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Draconids 2011: Outburst Observations by the Croatian Meteor Network

Damir Šegon · Željko Andreić · Peter S. Gural · Korado Korlević · Denis Vida · Filip Novoselnik · Ivica Skokić

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Abstract The predicted Draconid meteor shower outburst during October 2011 had been observed by a portion of the Croatian Meteor Network whose stations encountered clear weather. A total of 95 Draconid orbits have been calculated from 18 contributing stations, and in this paper we present results for 63 orbits obtained from the fully automatic observation and processing pipeline. Two methods of trajectory estimation were applied, showing better fit results using a linearly changing velocity model versus a constant

D. Šegon
Astronomical Society "Istra" Pula, Park Monte Zaro 2, 52100 Pula, Croatia
e-mail: damir.segon@pu.htnet.hr

D. Šegon · K. Korlević
Višnjan Science and Education Center, Istarska 5, 51463 Višnjan, Croatia
e-mail: korado@astro.hr

Ž. Andreić (✉)
Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Pierottijeva 6, 10000 Zagreb, Croatia
e-mail: zandreic@rgn.hr

P. S. Gural
351 Samantha Drive, Sterling, VA 20164, USA
e-mail: peter.s.gural@leidos.com

D. Vida · F. Novoselnik · I. Skokić
Astronomical Society Anonymus, B. Radića 34, 31550 Valpovo, Croatia
e-mail: denis.vida@gmail.com

F. Novoselnik
e-mail: novoselnikf@gmail.com

I. Skokić
e-mail: ivica.skokic@gmail.com

D. Vida · F. Novoselnik
Faculty of Electrical Engineering, University of Osijek, Kneza Trpimira 2B, 31000 Osijek, Croatia

velocity model. The estimated mean radiant position has been found to be at RA = 262.6°, Dec = +55.7°, with estimated geocentric velocity Vg = 20.7 km/s.

Keywords Meteors · Meteoroids · Draconids 2011

1 Introduction

The Draconid meteor shower outburst that occurred on 08 Oct 2011, had been predicted by various authors and described in several papers (Vaubaillon et al. 2011a; Maslov 2011; Asher and Steel 2012). All the Draconid outburst predictions were fairly similar with respect to the predicted time for peak meteor flux, but varied significantly on the level of activity that could be observed. While Vaubaillon, Watanabe and Sato predicted two outbursts of up to ZHR = 500, more conservative predictions by Maslov set the ZHR at only 50. Given the timing of the Draconid peak, Europe was the favored longitude for observation which conveniently fell within the Croatian Meteor Network's (CMN) region of multi-station coverage.

The CMN cameras have continuously monitored the sky, collecting meteor data over Croatia and its neighboring countries since 2007 (Andreić et al. 2008). Images are captured by 1004X video cameras equipped with 4 mm/F1.2 lenses using the SkyPatrol software application. The resultant files are then post-processed by both the MTP_Detector (Gural and Šegon 2009) and CMN software packages. The camera fields of view and the astrometry techniques applied, result in meteor detection position errors of about 0.06° or less (depending on capture resolution, the number of reference stars, and their spread across the focal plane). The standard CMN data processing pipeline ends with data products formatted for import into the software package UFOOrbit. This permits the orbital information generated to be compatible with existing data from the SonotaCo Network. The catalogues of meteor orbits generated by the CMN which cover the years 2007–2010 have already been published (Šegon et al. 2012; Korlević et al. 2013), and are available for download on the CMN web pages.

During the night of 08 Oct 2011, weather conditions over Croatia were quite variable. A low pressure system generating heavy storms and showers (not meteor in nature) had moved rapidly across Croatia. Its quick passage had opened up clear skies first for the north-western part of the CMN coverage region, and only later on for other stations in the network. The intensity of storms had been such that multistation observations of five sprites were made during that night. Despite the thunderstorms, skies cleared sufficiently so a total of 462 Draconids were recorded, of which 95 Draconid orbits have been calculated from multi-station data. In this paper are presented the data from a fully automatic process of capture, detection and astrometry, followed by the trajectory and orbit calculations made using a multi-parameter fit software package developed recently (Gural 2012).

2 Draconids as Observed from the Croatian Meteor Network

A total of 95 Draconid meteors were captured by at least two CMN cameras. These meteors have been further filtered by constraining the convergence angle (Qa) between intersecting observation planes, discarding meteors with Qa < 15° and leaving a set of 63 meteors captured by two or more stations: 34 from two stations, 21 from three, 5 from four, 2 from five and 1 from six stations. Simulations run with the multi-parameter trajectory fitting method showed that 15° is about the convergence angle below which observations have reduced reliability due to larger errors in estimation of the fit parameters. Two different models for velocity propagation were used in the trajectory estimation: a non-decelerating model (constant velocity marked as V0) and a constant deceleration model (linear change in velocity marked as V1). Results applying the constant deceleration model to observations are provided in the "Appendix" at the end of this paper.

