Comet C/2019 Y4 (ATLAS) disintegration photometry.

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(Submitted on 13.01.2021; Accepted on 25.06.2021)

Abstract. We present the results of CCD photometric observation of the comet C/2019 Y4 (ATLAS) during the time of its disintegration as it was approaching the Sun. We focus on photometric observations over the period of several nights between April 1 and April 14, 2020 when the comet was observable. Our initial aim, as part of our cometary program, was to use these data to determine the rotation period of the presumed cometary nucleus. Unfortunately, the comet disintegrated shortly before our observations started. However even though we could not determine the rotation of a single comet nucleus, we have obtained unique light curves that can provide evidence for the motions of nucleus fragments, including their rotation, shortly after their disintegration. The relevant light (photometric) curves that we present may be used as a basis for modeling the disintegration process in the future.
Key words: Photometry of comet disintegration

1. Introduction

The comet C/2019 Y4 (ATLAS) was discovered on December 28, 2019 in the ATLAS project research as an object of 19.6 magnitude (19.6m) [MPC 2019]. The ephemeris of the comet was suggesting that it could be visible by naked eye approximately in May 2020. We observed the comet and obtained photometric data. The primary goal was to study the rotation period of the nucleus. The cometary nucleus rotation process is an important topic of research [Kokotanekova et al. 2000].

We started the observations on April 1, 2020 at around the time when the comet C/2019 Y4 (ATLAS) broke up (disintegrated) [Ye and Zhang 2020]. We have obtained approximately 1000 files in the FITS format which allowed us to calculate the comet's photometric light curves for those nights when the observations with respect to the weather were possible. As shown below, the changes in the comet's magnitude have been remarkable and significantly larger than the errors of the individual measurements.

Even if the full light curve for this comet has been published [Yoshida 2020] we are not aware of any other photometric data over the period of those several nights and in so short intervals.

The disintegration of comets is the well-known process which has been studied intensely for many decades [Bobrovnikoff 1929]. Furthermore, it is known that the material of the meteor showers has its origin in the parent object, see e.g. the comet 1P/Halley, which is the parent object for the eta Aquarids shower [popastro 2021] . More recently, a detailed study of the disintegration of the comet C/2015 ER61 (PanSTARRS) was published [Sekanina 2017].

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We are aware that a comet disintegration is not a rare process. A widely known and publicized case was the disintegration and collision of Shoemaker-Levy 9 comet with Jupiter in 1994 that was well predicted [Sekanina 1993]. As the comets from the Oort Cloud approach the Sun, they become subject to stronger tidal forces by planets, as well as intense solar radiation vaporizing their surface ices, which leads to comet fragmentation. Such processes are already partly happening within the Oort Cloud, which is the primordial reservoir of comets, where they may be subject to tidal forces due to the Milky Way's gravitational field. These processes still pose very interesting and exciting questions [Wlodarczyk 2017]. We believe that observations of changes in the brightness of comet nuclei during their disintegration may provide useful data that can help answering some of the questions standing in front of us in this branch of science.

The term light curve of a comet refers primarily to changes in its magnitude during its orbit around the Sun or near the Sun. In such case, it is sufficient to determine the magnitude of the comet once per night. However, if we are interested in the rotation of the comet's nucleus, it is necessary to observe it for extended period, for example all night at one minute intervals. Like that, it may be possible to coincidentally record brightness changes during the comet disintegration, some of which may be attributed to the rotation of the nuclei.

2. The instruments and observations

The observatory "Júlia" (Vladimír Bahýl – VB) is equipped with 9.25 Schmidt-Cassegrain reflector (f/10) on the NEQ6/Pro mounting and we use the Moravian Instruments G2-1600 camera cooled to -20 deg Celsius as the light detector [Camera 2020]. The field of view of this setup is about 12 arc minutes. No filters were used during the observations. In terms of accuracy, our technical equipment is routinely used to perform photometry of asteroids, comets, and stars up to magnitude 20, while the SNR value is always greater than 20.

The following 3 different software packages were used for processing:

- SIPS software (developed by the Moravian Instruments specifically for their G2 class cameras) generated fits files of the measurements.
- Image quality of each file was then visually controlled using the Astrometrica 4.11 software package [Astrometrica 2020].
- Finaly the comet's magnitudes were determined with the AstroImageJ software package [AstroImageJ 2017] using only the highest quality fits files.

Basic data of the observations are shown in Table 1. The term "summed frames" means how many frames we added to obtain one FITS file.

The telescope used by Peter Nosal (PN) is a Newton 250 mm (f/4.8) on a fork mounting and equipped with the camera Cannon EOS 20D.

The private observatory of Drahomír Volný (DV) has a Newtonian telescope with $8''$(f/4.5) Orion mirror on the iOptron CEM120EC2 mount equipped with Atik460EXm camera.

All data have been reduced for the dark field bias and flat field exposures. They were then processed by the Statistica software package [Statistica 2020] to generate graphs and to realise the time series analysis. The graphs published

Table 1. Observations data

Date	Time (UT)	Exposure (sec.)	No. of summed frames	Observer
Apr. 1	20:24:05 – 22:50:03	60	4	PN
Apr. 2	19:32:24 – 01:55:24	30	5	VB
Apr. 4	19:25:34 – 01:40:58	30	1	VB
Apr. 5	19:17:07 – 01:09:37	30	1	VB
Apr. 6	19:31:26 – 01:33:43	30	1	VB
Apr. 7	19:23:02 – 01:25:56	30	1	VB
Apr. 8	19:03:29 – 01:40:07	30	1	VB
Apr. 10	19:45:25 – 19:48:43	30	1	VB
Apr. 14	20:27:25 – 01:28:28	30	1	VB
Apr. 14	23:08	240	30	DV

in this article were produced using the graphical software gnuplot [Williams, Kelley et al. 1986].

Last, but not least, we also sent our results (in relevant format) to the COBS database in the Crni Vrh Observatory [COBS 2020].

We would like to point out that the accuracy of our results is comparable with observations obtained by various other observers of this comet. We have calculated the mean square errors of all our data, which is 0.047 magnitude for all observation nights. The individual errors of any measurement of our data are provided in the annexed table 2 for all our magnitudes determinations. The errors are definitly smaller than the changes in magnitude that were found here during our observation period of this comet.

