NO. 192 HIGH RESOLUTION PLANETARY OBSERVATION*

by Gerard P. Kuiper

June 1971

ABSTRACT

High-resolution ground-based planetary observations, visual and photographic, have,for several decades,seemed to have reached a rather firm limit. The causes for this restriction are briefly reviewed. At the time when space probes make major advances possible, at incomparably higher levels of expenditure, the need arises to *re-examine* the limiting factors of earth-based planetary resolution. In addition to familiar refinements (of which seven are listed) carried somewhat further, a specific approach, yet insufficiently developed, is the study of the atmospheric boundary layer over the observatory site and the use of an appropriately *elevated* station. The required elevation may be determined acoustically.

---

* Presented at COSPAR Meeting, Seattle, June 21-July 2 1971; reissued from SPACE RESEARCH XII, 1972, pp. 1683-1687, with minor additions.

Planetary observation, both visual and photographic, has always depended on the best image quality (seeing) available. In this respect its main requirement is identical to that of double-star observation. Almost any observing site experiences exquisite seeing at some time. Sites differ in the *frequency* of such occurrences and in the more readily ascertainable total fractions of clear weather. Tropical sites have a large fraction of good seeing on the nights that are clear, though the frequency of clear nights depends on location and on the monsoon. For instance, at the Bosscha Observatory in Java the seeing is almost always satisfactory whenever the sky is clear, with visual resolution of 0.2 arc sec regularly achievable with the 60-cm visual telescope. In the latitudes 25-35° of both hemispheres, the fraction of clear nights is the largest (with local exceptions) and the seeing is good-to-excellent a fair fraction of the time, particularly close to the western shores of various continents. Large continental masses appear to have a disturbing effect on the air parcels so that good seeing is less frequent far away from these shores. This rule has only a statistical validity; exceptional weather conditions may occur anywhere.

With a large telescope of high quality, in excellent adjustment, the limit of *visual resolution* is always near the theoretical diffraction limit. I have observed double stars, of 0".06 (arc sec) separation, such as 20 Persei, repeatedly with the 82-inch telescope of the McDonald Observatory and measured the planet Pluto, the satellites of Saturn, and Triton of Neptune with the 200-inch Hale telescope. The measured diameter of Pluto was 0".23 ± 0.01 [1], and for the Saturn satellites and Triton [2] the following: "5 July 1954, Enceladus (0".08), Tethys (0".12), Dione (0".12), Rhea (0".24), Titan (0".67), Iapetus (0".195), all at 9.43 astr. units; and Triton (0".173) and Neptune (2".06), both at 30.1 astr. units". (Stars were found to have spurious disks of about 0".05, a value attributable to the Ross corrector lens at the prime focus, which for safety reasons had to remain in place during measurements, made in the prime focus cage).

High *photographic resolution* is not obtained nearly as readily as high visual resolution. This appears due to the fact that high visual resolution results from continued observation over many seconds to several minutes, during which the eye and brain reject all visual records that do not reach to the desired standard, and retain for "storage" only the best 10^3-10^4 individual impressions. The photographic plate can simulate this process to some extent by the use of multiple exposures. Also, the photography can be monitored, by the observer watching the image and selecting the best moments for the exposures or by some automatic device based on image size. During a program of systematic planetary photography with the 82-inch of the McDonald Observatory in 1948, using both color film and black-and-white, the resolution gap between visual and photographic observation was found to be a factor of about 4. Since then, with improved emulsions and improved thermal control of the air in both telescope and dome, the gap has been narrowed to about 2. Thus, the best photographic resolution obtained with the 61-inch telescope, whose Airy disk in visual light is 0.075 arc sec, is about 0.15 arc sec. (Achieved many times in the CONSOLIDATED LUNAR ATLAS, 1967, e.g. on the Clavius photograph used as the frontispiece). The finest Jupiter detail recorded on color film has dimensions of 0".12-0".15, though 0".2 is more common. Under good-to-average conditions of seeing there often is *no gap*, with all that is seen recorded photographically.

