Data analysis problems

Important!

All the cited figures and the table are included on separate pages which are signed by the number of the problems.

1.

a) Estimate the maximum altitude (in km) of matter in volcanic jet at the rim of Io. Calculate the velocity of gas at the starting point on Io surface and compare it to orbital and escape velocity V_1 and V_2. Remember to estimate the errors of your results! $R_{Io} = 1820$ km, $M_{Io} = 9 \times 10^{22}$ kg. (15 p)

b) Identify constellations on the picture, calculate the scale and angular size of the picture. Mark picture position on the attached map. Using the map try to estimate the coordinates of the meteors' radiant. Estimate the angular length of the longest trails.

The equatorial coordinates of Regulus: R.A. = 10^h08^m, Dec = +11°58', and the coordinates of Dubhe: R.A. = 11^h03^m, Dec = +61°45'. (15 p)

c) Based on the presented images recorded at apocentrum and pericentrum of the orbit, determine the eccentricity of the orbit of Moon and Earth. (15 p)

(45 p)

2. The figures show the light curve of a variable star based on visual brightness (V) estimates by the members of the variable star section of Hungarian Astronomical Association. It is clearly seen that the light curve is periodic.

a) Estimate the period of the light curve in days and its error. (35 p)

b) Estimate the amplitude of the brightness variation in magnitude. (5 p)

c) What kind of variable star could produce brightness variation and light curve with such a period and amplitude? (5 p)

(45 p)

3. The table lists the astrometric positions of the star designed by S2 which is orbiting around the supermassive black hole in the center of the Milky Way, Sgr A*. The data were collected by ESO's NTT and VLT telescopes between 1992 and 2009, and published by Gillessen et al (*ApJ Letters* **707** L114 (2009)).

The table contains seven columns:

(1) row number
(2) year of the astrometric observation (AEpoch)
(3) offset in Right Ascension (oRA) relative to Sgr A*
(4) uncertainty in oRA (e_oRA)
(5) offset in Declination (oDE) relative to Sgr A*
(6) uncertainty in oDE (e_oDE)
(7) telescope used in astrometric observation (Atel)

The position of the black hole is (0, 0), the offsets of S2 positions are measured in milliarcseconds (mas).

a) On a graph paper plot as many (oRA, oDE) positions of S2 as you can. If you use the scale factor of 1 mas mm^{-1} and scale the entire oRA axis between −100 and 80, and the entire oDE axis between −50 and 220, then you can plot the points quite easily. After correct plotting of the data the elliptical orbit of S2 around Sgr A* will be outlined. (15 p)

b) While plotting try to estimate the orbital period of S2 in years. (10 p) *Hint:* The data given in the table cover a slightly longer time span than the orbital cycle.

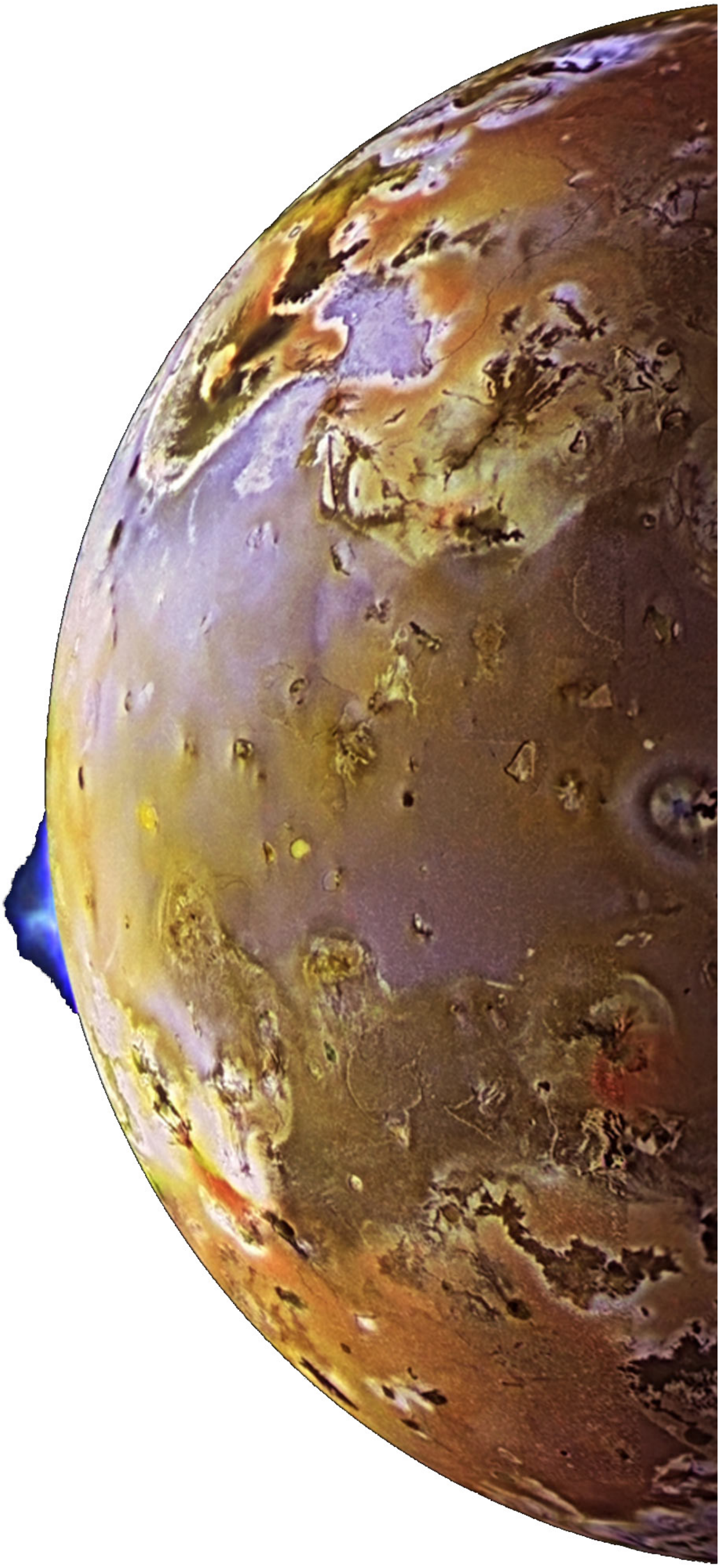
c) Estimate the semi-major axis of the orbit in milliarcseconds. (10 p) *Hints:* From the accurate orbit fitting by Gillessen et al. (2009), the eccentricity is $e \approx 0.88$, while the inclination of the orbit is $i \approx 135°$. S2 last approached the black hole on 19 May 2018. Remember the value of the orbital period determined in the previous task.

