Project 200: Photometry, Spectroscopy and Classification of Nova V475 Sct

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1. Aim:

1.1 The aim of this project is to reveal the type and distance to the nova V475 Sct using observations that employ equipment available to the amateur astronomer. Revealing the details of galactic novae, such as its distance and nova type, are fascinating endeavors for the amateur astronomer. Novae classification is an area where the amateur astronomer can make meaningful scientific contributions.

2. History of the discovery of the nova V475 Sct.

2.1 *Discovery and Pre-discovery Image Data.*

Nova V475 Scutum (Sct) was discovered on August, 28.58, 2003 UT by Hideo Nishimura of Kakegawa, Shizuoka-ken, Japan. (CBAT, 2003) The position of the nova was reported as RA 18h 49m 38s Dec -9^o 33' 45" equinox 2000.0. The discovery magnitude was reported as 8.5. V475 Sct is unique in that the original discovery by Nishimura was detected on photographic film using a 200 mm telephoto lens. Most present-day discoveries of this type are made by either visual

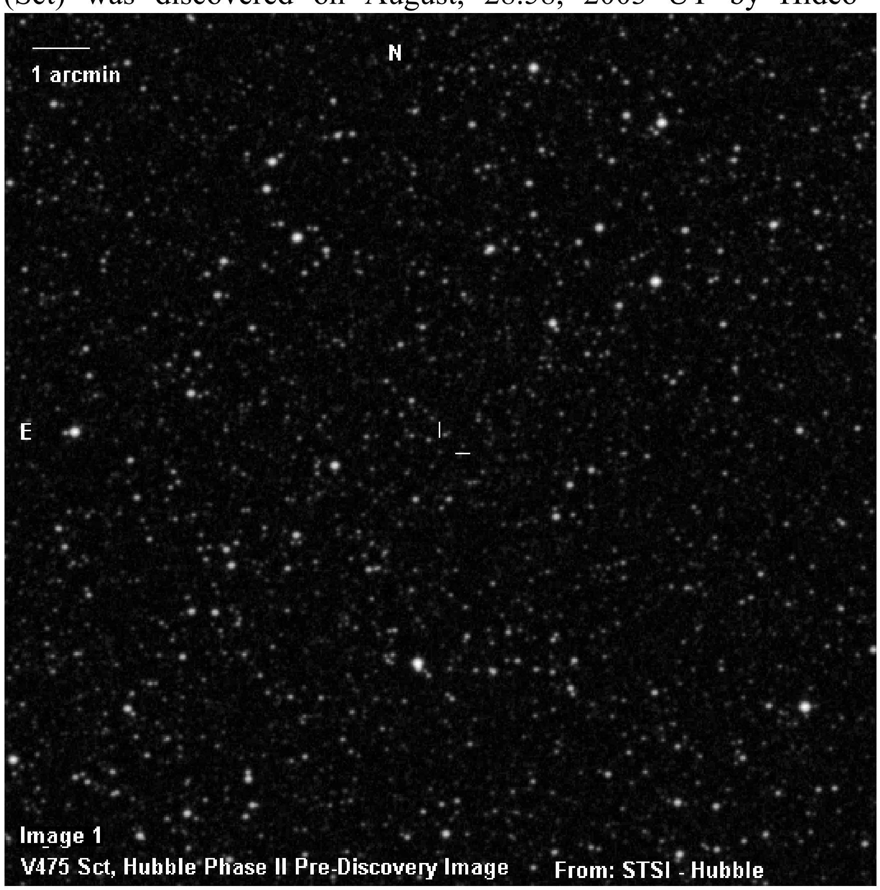


Image 1
V475 Sct, Hubble Phase II Pre-Discovery Image From: STSI - Hubble

observation or by the use of electronic imagers.

2.2 *The Progenitor Star*

The area of sky in which nova V475 Sct occurred was well documented before the occurrence. See Image 1. The star from which the nova forms is called the progenitor. The progenitor for V475 Sct is documented in the Guide Star Catalog II [GSC2 2001] as GSC2 S300220349902 with a magnitude of B=17.2. In the USNO B1.0 catalog, it is documented as USNO-B1.0 0804-00484139 with magnitudes B_1= 17.47, R_1= 15.87. (Monet 2003) The star is also documented in the USNO A2.0 catalog as USNO-A2.0 0750-148 33804 with magnitudes of B=17.2, R=16.4(Monet 1998) There is no documentation of variability in this progenitor star.

3. The Physics of a Nova

3.1 *The White Dwarf and Companion Star*

It is widely accepted that novae are close binary stars.(Hellier 2001) The central star is a white dwarf and the companion star is a late-type main-sequence star that still contains hydrogen in its outer shell. The white dwarf begins its life as a star of less than four solar masses [$M_\odot$] that has fused its supply of hydrogen into helium, carbon, oxygen neon and magnesium. The white dwarf then becomes a low volume star which has consumed all of its hydrogen, ejecting much of its mass into the formation of a local nebula cloud.(Barlow 1998) The mass of the white dwarf is sufficient that the electrons in the core become degenerate, or disengaged from their original atoms. The now ionized elements of carbon, oxygen, neon and magnesium align themselves in a crystalline-like lattice that allows for the maximum density of the star's mass.(Freedman 2002)

At this point, the white dwarf's mass is now greater than 1.4 $M_\odot$. The companion star is essentially a fresh supply of hydrogen for the small but massive white dwarf. If the companion star is within the gravitational field of the white dwarf, known as the Roche limit, hydrogen from the companion star is either attracted into an accretion disk that surrounds the white dwarf, or the gas is pulled directly onto the surface of the white dwarf. Because the white dwarf's gravity is so high, the hydrogen gas becomes compressed tightly onto the dying star's core.