Based on the V0 results, the calculated average begin and end heights for all Draconid meteors fainter than $m_v = -2.5$, were found to be $H_{beg} = 98$ km and $H_{end} = 88$ km, respectively. The resulting dependence of height parameters on estimated magnitude is presented in Fig. 1. It can be seen that beginning heights increase about 0.3 km per magnitude step, while the end heights have a somewhat larger dispersion such that for each magnitude brighter, a meteor penetrates 1.1 km deeper into the atmosphere. The average duration of the 2011 Draconids as seen by CMN cameras was found to be 0.66 s.

Average results on 63 meteors with Qa > 15° processed by the non-decelerating model (constant velocity) and constant deceleration model (linearly changing velocity) are shown in Table 1 listing geocentric radiant and mean orbital elements (error estimates represent one standard deviation):

A pair of graphs showing the single meteor radiant positions calculated by employing a non-decelerating (V0) and constant deceleration (V1) meteor propagation model from the multi-parameter fit solution is presented in Fig. 2.

The side-by-side orbit plots for the V0 and V1 models are shown on Fig. 3.

3 Discussion

As can be seen from the presented radiant and orbit plots, there is a significant difference in radiant positions as well as resulting orbits between the V0 and V1 models. The radiant spread is smaller for the constant deceleration model, which is also evident from the smaller standard deviations seen in the mean geocentric radiant RA and Dec. Moreover, the resulting mean aphelion distance of 5.0 a.u. for meteors calculated by using the non-decelerating model, puts meteoroids at orbits inside Jupiter's orbit—not in agreement with more precise observations of the Draconid meteors (Koten et al. 2007; Borovička et al. 2013). Results for the linearly changing velocity (or constant deceleration) model by contrast, puts the mean aphelion distance at 5.9 a.u., which is very close to the value reported for the main body of the Draconid's parent body: comet Giacobini–Zinner (6.0 a.u.). Thus, we may come to the conclusion that the constant deceleration model better describes the observed meteor trajectories than the more traditional zero-deceleration model approach. Also, in the case of the CMN Draconids observations, they are of sufficient accuracy for each meteor's deceleration to be detected.

Resulting mean radiant positions based on the V1 model have been found to be RA = 262.6° ± 2.2°, Dec = 55.7° ± 0.9°, and Vg = 20.74 ± 0.71 km/s, which is very close to radiant positions predicted by Maslov (RA = 263.3°, Dec =+55.8°, Vg = 20.9 km/s) (Maslov 2011) and Vaubaillon (RA = 263.2°, Dec =+55.8°, Vg = 20.9 km/s) (Vaubaillon et al. 2011b).

At the International Meteor Conference in La Palma, Spain (Šegon et al. 2013) we presented preliminary results on the Draconid outburst based on 53 orbits available at that moment. Preliminary analysis had shown that there may be two groups of orbits, which

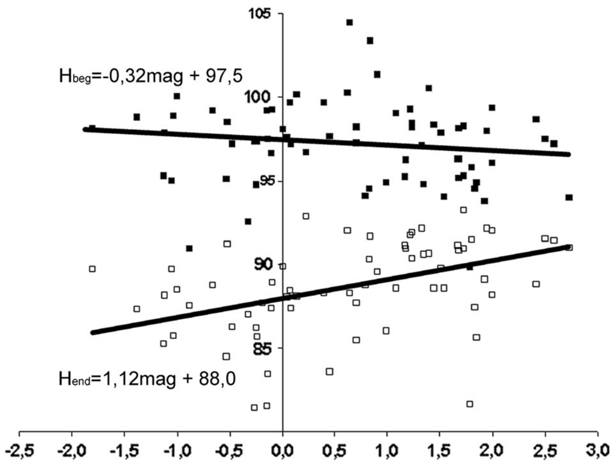

Fig. 1 Magnitude–height dependence for the 2011 Draconids fainter than $m_v = -2.5$

Table 1 Mean orbital parameters for different velocity propagation models

Orbit parameter	Non-decelerating model V0	Constant deceleration model V1
RA	261.7° ± 2.9°	262.6° ± 2.2°
DEC	55.3° ± 1.3°	55.7° ± 0.9°
Vgeo	20.00 ± 0.48 km/s	20.74 ± 0.71 km/s
1/a	0.336 ± 0.035 l/a.u.	0.296 ± 0.042 l/a.u.
q	0.995 ± 0.003 a.u.	0.996 ± 0.002 a.u.
e	0.665 ± 0.035	0.705 ± 0.041
i	30.6° ± 0.6°	31.5° ± 0.9°
peri	172.3° ± 2.4°	173.1° ± 1.7°
node	195.0° ± 0.1°	195.0° ± 0.1°

