A GUIDE FOR VISUAL OBSERVATIONS OF THE PLANET VENUS

The ALPO Venus Handbook

By:

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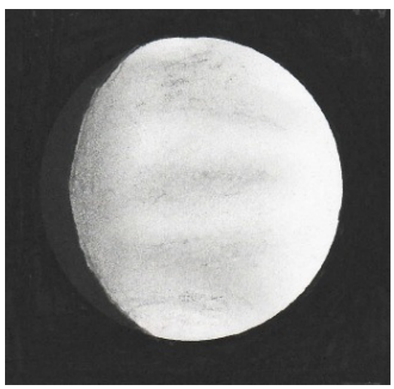

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Preface

Many of us who have been associated with the development and evolution of the ***Association of Lunar and Planetary Observers (ALPO)*** over the years strongly promote the fundamental guiding principle established and maintained by the organization, namely: *to encourage and coordinate regular investigations of the principal planets and other solar system constituents using telescopes and instrumentation normally available to amateur astronomers*. The planetary observer, therefore, realizes his greatest potential for making contributions to science: *a systematic, long-term, simultaneous monitoring of the Moon, principal planets and satellites, comets, meteors, and the Sun*. Observers who participate in our programs strive to successfully record variable phenomena at the surfaces and in the atmospheres of these solar system objects. Keeping up with our planetary neighbors provides the enthusiast with the prospect of shedding light on mysteries that remain unsolved.

A real advantage of the visual observer has always been his unique ability to perceive, at intervals of exceptional seeing, smaller and more delicate detail than, in the past, could normally be photographed by even the largest optical telescopes on Earth. Nowadays, however, outmoded film cameras have been replaced by high-sensitivity CCD imagers that are readily obtainable at reasonable prices. Digital imaging, which now occurs just as routinely as visual studies of Venus, affords observers with an opportunity to easily and systematically capture the notoriously elusive atmospheric cloud features on Venus at various wavelengths, especially in the UV and near-IR bands. While this handbook pertains mainly to visual observations of Venus, there is no doubt that digital imaging, ideally in a concurrent simultaneous observing program, helps confirm and categorize recurring patterns of atmospheric phenomena that occur among the cloud tops of Venus. This helps observers using both methods to establish limits of visibility of discrete features in integrated light (no filter) and at various wavelengths. So, drawings, visual numerical relative intensity estimates, and reports of features seen or suspected visually in the atmosphere of the planet, combined with simultaneous regular imaging of Venus in both UV, IR and other wavelengths, is extremely worthwhile.

This small handbook has been written for the amateur astronomer who wants to pursue an organized program of systematic visual observations of the planet Venus, a beautiful but exceedingly difficult object to observe. Prospective observers should carefully study the contents of this guidebook prior to going to the telescope, chiefly because the methods and techniques described herein should enable the participant in our programs to produce reliable systematic data for analysis. The writer is always pleased to offer assistance to the novice as well as more experienced observers, and those who desire to actively participate in the programs of the Venus Section should join the ALPO and support our overall organizational goals.

Current research on Venus, as well as work in other areas of lunar and planetary astronomy, can be found in various periodicals and contemporary textbooks. Our own official publication, where apparition reports and other articles appear, is the ***Journal of the Association of Lunar and Planetary Observers*** (historically known as *The Strolling*

Astronomer). Members of the ALPO receive this publication, available both in digital and printed form, as a privilege of various categories of membership. Much of its content is unlikely to be found anywhere else. Specialized bulletins, observing alerts, and samples of recent observations appear routinely on the Venus Section page of the official ALPO Website at http://www.alpo-astronomy.org. The ***Astronomical Almanac*** is also a helpful annual publication issued by the U.S. Government Printing Office and can be obtained from various media outlets, such as Sky Publishing Corporation. In addition, there are many good lunar and planetary ephemerides accessible on the internet, as well as excellent specialized computer programs such as ***WINJUPOS*** and ***WIMP*** that can be accessed from links provided on the aforementioned ALPO website. Presented at the end of this book is a fairly extensive list of references for addition authoritative and reliable information about Venus and planetary science as a whole.

The author sincerely thanks those colleagues who helped make this observing manual a reality, particularly our late Founder and Director Emeritus, Walter H. Haas, as well as a host of other individuals too numerous to list here. Without question, an expression of gratitude must go out to the myriad past and present Venus observers who helped our programs by contributing data in the form of descriptive reports, visual numerical relative intensity estimates, drawings and digital images. Those diligent efforts have permitted a refinement of our methods and techniques over the years. May the future hold for us all many rewarding and challenging moments at the telescope observing our solar system, all as a labor of love rooted in the fascination we all share with the night sky!

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Some Introductory Notes About Observing Venus

The planet Venus is one of the most beautiful objects one can witness in the night sky, familiar to most of us as a dazzling brilliant "evening star" or "morning star" surpassed in brightness only by the Sun and Moon. In fact, Venus can cast shadows on exceptionally dark nights, and if one knows where to look during daylight in a clear, transparent sky, the planet can be located without too much trouble. Venus approaches the Earth closer and subtends a larger apparent angle than any other planet in our solar system, and the initial impression is that, besides being easy to find, Venus is an accommodating object for the visual observer and those pursuing digital imaging alike. In practice, however, Venus poses some of the most difficult visual observational problems encountered in optical planetary astronomy. Even though the principal theme of this handbook is traditional visual observation of Venus, more will be discussed in a later section herein about the merits and additional benefits of supplementing visual work with digital imaging.

Situated at a mean distance of 0.7 AU from the Sun, Venus has a diameter of 12,100 km, very close to the size of the Earth (which has a diameter of 12,800 km in comparison), and periodically reaches a maximum elongation from the Sun of 47°. The dense atmosphere of Venus is composed mostly of CO_2 (~97%) and pale yellowish-white, opaque sulfuric acid clouds permanently hide its true surface from our view. These highly reflective clouds, together with the close proximity of Venus to the Earth in its orbit, contribute to the overwhelming brilliance of the planet. It is some 15 times brighter than the familiar star Sirius.

Venus looks essentially featureless in a small telescope, but occasionally its otherwise blank disk is mottled by dusky bands or patches at the threshold of vision. Such cloud structure is considerably more prominent in ultraviolet light (UV) due to the fact that some of the atmospheric constituents absorb in the UV region of the spectrum. Images captured at UV wavelengths with Earth-based telescopes or spacecraft usually reveal banded cloud patterns, but these atmospheric features characteristically lack many of the cyclonic whorls we see in the lower level clouds on Earth. Past Earth-based photographs and images taken in UV wavelengths were used to establish the fact that the clouds high in Venus' atmosphere rotate east to west between 3 and 5 days, a result that was later confirmed by spacecraft. This translates into an astounding wind velocity of 0.1 km/sec from the illuminated hemisphere to the dark side of Venus roughly 60 km above the planet's solid surface. This is referred to as "superrotation" whereby the higher atmosphere of Venus rotates much faster than the bulk of the planet. These astonishing upper atmosphere high-speed winds, however, diminish with decreasing altitude to substantially more gentle winds of about 1.0 m/sec at the surface.

Direct observational studies of the rotation of the solid surface of the planet are precluded by the dense cloud cover of Venus. It was not until the 1960's, through radar techniques, that the retrograde rotation rate of 243.1^d of Venus was discovered. This "backward" or retrograde rotation may be a result of some dynamic resonance that exists between Venus and the Earth. The revolution period of Venus is 224.7^d.

The original observations by Galileo in 1610 of the various phases of Venus provided early confirmation of the Copernican concept of the solar system. Ill-defined dusky features on Venus were first recorded by Fontana in 1645, although many felt that these were attributable to spurious optical and/or psycho-physical effects. Visual observations by Lomonosov in the late 18th century demonstrated that Venus has an atmosphere, and in 1793 Schröter discovered that when Venus was perceived to be at dichotomy (half phase), theory predicted that it should be gibbous, a phenomenon now called the ***Schröter Phase Effect***. From observational studies of illuminated cusp extensions, Schröter deduced that Venus has an atmosphere, and at the end of the 19th century (also from studies of cusp extensions) H.N. Russell did some quantitative work that resulted in a determination of the height of the illuminated layer of Venus' atmosphere (above the opaque cloud strata). Then, in 1928, Ross took UV photographs of Venus that showed streaky cloud features, thus lending credibility to their much earlier detection by visual observers. From about 1900, however, to the present day, we have learned practically all we know about Venus as a planet.

The first United States explorations of Venus were flybys by *Mariner 2* and *Mariner 5* in 1962 and 1967, respectively, while the *Venera* spacecraft were atmospheric entry probes launched by the Soviets in the meantime. The first *Venera* spacecraft were crushed by the high pressures in the atmosphere of Venus before reaching the planetary surface. On December 15, 1970, however, *Venera 7* made the first successful landing on the planet, sending back data to Earth. Subsequent *Venera* space probes touched down on Venus, culminating in *Venera 11* and *Venera 12* in 1978, which photographed the surface and continued to transmit information well into the 1980's. Results revealed a dry, barren, heavily rock-strewn landscape, and at Venus' ground level, the atmosphere appeared to be relatively transparent. Some photographs showed rounded bedrock outcroppings that were curiously indicative of weathering and erosion processes on the planet. During the early 1970's, the cloud properties of Venus were discovered to be due to minute droplets of 78 to 90% concentrated H_2SO_4 (sulfuric acid) The *Venera* spacecraft also recorded a high surface temperature and pressure, respectively, of 750°K and 90 atmospheres. *Venera 15* and *Venera 16*, in contrast to earlier spacecraft in the series, orbited Venus in 1983 utilizing radar techniques to make the first topographic maps of the surface beneath the visually opaque clouds. In 1985, the *Vega* spacecraft used balloons deployed into the atmosphere of Venus to send data to Earth for several days. The only mission to Venus by the United States in the 1970's was *Pioneer Venus*, consisting of an orbiter, *Pioneer 12*, and a multiprobe, *Pioneer 13*. The latter dispatched heat-resisting probes into the atmosphere of Venus, sending back data to Earth. *Pioneer 12* was "renamed" *PVO* or *Pioneer Venus Orbiter*, and it circled the planet until 1992, mapping the surface of Venus by radar, imaging cloud systems, studying solar effects, etc. From about 1987 through 1992, the ALPO Venus Section participated in an international effort to support the *PVO Program Team* in a study of the Ashen Light, a curious illumination of the night hemisphere of Venus recorded visually from Earth for many decades.

Radar studies from Earth, together with the gleanings from the *Venera*, *Vega*, and *Pioneer* missions noted above, all capped off by the magnificent results from the *Magellan* spacecraft in 1990-92 and ESA's highly successful *Venus Express* (VEX) mission from 2006 to 2015, show that Venus has been volcanically active. Several volcanic peaks that rise more than 10 km. above the plains of Venus were detected, and here and there "continents" rise as much as 5 km above the mean surface level of the planet. Upwelling of material in the mantle of Venus may have contributed to the existence of *coronae*, circular formations exceeding 100 km across. Meteorite impact craters also occur in places over the surface, but they are not particularly numerous. This suggests that Venus may have a surface about as young as that of the Earth, and seismic activity is indicated by the presence of tectonic fractures on the surface of the planet. It remains highly likely that some volcanic activity may be continuing today.

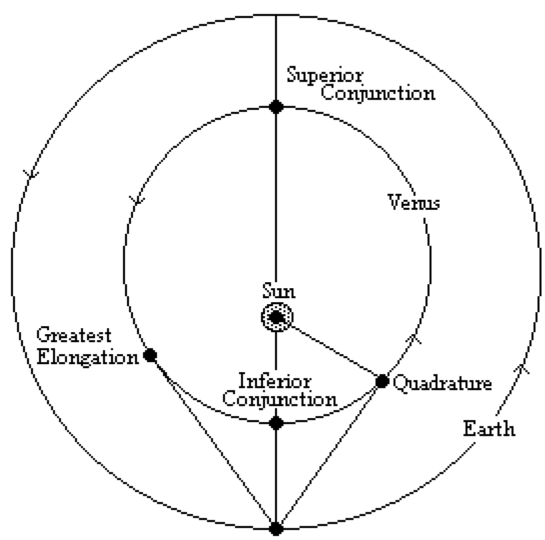
Despite these revelations by spacecraft, the planet Venus for over a century has thoroughly frustrated and perplexed the visual observer, regardless of experience or instrumentation. This has become known among Venus observers as *the condition of limited returns*, and is an underlying reason why many people impatiently tend to give up on observing the planet. Since the early 1900's, only a scanty amount of data of recognizable scientific worth has been generated by visual observers. One might ask, then, what can one hope to learn about Venus or contribute to science through continued visual observations? Indeed, why should anyone devote precious time and energy pursuing visual studies of a planet that seems so unlikely to yield much in the way of tangible information, regardless of one's observational diligence, enthusiasm, and patience? The response to such queries have to be carefully considered, because the reply must provide a rationale for the existence of the ALPO Venus Section, our various research programs now underway, and this book, as well as the past and future role of amateur astronomers in the visual study of a planet whose most remarkable feature is its virtually featureless disk!

In consideration of all of this, it should be pointed out that a tremendous number of past and present students of Venus have neglected to take the time to fully comprehend the extent of the complexities inherent in visual observations of the planet. A great majority of individuals have, in fact, expected far too much from visual observations, while some have been associated with ventures that have been grossly misdirected. Some people have come to the telescope expecting to make some startling new discovery. Without seeming unduly critical of those persons with good intentions, it should be stated that many individuals just have not known what to realistically look for on Venus, or where and how to invest the correct amount of time. These remarks, upon first examination, perhaps sound highly discouraging, and without the determination to read on, one might have an inclination to close this book at this point and abandon any thought of pursuing Venus visually. Such a perception would be overly presumptuous, because the author (as well as many dedicated colleagues) is far from willing to dismiss the possibility or probability of vital, positive contributions by visual observers to an understanding of Venus as a planet. These discussions are intended to provide justification for continued (but properly directed) visual studies of Venus, to outline theoretical methods and practical techniques for effective, reliable data acquisition, keeping in perspective all the while the unique problems of visual telescopic work we have addressed.

As suggested in the foregoing paragraphs, visual observations of the planet Venus should be carried out in a cooperative systematic research program to maximize opportunities for useful scientific contributions. In the ALPO Venus Section, our objective is to observe Venus on every possible clear night throughout an ***apparition*** of the planet, which runs from conjunction to subsequent conjunction with the Sun.

Venus is an ***inferior planet***, meaning that it has a smaller interior orbit to that of the Earth, and it exhibits phases just like the Moon. *Figure 1* shows the geometry of Venus' orbit about the Sun, as well as that of the Earth, and reference to this diagram should be made in the course of our present discussion. Because Venus is comparatively near the Sun, it is characteristically very bright, and the high albedo produces an excessive amount of glare. The rather faint and elusive markings on the disk of Venus, normally of very low contrast, become difficult to see as a result.

Figure 1.



Heliocentric Planetary Configuration of
Venus and the Earth

Controversy exists over the true nature of the dusky amorphous or somewhat streaky atmospheric features. It is not at all unusual for two observers, working on the same date with comparable instrumentation, to see striking dissimilar atmospheric phenomena on the planet.

Look at the heliocentric planetary diagram in *Figure 1* above. The arrows indicate the direction (prograde) of orbital motion (eastern) as well as the rotational direction of the Earth. An ***elongation*** is defined as the angle at the Earth between the Sun and the planet Venus, and in our discussion we will refer to both ***eastern elongation*** and ***western elongation***, according to whether Venus lies toward the East or West of the Sun in the terrestrial sky.

Elongations of particular geocentric significance are assigned special names:

0°	=	***Conjunction*** (***inferior conjunction*** occurs when Venus lies between the Earth and Sun, and ***superior conjunction*** occurs when Venus lies opposite the Sun from the Earth).
47°	=	***Greatest elongation*** (this is the maximum elongation of Venus, and it may be further defined as either ***greatest eastern elongation*** or ***greatest western elongation*** when Venus reaches approximately 47° East or West of the Sun as seen from Earth, respectively).

