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FURTHER PHOTOMETRIC MEASURES OF JUPITER'S SATELLITES AND URANUS, WITH TESTS OF THE SOLAR CONSTANT

BY

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In the summer of 1927 a second series of photometric measures of the satellites of *Jupiter* was undertaken in continuation of the work of 1926.[1] Mr. Stebbins arrived at Mount Hamilton on July 18, and after several days of preparation observations were made on every clear night until his departure on August 23, after which the work was continued by Mr. Jacobsen until the last of September. During this season it was convenient also to observe *Uranus* which was within a degree or so of *Jupiter*, the dates of opposition being September 22 for *Jupiter* and September 25 for *Uranus*.

The instrumental conditions were practically the same as in 1926, the only change in the photo-electric photometer being the introduction of bright-wire illumination for the guiding eye-piece. There was also added a diagonal prism for the telescope finder, and a small motor for the slow motion in right ascension. These improvements made the observing go somewhat faster, but otherwise the sensitivity and effectiveness of the installation were about the same. The diameter of the focal diaphragm was erroneously recorded in 1926 as 90″ instead of 70″ which was used in both seasons at Mount Hamilton. The larger diameter is the one in current use at Madison.

In 1927 it was not possible to find comparison stars quite as good as those of the previous season; the number was reduced to three, and these averaged somewhat fainter than the satellites, but were quite near the apparent magnitude of *Uranus*. The data from the Harvard catalogues are as follows:

TABLE I

COMPARISON STARS, 1927

	R. A. 1900	Decl. 1900	Visual magnitude	Photo-electric magnitude	Spectrum
20 Piscium	$23^h42^m.8$	$-3°19'$	$5^m.60$	$6^m.30$ 6.66	K0
27 Piscium	23 53.6	−4 7	5.07	5.77 6.07	K0
44 Piscium	0 20.3	+1 23	5.99	6.54 6.77	G5

The tentative photo-electric magnitudes were derived by adding the color-indices to the visual magnitudes, and the mean of the three, magnitude 6.20, was used as standard in subsequent reductions.

After the completion of the present series, it was decided to measure the color of all of the objects, and this was done with the photometer at Madison. By using a suitable pair of glasses, violet and yellow, a potassium cell gives accurate color-indices for stars not fainter than the sixth magnitude. For the colored glasses and cell concerned the following is the calibration from twenty-five stars:

Spectrum	Color-Index
F0	$-0^m.46$
F5	− .32
G0	− .16
G5	+ .01
K0	+ .20

On the basis of this calibration the equivalent spectra for the objects observed in 1927 were determined on five or more nights each as follows:

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[1] *Lick Obs. Bull.*, **13**, 1, 1927.

Satellite I	G9	Mean = G5
II	G5	
III	G4	
IV	G3	
Uranus	F9	
20 Piscium	G6	Mean = G5
27 Piscium	G6	
44 Piscium	G4	

Assuming the calibration to be correct, the probable error of the adopted spectrum for each object is about 1/30 of the interval G0 to K0, except for Satellite I where the probable error is 1/10 of the same interval.

The value of the extinction factor in the expression $0\overset{m}{.}20\ f \sec z$ was determined again in 1927 from a graph of the individual magnitudes of the comparison stars, 20 and 44 *Piscium*, and the resulting value, $f = 1.0$, was used for all of the objects except *Uranus*, where, because of the slightly earlier spectrum, the factor $f = 1.05$ was adopted. In 1926 the mean value used was about $f = 0.9$, but an exact value was not necessary; all of the measures were differential and the comparison stars were well distributed about the planet. Since the total extinction at the zenith distance concerned is about $0\overset{m}{.}3$, a change of 0.05 in the factor for *Uranus* produces a difference of $0\overset{m}{.}015$ in the resulting mean magnitude.

In Table II the observations are in the same form as in the preceding year. The day begins at Greenwich midnight. The angle a is the jovicentric elongation of the Earth from the Sun, or what we call the solar phase of the satellites. All magnitudes are referred to the mean of the comparison stars, and have already been corrected for atmospheric extinction.

TABLE II

Journal of Observations

1927 G. C. T.	a	Satellites I	II	III	IV	Uranus	Comparison stars 20 Psc	27 Psc	44 Psc	Remarks
July 23.428	$-10\overset{\circ}{.}59$	....	....	($5\overset{m}{.}991$)	($6\overset{m}{.}789$)	($6\overset{m}{.}308$)	($6\overset{m}{.}325$)	($5\overset{m}{.}724$)	($6\overset{m}{.}550$)	Poor, reject.
.462	−10.59	....	....	(5.986)	(6.737)	6.331	6.351	5.722	6.528	Large D. C.
24.412	−10.50	....	....	....	6.754	6.351	6.366	5.706	6.530	Large D. C.
.464	−10.50	$6\overset{m}{.}187$	$6\overset{m}{.}346$	5.606	6.736	6.310	6.331	5.732	6.538	Large D. C.
25.425	−10.41	6.263	....	....	6.795	6.316	6.333	5.732	6.535	
.469	−10.41	6.260	....	....	6.768	6.343	6.339	5.719	6.546	
26.408	−10.32	6.068	6.064	6.092	6.786	6.330	6.333	5.742	6.528	I and II close.
.454	−10.31	6.038	6.040	6.082	....	6.329	6.339	5.734	6.531	III and IV close.
27.399	−10.22	....	....	6.076	....	6.340	6.328	5.734	6.539	
.425	−10.22	....	....	6.058	....	6.313	6.336	5.725	6.536	
.469	−10.21	6.238	....	6.071	....	6.322	6.336	5.709	6.554	
28.401	....	....	....	....	....	6.327	6.343	5.736	6.523	
.417	....	....	....	....	....	6.322	6.333	5.736	6.528	
.446	....	....	....	....	....	6.319	6.339	5.732	6.531	
29.415	−10.01	....	....	5.916	6.800	6.330	6.344	5.744	6.512	
.467	−10.01	....	....	5.884	6.783	6.323	6.328	5.724	6.547	
.501	....	....	....	....	....	6.311	6.329	5.742	6.528	
30.398	−9.91	....	....	5.930	6.790	6.318	6.345	5.716	6.536	
.441	−9.90	....	....	5.913	6.793	6.317	6.343	5.726	6.528	
.475	....	....	....	....	....	6.323	6.324	5.725	6.548	
31.401	−9.79	....	6.292	5.984	6.790	6.319	6.341	5.729	6.529	
.444	−9.79	....	6.315	5.987	6.788	6.314	6.348	5.716	6.534	
.477	....	....	....	....	....	6.315	6.341	5.723	6.532	
Aug. 1.394	−9.67	....	....	....	6.809	6.315	6.325	5.722	6.551	
.419	−9.67	....	....	....	6.796	6.316	6.335	5.734	6.533	
.444	....	....	....	....	....	6.320	6.338	5.724	6.542	
2.410	−9.55	5.992	5.986	6.019	6.804	6.307	6.334	5.727	6.537	
.458	−9.55	6.014	5.971	6.026	6.805	6.331	6.333	5.724	6.541	
.490	....	....	....	....	....	6.308	6.329	5.722	6.545	
3.394	−9.43	....	....	6.013	6.811	6.319	6.340	5.722	6.538	
.433	−9.43	....	....	6.001	6.801	6.313	6.341	5.719	6.538	
.465	....	....	....	....	....	6.310	6.331	5.711	6.560	
5.390	−9.18	6.097	5.961	....	....	6.326	6.335	5.732	6.530	I poor.
.458	....	....	....	....	....	6.300	6.331	5.725	6.540	
.481	....	....	....	....	....	6.307	6.339	5.714	6.545	
6.382	−9.05	....	....	5.854	6.680	6.307	6.331	5.719	6.551	
7.401	−8.91	....	6.225	5.924	6.639	6.311	6.338	5.722	6.543	
.450	−8.91	....	6.230	5.916	6.619	6.303	6.332	5.718	6.547	
.483	....	....	....	....	....	6.314	6.333	5.726	6.540	
8.380	−8.78	....	....	....	6.592	6.308	6.334	5.726	6.538	
.416	−8.77	....	....	....	6.597	6.298	6.326	5.734	6.538	
.440	....	....	....	....	....	6.308	6.323	5.732	6.547	

TABLE II—(*Continued*)

