

NO. 177 PHOTOGRAPHIC OBSERVATIONS OF THE OCCULTATION
OF BETA SCORPII BY JUPITER

by Stephen M. Larson

April 1972

ABSTRACT

The occultation of the multiple star Beta Scorpii by Jupiter was observed visually and photographically from the Bosscha Observatory in Lembang (Java), Indonesia, on May 13, 1971. The photographs recorded the dimming of the stars as the light was differentially refracted by the Jovian atmosphere, and gave support to a scale height much greater than 8 and more nearly 30 km (Fig. 7). In addition, during the ingress of Beta Scorpii, *flashes* up to 1 second long were observed visually (while guiding in the reflex device of the camera) that occurred at irregular intervals, spaced by 2-8 seconds, over a total period of 7 minutes. Measurements of the position of the brightest component of Beta Scorpii during ingress shows refraction of approximately 1.4 before becoming unobservable.

1. Introduction

An observing run was made at the Bosscha Observatory in Lembang (Java), Indonesia, during the month of May 1971 (Larson 1971) in preparation for an extensive stay in the summer to observe Mars during its favorable opposition. The project involved the observation of Jupiter, Mars, and Mercury as a part of the continuing program of planetary photography which is carried out by this Laboratory (Kuiper 1972a, 1972b, Fountain and Larson 1972).

Taylor (1970) calculated the occultation of Beta Scorpii to occur at about 18^h UT on 13 May 1971, predicting that the best observations could be made from the region of the Indian Ocean. We had made no plans to observe the occultation since we understood that the Director of the Observatory, Dr. Bambang Hidajat, had planned to make visual timings of ingress and egress for Dr. W. B. Hubbard's program at the University of Texas. However, as soon as our equipment was adapted to the twin 60-cm refractor, it became evident that a program of photography would not interfere with Hidajat's visual timings and would, in fact, supply additional data. As there was no time to test for optimum image size and exposure times, the scale that was used (3.75 arc sec mm⁻¹; f/76) was chosen so that the exposures ($\frac{1}{2}$, 1 sec) would be minimized to give the best records of the instantaneous brightness of the star. This proved to be a good choice since the light from the "flashes" might not have been recorded otherwise.

2. Observations

The configurations of the objects observed during occultation are shown in Figure 1. Beta Scorpii is a B0.5V spectroscopic binary of visual magnitude 2.63 and has a companion of magnitude 9 at a distance of 0.5" (P.A. = 132°) (Hubbard, *et al.* 1972) which, under the observing conditions, could not be detected. Another star, SAO 159683, of visual magnitude 4.92, type B2V, and 13".64, North of Beta Scorpii (P.A. = 24°) (Hubbard, *op. cit.*) was also occulted. At the time, Jupiter was 10 days before opposition and was moving Westward by its equatorial diameter of 45".04, in about 2.5 hours.

The photographs were taken with the double 60-cm Zeiss refractor which has one objective corrected for blue light and one for yellow (Voûte 1933). The ingress of both stars was recorded with the visual refractor on Kodak 4X Panchromatic film with a Schott GG-14 yellow filter, and the egress of both stars was recorded on unfiltered Kodak 103-0 spectroscopic emulsion with the photographic telescope (Fig. 2). All black-and-white films were processed at the Observatory in Kodak D-19 for 6 minutes at 68°F.

Although the rainy season on Java is usually over by April, it lingered well into May, greatly reducing the anticipated observing time. Most of the night of May 13 was cloudy, but occasional clearing of the clouds allowed observation of the first ingress, while only incomplete coverage of the other events was obtained. As SAO 159683 disappeared, photographs were taken at a rate which was estimated to include the whole event on one 36-exposure roll, since changing film or cameras would take too much time. Between exposures, the occultation was observed visually through the reflex sight of the camera whose ground glass was replaced by clear glass with a reference cross-scratch. The star dimmed as expected with no peculiarities; the first ingress having a duration of only 60 seconds because of its location near Jupiter's equator. This series (Fig. 3) was the only event not hampered by clouds.

