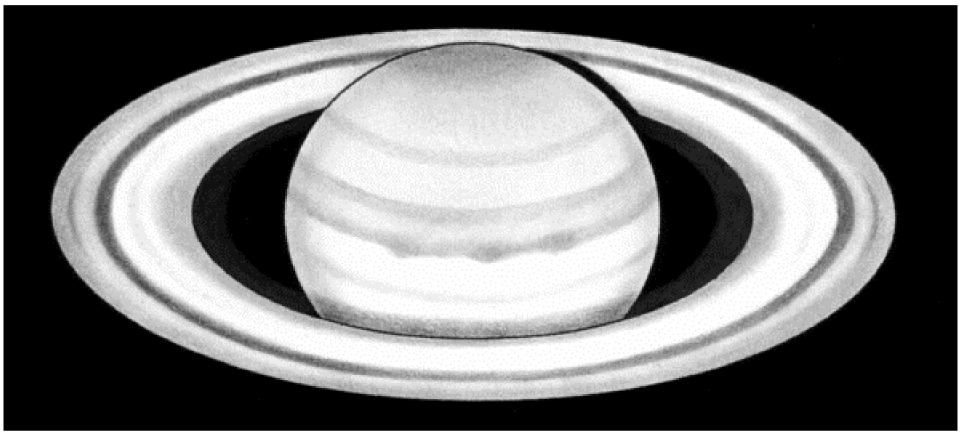
THEORY AND METHODS FOR VISUAL OBSERVATIONS OF SATURN



June 11, 2019

*Also Available in *.pdf format*

By: Julius L. Benton, Jr.

Coordinator
ALPO Saturn Section

PREFACE

The many observational programs carried out by ***the Association of Lunar and Planetary Observers (ALPO)*** over the years since its inception in 1947 have embodied a fundamental guiding principle: ***to encourage and coordinate regular, systematic investigations of the principal planets and other constituents of our solar system with instrumentation normally available to amateur astronomers***. Close ties between professional and amateur astronomers in ALPO research programs helped convince the scientific community that the amateur's greatest potential for making useful contributions to planetary science is ***a systematic, long-term, and simultaneous monitoring of the Sun, Moon, principal planets, satellites, comets, and meteors at wavelengths of light to which the eye has greatest sensitivity***.

There is no question that persistent observational surveillance of our solar system by dedicated ALPO observers has helped shed light on lingering mysteries about the Moon and planets, and most of this success is attributed to the unique ability of the visual observer to perceive, at intermittent times of exceptional seeing, smaller and more delicate details than could be normally be photographed in the past with even the largest optical instruments on Earth. Despite the appearance in recent years of more sophisticated computer-driven telescope mounts, CCD imaging systems, the importance of observations by purely visual methods has not diminished.

The visual observer who really wants to contribute something of value to planetary science can still do so if he is willing to meet certain challenges. This monograph has been written for the individual who is seeking gain an understanding of the observational theory and methodology involved in pursuing a worthwhile program of observing Saturn, its ring system, and accompanying satellites. If one carefully studies the contents of this manual prior to beginning routine telescopic observations of the planet, the methods and techniques presented herein will hopefully be instructive and helpful to the observer who wishes to produce the most useful and reliable data possible for analysis, whether one is conducting a purely visual program or utilizing digital imagers to capture images of Saturn at various wavelengths.

An overview of the history of Saturn observations, as well as a summary of our current knowledge about the planet itself, as well as an in-depth description of the many programs conducted by the ALPO Saturn Section, is beyond the scope of this monograph. A thorough discussion of all the observational programs of the ALPO Saturn Section is available in the author's recent book entitled ***Saturn and How to Observe It***, available from book-sellers such as Amazon.com and elsewhere. The most recent research on Saturn, including late-breaking news about the planet, can be found in various periodicals and also accessed via the Internet. Our official publication, in which apparition reports and observational alerts appear, is the ***Journal of the ALPO*** (subtitled ***The Strolling Astronomer***), which is presently published quarterly in printed format as well as a downloadable *.pdf document, and it frequently contains information about specialized lunar and planetary observations not often found elsewhere. Observing alerts and other on-line information about the ALPO Saturn Section, as well as the organization as a whole, can be accessed on the ALPO's web site at **<http://www.alpo-astronomy.org>**. The bibliography at the end of this book lists sources of additional authoritative information about Saturn and planetary science in general.

Many people supplied valuable assistance and thoughtful suggestions during the development and completion of this document. Above all, it has been the participation and support of numerous dedicated ALPO Saturn observers that really made this book possible, and it is to these individuals that the author extends his sincerest gratitude.

Julius L. Benton, Jr., Ph.D. — *Telephone: (912) 508-1087*
Coordinator, ALPO Saturn Section
ASSOCIATES IN ASTRONOMY — *E-Mail: jlbaina@msn.com*
P.O. Box 30545
Wilmington Island
Savannah, GA 31410 USA

CONTENTS

CHAPTER 1: INSTRUMENTATION AND CRITICAL FACTORS THAT AFFECT SATURN OBSERVATIONS

Visual observations of the planet Saturn and its satellites should be carried out systematically throughout any given apparition, starting early in the observing season after Saturn has just emerged from the solar glare and continuing until the planet again enters the domain of the Sun, at conjunction.

The *synodic period* for Saturn is roughly 378^{d} in length, meaning that in the course of an apparition (which lasts longer by a few days than one year on Earth), the planet will be well-placed for observation for about nine or ten months (depending on the observer's latitude). Widely-spaced observations are of limited value, and the importance of systematic observations by many individuals, all using standardized methods, cannot be stressed strongly enough. Our goal is to achieve a high incidence of simultaneous observations of variable phenomena on Saturn to confirm phenomena and increase the level of objectivity in our data.

1.1. Instrumentation

A lot has been written about telescopes of various types that can be used effectively in planetary observations, and we will not devote a great deal of space here to a rigorous discussion of instrument designs or their particular attributes, advantages, or disadvantages. The main consideration in selecting a telescope for pursuing planetary observations is simply optical and mechanical excellence. Since our basic objective is to see the most detail possible in the atmosphere of Saturn or in the rings, the telescope must deliver superior image quality, excellent contrast, and optimum resolution under the prevailing atmospheric conditions. Furthermore, the optics need to be clean, properly aligned, and everything mounted so as not to hinder reliable observational work. It has been demonstrated repeatedly that classical long-focus ***Newtonian reflectors*** or ***refractors*** (especially the newest ***apochromatic*** types) consistently give the level of performance required of a lunar and planetary telescope. Of course, there are instruments of other designs that have been proven to be completely satisfactory (e.g., ***Maksutovs, Schmidt-Cassegrains, and Schiefspieglers***).

Assuming quality optics and workmanship, the ***minimum aperture*** telescope for useful observations of Saturn is about 15.2 cm (6.0 in) for reflectors and 10.2 cm (4.0 in) for refractors, but many observers have gotten by with smaller instruments. The ***ideal aperture*** for viewing Saturn is probably the largest *quality* telescope that one can afford.

The ***eyepieces*** used with any telescope should be of the highest optical quality, and accompanying the eyepiece set should be a ***variable-density polarizer*** and a variety of ***color filters of known wavelength transmission*** (they are required for certain aspects of the Saturn observing program). Even at the cost of a little convenience, observers should try to avoid using ***star diagonals*** or accessories that change the orientation of the telescopic image of Saturn from the normal inverted and reversed astronomical view. Of course, the ***normal astronomical orientation*** of Saturn in the eyepiece is with South toward the top of the field of view, West to the left, and so forth. This is a field of view corresponding to a position of the planet between the zenith and the South point of the horizon from the Earth's northern hemisphere, and these are clearly sky directions, not to be confused with IAU directions discussed later in this monograph.

After acquiring the appropriate instrument and accessories, there can be no substitute for many hours spent at the eyepiece actually observing. Regular sessions at the telescope looking at Saturn will train the eye and, in time, will improve one's ability to detect subtle detail.

3.1.1. A Brief Word About Photography and CCD Imaging

Although this book is chiefly concerned with visual observations of Saturn, a few words should be said about ***lunar and planetary photography*** and ***CCD imaging***.

Many observers in the past often photographed the Moon and planets, taking both black and white and color exposures. Through trial-and-error efforts, using a variety photographic set-ups and techniques, some observers have produced impressive, high-resolution images with photographic film. Contemporary CCD imaging has basically replaced outmoded photographic methods and has now become a vitally important and worthwhile addition to the collection of visual data for any observing season.

The planet Jupiter and the Moon usually can be imaged fairly well because of the wealth of high-contrast detail, but attainment of optimum results demands careful planning, proper choice of suitable equipment, and a great deal of experimentation. Other solar system objects, including the planet Saturn, have offered in the past a significant challenge to the astrophotographer because of the sparsity of clearly-discernible features using film. For example, in the past film photography of Saturn revealed perhaps one or two belts, the Equatorial Zone (EZ), plus Cassini's division and a couple of major ring components. High-resolution CCD digital images of Saturn routinely capture discrete features and phenomena within specific belts and zones and ring components that is often beyond the threshold of detection by purely visual methods, (e.g., suddenly appearing and recurring prominent bright and dark spots on the planet's globe), in particular images at different wavelengths of light. Observers who have specialized in imaging Saturn using an optimum combination of filters and other equipment have typically achieved truly amazing results. There is no doubt that regular imaging of Saturn as a concurrent program with systematic visual observations, increases the overall success in recording important phenomena on the planet that is useful to science.

To maximize the value of visual and digital imaging endeavors, observers are urged to coordinate their work so that simultaneous investigations of Saturn can become the rule rather than the exception. In any observing season, an objective comparison of simultaneous data in the form of visual drawings and high-resolution CCD images of Saturn help shed light on the limits of visibility and reality of sometimes very elusive atmospheric or ring phenomena.

Discussion of the rapidly-changing equipment, methods, and techniques for successful imaging of Saturn is beyond the scope of this document. Nevertheless, up-to-date information on lunar and planetary imaging can usually be found in periodicals such as ***Astronomy***, ***Sky and Telescope***, and the ***Journal of the ALPO***, as well as numerous specialized texts. The author is always pleased to direct prospective observer who want to pursue digital imaging to the appropriate sources of authoritative information upon request.

It has been abundantly demonstrated in recent years, that CCD imaging has surpassed what has been possible I the past with ordinary photographic film, plus CCD's generate digital information which can be processed with specialized computer software to bring out the best detail in the images. The enormous dynamic range of CCDs and their high sensitivity to visual and other wavelengths makes them a valuable tool in lunar and planetary research. Observers have also achieved very good results using afocal methods to image Saturn using digital cameras, too.

1.2. 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 at another instant, the seeing may be "poor," the image appearing as though it is boiling or being seen through a moving fluid.

It is exceedingly important for the planetary observer to establish, as accurately and objectively 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 useful observations.

Most Saturn observers routinely use the numerical ***ALPO Standard Seeing Scale***, which ranges from 0.0 (the absolute worst possible seeing) to 10.0 (perfect seeing), with intermediate values assigned in accordance with one's best appraisal of the atmospheric seeing conditions (in the area nearest the planet in the sky). This scale is completely suitable for most observing situations, but it is rather subjective. More advanced planetary observers should consider a more quantitative seeing appraisal.

Attempts have been made to devise a scale that is a bit more objective, and the results abound in the literature. For instance, W.H. Pickering assigned descriptive notation to numerical categories based on the appearance of diffraction disks of a number of moderately brilliant 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 natural, therefore, to try to devise a meaningful scale based upon the relationship 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 one 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:

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

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 it is 2.2×10^{-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 inches, 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 by equation (3) below:

$$\frac{5.54''}{D_e} = \frac{5.54''}{0.2 inches} = 27.7''$$

under the stated conditions, where 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:

$$D' = eD$$

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-inch aperture, r***, which is a personal constant. The telescope used most frequently in planetary observation must be "stopped down" in aperture to precisely 1.0 inch. 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-inch 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-inch 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 gives the value, ***r′***. The efficiency 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 detrimental effects of atmospheric dispersion and differential refraction, which is pronounced at low altitudes. The stars should also be as near Saturn as possible, or at least at the same altitude as the planet. Observing Saturn when it is high in the sky, whenever possible, is extremely important.

The ***transparency*** of the atmosphere may be determined on a given date of observation by estimating as precisely as possible (using a reliable 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.

Visually estimating transparency 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 good 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). 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 Saturn. 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 Saturn, but essentially absent from the zenith, another approach might 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 Saturn under most conditions.

If there is a great deal of light interference from a nearby city, from the Moon, or from twilight, then the best that one can do is estimate the faintest star, to the nearest whole magnitude, that would be visible independent of the scattering light. 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.

1.3. Image Brightness

The ***surface brightness***, ***B***, of any planet may be conveniently expressed in ***stilbarnes*** (stilb), where 1.0 stilb is the luminance of 1.0 cd/cm^2 (candela per square centimeter) or 1.0 x 10^4 cd/m^2 (candela per square meter). The ***visual geometric albedo***, p_V, of Saturn is 0.461, which is the percentage of incident light that is reflected by the planet in the direction of the observer. The ***true surface brightness*** of Saturn has been determined to be about 0.018 stilb. This true surface brightness value for Saturn (as well as the rest of the planets) is 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 Mercury and Venus, for which the numerical value of the phase angle, ***i***, 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 opposition for a superior planet or at superior conjunction for an inferior planet), 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 and the Moon exhibit all possible phase angles, while superior planets like Saturn show only a small phase angle. Because the numerical value of the phase angle for Saturn never exceeds 0° by very much, and because the perihelion and aphelion distances are not appreciably dissimilar, the true surface brightness of 0.018 stilb for the planet does not change significantly.

Before the reflected light from Saturn 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 appears in *Table 1.1,* known as the ***filter transmission coefficient***, 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. The ***transmission coefficient for any telescope***, u_t, is at best 0.8 and more likely 0.6, or possibly 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 1.2*, which lists values of ***u*** as a function of T_r and the product $u_f u_t$. Thus, to use *Table 1.2*, the product $u_f u_t$ must be determined and the T_r ascertained precisely, and it is only necessary to read down the proper column in *Table 1.2* to find ***u***. Note that the ***atmospheric transmission factor or coefficient***, u_s, is given by equation (14) below:

$$u_s = \frac{u}{u_f u_t}.$$

As an example, suppose that $u_f = 0.25$ (for a Wratten filter #23A from *Table 1.1*), and $u_t = 0.8$. The product $u_f u_t$ is (0.25)(0.8) = 0.2. If $T_r = 5.5$, we may look in *Table 1.2* and find the value for ***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 L_s (in stilb), then the surface brightness of the planet in question, B_s, after the light has passed through the atmosphere is derived by equation (15) below:

$$B_s = u_s B + L_s.$$

If 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, 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, ***D***, in inches, magnification, ***M***, and pupillary diameter (aperture) in inches of the eye, **θ**, the ***apparent surface brightness***, ***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 $\boldsymbol{u_f L_t}$ = 0.0 assuming that the optics of the instrument are exceptionally free of dust and very clean.