We have only observed under a clear night sky and the relative air humidity was always less than 50%.

3. Results

The photometric observations are the main results of this study. They are presented in Figures 1 to 4 for each observing night. Let us look at one of them, Figure 1 (left), from the first night of observations. There were two large changes in the brightness of the comet (nuclei). First, a sudden brightening from nearly 10.4m, followed by a plateau at about 10.17m lasting for about 2 hour, and then briefly dimming to fainter than 10.4m before the brightening back to nearly 10.17m. There are also significant changes (on the Figure 1, right) from the night of April 2, 2020. The original FITS data from this night have been stacked to five in the Astrometrica first and then the stacked files have been subsequently processed by the AstroImageJ package. On the following nights the changes were greater or smaller but always significant. Even if the errors depicted in Figures 2, 3 and 4 are rather high, they do not overlap with the quasiperiodic variation of the luminosity of the fragments. This may be accepted as an important result of our observations. On April 8 and 14, the measurements were performed at a smaller cadence, still showing variations (Figure 4 (left)) and eventually a decrease in magnitude (Figure 4 (right)).

Figure 5 shows the average brightness for each night revealing the mean trend of a decrease in brightness after a brightening, as the comet disintegrated.

We have obtained more than 900 FITS frames. There is a possibility that they will be useful for later studies of deep comet disintegration processes. The period of the comet C/2019 Y4 (ATLAS) is more than six thousand years. And the comet disintegrated. It is thus clear that the observation data presented in this paper are no longer repeatable. These data (Julian Date, Magnitude and its error) are all given in Table 2.

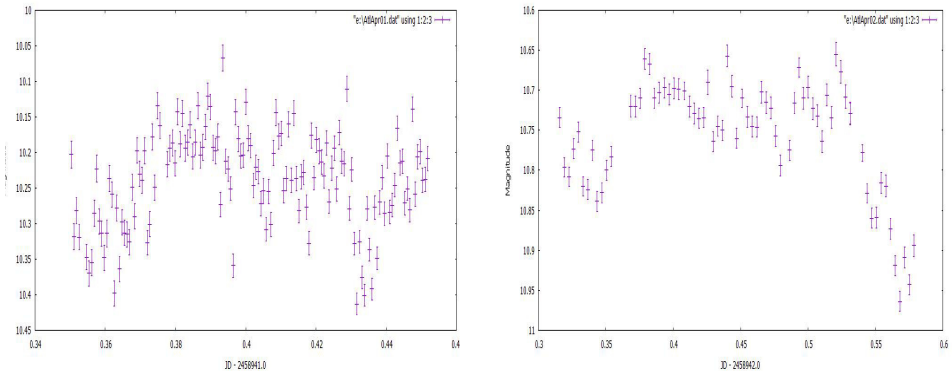

Fig. 1. The photometry of the comet C/2019 Y4 (ATLAS) for (left) April 1, 2020, and (right) April 2, 2020.

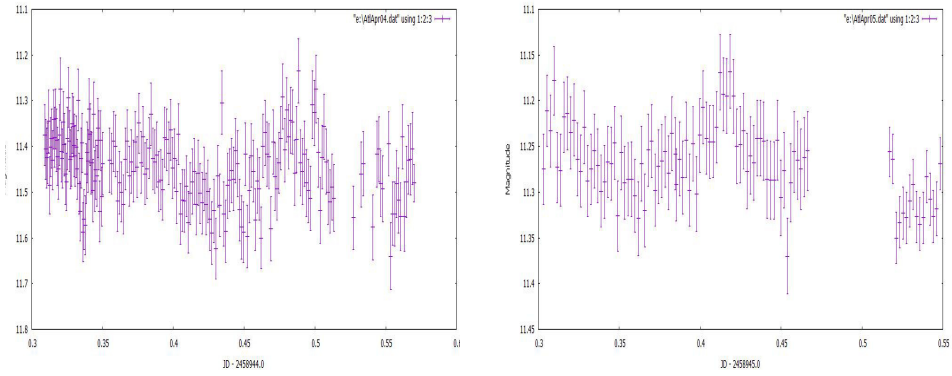

Fig. 2. The photometry of the comet C/2019 Y4 (ATLAS) for (left) April 4, 2020, and (right) April 5, 2020.

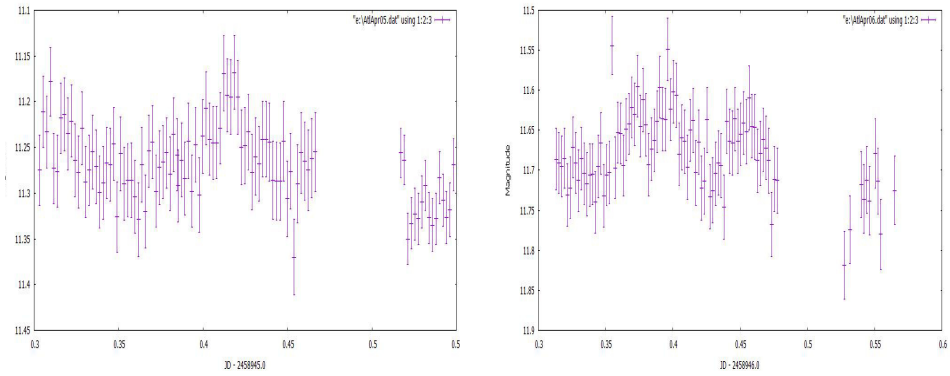

Fig. 3. The photometry of the comet C/2019 Y4 (ATLAS) for (left) April 6, 2020, and (right) April 7, 2020.