Venus may be seen at any elongation from the Sun from 0° to 47°, but it is never more than about 47° as seen from the Earth. Thus, as Earth-based observers, we do not see Venus at opposition or 180° from the Sun like superior planets (e.g., Mars, Jupiter, Saturn, and so on) which are exterior to the orbit of the Earth. The ***synodic period*** of Venus, or the time it takes for the planet to return to the same position in the sky relative to the Sun as seen from the Earth, is $583^{d}.92$, during which time one ***eastern (evening) apparition*** and one ***western (morning) apparition*** of Venus takes place (progressively as Venus orbits the Sun once from our vantage point on the Earth). It is the arbitrary, yet customary, procedure to follow Venus immediately after the planet emerges in the western sky from the prevailing glare of the Sun (by orbital eastward motion), to greatest eastern elongation (about 47°), to as close to inferior conjunction as the proximity of the planet to the Sun allows. Note that Venus has progressed during this time from its near-minimal angular diameter of around 10″.0 (when farthest from the Earth) and almost fully illuminated disk, through successive waning phases, culminating in a thin crescent and near-maximum angular diameter of roughly 64″.0 just prior to inferior conjunction and closest approach to the Earth. The observer sees the leading side of Venus during this interval, and because the planet rotates in a retrograde sense, a view from terrestrial dusk means that it is largely the dusk hemisphere of Venus that is being observed. The entire aforementioned ***observing season*** is referred to as an ***eastern (evening) apparition*** of Venus for the year in question.

A ***western (morning) apparition*** of Venus follows immediately after the above extended period of observation. Observers should begin looking for the planet just as it emerges from the solar glare west of the Sun in the morning sky before sunrise, and Venus is followed through western elongation (about 47°) to as close to superior conjunction as the proximity of the planet to the Sun and its own decreasing angular diameter will permit. Note that Venus is proceeding through waxing phases during this apparition, yet diminishing in angular diameter (a progression from crescent through gibbous phases). We are seeing Venus' trailing hemisphere during western apparitions and observing the dawn side of the planet at the time of terrestrial dawn.

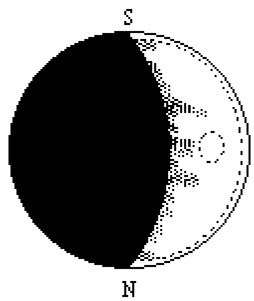


Figure 2 (a)

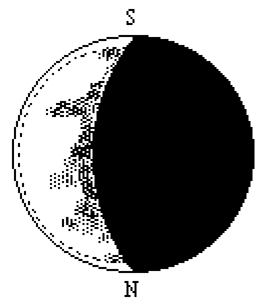


Figure 2 (b)

Look at *Figure 2 (a)*, which depicts Venus (markings greatly exaggerated) as it might appear in an astronomical telescope from the northern hemisphere of the Earth during a western (morning apparition of the planet. Note that as the phase increases from a crescent to ***dichotomy*** (half phase), then to a gibbous phase, the ***terminator*** (the geometric line extending from pole to pole separating illuminated and dark hemispheres) progresses toward the left in our view, all until the planet arrives at superior conjunction and full phase. *Figure 2 (b)* shows Venus as it may appear in the same telescope during an eastern (evening) apparition of the planet. Here, the phase progresses toward the left in our view, but the change is from gibbous, to dichotomy, then to crescent phases, leading up until the time of inferior conjunction. In *Figure 2 (a)* the phases are ***waxing***, while in *Figure 2 (b)* the phases are ***waning***. We will discuss more about telescopic images of Venus later.

Even though Venus may reach a maximum angular distance from the Sun of ~47°, the planet is still observed near the times of sunrise or sunset. If Venus is seen against a dark sky, the effects arising from the excessive brilliance of the disk are very pronounced. At evening apparitions, Venus is frequently low in the western sky where the effects of atmospheric differential refraction and prismatic dispersion destroy good image quality. Seeing conditions are so poor at such times that most observers have adopted a practice of viewing Venus only when has an altitude of ≥ 20° above the horizon. At times of western (morning) apparitions, it is possible to wait until the planet gains altitude and the background sky brightens considerably, and Venus can readily be followed into daylight. It is often desirable to observe Venus during daylight hours when most of the prevailing glare associated with the planet is gone or reduced, but observing Venus too far into the daylight hours can become a problem as solar heating produces turbulent air and resulting poor seeing. While it may seem difficult to look for Venus in daylight, it should be recalled that the planet is comparatively bright, and in practice, the observer can usually find Venus if knowledge of exactly where to look is obtained before the observing session. It is worth mentioning that observers find that the presence of a slight haze or high cloud often stabilizes and reduces glare conditions while improving definition.

Widely-spaced observations are of very little value, and the point of striving for systematic, regular studies carried out by a large team of experienced, dedicated individuals using similar equipment and methods cannot be stressed enough. The Venus Section seeks an intensified effort to increase the incidence of simultaneous identification of atmospheric phenomena on Venus to improve the objectivity of our data collected visually, chiefly because of the elusive nature of features in the atmosphere of the planet, a subject addressed earlier. More will be said about atmospheric markings on Venus later.

Instrumental Considerations

A lot has been written about telescope designs that can be employed effectively in conducting visual planetary observations. No attempt will be made here to discuss all instrument types in detail or the particular attributes, advantages, and disadvantages of various kinds of telescopes. The fundamental prerequisite in the choice of a telescope for lunar and planetary observation is simply optical excellence and mechanical stability. Since the observer is looking for delicate and unbelievably elusive dusky detail in the atmosphere of Venus, the serious observer needs an instrument that he can trust will give superior images, optimum contrast, and outstanding resolution (at least to the theoretical limit) under varying conditions of atmospheric seeing and transparency. Optics must be very clean, properly aligned, and everything mounted rigidly to permit observations with high magnifications. Experienced observers generally agree that a quality, long-focus apochromatic refractor is nearly the perfect instrument for lunar and planetary viewing. Yet, there are several other instrumental designs that can afford excellent views of the solar system. For example, in recent years some observers have even carried out completely satisfactory studies of Venus with premium-quality Dobsonian reflectors. So, the main thing is to actually get out and observe, no matter what kind of telescope is employed.

Given optical quality and mechanical stability, the minimum recommended aperture for useful observations of Venus and participation in all aspects of our programs is about 15.2 cm (6.0 in) for reflectors and 7.5 cm (3.0 in) for refractors. When observing Venus with smaller apertures, a suitable blend of large angular diameter and phase is necessary for successful detection of elusive disk features. This combination of factors occurs about midway between the times of greatest western elongation and superior conjunction, as well as between superior conjunction and greatest eastern elongation. During these intervals, Venus typically has an angular diameter of approximately 16″.0 and a gibbous phase. Use of magnifications within the range of about 50*D* to 80*D* (where ***D*** is the diameter of the telescope in inches) is often practical when Venus is high in the sky.

It is important not to overlook various accessories that come with, or are purchased to accompany, one's telescope. Eyepieces need to be of quality equal to that of the main optical system, and filters of known wavelength transmission should always be used. Admittedly, at the cost of a little comfort and convenience, one should avoid using star diagonals or any devices that orient the image of Venus contrary to what is normally seen "straight through" an astronomical inverting telescope.

Low-transmission filters increase contrast and definition while limiting the effects of irradiation. For Venus, Wratten blue (W38A) and violet (W47) filters are useful for uncontrasted detail, mainly because of the planet's yellowish atmospheric cloud layer. Alternating color variations from red to blue are frequently detected in the south polar region of Venus using Wratten red (W23A or W25), yellow (W12 or W15), and green (W57 or W58) filters. Variable-density polarizing filters add to the visibility of faint markings by reducing glare.

The normal astronomical view of Venus (orientation), pertaining here to the image we see in the normal telescopic inverted view, is with South toward the top of the field of view, West toward the left, and so forth (from the northern hemisphere of the Earth). It is important to remember that these correspond to sky directions, not necessarily *IAU* (*International Astronomical Union*) directions of the planet (which are complicated for Venus because of its obliquity and retrograde rotation).

When attempting to find Venus in daylight, which as noted earlier is a perfectly suitable time to view the planet (seeing permitting), an equatorial mounting with a reliable clock drive is of tremendous value.

It is worth reiterating that the newcomer to studies of Venus often finds the disk of the planet totally devoid of detail of any kind. This visual impression is not uncommon for even experienced observers. With time, the novice will be able to perceive delicate contrasts by training of the eye, and it will then be possible to see any fine detail when it is present. Once at the telescope, there can be no substitute for actual observing, and as we shall see, it is just as vital to report negative results (no markings) as it is to record features that are present. The fundamental goal is to strive for objectivity and seek to achieve realism in recording observations.

Utilization of the appropriate drawing blanks and report forms is required by the ALPO Venus Section if participants in our program expect to have their data included in our analysis and subsequent apparition reports. Forms are available at the cost of reproduction and postage from the ALPO Venus Section, and they can be conveniently downloaded at no cost from the ALPO Website.

It is the ultimate goal of the ALPO Venus Section to attempt to assemble a completely homogeneous mass of accurate, reliable observational data collected over many apparitions, permitting an exhaustive statistical analysis. It is hoped that we might derive enough from painstaking observation and analysis to help provide some answers to questions that continue to perplex us about Venus. These comments, and the foregoing discussion, constitute the author's rationale for the existence and activities of the ALPO Venus Section, our current programs, and our future endeavors. Information of lasting scientific value about Venus will remain the desired natural outgrowth of our programs so long as participants are willing to accept the necessary challenges, develop the basic skills at the telescope, and maintain a persistent, systematic, and objective approach to observation.

Astronomical Seeing and Transparency

The state of the Earth's atmosphere is a critical factor to consider when one is attempting visual research programs in planetary astronomy. ***Astronomical seeing*** is the result of a number of very slight differences in the refractive index of air from one point to another, and such variations are directly related to density differences, normally associated with temperature gradients, from one location to another. The observed effect of such random atmospheric deviations is an irregular distortion and motion of the image. At one time, the seeing may be "excellent," whereby no gross image fluctuations are noted over a fairly long time period, while on another occasion, the seeing may be "poor" with the image appearing to “boil” vigorously.

It is exceedingly important for the planetary observer to establish as accurately as possible, with as much objectivity as possible, the quality of the seeing at the time of observation. When the atmosphere is in a highly turbulent state, it becomes virtually impossible to achieve optimum resolution, and one is usually forced to wait until conditions are more favorable for reliable observational work.

Traditionally, observers employ a numerical scale of seeing, adopted by the ALPO as the ***standard seeing scale***. The accepted criterion ranges from 0.0 (the absolute worst possible seeing) to 10.0 (perfect seeing with totally steady images), and intermediate values are assigned in accordance with one's best appraisal of the atmospheric seeing conditions (in the area nearest the planet in the sky). Although there is unavoidable subjectivity in using this scale, regular usage has shown that it is suitable for most routine lunar and planetary observations. Advanced planetary observers might wish to consider more quantitative seeing determinations, however.

Attempts have been made to devise a scale that is somewhat more objective, and the results abound in the literature. For instance, Pickering assigned descriptive notation to numerical categories in reference to the appearance of the diffraction disks of a number of moderately bright stars. While being somewhat more accurate, the resulting sequence still omitted the critical relationship between atmospheric turbulence and resolution. Resolution is one of the most essential factors to consider in planetary work. It would seem, therefore, quite natural to try to devise a meaningful scale based upon the relationship just noted between resolution and seeing.

The image of a star as seen in a quality optical instrument with an unobstructed circular aperture (e.g., as in a refractor), assuming proper alignment and steady air, the diffraction pattern is a bright diffraction disk surrounded by concentric rings of illumination with interspersed dark zones. If the individual is observing a double star (the components of which are of the same visual magnitude), the separation of the two stars will or will not be accomplished by the instrument employed. Unless the separation of the diffraction patterns is at least equal to the radius of the central disk, the two stellar components will appear as one and unresolved. Increasing magnification will not enhance the capability of the optical system to resolve the stars, mainly because dimensions of the diffraction disks will increase in the same proportion as their separation. Increasing aperture, however, will decrease the size of the central diffraction disks without altering the separation of components. Thus, aperture is the key factor affecting resolution of the two stars.

The angular radius of the diffraction disk is given by *equation (1)* below:

$$\frac{1.22\lambda}{D} = (206,265'')$$

where λ is the wavelength and ***D*** is the aperture of the instrument (both values expressed in inches). It is known that the maximum visual spectral sensitivity of the human eye is attained at 5550Å (expressed in inches this is 2.2 x 10^{-5}) under photopic conditions. Thus, *equation (1)* becomes *equation (2)* below:

$$\frac{5''.54}{D}$$

where ***D*** is expressed in inches as before. Here we are defining a quantitative expression, the ***Rayleigh criterion***, of the angular separation between two stars of equal brightness and whether or not it will be possible to distinguish between them with the unaided eye or when using a given aperture. Clearly, the Rayleigh criterion is dependent upon wavelength and aperture.

Anatomically, the iris controls the amount of light that enters the eye through the pupillary aperture, which has a variable diameter from 2.0 mm to 8.0 mm depending upon the light intensity (field brightness) and in some instances the elasticity of the iris. In addition, it is known that visual acuity is pronounced within the pupillary aperture range from 2.0 mm to about 6.0 mm, and for pupillary diameters less than 2.0 mm, the resolution of two points of light against a dark background is diffraction limited. For larger pupillary apertures, beyond about 6.0 mm, aberrations set the limit on resolution of the eye.

If the assumption is made that the pupillary diameter of the eye is 0.2 in, or 5.0 mm, appropriate for most observing situations in planetary astronomy when the background of the sky is considered dark (i.e., no daylight observations), the resolution of the eye is given by *equation (3)* below:

$$\frac{5''.54}{D_e} = \frac{5''.54}{0.2\ \text{in.}} = 27''.7$$

under the stated conditions, where $\boldsymbol{D_e}$ is the diameter of the pupil of the eye expressed in inches. While the resolution predicted by *equation (3)* is 27″.7 for the eye under the stated conditions, the limit of resolution is probably much nearer 70″.0 or even 140″.0 in actual practice. Note that the Rayleigh criterion does not hold if the points of light are of unequal brightness, nor does it apply suitably to detail on extended objects like planets. It is important to realize that resolution depends upon contrast and image brightness when it comes to planetary work. If these considerations are applied, we may expect to find that Rayleigh's criterion is, at the very least, a fair approximate guide.

The minimum magnification that may be employed on a given aperture, ***D*** (expressed in inches), whereby the eye is expected to resolve everything the telescope resolves, is given by *equation (4)* below:

$$M_{\min} = \frac{v}{5''.54 / D}$$

where ***v*** is the resolution of the eye and ***D*** is the aperture of the telescope (in inches). If we adopt as the minimum resolution of the eye the very conservative value of 140″.0 as noted in explaining *equation (3)*, we may employ *equation (4)* to develop *equation (5)* below:

$$M_{\min} = \frac{140''.0}{5''.54 / D} = \frac{(140''.0)(D)}{5''.54} = 25D.$$

When magnifications of at least 25*D* are used on a given instrument, one may consider that the only factors limiting the telescope's resolution are its aperture and the seeing conditions. Because seeing is rarely perfect, the theoretical limits of resolution of a specific instrument are seldom attained.

One may express, therefore, the resolution of a certain instrument on a given night of observation as the ***effective aperture***, ***D′***, of the telescope. This value is given by *equation (6)* below:

$$D' = D_e$$

where ***e*** is the ***efficiency*** of the instrument.

There are a number of ways to determine the efficiency of a particular telescope on a given evening of observation. Before using the instrument, however, it is essential that the telescope be permitted to overcome thermal shock by adjusting adequately to the ambient temperature. The easiest method to ascertain the efficiency of any telescope is to derive the ***ideal resolution for a 1.0 in aperture***, ***r***, which is a personal constant. The telescope used most frequently in planetary observation must be "stopped down" to *precisely* 1.0 in of aperture. Next, the observer must select a number of double stars of about the same visual magnitude and with angular separations ranging from 4″.0 to 6″.0 (separations should be constant). The closest double star that can be barely resolved with a 1.0 in aperture provides the personal constant, ***r***, previously noted. This procedure must be attempted on a night of exceptional seeing. This constant, once determined, may be considered fairly stable and may not need checking for several months.

Now, during each observing session, the individual measures a second quantity known as the ***actual resolution for a 1.0 in aperture***, ***r′***. The closest double star that can be resolved using full aperture of the instrument in question is noted, and the separation distance of the double star is subsequently multiplied by the full aperture of the telescope used, in inches, which yields the value, ***r′***. The ***efficiency***, ***e***, of the telescope is given by *equation (7)* below:

$$e = \frac{r}{r'}$$

and the effective aperture, ***D′***, is determined by *equation (8)* below:

$$D' = \frac{rD}{r'}.$$

Once the observer has achieved some skill in measuring the effective aperture using this simple method, it may be possible for him to estimate fairly accurately the value of ***D′*** from previous experience by closely examining the stability and sharpness of the image.

