Observing and Understanding Uranus, Neptune and Pluto

By Richard W. Schmude, Jr.

A.L.P.O. Remote Planets Coordinator

Neptune: impression based on Voyager 2 images.

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Purpose and Goals

The Association of Lunar and Planetary observers (A.L.P.O.) is an international organization of observers dedicated to the study of the solar system. The two purposes of the A.L.P.O. remote planets section are: 1) educate the public about Uranus, Neptune and Pluto and 2) carry out research projects related to the remote planets. The specific goals of the research projects are:

1) Collect brightness and color measurements of the remote planets and their moons
2) Make drawings and CCD images of Uranus and Neptune
3) Monitor occultations and near miss occultations
4) Record the spectra of the remote planets
5) Gather historical measurements of the remote planets
6) Increase international collaboration with regards to remote planets work.

Chapter I: Summary of Current Knowledge

A. Uranus

Table 1 summarizes major historical developments related to Uranus while Table 2 lists facts and figures related to Uranus.

Unlike Earth, Uranus does not have a visible solid surface; instead the atmosphere blends into the deeper layers. Altitudes on Uranus (and Neptune) are reported in terms of atmospheric pressure. The composition of Uranus' atmosphere near 1.0 atmosphere of pressure is: 83% hydrogen, 15% helium and 2% methane (CH_4). Trace quantities of other gases are probably also present. Uranus' green color is due to the 2% methane which absorbs red light.

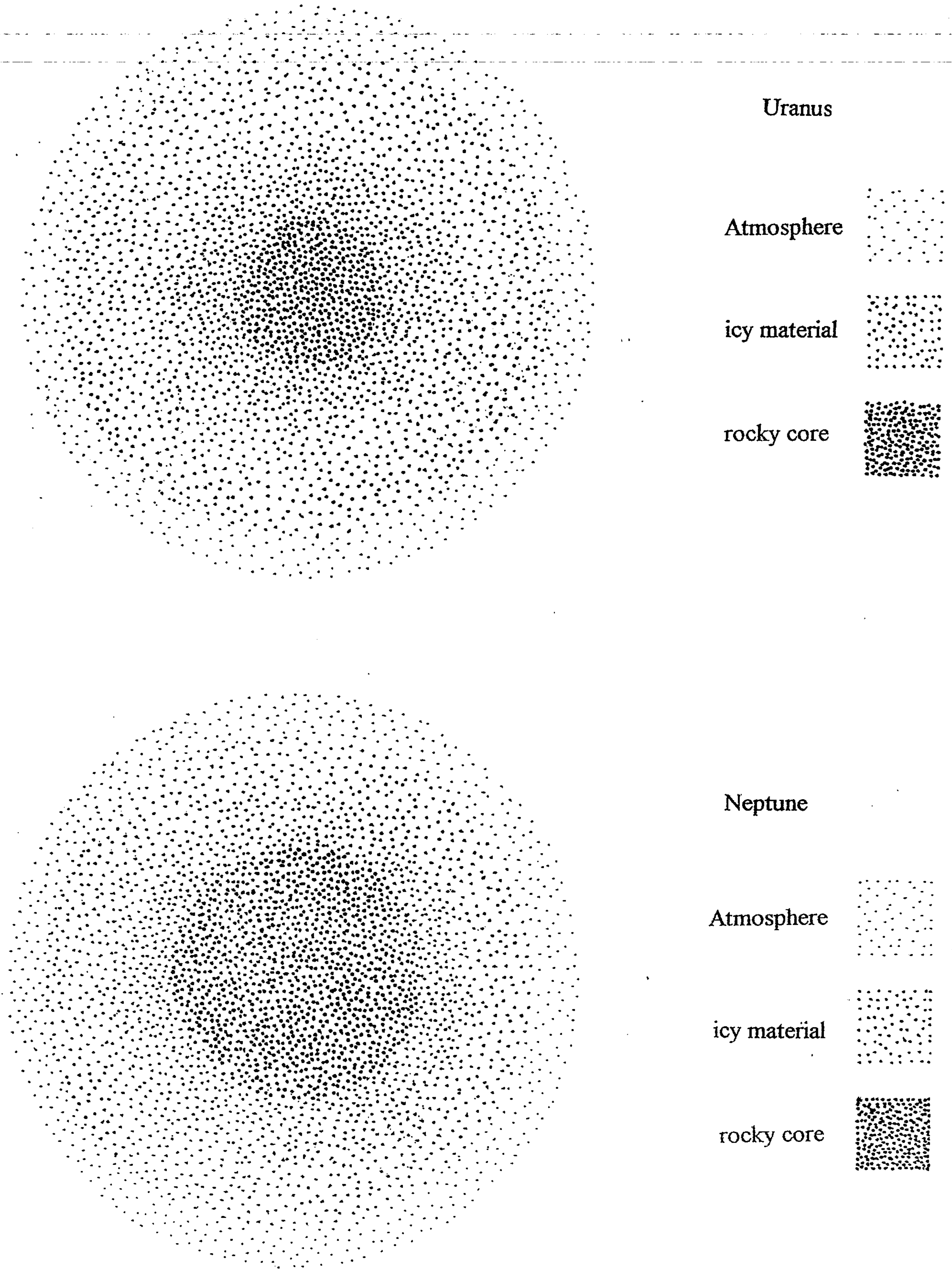
Uranus does have some atmospheric haze and there is a chance that this haze changes. A recent study suggests that the haze layer on Earth changes, and may influence the development of clouds (Rosenfeld 2000). Bright spots have been seen on Uranus from time to time. In one case, O'Meara (1984) spotted a bright spot on Uranus, and by watching the spot move he deduced a rotational period of 16.0 to 16.4 hours which is close to what Voyager observed. Voyager II confirmed that both lightening and aurora take place on Uranus.

Figure 1 illustrates the interior of Uranus. The top layer is an atmosphere which lies above an ice layer composed of the elements hydrogen, helium, carbon, nitrogen and oxygen. This ice layer is under high pressures and is believed to be at temperatures of several thousand degrees K. A small rocky core probably exists near the center. Uranus possesses a magnitude field which is tilted by 59° with respect to the rotational axis. The magnetic field traps changed particles emitted by the Sun and in some cases, these collide with the atmosphere causing aurora. Because of the large tilt in the magnetic field, aurora take place in the temperate latitudes instead of the polar latitudes.

Uranus has 11 rings. Ten of these are very narrow with widths of less than 100 km (60 miles) while the other ring is much wider but is also very diffuse. The ring particles are about as dark as coal which is much different than the icy pieces making up Saturn's rings. The rings of Uranus can not be seen through even the largest telescopes on Earth.

Uranus has 21 known moons. The largest 5 and their diameters are: Titania (1580 km or 982 miles), Oberon (1524 km or 947 miles), Ariel (1158 km or 720 miles), Umbriel (1172 km or 728 miles) and Miranda (480 km or 298 miles). Each of these five had a different geological past as

Figure 1: Models of the interiors of Uranus and Neptune.



shown by Voyager II. The brightness and color of these moons may change with the seasons; furthermore Voyager II only imaged about 50% of the surfaces of each of these moons.