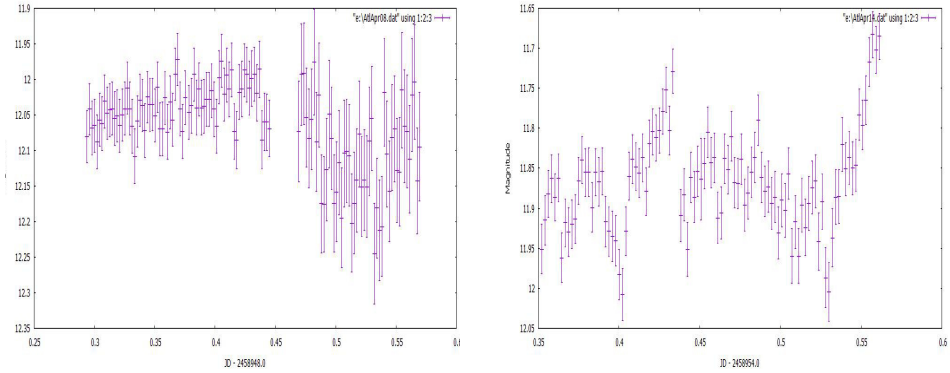

Fig. 4. The photometry of the comet C/2019 Y4 (ATLAS) for (left) April 8, 2020, and (right) April 14, 2020.

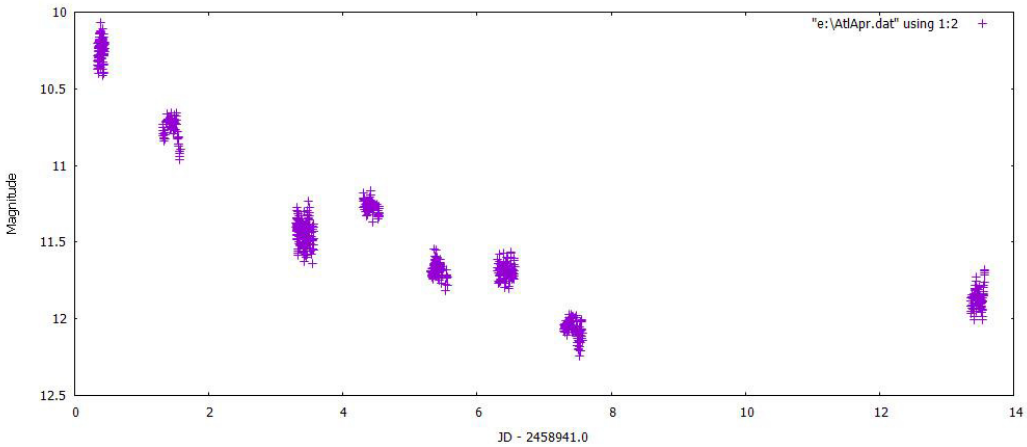

Fig. 5. The photometry of the comet C/2019 Y4 (ATLAS): the mean magnitude values from April 1 to April 14, 2020.

Conclusion

According to Ye and Zhang [Ye and Zhang 2020], the process of disintegration of comet C/2019 Y4 (ATLAS) started on March 20, 2020. Ye and Zhang (2020) reported that "Images taken on UT 2020 April 5.6-5.9 showed an elongated pseudo-nucleus measuring about 3 arcsec in length and aligned with the axis of the tail". As shown in Figure 6, our observations from April 1 to 14 also include this event. This is the reason why we consider our photometric results valuable.

It is also valuable that we observed the disintegrating comet over several nights during two weeks, each night almost continuously. The shape and character of the light curves for the individual nights of observation differs night from night. There are not the simple light curves of the comet's nucleus.

The partial "light curves" of the disintegrating core of the comet shown in Figures 1 to 4, in our opinion, may be interpreted as caused by the motions and/or rotation of the individual fragments of the disintegrating comet. These rotations, combined in the integral light with their albedos support that the individual fragments of the comet differ in their albedos and rotation. Quasiperiodic changes that we observed indicate that the rotation and albedos of the fragments could have played a role in the magnitude values.

The comets are usually observed with the aim to obtain their astrometric positions and their photometric values on the common light curve. See for example the home page of Seiichi Yoshida [Yoshida 2020]. However, based on the work presented in this paper, it is possible to conclude that it is worth observing the comets for more nights in a row and for as long time as possible. Ideally throughout the whole night.

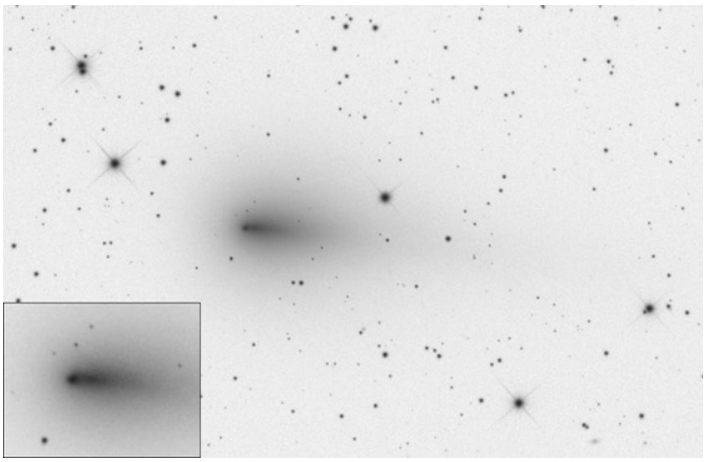

Fig. 6. The beauty of the C/2019 Y4 (ATLAS) in an image by D. Volný. Inset: Comet C/2019 Y4 (ATLAS) showing the nucleus broken into two fragments.

Acknowledgements

We thank to Dr. M. Husárik for valuable advice, help and assistance with preparation of the article in LaTeXenvironment. We also thank Dr. Galin Borisov for kindly reviewing this article multiple times.

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Appendix

Table 2: Our observations between 1 and 14 April, 2020.