Numerous details affecting the *thermal regimes of telescope and dome* must be watched if maximum photographic resolution is to be achieved. Unfortunately, insufficient attention has been given to these factors in some observatories built on excellent sites. Briefly, the requirements are: (i) the entire observatory area must have a good climate in the usual astronomical sense, not too far from the western shore of a continent or on a favorably-located island; (ii) the building must be elevated, for the slit opening to be well above the atmospheric boundary layer caused by local topographic features, trees, etc. This level is determined by tests with small balloons and smoke bombs which make the air flow pattern visible. (iii) The building itself should be cylindrical, with a hemispherical dome, having a slit that moves up and over (not horizontally moving doors). This cylindrical observatory should have a diameter not greater than necessary to house the telescope. (iv) The dome should be painted white (TiO_2), which reflects more than 3/4 of the incident sunlight and effectively re-radiates in the infrared the small part absorbed; thus the outer surface remains cool during the day and cools rapidly at night, preventing an updraft of warm air from the building in front of the dome slit. (v) The thermal inertia of the dome should be minimal to achieve equalization of temperatures at night. This is also the cheapest way of building a dome, since a single metal skin over a rib structure of I-beams suffices. (vi) Inside the dome one should have 3 or 4 large exhaust fans spread in azimuth, at about the observing level, capable of running at different speeds, adjusted during operations to cause an inflow of air through the slit at a rate not so rapid as to cause turbulence. This can be checked from the Foucault test. The best arrangement is found to depend on the wind direction and speed. (vii) Small exhaust fans are also placed around the primary mirror to prevent the formation of air bubbles over it with temperature slightly different from that of the ambient air. These bubbles are well known to all visual observers who have studied the Foucault patterns of bright stars. The average diameter of such bubbles, when permitted to form, appears to be 30-40 cm. (The 82-inch telescope showed usually about 20 of them; the 200-inch, approximately 100). The bubbles grow to full size in 10-30 seconds, and then take off and rise, being replaced by cooler air. The (warm) bubbles act like weak negative lenses and cause the telescopic image to be that of a multiple interferometer. Stellar images are usually confined to an overall diameter of about 0.3 arc sec, containing from 5 to 15 visible components which slowly move over each other with a relaxation time of a few seconds. In double-star observations, one picks the brightest of these images for measurement but planetary photography is, of course, degraded. Experience has shown that these bubbles can indeed be prevented.

Considerable study of photographic materials, image sizes, and development techniques is also essential. In our color photography we have found High-Speed Ektachrome or, more recently, Ektachrome EF, to be the most satisfactory, not used routinely, however. In addition to normal exposures, processed commercially, we expose several rolls at 1/4 of the normal time (1/8s vs. 1/2s for Jupiter at F/75, or F = 115m) and compensate for this by special processing. This may lead to distinctly improved definition though often increased graininess and lack of good color balance that must be verified and corrected in copying with normal exposures. We have also found that underexposed (dark-looking) color frames can be copied with corrective filters to normal-appearing frames. This also requires that some normal exposures are available for reference, though these may have less resolution.

An examination of some 12,000 color frames of Jupiter (and many more black-and-white frames) obtained since October 8, 1965, when operations with the 61-inch telescope started, showed that with no more than 1/4 of the telescope time assigned to planetary photography each month, on almost every month a series of exquisite color photographs was obtained, supported by approximately three times the number of black-and-white photographs taken through filters, ultraviolet to infrared. Important supplementary series were acquired each month.

As regards the *use* of planetary photographs, with low-contrast features such as the clouds of Venus, composite prints are the most informative: one may combine from 5 to 10 frames into a single print, increase the contrast, and take out mechanically a linear gradient across the terminator.

The *examination* of the color photographs is best made in binocular vision, using two selected frames. Then, one is able to reject immediately all minor defects, such as scratches, which would be retained, though reduced, in composites. Binocular vision further appreciably enhances visibility of faint contrasts and minute details, giving the impression of a gain in resolution of approximately 1.5 over single frames. Accordingly, this Laboratory is preparing a file of color copies for the planet Jupiter, all 20mm in diameter, containing all frames from the original set of 12,000, that appear to contribute independent information. This number is larger than might be expected since the resolution is not constant over the entire planetary disk, so that many frames must be consulted. The number of frames actually selected for copying is about 1,500. A companion file of supporting black-and-white filter photographs will also be produced. Because of the longer wavelengths and higher contrast, the High-Speed IR frames often show somewhat higher resolution.

The *wavelength dependence* of photographic resolution is interesting. On moderately good nights, the resolution may go as $1/\lambda$; on poor nights, no λ effect is noted. This agrees with the visual impression that on poor nights the blurred stellar images do not have a blue fringe. The $1/\lambda$ effect on good nights is probably due to the near-validity of the Rayleigh criterion for good images (deviations less than $\lambda/4$ in the wave front). The criterion may be satisfied from 0.7-0.9μm (High Speed IR), but not 0.35-0.5μm, making a factor of 2 difference in resolution. Unfortunately, fast films beyond 0.9μm are not available or they would further improve earth-based resolution in planetary photography with large telescopes, possibly further closing the resolution gap referred to. For low-contrast features no gap is present.