Table 1: Major historical developments related to Uranus.[a]

Year	Event
1781	Herschel discovers Uranus
1787	Herschel discovers Titania and Oberon
1851	Lassell discovers Ariel and Umbriel
1948	Kuiper discovers Miranda
1977	Elliot and others discover rings
1985-86	Scientists discover 10 new moons from Voyager II data
1986	Voyager II flies past Uranus
1997	Gladman discovers two new moons[b]
1998	Karkoschka discovers new moon[c]
1999	Kavelaars and Gladman discover three suspected new moons[d]

Table 2: Facts and figures related to Uranus.[a]

Quantity	Value	Quantity	Value
Diameter (km)	51,100	Average opposition Magnitude	+5.5
Mass (kg)	8.7×10^{25}	Average B-V color index	+0.56
Average density (g/cm^3)	1.3	Number of known Moons	21
Angular size of disc	3.7 arc-sec	Atmospheric composition	H_2, He, CH_4
Average distance from Sun	2.9×10^9	Geometric Albedo	0.51
Period of revolution	84 years	Polar flattening	0.023
Period of rotation	$17^h\ 14^m$	Color	pale-green

[a] Taken from: (Astronomical Almanac 2000), (Cruikshank and Morrison 1990) and (Zeilik 1997).

[b] (Sky and Telescope, 1998) [c] (Sky and Telescope, 1999a) [d] (Sky and Telescope, 1999b)

B. Neptune

Table 3 summarizes the major historical discoveries related to Neptune while Table 4 lists important facts of Neptune.

Like Uranus, Neptune does not have a visible solid surface. Neptune's atmosphere is made up of hydrogen and helium with about 1-2% methane. Unlike Uranus, Neptune emits more infrared light than it receives from the Sun. This extra infrared light may be the cause of the higher activity in Neptune's atmosphere. Several groups have imaged albedo features on Neptune and furthermore, Voyager II imaged both bright and dark features on that planet. One of the features imaged on Neptune is called the Great Dark Spot.

The Great Dark Spot was about 16,000 km (10,000 miles) long and 7000 km (4000 miles) wide in 1989. This feature was a huge anti-cyclonic storm system. By 1994, the Great Dark Spot had dissipated (Sky and Telesc. 1997). Several brighter clouds surrounded the Great Dark Spot in 1989 and one of these was called "Scooter" because it moved very quickly. The Hubble Space Telescope has imaged additional clouds on Neptune during the 1990s.

Neptune's interior is probably similar to that of Uranus; see Figure 1. Neptune probably has a larger rock core than Uranus (because of its higher density). Neptune has a magnetic field that is tilted to the rotational axis by 47°. This means that the aurora on Neptune occur in the mid-latitudes. The magnetic field of Neptune is weaker than the one on Uranus.

Neptune has at least four rings and three of them are called: Galle, Le Verrier and Adams in honor of the three men who discovered Neptune. The rings of Neptune are very diffuse and contain very dark particles similar to the rings of Uranus. At least one of the rings (Adams) contains several brighter arcs. Unlike the rings of Uranus, the rings of Neptune contain large amounts of dust.. The rings of Neptune are not visible through even the largest telescopes on Earth. People with small telescopes, however, may be able to detect the rings through stellar occultations.

Neptune has eight known moons, and the largest is Triton. Triton is about 75% the size of Earth's moon. Voyager II images reveal that Triton has a huge south polar cap extending down to about 30°S latitude. This polar cap has a pink color and may be made up of frozen nitrogen. Liquid nitrogen geysers occur on Triton. The geysers release liquid nitrogen that is warmer than the daytime surface temperature on Triton. Like Neptune, Triton undergoes seasons; however, each season is

about 41 years long. Currently it is summer in Triton's southern hemisphere and as a result, the polar cap may be becoming smaller. Nereid is a small moon that is within range of CCD cameras. Nereid remains far from Neptune's glare and it has an average opposition magnitude of +18.7.

Table 3: Major historical developments related to Neptune.[a]

Year	Event
1840s	Adams and Le Verrier suspect that an 8th planet in influencing Uranus' position
1846	Galle spots Neptune based on Le Verrier's predictions
1846	Lassell discovers Neptune's largest moon Triton
1949	Kuiper discovers Nereid
1970s-1980s	CCD images show cloud detail on Neptune
1984	Brahic, Hubbard and others discover a ring around Neptune
1989	Voyager II flies by Neptune
1989	Scientists discover 6 new moons and at least 3 rings from Voyager II data

Table 4: Facts and Figures related to Neptune.[a]

Quantity	Value	Quantity	Value
Diameter (km)	49,500	Average Opposition Magnitude	+7.8
Mass (kg)	1.0×10^{26}	Average B-V color index	+0.41
Average density (g/cm^3)	1.6	Number of known Moons	8
Angular size of disc	2.3 arc-sec	Atmospheric composition	H_2,He,CH_4
Average distance from Sun	4.5×10^9 km	Geometric Albedo	0.41
Period of revolution (years)	165	Polar Flattening	0.017
Period of rotation	$16^h\ 3^m$	Color	pale blue

[a] Taken from: (Astronomical Almanac 2000), (Cruikshank and Morrison 1990) and (Zeilik 1997).

C. Pluto

Unlike Uranus and Neptune, Pluto has a solid surface that is visible from outer space. Pluto is the only planet that has not been visited by a space probe; however, the Hubble Space Telescope has taken some fine pictures of the planet. Table 5 lists the major historical developments related to Pluto while Table 6 lists facts and figures related to the ninth planet.

Table 5: Major historical developments related to Pluto.[a]

Year	Event
1930	Tombaugh discovers Pluto
1978	Christy discovers Pluto's moon Charon
1980s	Pluto and Charon eclipse one another
1988	Pluto's diameter is determined to an accuracy of ~2%
1990s	Hubble Space Telescope images reveal large bright and dark spots on Pluto

Table 6: Facts and figures related to Pluto.[a]

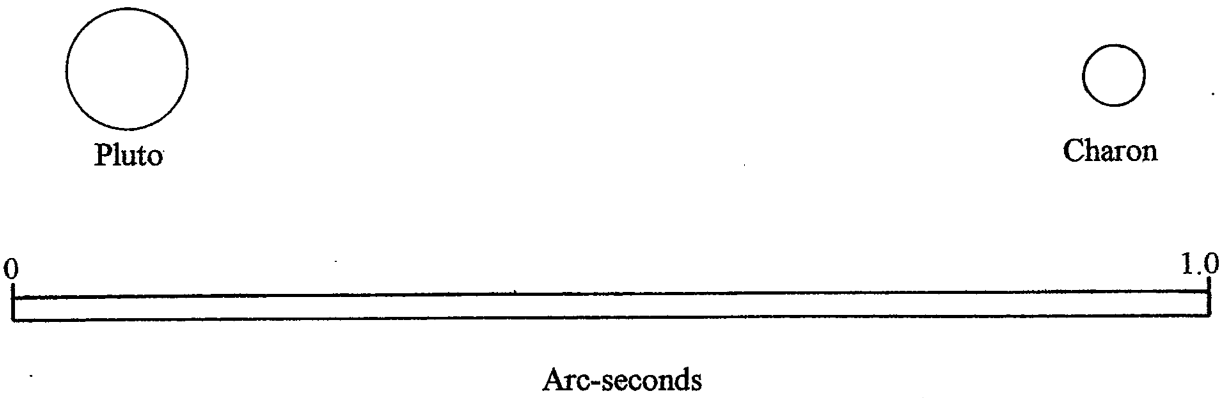
Quantity	Value	Quantity	Value
Diameter (km)	2300	Opposition Magnitude (2000)	+13.7
Mass (kg)	1.29×10^{22}	Average B-V color index	+0.80
Average density (g/cm^3)	2.0	Number of known Moons	1
Distance from Sun in 2000	4.5×10^9 km	Daytime temperature	~60 K
Average distance from Sun	5.9×10^9 km	Period of Revolution	249 years
Atmospheric composition	CH_4, N_2?	Period of Rotation	$6^d\ 9^h\ 18^m$

[a] Taken from: (Astronomical Almanac 2000), (Cruikshank and Morrison 1990) and (Zeilik 1997).