1927 G. C. T.	α	Satellites				Uranus	Comparison stars			Remarks
		I	II	III	IV		20 Psc	27 Psc	44 Psc	
Aug. 9.381	−8°64	$5^{m}979$	$5^{m}944$	$5^{m}963$	$6^{m}600$	$6^{m}320$	$6^{m}337$	$5^{m}724$	$6^{m}540$	
.437	−8.63	6.002	5.927	5.943	6.599	6.302	6.333	5.732	6.534	
.470	....	....	....	....	....	6.310	6.332	5.722	6.548	
10.370	−8.49	6.058	....	5.954	6.598	6.307	6.324	5.709	6.567	
.431	−8.48	....	....	5.937	6.587	6.298	6.323	5.722	6.554	
.464	....	....	....	....	....	6.301	6.337	5.713	6.550	
11.379	−8.34	5.932	6.199	5.918	6.636	6.304	6.329	5.712	6.555	IV poor.
.434	−8.33	5.907	....	5.890	6.587	6.282	6.323	5.724	6.554	
.469	....	....	....	....	....	6.300	6.329	5.722	6.548	
14.412	−7.88	....	6.135	5.835	6.609	6.289	6.340	5.732	6.529	Bright Moon.
.457	....	....	....	....	....	6.282	6.332	5.717	6.548	Bright Moon.
15.353	−7.73	....	....	5.854	6.592	6.282	6.327	5.729	6.543	Bright Moon.
.409	−7.72	....	....	....	6.644	6.290	6.332	5.732	6.537	Bright Moon.
.444	....	....	....	....	....	6.279	6.337	5.725	6.533	Bright Moon.
16.338	−7.57	....	5.853	5.895	6.629	6.298	6.340	5.706	6.556	
.384	−7.56	....	5.886	5.912	6.637	6.303	6.344	5.719	6.536	
.415	....	....	....	....	....	6.286	6.330	5.716	6.554	
17.331	−7.40	....	....	5.880	6.627	6.292	6.341	5.716	6.543	
.399	−7.39	6.015	....	5.878	6.641	6.306	6.342	5.719	6.539	
.429	....	....	....	....	....	6.305	6.334	5.723	6.545	
18.340	−7.23	5.836	6.131	5.842	6.636	6.281	6.330	5.724	6.545	
.393	7.22	5.825	6.144	5.841	6.615	6.288	6.333	5.716	6.548	
.427	....	....	....	....	....	6.282	6.328	5.721	6.548	
19.267	−7.07	....	....	....	(6.676)	(6.295)	(6.356)	(5.722)	(6.524)	Extinction test.
.294	−7.07	....	....	....	6.656	6.287	6.337	5.719	6.544	
.330	−7.06	6.001	....	....	6.634	6.290	6.340	5.716	6.546	
.372	−7.06	6.054	5.869	....	6.622	6.282	6.330	5.726	6.544	
.401	....	....	....	....	....	6.294	6.337	5.716	6.548	
20.329	−6.89	5.832	5.859	5.715	6.621	6.277	6.337	5.719	6.546	I and II close.
.379	−6.88	....	5.826	5.704	6.580	6.270	6.326	5.719	6.553	I and II close.
.411	....	....	....	....	....	6.292	6.337	5.715	6.544	
21.358	−6.71	6.005	6.074	5.774	6.562	6.299	6.339	5.730	6.531	I poor.
.400	−6.70	....	6.059	5.762	6.526	6.284	6.329	5.729	6.540	
.427	....	....	....	....	....	6.296	6.343	5.715	6.543	
22.326	−6.53	....	....	5.818	....	6.280	6.327	5.719	6.551	
.375	−6.52	....	....	5.820	....	6.284	6.336	5.706	6.555	
.403	....	....	....	....	....	6.288	6.333	5.719	6.547	
23.323	−6.35	....	5.822	5.833	6.488	6.276	6.330	5.729	6.539	
.364	−6.34	....	5.816	5.854	6.490	6.283	6.329	5.729	6.545	
.397	....	....	....	....	....	6.294	6.336	5.712	6.551	
24.317	−6.17	....	....	5.838	6.473	6.281	6.328	5.724	6.546	
.352	−6.17	....	....	5.810	6.445	6.264	6.338	5.726	6.535	
.378	....	....	....	....	....	6.270	6.330	5.736	6.534	
26.328	−5.81	5.946	....	....	6.448	6.274	6.338	5.719	6.539	
.365	−5.80	5.957	....	....	6.448	6.296	6.331	5.719	6.553	
.392	....	....	....	....	....	6.278	6.338	5.722	6.544	
29.344	−5.22	....	....	5.752	(6.481)	6.272	6.333	5.716	6.552	IV reject.
Sept. 2.299	−4.42	....	....	....	6.414	6.256	6.330	5.726	6.546	
.353	−4.41	5.816	....	....	6.416	6.269	6.323	5.743	6.538	
.385	....	....	....	....	....	6.280	6.324	5.721	6.552	
5.290	−3.80	5.654	6.000	5.686	6.426	6.271	6.327	5.716	6.559	
.347	−3.79	....	5.976	5.691	6.422	6.285	6.338	5.719	6.547	
.392	....	....	....	....	....	6.272	6.333	5.725	6.544	
6.278	−3.59	5.751	5.740	....	6.392	6.268	6.331	5.719	6.550	I incomplete.
10.296	−2.73	5.633	5.711	5.563	6.262	6.266	6.320	5.734	6.545	
.350	−2.72	5.635	....	....	6.261	6.272	6.343	5.732	6.529	
.387	....	....	....	....	....	6.259	6.330	5.726	6.546	
19.265	−0.80	(5.577)	5.935	5.548	6.138	6.269	6.346	5.704	6.551	I reject.
.326	−0.78	5.504	5.926	5.537	6.126	6.262	6.351	5.704	6.545	
.365	....	....	....	....	....	6.249	6.339	5.714	6.545	
20.237	−0.61	5.666	....	....	6.103	6.262	6.336	5.716	6.550	
.278	−0.60	5.649	....	....	6.111	6.268	6.335	5.709	6.552	
.310	....	....	....	....	....	6.269	6.340	5.716	6.542	
21.228	−0.44	....	5.652	5.617	6.103	6.261	6.330	5.722	6.551	

TABLE II—(*Continued*)

1927 G. C. T.	α	Satellites I	II	III	IV	Uranus	Comparison stars 20 Psc	27 Psc	44 Psc	Remarks
Sept. 21.281	−0°43	....	$5^{m}635$	$5^{m}600$	$6^{m}103$	$6^{m}271$	$6^{m}331$	$5^{m}714$	$6^{m}555$	
.318	....	....	....	....	....	6.263	6.328	5.714	6.559	
22.281	−0.33	....	5.819	5.573	6.079	6.266	6.352	5.714	6.534	
.327	....	....	....	....	....	6.272	6.341	5.705	6.550	
23.232	+0.36	....	....	5.556	6.067	6.265	6.339	5.716	6.545	
.291	+0.37	....	....	5.552	6.087	6.268	6.333	5.719	6.551	
.324	....	....	....	....	....	6.267	6.335	5.713	6.549	
24.217	+0.51	....	5.577	....	....	6.256	6.341	5.716	6.540	
.250	+0.51	....	5.636	....	....	6.266	6.336	5.714	6.549	
.278	+0.52	....	5.641	....	....	6.251	6.330	5.719	6.549	
25.215	+0.67	....	....	5.474	6.131	6.258	6.333	5.706	6.557	
.269	+0.70	....	....	5.472	6.100	6.264	6.323	5.712	6.568	
.304	....	....	....	....	....	6.263	6.331	5.722	6.550	
26.224	+0.90	$5^{m}562$	5.955	5.536	6.164	6.271	6.343	5.719	6.540	
.282	+0.91	5.551	5.929	5.532	6.130	6.276	6.333	5.726	6.538	
.319	....	....	....	....	....	6.280	6.334	5.715	6.548	
27.224	+1.11	5.686	....	....	6.172	6.254	6.330	5.719	6.554	IV poor.
.260	....	....	....	....	....	6.265	6.327	5.724	6.549	U. incomplete.
28.225	....	....	....	....	....	6.258	6.339	5.704	6.558	
29.214	+1.54	....	....	5.643	6.200	6.262	6.343	5.706	6.547	
.260	+1.55	....	5.849	5.645	6.191	6.267	6.337	5.712	6.552	
.297	....	....	....	....	....	6.264	6.328	5.722	6.549	

THE SATELLITES

The reduction to mean opposition of *Jupiter* was computed as before.

TABLE III

REDUCTION TO MEAN OPPOSITION, JUPITER

1927	July	20	$-0^{m}041$
		28	+ .014
	Aug.	5	+ .065
		13	+ .112
		21	+ .154
		29	+ .188
	Sept.	6	+ .213
		14	+ .229
		22	+ .235
		30	+ .230

In Table IV the results for each satellite are brought together; the date in the first column identifies the corresponding observation in Table II. The second column contains the orbital phase computed from the time of superior conjunction. Each magnitude in the third column is obtained from the one in Table II by applying the proper correction from Table III; for Satellite III, the correction of $0^{m}472$ has been applied for the sector used. The fourth column contains the correction for solar phase as it was determined in 1927. The reduced magnitudes in the fifth column are derived from the two preceding. The residuals in the sixth column are based upon the final light-curves, and in the seventh column these residuals are averaged for each date.

TABLE IV

REDUCED MAGNITUDES

Satellite I

1927		Orbital phase	At mean opposition	Reduction for α	Reduced magnitude	Residual	Mean residual
July	24	46°8	$6^{m}177$	$-0^{m}372$	$5^{m}805$	$+0^{m}036$	$+0^{m}036$
	25	242.4	6.259	− .370	5.889	+ .023	....
	25	251.3	6.257	− .370	5.887	+ .009	+ .016
	26	82.4	6.071	− .368	5.703	− .010	....
	26	91.8	6.041	− .368	5.673	− .035	− .022
	27	298.3	6.248	− .365	5.883	+ .005	+ .005
Aug.	2	67.4	6.041	− .348	5.693	− .039	....
	2	77.1	6.063	− .348	5.715	− .003	− .021
	5	313.8	6.165	− .338	5.827	− .037	− .037
	9	46.2	6.071	− .323	5.748	− .023	....
	9	57.6	6.094	− .322	5.772	+ .024	.000
	10	247.5	6.155	− .318	5.837	− .037	− .037
	11	92.9	6.035	− .314	5.721	+ .014	....
	11	104.0	6.011	− .314	5.697	− .007	+ .004
	17	238.3	6.151	− .285	5.866	+ .006	+ .006
	18	69.8	5.977	− .280	5.697	− .029	....
	18	80.6	5.966	− .280	5.686	− .028	− .028
	19	271.4	6.147	− .275	5.872	− .019	....
	19	280.0	6.200	− .275	5.925	+ .034	+ .008
	20	114.8	5.982	− .269	5.713	+ .006	+ .006
	21	324.4	6.160	− .263	5.897	+ .044	+ .044
	26	256.2	6.123	− .233	5.890	+ .007	....
	26	263.7	6.134	− .233	5.901	+ .013	+ .010
Sept.	2	246.4	6.019	− .183	5.836	− .036	− .036
	5	124.4	5.865	− .160	5.705	− .007	− .007
	6	321.9	5.965	− .152	5.813	− .043	− .043
	10	63.7	5.856	− .118	5.738	+ .002	....
	10	74.7	5.858	− .118	5.740	+ .020	+ .011
	19	90.0	5.811	− .036	(5.775)	(+ .067)	....
	19	102.4	5.738	− .035	5.703	− .001	− .001
	20	287.9	5.900	− .027	5.873	− .014	....
	20	296.3	5.883	− .027	5.856	− .024	− .019
	26	67.0	5.795	− .041	5.754	+ .023	....
	26	78.8	5.784	− .041	5.743	+ .027	+ .025
	27	270.6	5.919	− .050	5.869	− .022	− .022