Because of the clouds, the ingress of Beta Scorpii (Fig. 4) was first observed after it had already begun to dim; after about two minutes of the expected dimming, we noticed that it reappeared intermittently, with these reappearances lasting less than a second and occurring irregularly every 2-8 seconds. The first suspicion was that variation in the seeing was responsible for the flashes but after careful observation, it was obvious there was no correlation. The flashes continued to be observed for almost 7 minutes, bring-

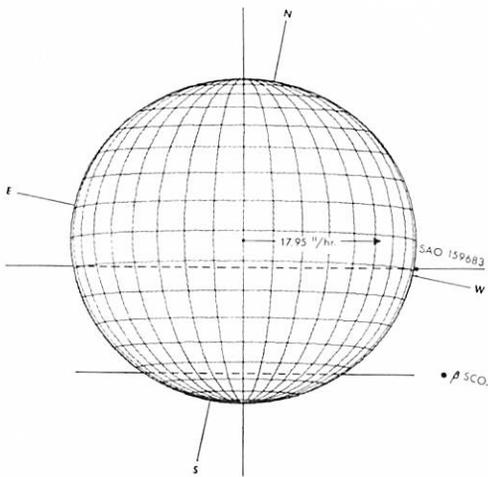


Fig. 1 Configuration of the occultation of ingress of SAO 159683

Fig. 2 (upper) Jupiter in yellow light near ingress of SAO 159683 (17^h44^m17^s UT); (lower) Jupiter in blue light after egress of Beta Scorpil (19^h49^m39^s UT)

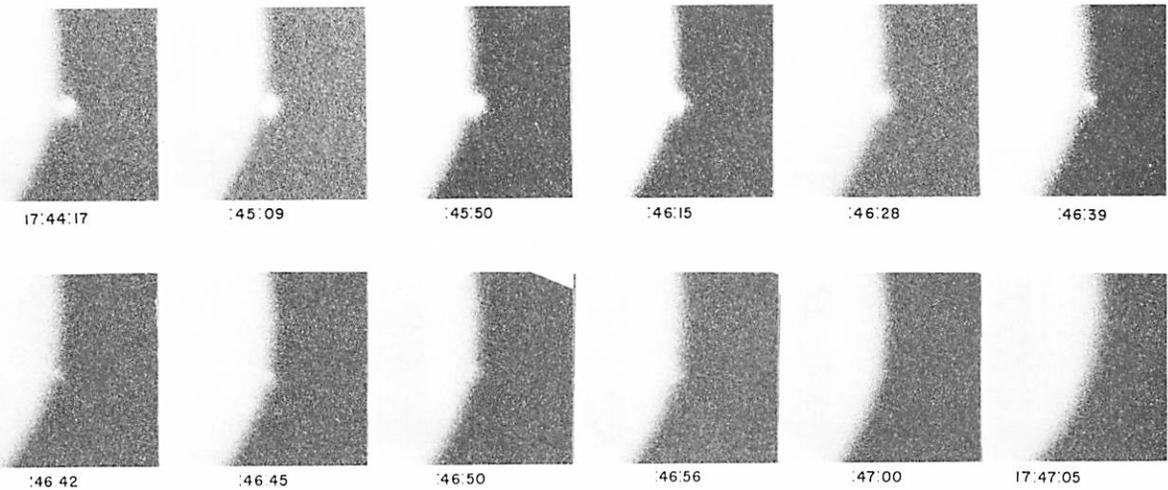
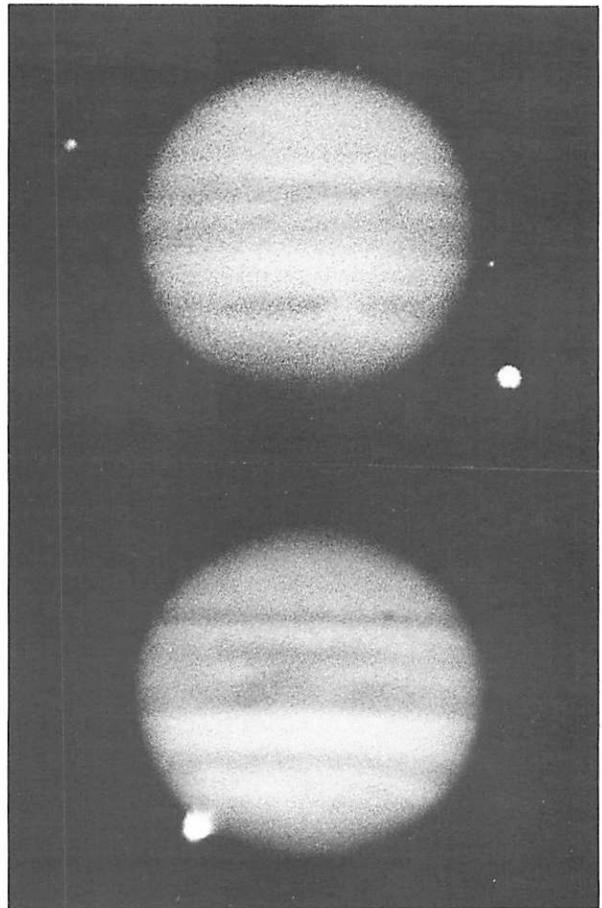