Pluto is both the smallest and faintest planet in the solar system. Through even the best earth based telescope, Pluto appears as a faint dot. The Hubble Space Telescope, however, has shown that Pluto has many bright and dark spots on its surface. Like the other planets, Pluto undergoes four seasons. One seasonal change which may be occurring on Pluto is a change in that Planet's light

curve. The light curve is a graph of brightness plotted on the vertical axis versus longitude which is plotted on the horizontal axis. The difference between the brightest and dimmest longitudes has increased by a factor of two between the mid 1950s and mid 1980s (Cruikshank and Morrison 1990). In 1998, Frank Melillo used a CCD camera (unfiltered) to measure Pluto's light curve (Melillo 2000). The light curve is different from the ones in the 1950s and 1980s. Methane ice has been detected on Pluto while water ice has been detected on Charon. The eclipses of Pluto and Charon allowed scientists to determine the diameters of Pluto and Charon to within ~2%. Charon has a diameter of 1190 km or 740 miles. Figure 2 illustrates the sizes of Pluto, Charon and their distance all drawn to scale.

Figure 2: Sizes of Pluto, Charon and their distance all drawn to scale. A bar indicating the size of 1.0 arc-second from the Earth is also shown for comparison.



Chapter II: Finding Uranus, Neptune and Pluto

A. Finding Uranus

The observer should begin his/her search of Uranus in dark skies away from city lights and should have a star chart and a finder chart of that planet. The observer should also carry out his/her search when Uranus is within 2 hours of transiting the meridian; at this point, Uranus is at its highest point in the sky. For observers north of 25°N during 2001, the approximate dates and respective times that Uranus transits the meridian are: April 15 (13:00 U.T.), May 15 (11:00 U.T.), June 15 (9:00 U.T.), July 15 (7:00 U.T.), Aug. 15 (5:00 U.T.), Sep. 15 (3:00 U.T.), Oct. 15 (1:00 U.T.) and Nov. 15 (23:00 U.T.). For every year after 2001, add 4.1 days to the dates listed so for example, in 2008, Uranus will transit the meridian at 5:00 U.T. on about Sep. 13.

Once a suitable location, date and time are selected, the observer begins the search by using the finder chart of Uranus and a star atlas to locate the general area where Uranus is located. (A finder chart is a map of an area of the sky containing the target object — Uranus in this case — along with nearby bright stars.) One uses the stars near Uranus as landmarks in finding that planet much like a driver uses road signs, traffic lights and buildings as landmarks when driving in an unfamiliar area. The many stars in the sky can at first overwhelm the beginner -- be patient; it took me nearly 20 minutes to identify the constellation Hercules when I first started observing variable stars. I highly recommend that the beginner carries out his/her first search of Uranus with a pair of **binoculars** and not a telescope. One should get a feel for the binoculars and carry out the search by first starting with a familiar constellation like Capricorn, Sagittarius or Lyra and then moving towards the area where Uranus is. Use the finder chart to confirm Uranus. Good finder charts for both Uranus and Neptune can be found in the Observer's Handbook of the Royal Astronomical Society of Canada or in Sky and Telescope Magazine.

If the beginner wishes to find Uranus with a telescope then a good finder scope is necessary. One must remember that most telescopes show things upside down and in many cases the telescope also invert images from left to right. If the beginner is not aware of these problems then he/she is headed for frustration! **Get to know the orientation of your finder scope and telescope.** Once

this is done carry out the search using the finder scope and then use low magnification on the main telescope. Once you suspect Uranus in the main telescope, increase the magnification to 200X and a disk should be visible unless the seeing is very poor. The task of identifying Uranus is made much easier with setting circles and computer slewing, but one should still know the orientation of his/her telescope to identify Uranus.

B. Finding Neptune

Neptune is three times more difficult to find than Uranus. The rules for finding Uranus apply to Neptune except that I would recommend using a large pair of binoculars like 10x70s. I would also recommend that the beginner try to find Uranus first before graduating on to Neptune. To identify the disc of Neptune at least average seeing is needed since Neptune's disc is only 2.3 arc-seconds in diameter. Neptune is quite faint in a 50 millimeter (2 inch) finder scope. A more extensive star atlas like Uranometria or the Millennium Star Atlas would be an important aid in finding Neptune. For 2001, the dates and approximate times that Neptune will transit the meridian are: April 1 (13:00 U.T.), May 1 (11:00 U.T.), June 1 (9:00 U.T.), July 1 (7:00 U.T.), Aug. 1, (5:00 U.T.), Sep. 1 (3:00 U.T.), Oct. 1 (1:00 U.T.) and Nov. 1 (23:00 U.T.). For every year after 2001, add 2.2 days to the dates so for example, Neptune will transit the meridian at 5:00 U.T. in 2009 on about Aug. 19.

C. Finding Pluto

Pluto is 100 times harder to find than Neptune. Look for Uranus and Neptune first before attempting the Pluto challenge. Like Uranus and Neptune, Pluto is best seen when it transits the meridian. For observers north of 25°N, during the decade of 2000 to 2010, the approximate dates and respective times that Pluto transits the meridian are: March 7 (11:00 U.T.), April 7 (9:00 U.T.), May 7 (7:00 U.T.), June 7 (5:00 U.T.), July 7 (3:00 U.T.), Aug. 7 (1:00 U.T.) and Sep. 7 (23:00 U.T.).

Two excellent finder charts for Pluto are published in the Observer's Handbook of the Royal Astronomical Society of Canada and in Sky & Telescope magazine. The Millennium Star Atlas or the electronic version of the Palomar Sky Survey are good star atlases to use in your search. Table 7 give a checklist for carrying out a search of Pluto.

Table 7: Checklist for carrying out a successful search of Pluto.

1. Atmosphere must be free of haze and moonlight
2. There must be little or no artificial light at your observing site; use a red flashlight
3. Collimate the telescope and make sure optics are clean
4. Use high light transmission eyepieces
5. Bring a detailed star atlas; if using a star atlas on the computer then place a red transparency in front of the screen to preserve night vision
6. Bring a Pluto finder chart
7. Begin search when Pluto is near the meridian
8. Check orientation of telescope in comparison to finder chart and star atlas before beginning search
9. Check optics periodically for dew; use a hair dryer to remove dew.
10. Good setting circles are helpful but are not necessary to find Pluto

Even with an excellent finder chart, telescope and sky conditions, it still took me almost an hour to find Pluto. The reason for this was that I did not get familiar with the orientation of the telescope. I used a star diagonal which flipped things from right to left and as a result I kept getting confused even though I knew I was near Pluto. The moral of this story is: **know the orientation of your finder scope and your telescope**. When viewing Pluto in the telescope make sure that you use an eyepiece that transmits as much light as possible. Generally the more expensive eyepieces transmit more light — ask your telescope dealer or a veteran deep sky observer about this.

Chapter III: Observing Programs

The A.L.P.O. remote planets section is interested in the meteorology of Uranus, Neptune and Pluto along with the color, brightness and shapes of the satellites of these planets. The existence of additional rings around Neptune (or Uranus) is also of interest. Seasonal changes in the brightness, color and appearance of the remote planets and their moons is of great interest to the section, and finally changes caused by the 11 year solar cycle are of interest as well. All of these are opportunities that the observer can participate in to advance science. There are eight areas where the observer with modest equipment can make a contribution.