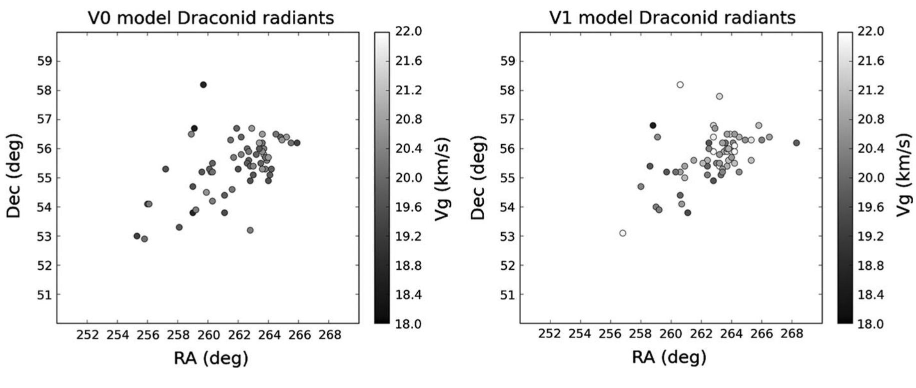

Fig. 2 Radiant positions calculated by the non-deceleration model (*left panel*) and constant deceleration model (*right panel*), with *grayscale* encoding the geocentric velocity Vg

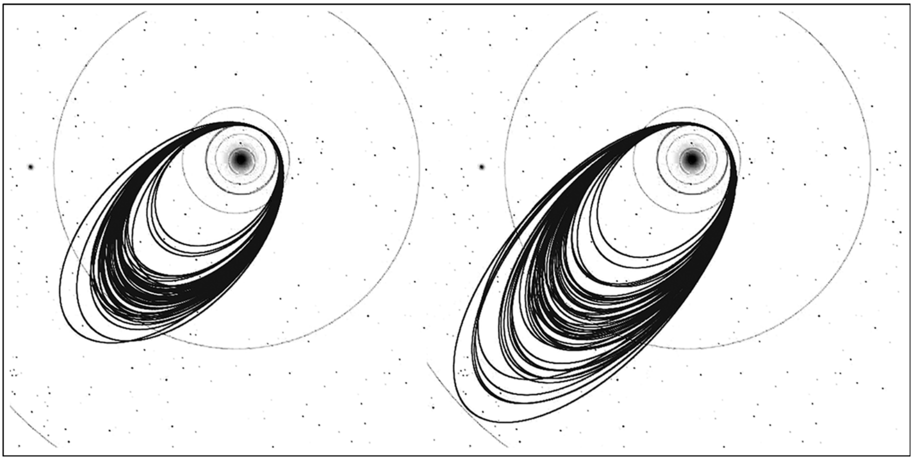

Fig. 3 Side-by-side orbit plots for V0 (*left*) and V1 (*right*) models with average aphelia near Jupiter's orbit

showed greatest separability in the argument of perihelion (peri) at a value of 172.5°. In the latest work reported herein, which is based on 63 orbits with recalculated orbital parameters and radiant positions for those two alleged groups, the results haven't changed significantly. Resulting orbital parameters as well as radiant positions are presented in Table 2.

The two mean hypothetical radiant positions differ by more than 3°, but there is no obvious difference in mean orbital elements, with the exception of the Argument of Perihelion which differs by about 3°, as well as slight differences in perihelion distance and eccentricity. One should also note that radiants with omega <172.5° show higher dispersion, having a sigma value higher than the omega >172.5° set.

To statistically quantify the possible bimodality indicated in the distribution of argument of perihelion measurements, a Gaussian mixture modeling (GMM) code by Muratov and Gnedin (2010) was employed which implements several statistical tests: kurtosis, Chi square statistics, Ashman's D (Ashman et al. 1994), and Hartigan's dip statistics HDS (Hartigan and Hartigan 1985). In addition, two more tests were used, bimodality coefficient BC (SAS Institute, Inc., 1989) and Akaike's information criterion AIC (Akaike 1974). GMM's best fit is a mixture of two normal distributions with peaks at 170.616° ± 0.511° and 173.856° ± 0.173° with a probability of only 3.5 % of unimodal distribution. Ashman's D gives a 22 %, HDS a 55 %, and kurtosis a 78 % probability of unimodal distribution. AIC characterizes the distribution as bimodal and BC as unimodal. The conclusion from these results is that the null hypothesis of a unimodal distribution cannot be rejected at a required significance level of 5–10 %, but since some tests do favor bimodal distribution, it cannot be ruled out either. The distribution for the argument of perihelion, as well as normalized histograms and kernel smoothing densities, are shown in Fig. 4.

We emphasize once more that these results are based only on observations made by the Croatian Meteor network and may still be improved upon in the precision of the orbital parameters once they are refined through manual processing. When the full dataset containing all the world-wide observations become available for this event, a re-check of the

Table 2 Mean orbital parameters for separated groups of the argument of perihelion

Orbit parameter	Omega <172.5° orbits	Omega >172.5° orbits
RA	259.7° ± 1.2°	263.8° ± 1.2°
DEC	55.0° ± 1.2°	55.9° ± 0.6°
Vgeo	20.42 ± 0.80 km/s	20.87 ± 0.63 km/s
1/a	0.316 ± 0.050 l/a.u.	0.289 ± 0.035 l/a.u.
q	0.994 ± 0.001 a.u.	0.997 ± 0.001 a.u.
e	0.686 ± 0.049	0.712 ± 0.035
i	31.1° ± 1.0°	31.7° ± 0.8°
peri	170.8° ± 1.0°	174.0° ± 0.9°
node	195.0° ± 0.0°	195.1° ± 0.1°