TABLE IV—(*Continued*)

Satellite II

1927	Orbital phase	At mean opposition	Reduction for α	Reduced magnitude	Residual	Mean residual
July 24	288°4	6^m336	-0^m190	6^m146	$+0^m005$	$+0^m005$
26	125.5	6.067	− .189	5.878	+ .024	....
26	130.2	6.043	− .189	5.854	− .004	+ .010
31	271.9	6.328	− .186	6.142	+ .003	....
31	276.2	6.351	− .186	6.165	+ .023	+ .013
Aug. 2	115.6	6.035	− .184	5.851	+ .005	....
2	120.5	6.020	− .184	5.836	− .012	− .004
5	57.9	6.029	− .181	5.848	+ .001	+ .001
7	261.8	6.305	− .179	6.126	+ .002	....
7	266.8	6.310	− .179	6.131	− .002	.000
9	102.7	6.036	− .176	5.860	+ .020	....
9	108.4	6.019	− .176	5.843	+ .001	+ .010
11	305.4	6.302	− .174	6.128	+ .010	+ .010
14	253.1	6.255	− .169	6.086	− .014	− .014
16	88.5	5.983	− .164	5.819	− .017	....
16	93.1	6.017	− .164	5.853	+ .017	.000
18	291.6	6.272	− .160	6.112	− .025	....
18	297.0	6.285	− .160	6.125	− .006	− .016
19	36.3	6.015	− .158	5.857	− .011	− .011
20	133.5	6.009	− .155	5.854	− .007	....
20	138.5	5.977	− .155	5.822	− .044	− .026
21	237.9	6.229	− .153	6.076	+ .019	....
21	242.2	6.215	− .153	6.062	− .008	+ .006
23	77.3	5.986	− .147	5.839	+ .002	....
23	81.5	5.981	− .147	5.834	− .002	.000
Sept. 5	313.4	6.211	− .100	6.111	.000	....
5	319.2	6.187	− .100	6.087	.000	.000
6	52.7	5.954	− .096	5.858	+ .008	+ .008
10	101.5	5.934	− .074	5.860	+ .021	+ .021
19	292.0	6.169	− .024	6.145	+ .007	....
19	298.2	6.160	− .023	6.137	+ .008	+ .008
21	131.3	5.887	− .013	5.874	+ .015	....
21	136.6	5.870	− .013	5.857	− .008	+ .004
22	238.2	6.054	− .010	6.044	− .015	− .015
24	74.7	5.811	− .015	5.796	− .041	....
24	78.0	5.870	− .015	5.855	+ .018	....
24	80.9	5.875	− .016	5.859	+ .023	.000
26	278.4	6.188	− .027	6.161	+ .018	....
26	284.3	6.162	− .027	6.135	− .008	+ .005
29	226.6	6.079	− .045	6.034	+ .006	+ .006

Satellite III

1927	Orbital phase	At mean opposition	Reduction for α	Reduced magnitude	Residual	Mean residual
July 23	86°7	5^m502	-0^m268	(5^m234)	(0^m000)	....
23	88.4	5.497	− .268	(5.229)	(− .008)	(-0^m004)
24	138.8	5.596	− .266	5.330	+ .019	+ .019
26	236.6	5.623	− .263	5.360	+ .004	....
26	239.0	5.613	− .263	5.350	− .006	− .001
27	286.5	5.614	− .261	5.353	+ .016	....
27	287.8	5.596	− .261	5.335	.000	....
27	290.0	5.609	− .261	5.348	+ .014	+ .010
29	28.0	5.467	− .257	5.210	+ .007	....
29	30.6	5.435	− .257	5.178	− .023	− .008
30	77.5	5.488	− .255	5.233	+ .009	....
30	79.6	5.471	− .255	5.216	− .011	− .001
31	128.0	5.548	− .253	5.295	.000	....
31	130.1	5.551	− .253	5.298	.000	.000
Aug. 2	229.1	5.596	− .248	5.348	− .009	....
2	231.5	5.603	− .248	5.355	− .002	− .006
3	278.6	5.596	− .246	5.350	+ .008	....
3	280.6	5.585	− .246	5.339	− .001	+ .004
6	69.1	5.456	− .238	5.218	+ .002	+ .002

TABLE IV—(*Continued*)

1927	Orbital phase	At mean opposition	Reduction for α	Reduced magnitude	Residual	Mean residual
Aug. 7	120°4	5^m532	-0^m235	5^m297	$+0^m014$	....
7	122.9	5.524	− .235	5.289	+ .002	$+0^m008$
9	220.2	5.583	− .229	5.354	− .004	....
9	223.0	5.563	− .229	5.334	− .024	− .014
10	270.0	5.579	− .226	5.353	+ .007	....
10	273.1	5.563	− .226	5.337	− .008	.000
11	320.8	5.549	− .223	5.326	+ .020	....
11	323.6	5.522	− .223	5.299	− .005	+ .008
14	113.6	5.483	− .213	5.270	.000	.000
15	161.1	5.507	− .210	5.297	− .037	− .037
16	210.7	5.553	− .207	5.346	− .011	....
16	213.0	5.571	− .206	5.365	+ .007	− .002
17	260.7	5.543	− .203	5.340	− .010	....
17	264.2	5.542	− .203	5.339	− .009	− .010
18	311.6	5.511	− .199	5.312	− .003	....
18	314.2	5.510	− .199	5.311	− .001	− .002
20	51.8	5.393	− .191	5.202	.000	....
20	54.3	5.383	− .191	5.192	− .012	− .006
21	103.7	5.457	− .187	5.270	+ .014	....
21	105.8	5.446	− .187	5.259	.000	+ .007
22	152.5	5.506	− .183	5.323	− .003	....
22	154.9	5.508	− .182	5.326	− .002	− .002
23	202.7	5.525	− .178	5.347	− .009	....
23	204.8	5.547	− .178	5.369	+ .013	+ .002
24	252.8	5.535	− .174	5.361	+ .009	....
24	254.6	5.507	− .174	5.333	− .019	− .005
29	146.3	5.469	− .151	5.318	.000	.000
Sept. 5	136.6	5.425	− .113	5.312	+ .005	....
5	139.5	5.430	− .113	5.317	+ .006	+ .006
10	29.1	5.314	− .083	5.231	+ .029	+ .029
19	121.5	5.310	− .026	5.284	.000	....
19	124.6	5.299	− .025	5.274	− .014	− .007
21	220.6	5.380	− .014	5.366	+ .008	....
21	223.3	5.363	− .014	5.349	− .009	.000
22	273.7	5.336	− .011	5.325	− .019	− .019
23	321.7	5.319	− .011	5.308	+ .002	....
23	324.7	5.315	− .012	5.303	+ .001	+ .002
25	61.7	5.236	− .022	5.214	+ .005	....
25	64.5	5.234	− .022	5.212	.000	+ .002
26	112.7	5.297	− .029	5.268	− .001	....
26	115.6	5.293	− .029	5.264	− .010	− .006
29	263.5	5.402	− .049	5.353	+ .004	....
29	265.8	5.403	− .050	5.353	+ .005	+ .004

Satellite IV

1927	Orbital phase	At mean opposition	Reduction for α	Reduced magnitude	Residual	Mean residual
July 23	262°9	6^m792	-0^m534	(6^m238)	($+0^m026$)	....
23	263.6	6.720	− .534	(6.186)	(− .026)	(0^m000)
24	284.1	6.744	− .532	6.212	− .003	....
24	285.2	6.726	− .532	6.194	− .022	− .012
25	305.9	6.791	− .530	6.261	+ .038	....
25	306.9	6.765	− .530	6.235	+ .011	+ .024
26	327.1	6.789	− .528	6.261	+ .027	+ .027
29	32.0	6.823	− .540	6.283	+ .022	....
29	33.1	6.806	− .540	6.266	+ .005	+ .014
30	53.3	6.820	− .538	6.282	+ .005	....
30	54.2	6.823	− .538	6.285	+ .007	+ .006
31	74.9	6.826	− .536	6.290	− .006	....
31	75.9	6.824	− .536	6.288	− .008	− .007
Aug. 1	96.4	6.852	− .533	6.319	+ .004	....
1	96.9	6.839	− .533	6.306	− .009	− .002
2	118.4	6.853	− .531	6.322	− .007	....
2	119.4	6.854	− .531	6.323	− .007	− .007

TABLE IV—(*Continued*)