Table 1.1

Numerical Data for Selected Wratten Color Filters

Filter No.	Color	%	Dominant Transmission	Extreme Transmission
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 Saturn is being observed in a reasonably dark sky, 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 5.0 mm. In this particular case, the equation (18) will be transformed into equation (19) below:

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

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

If one is interested in the magnification per inch of aperture, $\boldsymbol{M_i}$, which will give an apparent surface brightness, ***B′***, then equation (20) below may be employed:

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

Table 1.2

Factor *u* as a Function of T_r and $u_f u_t$

T_r		$u_f u_t = 0.8$		$u_f u_t = 0.6$		$u_f u_t = 0.4$		$u_f u_t = 0.2$
6.00	*u* =	0.64	*u* =	0.50	*u* =	0.30	*u* =	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

Table 1.3

Transmission Coefficient, *u*, as Derived from *Table 3.2* for Surface Brightness, *B´* (in stilb)					Optimum Magnification per Inch of Aperture for Saturn
1.0x10^{-5}	**1.0x10^{-4}**	**1.0x10^{-3}**	**1.0x10^{-2}**	**1.0x10^{-1} stilb**	
0.6	---	---	---	---	---
0.5	---	---	---	---	---
0.4	---	---	---	---	130
0.3	---	---	---	---	120
0.2	---	---	---	---	95
0.1	---	---	---	---	67
0.08	---	---	---	---	60
0.06	0.6	---	---	---	52
0.05	0.5	---	---	---	47
0.04	0.4	---	---	---	42
0.03	0.3	---	---	---	37
0.02	0.2	---	---	---	30
0.01	0.1	---	---	---	21
0.008	0.08	---	---	---	19
0.006	0.06	0.6	---	---	16
0.005	0.05	0.5	---	---	15
0.004	0.04	0.4	---	---	13
0.003	0.03	0.3	---	---	12
0.002	0.02	0.2	---	---	10
0.001	0.01	0.1	---	---	7
	0.008	0.08	---	---	6
	0.006	0.06	0.6	---	5

1.4. 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 $\boldsymbol{B_1}$ and $\boldsymbol{B_2}$, where $\boldsymbol{B_1 \geq B_2}$ as measured in stilb, the ***true contrast***, $\boldsymbol{c}$, between the two areas is derived using equation (21) below:

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

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

As may be observed through the telescope, the ***apparent contrast***, $\boldsymbol{c'}$, between two planetary surface features is defined by equation (22) below:

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

where $\boldsymbol{B'_1}$ and $\boldsymbol{B'_2}$ denote apparent surface brightness in stilb, and $\boldsymbol{B'_1 \geq B'_2}$.

We are specifically assuming that the surface features considered are fairly large in comparison with limiting resolution. The value $\boldsymbol{c'}$ will be appreciably different from that of $\boldsymbol{c}$ only when scattered light has been added to the image. If we are considering a difference between $\boldsymbol{B}$ and $\boldsymbol{B'}$ 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 Saturn during daylight hours. If the transparency, $\boldsymbol{T_r}$, is found to be about 5.5, if the transmission coefficient, $\boldsymbol{u_t}$, for the telescope is 0.6, if no filter is used, and if the optical components of the instrument are exceptionally clean, so that $\boldsymbol{L_t}$ = 0.0, it is possible to derive the value, $\boldsymbol{u}$, from *Table 1.2*. Under these given set of observational circumstances, $\boldsymbol{u}$ = 0.3. The surface brightness of the daylight sky is near 0.8 stilb, and the surface brightness of Saturn is 0.018 stilb. If the actual surface brightness of the Equatorial Zone (EZ) and the South Equatorial Belt (SEB) are taken to be 0.019 and 0.009 stilb, respectively, the true contrast, $\boldsymbol{c}$, is found employing equation (21) as

[(0.019)-(0.009)]/(0.019) = 0.526 or 0.5.

It is possible to derive the apparent surface brightness, $\boldsymbol{B'_{EZ}}$ and $\boldsymbol{B'_{SEB}}$, recalling that the effects of aperture and magnification have not yet been applied, using equation (17) modified to

$$B_{EZ}' = uB_{EZ} + u_f u_t L_s + u_f L_t$$

$$B_{SEB}' = uB_{SEB} + u_f u_t L_s + u_f L_t$$

whereby

$$u = u_f u_t u_s .$$

where the computation takes the form

B'_{EZ} = (0.3)(0.019) + (1)(0.6)(0.8) + 0.0 = 0.4857 stilb

B'_{SEB} = (0.3)(0.009) + (1)(0.6)(0.8) + 0.0 = 0.4827 stilb

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

[(0.4857)-(0.4827)]/(0.4857) = 0.0062.

Therefore, observing Saturn during daylight hours will be completely useless. The true contrast of 0.5 (or 50%) between the EZ and SEB has been reduced to 0.006 (less than 1.0%), below the limit of contrast perception 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 0° 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, $L^@{}_s$, due to scattered moonlight on a clear and otherwise dark night would be determined as

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

whereby the computation becomes

$L^@{}_s = [(4.1\mathrm{x}10^{-1})\ (8.0\mathrm{x}10^{-1})]/2.25\mathrm{x}10^5 = 1.46\mathrm{x}10^{-6}$ 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 2.0x 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 5.0x10^{-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.

In general, 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) takes the form as

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

defining ***Fechner's Constant***, and the values B_1 and 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 1.3*) it would be necessary for a significant reduction in magnification to occur. For Saturn, this is not possible, since even an apparent surface brightness of 0.01 stilb is virtually impossible to achieve (taking into consideration the fact that several transmission factors are affecting B'). For magnifications less than about 25*D*, as was emphasized earlier, the eye is usually not capable of resolving all that the optical system can resolve. Assuming that the lowest possible light level for reasonably good contrast perception is near 0.001 stilb, it is noted that one must still use much lower magnification than 25*D* for Saturn. Thus, larger apertures are usually required when seeing and transparency conditions permit.

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 comparatively dim planets like Saturn often disagree that lower powers will improve perception of delicate contrasts. There is a strong dependence, in truth, of contrast perception on the angular dimensions of various atmospheric features on Saturn (e.g., belts and zones), 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 encounter a surface brightness from 0.03 to 3 stilb for optimum visual work.

In *Figure 3.1*, 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).

Suppose that during a particular observation the size of the planetary surface features being studied and the apparent surface brightness of the planet are plotted on the graph in *Figure 1.1*. 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 $B_1 > B_2$.

Using *Figure 1.1* and *Table 1.3*, it has been possible to determine the approximate magnifications for use on the planet Saturn that will yield optimum contrast perception conditions, assuming excellent observing circumstances and reasonably clean 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. For Saturn's finest details, very high magnifications are necessary if one is to see them to advantage, this being from about 350X to 500X. It is obvious that large apertures are mandatory for good image characteristics at these powers. Larger surface features may be detected with low to moderate magnifications, in the range extending from about 200X to 400X. 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 Saturn 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*.

Suppose for the sake of example one is observing Saturn using a 4.0-inch refractor at 200X, and the observer desires to determine if this magnification is near the optimum. The optics are assumed to be very clean, whereby $\boldsymbol{u_t}$ = 0.6; $\boldsymbol{T_r}$ = 5.0; seeing, $\boldsymbol{D'}$, is determined to be 3.0 in. From *Table 1.2*, the value of $\boldsymbol{u}$ = 0.2, assuming no filter is employed. Using equation (19) the apparent surface brightness, $\boldsymbol{B'}$, is

$$B' = (25D^2uB)/(M^2) = [25(4^2)(0.2)(0.018)]/(200^2) = 3.6\text{x}10^{-5} \text{ stilb.}$$

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 3.0 inches (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

$$R_e = (5.54'')/(3.0) = 1.85''$$

Therefore, the smallest visible detail will be approximately $\boldsymbol{2R_e}$, as was previously noted, or 3.4″. We may now derive the ***apparent size*** of this detail as seen by the eye in the telescope using equation (28) below:

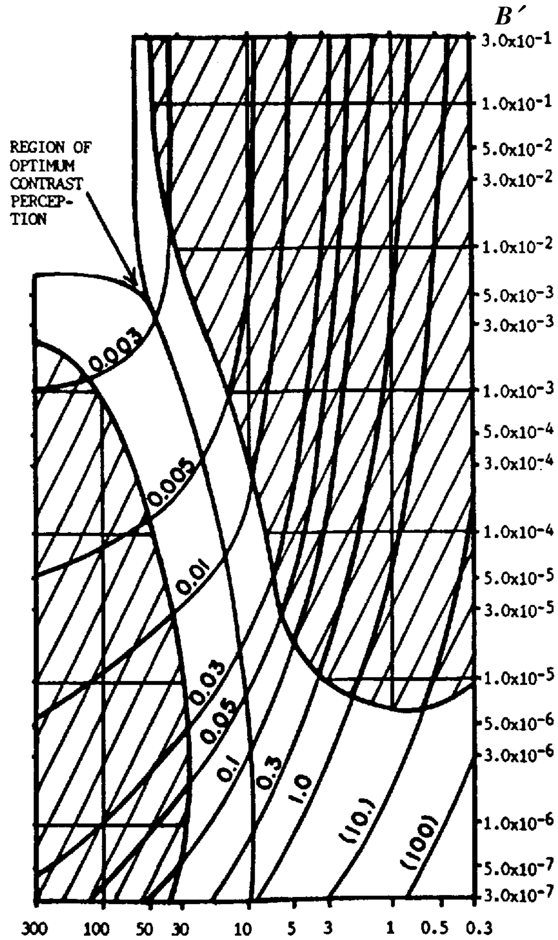
$$A = (M)(2R_e)$$

where $\boldsymbol{M}$ is the ***magnification*** and $\boldsymbol{R_e}$ is the ***effective resolution***. Our computation is, therefore, as follows

$$A = (200)(3.4'') = 680'' \text{ or } 11.3'$$

If this result is plotted on the graph in *Figure 1.1*, the point falls nearly on the line of optimum contrast perception, and we can be confident that 200X on the 4.0-inch refractor in our example is close to the optimum magnification.

Figure 1.1
Regions of Optimum Contrast Perception



Subtended Angle (Minutes of Arc)

Actually, a better presumed value for the apparent size of a spot of diameter, ***d***, or a linear feature of width, ***w***, smeared by the effective resolution, $\boldsymbol{R_e}$, 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 reflectivity's of component elements which 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 areas on Saturn, where B_2 denotes the darker background's true surface brightness in stilb and B_1 is the true surface brightness in stilb of a lighter area. The apparent surface brightness of the two areas will be given by the equation

$$B' = \frac{25D^2 u B_1}{M^2}$$

for the lighter area, and equation

$$B_2' = \frac{25D^2 u B_2}{M^2}$$

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, R_e, will be given by the equation (29) below:

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

where d is the true diameter of a circular spot in seconds of arc. For linear features (e.g., a Saturnian belt like the NEB or SEB) 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 recalling that the contrast will be unchanged by absorption as long as there is no scattered light, 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:

$$c' = c\left\{\frac{d^2}{(d + R_e)^2}\right\}$$

and

$$c' = c\left\{\frac{w}{w + R_e}\right\}$$

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 Saturn where the astronomer wishes to study belts on the globe of the planet 1/10th the polar diameter in width. The date of observation is 1980 March 25, and the ephemeris consulted shows that the polar diameter of Saturn would have a value of 16.0″ (seconds of arc). A belt 1/10th the polar diameter of Saturn would have a width, ***w***, of (16.0″)(1/10) = 1.6″. The telescope used is a 6.0-inch refractor at 300X with no filter and exceptionally clean, well-aligned optics. The appraised seeing is 5.5 inches 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, $\boldsymbol{L_s}$ is 0, and $\boldsymbol{T_r}$ is 5.5. The total transmission factor, ***u***, is found in *Table 1.2* to be 0.4. The true surface brightness of Saturn, ***B***, is 0.018 stilb, whereby the apparent surface brightness, ***B′***, by equation (19) is computed as

$$B' = \frac{25(6^2)(0.4)(0.018)}{300^2} = 7.2\text{x}10^{-5}\ \text{stilb.}$$

If a dusky belt of width, ***w***, is being sought on Saturn, and if the true surface brightness of the feature is taken to be 0.008 stilb, the apparent surface brightness of the feature, ***B′***, is

$$B' = \frac{25(6^2)(0.4)(0.008)}{300^2} = 3.2\text{x}10^{-5}\ \text{stilb.}$$

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 belt sought) may be determined using equation (21) as

$$c' = \frac{0.018 - 0.008}{0.018} = 0.555 \text{ or } 55.5\%.$$

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 $\boldsymbol{B'_1}$ represent the apparent surface brightness. The solution is found as

$$c' = \frac{(7.2\times10^{-5} - 3.2\times10^{-5})1.6}{7.2\times10^{-5}(1.6 + 1.0)} = 0.341 \text{ or } 34.1\%.$$

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, as

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

so that by using equation (30a) we have

$$\text{c}' = 0.555 \left[\frac{1.6}{1.6 + 1.0}\right] = 0.341 \text{ or } 34.1\%$$

Using equation (28b), the effective or limiting resolution of 1.0″ will smear the belt of width 1.6″ to

$$A = M\sqrt{w + R_e} = 300\sqrt{1.6 + 1.0} = 484.0'' \text{ or } 8.1'$$

at the eye of the observer. Plotting the derived values of 8.1′ and 3.2×10^{-5} stilb on the graph in *Figure 1.1*, it will be noted that the point lies just within the clear area below the line designated "optimum contrast perception," with an approximate value of 0.03. In our example, the true contrast of 55.5% has been reduced to 34.1%, and we may enhance contrast perception by increasing magnification. Again, as was pointed out earlier, more will be gained in this case by a slight increase in magnification in terms of contrast perception than will be lost due to a diminution in apparent image brightness.

In conclusion, the results outlined here concerning contrast perception have been based largely upon experimental research carried 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 are ill-defined for planetary features. Thus, in this case, lower magnifications than those suggested might be required to sharpen peripheral areas and improve perception of delicate, often elusive detail.

1.5. 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 phenomenon***. 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 viewing Saturn.

CHAPTER 2: DRAWING SATURN AND ITS RING SYSTEM

2.1. Observing Blanks and Forms

A series of carefully executed ***full-disk drawings*** of the planet Saturn and its accompanying ring system can provide an exceptionally valuable record of the changing aspect of the planet's atmosphere or phenomena associated with the rings. Unfortunately, freehand drawings of Saturn are usually quite difficult because of the constantly changing inclination of the plane of the rings from one apparition to another. The author has developed a series of blanks for the ALPO Saturn Section that can be conveniently utilized throughout any given observing season to correctly draw Saturn with the proper global oblateness and ring tilt. These blanks are available from the Saturn Section at the cost of reproduction and mailing, and they should be ordered prior to the start of the apparition in question. For convenience, a full set of these drawing blanks accompanies this monograph, and observers are granted permission to photocopy the forms, provided that they will be used strictly for the purpose of recording and submitting observations to the ALPO Saturn Section.

Each form includes a blank that depicts the proper outline of the globe of Saturn and its accompanying ring system. Careful attention should be paid to the value of **B** (not to be confused with the usage of ***B*** in connection with our discussion of planetary surface brightness, contrast, and color perception), which is the planetocentric (Saturnicentric) latitude of the Earth referred to the plane of the rings. **B** is found in ephemerides such as the ***Astronomical Almanac***, and it is positive, +, when northern portions of the globe and ring system can be seen from our vantage point; it is negative, –, when southern areas of Saturn and its rings are seen. **B** can vary from ±0° to nearly ±28°, and when **B** = 0.0°, the rings are edgewise to our line of sight. At ±28° the rings are open to their fullest extent (tilted into our line of sight at a maximum angle), and they are then observed to greatest advantage, as are northern or southern polar zones. Values of **B** are entered on the form selected (the correct blank to use on any particular date and ring tilt). After choosing the appropriate drawing blank, one is generally ready to proceed with drawing Saturn.

2.2. Executing the Drawing

There are a number of fundamental guidelines that need to be adhered to by anyone who desires to draw Saturn and its rings at the telescope. Before the drawing is actually initiated, and prior to coming to the telescope, it is wise to give serious thought to what basic items will be required while observing. A few of the more essential items are:

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

2. An artist's stump.

3. Clean erasers and/or erasing pencils of variable sharpness.

4. A red flashlight (a hiker's head lamp is a great convenience).

5. Accurate watch set to WWV/CHU time signals (specialized radios are available at small cost that receive WWV at 2.5, 5.0, 10.0, 15.0, and 20.0MHz or CHU at 7.33 and 14.33MHz).

Once at the eyepiece, it is best to spend a few moments looking at Saturn on a very general basis. Decide if the seeing and transparency of our own atmosphere is going to permit perception of enough detail to make a drawing feasible (the instrument's optical system should have been allowed to adjust to the ambient temperature before starting observation). If drawing Saturn is not possible because of bad seeing, a written report will suffice, with attention being paid to the general nature of the globe and rings. More subtle features near the threshold of vision should be described accordingly. If a drawing is attempted, it is still very important to accompany it with written notes for clarification of anything that was actually seen and drawn.