When a sufficient amount of hydrogen has accumulated, the gravitational pressure on the hydrogen is so great that a thermonuclear fusion reaction occurs at the star's surface. This explosion causes either a wind or a shell that blows some of the hydrogen and small amounts of the star's core out into space. It is this formation of either a wind or a shell that determines the type of nova that has been produced.(Williams 1992) The wind/shell effect will be discussed later in the paper.

Normally, the hydrogen gas which remains on the stellar surface would be pushed away from the star's core as the thermonuclear reaction proceeds and the reaction rate would diminish or self-regulate due to the loss of fuel and decrease in temperature. The gravity of the white dwarf is so great that the heat generated by the hydrogen burning does not expand the hydrogen. Instead, the hydrogen is held close to the star's surface where it continues to burn at an even more rapid rate. This process is called degenerate hydrogen burning and is what makes the nova burn so brightly.

Eventually, the hydrogen on the white dwarf's surface is completely consumed. If the companion star still has hydrogen to donate, and is still within the Roche limit, the process begins again and the nova recurs after some period. Hellier suggests that all novae are recurrent and than it is only the mass of the white dwarf and the supply of hydrogen that determine the period of the nova. (Hellier 2001)

3.2 *The Nebular Phase*

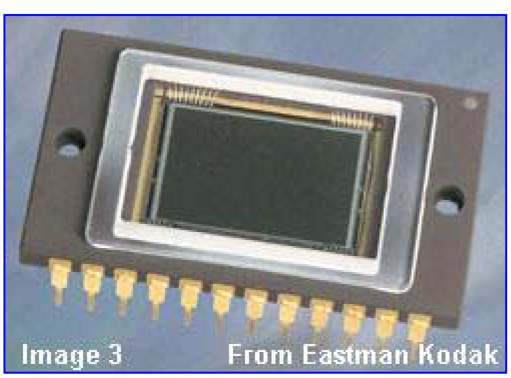
As mentioned in the previous section, at the point of ignition the nova ejects a quantity of the accumulated hydrogen and core-surface debris into space. The ejection temperature is high enough that all of this material exists in the form of gases. As the temperature cools to 1000-2000 K, atoms from the surface debris begin to condense into grains of dust. If the dust is sufficient, a shell is formed that greatly attenuates the amount of visible light escaping the nova. If little dist is formed, the expanding cloud of gas exists as a wind rather than a shell and there is little if any attenuation of the light from the nova. This process is called the nebular phase of the nova.(Hellier 2001)

4. Description of the equipment used for the observations.

4.1 *The Telescope*

The telescope used in this study is a 1970's vintage 0.36m Schmidt-Cassegrain that is housed in a permanent observatory. See Image 2. For this project, the telescope was operated at f/11. The instrumentation used for photometry and spectroscopy was placed at the Cassegrain focus of the telescope. The Cassegrain focus is the point at the back of the telescope where the focused image is projected by the secondary mirror.

4.2 *The CCD Camera*



The camera is an SBIG ST-10XME Charge Coupled Device (CCD) camera that uses a Kodak KAF3200ME detector.(1 SBIG 2002) (Kodak) See Image 3. The KAF3200ME is one of the newer generation blue-sensitized chips that have increased photo-response to the blue end of the spectrum as compared to previous generation devices. The chip also uses micro-lenses above each of the pixels in order to direct more of the photons onto the pixel surface and thus increases the chip's sensitivity.

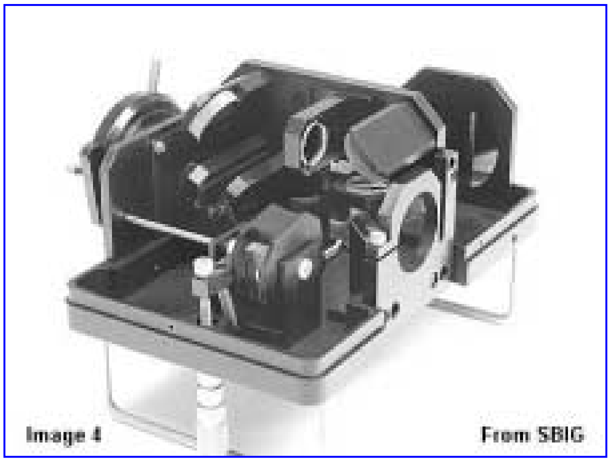


Image 4 From SBIG

4.2.1 *The Photometry Filters*

The filter set consists of five filters: Clear, B, V, R and I. The filters conform to the Johnson-Cousins spectral set and are supplied by Schuler Astro-Imaging. (Schuler 2002)(Dirsch 2002) The clear filter provides compensation for proper focusing of the system when no colored filter is in the light path.