A. Drawings

The discs of Uranus and Neptune have angular sizes of about 3.7 and 2.3 arc-seconds respectively and so excellent seeing conditions, high magnifications and excellent telescopes are all a must for having any chance of sighting detail on these remote worlds. Since the author has only looked at Uranus and Neptune through about a half dozen different telescopes, he will not comment on what the "minimum aperture" should be to have any hope of seeing detail on these planets. Magnifications of at least 200X and 350X are recommended for Uranus and Neptune respectively. Observers with large telescopes should attempt to use color filters to observer these two planets. The recommended filters for starting out are: #23 (orange), #15 (yellow) and #82 (blue). The darker #25 (red) and #58 (green) could be added as one gets used to the other filters. If an albedo feature is detected on either Uranus or Neptune, try to get a friend to examine the disk (but do not tell them what you saw) and then ask them what they see. If they describe what you saw then you have independent confirmation of the feature. The A.L.P.O., I.A.U. and B.A.A. remote planets coordinators should be contacted as soon as possible. With current technology, it is not possible to make drawings of Pluto or the moons of Uranus and Neptune. It may however be possible to see the shadows of the moons as they transit Uranus or the shadows of the rings on the disc of Uranus.

Drawings serve three purposes: 1) they show cloud changes, 2) they aid in the interpretation of brightness and color measurements and 3) they can yield information on rotation periods.

B. Eyeball Magnitude Estimates

Eyeball magnitude estimates of Uranus, Neptune and Pluto can be made by comparing their magnitudes to those of nearby stars. CAUTION: one should not use Johnson V-filter magnitudes in place of eyeball magnitudes; see Stanton (1999). The author has used the eyeball magnitudes of stars in the AAVSO star atlas. Active observers receive a finder chart for Uranus and Neptune every year showing the eyeball magnitudes of nearby comparison stars; these charts can be obtained from the author. Eyeball magnitudes are reported to the nearest 0.1 magnitudes.

Eyeball magnitudes serve two purposes: 1) they serve as an approximate indicator of brightness and 2) historical continuity. By historical continuity it is meant that data in 2000 can be compared to data made in the 19th century. If it is possible, the observer should try to use the same set of comparison stars for several years especially for Neptune.

C. Photoelectric Photometry

Photometry is a branch of astronomy that deals with the brightness of objects. The present coordinator has placed a large emphasis on photoelectric photometry. This technique can yield brightness or color values to an accuracy of 1% under ideal sky conditions. An instrument called a photoelectric photometer is needed in making accurate brightness measurements. The basic idea of photoelectric photometry is to measure the light coming from a star of known magnitude, measure the amount of light coming from the target object, and then compute the magnitude of the target object using an equation. A worked example is presented in Chapter V. Two corrections must be made to all magnitude measurements which are: extinction and color corrections; these are described in Chapter V.

Specific questions that accurate brightness and color measurements can answer include:

1) Do Uranus and Neptune change in brightness and color as a result of changing season?
2) Is the color and/or brightness of Pluto's surface changing?
3) Are there any short bursts of color or brightness changes taking place on Uranus or Neptune?
4) What is the shape and orientation of Nereid?
5) Do the polar caps on Triton get bigger and smaller with the seasons?
6) Does the 11 year solar cycle influence the brightness of Uranus and Neptune?

D. Charged Coupled Device (CCD) Photometry

The author has never made a photometric measurement using a CCD camera but he has attended a course on this procedure.

The CCD camera is an electronic camera that requires a computer and software. This instrument is ideal for carrying out precise brightness and color measurements of objects fainter than magnitude +12. Stray light from a nearby bright object can be subtracted out in a CCD image. The day may even come when A.L.P.O. members may be able to measure the brightness of Pluto and Charon separately using CCD cameras and adaptive optics. The benefits of CCD photometry are similar to those of photoelectric photometry.

E. Occultations

The astronomer may be able to contribute to our knowledge of the rings of Neptune by monitoring stellar occultations. A stellar occultation occurs when an object moves in front of a star and blocks out the star's light. One essential piece of equipment for occultation work is a time piece which is calibrated to the time signal of the United States Naval Observatory. This signal can be picked up with a short wave radio at frequencies of 2.5, 5.0, 10.0 and 15.0 megahertz. One may also get the time signal by accessing the U.S. Naval observatory web time signal through the URL: http://tycho.usno.navy.mil/cgi-bin/timer.pl or call the Naval Observatory at: 1-900-410-8463.

Occultation data may reveal new undiscovered ring arcs around Neptune or any changes occurring in the rings of Uranus and Neptune. If the star is bright enough, one may also want to watch it as it passes through the atmospheres of Uranus, Neptune and Pluto. The observer should however be forewarned that professional astronomers generally study occultations very well and so the scientific contribution of the amateur may be minimal in this area.

F. Spectroscopy

Spectroscopy is that branch of science that deals with the individual frequencies of light. Spectroscopy is a powerful technique which professional astronomers have used to determine the chemical composition, temperature and magnetic environment of planets and stars. Frank Melillo succeeded in photographing the spectrums of both Uranus and Neptune in 1999.

G. Historical Data

Old drawings, photographs and other measurements are always welcomed. The author strongly believes in historical continuity and will incorporate older data into recent reports. A second reason for the importance of historical data is the fact that Uranus, Neptune and Pluto have such long periods of revolution. Data spanning several decades are needed to understand seasonal changes on the remote planets.

H. Color Estimates

Observers are encouraged to describe the colors of Uranus and Neptune. Any strange changes should be immediately confirmed by a friend and reported to the coordinator. One of the goals of the author is to collect both eyeball and electronic data and then compare the two sets of data; in this way, data from the 19th and early 20th centuries can be compared to more recent data.

Chapter IV: Remote Planets Observing Form

The official A.L.P.O. remote planets observing form is shown on the following page. The form covers six types of observations which are: drawings, color estimates, photoelectric magnitude measurements, eyeball magnitude estimates, photographs/CCD images and occultation/near misses. If possible, please fill in as much information as possible, and if there is anything that you do not understand then leave it blank.

If you are making a drawing it is critically important to circle the N or S and P or F. The N or S means north or south; I want to know whether the top part is the north or south limb. The limb is the edge of the planet's disk. The P or F means preceding or following; I want to know whether the left limb is the preceding or following limb. The recorder is hoping that observers will orient their drawing so that the preceding/following goes along the horizontal and that north/south goes along the vertical. One can determine which side of the disk is north by nudging the telescope towards the south and the limb that approaches the edge of the field of view is the north limb. Similarly turn off the clock drive of the telescope and watch the disc appear to move; the preceding limb is that part which will move out of the field of view first.

Please also be aware that I would like the Universal time if possible. Universal time is computed by adding 4, 5, 6, 7 and 9 hours to the local standard daylight time for the eastern, central, mountain, pacific and Hawaii time zones. If observations are made during standard time then 5, 6, 7, 8 and 10 hours must be added for the eastern, central, mountain, pacific and Hawaii time zones to obtain Universal time. Daylight savings time begins at 2:00 am on the first Sunday in April and ends at 2:00 am on the last Sunday in October for most of the United States.

The seeing blank in the top blank of the observing form refers to how steady the atmosphere is; seeing is estimated on a scale of 10 = very steady air to 1 = very turbulent air. The transparency refers to how clear the air is; it is measured by reporting the faintest star magnitude that is visible to the naked eye. The telescope type blank refers to weather a refractor, Newtonian, Schmidt-Cassegrain, etc. was used in making the observation. For eyeball estimates in the bottom section, please indicate the magnification and aperture of your binoculars or telescope in the "Instrument" blank.