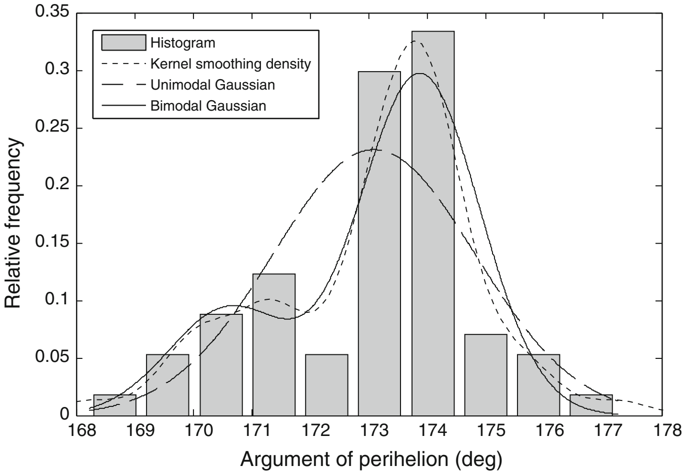

Fig. 4 Argument of perihelion normalized histograms and kernel smoothing densities for unimodal and bimodal Gaussian distributions

bi-modality hypothesis of two distinct groups of orbits can be revisited. Until then, the hypothesis stated in this preliminary work cannot be proven conclusively.

4 Summary

On October 8th 2011 the Draconid meteor outburst was observed with video cameras in the Croatian Meteor Network and the processing results have been presented. The resulting mean radiant position from fully automatic data processing is in agreement with the predicted positions for the trail produced from the 1900 passage of the comet. The observations differ by only 0.6° in right ascension and 0.2° in declination from the predicted radiant. More detailed analysis will be done on manually re-checked observations, since there are several long duration events covered with multiple cameras.

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Appendix of Draconids Meteor Trajectories and Orbits

Time-UT	N	Dur	Q	Hbeg		Hend		RAapp		DECapp	
18:19:13	2	0.54	16	102.8	1.2	92.5	1.2	264.8	1.5	58.4	1.5
18:20:31	2	0.76	15	100.8	0.3	85.7	0.3	267.7	0.5	55.4	0.3
18:34:01	2	0.56	67	99.7	0.5	88.7	0.5	268.1	1.7	56.0	0.8
18:42:21	3	0.36	60	95.2	1.1	88.2	0.9	265.2	2.4	54.8	0.9
18:57:17	2	0.60	30	99.0	1.2	87.9	1.1	265.4	2.0	55.3	1.0
19:05:14	2	0.39	21	94.5	0.4	86.7	0.5	269.8	2.3	57.0	0.9
19:10:52	2	0.73	20	103.0	1.2	89.4	0.9	267.8	3.6	56.9	0.5
19:10:52	5	0.68	73	100.0	0.1	87.2	0.1	268.4	0.8	56.7	0.3
19:11:39	2	0.48	74	96.2	0.3	87.1	0.3	268.9	1.1	56.2	0.6
19:13:13	4	0.64	30	98.0	0.3	85.6	0.2	268.4	1.2	56.1	0.4
19:17:44	2	0.50	27	97.9	0.2	88.7	0.6	266.5	6.3	56.6	0.5
19:17:55	3	0.40	67	97.2	0.8	90.4	0.7	261.3	3.6	54.3	0.8
19:20:29	2	0.96	63	102.4	0.1	84.6	0.1	267.4	0.9	56.6	0.2
19:23:32	3	0.44	78	98.8	0.5	90.1	0.3	273.5	4.4	57.0	0.4
19:31:24	2	0.39	32	96.0	0.5	89.0	0.4	267.2	2.0	56.8	0.5
19:32:06	2	0.57	53	95.3	1.5	84.7	1.5	268.8	1.6	57.3	1.3
19:34:46	3	0.74	17	99.2	0.3	85.2	0.8	270.1	7.5	57.2	1.2
19:39:22	3	0.57	44	97.2	0.3	87.1	0.3	267.8	1.4	56.5	0.3
19:43:26	2	0.74	19	97.8	0.2	84.5	0.2	268.8	1.7	57.0	0.2
19:47:55	2	0.44	17	96.4	0.6	88.8	0.5	265.8	6.3	56.4	1.1
19:50:30	2	0.64	49	99.6	0.2	88.7	0.2	268.6	3.5	56.2	1.6
19:53:08	3	0.92	19	99.4	0.1	82.7	0.1	270.3	1.1	56.6	0.2
19:55:34	2	0.48	16	98.6	0.4	90.5	0.3	266.7	1.6	55.4	1.7
20:01:43	2	0.36	20	96.0	0.3	90.0	0.3	264.4	3.3	55.6	1.8
20:03:26	2	0.76	17	99.1	0.2	85.8	0.2	267.9	1.2	57.9	0.9
20:07:40	3	0.59	29	95.4	0.2	85.2	0.2	269.2	2.4	57.3	0.5
20:08:10	2	0.36	22	98.3	0.4	92.0	0.4	269.1	2.7	57.6	2.9
20:09:48	2	0.36	56	96.2	0.5	90.2	0.5	265.5	2.8	56.8	0.5
20:10:47	2	0.32	25	94.1	0.4	88.6	0.5	269.6	4.5	57.5	2.8
20:10:51	3	0.32	69	95.5	0.8	90.2	0.6	266.1	5.1	56.6	2.2
20:11:47	2	0.48	16	99.9	0.5	91.6	0.6	269.8	4.5	57.7	1.3
20:12:22	2	0.32	65	93.5	0.3	88.6	0.2	265.7	3.9	58.5	1.7
20:15:24	2	0.64	18	98.7	0.5	88.4	0.7	264.6	7.4	57.0	0.7