Julian Date	Magnitude	Error	Julian Date	Magnitude	Error
2458941.35	10.203	0.019	0.41434	11.193	0.04
0.35112	10.318	0.018	0.41642	11.195	0.041
0.35184	10.282	0.018	0.4185	11.168	0.04
0.35256	10.319	0.018	0.42059	11.195	0.04
0.35472	10.347	0.018	0.42267	11.25	0.041
0.35544	10.37	0.018	0.42475	11.248	0.041
0.35616	10.355	0.018	0.42684	11.233	0.041
0.35687	10.285	0.018	0.42892	11.277	0.042
0.35759	10.223	0.019	0.431	11.26	0.042
0.35831	10.297	0.018	0.43309	11.268	0.041
0.35903	10.314	0.018	0.43517	11.241	0.041
0.35975	10.348	0.018	0.43725	11.241	0.041
0.36046	10.314	0.018	0.43934	11.244	0.043
0.36118	10.237	0.018	0.44142	11.286	0.042
0.36191	10.259	0.018	0.4435	11.287	0.043
0.36263	10.398	0.018	0.44559	11.287	0.042
0.36334	10.278	0.018	0.44767	11.243	0.044
0.36406	10.364	0.017	0.44975	11.306	0.041
0.36478	10.298	0.018	0.45184	11.276	0.042
0.3655	10.313	0.018	0.45392	11.37	0.042
0.36622	10.315	0.018	0.456	11.29	0.043
0.36693	10.326	0.017	0.45809	11.256	0.044
0.36765	10.249	0.018	0.46017	11.265	0.043
0.36838	10.29	0.018	0.46225	11.275	0.044
0.3691	10.197	0.018	0.46434	11.262	0.043
0.36981	10.23	0.018	0.46642	11.255	0.043
0.37053	10.239	0.018	0.51695	11.256	0.027
0.37125	10.198	0.018	0.51903	11.264	0.027
0.37197	10.327	0.017	0.52112	11.35	0.028
0.37269	10.301	0.018	0.5232	11.333	0.028
0.3734	10.178	0.018	0.52529	11.323	0.029
0.37412	10.249	0.018	0.52737	11.328	0.028
0.37485	10.134	0.018	0.52945	11.31	0.028
0.37557	10.162	0.018	0.53154	11.292	0.028
0.37773	10.217	0.018	0.53362	11.327	0.028
0.37845	10.194	0.018	0.5357	11.335	0.029
0.37917	10.187	0.018	0.53779	11.328	0.028
0.37988	10.215	0.018	0.53987	11.283	0.028
0.3806	10.143	0.018	0.54195	11.308	0.029
0.38132	10.188	0.018	0.54404	11.327	0.028
0.38204	10.145	0.018	0.54612	11.318	0.029
0.38275	10.194	0.018	0.5482	11.269	0.029
0.38347	10.186	0.018	2458946.313	11.686	0.061
0.3842	10.161	0.018	0.31543	11.691	0.059

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Table 2 – *Continued from previous page*

Julian Date	Magnitude	Error	Julian Date	Magnitude	Error
0.38492	10.206	0.018	0.31752	11.695	0.061
0.38564	10.186	0.018	0.3196	11.685	0.059
0.38635	10.134	0.018	0.32169	11.731	0.063
0.38707	10.204	0.018	0.32377	11.722	0.068
0.38779	10.193	0.018	0.32585	11.671	0.062
0.38851	10.164	0.018	0.32794	11.691	0.059
0.38922	10.121	0.018	0.33002	11.713	0.068
0.38994	10.136	0.018	0.3321	11.685	0.065
0.39067	10.193	0.018	0.33418	11.704	0.066
0.39139	10.198	0.018	0.33627	11.717	0.066
0.39211	10.178	0.018	0.33835	11.706	0.061
0.39282	10.273	0.017	0.34044	11.705	0.059
0.39354	10.067	0.018	0.34252	11.74	0.063
0.39426	10.212	0.017	0.3446	11.695	0.065
0.39498	10.223	0.017	0.34669	11.666	0.063
0.39569	10.251	0.017	0.34877	11.732	0.06
0.39641	10.359	0.016	0.35085	11.706	0.067
0.39714	10.143	0.018	0.35294	11.703	0.063
0.39786	10.181	0.018	0.35502	11.544	0.063
0.39858	10.205	0.017	0.3571	11.697	0.066
0.39929	10.204	0.017	0.35919	11.653	0.066
0.40001	10.129	0.018	0.36127	11.654	0.067
0.40073	10.18	0.017	0.36335	11.694	0.066
0.40145	10.19	0.017	0.36544	11.649	0.069
0.40216	10.246	0.017	0.36752	11.642	0.073
0.40288	10.221	0.017	0.3696	11.621	0.067
0.4036	10.227	0.017	0.37169	11.63	0.067
0.40433	10.272	0.017	0.37377	11.595	0.063
0.40505	10.254	0.017	0.37585	11.645	0.063
0.40576	10.308	0.016	0.37794	11.612	0.064
0.40648	10.255	0.017	0.38002	11.643	0.067
0.4072	10.301	0.017	0.3821	11.693	0.067
0.40792	10.201	0.018	0.38419	11.673	0.066
0.40863	10.144	0.018	0.38627	11.663	0.07
0.40935	10.177	0.018	0.38836	11.639	0.067
0.41008	10.173	0.017	0.39044	11.596	0.066
0.4108	10.254	0.017	0.39252	11.636	0.067
0.41152	10.237	0.017	0.39461	11.637	0.071
0.41223	10.16	0.018	0.39634	11.549	0.068
0.41295	10.239	0.017	0.39842	11.624	0.067
0.41367	10.145	0.018	0.4005	11.602	0.068
0.41439	10.237	0.017	0.40259	11.606	0.064
0.4151	10.282	0.017	0.40467	11.68	0.065
0.41582	10.234	0.017	0.40675	11.659	0.067
0.41654	10.228	0.017	0.40884	11.664	0.073
0.41727	10.277	0.017	0.41092	11.696	0.07
0.41799	10.328	0.016	0.413	11.65	0.068
0.4187	10.176	0.018	0.41509	11.638	0.073

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Table 2 – *Continued from previous page*

