin Balmer lines. The ultraviolet spectrum, with strong signatures of Fe II absorption, is reminiscent of the “iron curtain” observed in novae eruptions (Hauschildt et al. 1992; Shore et al. 1994). The narrow optical emission lines of iron and other metals are pumped by ultraviolet absorption lines through fluorescence (Shore & Aufdenberg 1993). In AS 325, the Na I absorption line and the Ca II H+K lines are likely residual absorption from the cool K giant component in that system. While most of the optical absorption lines from the cool star are erased by the hot continuum from the Be star, these lines are quite strong in early K giants and thus leave a residual signature in AS 325. These lines may also arise in the ISM, but the agreement between the observed Balmer-line velocity and the Na I and Ca II velocities, combined with the rather large equivalent widths of these lines (1.9 and 1.2 Å, respectively, for the stronger line in each doublet), argue against this interpretation.

### 3.7. Variability

Given the large amount of optical spectroscopy we have for these two stars, it is a natural extension to examine the spectral variability of each. While the gross properties of XX Oph remained constant throughout our observational campaign, AS 325 showed peculiar spectral signatures in 2004. Figure 7 illustrates

this difference; the Balmer absorption components become quite strong, and the Fe II lines show P-Cygni profiles in our newest spectrum. The appearance in the optical Fe II absorption features is likely connected to density variations in the wind. If the mass-loss rate of the hot star changes, adding more material to the wind, or if the wind begins to sweep up more material from the ambient ISM, the density of the surrounding gas will increase, leading to stronger absorption components.

Bopp & Howell (1989) presented a spectrum of AS 325 near the Na I D absorption lines that is quite different from the spectrum presented in Figure 2. In 1987, AS 325 was observed to have strong Na I D absorption lines, similar to those observed in Figure 2, but these absorption lines were accompanied by slightly redshifted emission peaks. The Na I D lines did not show a P-Cygni profile, but instead appear to be the superposition of two independent components. The Na I D emission lines are not present in any of our recent observations. Their disappearance may be related to changes in the photoionization background generated from the central hot star, which in turn changes the ionization state of low-ionization species such as Na I.

In 2004 March, the optical flux decreased by 1.5 mag in XX Oph, the deepest minimum in 37 yr (Sobotka 2004). Figure 8 shows the variations in the H $\alpha$  equivalent width compared to the ASAS-3 light curve presented by Sobotka (2004) and the variation in the H $\alpha$  line shape both before and during the photometric event. In its faint state, the H $\alpha$  equivalent width is 50% larger than before the event, and the presence of the P-Cygni absorption component is more pronounced after the onset of the photometric event. The appearance of the absorption component and the increased equivalent width indicates that the underlying continuum has faded from its normal state. Our spectra show that the continuum flux at H $\alpha$  decreased by a factor of 6 between 2003 July 5 and 2004 June 25. The lower continuum provides less flux to contaminate the absorption component, allowing the P-Cygni profile to become clear. The change in both the photometric flux and spectroscopic features requires dramatic variability; since evolved late-type stars tend to be highly variable, for example through pulsations or a dynamic mass-loss rate, we suspect the continuum variability is associated with a late-type star. The smooth decrease in optical flux shown in Figure 8 is reminiscent of an eclipse. While this could explain the decrease in the flux needed to produce the spectral variations, historical light curves of the system show that the system undergoes sporadic deep minima, often lasting years, reminiscent of R Coronae Borealis stars (Prager 1940). Although the photometric properties of XX Oph are similar to those of R Coronae Borealis stars, our spectra of XX Oph do not contain any of the spectral features characteristic of this class, particularly the strong C II Swan bands that appear in deep minima.

### 3.8. Longevity

It is interesting to note the similarities between the model presented here and that invoked to describe emission from

