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AN EARLY SPECTRUM OF NOVA V1494 AQUILAE

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INTRODUCTION

Nova Aquilae 1999 No. 2 (V1494 Aql) was discovered on Dec. 1.8. 1999 UT and was the brightest Galactic nova in recent years, reaching a maximum of about V=4.1. I observed it on December 5.1 UT when its magnitude was about V=5.6. My equipment was a 16-inch telescope and slit spectrograph with CCD camera. The spectral resolution was about 11 Angstroms (Å) to keep exposures short since the wind was strong. Five frames were combined into one with a signal-to-noise ratio (S/N) of 16 for a one-dimensional pixel on the continuum. Novae are complex objects. A summary of what is known and theorized about them may be helpful before discussing the observation.

WHAT IS A NOVA?

The pre-nova is an interacting binary with an orbital period of hours. It consists of a white dwarf and a normal star that is redder and less massive than the Sun. The red star is losing atmosphere to the white dwarf via a gas stream. This occurs when the red star overfills its Roche lobe - the boundary beyond which the gravity of the white dwarf becomes dominant. The gas stream forms a thin accretion disk around the white dwarf. The disk itself is a strange object perhaps being an infrared emitter at its outer edge while being a strong ultraviolet emitter at its inner edge. Matter in the disk migrates to the inner edge where it descends to the surface of the white dwarf. There it forms a thin hydrogen-rich envelope that accumulates, increases in temperature, and ultimately initiates a carbon-nitrogen-oxygen conversion cycle - a thermonuclear runaway. Briefly, at about $2x10^7$ K nuclear reactions begin. About 10^8 K violent convection in the envelope brings fresh material to the reaction site and transports unstable short-lived reaction products near to the surface where their decay releases enormous energy.

The result is a nova, an explosion that initially expels 10% to 50% of the envelope into space and produces great luminosity. Following the initial outburst, ejection of accreted gas becomes continuous until most or all of it is removed. This process is sustained by a radiation-driven stellar wind from the white dwarf and by angular momentum released through friction as the red star ploughs through the expanding material that surrounds both it and the white dwarf early in the eruption.

Both forces act to clear ejecta from the vicinity of the binary and to bring on the nova's nebular phase as ionizing radiation acts on expanding material at a distance. On average, a nova expels about $1x10^{-4}$ solar mass into the interstellar medium. It takes years for the binary to become a quiescent post-nova, which is essentially the binary's state before outburst. However, the accretion process probably resumes soon (reforming the disk if it was destroyed), in preparation for subsequent eruptions.

It is worth adding that some novae warn of their impending outbursts from 1-15 years in advance by increasing in brightness by 0.25-1.5 magnitudes. This synopsis follows Warner (1995).

THE SPECTRUM OF V1494 AQL

Figure 1 is a plot of the spectrum at 3.3 days after maximum. It covers 3200Å in the wavelength range 4500-7700Å (blue to near infrared) at a dispersion of about 5.4Å/pixel. For comparison, the spectrum of α Cassiopeiae, a K0 IIIa normal star, is also plotted. The shapes of the plots reflect both the energy distribution of the objects and the spectrograph's unique response to wavelength. Whereas the star has an absorption line spectrum, the nova, with its expanding shells, has prominent emission lines. Both have in common absorption lines from Earth's atmospheric oxygen and water. The "check marks" beneath the continuum in the nova spectrum indicate the approximate wavelength range of these molecular bands. I give suggested identifications for several neutral elements and ions in the nova and, in most cases, include their multiplet numbers. A multiplet is a subset of lines among the lines of a species, such as Fe II.