4.3 *The Spectrophotometer*

The spectrometer is a Model SGS spectrometer manufactured by Santa Barbara Instrument Group. (2 SBIG 2001) See Image 4. This instrument is a grating based spectrometer for use on amateur astronomy equipment. It contains both low and high-resolution gratings of 150 and 600 lines / mm respectively. The low-resolution grating gives a resolution of 10 angstroms (Å) using an 18-micron (μ) entrance slit. The high-resolution grating gives a resolution of 2.4 Å with a concurrent decrease in sensitivity.

4.3.1 A *Brief Explanation of the Spectra Reduction Software*

Dr. Alan Holmes, the designer of the SGS spectrometer, wrote the software that is used to reduce the raw spectral data. Image 5 shows a view of the main control screen for the software.

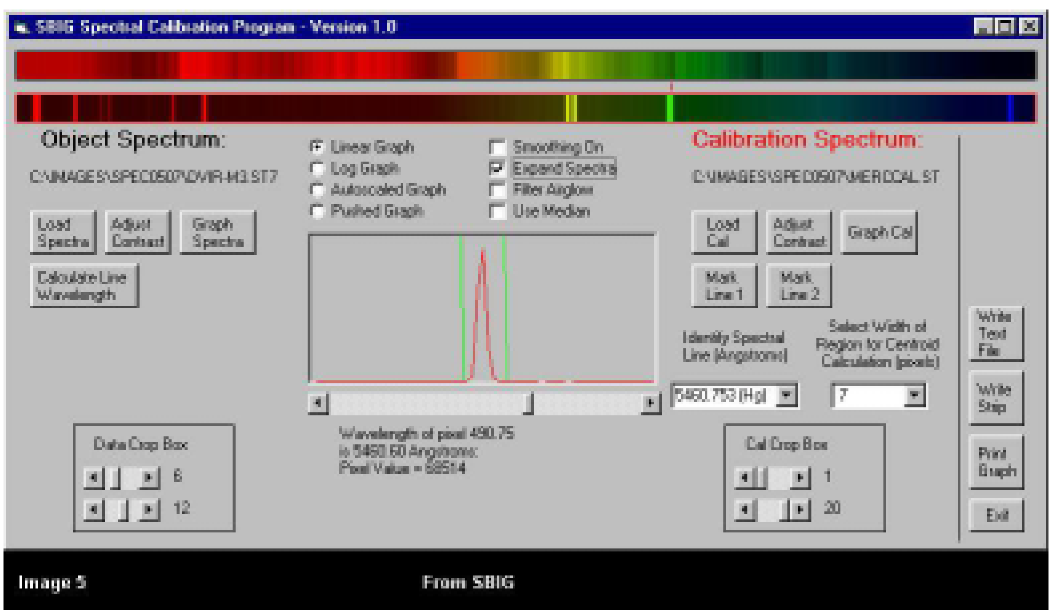


Image 5 From SBIG

The software, known as "Spectra", loads and displays the spectrum captured by the CCD camera. It then calibrates the spectrum with a known spectrum from a gas discharge lamp that has been taken using the same spectrometer. In this case, a neon lamp was used for calibration. The wavelengths of the peaks generated by the neon gas are known to great precision [+/- 0.001 Å]. Therefore, the neon spectrum acts as a scale against which the peaks of the nova spectrum may be calibrated for wavelength. By doing this, each pixel column across the x-axis of the CCD is assigned a central wavelength.

At low resolution, the SGS spectrometer has a resolution of 10 Å. The output of the diffraction grating is linear, so the number of angstroms per pixel is uniform across the width of the CCD spectrum. The Spectra program allows a separate wavelength to be assigned to two different peaks on the neon calibration spectrum and then calculates the central wavelength for every pixel along the x-axis of the spectrum in both the calibration spectrum and the nova's spectrum. The calibrated nova spectrum is then saved as a numerical text file for later interpretation.

5. Spectrometric data reduction

5.1 *Dominant Spectral Features*

Figure 1 shows four spectra of V475 Sct taken over a 38-day period. The most prominent feature of these spectra is the Hydrogen alpha [H alpha] peak located at 6563Å. This peak is caused by the ionization of the hydrogen on the white dwarf's outer surface. The heat and the resultant explosion caused by the hydrogen fusion reaction push the ionized hydrogen gas away from the star's surface. Small amounts of higher atomic weight elements from the star's surface are carried along with the expanding hydrogen gas. Notice that as time progresses the width of the H alpha peak increases slightly. The importance of this observation will be addressed later in the paper

The first spectrum was taken twelve days after maximum brightness and clearly shows the development of Fe II peaks in the 4900 Å and 5250 Å bands. These peaks slowly recede in intensity over the following 38 days. These Fe II peaks will be referred to again when the nova type is determined.