The initial step in any drawing of Saturn is to establish the correct relative locations of the belts and zones in accordance with the proper latitude, with close attention being given to the overall geometric appearance and actual width of these features. In practice, it is a good idea to sketch in lightly all of the readily apparent belts and zones, and this may be done at some leisure since rotation does not appreciably distort latitudes. The same procedures should be followed for the rings and their components and phenomena.

Utilization of the same eyepiece (and magnification) throughout the drawing session is encouraged. Of course, using variable magnifications to correctly represent features (and/or to confirm their presence when they may be questionable at lower powers), along with the use of color filters of known transmission, is recommended. Careful notes need to accompany the drawing as to equipment employed and when.

Now that the general details have been sketched in, it is time to enter on the forms the UT (Universal Time) of the "starting time" of the drawing. With some degree of haste, without sacrificing accuracy, fine details can be added to the drawing. Dashed lines are commonly used to set off bright areas or brilliant spots from their immediate environment. All areas represented on the drawing must be given equal emphasis, depicting actual and relative appearances. Shading-erasure techniques, often employed in making drawings of lunar features, give finesse and allow accurate representation of relative intensities and tones for belts, zones, ring components, and fine features. About 20 minutes should be all that elapses during this phase of the drawing, because rotation will begin to distort features with increased time.

A final examination of the completed drawing should be the next step. If everything is properly represented, the observer now records the UT of the "ending time" of the sketch.

Strip-sketches, not usually warranted for Saturn, may be useful if features persist long enough for CM transit timings. These are especially useful for showing a particular belt or zone through a span of rotational time, and they can be made directly on forms provided for recording CM transits. ***Sectional-sketches*** are also valuable as a means of giving emphasis to localized phenomena (e.g., spots, disturbances, festoons, etc.) examined under higher magnification. Sectional-sketches should be completed on a separate sheet of paper and attached to the main Saturn drawing form.

For all drawings, the following supporting data must be provided:

1. Observer's name, address, and location of the observing station.
2. Latitude, longitude, and height above mean sea level is important, but optional.
3. Telescope used, including magnification(s), all filters, and accessories.
4. Field orientation of the ocular(s).
5. Seeing (**D′**) and transparency ($\mathbf{T_r}$).
6. Start and End times of the drawing in UT.
7. CM longitudes for System I and II (from an appropriate ephemeris).
8. Critical evaluation of one's drawing accuracy and reliability.
9. Numerical value of **B** (from an ephemeris).

Room is provided on the standardized drawing blanks for most of this information, but careful checking is a good idea to be certain that nothing important is overlooked.

All drawings must be accompanied by sufficient, objective descriptions as to exactly what was seen. Some points to consider in providing such information are:

1. The location, characteristics, and general nature of disturbances, spots, or other phenomena in connection with belts, zones, or ring components.

2. Comparisons between regions of similar nature and latitude in opposite hemispheres (whenever possible); for example, comparing the SEBs with the NEBn. It is also possible to compare areas that are adjacent or similar in the same hemisphere (e.g., SEBs vs. SEBn).

3. General notes regarding the prominence of belts, zones, or ring components.

4. General width and extent of the ring shadow on the globe and the shadow of the globe on the rings.

5. Visibility and location of "intensity minima" in the rings, in addition to studies of Encke's and Cassini's divisions.

6. Notes on the bicolored aspect of the ring ansae.

7. General appearance and nature of the rings at edgewise presentations (when $\mathbf{B} = 0^{\circ}$).

8. Anything unusual or of particular significance.

Saturn, as was mentioned earlier, does not usually exhibit the same frequency and conspicuousness of atmospheric detail and activity as is so common on Jupiter. As a result, one is often disappointed with initial visual impressions of Saturn, especially at low powers. With time, however, it will be easier to see delicate features at the threshold of vision directly attributable to training of the eye during times of optimum image brightness and contrast.

2.3. The Purposes and Objectives of Drawing Saturn

Drawings of Saturn, with accompanying descriptive reports, have a three-fold purpose:

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

2. To establish a reliable concept of the overall phenomena perceived on Saturn.

3. To help maintain one's sensitivity to perceive subtle detail at the threshold of vision.

Long-term observations are being used to investigate "routine" seasonal activity, periodic outbursts (e.g., unusually prominent white spots), and other long-term changes that are suspected or readily apparent in the features on the globe and the relative visibility of various ring phenomena.

Short-term observations are chiefly concerned with the observation of bright and dark spots on the globe as a check on the rotation period in different latitudes, presumably in expectation that a reliable ephemeris will emerge that is analogous to that for Jupiter in the ***Astronomical Almanac*** (which already gives System I and System III data for Saturn). The ALPO Saturn Section now publishes System I, System II, and System III data on the ALPO website at **<www.lpl.arizona.edu/alpo>** for the convenience of observers. A good deal remains to be done to confirm rotation rates in different latitudes, particularly with respect to monitoring disturbances or spots that persist long enough for CM transits at higher northern or southern latitudes on Saturn. These continuing efforts may eventually persuade the Nautical Almanac Office to add ephemerides for System II longitudes to the ***Astronomical Almanac***.

Confirmation of infrequently observed features and suspected detail 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 particular phenomenon over a reasonable period of time, it is not easy to claim it as definitely established. These points justify the necessity and emphasize the critical requirement for an aggressive ***systematic, simultaneous observing program***, where individuals work independently but at the same time and date throughout a given apparition. As the years pass, more and more of the ALPO Saturn Section observers are participating in this endeavor, and this collective monitoring of variable phenomena in the atmosphere of Saturn and in the rings is improving the objectivity and reliability of data. It is being demonstrated by these and other international team efforts that a more complete, coherent, and realistic picture of Saturn is possible. As an example, we have already established from visual observations that faint belts are not just occasionally seen on the planet, and we know that faint, delicate details are more frequently perceptible within these global features, as well as in the ring components, if the proper observational methods are consistently used. Also, it has been demonstrated that, without taking into consideration the recent *Voyager* revelations, Cassini's division and Encke's gap are not the only such features seen in the rings of Saturn. Furthermore, visual observations have shown that Ring C can be seen not only at the ansae.

In the past, observers have made substantial advances in clarifying some of the controversial problems concerning Saturn. For example, consider these observational results:

1. Observations of numerous spots and festoons have been accumulated, most showing up in the equatorial latitudes of Saturn's globe.

2. Variability has been noticed in the rotation rate of the SEB through observations of some long-enduring spots.

3. Variations have been detected with regard to the belt and zone intensities that may be attributed to a seasonal effect.

4. Ring C has been observed at the ansae as well as in front of the globe of Saturn with small to moderate apertures.

5. Shadow intensity anomalies have been observed on quite a few occasions.

6. Definite confirmation of several "intensity minima" in the rings was accomplished prior to the *Voyager* missions.

7. Reasonably good confirmation occurred of the very tenuous, elusive Ring E (formerly known in ALPO literature as Ring D′) exterior to Ring A, prior to the *Voyager* flybys.

8. Identification of a remarkable series of dusky radial "spokes" in Ring B (and sometimes suspected in Ring A), occurred prior to the views by *Voyager*.

There is sufficient reason to believe that, as observing equipment and methods evolve and improve, a great deal more will emerge from systematic, simultaneous efforts in drawing, photographing, and describing Saturn. We simply need to continuously examine, criticize, refine, and develop our methods and techniques to perfection, where our work will always be useful, perhaps even vital, to the rest of the scientific community. There is no question that ALPO observations of Saturn have been a major contribution to the body of knowledge about the planet, and there is no reason to believe that these contributions will not continue.

2.4. Factors Affecting Reliability of Drawing Saturn at the Telescope

It is important to point out some of the things which contribute to drawing inaccuracies. One of these is repetitive ***style***, which can be easily avoided by experimentation with one's drawing form and technique. Another pitfall is depicting ***excessive boundary sharpness*** for belts and zones. It should be remembered that these features cannot be resolved so that edges are perfectly linear, crisply-defined features. If observers will utilize relatively blunt pencils when making drawings, the incidence of this problem can be diminished.

Differences in transparency and seeing affect drawings, and the best solution to this difficulty is to choose observing times when good seeing and optimum transparency can be attained (e.g., observing when Saturn is high above the horizon). ***Visual acuity***, where one person simply sees better than another, is a factor that is difficult to measure and correct for. ***Aperture of the telescope*** is critical, and the proper choice of instrument size will, within certain limits, dictate how much detail can be resolved. For example, observations with too small of an aperture usually means that the drawing will be considerably simplified. Larger instruments usually resolve more detail to sketch, all things being favorable, and comparing drawings with small apertures to those made with larger instruments can be very troublesome. Care must be taken to appraise the atmospheric conditions accurately, to use appropriate aperture and magnification, to seek optimum image brightness and contrast conditions, and to make careful mental and written notes of any anomalies that might exist with regard to one's overall visual acuity. One way to help overcome the latter problem is to evaluate the drawing objectively, and those who have certain visual deficiencies need to indicate these in estimating the level of confidence to be placed in the final drawing. Astigmatism, for example, is the worst of the visual problems of the eye, and observers suffering from this defect should wear their corrective lenses while observing.

Contrast sensitivity is variable from one person to another. Those who have poor contrast sensitivity, for instance, make drawings that consistently are devoid of detail and minute tonal differences. Faint detail on the planet is apparently beyond their visual threshold, and if one's efforts are constantly plagued by an inability to see any detail, particularly with larger apertures, one might consider even more aperture and proportionate magnification. Those with exceptionally good contrast sensitivity and perception often exaggerate tonal differences, and their drawings are often misleading. It is generally believed that an observer who is bothered by what appears to be an apparent inability to represent properly with a pencil a great range of tonal differences, probably has good or near-optimum contrast perception. Indeed, as one gains experience in observing and drawing Saturn, contrast sensitivity shows marked improvement.

Color sensitivity is yet another factor that affects drawings. It is clear that some eyes are particularly sensitive to specific wavelengths and less responsive to others. It is not uncommon for a person with a sensitivity toward blue, for example, to refer to a bluish zone on Saturn as the brightest zone on the globe. Another person may have a greater affinity for yellow light, and he may consequently say that a yellowish zone is more brilliant. If one knows that he has a specific psychophysical color sensitivity, it is easy to correct for it. Color-blind individuals are particularly handicapped, and they should not attempt absolute color estimates.

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

Fatigue critically affects drawings and data acquisition, and the observer should be adequately rested prior to coming to the telescope. Many experienced observers "pre-sleep" for a period of time that is equal to the anticipated observing session. ***Distractions*** can seriously affect accuracy of one's work, and every effort should be made to optimize concentration and attention to detail during the observing session.

2.5. Nomenclature and Field Orientation of the Image

Figure 2.1 presents the ***nomenclature system*** for Saturn's rings and globe, while *Table 2.1* lists the relevant abbreviations and symbolism used. In the figure, South (S) is at the top and West (W) is to the left by directions in the sky using a telescope that inverts and reverses the image (the normal astronomical telescopic view). Verbal descriptions must employ, without exception, the IAU system whereby East (E) is toward the left (true E on the planet), as indicated in *Figure 4.1*. Individuals should employ the correct reference nomenclature for Saturn in all cases when submitting drawings or any other observations. No observations will be used where alternate or non-standard abbreviations or nomenclature is employed, particularly in cases where it is impossible to correctly identify represented features.

At this point in our discussion, nomenclature for Saturn's ring system perhaps needs a little further clarification. ***Ring A*** is the usually-seen outermost component, ***Ring B*** is the inner middle portion of the ring system, and ***Ring C*** is the innermost visible component. A very tenuous ring component external to Ring A has been identified (first by ALPO observers) and classified as ***Ring E*** (confirmed by *Voyager*), but it does not appear on the diagram in *Figure 2.1*. Also missing from the diagram is the actual innermost ring component, internal to Ring C, known as ***Ring D*** (first discovered in 1970). The new outermost ring components, ***Ring F*** and ***Ring E***, are omitted (these were found by *Voyager* in 1980-81).

To provide a means for accurate and easy identification of ring divisions or more subtle ***intensity minima***, a system is utilized for denotation of these features. A capital letter and a number are assigned to the division, gap, or intensity minimum seen. The letter denotes what ring component the feature is located in, and the number indicates the relative position of the feature as a fraction of the distance outward from the globe into the ring. Encke's gap, for example, is designated ***E5*** because it is about halfway out from the globe of Saturn in Ring A. Likewise, Cassini's division is ***A0*** or ***B10*** since it is at exactly at the boundary between Ring A and Ring B. By convention, gaps occur within rings and divisions located between rings.

When Saturn is observed with a telescope that inverts and reverses the image (as seen in *Figure 2.1*), the globe casts a shadow on the ring system to the left (IAU) or East (E) prior to opposition, to the right or West (W) after opposition, and generally on neither side exactly at opposition (no shadow). It is of importance to correctly represent shadows on drawings.

Field orientation is an important consideration when drawing Saturn. In a standard astronomical telescope (no prismatic diagonal or other right-angle device to confuse image orientation) the sky directions of South (S) is at the top of the field of view and West (W) is to the left. This corresponds to a field lying ideally on the celestial meridian between the zenith and the south point of the horizon in the northern hemisphere of the Earth. In reducing many observations at the end of a given apparition, the author has seen numerous instances where errors in field orientation have been introduced into descriptive notes as a result of the use of star diagonals. So, to reiterate, it is strongly recommended that the use of *any* device that re-orients the telescopic image should be avoided if possible.

Remember that sky directions are not necessarily those of the IAU reference on the planet under observation. The ***International Astronomical Union*** (***IAU***) General Assembly in 1961 adopted a resolution whereby directions in astronomical literature must correspond to true directions on the planet observed or discussed. Look at *Figure 2.1* again, and note these directions carefully. Observers should always use the IAU system, but if sky directions are employed, they should be noted. Saturn observing forms have a space to check to indicate whether IAU or sky directions are used. *Figure 2.3* is an example of a drawing of Saturn at the telescope.

Prograde motion is from West to East, and features will move from right to left when Saturn is observed in the normal inverted and reversed view. Note that the ***following***, ***f***, limb of Saturn is West in IAU terminology; ***preceding***, ***p***, is East in the IAU sense.

Figure 2.1

Nomenclature for Saturn's Ring and Globe Features

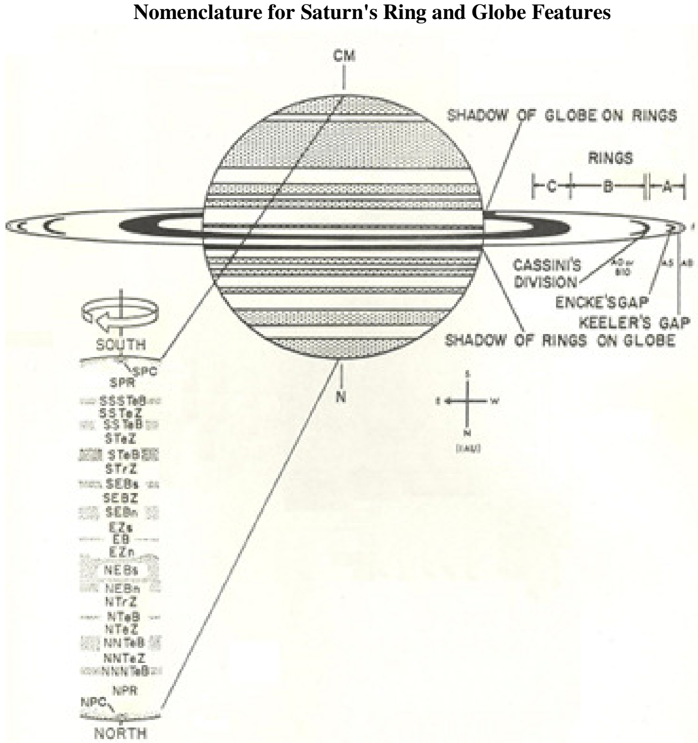


Table 2.2

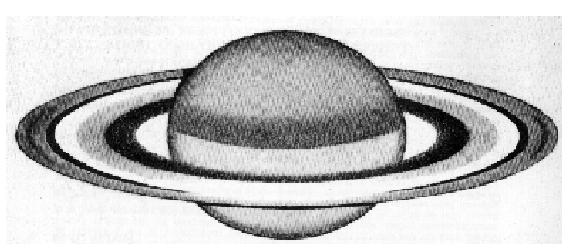
Abbreviations and Symbolism Used in *Figure 4.1* (other than N, S, E, W directions):

B	Belt	P	Polar
Z	Zone	n	North component
E	Equatorial	s	South component
R	Region	*p*	preceding
C	Cap	*f*	following
Te	Temperate	Tr	Tropical

Example: NEBn is North Equatorial Belt, N component; STeZ is South Temperate Zone; EZn is Equatorial Zone, N half.