Appendix continued

Time-UT	N	Dur	Q	Hbeg		Hend		RAapp		DECapp	
20:15:42	3	0.72	43	98.7	0.3	87.5	0.2	263.6	2.9	56.6	0.6
20:16:07	4	0.68	20	97.7	0.3	86.1	0.2	269.3	1.6	57.2	0.4
20:20:16	4	0.61	44	96.7	0.1	86.2	0.1	269.1	0.8	57.3	0.2
20:24:43	2	0.44	14	98.9	0.5	91.6	0.4	271.6	4.9	57.7	1.1
20:25:56	3	0.64	74	98.7	0.3	88.3	0.3	270.0	1.2	56.8	0.5
20:25:58	5	0.68	78	97.7	0.3	86.4	0.2	268.2	2.1	57.5	0.5
20:29:26	3	0.48	20	97.9	0.3	90.0	0.3	269.8	2.4	58.0	1.0
20:33:26	3	0.38	54	96.6	0.4	90.5	0.3	265.1	4.0	58.1	1.2
20:42:07	3	0.87	23	97.4	0.1	83.0	0.2	269.3	0.8	58.2	0.4
20:52:09	6	0.76	23	101.0	0.2	89.2	0.2	268.9	1.3	57.6	0.2
20:57:43	2	0.34	15	97.5	0.3	92.5	0.4	266.1	5.9	57.5	2.5
20:59:41	4	0.64	22	97.5	0.1	87.7	0.1	268.9	1.0	57.4	0.3
20:59:56	3	0.96	43	100.6	0.2	86.0	0.2	268.2	0.7	57.3	0.4
21:04:48	3	1.50	46	104.6	0.1	81.5	0.1	269.4	0.3	57.8	0.1
21:10:59	2	0.60	19	97.6	0.2	88.4	0.2	272.1	2.5	58.4	0.4
21:11:32	3	1.12	23	99.2	0.1	81.7	0.1	269.7	0.8	57.6	0.2
21:12:39	3	1.70	71	99.9	0.1	75.3	0.2	268.3	0.9	57.4	0.5
21:37:01	3	0.33	59	94.7	0.7	90.2	0.6	268.2	2.8	58.6	0.9
21:38:47	2	0.72	64	98.6	0.1	88.5	0.1	269.2	0.6	58.1	0.2
21:39:10	3	0.42	64	96.3	0.2	90.8	0.3	266.4	3.7	58.0	1.2
21:52:28	2	0.45	28	97.2	0.6	91.0	0.5	271.7	2.1	59.2	0.7
21:55:42	4	0.80	89	98.0	0.1	87.1	0.1	268.8	0.5	58.2	0.3
21:59:50	3	0.82	61	98.7	0.3	88.4	0.3	267.5	2.2	58.3	0.6
22:01:26	2	1.68	22	102.6	0.2	79.3	0.4	268.9	0.3	58.9	0.8
22:01:44	3	0.86	44	99.8	0.2	89.1	0.2	269.3	0.8	58.0	0.3
22:31:38	2	0.76	20	98.5	0.2	90.2	0.1	264.6	2.0	57.6	0.8
22:31:38	2	0.76	20	98.5	0.2	90.2	0.1	264.6	1.9	57.6	0.7
22:36:27	2	0.40	17	99.1	0.4	94.4	0.4	269.2	3.6	58.5	0.7
23:37:17	2	1.52	31	101.6	0.3	85.0	0.4	267.6	0.2	61.5	1.3
0:49:05	2	0.94	72	98.4	0.1	90.2	0.1	266.1	0.4	61.5	0.2