Julian Date	Magnitude	Error	Julian Date	Magnitude	Error
0.41942	10.236	0.017	0.41717	11.703	0.071
0.42014	10.182	0.018	0.41925	11.665	0.076
0.42086	10.198	0.017	0.42134	11.722	0.074
0.42157	10.214	0.017	0.42342	11.714	0.078
0.42229	10.233	0.017	0.4255	11.637	0.071
0.42301	10.187	0.017	0.42759	11.733	0.067
0.42374	10.269	0.017	0.42967	11.725	0.066
0.42446	10.222	0.017	0.43175	11.704	0.063
0.42517	10.194	0.017	0.43384	11.691	0.068
0.42589	10.251	0.017	0.43592	11.694	0.065
0.42661	10.172	0.017	0.43801	11.746	0.065
0.42733	10.212	0.017	0.44009	11.639	0.07
0.42804	10.216	0.017	0.44217	11.664	0.072
0.42876	10.111	0.018	0.44426	11.666	0.072
0.42948	10.279	0.016	0.44634	11.636	0.074
0.43021	10.224	0.017	0.44842	11.664	0.068
0.43093	10.328	0.016	0.45051	11.655	0.075
0.43164	10.413	0.016	0.45259	11.641	0.07
0.43236	10.326	0.016	0.45467	11.652	0.07
0.43308	10.376	0.016	0.45676	11.61	0.082
0.4338	10.401	0.015	0.45884	11.645	0.071
0.43451	10.279	0.016	0.46092	11.646	0.077
0.43523	10.337	0.016	0.46301	11.688	0.071
0.43595	10.392	0.016	0.46509	11.679	0.073
0.43668	10.277	0.016	0.46717	11.662	0.073
0.4374	10.349	0.016	0.46926	11.672	0.073
0.43811	10.27	0.017	0.47134	11.688	0.107
0.43883	10.235	0.017	0.47342	11.768	0.08
0.43955	10.286	0.016	0.47551	11.711	0.073
0.44027	10.205	0.017	0.47759	11.713	0.067
0.44098	10.284	0.016	0.52744	11.819	0.063
0.4417	10.274	0.016	0.53161	11.774	0.074
0.44242	10.246	0.017	0.53994	11.718	0.073
0.44314	10.166	0.017	0.54202	11.736	0.075
0.44387	10.215	0.017	0.54411	11.712	0.072
0.44458	10.212	0.017	0.54619	11.738	0.07
0.4453	10.271	0.017	0.55036	11.679	0.073
0.44602	10.251	0.017	0.55244	11.714	0.075
0.44674	10.281	0.016	0.55452	11.78	0.071
0.44745	10.139	0.017	0.56494	11.725	0.074
0.44817	10.259	0.017	2458947.308	11.664	0.076
0.44889	10.206	0.017	0.30961	11.616	0.074
0.44962	10.199	0.017	0.31169	11.685	0.078
0.45034	10.239	0.017	0.31378	11.643	0.075
0.45105	10.238	0.017	0.31586	11.689	0.075
0.45177	10.209	0.017	0.31794	11.643	0.073
2458942.316	10.734	0.013	0.32003	11.698	0.076
0.3194	10.796	0.012	0.32211	11.668	0.077

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Table 2 – *Continued from previous page*

Julian Date	Magnitude	Error	Julian Date	Magnitude	Error
0.32288	10.808	0.012	0.32419	11.769	0.075
0.32635	10.773	0.013	0.32628	11.753	0.077
0.32982	10.752	0.013	0.32836	11.677	0.071
0.33329	10.82	0.012	0.33044	11.763	0.074
0.33677	10.824	0.012	0.33253	11.641	0.082
0.34024	10.775	0.013	0.33461	11.578	0.079
0.34371	10.839	0.012	0.33669	11.714	0.079
0.34718	10.828	0.012	0.33878	11.724	0.061
0.35065	10.8	0.013	0.34086	11.683	0.059
0.35414	10.783	0.013	0.34294	11.629	0.061
0.36864	10.72	0.013	0.34503	11.758	0.059
0.37211	10.72	0.013	0.34711	11.645	0.063
0.37558	10.71	0.013	0.34919	11.699	0.068
0.37906	10.661	0.013	0.35128	11.743	0.062
0.38253	10.667	0.013	0.35336	11.709	0.059
0.386	10.71	0.013	0.35544	11.75	0.068
0.38947	10.703	0.013	0.38987	11.668389	0.065
0.3935	10.697	0.013	0.39074	11.721319	0.066
0.39711	10.705	0.013	0.39283	11.743868	0.066
0.40058	10.698	0.013	0.39491	11.573096	0.061
0.40406	10.699	0.013	0.39699	11.655153	0.059
0.40838	10.701	0.011	0.39908	11.660906	0.063
0.41223	10.72	0.013	0.40116	11.634466	0.065
0.4157	10.729	0.013	0.40324	11.676693	0.063
0.41917	10.735	0.013	0.40532	11.68711	0.06
0.42264	10.734	0.013	0.40741	11.742527	0.067
0.42568	10.69	0.015	0.40949	11.732375	0.063
0.4296	10.764	0.013	0.41158	11.796366	0.063
0.43307	10.745	0.013	0.41366	11.691413	0.066
0.43654	10.75	0.013	0.41574	11.672582	0.066
0.44002	10.657	0.014	0.41783	11.698995	0.067
0.44349	10.695	0.013	0.41991	11.711631	0.066
0.44696	10.76	0.013	0.42199	11.734142	0.069
0.45096	10.71	0.011	0.42408	11.630275	0.073
0.45512	10.733	0.013	0.42616	11.722526	0.067
0.45859	10.745	0.013	0.42824	11.65637	0.067
0.46207	10.746	0.013	0.43033	11.672442	0.063
0.46554	10.702	0.013	0.43241	11.692437	0.063
0.46901	10.715	0.014	0.43449	11.770801	0.064
0.47248	10.722	0.013	0.43658	11.701685	0.067
0.47596	10.757	0.013	0.43866	11.63862	0.067
0.47943	10.794	0.013	0.44074	11.739179	0.066
0.48637	10.775	0.013	0.44283	11.627019	0.07
0.48985	10.716	0.013	0.44491	11.710078	0.067
0.49339	10.672	0.012	0.44699	11.652287	0.066
0.49651	10.71	0.014	0.44908	11.623492	0.067
0.49999	10.696	0.014	0.45116	11.602263	0.071
0.50347	10.723	0.014	0.45324	11.700938	0.068

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Table 2 – *Continued from previous page*