Fig. 3 Ingress of SAO 159683; times in UT

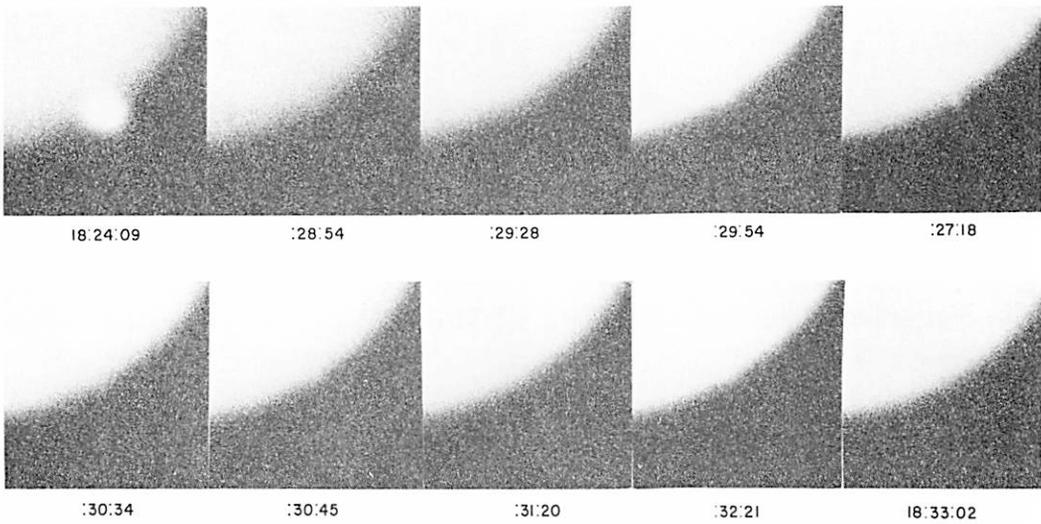


Fig. 4 Ingress of Beta Scorpii

ing the total time of ingress to nearly 8 minutes. No color could be observed during the flashes since the image was viewed through the yellow filter.

Although the egress of Beta Scorpii was underway when the clouds parted again (Fig. 5, upper), it took nearly 5 minutes to return to normal brightness. The clouds also prevented us from securing a good series of photographs of the egress of SAO 159683 (Fig. 5, lower). Table I summarizes the timing of egress and ingress along with the measured position angles.