A.L.P.O. Remote Planets Section Observing Form

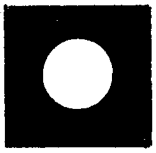
Name: ____________________ E-mail address: ____________________

Date (U.T.): __________ Start time (U.T.): __________ End time (U.T.): __________

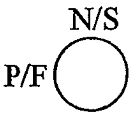
Telescope: Type: __________ Aperture: ________ Magnification: __________ Seeing: ______

Transparency: _____ Postal Address: ______________________________

Drawing



Drawing



Intensities

Planet: __________ Circle: N or S & P or F

Comments: ____________________

____

____

____

____

Photograph or CCD Image

Method: prime focus/eyepiece projection/CCD

Film: speed: __________ Type: __________

Exposure Time: ____________________

Developer: ____________________

Software used (CCD images): __________

Image scale information: __________

____

Comments: ____________________

____

Color Estimate

Planet: ________ Sky conditions: ________

Color description and comments: ________

____

____

____

____

Occultation/Near Miss

Planet: ____________________

Star: Name: ____________________

Right Ascension: ________ Declination: ______

Comments: ____________________

____

Photoelectric magnitude measurements: Include reductions on a separate sheet of paper.

Extinction correction made: yes or no Color correction made: yes or no Filter used: ______

Comparison Star: Name and B and V magnitudes: ____________________

Measured Planet magnitude: _____ Comments: ____________________

Eyeball magnitude estimates

Comparison Star: name: ________ Magnitude: ________ Source: ____________________

Planet: __________ Estimated Magnitude: ________ Instrument: ____________________

Chapter V: Photoelectric Photometry

A. The Photoelectric Photometer

The photoelectric photometer is a device that converts light into an electrical signal. One vital characteristic of a good photometer is that the electrical signal is directly proportional to the amount of light reaching the detector. Figure 3 illustrates the main steps in the photoelectric photometry process. Light first leaves an extraterrestrial object and heads towards Earth. This light then passes through the atmosphere. The amount of atmosphere that the light travels through depends on the elevation of the light source above the photometer's horizon. The higher up the light source is the less air the light must travel through; see Figure 4. It is not uncommon for the atmosphere to absorb 50% of the light heading towards the photometer. Once the light moves through the atmosphere, it enters the telescope and is focused onto the photometer detector. The light striking the detector is then converted into an electrical signal. Finally, the electrical signal is either sent to a readout, a computer or to a chart recorder.

Once the photometer is inserted and the telescope is balanced, one must look through the photometer and focus the telescope. The SSP-3 instrument has a flip mirror which directs light to either the observer's eye or to the detector. A small illuminated ring at the center of the photometer field of view defines the detector area; or in other words, if the star is in this ring then the star light will reach the detector when the mirror is flipped. More information on the SSP-3 photometer can be found in the SSP-3 manual (Optec, Inc., 1997); Optec routinely advertises in Sky and Telescope.

B. Collection of Photometric Data

The basic idea of photoelectric photometry is to first measure a star of known brightness and then measure an object (Uranus) of unknown brightness; the brightness of the unknown object can then be computed. The star serves as a calibration object and is called "the comparison star". It is necessary to use a comparison star, because the sky transparency changes from one night to the next. A typical set of measurements consists of 3 sky measurements, 3 comparison star measurements and then 3 more sky measurements. This is repeated for the target object and for the comparison star yielding 27 measurements like what is in Table 8. A sky measurement consists of pointing the

photometer-telescope assembly a short distance away from the comparison star and then flipping the mirror. Sky measurements must be taken for two reasons: 1) the sky contributes some light and 2) the photometer is offset to prevent negative readings. The offset means that even if no light enters the detector, the photometer will give a non-zero reading. Sky measurements are taken both before and after the comparison star to insure that the sky brightness has not changed. Three measurements of the comparison star are taken to insure better accuracy and that the sky transparency is not changing drastically. The three comparison star measurements should be within 2-3% of one another, otherwise, there may be transparency problems. An example of data reduction will be presented.

C. Evaluation of Photoelectric Data

I will work an example of a magnitude calculation from the photoelectric data in Table 8.

Table 8: Sample photoelectric data

Date: May 7, 2000 Filter used: V Comparison Star: γ-Capricorn

V-filter magnitude of γ-Capricorn is +3.67

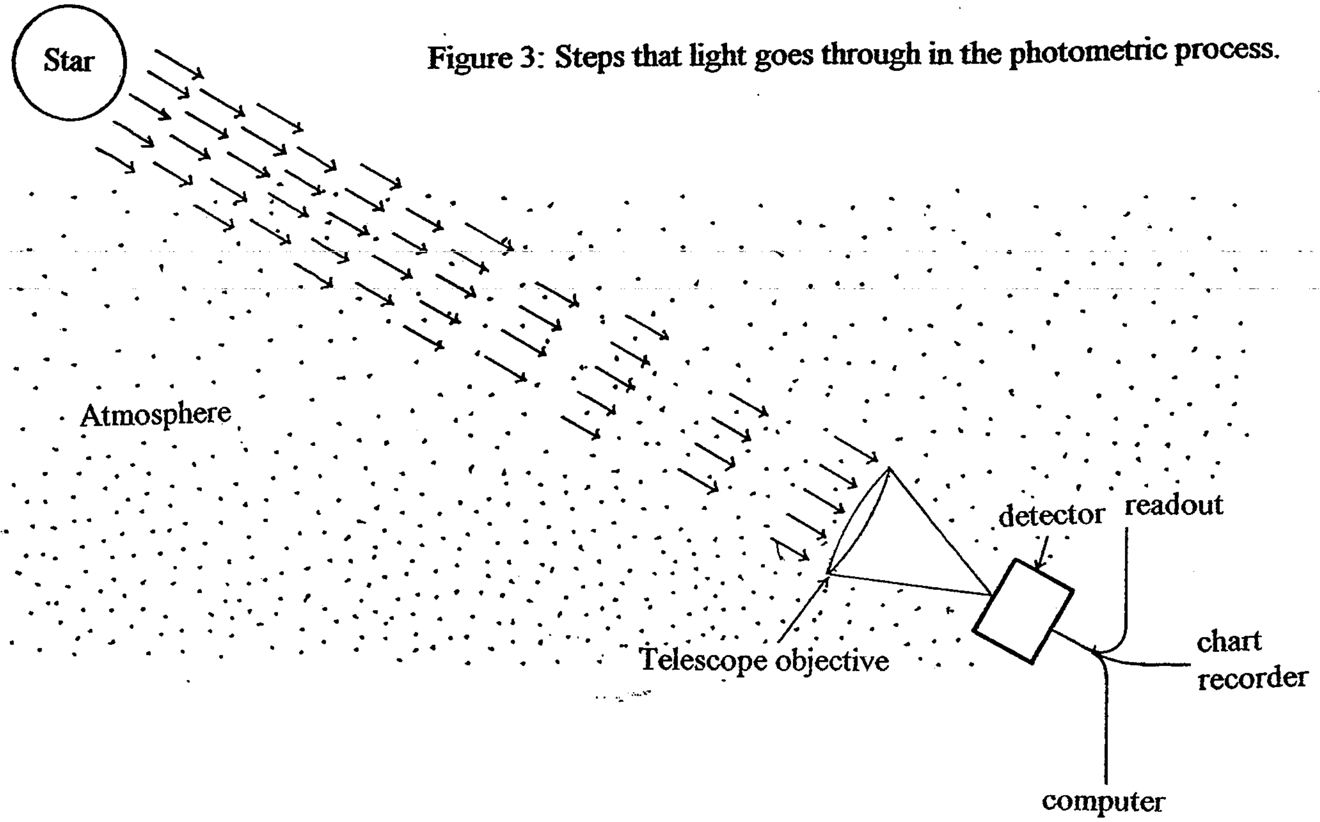
γ-Capricorn 9:08-9:11 U.T.			Uranus 9:15-9:17 U.T.			γ-Capricorn 9:18-9:21 U.T.		
Sky	Star + Sky	Sky	Sky	Uranus + Sky	Sky	Sky	Star + Sky	Sky
115	1167	115	109	271	109	113	1239	119
115	1166	114	108	272	108	112	1232	117
114	1180	115	108	272	108	111	1220	116

The V-filter magnitude of Uranus V_t is computed from (Hall and Genet, 1988):

$$V_t = V_C + \Delta v - k_V'(\Delta AM) + \varepsilon_V \Delta(B-V) \qquad (1)$$

where V_C is the magnitude of the comparison star (+3.67), Δv is the measured magnitude difference between Uranus and the comparison star (uncorrected for extinction and transformation), ε_V is the transformation coefficient for the V-filter, $\Delta(B-V)$ is the difference between the B-V values for Uranus and the comparison star, k_V' is the extinction coefficient in the V-filter and ΔAM is the difference in air mass between the comparison star and Uranus. The last two terms in equation 1 are treated later in this chapter, while Δv is treated below.