Figure 2.3

Sample Drawing of Saturn



CHAPTER 3: VISUAL PHOTOMETRY AND COLORIMETRY

3.1. Visual Numerical Relative Intensity Estimates: Visual Photometry

A complete and continuous record of variations in the relative intensities of different belts, zones, and ring components of Saturn is a valuable data source on any seasonal phenomena and other fluctuations over time. All observers should carry out regular intensity estimates, since there is a definite and rather uniform relationship between relative intensities and the real albedo values of Saturnian features.

The intensities of the different belts and zones on the globe of Saturn generally vary from one apparition to another, and there exists evidence to support the contention that the relative intensities of these features seldom remain constant from one Saturnian season to the next. The planet affords us with perhaps the best example in the solar system for determination of possible seasonal effects on belts and zones, because Jupiter has virtually no seasons at all. Forasmuch as the seasons on Saturn are so long by terrestrial standards, a project such as this is a very long enduring enterprise. Even so, observational data accumulated over a span of several years points to what might be a marked seasonal effect, despite the fact that many more observations are clearly needed.

For making ***visual numerical relative intensity estimates*** or ***visual photometry*** at the telescope, it is important for all observers to utilize, without exception, the ***ALPO Standard Intensity Scale***. The scale is composed of a numerical sequence from 0.0 (totally black or shadow condition) to 10.0 (most brilliant white condition). Intermediate values are assigned to features on Saturn to the nearest 0.1, whenever possible, using the scale. For the purpose of observing Saturn, it has been necessary to modify this scale to what is known as the ***ALPO Saturn Section Intensity Scale***. It is identical to the aforementioned scale except that the outer third of Ring B has been adopted (for most apparitions when Ring B can be seen) as the ***standard*** on the numerical sequence. The outer third is the brightest part of Ring B, and it has a stable intensity of 8.0 in integrated light (no filter). All other features on the globe and in the rings are estimated using this standard of reference. With practice, a very consistent, fairly objective, and accurate series of intensity estimates can be generated, but the key to success and reliability is regular usage of the scale in routine observations. *Table 3.1* gives the numerical intensity values established for the planet Saturn and its ring system as a *mean* indication of what can be expected for intensities of belts and zones.

Lengthy verbal descriptions of intensities should be avoided. So, make it a practice to rely on the numerical value assigned to features as an indication of their relative intensities. Room is provided on the standard observing forms for entering intensity values.

The procedure for carrying out visual numerical relative intensity estimates is quite simple in actual practice. At the eyepiece, one lists down all of the features seen (e.g., belts, zones, ring components, shadows, etc.) in integrated light (no filter) in order of decreasing brightness. The brightest feature is then compared with the standard of reference (outer third of Ring B), and it is assigned a relative numerical intensity. The same procedure is followed down the rest of the list, taking care to make relative comparisons as accurately as possible until the darkest features have been exhausted.

Localized spots and features are given attention in the same manner as are the principal belts, zones, and ring components. Several belts near the equatorial regions of Saturn show multiplicity on occasion, and belt components must be assigned individual intensities. Divisions or intensity minima in the rings must also be identified and estimated in accordance with the same technique.

If clear interpretations of relative numerical intensity estimates is to occur, one must try to optimize contrast sensitivity and perception using methods described earlier in this book. One must minimize psychophysical effects associated with small image size and low surface brightness through the use of appropriate apertures and magnifications, all under the best seeing conditions possible.

Systematic errors, which are likely to occur, may be corrected by the recognition and quantification of personal equations. Observers should try to ascertain what differences exist between their work and that of others (which might emerge from a simultaneous observing program), with the recognition of how "high" or how "low" personal estimates may be in reference to those gathered by experienced observers (using similar equipment and observing under analogous conditions). Random errors are much harder to detect and alleviate by correction, although the law of averages has a way of reducing these to a minimum.

Table 3.1

Standard Visual Numerical Relative Intensity Scale for Saturn in Integrated Light

Numerical Value		Descriptive Interpretation	Representative Saturnian Features
10.0		Brilliant White	*Brightest features of all*
9.0		Extremely bright	*Very brightest objects*
8.0	***STANDARD***	Very bright	*Very bright zone or ring (outer 1/3 of Ring B)*
7.0		Bright	*Ordinary bright zone or ring*
6.0		Slightly shaded	*dull zone*
5.0		Dull	*Dull zone; typical polar regions*
4.0		Dusky	*Polar regions; dusky belt*
3.0		Dark	*Ordinary dark belt*
2.0		Very dark	*Very dark belt*
1.0		Extremely dark	*unusually dark features*
0.0		Completely black	*Shadows*

When the rings of Saturn are near or precisely at edgewise orientation, Ring B is not always visible and useful as our intensity standard. Consequently, we must utilize another standard in such instances, which may be the Equatorial Zone (EZ) or some other feature. Careful attention is paid to any fluctuations in intensity that may occur with time for a feature to be temporarily chosen as a standard, and tradition has it that the EZ is the logical selection, despite the fact that this feature varies more widely than the outer third of Ring B does from apparition to apparition (e.g., white spots have occurred in this region from time to time). Announcements are made in the ***Journal of the ALPO*** prior to minimal ring inclinations so that observers know what area will be used as an intensity standard (as well as what numerical value will be assigned to this feature).

Many of our contributing observers live in other countries, and some organizations (e.g., *British Astronomical Association*) use intensity scales that differ fundamentally from the one in use by the ALPO Saturn Section. While efforts have been underway to standardize scales all over the world, there has only been limited success in coming up with a scale that suits everyone. Whenever possible, all observations contributed by observers who participate in the programs of the ALPO Saturn Section should use the ALPO scale. Data reduction is tedious and rather cumbersome when trying to convert from one scale to another, although computer programs exist which accomplish this task reasonably well.

3.2. Visual Color Estimates: Visual Colorimetry

Comparisons of the reflectivity of various regions on a particular planet at different wavelengths of light (visual) constitutes one of the more important methods of studying these bodies available to the planetary specialist. The way in which light is reflected from the visible surface of a planet or from its atmosphere can provide valuable information as to the chemical and physical composition of the planet.

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

Wratten color filters, which are manufactured and distributed by *Eastman Kodak*, are especially recommended. These filters (available in a variety of forms) are inexpensive, have accurate wavelength characteristics, and color stability persists a long time. *Table 3.2* lists the more frequently encountered Wratten filters, while *Figure 3.1* graphically represents the individual transmission characteristics.

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 ~5550Å (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 that has a 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.

Color filters, as mentioned earlier, are extremely useful in reducing the effects produced by scattered light in planetary atmospheres. It is known that blue wavelengths are scattered more than others, and when the observer attempts to look for a feature deep in planetary atmospheres, he encounters difficulties. Because the eye is particularly sensitive to shorter wavelengths when it is dark adapted, it is useful to filter out the atmospheric violet and blue light with a red or yellow filter when attempting to see surface details on a planet. In the case of Saturn, which has a relatively dense atmosphere, observations with blue filters will tend to show features that lie a bit higher in the atmosphere of the planet than could be detected with red or yellow filters.

Color filters are also helpful in reducing the effects of atmospheric dispersion, and when a planet is to be observed near the horizon, the use of a red or yellow filter will minimize the spurious color inherent in the image.

Irradiation, a contrast effect between areas if significantly different brightness levels, usually impairs resolution when the image is fairly bright. An increase in magnification will frequently improve the quality of the image, but employment of a low transmission filter or perhaps a good ***variable-density polarizer*** is often preferred over an indiscriminate use of magnification.

Table 3.2

Characteristics of Wratten Color Filters

Wratten #	Filter Color	% Visual Light Transmission	Dominant Å Transmission	Range of Wavelength Å Transmission (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 offering 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!

The technique of ***visual planetary colorimetry*** involves attempting relative numerical intensity estimates using color filters of known transmission and density. The standard intensity scale (introduced earlier) should always be used. Estimates should, without exception, be made first in integrated light (no filter), with the outer third of Ring B having an assigned intensity of 8.0 as before. Filter observations follow those in integrated light, all at the same magnifications, and the following Wratten filters are recommended as the ***tricolor series*** with specific aperture ranges:

Apertures <15.2 cm (6.0 in): *W23A (red-orange)*
W57 (green)
W38A (blue)

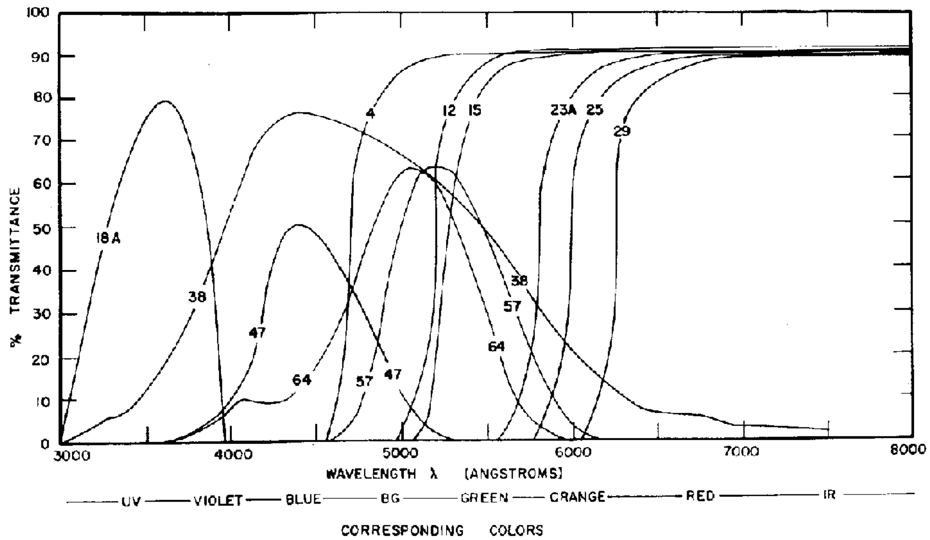
(Filters listed above have less density and are more useful with smaller apertures)

Apertures ≥15.2 cm (6.0 in): *W25 (red)*
W57 (yellow-green)
W47 (deep blue)

(Filters listed above are more dense and useful with low powers or larger apertures)

When planetary surface brightness is low, the filters useful with smaller apertures may be employed with larger instruments.

Figure 3.1
Wratten Filter Transmissions



The ***W23A*** (red-orange) filter will enhance red and yellow features, while darkening bluish areas. Cross-checking with the ***W38A*** (blue) filter will reveal a reversal of the effect noted with the W23A (red-orange) filter, whereby reddish and yellowish belts and zones are darkened. The ***W57*** (yellow-green) filter improves contrast by darkening both bluish and reddish belts and zones. Comparative studies with all three tricolor filters should prove interesting.

The ***W30*** (light magenta) filter is often called the ***universal color filter*** because it increases the threshold detection of low contrast markings on Saturn. It transmits both red and blue wavelengths, yet it suppresses green light. Meaningful results have been obtained on other planets as well because of the versatility of this filter.

A ***W82*** (light blue) color filter is extremely useful in visual latitude work on Saturn. It increases image contrast and sharpens boundaries between reddish and bluish features on the planet. At the same time, it does not appreciably reduce image brightness nor does it affect to any degree the visibility of the limb of Saturn.

A very interesting, yet poorly understood phenomenon associated with the rings of Saturn is the ***bicolored aspect of the rings***, whereby the West and East (IAU) ansae exhibit unequal brightness when viewed in integrated light (no filter), then alternately with red (W23A or W25) and blue (W38A or W47) filters. Observers have recorded this phenomenon when Saturn has been near the zenith where prismatic dispersion effects are minimal, simultaneous observations have been received which confirm this unequal brightness effect of the ring ansae, and the bicolored aspect has even been photographed successfully on a few occasions (see Chapters 1 and 2). One is tempted to believe that it is a real occurrence, and although not fully explained, this very curious phenomenon merits further serious study by Saturn observers.

Refractors, unless they are apochromatic, should be used with caution because of the spurious color introduced, especially those of large aperture and/or short focal length. Reflectors and catadioptrics are generally better for colorimetry, but the alignment and optical quality must be very good. Larger apertures are recommended when the seeing permits, and the apparent surface brightness of the planet must be as high as possible. Observations should be carried out when seeing and transparency conditions are good, and Saturn should be viewed when it is more than about 30° above the horizon to minimize atmospheric dispersion effects. The eye should be dark-adapted, and vision should be shifted frequently across the field of view and across the planetary disk. The standard data forms provided by the ALPO Saturn Section should be employed when recording observations.

Absolute color estimates made visually should be carried out by comparing Saturn with a satisfactory color standard. Estimates of absolute color have to be made with instruments in integrated light (no filter). A suitable color standard has been carefully investigated by the ALPO Saturn Section, and it employs some 500 colored paper wedges for comparative use. One should have normal color vision for this type of work, and the color standard should (ideally) be illuminated by a tungsten lamp filtered with a ***W78*** color filter. Simplicity in the descriptive notes is stressed, and the abbreviations introduced in *Table 3.3* should be entered on the standard observing forms. Where non-standard colors are to be entered, it is essential that the abbreviations or terminology be defined appropriately. Because of changing availability of reliable ***color standard wedges***, interested observers should request information on suppliers from the ALPO Saturn Section.

Table 3.3
Standard Color Abbreviations for Saturn Observations

Br	*Brown*	W	*White*	Gy-Bk	*Greyish-Black*
Bl	*Blue*	Bk	*Black*	Y-W	*Yellow-White*
Gy	*Grey*	Or	*Orange*	R-Br	*Reddish-Brown*
R	*Red*	Bl-Gy	*Bluish-Grey*	Or-R	*Orange-Red*
Gr	*Green*	Y-Or	*Yellow-Orange*	Or-Br	*Orange-Brown*
Y	*Yellow*	Bl-Br	*Bluish-Brown*	Gy-W	*Greyish-White*

One point should be mentioned in concluding this section. Some beginning observers have felt that, rather than making absolute color estimates (or to supplement such estimates), drawings with colored pencils could be useful. These have artistic appeal, but they should not be attempted for submission as observational data, chiefly because there is no satisfactory way to standardize such methods.

CHAPTER 4: LATITUDES OF SATURNIAN GLOBAL FEATURES

4.1. Measurement of Saturnian Latitudes

One of the most important quantitative research programs that can be conducted on the planet Saturn by visual means involves precise determination of latitudes of different belts on the globe of the planet. The measured latitude positions of these features may change periodically, and observational evidence indicates that the widths of belts and zones vary with time.

Four basic methods are available for the determination of Saturnian latitudes, but the procedure that will be most suitable will depend upon the sophistication of one's instrumentation. These methods are given brief consideration in the next few paragraphs, and they are presented in order of increasing reliability.

Measurement of latitudes from drawings of Saturn constitutes a rather large portion of the mass of data accumulated over the years by observers. Essential, of course, to the success of this method is the correct positioning of features relative to each other on the drawing blank provided, as well as the selection of the appropriate blank (driven by the value of **B**). Subsequent measurements can be made with some precision, although the level of subjectivity inherent in any drawing can be fairly high. Even so, experienced observers are capable of production of reliable sketches of Saturn, and as long as this is the case, the utilization of this technique will undoubtedly continue.

Measurement of latitudes from photographs of Saturn will tend to yield more accurate results when compared with the preceding technique, but this procedure was traditionally limited by the sparsity of detail ordinarily visible on photographs of the planet, even with fairly large telescopes. Good quality photographs often showed the more conspicuous belts, but their outlines tended to be indistinct due to the long exposures required or perhaps as a result of the grainy characteristics of the film emulsion. Consequently, positions of features on photographs in the past were often difficult to measure with any degree of consistency.