Julian Date	Magnitude	Error	Julian Date	Magnitude	Error
0.50694	10.732	0.014	0.45533	11.685878	0.067
0.51041	10.764	0.013	0.45741	11.60336	0.068
0.51388	10.706	0.014	0.4595	11.675843	0.064
0.51736	10.734	0.014	0.46158	11.652291	0.065
0.52083	10.655	0.015	0.46366	11.691431	0.067
0.5243	10.677	0.014	0.46575	11.674812	0.073
0.52777	10.708	0.014	0.46783	11.741582	0.07
0.53124	10.729	0.014	0.46991	11.804564	0.068
0.53124	10.729	0.013	0.472	11.785539	0.073
0.54035	10.778	0.01	0.47828	11.672375	0.071
0.5437	10.829	0.012	0.48037	11.75791	0.076
0.54717	10.86	0.012	0.48245	11.721877	0.074
0.55065	10.859	0.013	0.48454	11.720656	0.078
0.55413	10.816	0.013	0.48662	11.757631	0.071
0.5576	10.82	0.013	0.4887	11.677071	0.067
0.56107	10.873	0.013	0.49079	11.691635	0.066
0.56454	10.919	0.013	0.49287	11.698601	0.063
0.56801	10.964	0.012	0.49495	11.704696	0.068
0.57149	10.909	0.013	0.49704	11.698795	0.065
0.57496	10.943	0.013	0.49912	11.730644	0.065
0.57843	10.894	0.013	0.5012	11.608164	0.07
2458944.309	11.375	0.066	0.50329	11.597338	0.072
0.31	11.406	0.066	0.50537	11.64163	0.072
0.3107	11.425	0.066	0.50745	11.574911	0.074
0.31139	11.415	0.067	0.50954	11.563765	0.068
0.31209	11.345	0.068	0.51162	11.704837	0.075
0.31278	11.485	0.062	0.5137	11.696309	0.07
0.31348	11.402	0.065	0.51579	11.74138	0.07
0.31417	11.383	0.065	0.51787	11.724893	0.082
0.31487	11.43	0.065	0.51995	11.673314	0.071
0.31556	11.341	0.064	0.52204	11.68277	0.077
0.31626	11.38	0.066	0.52412	11.713568	0.071
0.31695	11.34	0.066	0.5262	11.715822	0.073
0.31765	11.387	0.068	0.52829	11.73043	0.073
0.31834	11.422	0.064	0.53037	11.681529	0.073
0.31903	11.45	0.065	0.53246	11.721206	0.107
0.31973	11.375	0.066	0.53454	11.684271	0.08
0.32042	11.275	0.068	0.53662	11.699213	0.073
0.32112	11.412	0.065	0.5387	11.732647	0.067
0.32181	11.427	0.065	0.54079	11.737193	0.063
0.32251	11.346	0.067	0.54287	11.723314	0.074
0.3232	11.396	0.068	0.54495	11.742576	0.073
0.3239	11.46	0.066	0.54704	11.706253	0.075
0.32459	11.478	0.063	0.54912	11.71838	0.072
0.32528	11.382	0.069	0.55121	11.605603	0.07
0.32598	11.293	0.066	0.55329	11.688236	0.073
0.32667	11.388	0.067	0.55537	11.619726	0.075
0.32737	11.428	0.064	0.55746	11.643811	0.071

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Table 2 – *Continued from previous page*

Julian Date	Magnitude	Error	Julian Date	Magnitude	Error
0.32806	11.423	0.064	0.55954	11.662811	0.074
0.32876	11.35	0.065	2458948.294	12.08	0.037
0.32945	11.357	0.065	0.29603	12.042	0.036
0.33015	11.398	0.068	0.29811	12.068	0.038
0.33084	11.421	0.067	0.3002	12.065	0.037
0.33154	11.401	0.068	0.30228	12.088	0.038
0.33223	11.45	0.065	0.30436	12.057	0.037
0.33293	11.299	0.067	0.30645	12.062	0.038
0.33362	11.482	0.066	0.30853	12.031	0.037
0.33432	11.542	0.065	0.31061	12.048	0.037
0.33501	11.426	0.065	0.3127	12.043	0.037
0.3357	11.392	0.064	0.31478	12.041	0.037
0.3364	11.588	0.064	0.31686	12.055	0.037
0.33709	11.56	0.066	0.31895	12.051	0.037
0.33779	11.573	0.065	0.32103	12.065	0.037
0.33848	11.46	0.066	0.32311	12.05	0.037
0.33918	11.413	0.067	0.3252	12.041	0.037
0.33987	11.432	0.068	0.32728	12.012	0.037
0.34057	11.318	0.066	0.32936	12.041	0.037
0.34126	11.374	0.067	0.33145	12.066	0.037
0.34196	11.436	0.068	0.33353	12.108	0.038
0.34265	11.435	0.066	0.33562	12.059	0.036
0.34335	11.497	0.068	0.3377	12.029	0.037
0.34404	11.33	0.071	0.33978	12.037	0.036
0.34473	11.476	0.066	0.34187	12.072	0.038
0.34543	11.451	0.065	0.34395	12.025	0.036
0.34612	11.464	0.067	0.34603	12.036	0.037
0.34682	11.36	0.065	0.34812	12.035	0.037
0.34751	11.387	0.065	0.3502	12.051	0.037
0.34821	11.542	0.066	0.35228	12.011	0.036
0.3489	11.387	0.065	0.35437	12.07	0.037
0.3496	11.51	0.065	0.35645	12.07	0.038
0.35029	11.438	0.068	0.35853	12.026	0.038
0.3551	11.43	0.069	0.36062	12.074	0.038
0.35649	11.437	0.066	0.3627	12.032	0.037
0.35788	11.389	0.066	0.36478	12.057	0.037
0.35926	11.399	0.067	0.36687	11.993	0.037
0.36065	11.52	0.065	0.36895	11.972	0.037
0.36204	11.479	0.068	0.37103	12.041	0.038
0.36343	11.5	0.065	0.37312	12.073	0.038
0.36482	11.527	0.065	0.3752	12.026	0.038
0.36621	11.428	0.067	0.37834	12.046	0.038
0.3676	11.388	0.068	0.38043	12.037	0.038
0.36899	11.465	0.066	0.38251	11.993	0.037
0.37038	11.433	0.069	0.38459	12.04	0.038
0.37177	11.454	0.067	0.38668	12.014	0.037
0.37316	11.39	0.066	0.38876	12.04	0.038
0.37454	11.445	0.067	0.39084	12.038	0.038