Figure 3: Steps that light goes through in the photometric process.



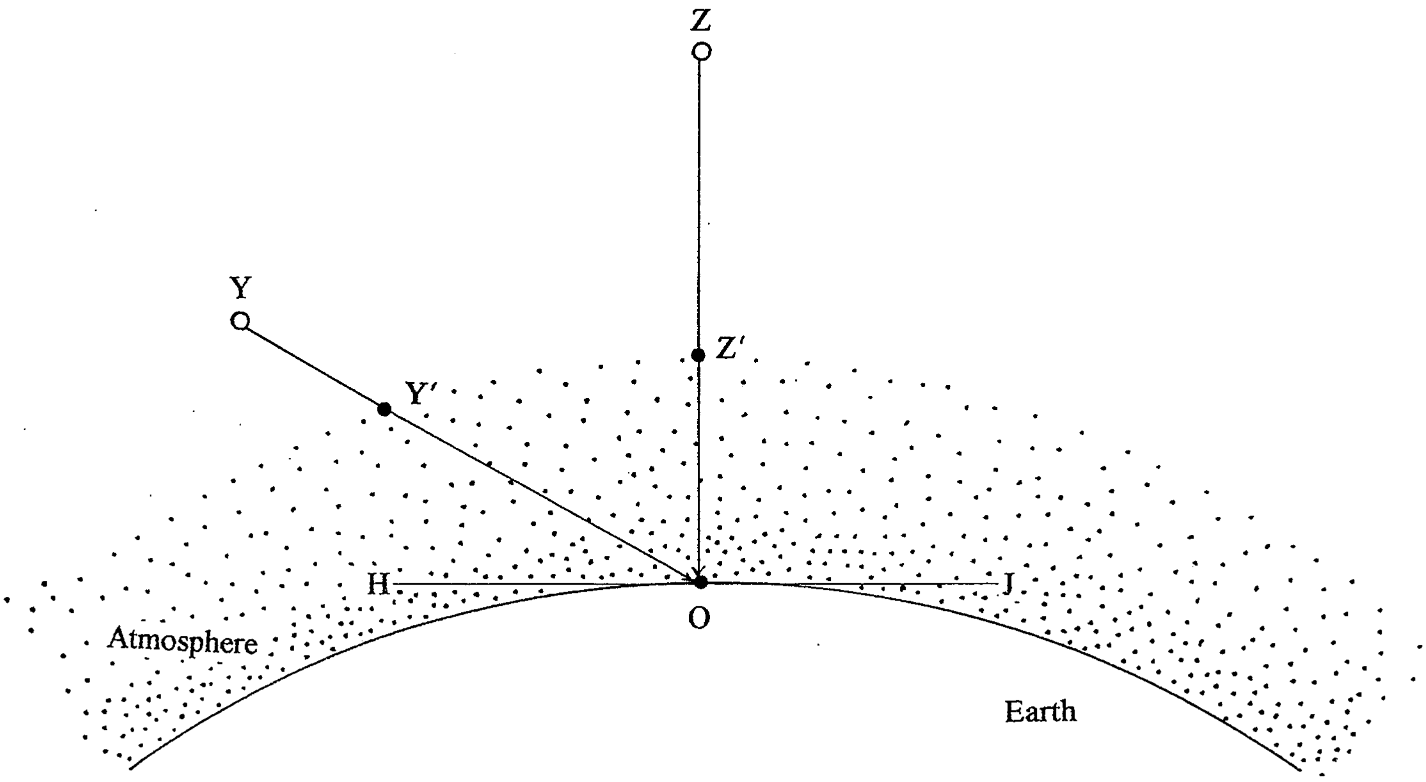


Figure 4: An illustration of equation (5) in the text. Celestial object Z is at the observer's zenith and the light from this object travels through a cross section of Earth's atmosphere designated as Z′O. The mass of air lying above segment Z′O is defined as 1.0 air mass. A ruler shows that segment Y′O is 1.6 times the length of Z′O and so light from star Y has to travel through 1.6 air masses. The observer is at point O and segment HJ is the observer's horizon.

One can write:

$$\Delta v = 2.500\log[C_C/C_t] \qquad (2)$$

where C_C is the counts for the comparison star and C_t is the counts for the target (the target is Uranus). When computing C_C and C_t, one must always subtract the sky measurements from the object+sky measurement. An example of calculating Δv is worked out using the data in Table 8.

γ-Capricorn (first set of measurement at 9:08-9:11 U.T.)

Average sky reading = 114.7	average star+sky reading = 1171	$C_C = 1056.3$

Uranus Measurement

Average sky reading = 108.3	average Uranus+sky reading = 271.7	$C_t = 163.4$

γ-Capricorn (second set of measurement at 9:18-9:21 U.T.)

Average sky reading = 114.7	average star+sky reading = 1230.3	$C_C = 1115.6$

I always like to take the average of the C_C measurement on either side of the C_t measurement; therefore the average C_C value is: $C_C = 1086.0$. The value of Δv is:

$$\Delta v = 2.500 \log[1086.0/163.4] = 2.056 \qquad (3)$$

D. Extinction Coefficients

The number of stellar magnitudes (f) of light the atmosphere absorbs is (to a good approximation):

$$f = k'/(\sin [A]) \qquad (4)$$

where k′ is the extinction coefficient in magnitudes per air mass and A is the altitude of the object

above the observer's horizon in degrees. The value of k′ changes from one night to the next, and furthermore, the value is usually highest during the summer. In a sense, k′ is a measurement of the sky transparency.

Figure 4 illustrates equation 4. In Figure 4, point O is the observer, Y and Z are the celestial objects and segment HJ is the observer's horizon. One air mass is defined as the quantity of gas extending from the ground up through the observer's zenith and into outer space (segment OZ′ in Figure 1). One can see that light from objects closer to the observer's horizon must travel through greater amounts of atmospheric gas; i.e. segment Y′O.

There are three ways of determining the altitude of an object (A). One way is to measure it with a piece of surveying equipment, a second way is to use computer software, and the third way is to calculate it by hand. I recommend one of the first two ways; however, I will describe the third method since this is what I have used.