5.2 *Determining the Nova's Rate of Expansion*

The rate of expansion of the nova is a key indicator when determining the nova type. The expansion rate can be measured by determining the width of the H alpha peak at its half-maximum. This width measurement is called the Full Width Half Maxima [FWHM] of the peak. The H alpha peak increases in width because it contains wavelengths of the heated hydrogen gas from across the face of the expanding nova. The portions of the nova's gas envelope that are heading towards the observer are slightly blue shifted, and the parts of the gas envelope that are traveling away from the observer are slightly red shifted. The faster the expansion rate, the wider the H alpha peak becomes. The expansion rate [velocity], v, can be calculated by using a derivation of the Doppler Law. This derivation is shown in Formula 1.

Formula 1 $$\mathbf{v = \Delta\lambda\ c / \lambda_0}$$

Where $\Delta\lambda$ equals the FWHM of the H alpha peak, c = the speed of light in a vacuum and λ_0 equals the wavelength of the H alpha line at rest.

Figure 2 illustrates the progressive widening of the H alpha FWHM peak and the calculated rate of expansion.

5.3 *Calculating Distance via Redshift*

The distance to the nova could be calculated by applying the Hubble Law after determining the redshift of the H alpha peak. The redshift is defined as $\Delta\lambda$ in the equation and would be the difference between the wavelength of the H alpha peak as measured in the spectrum and the H alpha wavelength at rest, λ_0. However, in this instance, the resolution of the spectrometer is not sufficient to detect any redshift in the displacement of the H alpha peak. Another method for estimating the distance to the nova will be shows in section 6.2.

6. Photometric date reduction

6.1 *Determining t_o and t_2*

The point of maximum brightness and the point at which the nova has lost two V band magnitudes of brightness are t_o and t_2 respectively. Figure 3 shows the light curve in the V band for the nova V475 Sct. The time frame covered is from before the t_o point and until 65 days after the t_o point. Table 1 shows the sources for this data.

6.2 *Estimating the Distance to the Nova*

A *standard candle,* in the jargon of astronomy, is an object that has a brightness that can be used to determine the distance to that same object. Della Valle, et al. made multiple observations of recent novae to which the distances were accurately known.(Della Valle 1995) Thus, they were able to use these novae at known distances as standard candles for determining the distances to other novae. The Della Valle paper developed a formula to determine the distance to a nova as a function of the time that it takes for the nova to lose two apparent magnitudes of brightness from its maximum value. See formula 2. Using the Della Valle formula it is possible to estimate a nova's absolute magnitude by knowing how long it takes for the nova to drop two magnitudes from it's maximum brightness. The absolute magnitude of a star is the brightness of the star if it were observed from a distance of 10 parsecs (pc). A parsec equals 3.26 light years [ly]. The apparent magnitude of a star is the magnitude that is perceived by an observer on Earth. The Della Valle relationship is:

Formula 2 $$\mathbf{M_v = -7.92 - 0.81\ \arctan\ (1.32 - \log\ (t_2) / 0.23)}$$

Where M_v equals the absolute V band magnitude of the nova and t_2 is the time in days for the nova to drop exactly two magnitudes in brightness in the V band. In the case of V475

Sct, the t_2 time was 25 days. Therefore, the absolute V magnitude of the nova is calculated to be -7.66.

Once the absolute magnitude of the nova has been determined, the distance to the nova can be calculated by using the distance modulus formula shown in Formula 3:

Formula 3 $$m_v - M_v = 5 \log (D) - 5 + A_v$$

Where $\mathbf{m_v}$ equals the apparent or observed magnitude of V475 Sct, **D** equals the distance to the nova in thousands of parsecs [Kpc] and $\mathbf{A_v}$ equals the galactic absorption of the light path for the nova in V band magnitudes per Kpc. The factor for galactic absorption was determined from the NED Coordinate & Extinction Calculator.(Schlegel 1998) The galactic absorption is the amount of light that is absorbed due to gas and dust in the galaxy per 1000 parsecs between the object and the observer. This factor is dependent on whether the angle of observation is through or along the plane of the galaxy. It is also dependent on the wavelength of the observation since red light is less disrupted by the intervening dust than is blue light. In the case of V475 Sct, the V band galactic absorption factor is 1.9 V magnitudes / Kpc. Therefore, the ratio between the Absorption, A_v, and the distance, D, should be ~1.9. This is because for every Kpc distant the nova is from the observer, the brightness should decrease by ~1.9 mag in the V band. The distance modulus equation is solved until the ratio between $\mathbf{A_v}$ and **D** is 1.9. The **D** value that fits the equation for V474 Sct is 2.1 Kpc or ~6800 Ly.

6.3 *Brightness change from Progenitor to Nova at Maximum*

The change in brightness from the magnitude of the progenitor star to the maximum brightness of V475 Sct can be calculated by using the relationship in Formula 4:

Formula 4 $$m_2 - m_1 = 2.512 \log (b_1 / b2)$$

Where $\mathbf{m_2}$ is the maximum brightness of V475 Sct, $\mathbf{m_1}$ is the magnitude of the progenitor star [the star before it became a nova] and where $\mathbf{b_1/b2}$ is the ratio of the change in brightness between the two states.(2 Freedman 2002) The progenitor star had a V magnitude estimate of 16.0 and the nova had a maximum brightness of V magnitude 8.0. Therefore, at maximum brightness, the nova outshined its progenitor star by a factor of 1526 times.

