Chapter 2

WORKSHOP PRESENTATIONS AND DISCUSSIONS

2.1 RADIUS AND MASS OF TITAN

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Introduction

Knowledge of the radius and mass of a satellite is fundamental to an understanding of its physical nature. Both quantities are needed to derive the density and the surface gravity, and the radius is also required for the interpretation of visible and infrared photometry in terms of albedo and brightness temperature. Of the two parameters, Titan's mass is by far the better known.

Titan's Mass

Titan's orbit is in resonance with that of Hyperion, and from its perturbations on the smaller satellite several investigators (e.g., Eichelberger 1911; Woltjer 1928; Jefferys 1954) have determined that its mass is 1.37×10^{26}g. These values have recently been reviewed by Kovalevsky (1970). Both from internally estimated errors and from the agreement among different authors using different techniques of analysis, it is apparent that the uncertainty in this mass is only about 1%. Even if the uncertainty were several times this value, the mass would still be one of the best-determined properties of this satellite.

Titan's Radius

The radius of Titan is, in contrast, a real problem. As seen from Earth, the apparent diameter of this satellite is only about 0.8 arcsec, and even under the best observing conditions, it is extremely difficult to measure the size of such a small object. The visual measurements have been reviewed and summarized by Dollfus (1970), and a recent note of mine (Morrison 1973) contains some additional comments on these techniques.

The most extensive and successful visual observations of the size of Titan and other satellites and asteroids of comparable angular dimensions have been made by several French observers, working primarily at the Pic du Midi Observatory with telescopes of modest aperture. The two instruments most applicable to Titan are the double-image micrometer, in which two images of the satellite are brought into tangency and their separation measured, and the diskmeter, in which an artificial image, with adjustable diameter, surface brightness, and limb darkening, is visually compared with the image of Titan. Both instruments have yielded diameters that are highly reproducible, but the systematic errors are extremely difficult to evaluate. Older, and slightly less reproducible, observations have also been made with filar micrometers at a number of observatories.

In his review of all these data, Dollfus (1970) finds a mean diameter in arcsec of 0.703 ± .10 for the filar micrometer measurements, of 0.700 ± .07 for the diskmeter measurements, and of 0.700 ± .06 for the double-image micrometer measurements. The resulting physical diameter is 4850 ± 300 km. If possible systematic uncertainties are allowed for, the actual uncertainty in this value is almost certainly larger, amounting to at least 10%.

Some calibration of possible errors is provided by recent very precise measurements of the sizes of the Galilean satellites Io and Ganymede, derived from timings of occultations of stars by the satellites. Since typical angular motions of satellites and asteroids are <0.05 arcsec/sec, a timing precision of 0.1 sec yields a precision of <0.005 arcsec in the size, which is at least an order-of-magnitude gain over the best visual measurements. The practical requirements are that the star be no more than about two magnitudes fainter than the occulting object and that the occultation be predicted sufficiently in advance to permit several photometric telescopes to be installed in the zone of visibility. Both of these requirements have been discussed in detail by O'Leary (1972). On 14 May 1971 Io occulted the 5th-magnitude star β Scorpii C. Photoelectric observations from four observing parties give a radius, on the assumption that Io is spherical, of 1830 ± 2 km (Taylor 1972). If the satellite has the figure expected for a tidally and rotationally distorted fluid, the mean radius is 1818 ± 5 km (O'Leary and van Flandern 1972). In June 1972, an occultation by Ganymede of an 8th-magnitude star was timed by three observing parties. From these data, Carlson et al. (1973) give a radius of 2635 km. The occultation radius of Io is 4% larger than the value given by Dollfus (1970) and that of Ganymede is 5% smaller; there is thus no indication of major systematic errors in the visually derived radii of these two satellites.

It is not clear whether the high accuracy of the visual measurements of Io and Ganymede will apply as well to Titan, which is smaller, has much lower surface brightness, and may, in consequence of its atmosphere, have substantially greater limb darkening. The absence of an optically thick atmosphere on any other small object makes attempts to calibrate the Titan observations against those of other satellites somewhat questionable. An alternative comparison might be with Neptune: here, the occultation diameter (Freeman and Lyngå 1970) is larger than the visual one by ∿0.07 arcsec, suggesting that limb darkening may indeed affect the visual techniques.

Stellar Occultation Measurements

I think we could all agree that the observation of an occultation of a star by Titan would be extremely valuable, both for determining an accurate radius, and, even more, for the study of its atmosphere, as discussed by Veverka (Chapter 3). If an occultation of a star of 8th magnitude or brighter were predicted, even with only a warning of a few weeks, then every effort should be made to obtain good photoelectric photometry. I note, however, that occultations even of stars of magnitude 9 or 10 could be used to measure the radius. The problem here is that our uncertainty in the positions of stars this faint precludes accurate prediction of events. In practice, an occultation will be predicted only if the star is in the SAO catalog, which is by no means complete at this magnitude level. We should seriously consider the value of a program of photographically examining the sky ahead of Titan in order to predict occultations. In order to take advantage of these predictions, it will also be necessary to have observers with high-quality portable photoelectric photometers who are willing to travel on short notice into the zone of visibility of the occultation, which will be, of course, about 5000 km wide. A modest level of funding for such a program could be a very good investment.

Summary

It is apparent from the preceding discussion that the radius of Titan is not well known at present, and that the uncertainty in the radius produces very substantial uncertainty in the density (proportional to r^{-3}) and in surface gravity, albedo, and thermal luminance (all dependent on r^2). I suggest that, for convenience, we all agree on a radius of 2500 km, which is a good round number. This value is 3% larger than the value based on the visual measurements, as interpreted by Dollfus (1970), and is 2% smaller than the value used by several recent infrared investigators (Morrison et al. 1972; Gillett et al. 1973; Joyce et al. 1973). I would also adopt an uncertainty (possibly optimistic) in this radius of ±10%. With this radius and the known mass, the density of Titan is 2.1 ± 0.6 g cm^{-3} and the acceleration of gravity at the surface is 145 ± 30 cm s^{-2}. Presumably this radius refers to approximately the cloud level, and if the clouds are a long way above the surface, the mean density of the solid body of the satellite will be higher. For many investigations, it is clear that a more accurate value of the radius would be useful.

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Danielson: Depending on the details of the model, the limb darkening on Titan could be either greater or smaller than on the Galilean satellites, so the sense of the correction is not necessarily to increase the radius of Titan.

Veverka: Gordon Taylor of the British Nautical Almanac Office has made a search for occultations of stars in the SAO catalog by Titan for about the next five years, and none are indicated. Thus we are unlikely to have a really high-quality event soon, although occultations of stars too faint to be in the SAO catalog but still bright enough to provide a good radius determination may take place. An alternative means of measuring the diameter of Titan is by high-speed photometry of occultations of Titan by the Moon. There will be a favorable event of this type in March 1974, and I intend to observe it.

Morrison: How accurate do you think the diameters from lunar occultations will be?

Veverka: I have not worked it out in detail, but certainly to a greater accuracy than we now have -- perhaps to a few tens of kilometers. Also, these occultations are frequent, so a number of events could be observed to refine the values.