In essence, then, a means of quantitatively evaluating the state of the atmosphere in relation to resolution has been achieved. The effective aperture, ***D′***, should be determined by experienced observers instead of making subjective estimates of the seeing. It must be stressed that stars used for ***r*** or ***r′*** should be as close to the zenith as possible to avoid effects of atmospheric dispersion and differential refraction, which is pronounced at low altitudes. The stars should also be as near Venus as possible, or at least at the same altitude as the planet.

It should be pointed out that Venus can successfully be observed in daylight or in twilight, times when the planet has sufficient altitude above the horizon for improved seeing. The observer may appraise the seeing before the sky is light during morning apparitions of the planet, and for evening apparitions, one may wait until Venus has set to try some estimates in the region of the sky (at the same altitude of observation) where the planet was during daylight or twilight. Of course, this is not very precise or as reliable as estimates made when Venus and comparison stars are above the horizon in a dark sky at the same time, but it is better than guessing. Also, as a last alternative, one might try to notice some condition of the sky during daylight hours as an indicator, as well as the quality of the image of the planet at the time of observation.

The ***transparency*** of the atmosphere may be determined on a given date of observation by estimating as precisely as possible, using an appropriate star atlas for reference, the visual magnitude of the faintest star that can be just barely perceived by the dark-adapted, unaided eye. This method, which was introduced many years ago, remains as the adopted technique for estimating transparency of the sky by ALPO observers, together with estimates or determinations of seeing just described.

Estimating transparency more quantitatively can be accomplished in two fundamental steps. The first requires one to determine accurately his ***personal correlation coefficient***, ***C***. This is easily achieved by using a reliable star atlas and finding the faintest star (to the nearest 0.25 visual magnitude) which can be seen by the dark-adapted, unaided eye in the zenith on a clear, dark, moonless night (away from artificial illumination as well). The magnitude obtained from this procedure is denoted, m_z, and *equation (9)* below will yield the correlation coefficient, ***C***, as:

$$C = 6.0 - m_z$$

Next, to enable one to derive the ***atmospheric transparency***, ***T_r***, on any given night of observation, it is necessary that the individual accurately estimate to the nearest 0.25 visual magnitude the faintest star discernible to the dark-adapted, unaided eye in the immediate vicinity of Venus. This generates the value denoted by, ***m_p***, and in making this determination it is assumed that there is no twilight, no moonlight, and no artificial light interference. The transparency, ***T_r***, of the atmosphere may then be computed using *equation (10)* below:

$$T_r = m_p + C\,.$$

Should there be any extraneous light in the region of the sky nearest Venus, but essentially absent from the zenith, another approach may be considered. It is necessary to first determine at the time of observation the faintest star visible in the zenith to the unaided, dark-adapted eye, denoted by ***m'_z***. Let ***Z*** denote the angle between the planet and the zenith, given by *equation (11)* below:

$$Z = 90° - A_p$$

where ***A_p*** refers to the altitude of the planet from the horizon. The value ***T_r*** may be derived from *equation (12)* below:

$$T_r = m'_z + C + 0.2(\sec Z)$$

where the factor 0.2 is suitable for use with observations of Venus under most conditions.

If there is a great deal of light interference from a nearby city, from the Moon, or from twilight, or in cases of daylight studies of Venus, then the best that one can hope for is an estimate of the very faintest star, to the nearest whole magnitude, that would be visible independent of the scattering light, regardless of whether or not an "educated guess" is implied. This is often made possible by reference to some other characteristic of the sky, such as its depth of blueness and clarity at twilight, etc. One must remember that transparency is a logarithmic expression of the light transmission properties of the atmosphere, not a function of extraneous or scattered light. Thus, ***T_r***, values will be affected by things like fog, mists, and haze, to mention a few factors.

Planetary Surface Brightness

The ***surface brightness***, ***B***, of any planet may be conveniently expressed in ***stilbarnes*** (***stilb***), where 1 stilb is the luminance of 1.0 cd/m^2 (candela per square meter) or 1.0 x 10^4 cd/m^2 (candela per square meter). In developing a suitable means for a quantitative evaluation of the surface brightness of any planetary body a standard value has been utilized of 0.235 stilb, representing the derived numerical surface brightness of the planet Mars at mean opposition and corrected for absorption. This value serves as the basis for determination of numerical figures for the other planets.

The ***visual geometric albedo***, $\boldsymbol{p_v}$, for each planet is known precisely, and this value is taken to mean the percentage of incident light that is reflected in the direction of the observer. For Venus, $\boldsymbol{p_v}$ is 0.586, and utilizing the aforementioned standard of 0.235 stilb, the true surface brightness of Venus at the following phase angles, ***i***, is:

$$i = 130° \qquad p_V = 1.8 \text{ stilb}$$

$$i = 90° \qquad p_V = 2.0 \text{ stilb}$$

$$i = 50° \qquad p_V = 2.9 \text{ stilb}$$

The determined true surface brightness values for the planets are not constant, varying both with the ***phase angle***, ***i***, or the planetocentric angle between the Earth and the Sun, and with the distance of the planet from the Sun. This is particularly the case for the inferior planets like Venus, for which the numerical value of phase angle becomes significantly greater than 0°, and as a consequence, the surface brightness of the planet in question will turn out to be appreciably less than the geometric albedo. A phase angle of 0° occurs when the hemisphere facing the Earth is fully illuminated (at superior conjunction for inferior planets or at opposition for superior planets), while 180° occurs when the facing hemisphere of the planet is completely dark (as is the case only at inferior conjunction for inferior planets). Inferior planets like Venus, and our Moon, exhibit all possible phase angles, while superior planets (e.g., Saturn) show only small phase angle variance. The numerical value of the phase angle for Venus ranges from 0° to 180°, and the true surface brightness of the planet changes significantly. For Venus, i = 90° corresponds to ***dichotomy*** (half phase), i = 50° to a gibbous phase of about 82% illumination, and i = 130° corresponds to a crescent phase of roughly 18% illumination.

Before the reflected light from the planet can reach the eye of the observer, it is somewhat diluted by absorption in the atmosphere, in the optical system of the instrument, and in any particular filter that might be employed during the course of the observation. The percentage of light transmission for a number of Wratten filters appear in *Table I*, known as the ***filter transmission coefficient***, $\boldsymbol{u_f}$. The transmission of light through the optical system of the telescope is a function of the number of optical surfaces that the light must pass through, the thickness of the lenses, the size of any obstructions in the optical path, the reflectivity of the mirrors, and the cleanliness of the optical surfaces. For Venus, the optical components of the telescope should be especially clean, because the planet is so bright that light scattered off dust particles will be exaggerated. The ***transmission coefficient for any telescope***, $\boldsymbol{u_t}$, is at best 0.8 and more likely 0.6 or even 0.4.

The ***total transmission factor***, ***u***, ultimately determined from *equation (13)* below:

$$u = u_f \; u_t \; u_s .$$

may be derived from *Table II*, which lists values of $\boldsymbol{u}$ as a function if $\boldsymbol{T_r}$ and the product $\boldsymbol{u_f u_t}$. Thus, to use the Table, the product $\boldsymbol{u_f u_t}$ must be determined and the $\boldsymbol{T_r}$ ascertained precisely, and it is only necessary to read down the proper column in *Table II* to find $\boldsymbol{u}$. Note that the ***atmospheric transmission coefficient***, $\boldsymbol{u_s}$, is given by *equation (14)* below:

$$\frac{u_s}{u_f\, u_t}.$$

As an example, suppose that $\boldsymbol{u_f}$ = 0.25 (for a Wratten filter #23A from *Table I*), and $\boldsymbol{u_t}$ = 0.8. The product $\boldsymbol{u_f u_t}$ is (0.25)(0.8) = 0.2. If $\boldsymbol{T_r}$ = 5.5, we may look in *Table II* and find the value for $\boldsymbol{u}$ of 0.10.

In addition to light that is lost by absorption, scattered light is added to the image of the planet by both the atmosphere and the optical system itself. If scattered light in the sky (moonlight or artificial illumination) is $\boldsymbol{L_s}$ (in stilb), then the surface brightness of the planet in question, $\boldsymbol{B_s}$, after the light has passed through the atmosphere is derived by *equation (15)* below:

$$B_s = u_s B + L_s.$$

If $\boldsymbol{L_t}$ is the scattered light (in stilb) within the optical system resulting from internal reflections off dust particles on the optical elements, etc., then the surface brightness of the image, $\boldsymbol{B_t}$, not yet corrected for aperture and magnification, is given by *equation (16)* below:

$$B_t = u_t\, u_s\, B + u_t\, L_s + L_t\,.$$

If a filter of transmission, $\boldsymbol{u_f}$, is employed, then the surface brightness, $\boldsymbol{B_f}$, of the image is given by *equation (17)* below:

$$B_f = u_f\, u_t\, u_s\, B + u_f\, u_t\, L_s + u_f\, L_t\,.$$

Of final importance in determining the apparent surface brightness of the image is the aperture of the telescope and the magnification. The image is brighter by the ratio of the area of the telescope's aperture to the area of the pupil of the eye, and it is fainter by the square of the magnification.

For a telescope of aperture, $\boldsymbol{D}$, in inches, magnification, $\boldsymbol{M}$, and pupillary diameter (aperture) in inches of the eye, θ, the apparent surface brightness, $\boldsymbol{B'}$, is derived by *equation (18)* below:

$$B' = \frac{D^2 (u_f\, u_t\, u_s\, B + u_f\, u_t\, L_s)}{\theta^2 M^2}$$

where $u_fL_t = 0.0$ assuming that the optics of the instrument are exceptionally free of dust and very clean.

TABLE I.

NUMERICAL DATA FOR WRATTEN COLOR FILTERS

No.	**Filter Color**	**%**	**Dominant Transmission**	**Transmission Range (Extreme)**
3N5	Yellow-Neutral	27	5700Å	4400-7000Å
8	Light-Yellow	83	5720	4600-7000
11	Yellow-Green	40	5500	4100-7000
12	Yellow	74	5760	5000-7000
15	Deep Yellow	66	5790	5100-7000
21	Orange	46	5890	5400-7000
23A	Orange-Red	25	6030	5700-7000
25	Red	14	6150	5900-7000
38A	Light-Blue	17	4790	3800-5650
47	Violet	1	4500	4000-5000
58	Green	24	5400	4950-5750
82A	Light-Blue	72	4770	4000-7000
30	Magenta	27	4200 & 6020	3000-9000

If Venus is being observed in a reasonably dark sky, as might be the case during eastern (evening) apparitions, and if the interference from artificial illumination is negligible, the pupillary diameter, θ, of the eye may be considered to be 0.2 in or 5.0mm. In this particular case, the *equation (18)* will be transformed into *equation (19)* below:

$$B' = \frac{25D^2uB}{M^2}$$

where ***u*** is the total transmission coefficient as before.

If one is interested in the ***magnification per inch of aperture***, M_1, which will give an apparent surface brightness, B', then *equation (20)* below may be employed:

$$M_1 = \frac{M}{D} = \sqrt{\frac{25uB}{B'}}.$$

TABLE II.

FACTOR u AS A FUNCTION OF T_r AND u_fu_t

T_r	$u_f u_t$ = 0.8	$u_f u_t$ =0.6	$u_f u_t$ = 0.4	$u_f u_t$ = 0.2
	***u* =**	***u* =**	***u* =**	***u* =**
6.00	0.64	0.50	0.30	0.15
5.75	0.50	0.40	0.25	0.13
5.50	0.40	0.30	0.20	0.10
5.25	0.30	0.24	0.16	0.08
5.00	0.25	0.20	0.13	0.06
4.75	0.20	0.15	0.10	0.05
4.50	0.16	0.12	0.08	0.04
4.25	0.13	0.095	0.06	0.03
4.00	0.10	0.075	0.05	0.025
3.75	0.08	0.06	0.04	0.02
3.50	0.06	0.05	0.03	0.015
3.25	0.05	0.04	0.025	0.013
3.00	0.04	0.03	0.02	0.01
2.75	0.03	0.024	0.016	0.008
2.50	0.025	0.02	0.013	0.006
2.25	0.02	0.015	0.010	0.005
2.00	0.016	0.012	0.008	0.004
1.00	0.006	0.005	0.003	0.0015
0.00	0.0025	0.002	0.0013	0.0006

In *Table III* appear solutions to *equation (20)* using the derived surface brightness of 2.0 stilb (i = 90°), 2.9 stilb (i = 50°), and 1.8 stilb (i = 130°) for Venus (these three values head the three columns in *Table III*). To use *Table III*, it is necessary to determine ***u*** from *Table II*, locating this value under the appropriate apparent surface brightness, ***B′***, in stilb in the Table. Reading across to the appropriate value of ***i***, which heads a column of magnifications per inch of aperture, one can find the suitable magnifications per inch of aperture to employ when observing Venus under the specified conditions. *Table III* will also be useful for purposes of optimizing contrast perception, discussed in the next section of this book.

TABLE III.

Transmission Coefficient, *u*, as Derived from Table II for Surface Brightness, B′ (in stilb)					**Optimum Magnification per Inch of Aperture for Venus at Given Phase Angles, *i***		
1.0×10^{-5}	**1.0×10^{-4}**	**1.0×10^{-3}**	**1.0×10^{-2}**	**1.0×10^{-1} stilb**	***i* = 90°**	***i* = 50°**	***i* = 130°**
0.008	0.08						
0.006	0.06	0.6					

0.005	0.05	0.5					150*D*
0.004	0.04	0.4			140*D*		130
0.003	0.03	0.3			120	150*D*	130
0.002	0.02	0.2			100	120	95
0.001	0.01	0.1			70	85	67
	0.008	0.08			63	76	60
	0.006	0.06	0.6		55	66	52
	0.005	0.05	0.5		50	60	47
	0.004	0.04	0.4		45	54	42
	0.003	0.03	0.3		39	47	37
	0.002	0.02	0.2		32	38	30
	0.001	0.01	0.1		22	27	21
		0.008	0.08		20	24	19
		0.006	0.06	0.6	17	21	16
		0.005	0.05	0.5	16	19	15
		0.004	0.04	0.4	14	17	13
		0.003	0.03	0.3	12	15	12
		0.002	0.02	0.2	10	12	10
		0.001	0.01	0.1	7	9	7
			0.008	0.08	6	8	6
			0.006	0.06	5	7	5
			0.005	0.05	5	6	
			0.004	0.04		5	
			0.003	0.03			
			0.002	0.02			
			0.001	0.01			

Perception of Contrast

Contrast is defined as the fractional difference in brightness between two objects. If two areas on the visible surface of a planet have true surface brightness B_1 and B_2, where $B_1 \geq B_2$ as measured in stilb, the ***true contrast***, c, between the two areas is derived using *equation (21)* below:

$$c = \frac{B_1 - B_2}{B_1}$$

If c is 0.0, then B_1 must equal B_2, and the two areas are of equal brightness. When c = 1.0, B_2 must be 0.0 (perceptibly black).

As may be observed through the telescope, the ***apparent contrast***, ***c′***, between two planetary surface features is defined by *equation (22)* below:

$$c' = \frac{B_1' - B_2'}{B_1'}$$

where B'_1 and B'_2 denote apparent surface brightness in stilb, and $B'_1 \geq B'_2$. We are specifically assuming that the surface features considered are fairly large in comparison with limiting resolution. The value ***c′*** will be appreciably different from that of ***c*** only when scattered light has been added to the image. If we are considering a difference between ***B*** and ***B′*** resulting from atmospheric and instrumental absorption, then the apparent contrast is not affected. For example, suppose that the brightness of the planetary image has been reduced by absorption in the atmosphere and in the optical system of the instrument used, and assume that the incidence of scattered light is so small as to be negligible, then we have *equation (23)* as follows:

$$c' = \frac{uB_1' - uB_2'}{uB_1'} = \frac{u(B_1' - B_2')}{uB_1'} = \frac{B_1' - B_2'}{B_1'} = c$$

whereby the contrast is unchanged by absorption provided there is no scattered light.