Satellite IV

1927		Orbital phase	At mean opposition	Reduction for α	Reduced magnitude	Residual	Mean residual
Aug.	3	$139^{\circ}6$	$6^{\mathrm{m}}866$	$-0^{\mathrm{m}}528$	$6^{\mathrm{m}}338$	$+0^{\mathrm{m}}012$	....
	3	140.5	6.857	− .528	6.329	+ .004	$+0^{\mathrm{m}}008$
	6	204.2	6.754	− .499	6.255	+ .024	+ .024
	7	226.2	6.719	− .495	6.224	+ .005	....
	7	227.3	6.699	− .495	6.204	− .014	− .004
	8	247.4	6.678	− .492	6.186	− .027	....
	8	248.1	6.683	− .492	6.191	− .022	− .024
	9	269.0	6.692	− .488	6.204	− .008	....
	9	270.2	6.691	− .488	6.203	− .009	− .008
	10	290.4	6.695	− .484	6.211	− .007	....
	10	291.7	6.685	− .484	6.201	− .017	− .012
	11	312.2	6.739	− .480	6.259	+ .033	....
	11	313.4	6.691	− .480	6.211	− .016	+ .008
	14	17.8	6.729	− .487	6.242	− .011	− .011
	15	38.1	6.717	− .481	6.236	− .029	....
	15	39.4	6.769	− .481	6.288	+ .020	− .004
	16	59.5	6.759	− .475	6.284	+ .001	....
	16	60.5	6.768	− .475	6.293	+ .010	+ .006
	17	81.0	6.762	− .469	6.293	− .008	....
	17	82.5	6.777	− .469	6.308	+ .006	− .001
	18	102.8	6.777	− .463	6.314	− .006	....
	18	104.0	6.756	− .463	6.293	− .027	− .016
	19	122.9	6.821	− .457	(6.364)	(+ .033)	....
	19	123.5	6.801	− .457	6.344	+ .012	....
	19	124.3	6.780	− .457	6.323	− .009	....
	19	125.2	6.768	− .457	6.311	− .021	− .006
	20	145.9	6.771	− .449	6.322	+ .007	....
	20	147.0	6.731	− .449	6.282	− .030	− .012
	21	168.2	6.717	− .442	6.275	+ .006	....
	21	169.1	6.682	− .442	6.240	− .028	− .011
	23	210.8	6.652	− .417	6.235	+ .009	....
	23	211.7	6.655	− .416	6.239	+ .013	+ .011
	24	232.3	6.642	− .410	6.232	+ .016	....
	24	233.1	6.614	− .410	6.204	− .012	+ .002
	26	275.8	6.625	− .396	6.229	+ .016	....
	26	276.7	6.625	− .396	6.229	+ .016	+ .016
	29	341.2	6.670	− .374	(6.296)	....	....
Sept.	2	66.9	6.617	− .327	6.290	+ .001	....
	2	68.1	6.619	− .327	6.292	+ .002	+ .002
	5	131.8	6.637	− .290	6.347	+ .015	....
	5	133.1	6.633	− .289	6.344	+ .013	+ .014
	6	153.3	6.606	− .277	6.329	+ .031	+ .031
	10	240.4	6.485	− .262	6.223	+ .009	....
	10	241.6	6.484	− .261	6.223	+ .009	+ .009
	19	75.0	6.372	− .069	6.303	+ .007	....
	19	76.3	6.360	− .068	6.292	− .005	+ .001
	20	96.1	6.337	− .053	6.284	− .030	....
	20	97.0	6.345	− .052	6.293	− .022	− .026
	21	117.6	6.338	− .038	6.300	− .029	....
	21	118.8	6.338	− .038	6.300	− .030	− .030
	22	140.5	6.314	− .030	6.284	− .041	− .041
	23	161.1	6.302	− .031	6.271	− .011	....
	23	162.4	6.322	− .033	6.289	+ .010	.000
	25	204.1	6.365	− .152	6.213	− .018	....
	25	205.3	6.334	− .153	6.181	− .050	− .034
	26	226.0	6.397	− .164	6.233	+ .015	....
	26	227.3	6.363	− .165	6.198	− .020	− .002
	27	247.7	6.405	− .176	6.229	+ .016	+ .016
	29	290.9	6.431	− .200	6.231	+ .014	....
	29	291.9	6.421	− .200	6.221	+ .003	+ .008

As before, we begin with the discussion of the comparison stars. Dividing the measures into two series, and taking the means, there is found:

TABLE V

MAGNITUDES OF COMPARISON STARS

1927	20 Piscium	27 Piscium	44 Piscium
July 23–August 23	$6^{\mathrm{m}}335$	$5^{\mathrm{m}}723$	$6^{\mathrm{m}}542$
P. E. one observation	±0.005	±0.006	±0.006
August 24–September 29	6.334	5.718	6.547
P. E. one observation	±0.005	±0.005	±0.005

There seems to be no difference in the quality of the earlier and later measures, and the average probable error of about $0^{\mathrm{m}}005$ may be compared with the values $\pm 0^{\mathrm{m}}008$ and $\pm 0^{\mathrm{m}}012$ for the two series of the preceding year. The second series of 1926 was taken under poorer conditions, but there is no apparent reason for the improvement of the present work over the first series of 1926 except that the stars were higher in the sky. As before, the mean of the comparison stars is a satisfactory standard of reference.

In the discussion of the variations of each satellite with orbital and solar phase it seems best to redetermine these light-curves on the basis of the present season only, and then to compare the two sets of results, rather than to attempt to make a uniform reduction of both seasons together. However, as a first guess the solar phase effects of 1927 were assumed to be the same as in 1926, and these were then corrected without prejudice in favor of keeping the changes small. After several approximations the following expressions were found, the phase being taken without regard to sign.

$$\begin{array}{lll} \text{Satellite I,} & m=m_o+0.046\alpha\ -0.0010\alpha^2 & \\ \text{II,} & m=m_o+0.0312\alpha-0.00125\alpha^2 & \\ \text{III,} & m=m_o+0.0323\alpha-0.00066\alpha^2 & \text{(A)} \\ \text{IV}_p, & m=m_o+0.090\alpha\ -0.0036\alpha^2 & \\ \text{IV}_f, & m=m_o+0.112+0.060\alpha-0.0019\alpha^2 & \end{array}$$

The expression in (A) for Satellite I was previously incomplete, as that satellite had not been measured near opposition; the expressions for II and III are about as before; but it is in the case of IV that the new measures have shown a complication. There is a difference between the solar phase effects on the two sides of this satellite, given in (A) for the preceding and following sides in the orbital motion as IV_p and IV_f respectively. At opposition Satellite IV brightens up much more on the front side, the difference being over a tenth of a magnitude. On consideration it is evident that for each position of a satellite in its orbit there will be a different solar phase effect. We always see the same side of our Moon when it is full, but it is not so simple for the satellites of *Jupiter*. In fact, with the combination of orbital- and solar phase variations the wonder is that we can get mean light-curves at all.

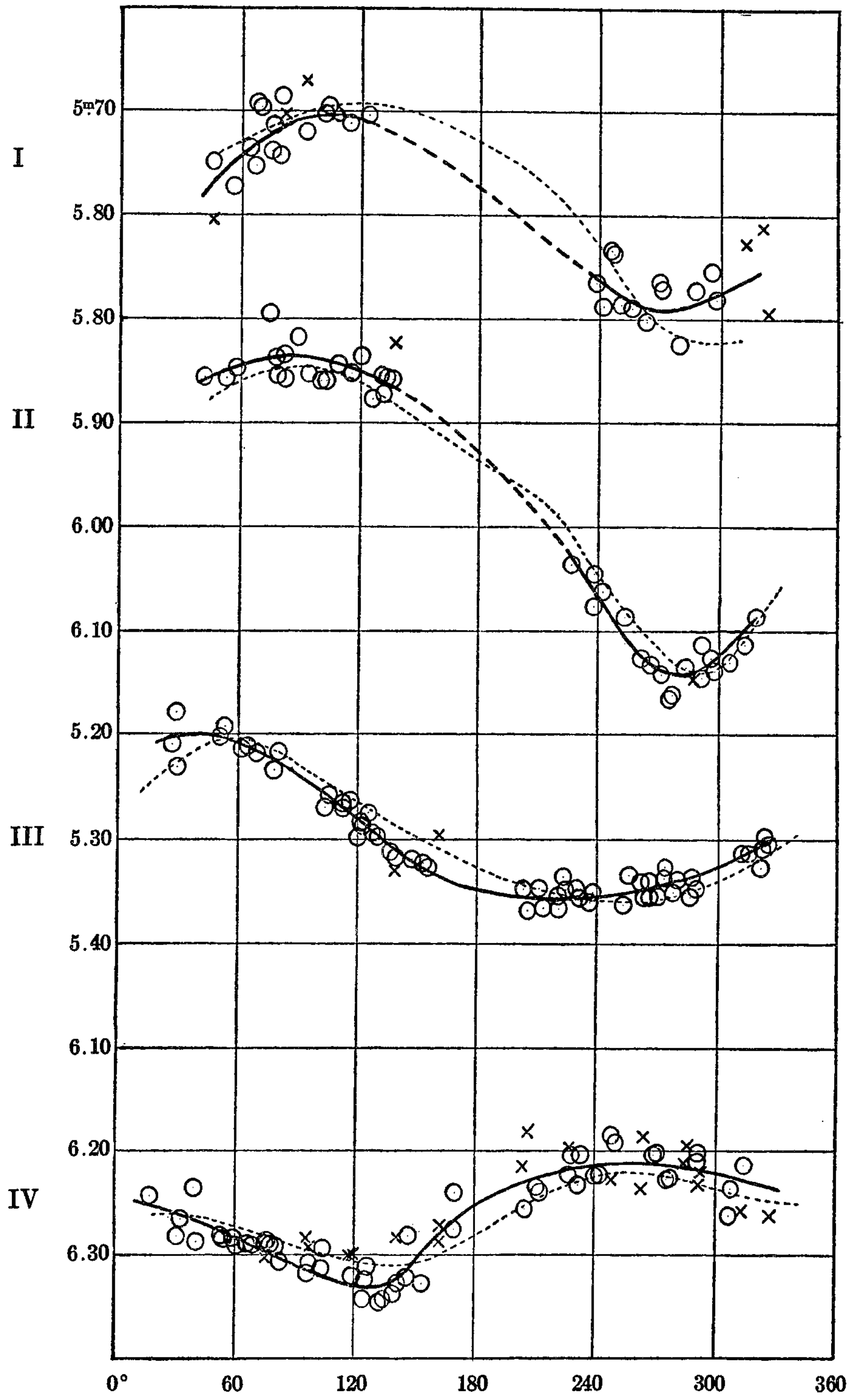

Fig. 1. Variations of Jupiter's Satellites with Orbital Phase.

Full curves, 1927; dotted curves, 1926. Crosses indicate poor measures, or those near opposition for Satellite IV.