The altitude (A) of any celestial object, in degrees, is computed from:

$$A = \text{inv}\sin\{\cos[\delta]\cos[\phi]\cos[h] + \sin[\delta]\sin[\phi]\} \qquad (5)$$

and the pathlength through the atmosphere, measured in air masses, is computed from:

$$AM = 1/\sin[A] \qquad (6)$$

In equation 5, δ is the declination of the celestial object, ϕ is the observer's latitude and h is the hour angle which is the angular distance between the object and the observer's meridian. (There is a + sign for north and a - sign for south for both δ and ϕ.) One can compute h from:

$$h = |\,T - TT\,| \times (15^\circ/\text{hour}) \qquad (7)$$

where T is the time of measurement and TT is the transit time; T - TT is computed in hours. The transit time is the time when the object crosses the meridian. Transit times at the prime meridian (0°

longitude) are listed in the Astronomical Almanac for the planets. Since the observer is probably west of the prime meridian, he/she will have to add the factor {X + (L - L′)/15} where L′ is the observer's longitude in degrees and both X and L are listed in Table 9 for different time zones. The {X + (L - L′)/15} term is in hours. Table 9 can be used regardless of whether the measurement is done during daylight savings time or during standard time.

Table 9: Values of X and L that must be used in computing the time that objects transit the observer's meridian as seen from North America and Hawaii.

Observer's time zone	Value of X	Value of L
Eastern	5	75°
Central	6	90°
Mountain	7	105°
Pacific	8	120°
Hawaii	10	150°

The transit time for the comparison star (TT_C) is computed from:

$$TT_C = TT_t + (RA_C - RA_t) \tag{8}$$

where TT_t is the transit time of the target (Uranus) and RA_C and RA_t are the right ascensions of the comparison star and target respectively. The units in right ascension match the units of time for TT_C.

The altitude of Uranus on May 7, 2000 at 9:16 U.T. will now be computed as an example:

Transit time of Uranus for prime meridian = $6^h\,31.6^m$ *(Astronomical Almanac 2000, p.E46)*
L = 75° (since the author is in the Eastern Time Zone) and X = 5 hours *(Table 9)*
Observer's longitude 84.9°
Transit time for Uranus (TT_t) = $6^h\,31.6^m + \{5 + (84.9^\circ - 75^\circ)/15\}$ hours = $12^h\,11^m$
$h = |9^h\,16^m - 12^h\,11^m\,|\,(15^\circ/\text{hour}) = |9.267 \text{ hour} - 12.183 \text{ hour}\,|\,(15^\circ/\text{hour}) = 43.74^\circ$ *(Eq. 7)*
Observer's latitude: $\phi = +33.8^\circ$ and Declination of Uranus: $\delta = -15.3^\circ$
$A = \text{inv}\sin\{\cos[-15.3^\circ]\cos[+33.8^\circ]\cos[43.74^\circ] + \sin[-15.3^\circ]\sin[+33.8^\circ]\} = 25.61^\circ$ *(Eq. 5)*
Number of air masses (Uranus) = $1/\sin[25.61^\circ] = 2.313$ air masses *(Eq. 6)*

The air masses for γ-Cap are computed in the same way except that equation 8 must be used.

One way to measure the extinction coefficient is to compare measurements of the same star at different times during the night. The extinction coefficient (k_V' for V filter) is computed from:

$$k' = k_V' = (2.500\log[C_{C2}/C_{C1}])/(AM_{C1} - AM_{C2}) \tag{9}$$

Where C_{C1} and C_{C2} are the counts at times 1 and 2 of the same star, and AM_{C1} and AM_{C2} are the number of air masses the star light had to travel through at times 1 and 2.

An example of the evaluation of k_V' is worked out using the data presented in Table 8.

Let time 1 be 9:08 to 9:11 U.T. and Let time 2 be 9:18 to 9:21 U.T.
$C_{C1} = 1056.3$ and $C_{C2} = 1115.6$ $\qquad \delta = -16.7^\circ$ for γ-Capricorn
Right Ascension of Uranus = $21^h\,33^m$ and Right Ascension of γ-Cap is $21^h\,40^m$
Transit time of γ-Capricorn = $12^h\,11^m + (21^h\,40^m - 21^h\,33^m) = 12^h\,18^m$ *(Eq. 8)*
$h = |\,9{:}09.5 - 12{:}18\,| \times 15^\circ = |9.1583 \text{ hours} - 12.3000 \text{ hours}\,| \times 15^\circ = 47.1^\circ$
A (time 1) = $\cos[-16.7^\circ]\cos[33.8^\circ]\cos[47.1^\circ] + \sin[-16.7^\circ]\sin[33.8^\circ] = 22.45^\circ$ *(Eq. 5)*
$AM_{C1} = 2.618$ air masses *(Eq. 6)*
$h = |\,9{:}19.5 - 12{:}18\,| \times 15^\circ = |9.3250 \text{ hours} - 12.3000 \text{ hours}\,| \times 15^\circ = 44.6^\circ$
A (time 2) = $\cos[-16.7^\circ]\cos[33.8^\circ]\cos[44.6^\circ] + \sin[-16.7^\circ]\sin[33.8^\circ] = 24.01^\circ$ *(Eq. 5)*
$AM_{C2} = 2.458$ air masses *(Eq. 6)*
$k_V' = k' = \{2.500\log[1115.6/1056.3] \div [2.618 - 2.458]\} = 0.371$ magnitude/air mass *(Eq. 9)*

Since V-filter data were used in the measurement of the extinction coefficient, the special symbol k_V' is used designate "the extinction coefficient in the V-filter". An extinction coefficient must be measured for each filter used.

One must now evaluate the $k'(\Delta AM)$ term in equation 1. The ΔAM is the difference in air mass between the comparison star and the target object (Uranus in this case). I have always used the convention of target - comparison star to keep track of the signs. As an example consider the data presented in Table 8:

Air mass of γ-Capricorn at 9:09:30* U.T. = 2.618 air mass *(9:09:30 is the average time)
Air mass of Uranus at 9:16 U.T. = 2.313 air mass
Air mass of γ-Capricorn at 9:19:30* U.T. = 2.458 air mass *(9:19:30 is the average time)

Average air mass of γ-Capricorn: (2.618 air mass + 2.458 air mass)/2 = 2.538 air mass
$k_V' = 0.371$ magnitude/air mass
$k_V'(\Delta AM)$ = (0.371 magnitude/air mass)(2.313 air mass - 2.538 air mass) = -0.083 magnitude

E. Color Correction Term

Not all photometers are created equally. Not all telescopes are created equally. These two facts present a problem if we are to compare photoelectric data from different people. This problem is solved when a single standard is adopted by everybody. One common standard is the Johnson UBVRI system. The $\varepsilon\Delta(B\text{-}V)$ term in equation 1 allows one to convert to the Johnson UBVRI system. The transformation coefficient ε must be measured for each filter and for each photometer and telescope. The quickest way to measure ε is to pick out a blue and a red star near each other. A red star will have a spectral class of G, K or M with a B-V value of at least 0.8 while a blue star will have a spectral class of O, B or A with a B-V value of less than 0.2. The transformation coefficient for the V filter (ε_V) is computed from (Hall and Genet, 1988):

$$\varepsilon_V = \{(V_B - V_R) - (v_B - v_R) + k_V'\Delta AM + k_V''\bar{X}[(B\text{-}V)_B - (B\text{-}V)_R]\}/[(B\text{-}V)_B - (B\text{-}V)_R] \quad (10)$$

where the subscripts refer to the Blue (B) and Red (R) stars, $(v_B - v_R)$ is the measured magnitude difference, $(V_B - V_R)$ is the difference in literature magnitude values and $[(B\text{-}V)_B - (B\text{-}V)_R]$ is the literature difference in the B-V values between the two star, k_V' is the extinction coefficient in the V filter, k_V'' is the color dependent extinction coefficient for the V filter, and $\bar{x}$ is the average of the comparison star and target air mass. In general, I have assumed that $k_b'' = -0.03$ and $k_v'' = k_r'' = k_i'' = 0$. The data below will be used as an example in computing the transformation coefficient ε_V.