As an additional example, suppose one is observing Venus during daylight hours. If the transparency, T_r, is found to be about 5.5, if the transmission coefficient, u_t, for the telescope is 0.6, if no filter is used, and if the optical components of the instrument are exceptionally clean, so that L_t = 0.0, it is possible to derive the value, ***u***, from *Table II*. Under these given set of observational circumstances, ***u*** = 0.3. The surface brightness of the daylight sky is near 0.8 stilb, and the surface brightness of Venus at dichotomy is 2.0 stilb. If the actual surface brightness of the illuminated disk of Venus, exclusive of any markings or cusp regions, is 2.0 stilb, and the actual surface brightness of barely perceptible dusky atmospheric features on the planet is 1.5 stilb, the true contrast, c, is found employing *equation (21)* modified as:

$$c = \frac{B_{\text{disk}} - B_{\text{mrk}}}{B_{\text{disk}}}$$

where B_{disk} denotes the actual surface brightness of the surrounding disk of Venus in stilb and B_{mrk} is the actual surface brightness in stilb of the dusky surface features on the disk. The computation using our modified equation above takes the form:

$$c = \frac{2.0 - 1.5}{2.0} = 0.25 \text{ or } 25\% .$$

It is possible to derive the apparent surface brightness, B'_{disk} and B'_{mrk}, recalling that the effects of aperture and magnification have not yet been applied, using *equation (17)* modified to:

$$B'_{\mathrm{disk}} = uB_{\mathrm{disk}} + u_f\,u_t\,L_s + u_f\,L_t$$

$$B'_{\mathrm{mrk}} = uB_{\mathrm{mrk}} + u_f\,u_t\,L_s + u_f\,L_t$$

whereby

$$u = u_f\,u_t\,u_s$$

where the computation takes the form

$$B'_{\mathrm{disk}} = (0.3)(2.0) + (1)(0.6)(0.8) + 0.0 = 1.08 \text{ stilb}$$

$$B'_{\mathrm{mrk}} = (0.3)(1.5) + (1)(0.6)(0.8) + 0.0 = 0.93 \text{ stilb}$$

and by using *equation (22)*, the observed contrast, c', is

$$c = \frac{B_{\mathrm{disk}} - B_{\mathrm{mrk}}}{B_{\mathrm{disk}}} = \frac{1.08 - 0.93}{1.08} = 0.1389 \text{ or } 13.9\%$$

Even for an object as bright as Venus, the brightness of the daylight sky is an appreciable fraction of the surface brightness of the planet, so we should stress the need for very clean optics and a deep blue sky in order to perceive features of even moderate actual contrast. Therefore, with certain limitations, Venus can be sought during daylight. The true contrast of 0.25 (or 25%) between the surrounding disk of Venus and the dusky markings in our example has been reduced to 0.139 or 13.9%, still within the contrast perception parameters of the eye (as will be discussed later).

The atmosphere of the Earth scatters moonlight as well as sunlight, and the true surface brightness of the sky is in proportion to the ratio of the brightness of the Sun and that of the Moon. For example, the surface brightness of the Sun, denoted by B_{sun}, is about 2.25 x 10^5 stilb, while that of the Moon, denoted by B_{moon}, is about 0.41 stilb (at Full Moon or 0º phase angle). If the sky brightness due to scattered light (sunlight), L^*_s, at noon on a clear, cloudless day is taken to be about 0.8 stilb, the sky brightness, $L^{\otimes}_s$, due to scattered moonlight on a clear and otherwise dark night would be determined by *equation (24)* as

$$L^{\otimes}{}_s = \frac{B_{\mathrm{moon}}(L^*{}_s)}{B_{\mathrm{sun}}}$$

whereby the computation becomes

$$L^{\otimes}{}_s = \frac{(4.1\,\mathrm{x}\,10^{-1})(8.0\,\mathrm{x}\,10^{-1})}{2.25\,\mathrm{x}\,10^{5}} = 1.46\,\mathrm{x}\,10^{-6} \text{ stilb}$$

This value is several orders of magnitude less than the true surface brightness of any of the planets (e.g., Neptune has a surface brightness of $2.0\text{x}10^{-3}$ stilb), and is, therefore, negligible.

An additional note of comparative interest might be the surface brightness of the sky on a clear, dark night outside the region of the Milky Way galaxy; assuming no artificial illumination, moonlight, or twilight, this value is about equal to $5.0\text{x}10^{-9}$ stilb.

So that the observer may achieve optimum contrast perception, and thus be able to detect markings on the visible surface of a planet, it is essential that the image be large and bright. The contrast sensitivity of the human eye may be evaluated in terms of the minimum perceptible difference in brightness between two contiguous areas, yet it is extremely difficult to obtain contrast perception that approaches the theoretical visual threshold in planetary studies. If one increases the magnification in an attempt to get a bigger image, the planet will frequently be too dim; also, if one lowers the magnification to remedy this problem (in an effort to achieve a brighter image), the result will often be an image so small that nothing can be seen to advantage on the planet. So, a happy medium is sought so that both requirements of large image size and brightness can be satisfied.

It has been shown by experiment that relative contrasts are best revealed if the surface brightness of the planet lies between 0.03 and 0.3 stilb. For this brightness range, contrast perception corresponds reasonably well with ***Fechner's Law***, for which *equation (25)* below

$$F_c = \frac{B_1 - B_2}{B_1}$$

defines ***Fechner's Constant***, and the values $\boldsymbol{B_1}$ and $\boldsymbol{B_2}$ are identical with those in *equation (21)*.

Experimentally, the threshold constant has been determined to be near 0.005, while in practice the value is probably nearer 0.02. In addition, it has been shown that the best contrast perception is attained when the surface brightness is about equal to 0.1 stilb. In order to have an apparent surface brightness, ***B′***, as high as 0.1 stilb (from *Table III*) it would be necessary for a significant reduction in magnification to occur. When the surface brightness of an object reaches a level of 300 stilb, when the surface brightness would be blinding in brilliance, the contrast perception would accordingly suffer tremendously. When the surface brightness is very low, around 0.001 stilb, discrimination of contrast also becomes troublesome. The very best contrast perception occurs when the surface brightness of an object is in excess of 0.1 stilb, and in order to get an observed surface brightness of 0.1 stilb, it is obvious from *Table III* that very minimal magnifications have to be utilized, even for the brightest planets in our solar system. Without the use of electronic image intensifiers, such image brightness levels (0.1 stilb) will not be obtained for Jupiter and the outer planets regardless of how low the magnification is.

For observations of Venus at phase angle *i* = 90° (dichotomy), for example, under favorable conditions (***u*** = 0.5), we require 16*D* to achieve 0.1 stilb (see *Table III*), which is only 64X on a 10.0 cm (4.0 in) refractor. For magnifications below 25*D*, as was emphasized earlier, the eye is usually not capable of resolving all that the optical system can resolve. Also, 64X on a 10.0 cm (4.0 in) refractor is not enough magnification to provide sufficient image size to see any markings on the disk of Venus. Recognizing that the lowest possible light level for reasonably good contrast perception is near 0.001 stilb, we must increase magnification while observing Venus to produce adequate angular image size and brightness for detection of atmospheric features of subtle contrast.

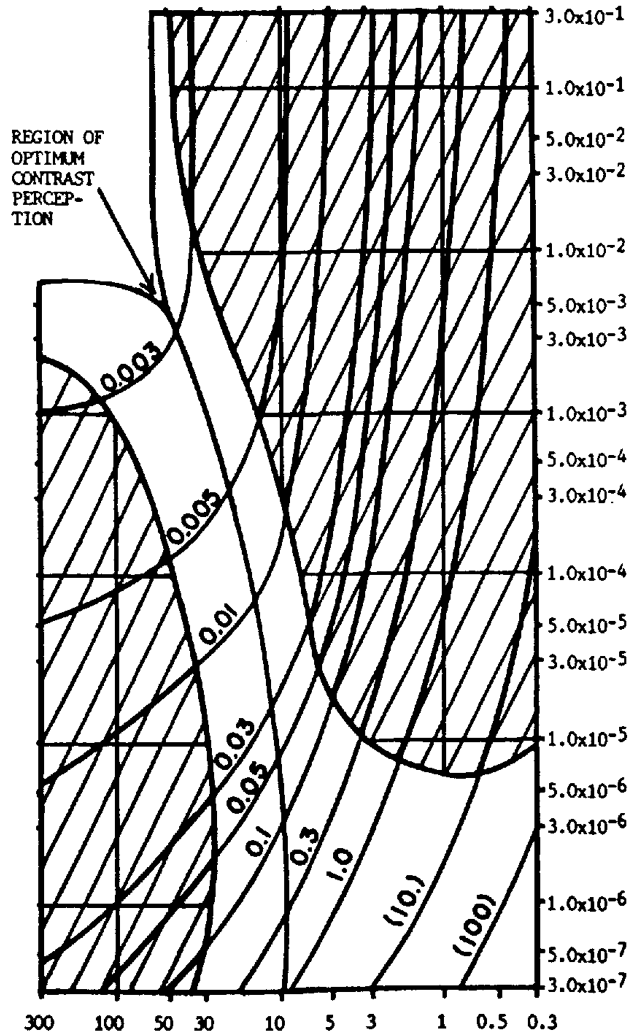
Image size is a factor that plays an even more significant role in contrast perception than does the level of surface brightness. Seasoned observers using high magnifications on planets like Venus often disagree that lower powers will improve perception of delicate detail and contrasts. There is a strong dependence, in truth, of contrast perception on the angular dimensions of various atmospheric features on Venus, and it turns out that more is usually gained in discrimination of delicate contrasts by a moderate increase in magnification than will be lost by the resulting diminution in apparent surface brightness. It is not to be implied that contrast perception will be made good by such a sacrifice. It will only be improved within certain critical limits. In any case, it is to be recalled that for the contrast perception to remain near the Fechner constant of 0.02, it is still required that we seek a surface brightness from 0.03 to 3 stilb for optimum visual work.

In *Figure 3*, the ideal contrast perception thresholds for the human eye under conditions in the laboratory are plotted as functions of ***B′*** the apparent planetary surface brightness, and the subtended angle of the contrasting feature at the eye (image size in minutes of arc).

Figure 3.

Regions of Optimum Contrast Perception

B´



Subtended Angle (Minutes of Arc)

Suppose that during a particular observation the size of the planetary surface feature being studied and the apparent surface brightness of the planet is plotted on the graph in *Figure 3*. If the plot falls above or below the line of optimum contrast perception, the magnification must be increased or decreased, respectively. Should the plot fall in the clear region of the graph, around the line of optimum contrast perception, then the best magnification is being used. Thresholds in excess of 1.0 can be achieved only for bright markings on dark backgrounds, the contrast being defined in this case by *equation (26)* below:

$$c = \frac{B_1 - B_2}{B_2}$$

where $\boldsymbol{B_1} > \boldsymbol{B_2}$.

Using *Figure 3* and *Table III*, it has been possible to determine the approximate magnifications for use on the planet Venus that will yield optimum contrast perception conditions, assuming excellent observing circumstances and reasonably clean, dust-free optics. Calculations have been made for those features which have an angular diameter nearly twice the Rayleigh criterion for resolution, as well as for features that comprise a significant fraction of the planetary dimensions. To detect any of the smallest dusky atmospheric details that might exist on Venus, very high magnifications are probably necessary, the range falling somewhere between 350X to 500X. Larger apertures are typically needed for good image characteristics at these powers. The larger or more diffuse disk features may become evident with low to moderate magnifications, in the range extending from about 200X to 300X. It is worth mentioning that, given any magnification in excess of 25*D*, the resolution of surface detail is at a maximum value when the contrast perception is also at the optimum level. This is chiefly a result of the fact that the Rayleigh criterion is valid only for sources of infinite contrast, while the surface details on any planet differ in brightness only to a small degree. Thus, the contrast has to be good for detail to be seen. The magnification ranges noted here can be considered as the upper limit on occasions when the conditions for viewing Venus are absolutely perfect. Lower magnifications are commonly found to be more useful under average conditions as long as they are not significantly less than 25*D*, and it is worth mentioning that Venus is likely to stand more magnification with smaller apertures than do most planets because of the overall brightness of Venus.

Suppose for the sake of example one is observing Venus using a 15.2 cm (6.0 in) refractor at 350X, and the observer desires to determine if this magnification is anywhere near the optimum. The optics are assumed to be very clean, whereby $\boldsymbol{u_t}$ = 0.6; $\boldsymbol{T_r}$ = 5.0; seeing, $\boldsymbol{D'}$ = 5.0 (derived from our quantitative methods noted earlier). From *Table II*, the value of $\boldsymbol{u}$ = 0.2, assuming no filter is employed. Using *equation (19)* the apparent surface brightness, $\boldsymbol{B'}$, is

$$B' = \frac{25D^2uB}{M^2} = \frac{25(6^2)(0.2)(0.018)}{350^2} = 2.64\text{x}10^{-5} \text{ stilb}$$

Following this procedure, it is necessary to determine the true angular size, in seconds of arc, of detail that can be seen with the instrument in question under the prevailing conditions.

Generally, as noted before, the smallest visible details of moderate contrast will be twice Rayleigh's criterion. Since the ***effective aperture***, $\boldsymbol{D'}$, is 5.0in (as determined in appraising the seeing), the ***effective resolution***, $\boldsymbol{R_e}$, is given by *equation (27)* below:

$$R_e = \frac{5''.54}{D'}$$

where the computation is, for our example above, as follows

$$R_e = \frac{5''.54}{5.0} = 1''.108.$$

Therefore, the smallest visible detail will be approximately ***2R_e***, as was previously noted, or 2″.216. We may now derive the apparent size of this detail as seen by the eye in the telescope using *equation (28)* below:

$$A = M(2R_e)$$

where ***M*** is the magnification and ***R_e*** is the effective resolution. Our computation is, therefore, as follows

$$A = (350)(2.216) = 775''.60 \text{ or } 12'.93.$$

If this result is plotted on the graph in *Figure 3*, the point falls nearly on the line of optimum contrast perception, and we can be confident that 350X on the 15.2 cm (6.0 in) refractor in our example is close to the optimum magnification.

Actually, a better presumed value for the apparent size of a spot of diameter, ***d***, or a linear feature if width, ***w***, smeared by the effective resolution, ***R_e***, is, by *equations (28a)* and *(28b)*, respectively:

$$A = (M)(d + R_e)$$

and

$$A = M\sqrt{(w + R_e)}.$$

In addition to the investigations into the methods of optimizing contrast perception, it is important to examine how apparent contrast differs from true contrast in a more rigorous manner. The apparent size of a planetary surface feature is simply the product of its true angular size, as viewed from the Earth, and the magnification employed. The brightness of surface features may be considered to be the mean of differential reflectivities of component elements that lie below the resolution threshold of the instrument in integrated light (no filter). Detrimental alterations in the contrast of surface markings may be attributed to the imposition of scattered light on the image and to smearing of the image by the finite resolution.

Consider two hypothetical diffuse regions on Venus, where ***B_2*** denotes the true surface brightness in stilb of the darker dusky atmospheric background and ***B_1*** is the true surface brightness in stilb of an overlying amorphous lighter region or spot. The apparent surface brightness of the two areas will be given by the equation

$$B_1' = \frac{25D^2uB_1}{M^2} \quad \text{for the lighter area}$$

and equation

$$B_1' = \frac{25D^2uB_2}{M^2} \quad \text{for the darker background}$$

employing *equation (19)* in both instances, as in the previous computations. From the definition of contrast, ***c***, given by *equation (21)*, the apparent contrast, ***c′***, considering features near or below the effective resolution, ***Re***, will be given by the *equation (29)* below:

$$c' = \frac{(B_1' - B_2')d^2}{B_1'(d + R_e)^2}$$

where ***d*** is the true diameter of a circular spot in seconds of arc. For irregular, roughly linear dusky features of width, ***w***, the equation for determining apparent contrast, ***c′***, becomes by *equation (30)* below:

$$c' = \frac{(B_1' - B_2')w}{B_1'(w + R_e)}$$

Knowing the value of ***c*** from *equation (21)*, and remembering that the contrast will be unchanged by absorption so long as there is no scattered light present, as noted in connection with *equation (23)* such that ***c*** = ***c′***, it is possible to simplify *equations (29)* and *(30)* under these circumstances to *equations (29a)* and *(30a)* below:

$$c' = c[d^2/(d + R_e)^2]$$

and

$$c' = c[w/(w + R_e)]$$

respectively.

It must be emphasized that the apparent contrast, ***c′***, is independent of the aperture of the telescope, the magnification employed, and the monochromatic absorption, as long as scattered light is not a factor. The ability of the eye to perceive contrast, however, is strongly dependent on all of these criteria.

Many may be led to assume, using *equations (29)* and *(30)*, that it is possible for the eye to detect contrasting markings having dimensions far below the Rayleigh criterion, but the apparent diameter of the feature must be taken into consideration. So, in order to have an increase in angular size or apparent size of a very small feature, there must be a corresponding increase in magnification. This increase in magnification is likely to reach the limit at which the final image is so faint that even the features of large apparent contrast are hard to scrutinize.