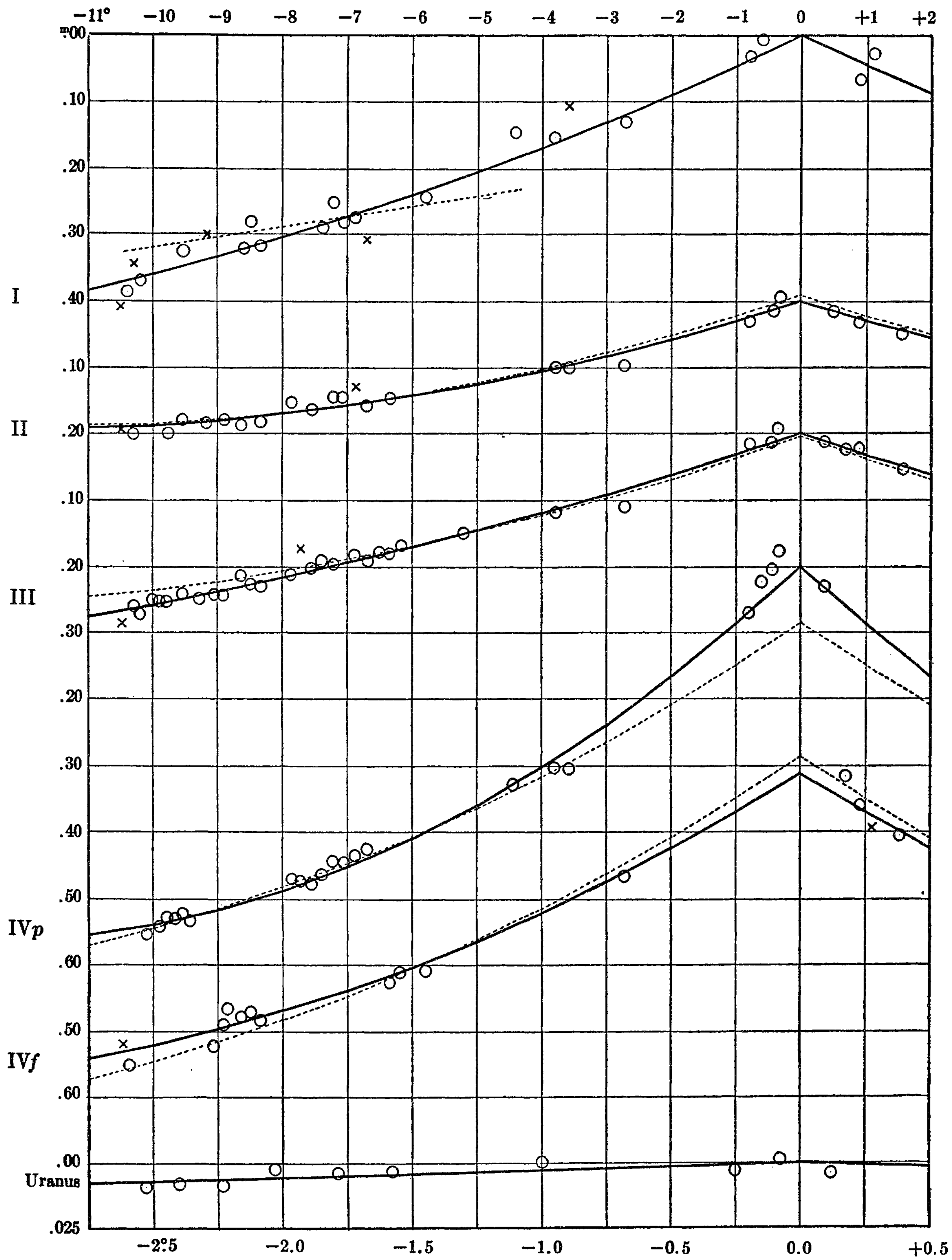

Fig. 2. Variations of Jupiter's Satellites and of Uranus with Solar Phase.

Full curves, 1927; dotted curves, 1926. Crosses indicate poor measures. The scale for Uranus is four times that for the satellites.

Fortunately this difference between two sides is much less for the inner three satellites and the expressions in (A) are sufficient. A test is given by the average of the residuals for small solar phase, say less than 1°, from which we obtain the following:

	I	II	III	IV
Preceding side brightens more than following side..................................	$-0^{m}037$	$-0^{m}004$	$+0^{m}002$	$+0^{m}123$

It is seen that the differences are negligible for II and III, while the effect for I is opposite in sign to that for IV. It is hopeless to attempt to distinguish between presentations of the satellites other than for the two sides as adopted. This dependence of the solar phase variation upon the orbital position of a satellite was missed in 1926 when there were no good observations near opposition.

The variations with solar phase are shown in Fig. 2, where the curves are the graphs of equations (A), while the plotted magnitudes are derived from the mean residuals of Table IV. For comparison the curves of 1926 are also indicated, the phase α being reversed in sign. The curves for the two seasons are made to intersect at $\alpha=7°$ for Satellite I, and at 6° for the others. Since the geocentric latitude of *Jupiter* was not zero at opposition, the minimum value of α was $0\overset{\circ}{.}32$, and in all strictness the solar phase cannot be represented by a light-curve in two dimensions. The agreement between the two seasons is satisfactory, and there is apparently not much difference in the light of any satellite at the same angular phase before or after opposition.

The orbital light-curves were derived from the reduced magnitudes in the fifth column of Table IV, and are given in Table VI. The mean magnitude for each satellite was determined by taking the averages of the magnitudes in Table VI for which the differences are printed, these being at symmetrical phases where the curves were pretty well determined in both seasons. To compare the two seasons, we must allow for the difference in the solar phase corrections, and this is best done by selecting as before a phase near the middle of both series, $\alpha=7°$ for Satellite I and 6° for the others. The comparison is then made as in Table VII, which gives also the ranges of variation with orbital phase.

TABLE VI

ORBITAL LIGHT-CURVES OF JUPITER'S SATELLITES

	I			II			III			IV		
Phase	1926	1927	Diff.	1926	1927	Diff.	1926	1927	Diff.	1926	1927	Diff.
20°	....	....	....	....	....	....	$5^{m}257$	....	....	$6^{m}348$	$6^{m}254$	....
30	....	....	....	....	....	....	5.241	$5^{m}202$	....	6.349	6.259	$-0^{m}090$
40	....	....	....	....	$5^{m}864$	....	5.228	5.200	$-0^{m}028$	6.350	6.267	− .083
50	$5^{m}910$	$5^{m}764$	....	$5^{m}876$	5.853	$-0^{m}023$	5.220	5.202	− .018	6.353	6.275	− .078
60	5.900	5.744	$-0^{m}156$	5.863	5.845	− .018	5.219	5.208	− .011	6.358	6.284	− .074
70	5.890	5.726	− .164	5.854	5.840	− .014	5.224	5.216	− .008	6.364	6.292	− .072
80	5.882	5.715	− .167	5.850	5.836	− .014	5.233	5.228	− .005	6.370	6.300	− .070
90	5.874	5.708	− .166	5.848	5.836	− .012	5.244	5.237	− .007	6.376	6.309	− .067
100	5.868	5.704	− .164	5.850	5.839	− .011	5.256	5.252	− .004	6.382	6.318	− .064
110	5.864	5.705	− .159	5.854	5.843	− .011	5.266	5.264	− .002	6.388	6.326	− .062
120	5.862	5.709	− .153	5.862	5.848	− .014	5.279	5.284	+ .005	6.393	6.331	− .062
130	5.863	....	....	5.874	5.856	− .018	5.291	5.298	+ .007	6.396	6.332	− .064
140	....	....	....	5.888	5.869	....	5.302	5.312	+ .010	6.396	6.325	− .071
150	....	....	....	....	....	....	5.312	5.323	....	6.394	6.304	− .090
160	....	....	....	....	....	....	5.323	5.334	....	6.387	6.284	....
170	....	....	....	....	....	....	5.332	5.342	....	6.378	6.266	....
180	....	....	....	....	....	....	5.341	5.348	....	6.367	6.252	....
190	....	....	....	....	....	....	5.348	5.353	....	6.356	6.242	....
200	....	....	....	....	....	....	5.355	5.356	....	6.344	6.234	....
210	....	....	....	....	....	....	5.360	5.357	....	6.332	6.227	− .105
220	....	....	....	5.992	....	....	5.365	5.358	− .007	6.322	6.221	− .101
230	....	....	....	6.016	6.036	+ .020	5.369	5.357	− .012	6.314	6.217	− .097
240	5.994	5.864	− .130	6.048	6.064	+ .016	5.372	5.356	− .016	6.309	6.214	− .095
250	6.024	5.876	− .148	6.075	6.096	+ .021	5.373	5.353	− .020	6.307	6.212	− .095
260	6.052	5.886	− .166	6.098	6.120	+ .022	5.373	5.350	− .023	6.307	6.212	− .095
270	6.073	5.891	− .182	6.120	6.137	+ .017	5.372	5.346	− .026	6.309	6.212	− .097
280	6.084	5.891	− .193	6.136	6.144	+ .008	5.368	5.341	− .027	6.312	6.214	− .098
290	6.090	5.885	− .205	6.142	6.140	− .002	5.362	5.334	− .028	6.317	6.217	− .100
300	6.091	5.877	− .214	6.139	6.127	− .012	5.355	5.326	− .029	6.323	6.221	− .102
310	6.089	5.868	....	6.120	6.108	− .012	5.346	5.317	− .029	6.328	6.226	− .102
320	....	5.858	....	6.092	6.086	....	5.334	5.307	− .027	6.333	6.231	− .102
330	....	....	....	6.060	....	....	5.323	....	....	6.336	6.236	− .100
340	....	....	....	....	....	....	5.310	....	....	6.339	....	....

TABLE VII

COMPARISON OF MEAN MAGNITUDES

	I	II	III	IV
Range, 1926	0^m229	0^m294	0^m155	0^m090
Range, 1927	0.187	0.308	0.158	0.120
Mean magnitude, 1926	5.967	5.979	5.307	6.347
Correction for a	−0.165	+0.009	−0.004	−0.084
Corrected magnitude, 1926	5.802	5.988	5.303	6.263
Mean magnitude, 1927	5.798	5.976	5.293	6.261
1927–1926	−0.004	−0.012	−0.010	−0.002
Residual	+0.003	−0.005	−0.003	+0.005

The small average difference of -0^m007 between seasons represents simply the chance agreement of the adopted magnitudes of the two sets of comparison stars based upon the Harvard visual magnitudes. It did not seem worth while to inter-compare these stars photo-electrically as they are some thirty degrees apart in the sky, and, to eliminate the extinction, measures must be made with both groups at a low altitude. A single measure of two of the stars, one in each group, made the satellites 0^m015 brighter in 1927 than in 1926, but this is of no significance.