Time-UT	N	Dur	Q	RAg		DECg		Vinf		Vg	
18:19:13	2	0.54	16	260.6	7.1	58.2	7.7	24.5	2.5	22.0	3.3
18:20:31	2	0.76	15	263.3	1.8	55.1	1.2	22.8	0.3	20.1	0.4
18:34:01	2	0.56	67	263.8	2.7	55.6	2.0	23.8	0.4	21.2	0.5
18:42:21	3	0.36	60	260.7	3.8	54.1	3.3	23.4	0.8	20.7	1.0
18:57:17	2	0.60	30	260.6	5.5	54.4	4.2	22.7	0.9	19.9	0.9
19:05:14	2	0.39	21	265.3	4.0	56.3	2.7	24.2	0.6	21.6	0.7
19:10:52	2	0.73	20	262.5	5.0	56.2	4.1	22.5	0.5	19.7	0.5
19:10:52	5	0.68	73	263.5	1.5	55.9	0.8	23.4	0.2	20.8	0.2
19:11:39	2	0.48	74	264.2	2.6	55.5	1.5	23.8	0.5	21.2	0.5
19:13:13	4	0.64	30	263.7	2.8	55.4	1.6	23.6	0.4	21.0	0.5
19:17:44	2	0.50	27	261.5	7.5	55.6	6.8	23.5	0.6	20.9	0.7

Appendix continued

Time-UT	N	Dur	Q	RAg		DECg		Vinf		Vg	
19:17:55	3	0.40	67	256.8	5.0	53.1	4.1	24.3	0.6	21.9	0.7
19:20:29	2	0.96	63	262.4	1.8	55.6	1.1	23.6	0.2	21.0	0.3
19:23:32	3	0.44	78	268.3	6.2	56.2	5.2	22.5	0.7	19.8	0.7
19:31:24	2	0.39	32	262.8	3.6	55.9	2.6	25.1	0.6	22.6	0.7
19:32:06	2	0.57	53	263.9	3.6	56.5	2.5	24.1	0.7	21.6	0.7
19:34:46	3	0.74	17	264.9	7.5	56.3	8.2	23.3	0.4	20.6	0.5
19:39:22	3	0.57	44	262.4	3.0	55.4	1.7	22.6	0.4	19.9	0.4
19:43:26	2	0.74	19	263.7	2.6	55.9	1.8	23.7	0.3	21.2	0.4
19:47:55	2	0.44	17	260.6	8.8	55.2	7.0	23.4	0.9	20.8	0.9
19:50:30	2	0.64	49	262.8	4.5	54.9	3.9	22.4	0.4	19.6	0.4
19:53:08	3	0.92	19	265.3	2.0	55.6	1.2	23.8	0.3	21.2	0.3
19:55:34	2	0.48	16	261.1	3.6	53.8	2.0	22.3	0.4	19.5	0.5
20:01:43	2	0.36	20	259.0	5.3	54.0	3.3	22.9	0.5	20.3	0.6
20:03:26	2	0.76	17	262.8	2.8	56.8	1.6	23.9	0.4	21.4	0.5
20:07:40	3	0.59	29	263.7	3.1	56.0	2.4	23.2	0.3	20.6	0.3
20:08:10	2	0.36	22	263.6	5.2	56.2	3.1	22.8	0.7	20.1	0.8
20:09:48	2	0.36	56	259.7	4.4	55.2	3.1	22.4	0.5	19.7	0.6
20:10:47	2	0.32	25	264.1	6.5	56.2	4.4	23.1	0.7	20.4	0.9
20:10:51	3	0.32	69	260.9	10.4	55.0	7.3	23.7	1.1	21.1	1.3
20:11:47	2	0.48	16	264.5	5.9	56.4	5.2	23.6	0.7	21.0	0.7
20:12:22	2	0.32	65	258.8	8.2	56.8	4.4	21.5	0.7	18.5	0.8
20:15:24	2	0.64	18	258.6	11.4	55.4	8.5	22.5	0.8	19.7	1.0
20:15:42	3	0.72	43	258.0	3.8	54.7	3.0	23.0	0.2	20.4	0.3
20:16:07	4	0.68	20	264.0	3.0	55.9	1.6	23.7	0.4	21.1	0.4
20:20:16	4	0.61	44	263.8	1.6	56.0	1.0	23.6	0.2	21.0	0.2
20:24:43	2	0.44	14	266.0	6.2	56.3	5.2	23.1	0.5	20.4	0.6
20:25:56	3	0.64	74	264.5	3.7	55.2	1.5	23.2	0.6	20.5	0.6
20:25:58	5	0.68	78	262.5	3.0	56.0	2.2	23.1	0.4	20.4	0.5
20:29:26	3	0.48	20	264.2	3.2	56.5	2.4	23.4	0.4	20.7	0.4
20:33:26	3	0.38	54	259.1	5.2	56.4	4.4	23.2	0.4	20.5	0.6
20:42:07	3	0.87	23	263.7	1.8	56.5	0.9	23.4	0.2	20.8	0.2
20:52:09	6	0.76	23	263.2	1.8	55.8	1.3	23.4	0.2	20.7	0.2
20:57:43	2	0.34	15	260.3	6.9	55.2	6.0	22.8	0.4	20.1	0.5
20:59:41	4	0.64	22	263.0	2.2	55.5	1.1	23.0	0.2	20.3	0.2
20:59:56	3	0.96	43	263.2	2.3	55.4	0.7	24.3	0.3	21.9	0.4
21:04:48	3	1.50	46	264.2	0.7	56.1	0.3	24.3	0.1	21.9	0.1
21:10:59	2	0.60	19	266.5	4.1	56.4	2.8	23.4	0.4	20.8	0.5
21:11:32	3	1.12	23	264.0	1.3	55.7	0.6	23.3	0.1	20.7	0.1
21:12:39	3	1.70	71	262.4	1.4	55.1	1.0	22.9	0.1	20.3	0.2
21:37:01	3	0.33	59	262.8	7.0	56.4	3.9	24.3	1.0	21.8	1.1
21:38:47	2	0.72	64	264.2	2.3	55.9	0.6	24.4	0.3	22.0	0.4
21:39:10	3	0.42	64	260.9	6.3	55.4	4.0	23.4	0.6	20.8	0.6
21:52:28	2	0.45	28	265.8	6.0	56.8	2.4	23.7	0.5	21.2	0.6