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Table 2 – *Continued from previous page*

Julian Date	Magnitude	Error	Julian Date	Magnitude	Error
0.37593	11.349	0.065	0.39293	12.028	0.038
0.37732	11.435	0.067	0.39501	12.028	0.038
0.37871	11.378	0.066	0.39709	12.016	0.038
0.3801	11.46	0.067	0.39918	12.042	0.038
0.38149	11.449	0.064	0.40126	12.066	0.038
0.38288	11.404	0.066	0.40334	11.997	0.038
0.38427	11.33	0.068	0.40543	11.974	0.038
0.38566	11.427	0.068	0.40751	12.021	0.037
0.38705	11.433	0.069	0.40959	11.994	0.038
0.38844	11.418	0.07	0.41168	12.014	0.038
0.38982	11.477	0.065	0.41376	11.987	0.038
0.39121	11.473	0.065	0.41584	12.073	0.039
0.3926	11.495	0.067	0.41793	12.085	0.04
0.39399	11.38	0.066	0.42001	12.018	0.038
0.39538	11.385	0.067	0.42209	12.014	0.039
0.39677	11.415	0.068	0.42418	11.987	0.038
0.39816	11.364	0.067	0.42626	11.993	0.038
0.39955	11.447	0.066	0.42834	12.012	0.038
0.40094	11.426	0.065	0.43043	11.999	0.039
0.40233	11.499	0.069	0.43251	11.993	0.038
0.40371	11.374	0.066	0.43459	12.019	0.039
0.4051	11.548	0.066	0.43668	11.986	0.04
0.40649	11.518	0.067	0.43876	12.085	0.041
0.40788	11.519	0.068	0.44084	12.06	0.04
0.40927	11.487	0.067	0.44293	12.06	0.04
0.41066	11.566	0.068	0.44501	12.069	0.04
0.41205	11.503	0.067	0.46938	12.073	0.07
0.41344	11.477	0.071	0.47147	11.993	0.071
0.41483	11.454	0.072	0.47355	11.992	0.072
0.41621	11.526	0.068	0.47564	12.054	0.07
0.4176	11.458	0.071	0.47772	12.083	0.069
0.41899	11.503	0.066	0.4798	12.056	0.071
0.42038	11.524	0.067	0.48189	11.976	0.075
0.42177	11.471	0.07	0.48397	12.088	0.07
0.42316	11.526	0.068	0.48605	12.022	0.073
0.42455	11.499	0.068	0.48814	12.175	0.069
0.42594	11.56	0.066	0.49022	12.176	0.067
0.42733	11.589	0.068	0.4923	12.127	0.071
0.42872	11.541	0.069	0.49439	12.049	0.076
0.4301	11.624	0.067	0.49647	12.083	0.072
0.43149	11.465	0.068	0.49855	12.174	0.068
0.43288	11.529	0.068	0.50064	12.158	0.071
0.43427	11.304	0.069	0.50272	12.117	0.073
0.43566	11.548	0.07	0.5048	12.195	0.07
0.43705	11.586	0.068	0.50689	12.104	0.075
0.43844	11.486	0.071	0.50897	12.101	0.073
0.43983	11.474	0.068	0.51105	12.107	0.072
0.44122	11.453	0.071	0.51314	12.202	0.069

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Julian Date	Magnitude	Error	Julian Date	Magnitude	Error
0.44261	11.471	0.069	0.51522	12.174	0.072
0.444	11.41	0.07	0.5173	12.142	0.073
0.44538	11.438	0.071	0.51939	12.077	0.074
0.44677	11.539	0.067	0.52147	12.151	0.07
0.44816	11.577	0.07	0.52355	12.142	0.071
0.44955	11.587	0.066	0.52564	12.151	0.071
0.45094	11.417	0.069	0.52772	12.087	0.076
0.45233	11.597	0.069	0.5298	12.055	0.073
0.45372	11.496	0.071	0.53189	12.245	0.071
0.45511	11.42	0.069	0.53397	12.181	0.07
0.4565	11.454	0.067	0.53605	12.212	0.071
0.45789	11.561	0.067	0.53814	12.207	0.07
0.45928	11.475	0.07	0.54022	12.018	0.076
0.46066	11.493	0.069	0.54231	12.105	0.074
0.46205	11.6	0.067	0.54439	12.157	0.071
0.46344	11.399	0.069	0.54647	12.082	0.074
0.46483	11.37	0.071	0.54856	12.07	0.074
0.46622	11.417	0.07	0.55064	12.128	0.073
0.46761	11.422	0.071	0.55272	12.13	0.076
0.469	11.58	0.07	0.55481	12.015	0.081
0.47039	11.391	0.07	0.55689	12.066	0.079
0.47178	11.466	0.073	0.55897	12.073	0.08
0.47317	11.493	0.067	0.56106	12.112	0.075
0.47455	11.436	0.066	0.56314	12.022	0.08
0.47594	11.382	0.07	0.56522	12.004	0.081
0.47733	11.291	0.071	0.56731	12.143	0.075
0.47872	11.408	0.069	0.56939	12.095	0.076
0.48011	11.32	0.07	2458954.352	11.951	0.031
0.4815	11.379	0.07	0.35425	11.915	0.031
0.48289	11.343	0.071	0.35634	11.882	0.03
0.48428	11.347	0.071	0.35842	11.863	0.03
0.48567	11.458	0.071	0.3605	11.886	0.029
0.48705	11.385	0.072	0.36259	11.862	0.029
0.48844	11.235	0.071	0.36467	11.962	0.031
0.48983	11.435	0.072	0.36675	11.918	0.03
0.49122	11.455	0.072	0.36884	11.93	0.031
0.49261	11.416	0.07	0.37092	11.92	0.031
0.494	11.48	0.073	0.373	11.913	0.03
0.49539	11.497	0.069	0.37509	11.866	0.029
0.49678	11.513	0.07	0.37717	11.84	0.029
0.49817	11.309	0.073	0.37925	11.855	0.03
0.49956	11.326	0.071	0.38134	11.855	0.03
0.50094	11.274	0.074	0.38342	11.899	0.031
0.50233	11.414	0.075	0.3855	11.855	0.03
0.50372	11.54	0.072	0.38759	11.867	0.03
0.50511	11.424	0.069	0.38967	11.854	0.029
0.5065	11.357	0.071	0.39175	11.917	0.032
0.50789	11.433	0.071	0.39384	11.929	0.031