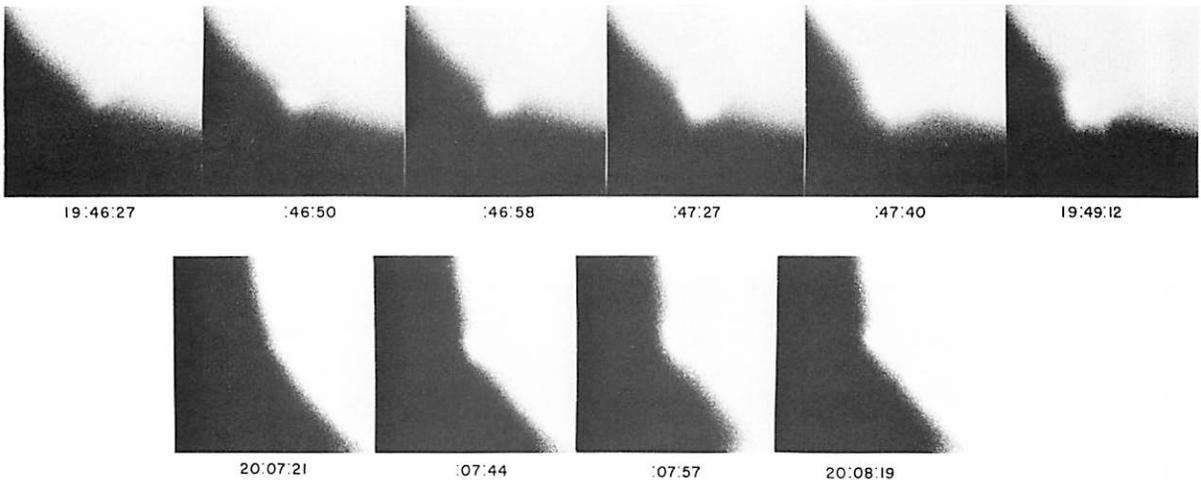


Fig. 5 (upper) egress of Beta Scorpii; (lower) egress of SAO 159683

TABLE I

Timings of Ingress and Egress (UT)

Sequence	SAO 159683	P. A.	Beta Scorpii	P. A.
Start dimming	17 ^h 46 ^m 15 ^s	271°.5	18 ^h 24 ^m 34 ^s *	229°.6
Ingress	17 47 04		18 32 21 +	
Egress	20 07 21		#	
End of brightening	20 08 07	111°.1	19 47 40	153°.0

* Clouds prevented accurate determination
 + Last flash photographed
 # Brightening underway at first observation

3. Measurements

The images were later measured both by projection onto a computer-drawn Zenographic grid that had been carefully positioned with the edge of the film and orientation trails for reference and, independently, in a projection comparator (described in *LPL Comm. No. 179*). Both methods gave the same results, i.e., as Beta Scorpii dimmed or brightened, it appeared to move along the limb of Jupiter by refraction (Fig. 6). The maximum displacement of Beta Scorpii after ingress measured 1".4. Because of the geometry, the effect for SAO 159683 was too small to be measured.

An estimated light curve (Fig. 7) was constructed, based on the diameter of the star images approximately normalized for contrast, density, and the

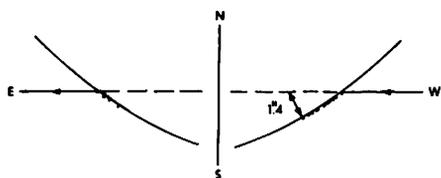


Fig. 6 Displacement of Beta Scorpii

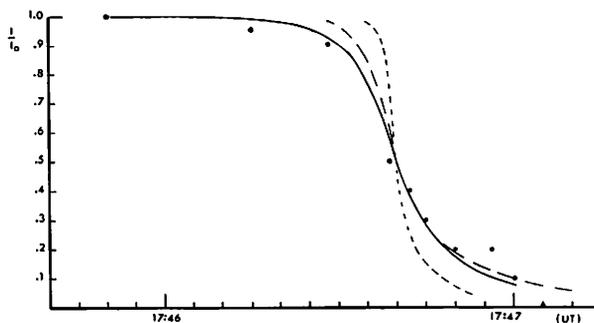


Fig. 7 Estimated light curve of ingress of SAO 159683 and Beta Scorpii with theoretical curves for atmosphere with scale heights of 12 km (short dashes) and 32 km (long dashes)