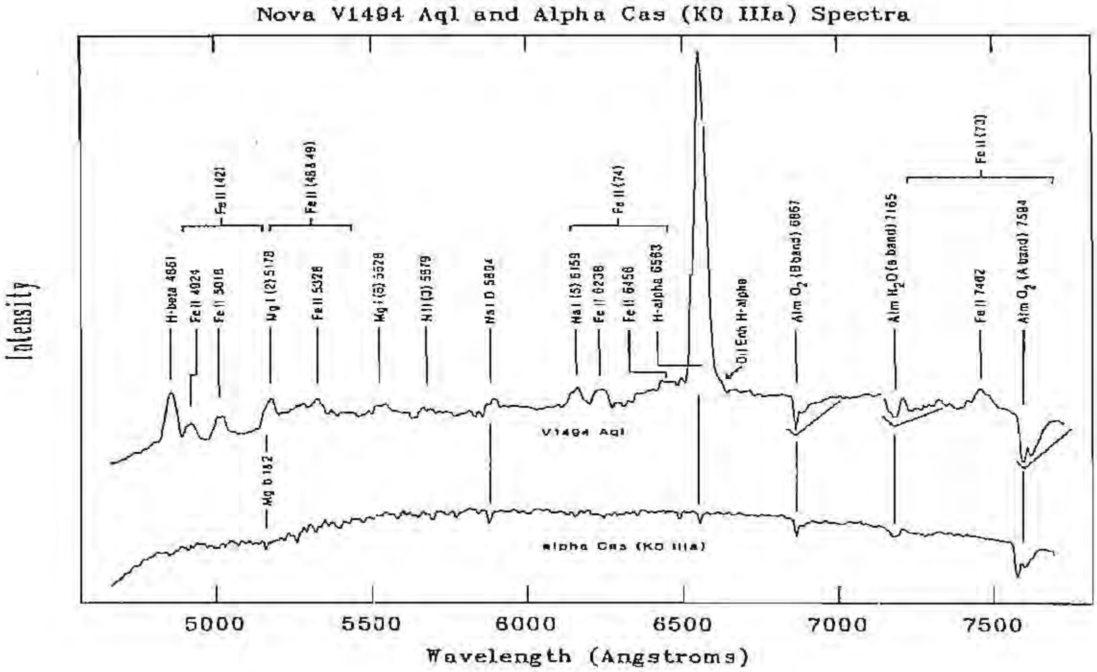

Figure 1: Plot of the spectrum of Nova V1494 Aql taken on December 5.1, 1999 UT. The spectral resolution is about 11Å and the wavelength range is 4500-7700Å with a dispersion of 5.4Å/pixel. The spectrum of α Cas, a normal star with spectral type and luminosity class K0 IIIa, is included for comparison.

Novae have many emission lines which come and go throughout the event. My suggested identifications are based on comparison with spectra in Williams et al. (1991) and Williams, Phillips, and Hamuy (1994). At about 1.5 magnitudes below maximum, V1494 Aql was probably in the "principal spectrum" stage. Weak P Cygni absorption lines are present for some emission lines. Strong Balmer (neutral hydrogen), Mg I, Na I, and Fe II emission lines are obvious. Novae change constantly and are not confined to one stage at a time. Figure 1 shows a mixture of "principal spectrum" and "diffuse enhanced spectrum". The bulge at the continuum on the red side of the Hα line (arrowed in Figure 1) is probably "diffuse enhanced" Hα emission which is observational evidence for continuous ejection as described above.

GROUP, PHASE, AND SUBCLASS

McLaughlin (1942) described stages of development in novae based on the appearance of their spectra. I use his terminology in the previous section. Williams, Phillips, and Hamuy (1994) suggested that most novae belong to one of two general groups (Fe II or He/N) based on the strength of certain emission lines near maximum light. Williams et al. (1991) classified novae according to four phases (permitted, auroral, nebular, and coronal), each with subclasses, which are based on the strengths of selected non-Balmer emission lines in the range 3400-7500Å. V1494 Aql may belong to the "Fe II" group due to the prominence of ist singly ionized iron emission lines. No helium lines are obviously present.