d) According to Gillessen et al. (2009) the distance to the center of the Milky Way is $R_0 \approx 8.3$ kpc. Give the semi-major axis of the orbit in Astronomical Units (AU). (10 p)

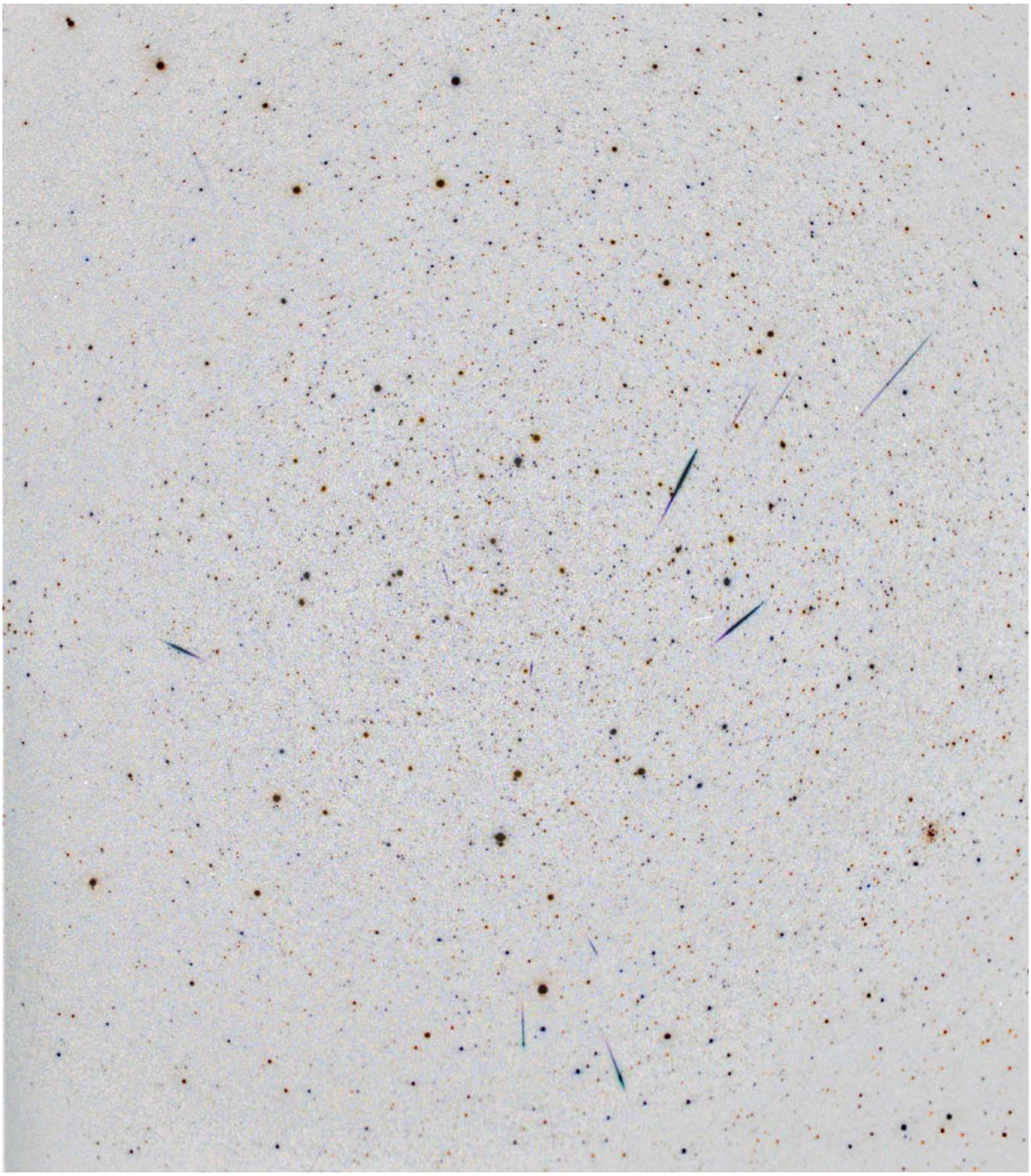
e) Calculate the mass of the supermassive black hole Sgr A*. (15 p)