Consider at this point a specific practical observational situation for Venus where the astronomer desires to perceive banded dusky features on the disk of the planet 0.1 the angular equatorial diameter in width. The date of observation is 1988 April 5, and the ephemeris consulted shows that the polar diameter of Venus is 23″.92 (seconds of arc). A small feature 0.1 the polar diameter of Venus would have a width, ***w***, of (23″.92)(0.1) = 2″.392. The telescope used is a 15.2 cm (6.0 in) refractor at 575X with no filter and exceptionally clean, well-aligned optics. The appraised seeing is 5.5 in. for ***D′***, and $\boldsymbol{R_e}$ is 1″.0. The value for $\boldsymbol{u_t}$ is 0.8, $\boldsymbol{u_f}$ is 1.0 (no filter), $\boldsymbol{L_t}$ is 0.0, $\boldsymbol{L_s}$ is 0.0, and $\boldsymbol{T_r}$ is 5.5. The total transmission factor, ***u***, is found in *Table II* to be 0.4. The true surface brightness of Venus, ***B***, at dichotomy (where *i* = 0° or 50% illuminated as we see the planet from Earth) is 2.0 stilb, and the apparent surface brightness, ***B′***, by *equation (19)* is computed as

$$B' = \frac{25(6^2)(0.4)(2.0)}{575^2} = \frac{720}{330625} = 2.178 \text{x} 10^{-3} \text{ stilb}$$

If a dusky atmospheric feature on Venus of width, ***w***, is being sought, and if the true surface brightness of the feature is taken to be 1.4 stilb, the apparent surface brightness of the feature, $\boldsymbol{B_1}$, is

$$B' = \frac{25(6^2)(0.4)(1.4)}{575^2} = \frac{504}{330625} = 1.524 \text{x} 10^{-3} \text{ stilb}.$$

Now, the true contrast between ***B*** (which may be taken as the surface brightness of the background) and $\boldsymbol{B_1}$, (the surface brightness of the banded dusky feature being sought) may be determined using *equation (21)* as

$$c = \frac{B - B_1}{B} = \frac{2.0 - 1.4}{2.0} = 0.300 \text{ or } 30.0\% .$$

The apparent contrast, ***c′***, by *equation (22)* is

$$c' = \frac{(B' - B_1')w}{B'(w + R_e)}$$

where ***w*** is the width of the belt being sought, $\boldsymbol{R_e}$, is the effective resolution, and ***B*** and ***B*** $\boldsymbol{'_1}$ represent the apparent surface brightness. The solution is found as

$$c' = \frac{[(2.178 \text{x} 10^{-3}) - (1.524 \text{x} 10^{-3})]2.392}{(2.178 \text{x} 10^{-3})(2.392 + 1.0)} = \frac{0.0015644}{0.0073878} = 0.213 \text{ or } 21.2\% .$$

In our computation it is interesting to recall the relationship between ***c*** and ***c′***, noted in *equation (23)*, when scattered light is not a factor, is

$$c = \frac{(B - B_1)w}{B(w + R_e)} = \frac{(B' - B_1')w}{B'(w + R_e)} = c'$$

so that by using *equation (30a)* we have

$$c' = 0.300\frac{2.392}{2.392+1.0} = 0.212 \text{ or } 21.2\%$$

Using *equation (28b)*, the effective or limiting resolution of 1″.0 will smear the banded dusky feature of width 2″.392 to

$$A = M\sqrt{w+R_e} = 575\sqrt{2.392+1.0} = 1062''.32 \text{ or } 17'.71$$

at the eye of the observer. Plotting the derived values of 17′.71 and 1.524×10^{-3} stilb on the graph in *Figure 3*, it will be noted that the point lies in the clear area just a little above the line designated "optimum contrast perception," with an approximate value of 0.004. In our example, the true contrast of 30.05% has been reduced to 21.2%, and we may enhance contrast perception by increasing magnification. Yet, we are already very near 100*D* with the telescope in question, which might not be feasible with the prevailing conditions of seeing and transparency. While it is true that more is often gained by a slight increase in magnification in terms of contrast perception than will be lost due to a diminution in apparent image brightness, we are faced with "pushing" the optical system to its limits in these observing circumstances. Venus' dusky features are already known to be at the threshold of vision and of relatively poor contrast. Here, the observer is likely to question whether features really exist or not. Therefore, a lot of observational experimentation is required to obtain maximum contrast perception and image size and brightness on a given night of observation. Because of the elusive nature of the features seen or suspected in the atmosphere of Venus, the ALPO Venus Section stresses simultaneous observations by independent observers.

The foregoing comments concerning contrast perception have been based largely upon experimental research carried out under controlled situations, and they are considered to be approximate scenarios that could be encountered in actual planetary observation. There are, however, some factors that cannot be overlooked in the final analysis. For example, since planets are generally observed against dark sky backgrounds, there may be some psychophysical influences on contrast perception. Also, turbulent seeing conditions often spread out and initiate boundaries that may be already ill-defined for planetary features, especially on Venus. Thus, in this case, lower magnifications than those suggested might be required to sharpen peripheral areas and improve perception of delicate, often elusive detail.

Perception of Color

The surface brightness of a planet is of far greater significance in ***visual color perception*** than in contrast perception. Because of the duplicity of vision, the states of scotopia and photopia are mediated by two types of photo-receptive cells in the retina. ***Scotopic vision*** involves the retinal ***rods***, and the response is that of the dark-adapted eye. The levels of luminance in scotopic vision are so low that the retinal cones are not stimulated, and there is no color vision. On the other hand, ***photopic vision*** involves the retinal ***cones***, and at higher levels of luminance needed for their function color vision is possible. The color-sensitive cones cannot generally function at light levels below about 3.0×10^{-6} stilb, and if the image of any given planet is exceedingly dim, it is likely that a number of chromatic illusions will interfere with the observation, rendering the results highly questionable.

At 3.0×10^{-6} stilb, the approximate point where there is a transition between scotopic and photopic vision, the eye is affected by the ***Purkinje phenomenon*** (particularly as the threshold of scotopic vision is attained) whereby colors appear bluer than normal. From 5.0×10^{-5} to 5.0×10^{-3} stilb, above the brightness range where the Purkinje phenomenon is prevalent, another complex illusion is encountered, known as the ***Bezold-Brüke effect***. Accordingly, the colors red, green, blue, and yellow will appear as normal, but the hues yellow-green and orange appear more yellowish; blue-green and violet look much bluer. All this takes place as the brightness diminishes. Thus, it is apparent that the reddish or greenish colors are subtracted somehow. As the planetary surface brightness level becomes very great, all colors show a marked reduction in their saturation.

Direct color estimates are dependent upon the angular extent of the feature being observed, and especially for blue, green, and violet hues, the color becomes more saturated as the area increases. Small features of an apparent angular size of less than about 10″.0 are affected such that the colors of violet or yellow-green look grey. Other colors look bluish-green or reddish-orange. On a more practical note, it is recommended that the observer frequently shift his eye from one point on the visible surface of the planet under study to another adjacent location, chiefly because keeping the eye essentially fixed upon any one spot for a long period of time will tend to produce fading in color and contrast of adjacent areas of differing color and contrast.

Simultaneous contrasts, produced when one color is superimposed upon a background of a different hue, present numerous problems for the planetary observer. Neutral or unsaturated colors, which are superimposed on more saturated hue backgrounds, frequently assume the complimentary color of the background. Grey, for instance, on a reddish background appears greenish!

From an exhaustive investigation of these phenomena, it has been concluded that induced contrast colorations are more or less insensitive to fluctuations in surface brightness, and the more saturated the surrounding hue, the more obvious will be the contrast-induced color. Also, the contrast-generated effects become more noticeable the longer one stares at a particular region, the smaller the size of the feature, and the more indistinct the boundaries (as may result from poor seeing or excessive magnification).

Absolute color estimates by visual means are made less subjective and more standardized as a method if one employs color reference charts (available from a variety of photographic or art suppliers) when observing. Since the planet Venus does not generally exhibit vivid colors as do many of the other planets, particularly Mars, Jupiter, and Saturn, it is unlikely that the practicing observer will encounter many of these situations discussed concerning color phenomena. Instead, one will usually be dealing with shades of grey against a bright pale yellowish-white disk of Venus. Nevertheless, it is important to be aware of how color perception is interrelated with image brightness and contrast perception in visual observations.

The Illuminated Hemisphere of Venus: Making Drawings

Direct visual observations of the planet Venus, as well as those using color filter techniques, show varying differences in recorded detail at the visible surface (actually the atmosphere) of the planet. The real surface features of Venus are permanently obscured by a generally opaque atmospheric blanket which, in integrated light (no filter), appears light yellow or yellowish-white. When Venus is observed or photographed in infrared (IR) or red wavelengths, the disk of the planet usually appears quite featureless, while at much shorter wavelengths of light a variety of markings, which seem to favor an extremely dense cloud layer, become barely perceptible. Rather large, typically diffuse, and roughly parallel (or perhaps radial) banded dusky markings, which commonly are observed in the equatorial regions of the planet, are sometimes seen on photographs exposed at visual and ultraviolet (UV) wavelengths. In addition, drawings made by observers using a number of color filters of known transmissions, as well as those executed in integrated light, reveal similar dusky features on occasion. Such markings are known to change their shape and orientation within a fairly short period of time, often within a day or so. Other low-contrast, quasi-permanent markings can be detected in yellow light, while bright clouds may be seen at one time or another near the cusps of Venus. On many occasions, the disk of Venus may just simply be devoid of features altogether.

Recent investigations have revealed only a slight to moderate correlation between markings typically seen on ultraviolet (UV) photographs and those shown on drawings or photographs taken at longer wavelengths. Studies of the wavelength dependence of features on Venus with narrow band interference filters have indicated that the contrast of the markings falls off rapidly at wavelengths longward of about 3800Å, becoming almost zero at 4200Å. This upper limit is extremely close to the lower limit of visibility of the average human eye, probably precluding their visibility to many observers. It is possible, however, that the infrequent yellowish markings may be detected by the experienced eye with some confidence, but a great deal is dependent upon the contrast conditions at the time of observation as well as one's own visual sensitivity to the delicate contrast differences. Some investigators have shown that, by producing artificial effects similar to those on Venus, the markings seen on the planet cannot be attributable entirely to varied psycho-physical reactions. Ideally, then, visual work is best carried out when contrast conditions are at an optimum level, and more often than not, these criteria are met when Venus is seen against a light background.

Upon examination of the wealth of observational data in the archives of the ALPO Venus Section, the bulk of which dates from the early 1950's to the present, a tentative pattern emerges for the markings at the visible surface of the planet. These are listed in the following categories below, and examples of some of these features can be seen in *Figure 4 (a)*, *(b)*, and *(c)* all contributed by dedicated ALPO Venus observers:

1. ***Banded Dusky Markings:*** Dusky streaks that may characteristically run parallel to one another across the illuminated portion of the planet, perpendicular to the line of the cusps.
2. ***Radial Dusky Markings:*** Typically, these bear some resemblance to a "spoke" pattern that seems to converge at the subsolar point, especially apparent in UV images or sometimes with W47 (violet) or (W25) red filters.

3. ***V, Y, or ψ (psi) shaped dusky clouds*:** These curious horizontally aligned clouds are almost exclusively captured in UV images, but they have been rarely discernable with a W47 (violet) filter with larger apertures.

4. ***Irregular Dusky Markings:*** Elongated or roughly linear dusky streaks showing no pattern that is recognizable.

5. ***Amorphous Dusky Markings:*** Shaded features which exhibit no form, definitive shape, or pattern.

6. ***Bright Spots or Regions:*** Exclusive of cusp regions, these are seen as brightenings that often appear much lighter in intensity that the surrounding portions of the illuminated disk.

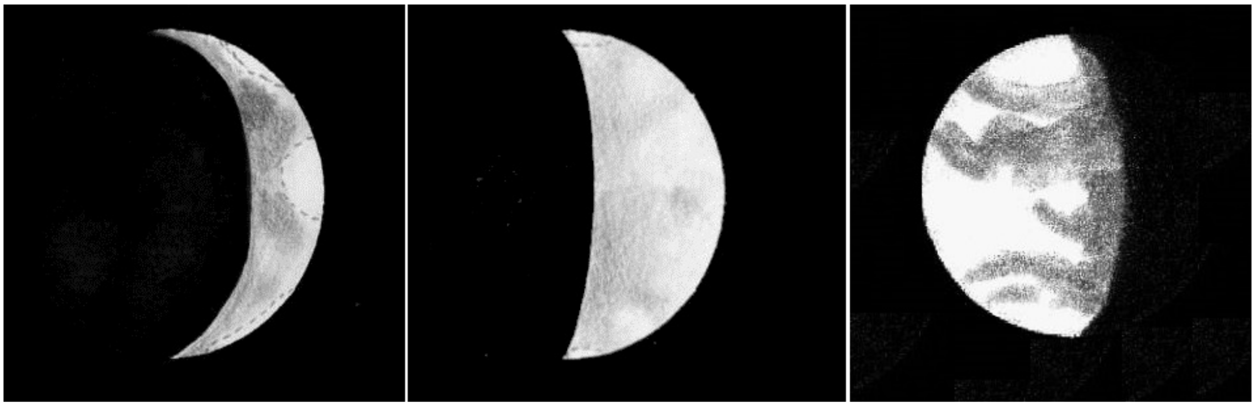


Figure 4 (a)
Drawing Courtesy of M. Legrand
2014 February 18 08:17UT

Figure 4 (b)
Drawing Courtesy of M. Legrand
2014 March 09 07:03UT

Figure 4 (c)
Drawing Courtesy of D. Niechoy
2015 March 19 16:31UT

It is clear from a statistical examination of the data that the amorphous dusky markings, irregular dusky streaks, parallel banded markings, and the various bright areas or spots appear more commonly at visual wavelengths and are detected at various times by the more experienced, systematic observer of Venus. Those markings that are detectable only at UV wavelengths may well conform to a similar pattern as those seen visually, but the correlation between those features seen on UV photographs and those detected visually is poor, as noted earlier. The radial dusky markings, as well as V, Y, or ψ (psi) shaped dusky clouds, seem to favor UV photographs, but there exists some evidence to suggest that a faint radial pattern may be visible in violet and red filters. Furthermore, it has been shown in recent years, following an examination of images taken at different wavelengths, that there is a curious reversal of intensity of features at longer wavelengths (i.e., those markings that show up dark at UV wavelengths are bright in red light). Clearly, any recognizable correlation between the data accumulated by these methods can prove to be of great significance, while simultaneous observations of features in the atmosphere of Venus at different wavelengths and varying contrast conditions can shed some additional light on the actual morphology and visibility of the elusive markings on the planet.

An objective series of carefully executed drawings of the planet Venus can provide an exceptionally valuable record of the changing aspect of the planet's atmosphere. Drawing Venus at the telescope can pose some real challenges, however, owing to the planet's variable angular diameter and changing phase throughout an apparition. The ALPO Venus Section has prepared standard report forms with blanks for drawing Venus. Reference to a suitable ephemeris, such as the ***Astronomical Almanac*** (published each year by the Superintendent of Documents of the U.S. Government Printing Office in

Washington, DC) or ***WINJUPOS*** or ***WIMP*** (that can be accessed from links provided on the aforementioned ALPO website), will permit the observer to look up the ***angular diameter***, **D**, of Venus in arc seconds throughout the year, as well as the ***visual magnitude***, ***v***, the ***phase***, k_C, and the ***phase angle***, ***i***. These parameters will permit the correct representation of the geometry of the ***terminator*** (the line running from pole to pole separating the light and dark hemispheres) on the drawing blank, and will allow depiction of whether the planet exhibits a crescent, half, or gibbous phase (see *Figure 5*). It will be noted in *Figure 5* that two dotted lines "**a ----- b**" and "**c ----- d**" appear in the diagram, representing two parameters required in the calculation of the phase of Venus. We will return to phase calculations later in our discussion. *Figure 5* shows Venus with a crescent phase as seen in an inverting astronomical telescope from the northern hemisphere of the Earth, and the terminology given in the diagram will be used in our discussions here.

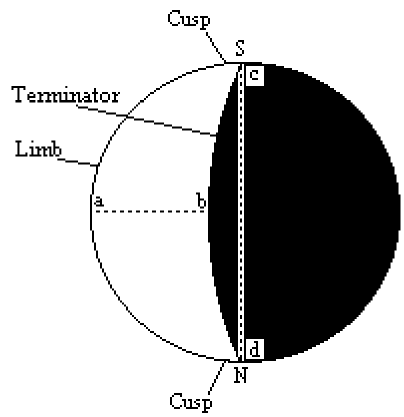


Figure 5

Before a drawing is actually initiated, and prior to coming to the telescope, it is wise to devote serious consideration to some rudimentary items that will be necessary while observing. A few of the more essential items are listed below:

1. A complete set of pencils of varying hardness and sharpness.

2. An artist's stump, clean erasers and/or erasing pencils of varying sharpness.

3. A red flashlight (a hiker's head lamp is ideal for this purpose, because it frees both hands for drawing and for operating the telescope).