6.4 *Estimating the Position of the Nova in the Galaxy*

The relative position of V475 Sct should be attainable since estimates have been calculated for its distance. The direction of the nova from earth are available as galactic coordinates in SIMBAD.(SIMBAD 2003) The values given in SIMBAD for the galactic coordinates of V475 Sct are longitude 24.2 and latitude –3.95. The galactic plane has a coordinate system in which the measurements are in degrees with the Earth being in the center of the coordinates. Northern values of latitude above the plane are positive and southern values of latitude are negative and lie below the galactic plane. Starting at the galactic center as viewed from earth, the longitude degree value become positive when going eastward [toward Orion] and negative when going westward. Therefore, the nova lies 24.2 degrees east of the galactic center as seen from Earth and 3.95 degrees below the galactic plane at a distance of ~2.1 Kpc. Image 6 gives a two dimensional pictorial representation of the approximate location of V475 Sct in the Milky Way and its position relative to Earth. From Image 6, it can be seen that V475 Sct lies on the back edge of the Sagittarius arm of our Galaxy. V475 Sct lies in the same general direction but is slightly further distant than the open clusters M26 [at a distance of 5000 ly] and M11 [at a distance of 5460 ly].

7. Nova Classification

7.1 *The Two Basic Types of Novae*

Typical novae are classified as "Fast" or "Slow" with the difference being that fast novae reach their t_2 point in less than 12 days, while slow novae show a t_2 point of greater than 12 days. In addition, fast novae tend to have a maximum M_v of -9. The progenitors of these novae tend to lie close to the galactic plane (within 100 pc) and come from Population I type [more recent] stars. The white dwarf progenitors of fast novae tend have a mass greater than 1 $M_\odot$. The typical fast nova also has a Helium/Nitrogen [He/N] type spectrum meaning that these elemental lines are common and strong in the spectra. Also, the stronger spectral lines tend to possess flat, jagged tops.(Delle Valle 1998) Williams reports that the He/N type novas tend to have broad peaks with expansion velocities extending to 5000 Km/sec in spectra taken early after t_0.(Williams 1992)

Slow novae tend to have maximum M_v of less than -7.5 and have a Fe II spectroscopic classification meaning that Fe II lines are common and strong when compared to the fast novae spectra. The novae also tend to lie further from the galactic plane (more than 1000 pc) and are composed typically of Population II [older] stars which makes the white dwarf component more likely to be less than 1 $M_\odot$.(Delle Valle 1998) Williams reports that the Fe II type novas tend to have narrow peaks with expansion velocities seldom above 2500 km/sec in early spectra.(Williams 1992)

7.2 *Classification of V475 Sct*

The t_2 of V475 Sct has been shown to be 25 days by photometric examination. The spectrum of V475 Sct shows definite Fe II lines in the early spectra as seen in Figure 1. The expansion velocity, which was derived from the spectral peak widths, showed a maximum velocity of 1882 Km/sec., and these peaks are sharp and narrow in appearance. The M_v for V475 Sct, at –7.66, lies slightly above the maximum predicted by Delle Valle for slow novae but is significantly lower than the maximum of –9 M_v predicted for fast novae. SIMBAD reports that the galactic latitude of V475 Sct is only -3.95^o. At a distance of 2094 pc, the distance from the nova to the galactic plane would only be 144 pc. [sin 3.95^o x 2094 pc = 144 pc] Therefore, V475 Sct would be classified as a <u>Slow, Fe II</u> type nova and would be expected to have a <u>progenitor that is a Population II star</u>. The <u>white dwarf component is likely to be less than 1 $M_\odot$</u>. However, <u>this particular nova is slightly brighter and lies much closer to the galactic plane than the typical slow nova.</u>

8. Sources for Errors

8.1 *Possible errors in A_v*

A main source for error in the calculation of the distance to V475 Sct is the A_v value used for the galactic absorption. The NED database reports that these values are suspect because of large variations in the density of the galactic plane from one section to another for objects that lie very close to the galactic plane [< 5^o].

8.2 *Photometric Errors*

The errors in photometry on these readings are known for the author's work and are limited to a standard deviation of +/- 0.04 for the author and a standard deviation of +/- 0.01 for the photometric sequence that was used for the comparison stars around V475 Sct.(Henden 2003) This total error of +/- 0.05 on the magnitudes used for determining the t_0 and t_2 dates is negligible when compared to the assumptions used in the distance calculations. They would also have little impact on the determination of the type of the nova as it applies to a fast or slow nova. [t_o and t_2 dates]

8.3 *Spectroscopic Errors*

The errors seen in the spectroscopic observations were mainly limited to an accurate calibration of the wavelength axis of the spectrum. The software used in this application allows only two points from the calibration spectrum to be used as markers for calibration the object spectrum. Professional spectroscopic programs allow for the use of several calibration points to be used in the calibration process. This use of extra markers tends to average out errors caused in the calibration process.