effect of the limb of Jupiter. The curve is not precise due to the variables mentioned above, especially the photographic edge effects introduced by Jupiter's limb. It is, however, sufficient to support higher values of the scale height than those obtained by Baum and Code (1953). The theoretical light curves were calculated assuming that extinction is negligible compared to atmospheric dispersion so that

$$vt/H = (I_0/I - 2) + \log_e (I_0/I - 1)$$

where v = apparent velocity of the star normal to the limb,
 t = time,
 I_0 = normal brightness of the star,
 and I = observed brightness of the star,

(Baum and Code, *op.cit.*). The much larger scale height, of about 30 km, implies a lower mean molecular weight and/or a higher temperature, since

$$H = RT/\mu g,$$

where R = gas constant, T = absolute temperature, μ = molecular weight, and g = surface gravity.

The above article was written before the results by Hubbard *et al.* (1972) were known. Dr. Hubbard later pointed out to the writer that the present results are in general accord with his.

4. Summary

It is obvious from the scatter in the light curves of SAO 159683 that departures from an isothermal atmosphere are present. Despite the lack of photometric accuracy compared to others (Hubbard, *op. cit.*), the presence of light variations (flashes) in the toe of the light curve was recorded. The complicated atmospheric density profile shown by Hubbard is present in the form of layering, perhaps with areas of turbulent mixing affecting the light curve in the same manner as scintillation. The greater scale height supports both the high temperatures observed, especially in the equatorial region, and a lower mean molecular weight.

Acknowledgments. Dr. Bambang Hidajat, Director of the Bosscha Observatory, and his wife, Estiti, made the visit a success through their hospitality, helpfulness, and cooperation. Dr. Hidajat allowed us complete access to the telescope and observatory facilities, and always filled our needs. Dr. G. P. Kuiper was responsible for the initiating and financing (through a University of Arizona grant) of the trip; while the USAID and UNESCO offices in Djakarta helped by providing transportation and arrangements. Dr. W. Hubbard made helpful criticisms of the draft. My wife, Faye, assisted in the observing and accurately recorded the times. Mr. J. Barrett wrote the computer program for the light curves and Mrs. B. Vigil helped prepare the illustrations. The Planetary Photography Program is supported by NASA Grant No. NGL-03-002-002.

REFERENCES

- Baum, W. A. and Code, A. D. 1953, "A Photometric Observation of the Occultation of σ Arietis by Jupiter", *A. J.*, 58, 108.
- Fountain, J. W. and Larson, S. M. 1972, *LPL Comm. Nos. 174 and 175*.
- Hubbard, W. B., Nather, R., Evans, D. S., Tull, R. G., Wells, D. C., van Citters, G. W., Warner, B., van den Boot, D. 1972, "The Occultation of Beta Scorpii by Jupiter and Io. I. Jupiter", *A. J.*, 77, 41.
- Kuiper, G. P. 1972a, "Lunar and Planetary Laboratory Studies of Jupiter", *Sky and Telescope*, 43, 4, 75.
- Kuiper, G. P. 1972b, *LPL Comm. Nos. 172 and 173*.
- Larson, S. M. 1971, "The Bosscha Observatory in Indonesia", *Sky and Telescope*, 42, 70.
- Taylor, G. E. 1971, "Occultation of Beta Scorpii by Jupiter", *IAU Circular No. 2279*, Sept. 29.
- Voûte, J. 1933, *Bosscha Obs. Ann.*, 1, Pt. 1.
- Westphal, J. A. 1969, "Observations of Localized 5-micron Radiation from Jupiter", *Ap. J.*, 157, 1636.