4. An accurate watch or smartphone set to reliable ephemeris time signals.

Utilization of the same eyepiece (and consequently the same magnification) throughout the drawing session is recommended, but varying magnifications might help one correctly represent smaller features. Color filters will also improve visibility of markings and reduce glare. Careful notes should always accompany the drawing, listing equipment and accessories used and when.

When attempting a drawing of Venus, it is extremely important to record the delicate shadings with the greatest care possible, noting any degree of uncertainty that may exist regarding their actual visibility. The ALPO Venus Section has adopted a ***Scale of Conspicuousness*** to add some objectivity and quantitative emphasis to the observational technique (see *Table I*). Usually, individual features on the disk of Venus are assigned ratings, but sometimes it may simply suffice to use the numerical scale in *Table I* for the entire disk of the planet. In either case, the use of the scale should clearly indicate what is intended; that is, a rating for individual features or for the whole disk. An entry on the observing forms provided by the ALPO Venus Section is set aside for assignment and selection of numerical, categorical values.

The initial step in executing a drawing of the planet Venus is to establish the correct relative location of disk features, with close attention being given to the overall geometric appearance and actual extent of any features. Once the general details have been sketched in, it is time to enter the accurate starting Universal Time (UT) on the form. Fine details should be carefully sketched in, using dashed lines to set off bright areas or spots from the surrounding disk. All areas represented on the drawing must be given equal emphasis, depicting actual and relative appearances. Shading-erasure techniques, often utilized in lunar drawings, give finesse and permit proper representation of relative intensities and tones for grosser markings as well as fine features. One should be able, with practice, to execute a drawing of Venus in about 20 minutes.

TABLE IV.

ALPO Scale of Conspicuousness Ratings

0.0	....	*Nothing seen or suspected visually*
3.0	....	*Nothing certain; vague suspicions only*
5.0	....	*Suspicion of markings; still indefinite*
7.0	....	*Strong suspicion of markings*
10.0	....	*Markings are definitely observed*

Figure 6 is an observing form for Venus. On this form, there is a section for indicating one or more categories of atmospheric features that may be visible on the planet. It is just as valuable to record negative observations (i.e., checking the category of "no markings seen or suspected") as it is to report the presence of actual markings, because all results are utilized to produce a reliable statistical study of what kinds of features are seen on Venus on a long-term basis and under what conditions. Correlation with the scale of conspicuousness should be accomplished in descriptive notes that accompany observational reports.

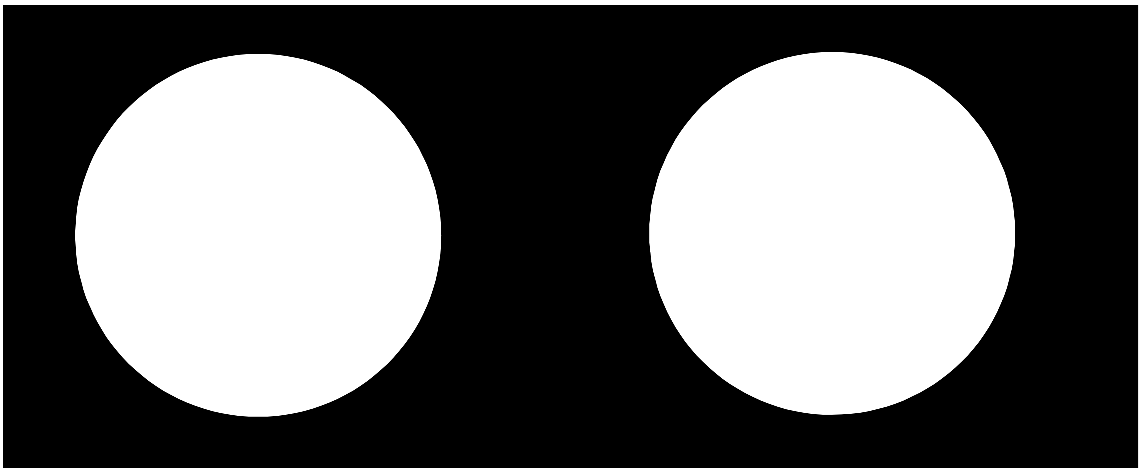


Figure 6

Association of Lunar and Planetary Observers (ALPO): Venus Section

ALPO Visual Observation of Venus

Drawing Blank | *Intensity Estimates Blank*

S | S

N | (*all coordinates are IAU*) | N

Observer________________________________Location____
UT Date ______________ UT Start ________________ UT End ________________ D = ___________″ k_m = ___________ k_c = _____________
m_v = ____________ Instrument ____ Magnification(s) ______________ x_{min} ______________ x_{max}
Filter(s) IL(none) ____________ f_1 ____________ f_2 ____________ f_3 ______________ Seeing ________________ Transparency _________________

Sky Illumination (*check one*): [ ] Daylight [ ] Twilight [ ] Moonlight [ ] Dark Sky

Dark Hemisphere (*check one*): [ ] No dark hemisphere illumination [ ] Dark hemisphere illumination suspected [ ] Dark hemisphere illumination [ ] Dark hemisphere darker than sky

Bright Limb Band (*check one*): [ ] Limb Band not visible [ ] Limb Band visible (complete cusp to cusp) [ ] Limb Band visible (incomplete cusp to cusp)

Terminator (*check one*): [ ] Terminator geometrically regular (no deformations visible) [ ] Terminator geometrically irregular (deformations visible)

Terminator Shading (*check one*): [ ] Terminator shading not visible [ ] Terminator shading visible

Atmospheric Features (*check, as applicable*): [ ] No markings seen or suspected [ ] Radial dusky markings visible [ ] Amorphous dusky markings visible [ ] Banded dusky markings visible [ ] Irregular dusky markings visible [ ] Bright spots or regions visible (exclusive of cusp regions)

Cusp-Caps and Cusp-Bands (*check, as applicable*): [ ] Neither N or S Cusp-Cap visible[ ] N and S Cusp-Caps both visible [ ] N Cusp-Cap along visible [ ] S Cusp-Cap alone visible [ ] N and S Cusp-Caps equally bright [ ] N and S Cusp-Caps equal size [ ] N Cusp-Cap brighter [ ] N Cusp-Cap larger [ ] S Cusp-Cap brighter [ ] S Cusp-Cap larger [ ] Neither N or S Cusp-Band visible [ ] N and S Cusp-Bands both visible [ ] N Cusp-Band alone visible [ ] S Cusp-Band alone visible

Cusp Extensions (*check, as applicable*): [ ] No Cusp extensions visible [ ] N Cusp extended (angle = ______°) [ ] S Cusp extended (angle = ______°)

Conspicuousness of Atmospheric Features (*check one*): [ ] 0.0 (nothing seen or suspected) [ ] 3.0 (indefinite, vague detail) [ ] 5.0 (suspected detail, but indefinite) [ ] 7.0 (detail strongly suspected) [ ] 10.0 (detail definitely visible)

IMPORTANT: Depict morphology of atmospheric detail, as well as the intensity of features, on the appropriate blanks at the tope of this form. Attach to this form all supporting descriptive information, and please do not write on the back of this sheet. The intensity scale is the *Standard ALPO Intensity Scale*, where 0.0 = completely black ⇔ 10.0 = very brightest features, and intermediate values are assigned along the scale to account for observed intensity of features.

A final examination of the completed drawing should now occur, and if everything is properly represented, one should record on the observation form the UT when the drawing ended. One may safely put aside the drawing at this time, but it is important to provide the following information along with the drawing on the form:

1. Observer's name, address, and location of the observing site.
2. Latitude, longitude, and height above mean sea level is useful optional information.
3. Telescope employed, magnification(s), filter(s), and other accessories.
4. Field orientation of the ocular(s).
5. Seeing and Transparency.
6. Starting and ending times of the drawing in UT.
7. A critical description of one's drawing accuracy and reliability (the confidence level).

8. The values for the visual magnitude (***m_v***), angular diameter (**D**), theoretical phase value (***k_c***), and measured phase (***k_m***) should be entered on the form (refer to an appropriate ephemeris for these data).

As stated previously, observers frequently come away from the telescope disappointed with initial impressions of Venus. With time, it becomes easier to detect delicate detail at the threshold of vision, and this amounts to nothing more than a training of the eye during periods of optimum image brightness and contrast, although it should be reiterated that even very experienced observers record a completely blank disk of Venus occasionally.

Drawings of Venus, therefore, have a two-fold purpose:

1. To keep one constantly aware of any activity on the planet.

2. To establish a reliable concept of the overall phenomena perceived in the atmosphere of Venus.

Confirmation of observable features and suspected detail on Venus is another major objective. In order to positively confirm a feature, some very extensive work by many observers is required, and unless several people are certain of a specific phenomenon over a reasonable period of time, it is risky to claim it as definitely established. These points justify the necessity for a systematic, standardized observing program, together with the implementation and maintenance of a ***simultaneous observing program***, where observers work independently but study Venus on the same observing date and at the same time, using similar equipment. Monitoring, and confirming, the ill-defined and variable phenomena in the atmosphere of the planet over a long span of time adds needed objectivity to the observational endeavor. With Venus, duplication of effort and objectivity cannot be overemphasized!

There is sufficient reason to believe that, as observing equipment and methods evolve and improve, a great deal more will emerge from our systematic efforts in drawing and describing Venus. We simply need to continuously examine, refine, and develop our methods and techniques to as close to perfection as possible, where our work will always be worthwhile as scientific data. There is no question that ALPO observations of Venus can remain a major contribution to the body of knowledge about the planet.

Getting back to drawings, it is important to look at some of the ***factors that affect drawing accuracy***. It is important for observers to try to overcome a tendency toward ***stylism*** by experimentation, aimed at increasing objectivity and reducing bias. In many cases, observers show ***too sharp a boundary*** to atmospheric features, but these markings are always diffuse and ill-defined rather than being perfectly linear or sharp features. If observers use blunt pencils when making their drawings, the pitfall of portraying edges of atmospheric features as sharply defined features will diminish significantly.

Differences in transparency and seeing affect drawings, as well as ***visual acuity***, where one person simply sees better than another. ***Aperture of the instrument*** is a contributing factor to drawing accuracy, too; that is, in large telescopes, more detail is usually seen or becomes visible when the same markings may not be detected at all in a smaller instrument. Thus, comparative evaluations of observations made with different instruments can be risky, and the analyst must be extremely careful.

Contrast sensitivity, and the fact that people possess differing degrees of it, can affect drawings and the incidence of recorded detail. It is generally held that an observer who is bothered by an apparent inability to represent properly with a pencil a great range of tonal variations, probably has good or near-optimum contrast discrimination. Contrast sensitivity usually improves with observational experience.

Observers who make errors systematically with regard to ***proportion*** may draw features too large or too small relative to one another or to the planetary disk. If the magnification is too low, it is just possible that ***irradiation*** might produce an effect whereby darker areas appear smaller in proportion to lighter areas. Using magnifications that are too high frequently may cause one to draw dark features or regions too large in relation to the disk of Venus. ***Positional errors*** significantly affect drawings also, and care must be exercised in establishing the location of one feature relative to another. Systematic errors in proportional and position can be corrected for or reduced by making simulated sketches of the planets and comparing the results.

Fatigue critically affects drawings and other observations, and one should rest sufficiently before sitting down at the eyepiece for lengthy observations of Venus. Also, minimizing ***interruptions*** will improve concentration and insure greater accuracy. Distractions can be virtually eliminated by proper advance planning to achieve relative isolation during the critical aspects of the sketch and data acquisition.

Field orientation is an important consideration in drawing Venus. Refer back to *Figure 5*. In the standard astronomical telescope, without a prismatic or mirror diagonal (or any other device that may re-orient the telescopic image), the sky directions of South (S) and North (N) are as shown in *Figure 5*. Also, West (W) is to the left and East (E) is toward the right in the diagram. These directions are appropriate when the individual is observing from the northern hemisphere of the Earth. Use of any device that changes the orientation of the image of Venus should be avoided at all cost, not only because light loss occurs and internal reflections can degrade the view, but mainly due to the fact that confusion is introduced as to which direction is which. *The IAU (International Astronomical Union) General Assembly* in 1961 adopted a resolution whereby directions in astronomical literature and illustrations must correspond to true directions on a planet or satellite. In the case of Venus, the planet rotates in a retrograde fashion (East to West) because of the inclination of the equator of the planet relative to the orbital plane (greater than 90°); for Venus, the planet rotates retrograde with a sidereal period of $243^{d}.1$ with its equator inclined only 3° to its orbital plane (conveniently this obliquity is written as +177° to indicate retrograde behavior, where an obliquity of >90° indicates retrograde rotation). We will not attempt to try to define visual impressions of rotation, because features are not permanent on the disk of Venus. It is not possible to perceive rotation based on motion of markings to any degree of accuracy by visual means, and we will *always* use sky directions to describe Venus rather than IAU terminology due to the confusion of retrograde motion. Venus is one of the few planets where we deviate from the practice of recording directions in the IAU sense.

Visual Photometry, Intensity Estimates, and Visual Colorimetry

Techniques of ***visual photometry*** involve estimating the relative intensities of markings seen on Venus using the standard ***ALPO Numerical Relative Intensity Scale***. Refer to *Table V* for a listing of intensity values and their meaning for the planet Venus.

TABLE V.

Visual Numerical Relative Intensity Scale for Venus

0.0	....	*Completely black (shadows)*
4.0	....	*Dusky; densely shaded*
6.0	....	*Slightly shaded*
8.0	....	*Very bright*
10.0	....	*Brightest features; strikingly brilliant*

The scale in *Table V* ranges from 0.0 (completely black) to 10.0 (most brilliant), and intermediate values are assigned in steps along the scale. The intensity scale is intended to assist the observer in describing markings and their intensity (brightness or darkness) relative to one another. Ordinarily, observers rate the brightest portions of the disk as 9.0 or 10.0 on the scale, faint dusky markings about 7.0, and unusually dark features about 6.0. These numerical values are entered on observing forms in a supplementary sketch of Venus beside the actual drawing of the planet. Visual photometry is carried out in integrated light (IL) initially, just as are drawings, then pursued with filters of known wavelength transmission. No intensity values should be entered on the drawing itself; always use the supplementary blank on the observing form to indicate the appropriate values. A comparison of the reflectivities of various regions on a particular planet at different visual wavelengths of light constitutes one of the more important methods of studying these bodies available to planetary observers. The way in which light may be reflected from the visible surface of a planet or from its atmosphere can provide valuable information as to the chemical and physical conditions of the planet.

Given that a specific color filter will afford transmission in only a very definite range of wavelengths, the most useful and readily available means with which to attempt ***visual colorimetry*** of Venus is by employing color filters of precisely determined wavelength transmissions. Such color filters can be of tremendous importance in helping observers differentiate between light that is reflected from various levels of the planetary atmosphere, they may aid him in providing a means for improving contrast between regions of dissimilar tone or hue, and they are useful in minimizing image deterioration resulting from atmospheric scattering of light and dispersion.

Wratten color filters are especially recommended. They are relatively inexpensive, have accurate wavelength characteristics, and maintain their color stability for a fairly long time. *Table VI* lists the more frequently used Wratten filters, including their range and dominant transmission. Some observers prefer to use *Schott* and *Dufay* color filters, and they have analogs among the Wratten series for comparison purposes.

As is generally known, the retina of the eye consists of two basic types of nerve endings that are light sensitive, the rods and cones. The ***rods*** are responsive only to variations in the intensity of illumination, and they are responsible for one's night vision. Daylight vision, therefore, may also be attributed to the activity of the rods in relation to differences in light intensity. The ***cones***, however, are specifically responsive to color sensations, and they are responsible for color vision. The rods and cones are active simultaneously under a variety of light conditions, but their functions clearly are not the same.

The normal range for visual sensations of the human eye is from 3900Å to 7100Å, although it is well to remember that this range may vary among people. Maximum visual sensitivity is attained at about 5500Å (yellow-green light), but as the brightness level diminishes, the optimum sensitivity point shifts toward shorter wavelengths (i.e., toward the blue end of the spectrum). This peculiar effect is called the ***Purkinje phenomenon***.