Another source of errors in the spectrum analysis is the introduction of spurious light sources. One of the last spectrums taken of V475 Sct was taken during an aurora. This caused several new peaks to occur in the spectrum. These peaks were associated with oxygen and nitrogen and were of course, a result of the ionized atmosphere rather than the nova. The spectrum was not used in the project.

9. Conclusions

9.1 Determination of the Nova Type

The determination of nova type is primarily based on the time from t_0 to t_2. This nature of observation can be accomplished with minimal training by most amateur astronomers. In the case of V475 Sct, the author accomplished this task using a telescope equipped with a Johnson-cousins filter set and a CCD camera. For most bright novae, the task could easily be accomplished by direct observation using a modest telescope or binoculars. Direct observation involves making magnitude estimates of the nova against nearby comparison stars.

In determining the nova type, the spectroscopic data collected at the amateur level can support conclusions drawn from the photometric data and give more insight into the peculiarities of the particular nova. However, amateur spectroscopy is limited to relative bright objects. In the case of the author's camera-spectrometer-telescope combination, spectra of stars fainter than V magnitude 15 become lost in background noise.

9.2 Determination of the Estimated Distance to the Nova

Again, estimating the distance using the Della Valle relationship requires only the values of t_0 to t_2 to be determined. This data can easily be accomplished by the amateur using a modest telescope or binoculars.

9.3 Determination of the Expansion Rate of the Nova

Measurement of the expansion rate of the nova requires that the amateur avail himself or herself of a spectrometer. While commercial amateur spectrometers are beyond the means of most amateurs, many astronomy clubs and many small colleges are able to own such devices. Spectrometers need not be expensive, though. A simple transmission diffraction grating placed between the telescope and the CCD camera makes a very nice 'slitless' spectrometer that, if used carefully, can produce quite usable spectra for amateur use.(Gavin 1999)

The general conclusion from this paper is that amateur astronomers can make meaningful scientific contributions by performing careful observations on modest equipment.

V475 Sct should be followed closely. At a distance of 6800 ly, the nova is 'relatively' close. If the nova has indeed erupted before, the shell of previous debris may become visible in the next few months, as did the shell of V838 Mon. The shell structure of V838 Mon is quite visible and is approximately three times the distance from Earth as V475 Sct. V838 Mon has recently been estimated to have erupted at a distance of 19,600 ly. (Bond 2003)

Acknowledgments:

This research has made use of the USNOFS Image and Catalogue Archive, operated by the United States Naval Observatory, Flagstaff Station
http://www.nofs.navy.mil/data/fchpix/

This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France

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http://simbad.u-strasbg.fr/sim-id.pl?protocol=html&Ident=v475+sct&NbIdent=1&Radius=10&Radius.unit=arcmin&CooFrame=FK5&CooEpoch=2000&CooEqui=2000&output.max=all&o.catall=on&output.mesdisp=N&Bibyear1=1983&Bibyear2=2003&Frame1=FK5&Frame2=FK4&Frame3=G&Equi1=2000.0&Equi2=1950.0&Equi3=2000.0&Epoch1=2000.0&Epoch2=1950.0&Epoch3=2000.0

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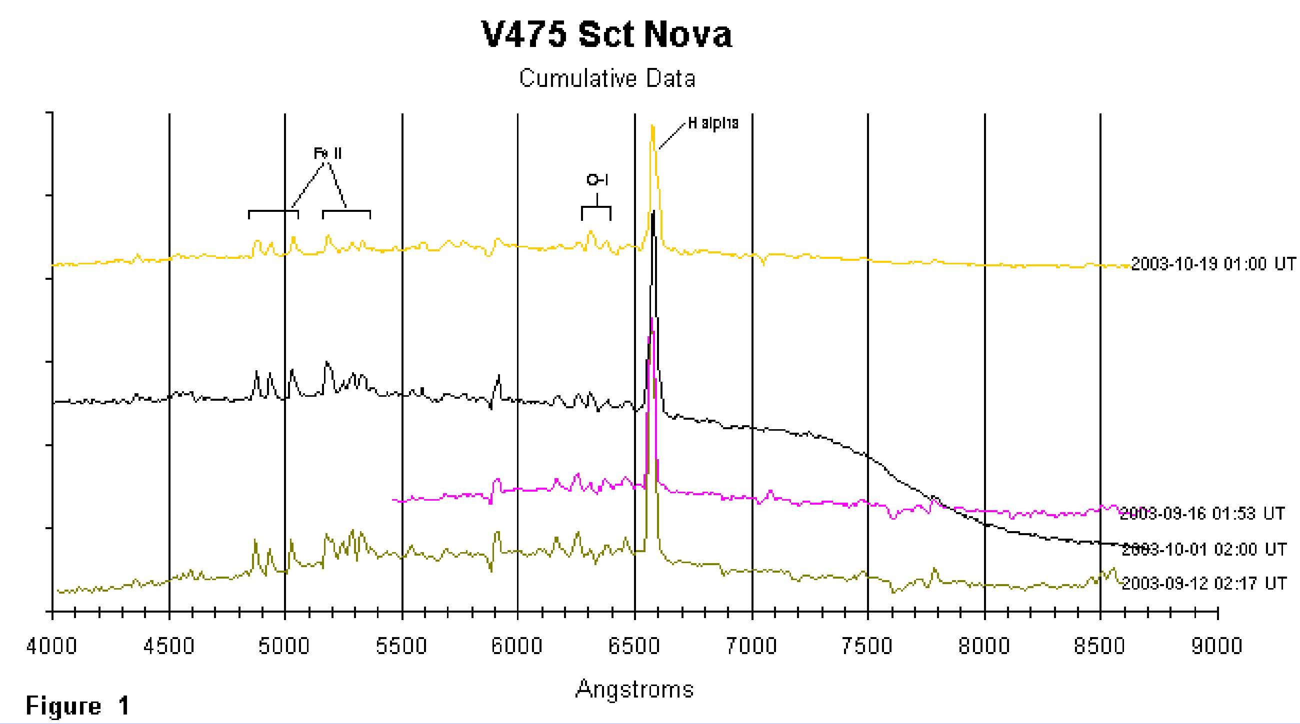