Appendix continued

Time-UT	N	Dur	Q	RAg		DECg		Vinf		Vg	
21:55:42	4	0.80	89	263.2	1.5	55.5	0.5	23.3	0.2	20.7	0.2
21:59:50	3	0.82	61	262.1	2.7	55.5	2.5	23.7	0.2	21.1	0.2
22:01:26	2	1.68	22	263.4	2.0	56.2	0.3	23.4	0.2	20.8	0.3
22:01:44	3	0.86	44	263.4	3.2	55.3	0.8	23.3	0.4	20.7	0.5
22:31:38	2	0.76	20	259.2	3.2	53.9	1.9	23.0	0.3	20.3	0.3
22:31:38	2	0.76	20	259.2	3.3	53.9	1.8	23.0	0.3	20.3	0.3
22:36:27	2	0.40	17	263.4	6.8	55.2	4.0	23.0	0.6	20.4	0.7
23:37:17	2	1.52	31	263.2	2.2	57.8	0.8	24.0	0.3	21.5	0.4
0:49:05	2	0.94	72	262.9	0.6	56.7	0.6	23.4	0.1	20.7	0.1

Time-UT	JDT	e		q		incl		peri		node
18:19:13	2455843.26334943	0.710	0.264	0.996	0.001	33.9	4.5	172.5	12.8	194.962
18:20:31	2455843.26424994	0.685	0.041	0.996	0.001	30.6	0.7	173.4	1.0	194.963
18:34:01	2455843.27362819	0.742	0.056	0.997	0.001	32.0	0.9	173.9	1.7	194.972
18:42:21	2455843.27940648	0.729	0.103	0.994	0.003	31.1	1.6	171.3	2.4	194.978
18:57:17	2455843.28977707	0.675	0.118	0.994	0.003	30.3	1.9	171.2	3.3	194.988
19:05:14	2455843.29529976	0.755	0.082	0.998	0.002	32.6	1.4	175.2	2.5	194.993
19:10:52	2455843.29921443	0.638	0.102	0.996	0.003	30.6	1.5	173.1	3.4	194.997
19:10:52	2455843.29921635	0.706	0.023	0.997	0.001	31.7	0.4	173.8	1.0	194.997
19:11:39	2455843.29975145	0.746	0.055	0.997	0.001	31.9	0.8	174.2	1.6	194.998
19:13:13	2455843.30085064	0.730	0.057	0.997	0.001	31.7	0.8	173.8	1.8	194.999
19:17:44	2455843.30397727	0.709	0.164	0.995	0.001	31.8	2.5	172.3	5.8	195.002
19:17:55	2455843.30411192	0.792	0.107	0.990	0.003	32.1	1.8	168.2	3.4	195.002
19:20:29	2455843.30589487	0.718	0.033	0.996	0.001	31.8	0.6	173.0	1.2	195.004
19:23:32	2455843.30800839	0.664	0.124	0.999	0.002	30.4	1.9	177.3	4.3	195.006
19:31:24	2455843.31347073	0.814	0.080	0.996	0.002	33.7	1.3	173.3	2.2	195.011
19:32:06	2455843.31396340	0.743	0.081	0.997	0.001	32.7	1.3	174.2	2.0	195.012
19:34:46	2455843.31581241	0.694	0.190	0.998	0.003	31.5	2.9	174.9	5.7	195.014
19:39:22	2455843.31900089	0.663	0.049	0.996	0.002	30.5	0.8	172.8	2.0	195.017
19:43:26	2455843.32182399	0.729	0.048	0.997	0.001	32.1	0.8	173.9	1.9	195.019
19:47:55	2455843.32494612	0.708	0.183	0.995	0.001	31.5	2.5	171.5	6.5	195.023
19:50:30	2455843.32673918	0.661	0.091	0.996	0.003	30.1	1.4	173.0	3.2	195.024
19:53:08	2455843.32856140	0.747	0.037	0.997	0.001	31.9	0.6	175.0	1.3	195.026
19:55:34	2455843.33025781	0.668	0.054	0.995	0.003	29.6	1.0	171.5	2.5	195.028
20:01:43	2455843.33452634	0.693	0.088	0.993	0.005	30.6	1.4	170.0	3.9	195.032
20:03:26	2455843.33572174	0.718	0.055	0.996	0.001	32.6	0.9	173.5	1.7	195.033
20:07:40	2455843.33866059	0.694	0.062	0.997	0.002	31.5	0.9	174.0	2.2	195.036
20:08:10	2455843.33900731	0.661	0.086	0.997	0.003	30.9	1.6	173.9	3.4	195.037
20:09:48	2455843.34013913	0.640	0.079	0.994	0.003	30.3	1.2	170.7	3.2	195.038
20:10:47	2455843.34081880	0.681	0.118	0.997	0.003	31.3	1.9	174.3	4.4	195.038
20:10:51	2455843.34087343	0.733	0.205	0.995	0.002	31.9	3.2	171.7	7.4	195.038
20:11:47	2455843.34151659	0.713	0.141	0.997	0.003	32.0	2.0	174.6	4.1	195.039