Measurement of latitudes from CCD or digital images of Saturn constitutes better method than the older procedure in the past of measuring photographs. Digital images can frequently show a wealth of detail, including belts and zones whose edges might not otherwise be clearly defined on photographs. Observers who have the capability of doing digital imaging are encouraged to submit their work for latitude measurement and analysis.

Measurement of latitudes with a filar micrometer is without question the most reliable technique, but the method requires a rigid mounting and a reliable, accurate clock drive with variable speed tracking adjustments. Of course, a good filar micrometer is essential, but the acquisition of one has become nearly impossible in recent years. If an observer is fortunate enough to have a filar micrometer, no opportunity should be missed to make latitude measurements when seeing conditions permit. The ALPO Saturn Section should be consulted on where filar micrometers may be procured.

4.2. Latitude Derivation from Measurements

Once the initial measurements have been obtained, regardless of the method, one must utilize the appropriate computations to provide the eccentric (mean), planetocentric, and planetographic latitudes of features on the central meridian (CM) of longitude of Saturn.

If X_n denotes the measured distance of the feature from the north (N) end of the CM (on the limb) and if X_s is its distance from the south (S) end (on the opposite limb) of the CM, in arbitrary units, then one may use equation (31) below:

$$y = \frac{1}{2}(X_s - X_n)$$

where it will be noted that, ***y***, is positive (+) for features north of the center of the disk and negative (-) for features south of the center. Let, ***r***, be the measured polar radius of Saturn in the same units as $\boldsymbol{X_n}$, $\boldsymbol{X_s}$, and ***y***. Let, ***R***, be the ratio of the equatorial radius of the planet to its polar radius, which is about 1.12 for the planet Saturn. Let, **B**, denote the Saturnicentric latitude of the Earth, or the tilt of the axis of Saturn toward the Earth. **B** may be found in an appropriate ephemeris, as noted previously in this book. **B′** is the saturnicentric latitude of the Sun referred to the ring plane.

The ***eccentric (mean) latitude***, ***E***, of the feature is computed by means of equation (32) below:

$$\tan B' = R \tan B$$

where **B** and **B′** are positive (+) when north, and equation (33) below:

$$\sin (E - B') = \frac{y}{r}.$$

The ***planetocentric (Saturnicentric) latitude***, ***C***, of the feature is derived from equation (34) below:

$$\tan C = \tan \frac{E}{R}.$$

The ***planetographic (Saturnigraphic) latitude***, ***G***, of the feature may be determined using equation (35) as:

$$\tan C = R \tan E.$$

The ***eccentric (mean) latitude***, ***E***, will always be near the arithmetic mean of the planetocentric and planetographic latitudes, and this numerical rule is illustrated by equation (36) as follows:

$$\frac{C + G}{2} = E.$$

For many years, only planetocentric latitudes had been computed for Saturn, chiefly as a result of the common belief that these numerical values were more relevant to the observer on the Earth's surface. Planetographic latitude is perhaps more familiar to the observer of Jupiter, but it is just as easily applied to Saturnian features by using the appropriate formulas. It has even been pointed out that eccentric (mean) latitudes are actually more convenient that the other two types of latitude measure. It has been shown that the sine of the eccentric (mean) latitude is the fraction of the polar semidiameter of Saturn when the Earth is overhead at the equator of the planet. Furthermore, the product of the cosine of the eccentric latitude and the equatorial radius of the planet is the radius of rotation in that specific latitude.

4.3. A Visual Method for Estimating Latitudes

The four methods described in the preceding paragraphs have their particular advantages and disadvantages, and one observer might prefer one of the methods while another individual may desire to use a different one, largely driven by equipment and observing experience. A fifth technique, however, for determining Saturnian latitudes has been adopted by the ALPO Saturn Section in the last twenty years, sometimes referred to as the ***Haas technique***, after the observer who introduced and perfected the method, Walter H. Haas (Director Emeritus of the ALPO).

The fifth method is purely visual and can be employed directly at the eyepiece. ***Direct visual latitude estimates*** are made of the fraction of the polar radius subtended on the CM of the planet by the belt whose latitude is desired, and the value, ***y***, is measured along the CM of Saturn as the distance from the center of the disk to the feature being observed (+ when north), divided by the distance, ***r***, from the center of the disk to either the N or S limb. The center of the disk may be located fairly precisely by reference to the symmetry of the ring system, and it should be obvious that ***y/r*** is equal to 1.0 at best. The ***ratio***, ***y/r***, is estimated to the nearest 0.01 whenever possible, and once this ratio has been determined visually, it is a simple procedure to compute the latitude of the feature using the equations introduced earlier. The ALPO Saturn Section has developed computer programs that enable quick computation of the various latitudes, and observers who desire a copy of the program (available on IBM-format diskettes) should contact the author.

Latitude estimates obtained by the visual technique are considerably reliable once the method is fully understood and used for several apparitions. A ***personal equation*** may be applied after one has mastered the visual procedure, and it is possible to know how accurate one's work is when compared with that of others. The technique is very easy to use, and it is possible to generate a large number of accurate, reliable estimates in a short span of time. Further, the method can be successfully applied to faint global features that frequently do not photograph well. To enhance visual contrast of those features being estimates, use of a W82 filter is highly recommended. Belt edges will be sharpened with this filter, and bluish and reddish features can be distinguished better when they lie adjacent to one another.

The ratio, ***y/r***, obtained in this visual procedure may be recorded on the standard observing forms provided by the ALPO Saturn Section, along with intensity and colorimetric estimates, already presumably entered on the form.

CHAPTER 5: CENTRAL MERIDIAN (CM) TRANSIT TIMINGS

On occasion, discrete detail is visible in the belts and zones on the globe of Saturn, and such phenomena is similar in form although much less distinct than are such markings seen in the atmosphere of Jupiter. Projections or appendages from the belts sometimes leading into extended festoons, or bright spots in the zones, comprise the most frequently recorded types of atmospheric phenomena on Saturn. Such fine detail is quite rare, and even when present, it is often accessible only to moderately large apertures. Thus, it is inadvisable for any individual with instruments smaller than about 15.2 cm (6.0 in) to adopt the recording of such features as a sole observing program. Nonetheless, when particularly prominent and long-enduring spots or disturbances on the globe become visible, CM transits are immensely important. Rotation rates at different belt or zone latitudes on Saturn are not well enough established due to the sparsity of detail for transit timings, especially at higher latitudes.

As the planet rotates in a prograde fashion (W to E in the IAU sense), whereby features are progressively carried across the globe from right to left in the simply inverted view (from the northern hemisphere of the Earth), markings become situated on the CM at different times. It is of interest to record the time of each CM event precisely. Furthermore, there is strong evidence that Saturn rotates in at least two systems like Jupiter, although more objective, confirmed evidence of differential rotation is desired.

Any feature that can be followed for a month, even if the CM transit timings are off by a minute or so, can yield some valuable results. Research reveals that the rotation of the equatorial region of Saturn takes place in $10^h14^m13.0^s$, which means that 7 rotations of the globe occur in about 71.5^h, and further transit timings can be attempted for the same feature (if it persists) within about 3.0^h of the initial time. This rotation rate seems to be fairly well established for short-lived phenomena, which seems to be a characteristic of Saturn, and we will refer to this region as ***System I***, which includes the NEB (North Equatorial Belt), SEB (South Equatorial Belt), and the EZ (Equatorial Zone), inclusive of the often ill-defined EB (Equatorial Belt).

Regions north or south of System I show rotation rates of $10^h38^m25.0^s$, and one can predict subsequent returns to the CM of features in about 3.0^h of the first transit after a period of some 74.3^h elapses. These areas are called ***System II***, in accordance with the nomenclature system adopted by the ALPO Saturn Section. Saturn's internal rotation rate of $10^h30^m39.0^s$ is based on the periodicity of radio emissions, and is defined ***System III***, but this radio rate has little importance for visual observers.

Saturn CM longitude ephemerides have been published by the ALPO Saturn Section on an annual basis on the ALPO website at **<www.lpl.arizona.edu/alpo>** for the convenience of observers. Observers can use these data to predict subsequent returns of features to the CM of Saturn on any given night of observation, provided that the phenomena last long enough for recovery. The ***ALPO Saturn CM longitude ephemerides*** for System I and System II give longitudes of Saturn's geocentric CM for the illuminated (apparent) disk 0.0^h UT for each day of the year. Incorporating corrections for phase, light-time, and the planetocentric longitude of the Earth, the ALPO System I longitudes were originally based on a precise sidereal rotation rate of 844.0° per day (or $10^h14^m13.08^s$). Later, this value was changed to agree with the IAU rate of 844.300°/day ($10^h14^m00.00^s$). System I is intended for use with features in the NEB, SEB, and EZ. System II, which is intended for the rest of the globe of Saturn, excluding the NPR and SPR (North Polar Region and South Polar Region, respectively), assumes a sidereal rotation rate of precisely 812.0° per day (or $10^h38^m25.42^s$). As before, the accuracy of these rates is governed by latitude-dependent factors that are not well established. Yet, longitudes derived from the tables should give conveniently small drift rates in most cases.

Although the proper choice of one of these two systems will usually give small drift rates for most short-lived features, observers should note that the rotation rates of Saturn's features are highly variable. Periods observed have ranged from 10^h02^m (at the equator) to 11^h03^m (57.0° planetocentric latitude). Thus, it is only coincidence that the recently-discovered radio rotation rate of $10^h39.4^m \pm 0^m.15$ (810.76° ± 0.19°/day) is close to the ALPO System II. Also, the ***Astronomical Almanac 1981*** adopted a Saturnian System I rotational rate of 841.558°/day ($10^h16^m00^s$) and a System III radio rate of 822.000°/day ($10^h30^m39.4^s$).

In 1980, a change took place in System I, such that the ***International Astronomical Union*** (***IAU***), in apparent ignorance of the ALPO system that had been in use for many years, adopted a sidereal rotation rate of 844.300°/day ($10^h14^m00.00^s$) for System I for use in the annual ***Astronomical Almanac***. As discussed, the ALPO system used 844.000°/day ($10^h14^m13.08^s$). In recent years, the two System I rates were synchronized by the ALPO, resulting in the adoption of the IAU period of 844.300°/day ($10^h14^m00.00^s$) for use in the ***Saturn CM longitude ephemerides***.

System III, as noted earlier, refers to Saturn's internal rotation rate, but it is possible to convert System II longitudes to System III by equation (37) below:

$$System\ III = System\ II - 1.2061°\,(JD - 2447908)$$

where ***JD*** is the Julian Day with an accuracy of about ± 0.1°.

Recall that there is convincing evidence for a multiplicity of rotation rates for Saturn, so observers should make every effort to obtain CM transit timings of long-lived features (combined with latitude estimates or measurements) so that the pattern of Saturn's atmospheric rotation and circulation can be better understood.

Making reference to the aforementioned ephemerides, it is perhaps worthwhile to consider an example of the usage of these tables. Assume that a bright spot in the NEBs is observed to transit the CM at 09^h57^m UT on 1995 May 15^d. Since the NEBs falls in System I, we may extract the following values from an ephemeris (in this instance, the older formerly published ***ALPO Solar System Ephemeris*** was used):

System I CM @ 0^h UT on 1995 May 15^d		356.16°
+ Motion of System I CM in:	*09^h*	316.61
	50^m	29.32
	7^m	4.10
System I CM @ 09^h57^m UT on 1995 May 15^d		706.19°
Subtract 360°		360.00–
Solution		346.19°

Note that one should always subtract 360° from values greater than 360°. To be realistic, the results should be rounded off in visual timings to the nearest whole degree. Given a feature of known longitude, the ephemerides may be used to work backward to predict when the feature will next transit. Here it helps to bear in mind that System I longitudes repeat in close to 3 terrestrial days, while System II longitudes repeat in close to 4 terrestrial days.

The simplest procedure for timing CM transits is to estimate to the nearest whole minute the time when the feature is considered to be exactly midway between the E and W limbs of the planet. Times should always be given in Universal Time (UT), obtained by listening to (or synchronizing an accurate digital watch to) WWV or CHU time signals. An even more accurate procedure involves making CM transit timings in the form of three separate estimates:

1. the last minute when the feature is definitely on the ***following***, ***f***, side of the CM.
2. the last minute when the feature is exactly centered on the CM.
3. the last minute when the feature is definitely on the ***preceding***, ***p***, side of the CM.

All transits of CM features should be accompanied by a full description of the seeing and transparency conditions using the procedures discussed earlier in this book, instrumental factors, etc. It is essential to include a description of the feature observed, the measured or estimated latitude of the marking (or the belt or zone in which it is located), and a sectional drawing to emphasize the morphology of the feature. Forms are available from the ALPO Saturn Section to facilitate effective recording of the above data.

Once transit timings are received by the ALPO Saturn Section for a particular feature, providing that a useful minimum number of transit timings are submitted, it is possible to ascertain the rotation period of any individual spots or disturbances by developing drift charts. Only on rare occasions, however, does discrete detail appear on the globe of Saturn that persists long enough to allow derivation of rotation rates in a given latitude. When such recurring spots or disturbances appear on the planet, CM transits are, therefore, extremely valuable.

Observers should refer to *Appendix A* which contains a sample form for recording observations of CM transits of features detected on Saturn's globe. A blank, adjacent to the space for recording CM transit data, is provided on the form for strip- or sectional-sketches of the observed feature which is crossing the CM.

CHAPTER 6: STUDIES OF SATURN'S RING SYSTEM

6.1. Ring Components, Divisions, and Intensity Minima

In our previous discussions, we learned that there are three major, or classical, ring components making up the ring system of Saturn, at least for most observers on Earth. Without the ring system, Saturn would undoubtedly be classed as rather dim, unimpressive, and tranquil planet in comparison with neighboring Jupiter. As we mentioned in earlier chapters, the rings are responsible for much of Saturn's brightness, and there is nothing comparable to them, at least in terms of prominence and extent, anywhere in the solar system.

The ***three major or classical ring components***, as depicted earlier in *Figure 2.1*, are ***Ring A*** (the usually seen outermost component), ***Ring B***, (the central, broader ring), and ***Ring C*** (the inner dusky Crape ring). Ring A and Ring B are separated by a dark division called ***Cassini's division*** (***A0*** or ***B10***) in keeping with the terminology introduced previously. Cassini's division is visible with ease in a 6.0 cm (2.4 in) refractor when the rings are fully open to our line of sight.

Halfway out from the globe of Saturn in Ring A is a gap, although less well defined as Cassini's division, is known as ***Encke's gap*** (***A5***). It is seen readily in large telescopes in good seeing, and some observers have described it as being multiple on occasion, resulting in the designation "Encke's complex." Further out from the globe of Saturn in Ring A is the narrow ***Keeler's gap (A8)***. Ring C is by far the faintest of the ring components described, but it still may be seen in a fairly small telescope (at the ansae) when seeing and transparency conditions are excellent.

As we saw in Chapter 2, in addition to the three major ring components described above, there is a very elusive innermost ***Ring D***, located just internal to Ring C. Some individuals have suggested that they have seen Ring D visually in front of the globe on occasion (or perhaps the shadow of Ring D), but confirmation of these sightings is lacking. External to Ring A is a very tenuous, broad ***Ring E***, the initial observations of which date back to the 1907-08 apparition when the rings were edgewise to the Earth. Ring E was also confirmed by the *Voyager* missions of 1980-81 along with the discovery of two other components. These are ***Ring F***, just outside Ring A, and a more tenuous ***Ring G***, extending outward from Ring F. Both components F and G are within the confines of Ring E, however, so Ring E remains the outermost of the known ring components. Ring F and Ring G have very little importance to visual observers on Earth except perhaps when occultations of stars occur by the rings. Even then, it is very uncertain whether amplitude data caused by Ring F or Ring G can be monitored from Earth.

Aside from the clearly defined Cassini's division and Encke's gap, observers have reported for many years various ***intensity minima*** in the rings that interrupt the otherwise continuous ring components. These fine, elusive "divisions" were found by the *Voyager* spacecraft to definitely exist in great multitudes, thus the rings are hardly continuous across their breadth. Those intensity minima that are conspicuous in the photos taken by *Voyager* probably could be detected from Earth when seeing cooperates, but the very largest instruments are usually necessary for such observations. The characterization and positioning of such observed intensity minima is of great importance, particularly because they vary both in prominence and in position with time (as firmly established by the *Voyager* missions). Because of the actual myriad abundance of these features, there is little hope that the observer on Earth will discover any new intensity minima in the rings. Even so, it would be meaningful to record suspected or confirmed intensity minima and compare the results with those of *Voyager*, particular with respect to the positions of the more prominent features.