Figure 1

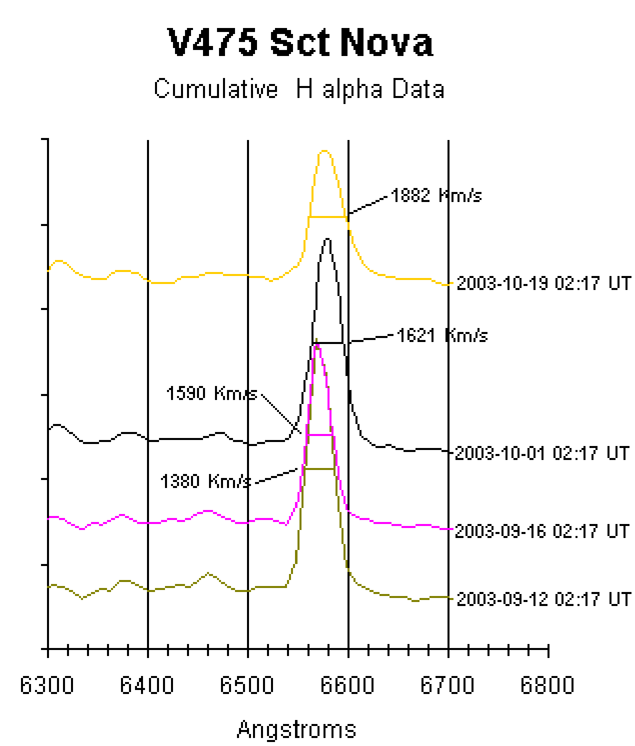


Figure 2

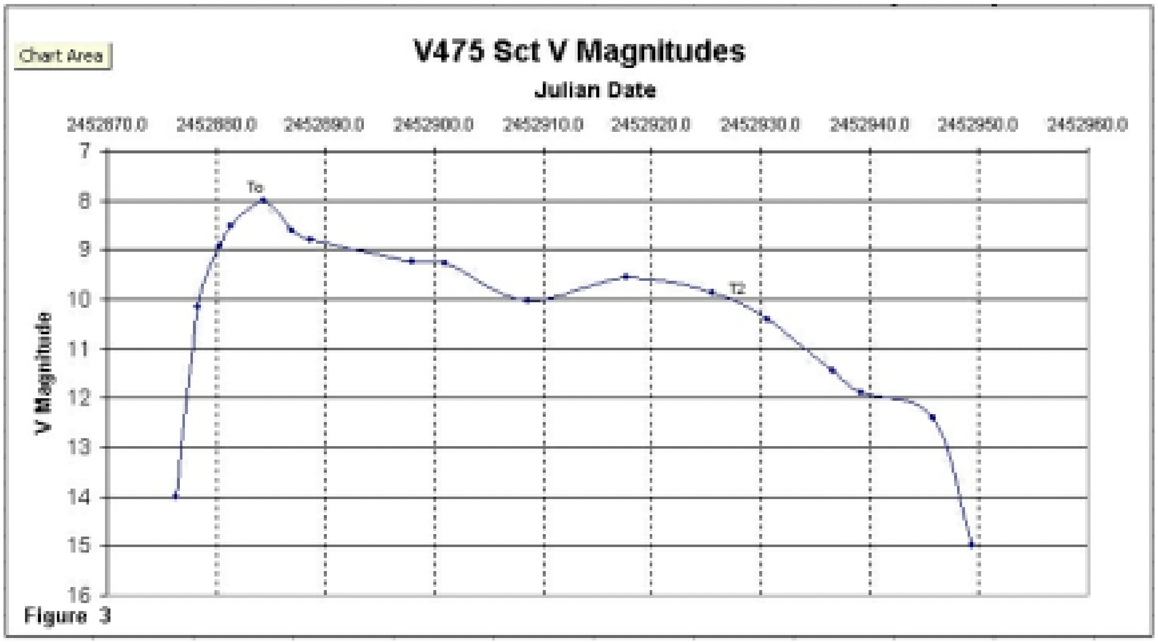
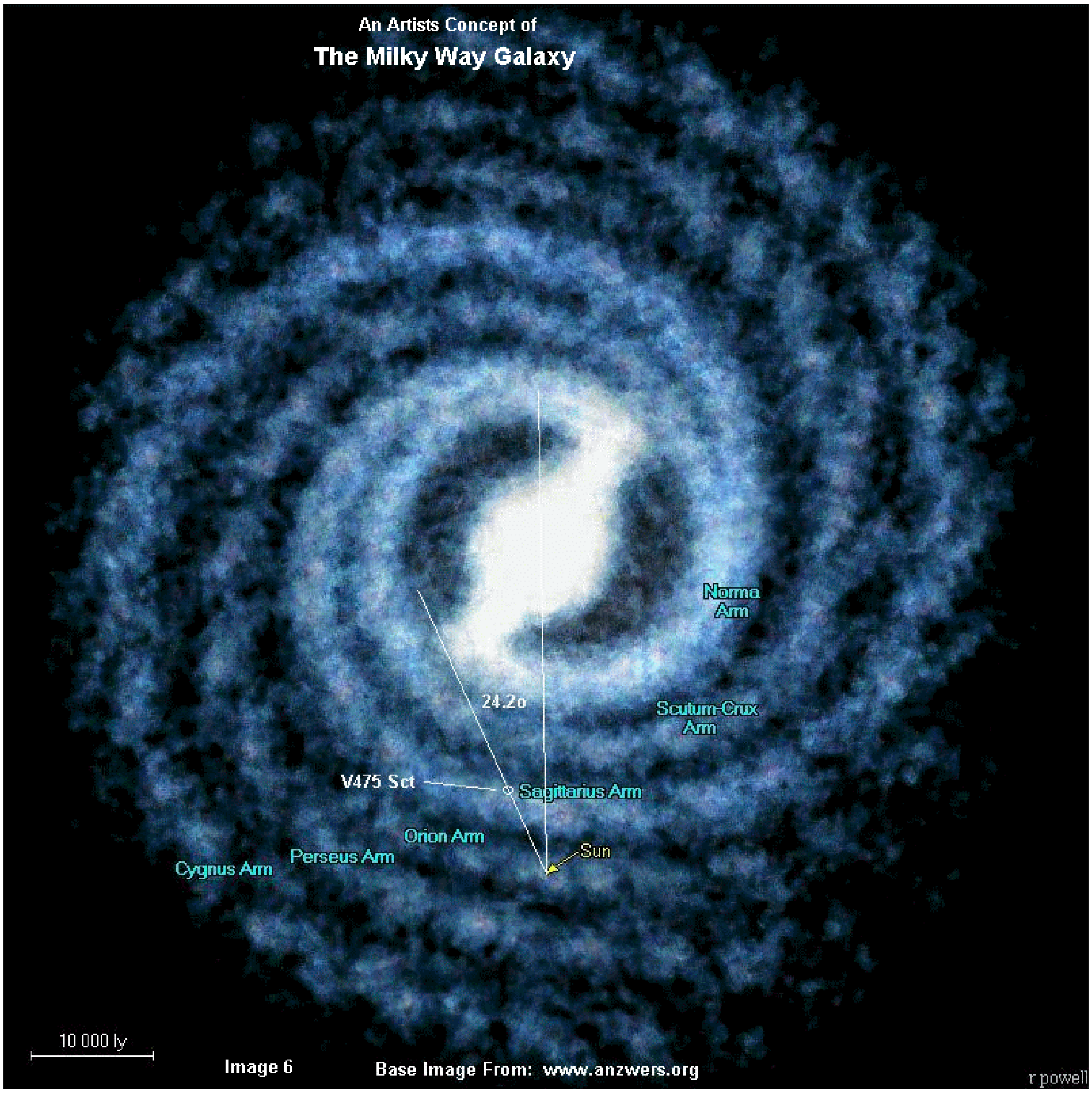


Figure 3

Table 1

	Date	JD	V Mag	Source
	20030824.1	2452876.4	14	ASAS Survey
	20030826.1	2452878.4	10.15	LIL
	20030828.1	2452880.4	8.94	ASAS Survey
	20030829.4	2452881.4	8.5	H. Nishimura
T_o	20030901.83	2452884.4	8	TSc
	20030904.4	2452886.9	8.6	Rod Stubings
	20030906.2	2452888.7	8.81	DRS
	20030915.4	2452898.0	9.24	Njh
	20030918.4	2452901.0	9.27	Njh
T_2	20030926.1	2452908.6	10.02	DRS
	20031005.1	2452917.6	9.57	DRS
	20031013.2	2452925.5	9.87	DRS
	20031017.2	2452930.5	10.40	DRS
	20031024.2	2452936.6	11.46	DRS
	20031026.8	2452939.1	11.90	Michel Verdenet [1]
	20031103.3	2452945.9	12.40	Hiroshi Matsuyama[2]
	20031106.9	2452949.4	15.00	DRS

Author: DRS
[1] AFOEV President
[2] Australia


An Artists Concept of
The Milky Way Galaxy
Norma
Arm
24.2o
Scutum-Crux
Arm
V475 Sct
Sagittarius Arm
Orion Arm
Sun
Perseus Arm
Cygnus Arm
10 000 ly
Image 6
Base Image From: www.anzwers.org
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