One's color sensitivity is also affected by various physical conditions existing within the eye itself, with the color or wavelength of light, and with image brightness. As the aperture of the instrument is increased, there will be a corresponding increase in the apparent image brightness with respect to a given magnification. Thus, the color response of the cones is improved. Since it appears that color sensations are produced by composite reactions of the red, green, and blue-sensitive cones, it is possible for one to observe on one of the three cone-sensitive wavelengths by employing a single filter which has its dominant wavelength close to the natural response of the cone. The color of any visible feature on the planet being observed may be determined by comparing its intensity as viewed separately with red, green, and blue filters. The importance of using color filters in making visual relative numerical intensity estimates of planetary features is, therefore, recognized.

So, it is important to establish the differences in the appearances of the disk and markings of Venus at different wavelengths. Using the methods of visual photometry as before, but now placing a color filter of known transmission in the optical path, numerical estimates of intensity and conspicuousness, as well as drawings, can take place. For visual colorimetry of Venus, the following filters are highly recommended:

W47 (violet) or W38A (blue), W23A (red-orange) or W25 (red), W57 (green)

These filters, in accordance with our discussion, transmit mutually exclusive portions of the visual spectrum.

TABLE VI.

CHARACTERISTICS OF TRADITIONAL WRATTEN COLOR FILTERS

No. & Color		% Visual Light Transmission	Dominant (Å) Transmission	Range(Å) of Trans (10%)
87	Infrared (90%)	0.0001%	7570Å	7600Å-9500Å
88A	Infrared	0.002	7480	7250-9500
89B	Infrared	0.013	7180	7000-9500
70	Deep Red	0.300	6760	6600-7000
29	Deep Red	6.000	6320	6150-7000
25	Red Tricolor	14.000	6150	5900-7000
23A	Red-Orange	25.000	6030	5700-7000
106	Orange-Red	34.000	5893	5200-7000
21	Orange	46.000	5890	5410-7000
15	Deep Yellow	66.000	5790	5190-7000
12	Yellow	74.000	5760	5050-7000
8	Light Yellow	83.000	5720	4750-7000
4	Light Yellow	88.000	5690	4620-7000
58	Yellow-Green	24.000	5403	4958-5800
57	Yellow-Green Tri	33.000	5363	4758-5900
57A	Yellow-Green	37.000	5338	4752-5900
60	Green	26.000	5257	4770-5750
40	Green	34.000	5162	4620-5800

64	Blue-Green	25.000	4973	4390-5700
82	Light Blue	81.000	4778	3690-5600
38	Light Blue	43.000	4835	3410-5550
38A	Blue	17.000	4790	3610-5650
39	Dark Blue	1.000	4510	3150-4800
47	Deep Blue Tri	3.000	4638	4050-5000
47B	Dark Blue	1.000	4494	3900-4650
48	Dark Blue	2.000	4665	4230-4950
35	Magenta	0.400	5669	3400-4500 & 6600-7000
30	Light Magenta	27.000	4200 & 6020	3000-9000
18A	Ultraviolet (80%)	0.0004	3500	3200-3900

Most of the filters listed above are available as optical glass mounted filters from various suppliers. All are standard Eastman Kodak filters, although the listing is subject to modification. Current filter offerings can be found in specific Eastman Kodak publications, and these may be ordered through local camera supply stores or dealers. Filters manufactured by other companies which list no wavelength transmissions should never be used for observing the planets!

Cusp Caps, Cusp Bands, Cusp Extensions, and The Bright Limb Band

In addition to markings described previously with respect to the atmosphere of Venus, fairly prominent bright areas, located in the same relative proximity as the ***cusps*** (or "horns") of Venus have been referred to variously as the ***cusp caps***. They are visible mostly around the time when Venus is in crescent phase, but they have been spotted at gibbous phases, too. As to the real nature of the cusp caps, controversy persists, and some individuals even regard them as nothing more than a contrast effect. Observational evidence does not support this view, however, especially since they have been revealed on UV photographs. They are, of course, not permanent features, they have absolutely no relation to any "polar caps" erroneously described by careless observers in past years, and they do not exhibit the same appearance from one time to another.

The cusp caps do not always appear at the true cusps of Venus. Instead, they have been seen well away from the cusps, assuming various irregular shapes and frequently extending down the limb of the planet as an amorphous bright patch. Sometimes the cusp caps appear "connected" by a narrow ***bright limb band*** that extends along the bright limb of Venus, but observers report that it does not always have continuity from cusp to cusp. In addition, the cusp caps have been noted to possess a dark border on occasion, called ***cusp bands***, probably due to a contrast phenomenon. Investigators have noted a systematic pattern of fluctuation with respect to changes in size and overall brightness of the cusp bands, and it would be interesting to examine this hypothesis by making simultaneous observations.

When Venus approaches inferior conjunction, it is noticed that the cusps are often extended dramatically into a ***halo*** completely encircling the unilluminated portion of the planet's disk (see *Figure 7*).

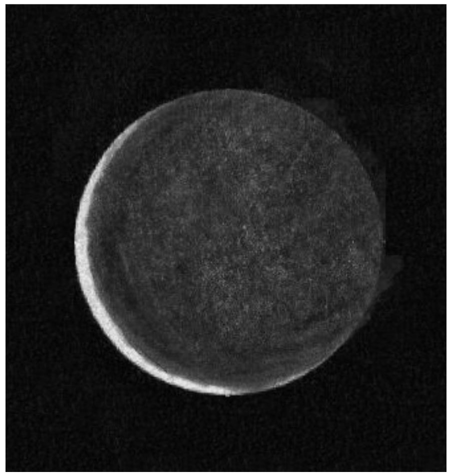


Figure 7
Drawing Courtesy of D. Niechoy
2015 August 01 12:04UT

This effect is caused by sunlight being reflected through the atmosphere of the planet forming a ring of light, as it appears to us in our telescopes on Earth. Such extensions of the cusps are composed of a brighter geometric extension of the crescent and a fainter such extension around the complete limb of Venus. It is important to monitor the width, relative brightness, and any color associated with this feature. Also, it is valuable to try to make a very careful measurement or estimate of the angle from the true cusp to the tip of the extension subtended at the center of the disk of Venus. A good protractor can be utilized for this purpose for measuring cusp extensions represented on drawings of the planet.

Asymmetries have been noted between the northern and southern cusps of Venus, and it is worth comparing the two to determine which one is the more prominent, which one is larger, and which one exhibits a blunting or a widening effect, as well as any associated cusp bands. Dichotomy is the best time to try to observe Venus for these irregularities.

Verbal notes on all aspects of cusp phenomena described herein are quite important, and space is provided on the standard observing forms for recording data associated with the cusps of Venus (refer back to the observing form in *Figure 6*).

The Terminator of Venus and Schröter's Effect

Terminator irregularities are worth looking for on Venus. The boundary separating the light and dark hemispheres of the planet, known as the ***terminator***, is ideally a smooth half ellipse, entirely symmetrical with the apparent equator. The basic shape of the terminator changes as the phase changes, but other irregularities have been seen which are unexpected. ***Local deformations*** in the terminator, frequently visible as "dents" or "bumps" along the otherwise curved line have been reported, and it is not unusual for either the northern or southern portions of the terminator to appear concave or convex around the time of dichotomy. Flat segments may be reported at gibbous and crescent phases, and some investigators have attributed these large-scale deformations to the dusky markings near the terminator. The dusky features may tend to blend together to form what appears as ***terminator shading*** (although the terminator shading has been seen without other markings being present), or these markings may conspire to give the terminator an appearance of indentation or bulging. These phenomena, when suspected or confirmed, should be drawn on the appropriate blanks provided by the ALPO Venus Section, and the data called for with respect to terminator geometry and shading should be supplied (see *Figure 6*). As always, descriptive notes are helpful for clarification.

The ***predicted phase*** of Venus, denoted as k_c, is the ratio of the area of the illuminated portion of the apparent disk to the area of the entire apparent disk regarded as circular. This predicted phase is found in an appropriate ephemeris, determined accurately from the geometry of the orbits of Venus and the Earth. Yet, it does not always correspond with the ***observed phase***, or k_m, on the date of observation. This is particularly the case at the time of dichotomy (half phase, when the terminator is exactly straight from pole to pole, such that k_c = 0.500 or 50%). This discrepancy is known as ***Schröter's Effect*** after the scientist who first recognized it. The observed date of dichotomy has varied from the predicted date by an average of about 7 to 8 days. The cause of this anomaly is not really known, but it has been suggested that it may be mainly psychological. Also, it may be that real physical changes on Venus affect this discrepancy in phase determination.

The most effective means for determining the phase of Venus is to attempt to make careful sketches of the apparent phase, and then take measurements from the drawing. Look back at *Figure 5*, giving notice to the dotted lines "**a ----- b**" and "**c ----- d**" that appear in the diagram. The phase, $\boldsymbol{k_m}$, is determined by using *equation (31)* below:

$$k_m = \frac{ab}{cd}$$

where the values ***ab*** and ***cd*** are, respectively, distances from limb to terminator and from pole to pole. Suppose we use the diagram in *Figure 5* as an example of measurement of phase. Suppose we measure the distance ***ab*** as 21 mm and distance ***cd*** as 41 mm, then use *equation (31)* to compute $\boldsymbol{k_m}$ as follows:

$$k_m = \frac{21}{51} = 0.412$$

where the phase is less than 0.500 and crescent (41.2% illuminated).

Table VII gives predicted dates of dichotomy from 1994 through 2010, and observers may utilize these data to plan observational programs. One should observe Venus about 15 days prior to and following predicted dichotomy, recording observations carefully and drawing Venus' with the shape of the terminator just as it is seen on the dates of observation. Filter techniques are valuable, since dichotomy may differ with wavelength of light, as observations over many years have shown. The observer can calculate $\boldsymbol{k_m}$ after each observation and arrive at a date of dichotomy based on his observations, then comparing the results with the predictions.

TABLE VII.

Computed Dates of Theoretical Dichotomy of Venus in Universal Time (UT) 2015 – 2025

2015	Jun	06.38
	Oct	25.27
2017	Jan	14.56
	Jun	04.26
2018	Aug	15.22
2019	Jan	05.81
2020	Mar	27.04
	Aug	12.88
2021	Oct	28.61
2022	Mar	21.25

2023	Jun	04.13
	Oct	22.91
2025	Jan	12.09
	Jun	01.90

The Dark Hemisphere of Venus and the Ashen Light

For centuries various individuals have reported a very faint illumination of the dark hemisphere of Venus, known as the ***Ashen Light***. (See *Figure 8*). Although the origin is obviously different, the Ashen Light has been said to resemble the Earthshine that we can see on the dark portion of the crescent Moon.

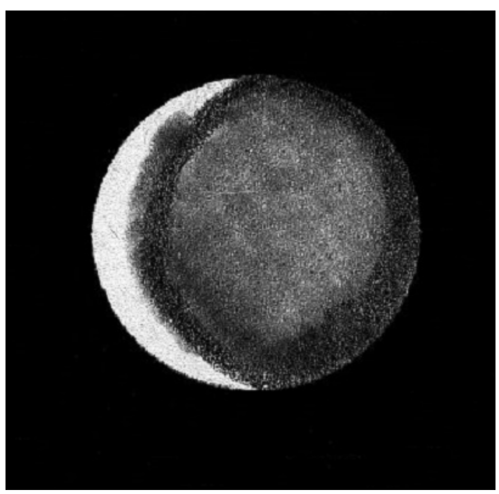


Figure 8
Drawing Courtesy of D. Niechoy
2013 December 10 16:13UT

The Ashen Light was first recorded in 1643 by the Italian observer G. Riccioli, and it was seen by noted astronomers such as J. Schröter and W. Herschel. Members of the British Astronomical Association reported frequent sightings of the Ashen Light during the eastern (evening) apparition of Venus in 1956 and 1957-58, times when solar activity was near maximum. Yet, no Ashen Light was detected during subsequent western (morning) apparitions by the same group of observers, nor were there any significant sightings of the phenomenon during the next solar maximum in 1968-69.

Modern era research by Newkirk in 1959 using spectroscopy revealed certain spectral lines, and Levine in 1969 discovered a correlation between the Ashen Light and geomagnetic activity of the Earth, which suggested energetic solar particles as a source. No direct evidence from spacecraft for or against the Ashen Light has been forthcoming.

The Ashen Light is quite rare, and it is extremely difficult to perceive, mostly requiring Venus to be observed against a black sky. The contrast of the extremely brilliant crescent with the dark hemisphere of Venus is a major factor that makes observations so difficult. It is recommended that serious observers employ an eyepiece that has a ***crescentic occulting bar*** installed to block the illuminated disk.

Curiously, there have been several reports of the Ashen Light against a light background sky, even during the day when Venus is not far from the Sun in angular distance (near inferior conjunction). If this phenomenon can be allegedly perceived against a bright daylight sky, obviously the intrinsic brilliance of the Ashen Light must be very great, and if Venus was being observed simultaneously by someone in a location where the planet was seen against a dark sky, one would expect that the phenomenon would be exceedingly prominent to that observer! Yet, there are no such confirmed observations of the Ashen Light anywhere near this brilliant. This implies that either considerable doubt must be placed in reports of the dark side illumination in daylight, or there must be some basic relationship between the position and phase of Venus as seen from the Earth, together with the physical mechanism causing the phenomenon. This would make the Ashen Light phenomena visible only near inferior conjunction when Venus is never seen against a dark sky. The only conceivable physical mechanism of the Ashen Light that would be dependent on the phase or position of Venus as seen from the Earth would be actual Earthshine, but computations demonstrate conclusively that a theoretical Earthshine would be far below the threshold of visibility. Since numerous observers have reported the Ashen Light, even when it is visible in a bright daylight sky, the phenomenon cannot be dismissed. We just do not know the cause of the Ashen Light, but there are some current theories as to its source:

1. It is possibly caused by CO_2 in the atmosphere of Venus being split by energetic UV radiation, emitting a greenish glow, somewhat like aurorae seen on Earth.

2. Others attribute the Ashen Light to lightning storms occurring in the atmosphere of Venus.

3. Still others say the Ashen Light is merely an illusion, since no spacecraft has yet conclusively detected the Ashen Light.

A careful Ashen Light patrol continues to be a valuable endeavor to try to establish the existence and nature of the phenomenon. There is ample space on the ALPO Venus Section observing forms for recording notes about the presence or absence of the Ashen

Light. Particular attention should be paid to the brilliance of the phenomenon, the distribution of brightness or intensity across the unilluminated hemisphere, and any color associated with the sighting of the Ashen Light. There have been some accounts of the Ashen Light either hugging the terminator or else forming a halo around the dark limb of Venus (not to be confused with the halo of the illuminated atmosphere near inferior conjunction due to cusp extensions). If a particularly prominent Ashen Light display is detected, observers should make every effort to alert other individuals who might be able to simultaneously confirm it. So that we might be sure that the apparent Ashen Light is not an illusion, different magnifications (and a variety of color filters) and telescopes should be used, with attempts to see it against a dark sky whenever possible. Furthermore, observers are urged to try to image the elusive Ashen Light in a simultaneous observing program when it is reported visually.

It is important for observers to record both positive and negative observations of the Ashen Light throughout an apparition of Venus. One should note, however, that the Ashen Light is almost invariably seen during eastern (evening) apparitions, at terrestrial evening on the dusk hemisphere of Venus. If this can be established and verified, we may be able to infer possible auroral sources or a lightning basis for emissions. But, the bias toward evening apparitions may simply be due to more intensive coverage of Venus during these times. Here again we have justification, as well as strong encouragement, for observers to pursue Venus *every* apparition. We are seeking a large number of reliable, systematic, and simultaneous observations of Venus by individuals throughout the world at morning and evening apparitions, with no bias toward either period. As was noted earlier, individuals ideally should try to use a crescent occulting bar in the eyepiece to hide the illuminated hemisphere of Venus. Such a device can either be procured commercially or constructed by the observer.

Filters employed in searching for the Ashen Light should be transparent to blue or purple wavelengths while suppressing green light, as is common with W38A or W47 filters. In particular, a W35 (purple) filter, with a peak response of 4430Å, has been shown to be extremely suitable for observations of the phenomenon. In all cases, a list of accessories used to help improve the visibility of the Ashen Light should be reported when submitting observations.