Studies have revealed that there have been about 10 recognized intensity minima in addition to Cassini's division, Encke's gap, and Keeler's gap that have been recorded from Earth. As noted, large telescopes are required to view these elusive features with any real success, and measurements of their positions relative to the component they occur in, as well as to each other, are important. Use of the previous accepted method of assigning nomenclature to the intensity minima in each ring component should be adhered to (e.g., B2, B3, etc.).

6.2. Visual Photometry and Colorimetry of the Rings

Relative numerical intensity estimates of the rings and their inclusive details are made in much the same manner as those for global features, as we discussed in the previous treatment of visual photometry and colorimetry. It is generally known that, with instruments in excess of 7.5 cm (3.0 in), the rings will not appear uniform in intensity. The outer portion of Ring B is significantly brighter than the inner two-thirds of the component on most occasions. Thus, the ALPO Saturn Section has assigned the outer third of Ring B an arbitrary intensity of 8.0 as the ***standard*** of comparison. Ring A, usually dimmer than Ring B throughout, has been shown to exhibit intensity variations across its breadth. ***Radial or "spoke" features*** in Ring B (substantiated as real phenomena by *Voyager* cameras), as well as various bright spots in some ring components, have been reported on rare occasions. These were all characteristically short-lived, poorly-defined features. Some observers have suggested a possible relationship between the curious bicolored aspect of the rings and these non-uniform intensity features, but no confirming evidence has been received. The ***Terby white spot***, resulting undoubtedly from a contrast phenomenon, has been frequently recorded adjacent to the shadow of the globe on the rings.

In making relative numerical intensity estimates of the rings, it is customary to list the components down in order of conspicuousness from brightest to darkest, assigning them numerical values on the scale. Spots and other localized phenomena may be shown to advantage on sectional sketches with accompanying intensity values listed alongside. Space is provided on the standard report forms supplied by the ALPO Saturn Section for such observations.

Descriptive notes and intensity estimates of the shadow of the rings on the globe of Saturn and of the shadow of the globe on the rings should not be overlooked as part of the data accumulated in the course of an observation. The ***shadow of the rings on the globe*** will depend entirely upon the planetocentric latitude of the Earth and Sun, which does not necessarily change over at opposition. This is a function as to when the Earth passes through Saturn's orbital plane.

It is important to recognize that the ***shadow of the globe on the rings*** changes with time. Prior to opposition, the shadow of the globe on the rings is seen to the E (IAU) of the globe or to the left in the simply inverted view. After opposition, the shadow shifts to the W or to the right of the globe (IAU) in the same telescopic field.

Visual colorimetric studies of the rings of Saturn are of tremendous importance as a regular endeavor, and of particular interest is the controversial ***bicolored aspect of the rings***, which refers to a definite variation in brightness that is reported from time to time with regard to the E and W ansae (IAU). This brightness difference is sometimes detected in integrated light (no filter) and more frequently through the alternating usage of color filters (see our previous discussion on this topic).

Relative numerical intensity estimates, attempted initially in integrated light, can be of additional value if consistently pursued with filters of known wavelength transmissions. Such filters should transmit mutually exclusive visual spectral regions, and the results of such color filter work can be entered on the observing forms along with integrated light estimates.

Absolute color work on the rings of Saturn is not of much real value unless a standard of reference is employed regularly (refer to our previous discussion on colorimetry).

6.3. Occultations of Stars and Other Bodies by the Rings

Every observing session should be preceded by a preliminary survey of the sky in the immediate vicinity and direction of Saturn's orbital motion (apparent) for stars that might be occulted by the ring system of by the globe of the planet. Occultation predictions are usually issued in standard astronomical ephemerides or periodicals so that the observation of ***occultations of stars by the rings or globe*** can be planned.

Occultations of stars by the rings present unusual opportunities for detection from Earth the positions of intensity minima in the ring components. Variations in the brightness of the star during its passage behind the ring system can reveal intensity differences that would not otherwise be perceptible with the same aperture. Unfortunately, only reasonably large instruments are useful in this kind of program. For instance, a 15.0 cm (6.0 in) refractor will reveal a 7th magnitude star in occultation behind Ring A, while a 25.0 cm (10.0 in) instrument will be challenged by an 8th magnitude star. Ring A, on the whole, is much less dense than Ring B. This is not intended to imply that observers with smaller apertures should not attempt such observations, but work with any small instrument should be limited to brighter stars (which are, unfortunately, all too rarely occulted by Saturn). Indeed, even observations where one determines the times of contact with the planet's limb or ring edges are of great value. Although the star may be hidden most of the time while it is behind the rings, it may suddenly appear when behind an area of lesser density and be visible in the smaller telescope.

When reporting observations of occultations of stars by the rings, accurate determination of one's geographic coordinates is important. This derivation is facilitated by using a topographic map or global positioning system (GPS) to ascertain geodetic positions. In addition, the timing of events should be made to the nearest whole second or better. Proper identification of the star in occultation, its visual magnitude, and its spectral classification is essential, with reference made to the sources that provided the accompanying data. Running a tape recorder simultaneously with WWV or CHU time signals, making verbal responses in order to identify events of the occultation, is a very useful and versatile method. All occultation observations should be communicated to the ALPO Saturn Section immediately. When an occultation is expected, the Section will alert interested observers in advance. Many astronomical periodicals carry such predictions, but not all possible occultations will always be forecasted.

6.4. Edgewise Ring Presentations

All observations of the ring system must include an accurate determination of the numerical value of **B** on the date of observation. Note that **B** is the planetocentric latitude of the Earth referred to the ring plane, and **B** is positive (+) when the northern portions of the rings are seen and negative (–) when the south face of the rings is inclined toward our line of sight. **B** is equal to 0.0° when the rings are edgewise to our line of sight. Recall that **B** can be found in a suitable ephemeris for any date of the year, and it is required that one refer to values of **B** when selecting drawing blanks. Over a span of about 14 years, **B** values will vary from 0.0° (edgewise presentation of the rings) through ± 27° (maximum inclination to our line of sight).

Throughout the sidereal revolution period of $29^{y}.5$ for Saturn, the intersection of the orbit of the Earth and the plane of the ring system takes place only twice, at intervals of $13^{y}.75$ and $15^{y}.75$. The two periods are of unequal length because of the ellipticity of Saturn's orbit about the Sun, and the rings are edgewise to our line of sight at these times (**B** = 0^{o}). Astronomically speaking, such events are considered quite rare and particularly noteworthy.

During the $13^{y}.75$ period, the south (S) face of the rings and the southern hemisphere of the globe is inclined toward the Earth, and Saturn passes through perihelion during this interval. In the larger $15^{y}.75$ period, Saturn passes through aphelion, and the north (N) face of the rings and northern hemisphere of the globe is exposed to observers on Earth.

At times of edgewise orientation of Saturn's rings, it is of considerable importance for individuals to determine just how close to the theoretical edge-on positions the rings can actually be seen with a given telescope. The apparent disappearance of the ring system (see *Figure 8.1*), which often occurs a number of times during a short interval, can be ascribed to one or more of the geometric circumstances as follows:

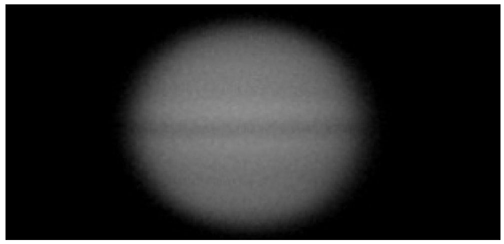
1. The Earth may be in the plane of the rings so that only their edge is presented to viewers, and since the rings are quite thin, they may be temporarily lost to even the largest telescopes.

2. The Sun may be in the plane of the rings so that only their edge is illuminated.

3. The Sun and Earth may be on opposite sides of the ring plane, so that what observers see on Earth are regions that are illuminated only by light that is passing through the rings (forward scattering).

Figure 8.1

S



N

Edgewise Presentation of Saturn's Rings in 2009
Shadow of the Rings on the Globe is visible, plus a few major belts and zones

Larger instruments, in the range of 30.0 cm (12.0 in) through 41.0 cm (16.0 in), have traditionally permitted observations of the sunlit side of the ring system up to within a few days or even hours of the dates and times of theoretical edgewise presentation. With regard to the dark side, the visibility may elude observers for several days or even weeks prior to and following edgewise presentations. Thus, there is a general asymmetry with respect to the extent, appearance, and brightness of the rings of Saturn at such times. For instance, especially near the precise edgewise orientation of the ring system, a lack of uniformity in brightness might be exhibited as one or more condensations of light along the otherwise dark ring surface.

A meaningful endeavor is to measure the surface brightness of the illuminated and dark ring surfaces throughout the apparition at various distances from the globe of Saturn. One uses the globe as the reference point for visual numerical relative intensity estimates (employing the ALPO scale as described earlier). The outer third of Ring B at an assigned value of 8.0 cannot be used when the rings are edgewise, and one must refer instead to the EZ as a possible standard at such times. The EZ is usually assigned the arbitrary value of 7.0 for comparison purposes.

It has been discussed variously among Saturn observers that the intensity of the ring system at different positions might be proportional to the particle density (confirmed by *Voyager*). The light passing through the ring from the illuminated surface is, therefore, complementary. In other words, the intensity of the dark side is opposite that of the sunlit side. Thus, the outer third of Ring B, instead of being the brightest portion of the rings under sunlight conditions, would be the darkest area. Ring A would, in the same scenario, be significantly brighter, and Ring C would be the brightest component of all. Complications will obviously result from light being reflected onto the rings by the planet's globe. Yet, such illumination should vary essentially as the inverse square of the distance from the planet.

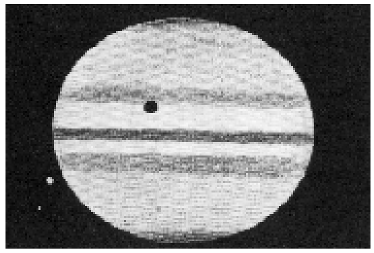
The very elusive, vast, and dusky Ring E has elicited some mixed impressions during the past edgewise apparitions, times when Ring E is presumably easier to see from Earth. The question of the existence of Ring E has been answered by the *Voyager* missions, but controversy persists in some circles as to the visibility of the component in Earth based telescopes.

Anytime the dark side of the ring system is presented to Earth, bright stellar-like points of light may be seen along the extent of the ring. Such a phenomenon is characteristically obvious when the rings are nearly edgewise, as was pointed out before. If present, satellites will normally look like beads of light along the linear extent of the ring, and because of atmospheric turbulence above the Earth's surface, the star-like points may scintillate or twinkle, a very beautiful spectacle. It should be emphasized, however, that beads of light are seen *without* known satellites contributing to their visibility. Their cause has been attributed to sunlight passing through major ring divisions, illuminating adjacent ring particles. It is worthwhile for observers to show on drawings the specific locations of such phenomena, the times that they are seen, and their relative intensities. It has also been suggested that comparisons of the brightness of these condensations could be made using Saturn's satellites as brightness reference standards. Finally, extra-planar ring particles (suspected over the years in Earth-based observations and detected by *Voyager*) are more likely to be seen from Earth at edgewise presentations of the rings. Extra-planar particles would resemble a faint "haze" above or below the plane of the rings, but the glare from globe or the rings themselves will often complicate matters.

When the ring plane passes through the Sun, the best opportunity arises for observation of transits, occultations, shadow transits, and eclipses of those satellites within or near the equatorial plane of Saturn (see *Figure 8.2*).

Figure 8.2

S



N

Titan visible to the left of Saturn's globe, with shadow of Titan in transit across the planet on April 17, 1980

CHAPTER 7: VISUAL STUDIES OF THE SATELLITES OF SATURN

The planet Saturn is attended by eighteen or so satellites, eight of which may be observed with most telescopes normally available to the amateur astronomer. Visual observations of the satellites of Saturn are made more difficult owing to their intrinsic faintness combined with their proximity to the brilliant globe and rings of the planet. In addition, the visibility of the satellites is affected by the changing inclination of the ring plane to our line of sight and their distance from the primary, which also varies.

In terms of magnitude, most of the Saturnian satellites have fairly small amplitudes, although the nature and extent of any observable brightness variations is still not fully understood, even following the Voyager flybys. *Table 9.1* lists the satellites of Saturn that have any importance to the observer on Earth, including some fundamental data on the more accessible ones to instruments of moderate aperture. A standard form for recording data appears in *Appendix A*.

Perhaps the most significant contribution that planetary observers can make concerning Saturn's satellites is a long, systematic, and accurate series of ***visual magnitude estimates***. The only truly reliable means by which visual magnitudes of the satellites can be estimated involves utilization of standard stars of calibrated brightness, such as might be the case when Saturn passes through a star field in which magnitudes have been precisely determined. One possible source of reliable star charts is the ***American Association of Variable Star Observers (A.A.V.S.O.)***. Unfortunately, Saturn is seldom located in variable star fields that are covered by A.A.V.S.O. star charts, and individuals must use conventional star atlases and catalogues that go faint enough and which have reliable magnitudes. The ***ALPO Solar System Ephemeris*** occasionally plots background stars for comparative magnitude estimates.

Even though the satellite ***Titan*** (S7) has been shown to have a variable magnitude, its amplitude is not appreciable and can serve as a last-resort comparison standard (assuming that the magnitude of Titan is fairly stable at 8.4). Data show that the amplitude of Titan is less well-established, but it does not appear to show the amplitude fluctuations like the other satellites which have measured magnitude changes (see *Table 7.1*).

Using a computer program, the ALPO Saturn Section has adopted the practice of plotting the path of Saturn through the background stars during any given apparition of the planet. This procedure can also be attempted manually using any number of reliable star atlases with suitable faintness thresholds. The Saturn Section will alert observers when the planet crosses a star field of appropriate calibrated stars.

So, visual photometry of the satellites when Saturn can be effectively attempted when the planet crosses a suitable star field. At least two stars of well-established visual magnitudes are selected, having also about the same color and brightness of the satellite to be estimated. One of these stars should be slightly fainter and the other slightly brighter than the satellite in question. The differences in brightness should exceed 1.0 magnitude, however, and the difference in brightness between the two comparison stars is divided into 10ths. The brightness of the given satellite is placed between the two within the scheme. For example, suppose that a given satellite is only slightly fainter than a star, ***X***, but quite a bit brighter than a star, ***Y***. If the satellite is, say, about 0.3 fainter than ***X***, and hence 0.7 brighter than ***Y***, we would write the observation as:

$$X(0.3)V_{os}\ Y(0.7)$$

where $\boldsymbol{V_{os}}$ denotes the visual magnitude of the satellite, yet underived. If the magnitudes if the stars ***X*** and ***Y*** are found to be, from an appropriate star atlas and catalogue, respectively 9.2 and 10.5, the reduction takes the form:

Given:	Star **X** has a visual magnitude, $\mathbf{m_V}$, of 9.2
	Star **Y** has a visual magnitude, $\mathbf{m_V}$, of 10.5
Find:	**X** - **Y** or (9.2) - (10.5) = 1.3
Find:	Product of 1.3 and the fraction by which the satellite is fainter than **X**; that is, (1.3)(0.3) = 0.39
Add:	0.39 and the value of **X**; that is, (0.39) + (9.2) = 9.59

or 9.60 (rounding off)
Answer: 9.6 (visual magnitude of the satellite)

When using comparison stars, it is essential that proper identifications be made of the stars employed as reference objects. Furthermore, proper identification of the satellite in question is necessary. Accompanying information, as recorded on the specific observing forms, should include:

1. Satellite being estimated.

2. Comparison stars and related data on them.

3. UT of the estimate.

4. Altitude of Saturn from the horizon.

5. Seeing and transparency.

6. Instrument information.

7. Observer and location of observing station.

Identification of satellites is a somewhat easy task employing the appropriate ephemeris and tabulated data. Again, care must be taken to insure that the satellite positions are accurate for the date and time in question. Proper identification of the satellite in the eyepiece must also be carefully accomplished. Following instructions outlined in publications like the ***Astronomical Almanac*** will facilitate this process. Fortunately, ***Sky and Telescope*** has started publishing finder charts to help observers identify Saturn's satellites (similar to those that have appeared in that magazine for Jupiter).