Color photography has added a new dimension to photography of the planets. For Jupiter and Saturn the classification of clouds by color almost certainly is a classification by composition; and presumably also one of elevation within the atmosphere. The belts, when observed under the best conditions, usually break up into dozens of individual clouds all of the same color, suggesting a repetitive process of their formation. They appear analogous to terrestrial cloud streams formed by large forest fires or volcanic eruptions. The study of the Jovian planets will be one of the most active scientific endeavors of the 1970's; ground-based astronomy, if carried to the limits of its capabilities, will be able to contribute greatly in two main areas: atmospheric circulation and cloud composition. With still better facilities, resolutions down to 0.10 arc sec should be achievable on a fairly regular basis, on both High-Speed IR and fast color film.

Data processing, with allowance for the image blur function, can always yield another factor of about 2 in image definition, as was first demonstrated in 1956 at Johns Hopkins University, and has, for example, been practiced in the processing of the Ranger television records by the Jet Propulsion Laboratory in NASA's Ranger Reports (1965, 1966).

Reference must also be made to the exquisite planetary photography with the new 108-cm telescope at the Pic-du-Midi, clearly a superior site that will merit further development; to the important comparative site tests in California by Walker [3], recently extended to other sites in North and South America and Australia [4]; and the extensive tests carried out from July 1965 to October 1969 in France, Spain, and Baja California, by the Paris-Meudon Observatory team (interim reports by INAG). Earlier notable contributions are those by F. G. Pease with the 100-inch telescope of the Mt. Wilson Observatory (lunar and planetary photography in the 1920's); with the Lick 36-inch telescope by J. H. Moore and F. Chappell (the moon about 1937) and by H. M. Jeffers (Mars 1950-1960); by R. B. Leighton with the Mt. Wilson 60-inch telescope in 1960's, by M. L. Humason with the 200-inch [5] and by G. H. Herbig with the Lick 120-inch telescope, both at the coudé focus; by W. S. Finsen with the 26-inch telescope of the Union Observatory (Mars in 1954 and 1956 [5]); and by E. C. Slipher with various telescopes, especially the Lowell Observatory 24-inch and the Lamont-Hussey 27-inch at Bloemfontein, South Africa [6]. The total photographic program represents a tremendous effort (about 1,000,000 planetary and lunar photographs). This may have created the general impression among astronomers that the limits of this technique have been reached. No doubt further progress will be difficult and will require additional refinements and even new approaches if not better observing sites; but it is also true that *resolutions of 0".1 must be achievable photographically as they have been achieved visually at all large observatories since the 1890's.*

It is probable that the most important advance still within reach is one of seeking the *optimum elevations* above selected observing sites. Related to this is the determination of the vertical distribution of seeing disturbances within the first few hundred feet above the ground, the region usually assumed to be responsible for the major part of the seeing disturbances, and improved dome-tower design, so as to avoid the creation of new local disturbances. The atmospheric profile may be tested for irregularities in the refractive index by acoustical methods having a sensitivity some 1700x the optical sensitivity [7]. The premium on achieving resolution of about 0".1 regularly, especially during the next decade in the study of Jupiter and Saturn, is so great, in view of the prohibitively expensive alternative of observing changing cloud-covered surface from space probes, that these further efforts in ground-based photography are warranted. It is true that a resolution of 0".1 might be achievable also from a 1-3m telescope in orbit, but the problems with this approach may have been underestimated. In any case, ground-based planetary photography of highest possible resolution will remain a prime goal.

Acknowledgments: Study of photographic materials and development techniques have been carried out at this Laboratory with great competence and persistence by R. le Poole, J. Fountain, S. Larson, and R. B. Minton.

REFERENCES

[1] G. P. Kuiper, *Publ. Astr. Soc. Pacific, 62,* 133 (1950).
[2] *Trans. Int. Astron. Un., 9,* 250 (1955).
[3] M. F. Walker, *Publ. Astr. Soc. Pacific, 82,* 672 (1970).
[4] M. F. Walker, *Publ. Astr. Soc. Pacific, 83,* 1401 (1971).
[5] Summarized with reproductions in Chapters 16 and 17 of PLANETS AND SATELLITES: THE SOLAR SYSTEM, VOL. III, University of Chicago Press 1961.
[6] E. C. Slipher, BRIGHTER PLANETS, National Geographic Society and Lowell Observatory 1964.
[7] Freeman F. Hall Jr., "Acoustic Remote Sensing of Temperature and Velocity Structure in the Atmosphere", STATISTICAL METHODS AND INSTRUMENTATION IN RADIO METEOROLOGY, A. G. Kjelaas, ed., Teknologisk Forlag A/S, Oslo (1971).