The orbital light-curves are shown in Fig. 2 where the dotted curves of 1926 are reduced to the same mean magnitudes as those of 1927. The curves of the second season were drawn quite independently of the previous curves, and no effort was made to find either agreement or disagreement between the two seasons. The observations of Satellite I are now numerous enough to show the inferior quality of measures close to the planet, and the curves for that satellite are in poorest agreement. No real differences seem to be established between the curves for each satellite, either in the orbital variations in Fig 1, or in the solar phase variations in Fig. 2. Our photo-electric results therefore do not give weight to any assumption of meteorological changes on the surfaces of these bodies.

The method of reduction of the observations of 1926 has been severely criticized by Guthnick,[2] and the following paragraphs have been written by Mr. Stebbins in explanation of the points on which there is disagreement.

The chief criticism by Guthnick is that my allowance for atmospheric extinction was too small; that the factor by which the visual extinction was multiplied instead of being about 0.9, which I used for Mount Hamilton, should have been about 1.5, which he uses at Babelsberg. He says there is no reason to anticipate that a mountain station would have a clearer sky than a station near sea level. As it is incredible that anyone could advance this idea seriously it would seem that there must be some misunderstanding, so I quote the original.[3] " . . . . . auch die Meereshöhe des Beobachtungsortes wird, wenn sie nicht sehr bedeutend ist, keinen wesentlichen Einfluss auf die Extinktionsfaktoren haben. Ob die Extinktionsfaktoren mit zunehmender Meereshöhe ab- oder zunehmen, ist von vornherein nicht zu sagen." The only way I can make sense out of this is to assume that he means that a high-altitude station may be no better than a lower station several thousand miles away. However, one glance at the Mount Hamilton sky by day or by night would convince Guthnick that he is mistaken.

The amount of the atmospheric extinction at the Lick Observatory is not a matter of opinion or conjecture; it can be measured and stated in figures. Adopting the expression $0^m20\, f \sec z$, for the total extinction, the factor f varies with the photo-electric cell, with the spectral class of the stars measured, and, in all strictness, with the nightly or even hourly change in the transparency of the air. The data upon which I base my adoption of a factor smaller than Guthnick's are as follows:

(1) The determination in 1926 from two comparison stars taken on many nights, $f=0.88$ for spectrum G0. Guthnick's rejection of this value will be discussed in the sequel.

(2) A similar determination in 1927, $f=1.0$ for spectrum G5. This is the value used in the present paper.

(3) A determination made in 1915 on fifteen nights,[4] $f=1.0\pm0.024$ (p.e.) for stars of spectrum A0 measured with a rubidium cell.

(4) The long series of measures by Abbot[5] at Mount Wilson and Washington, D. C. Taking his results for $\lambda=4600$ A, the approximate region of maximum sensitivity of a potassium cell, there follows:

	Mount Wilson	Washington
Transmission at zenith	0.84	0.65
Corresponding extinction in magnitude	0.19	0.47
Factor, f	0.95	2.35

The factor for Washington is two and one-half times that at Mount Wilson, a quantitative measure of the superiority of the California sky. Anyone familiar with both Mount Wilson and Mount Hamilton knows that a good sky at either station is better than a fair sky at the other, and it is not stretching matters to put Babelsberg in a class with Washington rather than with Mount Hamilton.

Despite the foregoing evidence, Guthnick has reduced my 1926 observations of *Jupiter's* satellites all over again on the basis of the extinction at Babelsberg.

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[2] *Sitzungsberichte der Preussischen Akademie*, 1927, p. 112.

[3] *loc. cit.*, p. 116.

[4] *Lick Obs. Bull.*, **8**, 187, 1916.

[5] *The Sun*, p. 297.

To begin with, he objects to my determination of the factors because the extreme range of zenith distance of the stars used was only from 51° to 64°, giving a range of extinction of 0.122 magnitude. Here he overlooks the fact that if the range of the extinction of the comparison stars is small, that of the satellites is still smaller, and any errors in the differential extinction must practically vanish. Nevertheless, he carries the work through and concludes on the basis of his improved extinction corrections that he has diminished the average deviations of the observations of the satellites from the light-curves by as much as 30 per cent. I shall show that this is an illusion.

The magnitude of a satellite as used for a light-curve is dependent not only upon the correction for extinction but also upon the large correction for solar phase. If we compare the first observation of Satellite I in my Table IV and his Table I, my reduced magnitude is $5^{\mathrm{m}}.921$ against his $5^{\mathrm{m}}.858$. The discrepancy is $0^{\mathrm{m}}.063$, but the difference in our corrections for solar phase is $0^{\mathrm{m}}.069$, leaving a remainder of $0^{\mathrm{m}}.006$ due to extinction. The average of all the similar values for Satellite I is $0^{\mathrm{m}}.005$, and it is only deviations from this constant difference that affect the accordance of the results. The net difference of $0^{\mathrm{m}}.001$, due to extinction, applied with the proper sign to my first residual changes it from $+0^{\mathrm{m}}.013$ to $+0^{\mathrm{m}}.014$. In the same way, applying these net differences as corrections to the residuals in my Table IV, there follow:

	I	II	III	IV
Average deviation one observation, extinction S	$\pm 0^{\mathrm{m}}.0064$	$\pm 0^{\mathrm{m}}.0128$	$\pm 0^{\mathrm{m}}.0113$	$\pm 0^{\mathrm{m}}.0110$
Average net difference of extinction, S–G	±0.0014	±0.0026	±0.0028	±0.0034
Average deviation one observation, extinction G	±0.0060	±0.0132	±0.0122	±0.0114

Instead of diminishing my residuals, the effect of changing to Guthnick's extinction is to increase them.

The improvement which Guthnick claims, was secured not by his revised extinction corrections but by his use of free-hand curves to represent the solar phase effect, together with his injection of spurious dips (Einsenkungen) in the maxima of the orbital curves of three satellites. I, too, could have made the residuals smaller, but I was anxious not to introduce bias in testing the solar constant, and I represented the solar phase effect by a second-degree expression, leaving some outstanding errors, which, however, did not affect the orbital curves or the tests of the solar constant. The extra minima which Guthnick puts into my curves are based largely upon measures which I had labelled as of inferior precision.

Another test of the extinction is given by the comparison stars, where there is no question of light-curves or of solar phase effects; the residuals are formed from simple means. Taking the series 1926 August 14 to September 14 in my Table V, upon which were based my light-curves, we have for the four comparison stars:

	(1)	(2)	(3)	(4)
Probable error one observation, extinction S	$\pm 0^{\mathrm{m}}.0093$	$\pm 0^{\mathrm{m}}.0066$	$\pm 0^{\mathrm{m}}.0078$	$\pm 0^{\mathrm{m}}.0070$
Probable error one observation, extinction G	±0.0100	±0.0070	±0.0079	±0.0075

Here again there is no improvement with the use of Guthnick's extinction.

A minor point which Guthnick makes is that it is not permissible to use the same extinction factor for all four satellites, especially as he can see in the telescope the progressive difference in color from Satellites I to IV, ranging from reddish (rötlich) to blue-gray (blaugrau) respectively. I simply bunched the lot and called them all G0 like the Sun, whereas Guthnick guesses a spectrum for Satellite II and determines the others differentially from their photo-electric and visual magnitudes, including also a manufactured solar phase correction for Satellite I. In this way he gets colors equivalent to spectra of F1 to G5, a much larger range than I have measured in 1927, namely G3 to G9. My preference is naturally for the latter values.

If Guthnick's criticisms of my photo-electric results are demonstrably in error, he is still more difficult to follow in his conclusions from his own visual observations. He exhibits[6] a set of wavy curves for the satellites, which he contrasts with the relatively smooth photo-electric curves. The accuracy which he secures is indicated by the residuals of his normal points, and from the four graphs I find the following:

	I	II	III	IV
Average deviation one normal	$\pm 0^{\mathrm{m}}.008$	$\pm 0^{\mathrm{m}}.013$	$\pm 0^{\mathrm{m}}.006$	$\pm 0^{\mathrm{m}}.019$

Anyone familiar with stellar photometry will recognize this as an extraordinary precision in visual work, especially for Satellites I and III. But why are the results so discordant for Satellite IV? Guthnick's procedure is to combine groups of several observations into normal magnitudes and then to draw curves through the normals. The reason for the larger residuals for Satellite IV is simply that he has drawn a smoother curve than for the other satellites. By making the curve for IV about as wavy as that for III the residuals would all be zero.

We can test the accordance to be expected in these normals by going back to his original measures,[7] where he gives the mean error of an observation as derived from the individual residuals. I assume that his mean error (m.F.) is the same as what I call the average deviation, since the mean error in its technical sense cannot be determined from the residuals from a free-hand curve. Collecting his data we have:

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[6] *loc. cit.*, pp. 131–134.

[7] *Sitzungsberichte der Preussischen Akademie*, 1907, p. 344.

	I	II	III	IV
Number of single observations	155	210	113	107
Number of normals	43	39	30	24
Mean error of one observation, according to Guthnick	±0^{m}081	±0^{m}085	±0^{m}075	±0^{m}095
Mean error of a normal, computed	±0.043	±0.037	±0.039	±0.045
Average deviation of a normal, scaled from curve	±0.008	±0.013	±0.006	±0.019

Comparing the last two quantities in each column it is evident that by drawing wavy curves Guthnick has cut down the average deviation of a normal, and thus has increased the apparent weight of his results up to as much as forty-fold. This fictitious accuracy is likely to be misleading even to the observer himself, and when he compares two of his curves of the same satellite, derived in different seasons, he seems to think that the differences are real and due to changes on the surface of the satellite. There is no need of dodging the issue: most of the fluctuations in Guthnick's curves, and the differences which he gets between seasons, look to me like errors of observation.

To summarize, I am unable to accept a single one of Guthnick's improvements in the reduction of my photo-electric measures. His claim that the sky in the neighborhood of Berlin will serve as a standard of excellence the world over certainly needs modification, and in my judgment his visual observations of the satellites of *Jupiter*, taken twenty years ago, are not of an accuracy on which to base many conclusions.