Observers who have photoelectric photometers may contribute measurements of Saturn's satellites, but sophisticated techniques are required to correct for scattered light surrounding Saturn and its rings.

When the plane of the rings passes through the Sun, the best opportunity exists for observing transits, shadow transits, occultations, and eclipses of those satellites which are near the planet's equatorial plane. Small apertures are usually insufficient to produce good views of most phenomena of Saturn's satellites, except perhaps with the case of Titan. Larger telescopes generally make observations of events involving the satellites more worthwhile. Yet, controversy still persists as to whether shadow transits of any of the satellites other than Titan are visible from Earth with large instruments. Nearly all of the satellites are presumed to be too small to cast umbral shadows onto the globe of the planet Saturn.

Table 7.1
Satellites of Saturn for Visual Observation

Name and Designation of Saturnian Satellite		**Average Apparent Diameter**	**Visual Magnitude @ Mean Opposition**	**Amplitude**
S1	*Mimas*	0.15″	12.10 m_v	?
S2	*Enceladus*	0.13	11.77	?
S3	*Tethys*	0.28	10.27	0.25 - 0.50
S4	*Dione*	0.27	10.44	0.25 - 0.50
S5	*Rhea*	0.35	9.76	0.25 - 0.50
S6	*Titan*	0.70	9.39	0.24 - 0.60?
S7	*Hyperion*	0.10	14.16	?
S8	*Iapetus*	0.28	9.5 - 11.0	1.50 - 2.00

Those individuals who can obtain precise timings (UT) to the nearest second of ingress, CM passage, and egress of a satellite or its shadow across the globe of the planet at or near edgewise presentations of the rings should immediately dispatch such data to the ALPO Saturn Section. The belt or zone on the planet crossed by the shadow or satellite should be included in the reported data. Intensity estimates of the satellite, its shadow, and the belt or zone it is in front of can be very useful as well, and drawings of the immediate area at a given time during the event can be especially valuable.

Finally, at edgewise presentations, it is interesting to note that satellite magnitudes are easier to estimate because of the reduced glare. Brightness corrections that must be made are then generally a function of the apparent distance of the satellite from the planet.

Visual observations of any markings on Saturn's satellites are beyond the scope of our efforts, except perhaps in the case of Titan. Large instruments are clearly dictated, along with nearly perfect seeing conditions, for resolution of Titan as a disk. Few observers, using very large apertures, have submitted observations of phenomena on Titan, and those who have examined the *Voyager* and *Cassini* images of this satellite can easily understand why!

CHAPTER 8: SIMULTANEOUS OBSERVATIONS

The ***Saturn Simultaneous Observing Program***, hereinafter referred to as the ***SSOP***, was organized in recent years in an effort to reduce substantially the number of observational variables and the level of subjectivity that is inherent in visual studies of the planet.

There are many areas in which improvements can be made in the way that observations are executed to increase the incidence of supporting and confirmed data. The purpose of the SSOP is to provide a means for data acquisition by way of systematic, simultaneous efforts on the part of a large number of experienced observers over a long period of time.

Observations should take the form of full-disk drawings of Saturn using standard forms, sectional sketches to emphasize regions of special interest, visual numerical relative intensity estimates in integrated light and using color filters of known wavelength transmission, investigations of ring phenomena, and studies of the brighter satellites. One might also include latitude estimates and measurements. Detailed descriptions of each of these programs were already discussed in detail in preceding chapters of this book, and those who wish to participate and be effective in the SSOP should master the observational theory and applications presented.

A major underlying impetus for organizing the SSOP is the relatively frequent problem encountered when one must ascertain whether or not any detail shown on drawings of Saturn are real or illusory. The individual who must carefully examine and analyze the mass of data submitted each apparition must make critical decisions often based upon very subjective and often scanty data, and for the sake of scientific accuracy, it is essential that methods and techniques become more objective, systematic, and reliable by virtue of confirmation by many observers. Observers with at least some practical experience at the eyepiece looking at Saturn, and those who have carefully studied the material in this book, are invited to participate in the SSOP. By ***simultaneous observations*** we mean independent, systematic studies of Saturn using the same methods, similar equipment, and standardized reporting techniques, all taking place at the same time on a given date of observation. Instrumentation should conform to the criteria outlined in this manual, and telescopes should be well-adjusted, as similarly equipped as possible, and of the highest optical and mechanical quality.

After familiarization with the general observing techniques and programs of the ALPO Saturn Section, the observer should contact the Section for a copy of the ***SSOP Monthly Observing Schedule*** (prepared periodically for each apparition). Observers, working independently, should follow the basic format as presented below in an attempt to carry out simultaneous work with everyone else in the SSOP:

STEP 1: *Ascertain accurate observing times (UT) and dates (precise times can be derived from WWV or CHU time signals) for start and finish of session.*

STEP 2: *Evaluate seeing and transparency during observing session.*

STEP 3: *Proceed with visual numerical relative intensity estimates of global and ring features (photometry and colorimetry).*

STEP 4: *Perform full-disk (using appropriate drawing blanks) and sectional sketches.*

STEP 5: *If possible, execute photography of Saturn following the drawing (or in place of a drawing).*

STEP 6: *Factor in CM transits, latitude estimates, and satellite observations as applicable during the observing session.*

Although observations are largely visual, there is no reason why those who regularly photograph the planets should not actively participate in the SSOP. Photographs of Saturn can be compared with visual work carried out at the same time.

The time required to execute and complete observations should fall within a period of about 30 minutes, but this is only presented as a guide. Observing should simply follow the SSOP schedule so that coverage will be as thorough as possible. When anyone notes unusual phenomena (e.g., long-enduring spots, belt or zone anomalies, ring phenomena of uncommon variety, etc.), an alert can be issued to other observers in the program. Dispatch of such information can be accomplished by telephone, e-mail, etc.

REFERENCES

Benton, J.L., Jr., A Handbook for Observing the Planet Saturn. Savannah: Review Publishing Co., 1971.

----------------Saturn and How to Observe It. London: Springer-Verlag., 2005.

Blanco, V.M., and McCuskey, S.W., Basic Physics of the Solar System. Boston: Addison and Wesley, 1961.

Chapman, C.R., and Cruikshank, D.P., Observing the Moon, Planets, and Comets. (original unpublished manuscript).

Eastman Kodak Co., 1966, "Kodak Wratten Filters for Scientific and Technical Use," Pamphlet, 22nd. Edition. Rochester: Kodak (Revised).

Gehrels, T., and Matthews, M.S., Ed., Saturn. Tucson: University of Arizona Press, 1984.

Gordon, R.W., 1979, "Resolution and Contrast," J.ALPO, 27, (9-10): 180-189.

Haas, W.H., 1967, "Latitudes on Saturn: A Note on Comparing Methods," J.ALPO, 20, (7-8): 133-135.

Haynes, K.H., Flasar, M., Krupp, N., Stallard, T., Ed., Saturn in the 21st Century. Cambridge: Cambridge University Press, 2019.

Le Grand, Y. Light, Color, and Vision. New York: Wiley, 1957.

OSA, 1963, The Science of Color. Ann Arbor: Committee on Colorimetry of the Optical Society of America, 1963.

Proctor, R.A., Saturn and Its System. London: Longmans, 1865.

Reese, E.J., Measurements of Saturn in 1969. Las Cruces: NMSU Observatory Publications, 1970.

Roth, G.D., Handbook for Planetary Observers. London: Faber and Faber, 1971.

----------, Tashenbuch für Planetenbeobachter. Mannheim: Bibliographisches Institut, 1966.

Sidgwick, J.B., Amateur Astronomer's Handbook. London: Faber and Faber, 1971 (3rd Edition).

--------------, Observational Astronomy for Amateurs. London: Faber and Faber, 1971 (3rd Edition).

Stevens, S.S., Ed., Handbook of Experimental Psychology. New York: Wiley, 1951.

Van de Hulst, H.C., Light Scattering by Small Particles. New York: Wiley, 1957.

Vaucouleurs, G. de, Physics of the Planet Mars. London: Faber and Faber, 1954.

Vitous, J.P., 1962, "Observations of Planetary Color," J.ALPO, 16, (1-2): 35-37.

Woodworth, R.S., and Schlosberg, H., Experimental Psychology. New York: Holt, 1954 (Revised)

Association of Lunar and Planetary Observers (ALPO): The Saturn Section

Central Meridian (CM) Transit Data and Sectional Sketches
(Attach this form to main observation form)

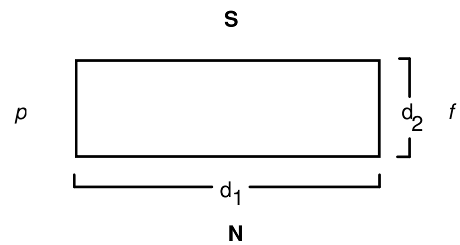
Observer: ____

Object: __________________________________

UT Date:________ UT Time:__________

Location:____________________(do sectional drawing at right)

CM I: ________° CM II: ________° d_1: _______″ d_2: _______″

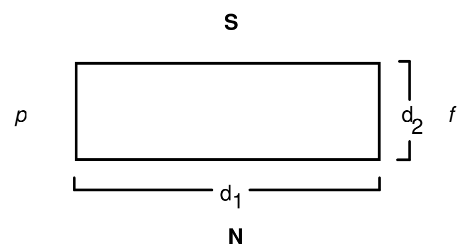


Object: __________________________________

UT Date:_______ UT Time:__________

Location:____________________(do sectional drawing at right)

CM I: ________° CM II: ________° d_1: _______″ d_2: _______″

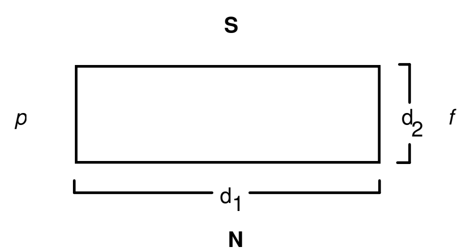


Object: __________________________________

UT Date:_________ UT Time:_________

Location:____________________(do sectional drawing at right)

CM I: ________° CM II: ________° d_1: _______″ d_2: _______″

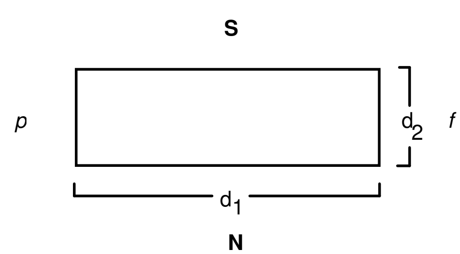


Object: __________________________________

UT Date:______ UT Time:__________

Location:____________________(do sectional drawing at right)

CM I: ________° CM II: ________° d_1: _______″ d_2: _______″



Sectional Sketch Notation: d_1 = longitudinal extent in arc sec (″) *p* = preceding
(All directions are IAU) d_2 = latitudinal extent in arc sec (″) *f* = following

Association of Lunar and Planetary Observers (ALPO): The Saturn Section

ALPO Visual Observation of Saturn's Satellites
(Attach this observation form to the main observing form for the same observing date)

Observer: ________________________________ UT Date: ___________

Reference Used for Locating Satellites____

Basic Symbolism Employed:

V_{os} = Visual magnitude of Saturn's satellite (computed from estimate)
X = Magnitude of Comparison Star (brighter reference star)
Y = Magnitude of Comparison Star (dimmer reference star)
> = Brighter than
< = Dimmer than

NOTE: *All magnitudes are visual magnitudes derived from a reliable star catalogue for comparison stars*

Satellite (*name*)	**Comparison Stars Utilized in Estimates**				**Magnitude Estimates for Satellites**		
	Star X *Designation*:		**Star Y** *Designation*:		**Tenths < X**	V_{os}	**Tenths > Y**
	Visual Mag	*RA DEC*	*Visual Mag*	*RA DEC*			

Source Utilized for Comparison Stars:

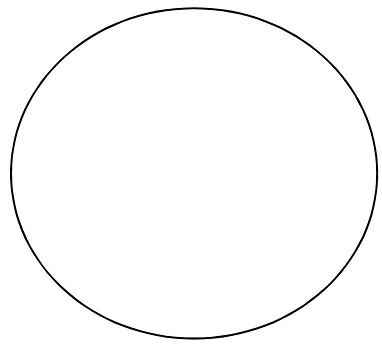
Descriptive Notes:

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

ALPO Visual Observation of Saturn for B = 0° (edgewise rings) through B = ± 4°

(*Rings are always omitted on drawing blanks for values of* B ≤ 4°)

S



N

Coordinates (check one): [ ] IAU [ ] Sky

Observer__________________________________Location____

UT Date (start) ___________________ UT Start _______________ CM I (start) _____________° CM II (start) _____________° CM III (start) ________________°

UT Date (end) ___________________ UT End ______________ CM I (end) _____________° CM II (end) _____________° CM III (end) ________________°

B = __________° B′ = __________° Instrument ____ Magnification(s) ___________ x_{min} _________ x_{max}

Filter(s) IL(none) ______________ f_1 ______________ f_2 ______________ f_3 ______________ Seeing ________________ Transparency ____________________

Saturn **Global and Ring Features**	**Visual Photometry and Colorimetry** **IL**	**f_1**	**f_2**	**f_3**	**Absolute Color Estimates**	**Latitude Estimates** **ratio y/r**

Bicolored Aspect of the Rings: (*always use IAU directions*)

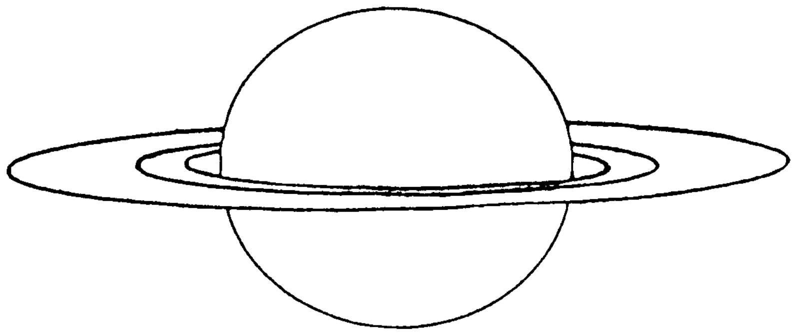
No Filter (IL) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa
Blue Filter (_________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa
Red Filter (_________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

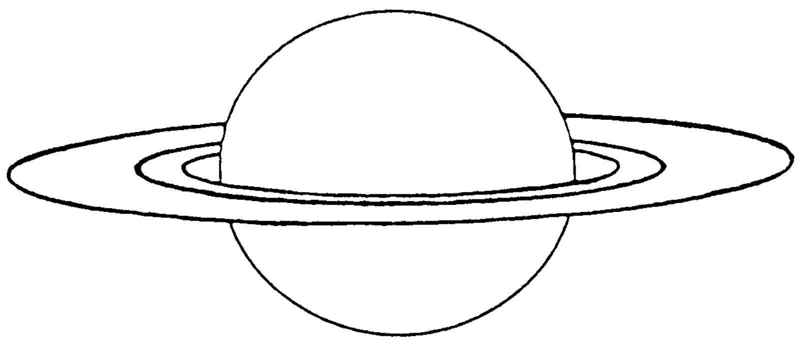
IMPORTANT: Attach to this form all descriptions of morphology of atmospheric detail, as well as other supporting information. Please do not write on the back of this sheet. The intensity scale employed is the *Standard ALPO Intensity Scale*, where 0.0 = completely black ⇔ 10.0 = very brightest features,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

Association of Lunar and Planetary Observers (ALPO): The Saturn Section

ALPO Visual Observation of Saturn for B = ± 6° to ± 8°

S





N

Coordinates (check one): [ ] IAU [ ] Sky

Observer________________________________ Location ____

UT Date (start) _________________ UT Start ______________ CM I (start) ____________° CM II (start) ____________° CM III (start) ______________°