On December 5 the phase appears to be "permitted." This means that the strongest non-Balmer emission line was a permitted transition (i.e. Fe II 5018Å) and that the spectrum lacked emission lines from forbidden transitions, such as [Fe X], [O III], and [Ne V]. The iron subclass is probably correct based on the strength of Fe II 5018Å.

LINE PROFILES

The speed, orientation, and opacity of expanding material influence the shape of emission lines that arise from it. Novae ejecta are often described as shells but this is not meant to imply only spherical symmetry. A shell could be a ring of matter expanding in the equatorial plane of the binary or blobs of gas ejected along the polar axis. Depending on the opacity of expanding material, an observer whose line of sight is in or near the plane of expansion may find that emission lines are wide and their peaks are saddle-shaped. The blue and red cusps of the saddle correspond, respectively, to the shell's fast-moving leading edges which are traveling toward and away from the observer.

This effect can be observed when the ejecta begin to thin which permits a view deep into the shells. If the plane of expansion is not in the line of sight, or even if it is but the material is still too opaque, emission lines will not have saddle-shapes (Payne-Gaposchkin 1957 and Hauschildt 2000).

There is little evidence of saddle-shaped peaks on December 5 probably because the ejecta were too dense. From December 3 to 7 the Hα emission line's P Cygni profile (defined in the next section) steadily weakened and disappeared (Gavin 2000) which indicates that expansion was thinning the ejecta. A possible example of saddle shape is the Fe II line at 5018Å in Figure 2. Since the spectral resolution was low the line could be a blend of He I 5015Å and Fe II 5018Å. I examined spectra in Williams et al. (1991) and Williams, Phillips, and Hamuy (1994) to learn when and where HeI lines appear.

Shortly after outburst some novae showed Fe II lines without He I lines. Later, Fe II and He I were both present.

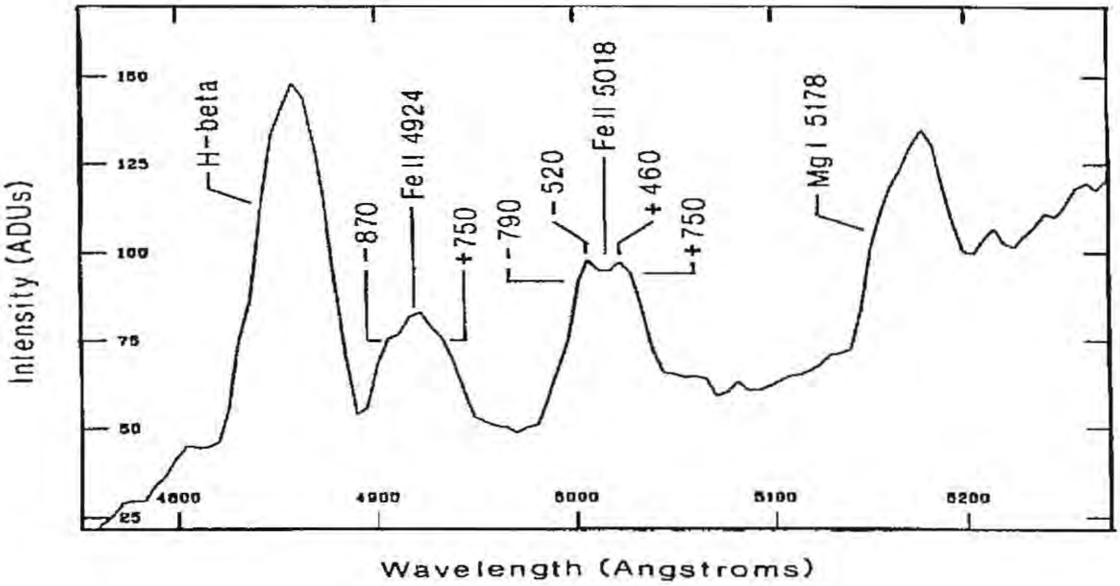

Figure 2: Velocities for the broad peaks of Fe II 4924Å and 5018Å. Positive values indicate recession while negative values indicate approach in units of km/s. Although it is not apparent at this plot scale, the blue side of Hβ shows poorly resolved P Cygni absorption with a velocity of 1600 km/s. The emission line has 2300 km/s FWHM.