The ALPO Venus Section, along with several other astronomical organizations all over the world, began participating in 1988 in an intensive effort by *Pioneer Venus* scientists to study the Ashen Light. The *Pioneer Venus Orbiter*, hereinafter referred to as the *PVO*, began orbiting Venus in 1978 in a near-polar orientation. The spacecraft carried an instrument package that permitted observation of atmospheric features on Venus, as well as studies of interactions between the Sun and Venus as well as the interplanetary neighborhood, and *PVO* had aboard an ultraviolet spectrometer that monitored airglow and auroral effects in the far UV on Venus. The *PVO* had no equipment to directly monitor the Ashen Light at visual wavelengths, and this is the reason why *PVO* studies required visual observations by ALPO and other organizations.

Instrumentation on board *PVO* permitted measurement of electromagnetic fields, providing information about plasma conditions in the solar wind and the region near Venus, and these devices have been crucial in investigations of the occurrence of lightning on Venus. The *PVO* remained in operation, transmitting data back to Earth, until it entered the atmosphere of Venus in 1992. In fact, *PVO* reportedly had enough propellant for orientation to optimize viewing of high-interest phenomena on Venus.

So, the intent of the joint *PVO* and Earth-based ALPO programs was to compare visual observations with spacecraft field, particle, and UV measurements. Specific attention focused on solar wind conditions, UV emissions, evidence for lightning, and abnormal fluxes of energetic particles. Earth-based solar studies, solar wind phenomena monitored by other spacecraft, and geomagnetic indices also became a part of the overall data acquisition endeavor. Also, these studies coincided with another approaching solar maximum.

Almost all of the optical (visual) observations fell into the capable hands of well-equipped amateur astronomers throughout the world, with a networking of individuals and organizations to optimize opportunities for systematic, standardized simultaneous observations. Work by observers separated by longitude (and thus observing times) enabled acquisition of data for study of the duration of any Ashen Light phenomena detected.

The initial *PVO* observing campaign centered around the inferior conjunction of Venus that occurred on June 13, 1988. The response was excellent, with observations conducted by individuals all over the world using instruments of various designs that ranged in aperture from 5.1 cm (2.0 in) to 91.4 cm (36.0 in). Viewing of Venus occurred in integrated light and with the use of color filters, and participants usually supplied adequate supporting documentation of seeing and transparency conditions, observing dates and times, magnifications employed, etc. Emerging from the database of some 700 submitted observations, spanning 120 days prior to and after the June 13, 1988 inferior conjunction, were 190 positive reports of the Ashen Light. Cautiously, the *PVO* team felt that these positive sightings were a strong argument for the reality of the Ashen Light, but at the same time, the actual cause of the phenomenon remained unclear. For example, attempts to correlate 1988 Ashen Light observations with solar-related phenomena was hindered by the fact that the observing period was unusually quiet! No correlation could be established between solar wind or solar particle features at Venus and the Ashen Light, and it was not possible to duplicate the historical asymmetry in reports of the Ashen Light between evening and morning apparitions, which would have supported the lightning hypothesis. The *PVO* team recommended that all future Ashen Light observations be conducted on a routine and simultaneous basis, in support of the goals of the ALPO Venus Section. Continuous monitoring of Venus for the Ashen Light emissions for *many* observing seasons, ideally employing CCD imagers of suitable sensitivity and dynamic range, could establish conclusive evidence of the existence of dark side illumination on the planet.

Before we leave the subject of the dark hemisphere of Venus, we it would be remiss not to mention a phenomenon known as the ***projection of the unilluminated hemisphere*** against a bright sky. Frequently, the dark hemisphere of Venus appears *darker* than the background sky, particularly when the planet is seen in daylight. No physical process seems to account for such a phenomenon. There seems to be no mechanism whereby the dark hemisphere can *actually* be darker than the background sky except when Venus is seen projected against the extreme outer solar corona or the Zodiacal Light, circumstances that would be favorable about two weeks before the planet enters inferior conjunction. There appears little doubt that this is an effect produced in the eye by the sharp contrast in brightness between the planet Venus and the surrounding sky, usually noticed when magnifications are very low. The effect may be seen when Venus is at gibbous phases and when powers of $\leq 10D$ are used.

> ***Experiment:*** *Here is an interesting demonstration, which if performed correctly, helps illustrate the illusory effect of a darker unilluminated hemisphere against a brighter background. Cut a crescent from a sheet of slightly translucent paper, placing it in front of a piece of ground glass which is strongly illuminated from behind. Unaided-eye observations from a distance of twenty or more feet will usually show an illusional dark area adjacent to the terminator of the crescent, and if the crescent is thin the eye may tend to "finish the circle" and create the illusion of the unlit portion of the circle being darker than the background.*

Systematic Digital Imaging of Venus

Although this handbook is devoted almost exclusively to visual observations, it would be wholly remiss not to discuss the ever-increasing endeavor of digital imaging of Venus at visual, UV, and near-IR wavelengths. It is exceedingly important to compare various wavelength images with drawings and other purely visual observations, looking for similarities and trying to understand differences and limitations of methods and techniques.

Attempts at imaging Venus at visual wavelengths, while interesting, often produce results that are devoid of any markings, even when simultaneous visual observations sometimes suggest the presence of atmospheric features. This is because of the low contrast of atmospheric phenomena on Venus in integrated light and normal visual wavelengths. On the other hand, ultraviolet (UV) images typically show substantial detail. Of course, observers should continue to image the planet at visual wavelengths as well as imaging Venus at UV and near-IR wavelengths. Imaging the planet simultaneously while visual drawings of the planet are being executed by other observers is especially worthwhile. In this way, it will be possible to ascertain limits of visibility of the atmospheric features of Venus in various wavelengths and enhance the objectivity of our data.

Excellent UV images can be made by observers using reflecting telescopes of about 20.3 cm (8.0 in) aperture, employing appropriate UV filters. See examples in *Figures 9 (a), (b)* and *(c)* furnished by experienced ALPO Venus observers.

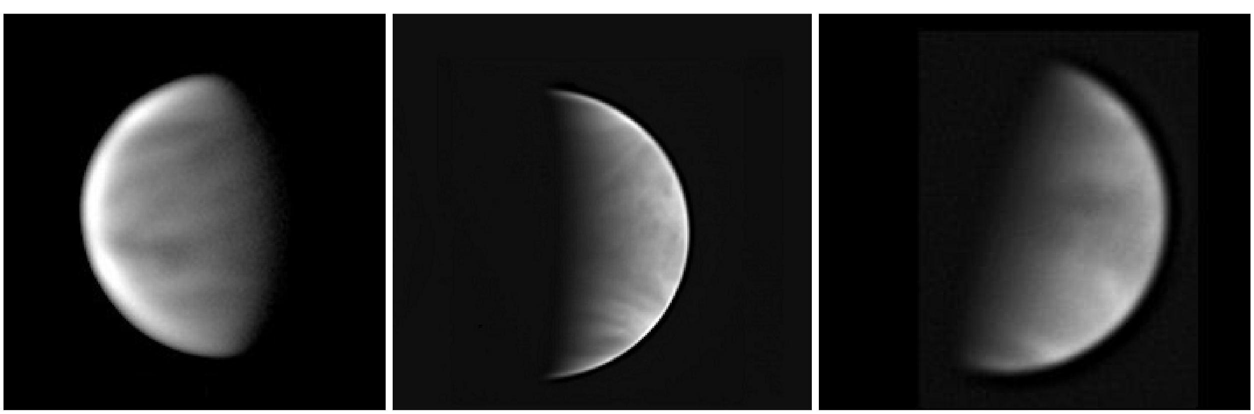


Figure 9 (a)
UV Image Courtesy of C. Pellier
2015 April 14 17:47UT

Figure 9 (b)
UV Image Courtesy of C. Viladrich
2012 August 08 05:18UT

Figure 9 (c)
UV Image Courtesy of R. Schrantz
2009 June 23 10:50UT

Because ordinary optical glass is not normally transparent to UV light, the use of refracting telescopes is ruled out, unless they have special optical substrates. The corrector plates of some catadioptric optical systems, such as Maksutovs and Schmidt-Cassegrains, do pass sufficient UV wavelengths and produce reasonably good images. For optimum results, a UV filter should be employed with a maximum transmission between 3200Å and 3700Å with simultaneous blockage of red wavelengths. This range is chosen because O_3 (ozone) in the Earth's atmosphere absorbs light incoming at wavelengths shorter than about 3200Å, and the markings on Venus themselves fade in prominence at wavelengths longer than 3700Å. A W18A ultraviolet filter has all of these desired characteristics, but there are more modern filters available that have similar wavelength transmissions (e.g., *Astrodon* or *Schott UG-1* UV filters coupled with a suitable IR blocking filter). Regular digital imaging at various wavelengths may ultimately turn out to be especially valuable in studies of the elusive Ashen Light.

An interesting digital imaging project for Venus observers involves trying to capture the thermal IR wavelength emission from the hot surface of the night side hemisphere of the planet at 10,000Å (1µ). This is because CO_2 gas comprising roughly 97% of the atmosphere of Venus allows transmission of thermal IR energy emanating from the surface at exactly 10,000Å (1µ). To be successful, however, observers must image Venus when the planet is near inferior conjunction and when the crescent phase, $\boldsymbol{k_c}$, is less than 0.180 to 0.020 (18.0% to 20.0% illuminated), allowing the crescent to be thin enough so that the dark hemisphere can be imaged without the much brighter illuminated portion completely saturating the image. Also, Venus needs to at an altitude between 10° to 18° above the western horizon at sunset and with the Sun at about 5° or so below the horizon so that the sky background is not too bright. Instrumentation required for imaging the dark hemisphere's thermal emission include the following:

1. An IR filter passing wavelengths of 9800Å to 10,000Å (0.98µ to 1µ).

2. Telescope with focal ratios of about f/10 to f/12 and optics able to pass IR wavelengths.

3. Minimum telescope apertures of 7.0cm to 20cm, although slightly larger instruments will afford better resolution in the 9800Å to 10,000Å (0.98µ to 1µ) range.

4. Successful imaging of the weak thermal energy often requires exposures of 5 to 10 seconds.

Amateur ALPO Venus Section imaging of the dark hemisphere thermal IR illumination dates back to May 12, 2004, when Christophe Pellier of Bruz, France, using a 35.6 cm

(14.0 in) SCT, an ATK-1HS CCD camera equipped with a 10,000Å (1µ) captured an historically unprecedented image between 20:04-20:43UT as shown in *Figure 10*. Pellier also followed up his amazing work with additional sequential IR images of the dark hemisphere illumination from May 16, 2004 through May 21, 2004 using the same instrumentation as depicted in *Figure 11*. It should be pointed out as well that his images over several days in 2004 surpassed the efforts heretofore by ground-based professional astronomers. What his images showed was the hot surface of Venus in the near-IR, the light penetrating the dense clouds of the planet. The mottling that appeared in Pellier's images can be explained, not as Venusian atmospheric features, but as bright higher-elevation (warmer) terrain and dark lower (cooler) surface areas in the IR. Furthermore, the appearance of these features was similar in all of his images and persisted over the span of his imaging efforts in May 2004. Because of the methodology and instrumentation Pellier employed was rather uncomplicated, more and more Venus observers in subsequent years have been successful in imaging the dark hemisphere thermal IR illumination. This important observational endeavor should continue in the future and be included as part of all imaging activities by ALPO Venus observers.

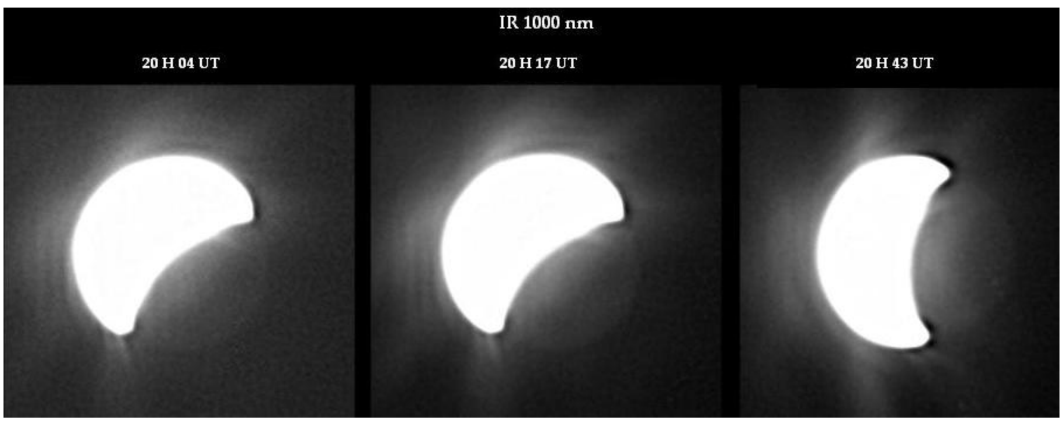
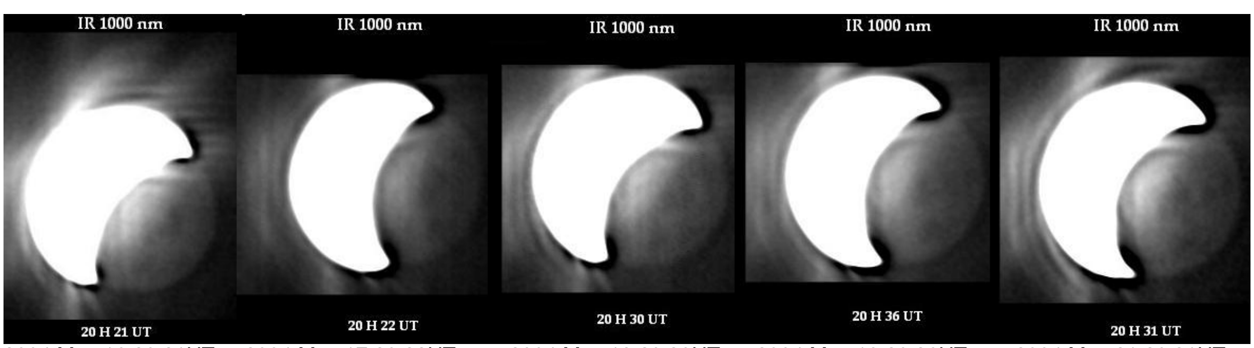


Figure 10
IR Image Courtesy of C. Pellier
2004 May 12 20:04-20:43UT



2004 May 16 20:21UT 2004 May 17 20:22UT 2004 May 18 20:30UT 2004 May 19 20:36UT 2004 May 21 20:31UT

Figure 11
All IR Images Courtesy of C. Pellier

Simultaneous Observations

We have already discussed some of the unique difficulties associated with visual studies of Venus. Any opportunity that substantially increases the incidence of confirmed observational data should be taken advantage of as a means for reducing subjectivity in visual work. The atmospheric features and phenomena of Venus are elusive, as we have seen, and it not unusual for two observers looking at Venus at the same time to derive somewhat different impressions of what is seen. Our challenge is to establish which features are real on any given date of observation, and the only way to build confidence in any database is to increase observational coverage on the same date and at the same time. Therefore, the ideal scenario would be to have simultaneous observational coverage throughout any apparition.

Simultaneous observations are defined as independent, systematic, and standardized studies of Venus carried out by a large group of observers using the same techniques, similar equipment, and identical observing forms to record what is seen. While this standardized approach emphasizes a thorough visual coverage of Venus, it is also intended to stimulate routine photography (both visual and ultraviolet) and CCD imaging of the planet. By these exhaustive efforts, we would hope to be able to at least partially answer some of the questions that persist about the existence and patterns of atmospheric phenomena on Venus.

The same fundamental methods and techniques utilized by those who regularly observe Venus should be employed in the simultaneous effort. Further, through proper organization and enlistment of many individuals in our programs worldwide, we might establish simultaneous observations as the rule rather than as the exception. For Venus, indeed, simultaneous work should be of the highest priority, again because of the obstacles to successful visual observations already mentioned. No attempt is made here to outline a schedule of observation for the ***Venus Simultaneous Observing Program,*** hereinafter referred to as ***VSOP***, because of the need to establish the relative proximity of individuals who will participate in the effort. Until recently, we simply strived to achieve a higher incidence of simultaneous observations by encouraging everyone to carry out an intense and routine monitoring of Venus. Because observational coverage has been very good in recent years, the incidence of simultaneous observations has increased dramatically, but we still desire to improve the probability for synchronized work. So, to reach our goal of getting the highest incidence possible of simultaneous observations, the VSOP was implemented. Each apparition, VSOP participants are provided a schedule of dates and times in consideration of the relative proximity of team members for planning purposes. While VSOP participation is sought from our most experienced observers, everyone is encouraged to begin a transition from a program of regular observation to one of simultaneous observation. This evolution is accomplished under the supervision and guidance of the ALPO Venus Section, and inquiries are invited from those who wish to make a commitment to participating in the VSOP.

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