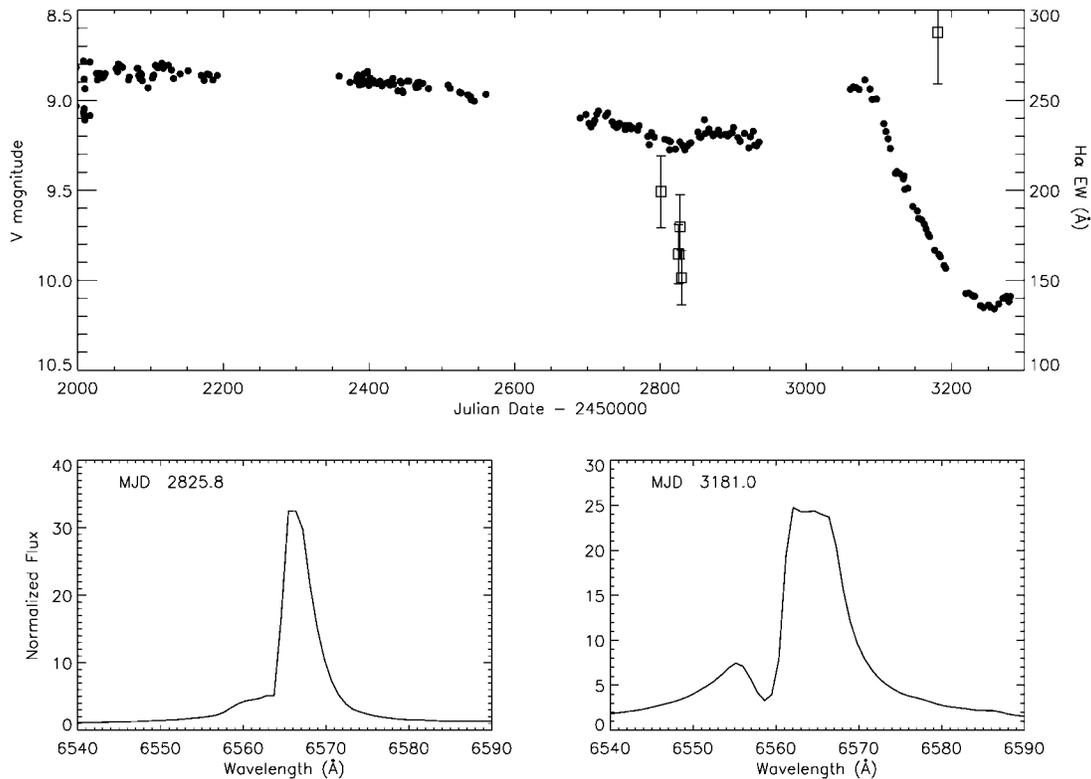


FIG. 8.—Spectral and photometric variability of XX Oph. The top panel shows the ASAS-3  $V$  magnitude of XX Oph from Sobotka (2004) by filled points; the open squares show the  $H\alpha$  equivalent width measured from our spectra. When XX Oph is in its faint state, the  $H\alpha$  equivalent width increases by nearly 50%. The bottom panels illustrate the  $H\alpha$  line morphology both before and during this photometric event. While XX Oph is in its faint state, the absorption component of the P-Cygni profile becomes apparent, while in its normal state the  $H\alpha$  line is merely asymmetric. Although the peak flux is less while the star is in its faint state, the width of the line is larger, increasing the equivalent width of the line. The change in the  $H\alpha$  profile and equivalent width are likely due to variability in the late-type component in the system.

nova eruptions (Gaposchkin 1957; Williams 1992). It is natural to ask, therefore, if the emission observed in XX Oph and AS 325 could be described by the nova model. The key characteristics of the spectrum of XX Oph have remained constant since Merrill’s work in the first half of the 20th century. In contrast, the nova phase with similar emission features lasts only a few weeks. Thus, the nova interpretation cannot describe the longevity of the observed features in XX Ophiuchi and AS 325.

Using his photographic spectra, Merrill (1951) measured the velocities of the metal and hydrogen emission features and found them to be nearly the same as those presented here. In 1951, however, the absorption component of the hydrogen lines was measured to be approximately  $-60 \text{ km s}^{-1}$ , nearly a factor of 4 slower than we measure more recently. From the velocity differences between 1951 and 2004, it appears the structure of the outflowing wind from XX Oph has changed between these two observational epochs. In order to create the measured velocity shifts, either the maximum speed of the wind or the density in the wind must have increased. An increased mass-loss rate could also explain the photometric variation seen in XX Oph; if the

mass-loss rate increases, the system may become more heavily obscured, resulting in a drop in visible flux. Future high-resolution spectroscopic monitoring of both stars is needed to understand the systematics of the wind associated with this system.

#### 4. CONCLUSIONS

We have obtained new optical and infrared spectra as well as archival far-ultraviolet spectra of the two “iron” stars XX Oph and AS 325. The two stars are quite similar, contrary to claims in the literature, indicating that these two systems are examples of one class of object. Our new data indicate that both of these stars are binary systems with a hot Be component, as well as an evolved late-type star. The forest of Fe II lines observed in the optical are likely pumped by ultraviolet Fe II absorption lines through fluorescence, and the Balmer P-Cygni profiles arise in the expanding wind around each system. We find that the velocity of the absorption component of the Balmer lines in XX Oph is larger than that measured in the past, evidence that the stellar wind in XX Oph has accelerated over the past 50 yr—a sign that these stars are dynamic and possibly

observed in a short-lived phase. We also examine the spectral variability of XX Oph during a deep photometric fading and find that the shape and strength of the  $H\alpha$  line changes quite strongly during the event. Further follow-up spectroscopic observations are vital in order to understand the connection between the peculiar photometric and spectral variability in these stars. In order to probe the stellar properties of XX Oph and AS 325, infrared spectra are needed to penetrate the forest of iron lines and the continuum from the hot component that confuses the observed continuum in the optical. In a future paper, we will present near-infrared integral field spectra of these two stars and an archival *ISO* spectrum that more directly probe both XX Oph and AS 325.

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