When He I 5015Å was present, helium lines at other wavelengths tended to be present. I could not identify other helium lines in Figure 1 which implies that He I 5015Å is absent. At three days past maximum, it is likely that conditions needed to excite He I did not yet exist in V1494 Aql (Hauschildt 2000). The feature at 5018Å is an ambiguous example of a saddle-shaped peak but enough evidence exists to treat it as unblended Fe II.

EXPANSION VELOCITIES

The rate of expansion can be found from an emission line and its related blueshifted absorption line. This combination, called a P Cygni profile, shows the presence of an expanding shell of gas. That part of the shell which is directly in the observer's line of sight to the hot "photosphere" of the nova will produce absorption. Because the shell is expanding toward the observer, the absorption line will be blueshifted. The majority of the shell, which is not superimposed on the photosphere, will create an emission line. The following equation can be used to translate a shift in wavelength into radial velocity:

$$[v / c] = [w(obs) - w(rest)] / w(rest)$$

where v is the radial velocity, c is the speed of light, w(obs) is the observed wavelength, and w(rest) is the rest wavelength.

In Figure 3 the "shelf" in the blue side of the Hα line is a P Cygni absorption line that has been blurred by combining the five low S/N frames. I computed expansion velocities at the blue edge of absorption and at full width and half of maximum intensity (FWHM) for emission. Following is a comparative table of results.

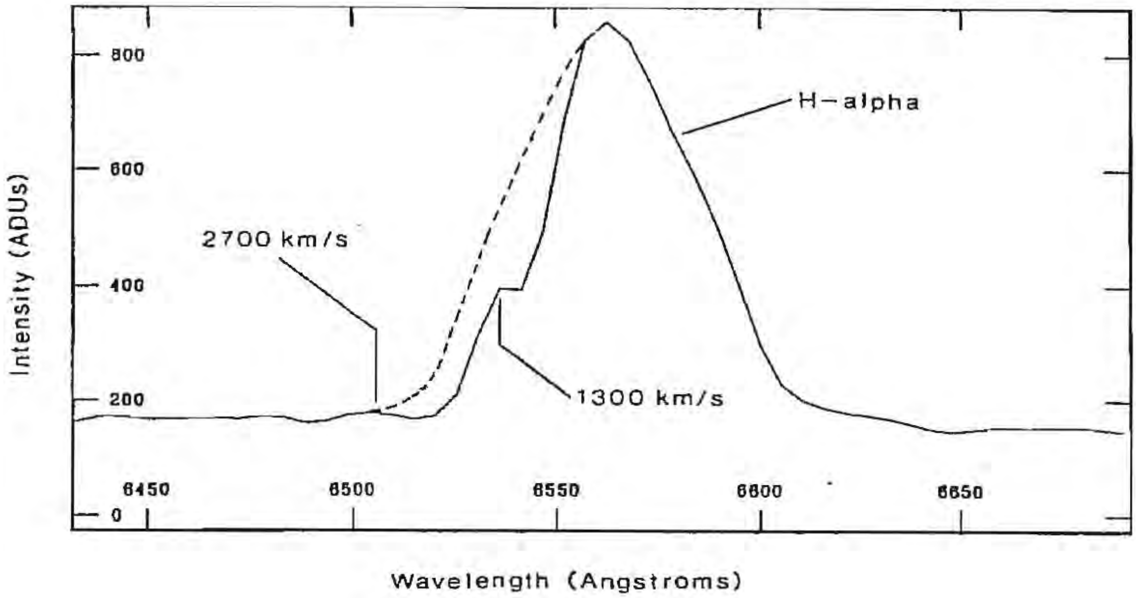

Figure 3: Hα-emission line profile with 2000 km/s FWHM. P Cygni absorption has velocities of 1300 km/s and possibly 2700 km/s. The dashed curve is a reversed version of the red side of the line.