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Julian Date	Magnitude	Error	Julian Date	Magnitude	Error
0.50928	11.5	0.07	0.39592	11.935	0.031
0.51067	11.521	0.069	0.39801	11.941	0.031
0.51206	11.489	0.072	0.40009	11.983	0.032
0.51345	11.513	0.073	0.40217	12.008	0.033
0.52714	11.556	0.07	0.40426	11.929	0.03
0.53269	11.461	0.071	0.40634	11.86	0.03
0.53408	11.438	0.071	0.40842	11.839	0.03
0.54103	11.577	0.071	0.41051	11.848	0.03
0.54377	11.417	0.072	0.41259	11.856	0.03
0.54515	11.406	0.071	0.41467	11.837	0.03
0.54654	11.481	0.072	0.41676	11.879	0.03
0.54793	11.493	0.072	0.41884	11.819	0.029
0.5521	11.394	0.07	0.42092	11.804	0.029
0.55349	11.64	0.073	0.42301	11.812	0.029
0.55488	11.547	0.069	0.42509	11.803	0.028
0.55627	11.548	0.07	0.42717	11.779	0.028
0.55765	11.482	0.073	0.42926	11.752	0.029
0.55904	11.518	0.071	0.43134	11.803	0.03
0.56043	11.553	0.074	0.43342	11.729	0.028
0.56182	11.379	0.07	0.43831	11.909	0.033
0.56321	11.554	0.076	0.4404	11.883	0.032
0.5646	11.478	0.078	0.44248	11.951	0.034
0.56599	11.43	0.075	0.44456	11.861	0.032
0.56738	11.428	0.077	0.44665	11.886	0.032
0.56877	11.405	0.078	0.44873	11.854	0.031
0.56991	11.48	0.04	0.45081	11.864	0.051
2458945.303	11.275	0.038	0.4529	11.844	0.032
0.3055	11.211	0.039	0.45498	11.805	0.031
0.30758	11.233	0.039	0.45707	11.843	0.031
0.30966	11.178	0.037	0.45915	11.837	0.031
0.31175	11.273	0.038	0.46123	11.912	0.032
0.31383	11.276	0.039	0.46332	11.906	0.032
0.31591	11.218	0.039	0.4654	11.838	0.031
0.318	11.214	0.04	0.46748	11.852	0.031
0.32008	11.235	0.04	0.46957	11.81	0.031
0.32216	11.221	0.039	0.47165	11.868	0.031
0.32425	11.264	0.04	0.47373	11.869	0.031
0.32633	11.277	0.039	0.47582	11.839	0.031
0.32842	11.229	0.04	0.4779	11.896	0.033
0.3305	11.288	0.039	0.47998	11.881	0.032
0.33258	11.275	0.039	0.48207	11.855	0.032
0.33467	11.255	0.04	0.48415	11.836	0.031
0.33675	11.271	0.04	0.48623	11.79	0.031
0.33883	11.299	0.039	0.48832	11.861	0.031
0.34092	11.289	0.04	0.4904	11.879	0.032
0.343	11.267	0.039	0.49248	11.873	0.032
0.34508	11.269	0.04	0.49457	11.894	0.032
0.34717	11.246	0.04	0.49665	11.886	0.032

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Table 2 – *Continued from previous page*

Julian Date	**Magnitude**	**Error**	**Julian Date**	**Magnitude**	**Error**
0.34925	11.326	0.039	0.49873	11.931	0.033
0.35133	11.257	0.04	0.50082	11.89	0.033
0.35342	11.29	0.04	0.5029	11.903	0.033
0.3555	11.286	0.04	0.50498	11.857	0.032
0.35758	11.286	0.04	0.50707	11.96	0.034
0.35967	11.304	0.04	0.50915	11.917	0.033
0.36175	11.329	0.04	0.51123	11.96	0.034
0.36383	11.269	0.041	0.51332	11.896	0.033
0.36592	11.32	0.04	0.5154	11.924	0.035
0.368	11.254	0.039	0.51748	11.894	0.034
0.37008	11.244	0.04	0.51957	11.874	0.033
0.37217	11.298	0.04	0.52165	11.866	0.033
0.37425	11.272	0.041	0.52374	11.942	0.036
0.37634	11.266	0.04	0.52582	11.892	0.035
0.37842	11.256	0.039	0.5279	11.987	0.037
0.3805	11.279	0.04	0.52999	12.005	0.037
0.38258	11.236	0.041	0.53207	11.937	0.036
0.38467	11.258	0.04	0.53415	11.886	0.034
0.38517	11.292	0.04	0.53624	11.885	0.034
0.38725	11.264	0.04	0.53832	11.82	0.034
0.38933	11.284	0.04	0.5404	11.851	0.033
0.39142	11.243	0.041	0.54249	11.837	0.033
0.3935	11.298	0.04	0.54457	11.85	0.033
0.39558	11.247	0.041	0.54665	11.846	0.032
0.39767	11.302	0.041	0.54874	11.783	0.032
0.39975	11.238	0.04	0.55082	11.796	0.031
0.40183	11.207	0.04	0.5529	11.765	0.031
0.40392	11.241	0.04	0.55499	11.717	0.03
0.406	11.245	0.04	0.55707	11.683	0.029
0.40809	11.245	0.04	0.55915	11.702	0.029
0.41017	11.229	0.039	0.56124	11.685	0.029
0.41225	11.169	0.041			