Perhaps this is the place to state also that I fear that not much can be got from the photographic series by Schütte in *Astronomische Nachrichten*, **218**, 273, 1923. He found a range in the orbital period of more than a whole magnitude for every one of the satellites, or up to twelve times the variation shown by the photo-electric observations.

URANUS

The measures of *Uranus* in Table II have been reduced in the same manner as those of the satellites of *Jupiter*. The reduction to mean opposition is given in Table VIII.

TABLE VIII

REDUCTION TO MEAN OPPOSITION, URANUS

1927 July 20	−0^{m}268
28	− .255
Aug. 5	− .243
13	− .232
21	− .222
29	− .214
Sept. 6	− .208
14	− .204
22	− .202
30	− .202

In Table IX are the magnitudes of *Uranus*. The date in the first column identifies the observation in Table II. In the second column is the solar phase α. The rotational phase in the third column is computed from the elements:

$$t_0 = 1928 \text{ July } 23.000 \text{ G.C.T.} + 0^d451 \times E.$$

The magnitude in the fourth column is derived from the magnitude in Table II by applying the correction in Table VIII. The residuals in the fifth column are based upon the magnitudes in the preceding column and equation (B); and the mean residual for each night is given in the last column.

TABLE IX

MAGNITUDES OF URANUS

1927	α	Rotational phase	At mean opposition	Residual	Mean residual
July 23	−2°60	0^{d}428	(6^{m}046)	(+0^{m}022)	....
23	−2.60	0.011	6.069	+ .001	+0^{m}001
24	−2.58	0.059	6.090	+ .022	....
24	−2.58	0.111	6.049	− .019	+ .002
25	−2.56	0.170	6.057	− .011	....
25	−2.56	0.214	6.084	+ .016	+ .002
26	−2.53	0.251	6.073	+ .005	....
26	−2.53	0.297	6.072	+ .004	+ .004
27	−2.51	0.340	6.084	+ .016	....
27	−2.51	0.366	6.057	− .011	....
27	−2.51	0.410	6.066	− .002	+ .001
28	−2.48	0.440	6.073	+ .005	....
28	−2.48	0.005	6.068	.000	....
28	−2.48	0.034	6.065	− .003	+ .001
29	−2.46	0.101	6.077	+ .009	....
29	−2.45	0.153	6.070	+ .002	....
29	−2.45	0.187	6.059	− .009	+ .001
30	−2.43	0.182	6.067	− .001	....
30	−2.43	0.225	6.066	− .002	....
30	−2.43	0.259	6.072	+ .004	.000
31	−2.40	0.283	6.069	+ .002	....
31	−2.40	0.326	6.065	− .002	....
31	−2.40	0.359	6.066	− .001	.000
Aug. 1	−2.38	0.374	6.067	.000	....
1	−2.37	0.399	6.068	+ .001	....
1	−2.37	0.424	6.072	+ .005	+ .002
2	−2.35	0.037	6.061	− .006	....
2	−2.34	0.085	6.085	+ .018	....
2	−2.34	0.117	6.062	− .005	+ .002
3	−2.32	0.119	6.074	+ .007	....
3	−2.32	0.158	6.068	+ .001	....
3	−2.31	0.190	6.065	− .002	+ .002
5	−2.25	0.311	6.084	+ .017	....
5	−2.25	0.379	6.058	− .009	....
5	−2.25	0.402	6.065	− .002	+ .002
6	−2.22	0.401	6.067	.000	.000
7	−2.19	0.067	6.072	+ .005	....
7	−2.19	0.116	6.064	− .003	....
7	−2.19	0.149	6.075	+ .008	+ .003
8	−2.16	0.144	6.070	+ .003	....
8	−2.16	0.180	6.060	− .007	....
8	−2.16	0.204	6.070	+ .003	.000
9	−2.13	0.243	6.084	+ .017	....
9	−2.12	0.299	6.066	− .001	....
9	−2.12	0.332	6.074	+ .007	+ .008
10	−2.09	0.330	6.072	+ .005	....
10	−2.09	0.391	6.063	− .004	....

TABLE IX—(*Continued*)

1927	a	Rotational phase	At mean opposition	Residual	Mean residual
Aug. 10	−2°09	$0^{d}424$	$6^{m}066$	$-0^{m}001$	$0^{m}000$
11	−2.06	0.437	6.070	+ .004	....
11	−2.05	0.041	6.048	− .018	....
11	−2.05	0.076	6.067	+ .001	− .004
14	−1.95	0.313	6.059	− .007	....
14	−1.94	0.358	6.052	− .014	− .010
15	−1.91	0.352	6.053	− .013	....
15	−1.91	0.408	6.061	− .005	....
15	−1.91	0.443	6.051	− .015	− .011
16	−1.87	0.435	6.071	+ .005	....
16	−1.87	0.030	6.076	+ .010	....
16	−1.87	0.061	6.059	− .007	+ .003
17	−1.84	0.075	6.066	.000	....
17	−1.83	0.143	6.080	+ .014	....
17	−1.83	0.173	6.079	+ .013	+ .009
18	−1.80	0.182	6.056	− .010	....
18	−1.79	0.235	6.063	− .003	....
18	−1.79	0.269	6.057	− .009	− .007
19	−1.76	0.207	(6.071)	(+ .005)	....
19	−1.76	0.234	6.063	− .003	....
19	−1.76	0.270	6.066	.000	....
19	−1.75	0.312	6.058	− .008	....
19	−1.75	0.341	6.070	+ .004	− .002
20	−1.72	0.367	6.054	− .012	....
20	−1.71	0.417	6.047	− .018	....
20	−1.71	0.449	6.069	+ .004	− .009
21	−1.67	0.043	6.077	+ .012	....
21	−1.67	0.085	6.062	− .003	....
21	−1.67	0.112	6.074	+ .009	+ .006
22	−1.63	0.109	6.059	− .006	....
22	−1.63	0.158	6.064	− .001	....
22	−1.63	0.186	6.068	+ .003	− .001
23	−1.59	0.204	6.057	− .008	....
23	−1.59	0.245	6.064	− .001	....
23	−1.59	0.278	6.075	+ .010	.000
24	−1.55	0.296	6.063	− .002	....
24	−1.55	0.331	6.046	− .019	....
24	−1.55	0.357	6.052	− .013	− .011
26	−1.46	0.052	6.058	− .007	....
26	−1.46	0.089	6.080	+ .015	....
26	−1.46	0.116	6.062	− .003	+ .002
29	−1.33	0.362	6.058	− .006	− .006
Sept. 2	−1.15	0.258	6.046	− .018	....
2	−1.15	0.312	6.059	− .005	....
2	−1.14	0.344	6.070	+ .006	− .006
5	−1.01	0.092	6.063	− .001	....
5	−1.00	0.149	6.077	+ .013	....
5	−1.00	0.194	6.064	.000	+ .004
6	−0.96	0.178	6.060	− .003	− .003
10	−0.77	0.137	6.060	− .003	....
10	−0.76	0.191	6.066	+ .003	....
10	−0.76	0.228	6.053	− .010	− .003
19	−0.32	0.086	6.067	+ .005	....
19	−0.32	0.147	6.060	− .002	....
19	−0.31	0.186	6.047	− .015	− .004
20	−0.27	0.156	6.060	− .001	....
20	−0.27	0.197	6.066	+ .005	....
20	−0.27	0.229	6.067	+ .006	+ .003
21	−0.22	0.245	6.059	− .002	....
21	−0.22	0.298	6.069	+ .008	....
21	−0.22	0.335	6.061	.000	+ .002
22	−0.17	0.396	6.064	+ .003	....
22	−0.17	0.442	6.070	+ .009	+ .006
23	−0.12	0.445	6.063	+ .002	....

TABLE IX—(*Continued*)

1927	a	Rotational phase	At mean opposition	Residual	Mean residual
Sept. 23	−0°12	$0^{d}053$	$6^{m}066$	$+0^{m}005$	....
23	−0.12	0.086	6.065	+ .004	$+0^{m}004$
24	−0.08	0.077	6.054	− .007	....
24	−0.08	0.110	6.064	+ .003	....
24	−0.08	0.138	6.049	− .012	− .005
25	−0.04	0.173	6.056	− .005	....
25	−0.04	0.227	6.062	+ .001	....
25	−0.04	0.262	6.061	.000	− .001
26	+0.05	0.280	6.069	+ .008	....
26	+0.05	0.338	6.074	+ .013	....
26	+0.05	0.375	6.078	+ .017	+ .013
27	+0.09	0.378	6.052	− .009	....
27	+0.09	0.414	6.063	+ .002	− .004
28	+0.14	0.026	6.056	− .005	− .005
29	+0.19	0.113	6.060	− .001	....
29	+0.20	0.159	6.065	+ .004	....
29	+0.20	0.196	6.062	+ .002	+ .002

To determine the solar phase effect for *Uranus*, the normal magnitudes were formed as in Table X. The first column gives the solar phase, the second, the mean magnitude from Table IX, the third, the final residual, from equation (B), and the fourth, the number of observations.

TABLE X

NORMAL MAGNITUDES OF URANUS

a	Magnitude	Residual	No. Obs.
−2°53	$6^{m}070$	$+0^{m}002$	13
−2.40	6.068	+ .001	15
−2.23	6.069	+ .002	13
−2.03	6.063	− .003	14
−1.79	6.065	− .001	16
−1.58	6.064	− .001	15
−1.00	6.061	− .003	11
−0.25	6.063	+ .002	11
−0.08	6.060	− .001	9
+0.12	6.064	+ .003	9

From the magnitudes of Table X was derived the following expression, where as before *a* is taken without regard to sign:

$$m = 6.0607 + 0.0028a \qquad \text{(B)}$$
$$\pm 12 \qquad \pm 7$$

The change of magnitude with solar phase is almost negligible, being only $0^{m}007$ for the 2°6-range of phase covered. This solar phase variation, with the residuals from Table X, is shown in Fig. 2.