UT Date (end) __________________ UT End_____________ CM I (end____________° CM II (end) ____________° CM III (end) _____________°

B = _________° B′ = _________° Instrument ____ Magnification(s) _________ x_{min} __________ x_{max}

Filter(s) IL(none) _____________ f_1 _____________ f_2 _____________ f_3 _____________ Seeing _______________ Transparency _________________

Saturn Global and Ring Features	Visual Photometry and Colorimetry IL	f_1	f_2	f_3	Absolute Color Estimates	**Latitude Estimates** ratio y/r

Bicolored Aspect of the Rings: (*Always use IAU directions*)

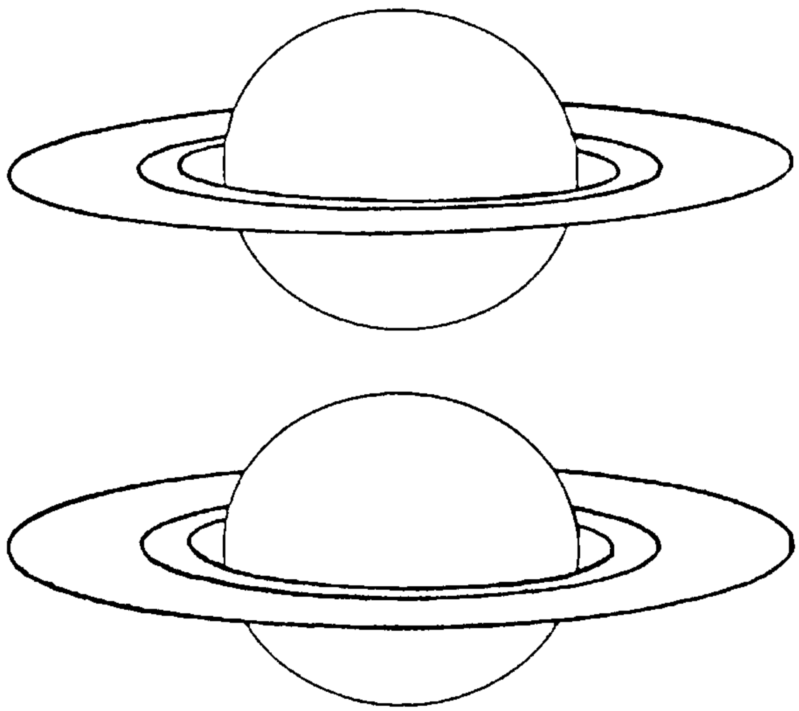
No Filter (IL) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa
Blue Filter (________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa
Red Filter (________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

IMPORTANT: Attach to this form all descriptions of morphology of atmospheric detail, as well as other supporting information. Please do not write on the back of this sheet. The intensity scale employed 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.

Association of Lunar and Planetary Observers (ALPO): The Saturn Section

ALPO Visual Observation of Saturn for B = – 10° to ± 12°

S



N

Coordinates (check one): [ ] IAU [ ] Sky

Observer__________________________________Location____

UT Date (start) __________________ UT Start ______________ CM I (start) ____________° CM II (start) ____________° CM III (start) _______________°

UT Date (end) __________________ UT End _____________ CM I (end) ____________° CM II (end) ____________° CM III (end) ______________°

B = _________° B′ = _________° Instrument ____ Magnification(s) ___________ x_{min} _________ x_{max}

Filter(s) IL(none) _____________ f_1 _____________ f_2 _____________ f_3 _____________ Seeing _______________ Transparency __________________

Saturn Global and Ring Features	**Visual Photometry and Colorimetry IL**	**f_1**	**f_2**	**f_3**	**Absolute Color Estimates**	**Latitude Estimates ratio y/r**

Bicolored Aspect of the Rings: (*Always use IAU directions*)

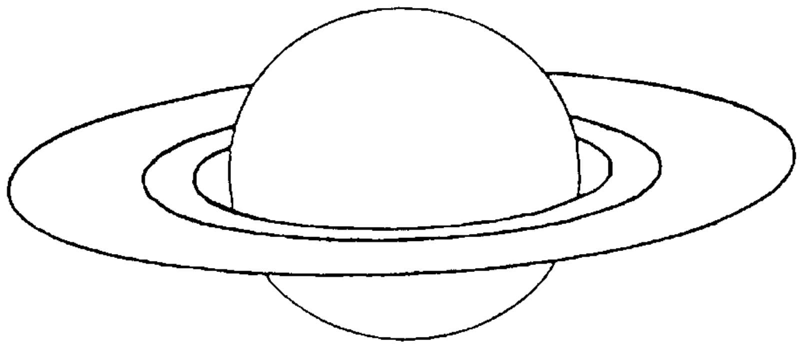
No Filter (IL) (*check one*):	[ ] E ansa = W ansa	[ ] E ansa > W ansa	[ ] W ansa > E ansa
Blue Filter (________) (*check one*):	[ ] E ansa = W ansa	[ ] E ansa > W ansa	[ ] W ansa > E ansa
Red Filter (________) (*check one*):	[ ] E ansa = W ansa	[ ] E ansa > W ansa	[ ] W ansa > E ansa

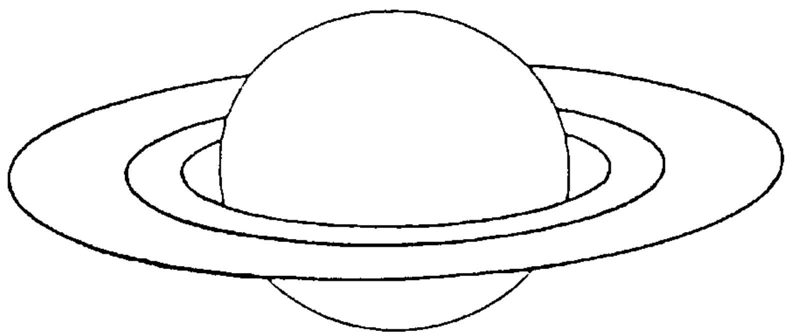
IMPORTANT: Attach to this form all descriptions of morphology of atmospheric detail, as well as other supporting information. Please do not write on the back of this sheet. The intensity scale employed is the *Standard ALPO Intensity Scale*, where 0.0 = completely black ⇔ 10.0 = very brightest features,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

Association of Lunar and Planetary Observers (ALPO): The Saturn Section

ALPO Visual Observation of Saturn for B = – 14° to ± 16°

S





N

Coordinates (check one): [ ] IAU [ ] Sky

Observer ________________________________ Location ____

1. UT Date (start) __________________ UT Start ______________ CM I (start) ____________° CM II (start) _____________° CM III (start) ______________°

UT Date (end) __________________ UT End _____________ CM I (end) ____________° CM II (end) _____________° CM III (end) _____________°

B = _________° B′ = _________° Instrument ____ Magnification(s) ___________ x_{min} _________ x_{max}

Filter(s) IL(none) ______________ f_1 ______________ f_2 ______________ f_3 ______________ Seeing ________________ Transparency __________________

Saturn Global and Ring Features	Visual Photometry and Colorimetry IL	f_1	f_2	f_3	Absolute Color Estimates	Latitude Estimates ratio y/r

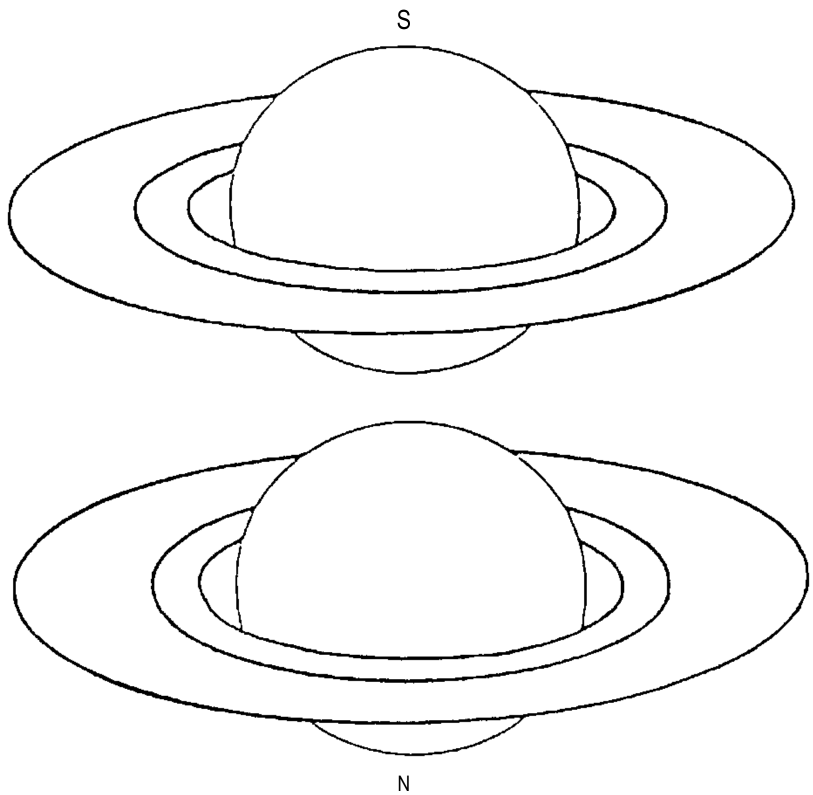
Bicolored Aspect of the Rings: (*Always use IAU directions*)

No Filter (IL) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa
Blue Filter (_________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa
Red Filter (_________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

IMPORTANT: Attach to this form all descriptions of morphology of atmospheric detail, as well as other supporting information. Please do not write on the back of this sheet. The intensity scale employed 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.

Association of Lunar and Planetary Observers (ALPO): The Saturn Section

ALPO Visual Observation of Saturn for B = – 18° to ± 20°



Coordinates (check one): [ ] IAU [ ] Sky

Observer________________________________Location____

UT Date (start) ______________ UT Start _____________ CM I (start) ____________° CM II (start) ______________° CM III (start) ________________°

UT Date (end) ______________ UT End _____________ CM I (end) ____________° CM II (end) _____________° CM III (end) _______________°

B = _________° B′ = _________° Instrument ____ Magnification(s) _____________ x_{min} ____________ x_{max}

Filter(s) IL(none) _____________ f_1 _____________ f_2 _____________ f_3 ____________ Seeing _______________ Transparency ________________

Saturn Global and Ring Features	Visual Photometry and Colorimetry IL	 f_1	 f_2	 f_3	 Absolute Color Estimates	Latitude Estimates ratio y/r

Bicolored Aspect of the Rings: (*Always use IAU directions*)

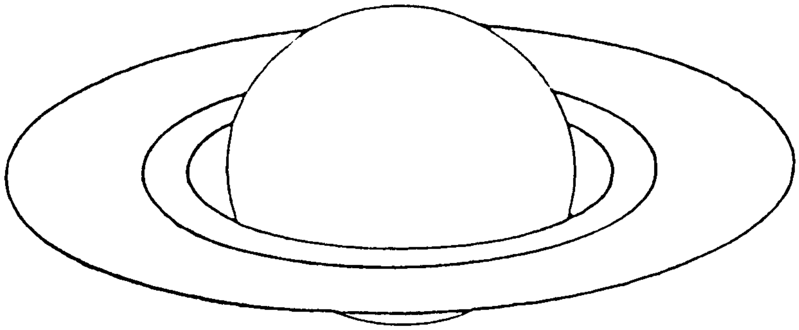
No Filter (IL) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa
Blue Filter (________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa
Red Filter (________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

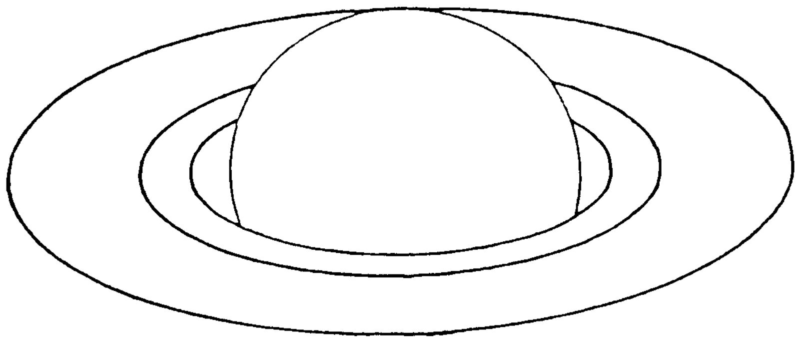
IMPORTANT: Attach to this form all descriptions of morphology of atmospheric detail, as well as other supporting information. Please do not write on the back of this sheet. The intensity scale employed is the *Standard ALPO Intensity Scale*, where 0.0 = completely black ⇔ 10.0 = very brightest features,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

Association of Lunar and Planetary Observers (ALPO): The Saturn Section

ALPO Visual Observation of Saturn for B = – 22° to ± 24°

S





N

Coordinates (check one): [ ] IAU [ ] Sky

Observer__________________________________Location____

UT Date (start) _______________ UT Start ______________ CM I (start) _____________° CM II (start) _______________° CM III (start) _________________°

UT Date (end) _______________ UT End ______________ CM I (end) _____________° CM II (end) _______________° CM III (end) _______________°

B = __________° B′ = __________° Instrument ____ Magnification(s) _____________ x_{min} ______________ x_{max}

Filter(s) IL(none) ______________ f_1 ______________ f_2 ______________ f_3 _____________ Seeing _______________ Transparency ____________________

Saturn **Global and Ring Features**	**Visual Photometry and Colorimetry** **IL**	**f_1**	**f_2**	**f_3**	**Absolute Color Estimates**	**Latitude Estimates** **ratio y/r**

Bicolored Aspect of the Rings: (*Always use IAU directions*)

No Filter (IL) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

Blue Filter (_________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

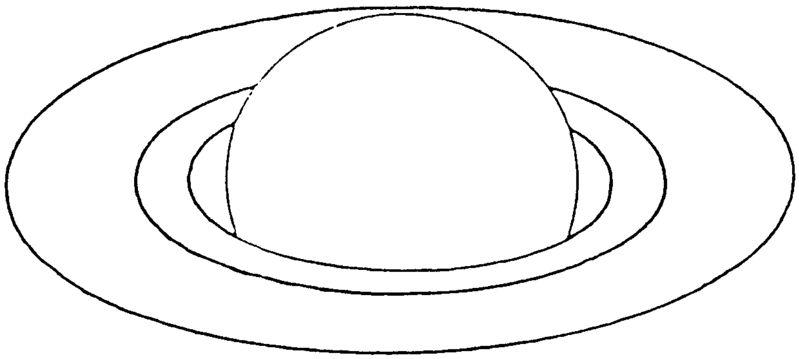
Red Filter (_________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

IMPORTANT: Attach to this form all descriptions of morphology of atmospheric detail, as well as other supporting information. Please do not write on the back of this sheet. The intensity scale employed 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.

Association of Lunar and Planetary Observers (ALPO): The Saturn Section

ALPO Visual Observation of Saturn for B = – 26° to ± 28°

S



N

Coordinates (check one): [ ] IAU [ ] Sky

Observer__________________________________Location____
_

UT Date (start) _________________ UT Start _____________ CM I (start) ___________° CM II (start) ________________° CM III (start) __________________°

UT Date (end) ____________ UT End _____________ CM I (end) ____________° CM II (end) ________________° CM III (end) __________________°

B = _________° B′ = __________° Instrument ____ Magnification(s) _____________ x_{min} _____________ x_{max}

Filter(s) IL(none) _____________ f_1 _____________ f_2 _____________ f_3 _____________ Seeing __________________ Transparency ____________________

Saturn	**Visual Photometry and Colorimetry**					**Latitude Estimates**
Global and Ring Features	**IL**	**f_1**	**f_2**	**f_3**	**Absolute Color Estimates**	**ratio y/r**

Bicolored Aspect of the Rings: (*Always use IAU directions*)

No Filter (IL) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

Blue Filter (_________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

Red Filter (_________) (*check one*): [ ] E ansa = W ansa [ ] E ansa > W ansa [ ] W ansa > E ansa

IMPORTANT: Attach to this form all descriptions of morphology of atmospheric detail, as well as other supporting information. Please do not write on the back of this sheet. The intensity scale employed 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.