Observer	December (UT 1999)	Hα v (km/s)	Hα FWHM (km/s)
Ayani (1999)	2.4	1020	1700
Moro et al. (1999)	2.71	1850	1300
Bryan	5.1	1300	2000
Gavin (2000)	5.7	1050	--

Hβ has a very weak P Cygni profile. The velocity at its blue edge is 1600 km/s and the emission line has 2300 km/s FWHM. The difference in velocities for Hα and Hβ implies that their sources were at different depths in the ejecta. Higher velocities occur toward the outer edge while lower velocities mean greater depth. Even weaker P Cygni absorption might exist at the blue edges of both emission lines. With doubt, I found 2700 and 3300 km/s for Hα and Hβ, respectively.

The broad peaks of Fe II emission lines at 4924, 5018, 6238, and 6456Å yielded 800, 800, 900, and 1000 km/s, respectively. The velocity for the blue and red peaks of the 5018Å line was 500 km/s. The uncertainties for all measurements are large because the spectrograph's resolution was about 500 km/s. The central values are probably good enough to give an idea of the expansion rates in this nova.

ACKNOWLEDGMENTS

I appreciate assistance from Harold Corwin, Peter Hauschildt, Jocelyn Tomkin, and Robert Williams during preparation of this paper. Also, I thank Maurice Gavin for access to his excellent series of spectra of V1494 Aql. Maurice has made these observations available at his web site, http://www.astroman.fsnet.co.uk/naql2.htm, where you can see the convincing saddle-shape of the broad Hα emission line peak during mid-December.

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References of Spectrograph Design (Short Version)

J. Draeger

1 Introduction

Spectroscopy offers a deep insight into the nature of an astronomical object. Hence, more and more amateur astronomers become interested in this special observation technique. Whereas it is easy to buy a small spectrograph for educational purposes, the instrumentation required for scientific purposes is usually much more expensive. Furthermore, it has to meet the personal, in many cases very specific requirements. Consequently, amateur astronomers are often enforced to construct and build a device by themselves. Such an ambitious projects starts usually with a study of the available bibliography. It is the intention of this paper to simplify the otherwise very time-consuming search for suitable papers and books. Though the references presented here contain most of the standard references about spectrographs, the bibliography never aims at completeness. Both simple solutions like the usage of photographical trick lenses and spectrographs based on interferometric principles are omitted. Furthermore, the list is to some extent oriented at the requirements of the author, which is currently buidling two spectrographs himself.

The paper do not consider spectroscopy as isolated area of research, but as one of several techniques for analyzing the physical characteristics of an astronomical object. In many cases, informations produced by photometry and polarimetry are used as well for measuring physical data. If they are performed simultaneously with spectroscopical observations, one speaks of spectrophotometry and spectropolarimetry, respectively. Of course, the remarks valid for photometry and polarimetry are holding for spectrophotometry and spectropolarimetry, too; hence, discussions of these methods are contained in the literature list as well.

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IR Calibration: [120, 185, 268, 276]

IR Photometry: [1, 6, 35, 51, 117, 133, 185, 265, 320]

6 Polarimeters

Theory: [20, 49, 61, 116, 126, 148, 158, 171, 260, 283]

Design: [17, 86, 98, 126, 148, 153, 171, 173, 209, 231, 249, 279, 280, 283]

Magnetometer: [171, 283]

Observations: [60, 248]

Errors: [17, 214, 281, 283]

Data Reduction: [11, 171, 214, 231, 287, 283]

Additional informations of high value can be found in documents like the preliminary and critical design reviews for state-of-the-art instruments of large telescopes.

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