When the observations of *Uranus* were begun in 1927 it was supposed that we would find the same variation as announced by Leon Campbell,[8] who, with a visual photometer, determined a light-range of 0.15 magnitude in 0.451 days, presumably the rotation period of the planet. This may be tested by grouping the observations of Table IX into normals on the basis of Campbell's period, as is done in Table XI. Each normal comprises six observations, taking the mean of the phases and of the corresponding residuals.

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[8] *Harvard Circular*, No. 200, 1917.

TABLE XI

Test of Uranus for Rotational Variation

Phase	Mean residual	Phase	Mean residual
0^{d}024	0^{m}000	0.242	+0^{m}002
0.053	+ .001	0.266	− .002
0.078	+ .002	0.292	+ .003
0.094	+ .004	0.317	.000
0.113	− .002	0.336	+ .004
0.133	+ .001	0.355	− .007
0.152	+ .003	0.373	− .004
0.168	.000	0.400	− .001
0.184	− .006	0.421	− .002
0.195	+ .002	0.443	+ .002
0.221	.000	....	....

From the residuals of Table XI there is found,

Probable error of one normal = ±0^{m}0020,

which is small enough to exclude the possibility of variation during the interval of observation. The individual measures by Campbell have not been published, so it is not possible to judge of their accuracy, but on the basis of the photo-electric observations we shall have to call *Uranus* as nearly constant in light as any object in the sky.

The Solar Constant

The results on *Jupiter's* satellites and on *Uranus* may be used for a test of the constancy of the solar radiation in the same manner as in 1926. For each object the mean residual on a night presumably includes the reflected effect of any change in the Sun. The mean results of the satellites are of such different weights that the residuals of two or more satellites were combined according to the following scheme.

Weight 1—One poor observation.
" 2—One good or two poor observations.
" 3—Two or more good observations.

In Table XII the weight assigned to the mean residual is the sum of the individual weights, plus one unit for each satellite after the first, all divided by 3 and rounded off to indicate the quality of the mean. Because of the complicated solar phase effect the residuals for Satellite IV from September 19 to 29 were not used; also the measures of II and III were discarded on September 22, the date of opposition, when all the satellites were measured slightly bright. For *Uranus* there were a number of nights with fewer measures but these do not happen to give the large residuals.

TABLE XII

Mean Residuals by Nights

	II		III		IV		Mean		Uranus	
1927	Residual	Wt.	Residual	Wt.	Residual	Wt.	Residual	Wt.	Residual	Wt.
July 23	....	..	(−0^{m}004)	0	(0^{m}000)	0	....	..	+0^{m}001	1
24	+0^{m}005	1	+ .019	1	− .012	1	+0^{m}004	2	+ .002	2
25	....	..	....	..	+ .024	3	+ .024	1	+ .002	2
26	+ .010	3	− .001	3	+ .027	1	+ .008	3	+ .004	2
27	....	..	+ .010	3	....	..	+ .010	1	+ .001	3
28	....	..	....	..	....	..	....	..	+ .001	3
29	....	..	− .007	3	+ .014	3	+ .004	2	+ .001	3
30	....	..	− .001	3	+ .006	3	+ .002	2	.000	3
31	+ .013	3	.000	3	− .007	3	+ .002	3	.000	3
Aug. 1	....	..	....	..	− .002	3	− .002	1	+ .002	3
2	− .004	3	− .006	3	− .007	3	− .006	3	+ .002	3
3	....	..	+ .004	3	+ .008	3	+ .006	2	+ .002	3
5	+ .001	2	....	..	....	..	+ .001	1	+ .002	3
6	....	..	+ .002	2	+ .024	2	+ .013	2	.000	1
7	.000	3	+ .008	3	− .004	3	+ .001	3	+ .003	3
8	....	..	....	..	− .024	3	− .024	1	.000	3
9	+ .010	3	− .014	3	− .008	3	− .004	3	+ .008	3
10	....	..	.000	3	− .011	3	− .006	2	.000	3
11	+ .010	2	+ .008	3	+ .008	2	+ .009	3	− .004	3
14	− .014	2	.000	2	− .011	2	− .008	3	− .010	2
15	....	..	(− .037)	0	− .004	3	− .004	1	− .011	3
16	.000	3	− .002	3	+ .006	3	+ .001	3	+ .003	3
17	....	..	− .010	3	− .001	3	− .006	2	+ .009	3
18	− .016	3	− .002	3	− .016	3	− .011	3	− .007	3
19	− .011	2	....	..	− .009	3	− .010	2	− .002	3
20	− .026	1	− .006	3	− .012	3	− .011	3	− .009	3
21	+ .006	3	+ .007	3	− .011	3	+ .001	3	+ .006	3
22	....	..	− .002	3	....	..	− .002	1	− .001	3
23	.000	3	+ .002	3	+ .011	3	+ .004	3	.000	3
24	....	..	− .005	3	+ .002	3	− .002	2	− .011	3
26	....	..	....	..	+ .016	3	+ .016	1	+ .002	3
29	....	..	.000	2	....	..	.000	1	− .006	1

TABLE XII—(*Continued*)

1927	II Residual	II Wt.	III Residual	III Wt.	IV Residual	IV Wt.	Mean Residual	Mean Wt.	Uranus Residual	Uranus Wt.
Sept. 2	....	..	....	..	$+^{m}002$	3	$+^{m}002$	1	$-^{m}006$	3
5	$^{m}000$	3	$+^{m}006$	3	+ .014	3	+ .007	3	+ .004	3
6	+ .008	2	....	..	+ .031	2	+ .020	2	− .003	1
10	+ .014	2	+ .029	2	+ .009	3	+ .016	3	− .003	3
19	+ .008	3	− .007	3	(+ .001)	3	.000	2	− .004	3
20	....	..	....	..	(− .026)	3	....	..	+ .003	3
21	+ .004	3	.000	3	(− .030)	3	+ .002	2	+ .002	3
22	(− .015)	2	(− .019)	2	(− .041)	2	(− .017)	..	+ .006	2
23	....	..	+ .002	3	(.000)	3	+ .002	1	+ .004	3
24	.000	3	....	..	....	..	.000	1	− .005	3
25	....	..	+ .002	3	(− .034)	3	+ .002	1	− .001	3
26	+ .005	3	− .006	3	(− .002)	3	.000	2	+ .013	3
27	....	..	....	..	(+ .016)	1	....	..	− .004	2
28	....	..	....	..	....	..	....	..	− .005	1
29	+ .006	2	+ .004	3	(+ .008)	3	+ .005	2	+ .002	3

Disregarding the weights in Table XII, the average of the forty-one mean residuals for the satellites is $\pm 0^{m}006$, and rejecting three nights of small weight, July 25, August 8, and 26, this is reduced to $\pm 0^{m}005$. The corresponding value from twenty nights in 1926 was $\pm 0^{m}004$, so there is not much difference between the two seasons.

For *Uranus* the accordance is somewhat better. Forty-seven nights give an average deviation of $\pm 0^{m}0036$, and as the residuals depend upon the two constants in (B), the probable error of a night's result is $\pm 0^{m}0031$. Quite apart from the final accordance, our feeling during the course of the observations was that one good measure of *Uranus* was worth all that could be got from the satellites. The sky correction was much smaller than that for the satellites, and the planet was nearer the average brightness of the comparison stars.

If there was any marked solar variation during the interval of 1927 it should show in a parallel run of the residuals for the mean and *Uranus* in Table XII, but an inspection shows that there is practically no connection between them. The only possibility of such an effect is in the ten days following August 14, but the agreement there is probably a coincidence. An outstanding discordance is on September 26, one day after the opposition of *Uranus*, when the planet was measured faint by $0^{m}013$. To all appearances the observations were reliable on that date, and the internal agreement was satisfactory. The satellite measures at the same time give a residual of $0^{m}000$, so we can scarcely suspect a sudden jump in the solar radiation.

The results on the satellites in 1926 were compared by Abbot with his solar measures without finding any connection between the two series, though his measures showed no marked change in the Sun during the short interval of comparison. From the data communicated by Dr. Abbot in a private letter we find the average deviation of a day's result on the solar constant to be ±0.37 per cent. The corresponding average deviation from the observations of *Jupiter's* satellites on the same twenty dates was ±0.0040 magnitude or ±0.37 per cent, by coincidence exactly the same accordance as that of the Smithsonian measures. The only conclusion to be drawn from this comparison is that the Sun did not change much during the interval, and the same result will probably follow for 1927.

After an experience of two seasons we are not very optimistic over the use of observations of *Jupiter's* satellites for testing the solar constant over long periods. The oppositions of *Jupiter* are now running into the winter season for the northern hemisphere, and nightly observations are not possible at any observatory possessing a photo-electric photometer. Due to the solar phase variations the satellites are not as good reflectors as was anticipated, though they should still serve to detect any change in the Sun as great as say two or three per cent.

With *Uranus*, however, the case is more favorable. If the planet itself should show no more variation than in 1927, it would make an excellent object for continued tests of the Sun. The photometric measures of *Uranus* are much more satisfactory than those of the satellites, and, because of the slower motion of the planet in the sky, the same comparison stars may be used for a longer time. Of course with observations of a single object it is not possible to distinguish between sudden variations of the planet and of the Sun, and confirmation of such variations would have to come from elsewhere.

SUMMARY

The photometric measures of *Jupiter's* satellites in 1927 confirm in all essential details the results of the previous season, and give improved light-curves for the orbital and solar phase variations, especially near opposition. No change whatever has been found in the mean magnitude or in the character of variation of any of the satellites. It is shown that the criticisms of the methods of reduction used in this work are without foundation.

The planet *Uranus* was also observed in 1927 and found to be remarkably constant in light, there being no short-period variation as previously announced from visual observations.

The test of the solar constant given by the results on the satellites and on *Uranus* shows that on forty-seven nights there was no change in the Sun large enough to be detected; the average deviation of a result from one night being ±0.006 magnitude for the satellites and ±0.0036 magnitude for *Uranus*.

We are indebted to Associate Director Aitken for his support of this investigation and to various members of the Observatory staff for assistance in recording the observations.

MADISON AND MOUNT HAMILTON,
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END OF VOLUME XIII.