Date: April 23, 2000

Red star: o-Virgo B-filter magnitude = 5.10 V-filter magnitude = 4.11 B-V = 0.99

Blue star: π-Virgo B-filter magnitude = 4.80 V-filter magnitude = 4.67 B-V = 0.13

Raw data:

o-Virgo			π-Virgo		
Sky	Star+Sky	Sky	Sky	Star+Sky	Sky
83	1409	84	83	908	84
82	1409	83	83	909	84
82	1410	83	84	916	84

Extinction coefficient ($k_V' = 0.368$ magnitude/air mass for April 23, 2000)

o-Virgo data was collected through 1.110 air masses, and $C_C = 1326.5$ for o-Virgo

π-Virgo data was collected through 1.134 air masses, and $C_C = 827.3$ for π-Virgo

assume k_V'' equals 0 so the $k_V''\bar{x}[(B\text{-}V)_B - (B\text{-}V)_R]$ term in equation 10 equals 0

$v_B - v_R = 2.500\log[1326.5/827.3] = 0.513$

$(B - V)_B = 0.13$ and $(B - V)_R = 0.99$

$\varepsilon_V = \{0.56 - 0.513 + [(0.368 \text{ mag/air mass})(1.134 \text{ air mass} - 1.110 \text{ air mass}) + 0\}/(0.13\text{-}0.99)$

$\varepsilon_V = [(0.56 - 0.513 + 0.009)/(-0.86)] = -0.065$

In the box above and in equation 10, I have chosen π-Virgo to be the variable and have always done variable minus comparison star to keep the signs consistent.

Finally getting back to equation 1, the $\varepsilon_V\Delta(B\text{-}V)$ term can now be evaluated remembering that

B-V = 0.56 for Uranus, and always remember that it is target - comparison star. The final magnitude of Uranus based on equation 1 can now be evaluated as:

$$V_t = 3.67 + 2.056 - -0.083 + -0.065(0.56 - 0.32) = 5.7934 \sim 5.79.$$

so $V_t = 5.79$.

Remember that the B-V values of Uranus and γ-Cap are 0.56 and 0.32 respectively. Since the comparison star magnitude is known to only two places beyond the decimal point, one can only report a Uranus magnitude to two places beyond the decimal point.

Chapter VI: Data Bank

The breakdown of the A.L.P.O. Remote Planets data is: 1110 Photoelectric measurements, 1236 eyeball magnitude measurements, 89 drawings and 29 photographs/CCD images. The photoelectric data is organized in Table 10.

Table 10: photoelectric magnitude data as of July 14, 2000.

Year	Planet	U-filter	B-filter	V-filter	R-filter	I-filter	Total
1989	Uranus	0	0	19	0	0	19
1989	Neptune	0	0	7	2	0	9
1990	Uranus	0	0	1	0	0	1
1990	Neptune	0	0	1	0	29	30
1991	Uranus	1	17	53	4	7	82
1991	Neptune	0	13	36	1	5	55
1992	Uranus	10	23	32	10	4	79
1992	Neptune	0	11	14	0	3	28
1993	Uranus	10	34	34	19	19	116
1993	Neptune	0	27	29	18	17	91
1994	Uranus	0	15	16	13	13	57
1994	Neptune	0	11	12	11	11	45
1995	Uranus	1	7	8	7	7	30
1995	Neptune	0	8	10	6	5	29
1996	Uranus	0	5	19	2	1	27
1996	Neptune	0	5	25	0	0	30
1997	Uranus	0	0	57	0	31	88
1997	Neptune	0	4	20	0	0	24
1998	Uranus	0	10	41	0	0	51
1998	Neptune	0	11	31	0	0	42
1999	Uranus	0	23	46	1	9	79
1999	Neptune	0	28	43	2	10	83
2000	Uranus	0	0	4	0	0	4
2000	Neptune	0	0	11	0	0	11

Appendix I: Definitions of Equation Symbols

k_V'	extinction coefficient for the V filter in magnitude/air mass
V_t	V magnitude of Uranus
V_C	V magnitude of the comparison star
Δv	measured magnitude difference (uncorrected for extinction and color)
ΔAM	difference in air mass between the comparison star and the target
ε_V	transformation coefficient for the V-filter
$B-V$	difference between the B and V filter magnitudes
C_C	counts of the comparison star
C_t	counts of the target
f	fraction of light that the atmosphere absorbs
k'	extinction coefficient in magnitude/air mass for any filter
A	Altitude of an extraterrestrial object (above the observer's horizon in degrees)
δ	declination of a celestial object
ϕ	observer's latitude
h	hour angle (angular distance between the object and the meridian in degrees)
T	time of measurement
TT	transit time (time that the object transits the meridian)
X	a constant listed in table 9
L	a constant listed in table 9
L'	Observer's longitude in degrees
TT_C	Transit time of the comparison star
TT_t	Transit time of the target (Uranus in the examples)
RA_C	Right ascension of the comparison star
RA_t	Right ascension of the target (Uranus in the examples)
C_{C2}	Counts of star at time 2 (Used in the evaluation of k_V')
C_{C1}	Counts of star at time 1 (Used in the evaluation of k_V')
AM_{C1}	Air mass of the star at time 1 (Used in the evaluation of k_V')
AM_{C2}	Air mass of the star at time 2 (Used in the evaluation of k_V')
v_B-v_R	Difference in measured magnitudes of the blue and red stars (evaluation of ε_V)
V_B-V_R	Difference in literature V magnitudes of the blue and red stars (evaluation of ε_V)
$(B-V)_B$	Difference between B and V literature magnitude of the blue star (evaluation of ε_V)
$(B-V)_R$	Difference between B and V literature magnitude of the red star (evaluation of ε_V)
k_V''	Color dependent extinction coefficient in the V filter
$\bar{x}$	Average of the comparison star and target air mass
ε	Transformation coefficient for any filter

Glossary

A.L.P.O.: The Association of Lunar and Planetary Observers. This is an international organization of astronomers interested in solar system studies.

Aurora: the northern lights; a glow in the sky which occurs when charged particles strike the atmosphere.

CCD: Charge coupled device; this is an electronic camera.

Charged particles: essentially protons and electrons

Comparison Star: a star with a known brightness that is used as a standard when measuring the magnitude (or brightness) of a target object like Uranus or Neptune

Density: ratio of mass to volume

g/cm³: a unit of density meaning grams per cubic centimeter; water has a density of 1.0 g/cm^3

ice: a term used to describe a mixture of the lighter elements especially hydrogen, carbon, nitrogen and oxygen. Do not confuse this word with frozen water.

Infrared light: a form of radiation very similar to heat.

K: a symbol for degrees Kelvin. Zero Kelvin = -460°F and a change of 1.0 K equals 1.8°F

kg: a metic unit of mass; 2.2 kg equals 1.00 pound

km: a metric unit of distance; 1.609 km equals 1.00 mile

Magnitude: the brightness of an object. The Sun has a magnitude of about -26.8, a full moon has a magnitude of about -12.8 and the north star has a magnitude of +2.1.

Meridian: a line running through the zenith and the north celestial pole (near the north star)

Occultation: an event where an object blocks out a star as seen from the Earth

Photoelectric Photometry: The use of an electrical instrument in measuring the brightness of an object.

Photometry: the branch of astronomy that deals with the measurement of brightness

Prime Meridian: Longitude = 0°; the prime meridian runs through Greenwich, England

Transit Time: the time that an object reaches the Observer's meridian.

U.T.: Universal Time.

Zenith: the point directly overhead

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