Appendix continued

Time-UT	JDT	e		q		incl		peri		node
20:12:22	2455843.34191750	0.546	0.113	0.994	0.007	29.5	1.8	170.4	6.5	195.040
20:15:24	2455843.34403204	0.634	0.192	0.993	0.003	30.5	3.2	170.0	9.5	195.042
20:15:42	2455843.34423975	0.680	0.068	0.992	0.004	31.0	1.1	169.4	3.0	195.042
20:16:07	2455843.34452820	0.730	0.048	0.997	0.001	32.0	0.8	174.1	2.0	195.042
20:20:16	2455843.34740678	0.720	0.029	0.997	0.001	31.9	0.4	174.0	1.1	195.045
20:24:43	2455843.35050164	0.687	0.132	0.998	0.003	31.2	1.9	175.7	4.3	195.048
20:25:56	2455843.35133689	0.712	0.057	0.997	0.002	31.1	0.9	174.3	2.5	195.049
20:25:58	2455843.35137130	0.679	0.061	0.996	0.002	31.3	1.0	173.0	2.1	195.049
20:29:26	2455843.35377699	0.694	0.062	0.997	0.002	31.8	1.1	174.4	2.2	195.051
20:33:26	2455843.35655395	0.659	0.100	0.994	0.005	31.7	1.6	170.7	4.2	195.054
20:42:07	2455843.36257975	0.693	0.025	0.997	0.001	31.8	0.5	174.1	1.2	195.060
20:52:09	2455843.36955352	0.706	0.032	0.997	0.001	31.6	0.5	173.6	1.2	195.067
20:57:43	2455843.37341395	0.665	0.140	0.995	0.001	30.8	2.1	171.3	5.2	195.071
20:59:41	2455843.37477492	0.687	0.031	0.996	0.001	31.0	0.5	173.3	1.5	195.072
20:59:56	2455843.37495811	0.780	0.029	0.996	0.001	32.6	0.6	173.4	1.6	195.072
21:04:48	2455843.37832762	0.770	0.010	0.997	0.000	32.8	0.2	174.3	0.5	195.075
21:10:59	2455843.38262524	0.712	0.074	0.998	0.002	31.7	1.2	176.0	2.9	195.080
21:11:32	2455843.38301308	0.711	0.016	0.997	0.001	31.5	0.3	174.1	0.9	195.080
21:12:39	2455843.38377927	0.688	0.028	0.996	0.001	30.8	0.4	172.7	1.0	195.081
21:37:01	2455843.40070767	0.751	0.131	0.996	0.001	33.0	1.9	173.4	5.4	195.097
21:38:47	2455843.40192993	0.781	0.030	0.997	0.001	32.9	0.5	174.2	1.6	195.099
21:39:10	2455843.40220287	0.706	0.106	0.995	0.006	31.6	1.7	171.7	4.5	195.099
21:52:28	2455843.41142979	0.719	0.076	0.998	0.004	32.3	1.1	175.7	4.3	195.108
21:55:42	2455843.41368464	0.709	0.017	0.996	0.001	31.4	0.3	173.5	1.1	195.110
21:59:50	2455843.41655552	0.727	0.058	0.996	0.002	31.9	0.9	172.7	2.1	195.113
22:01:26	2455843.41766387	0.700	0.016	0.997	0.001	31.7	0.4	173.8	1.5	195.114
22:01:44	2455843.41786696	0.715	0.034	0.996	0.002	31.3	0.6	173.5	2.3	195.114
22:31:38	2455843.43863432	0.701	0.047	0.993	0.003	30.7	0.7	170.0	2.5	195.135
22:31:38	2455843.43863432	0.701	0.045	0.993	0.003	30.7	0.7	170.0	2.6	195.135
22:36:27	2455843.44197960	0.697	0.102	0.996	0.005	31.0	1.8	173.5	4.9	195.138
23:37:17	2455843.48422200	0.702	0.023	0.997	0.001	33.1	0.4	174.1	1.8	195.180
0:49:05	2455843.53408028	0.681	0.013	0.996	0.001	31.8	0.2	173.5	0.5	195.230

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