(60 p)

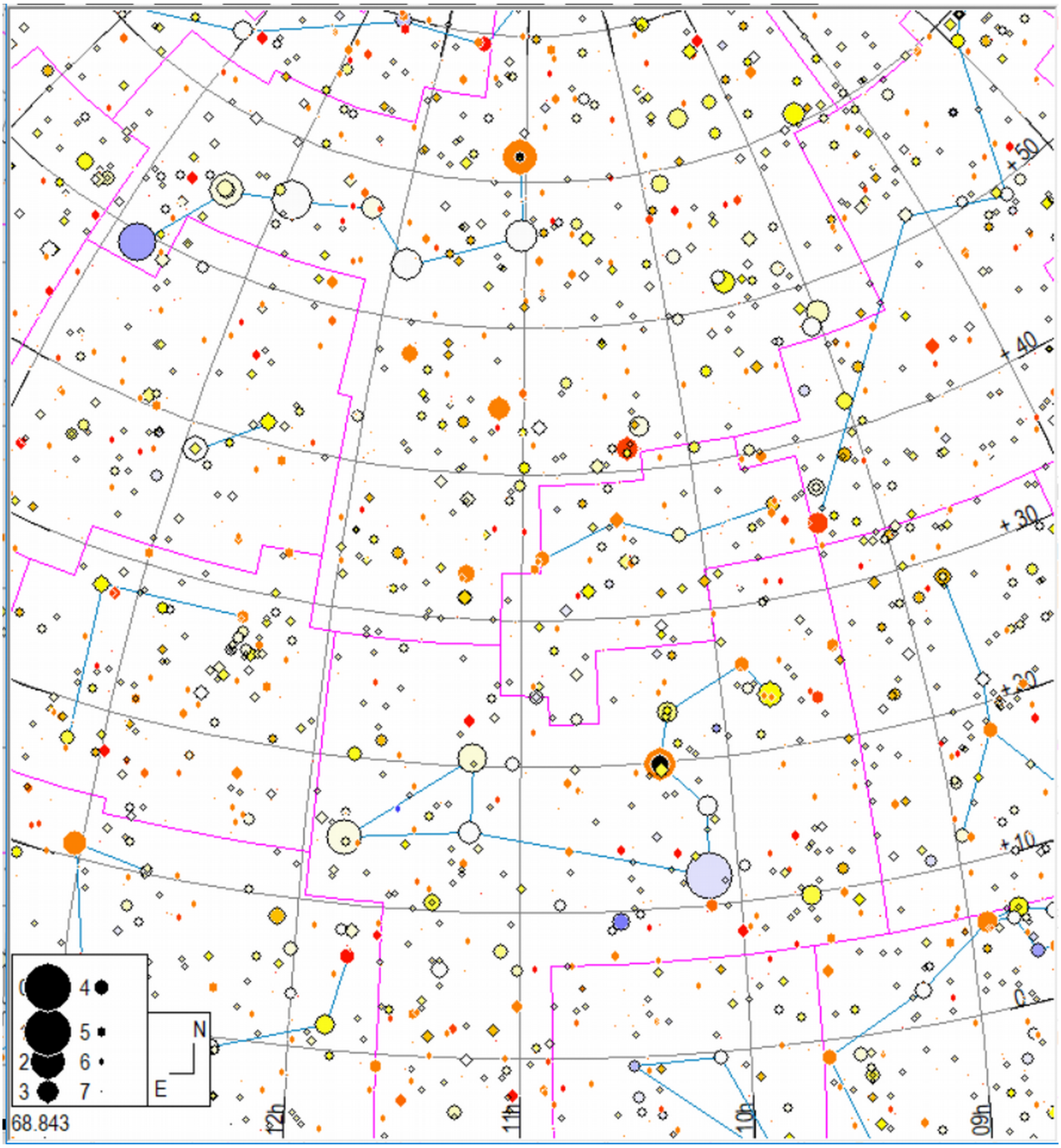
1 a)



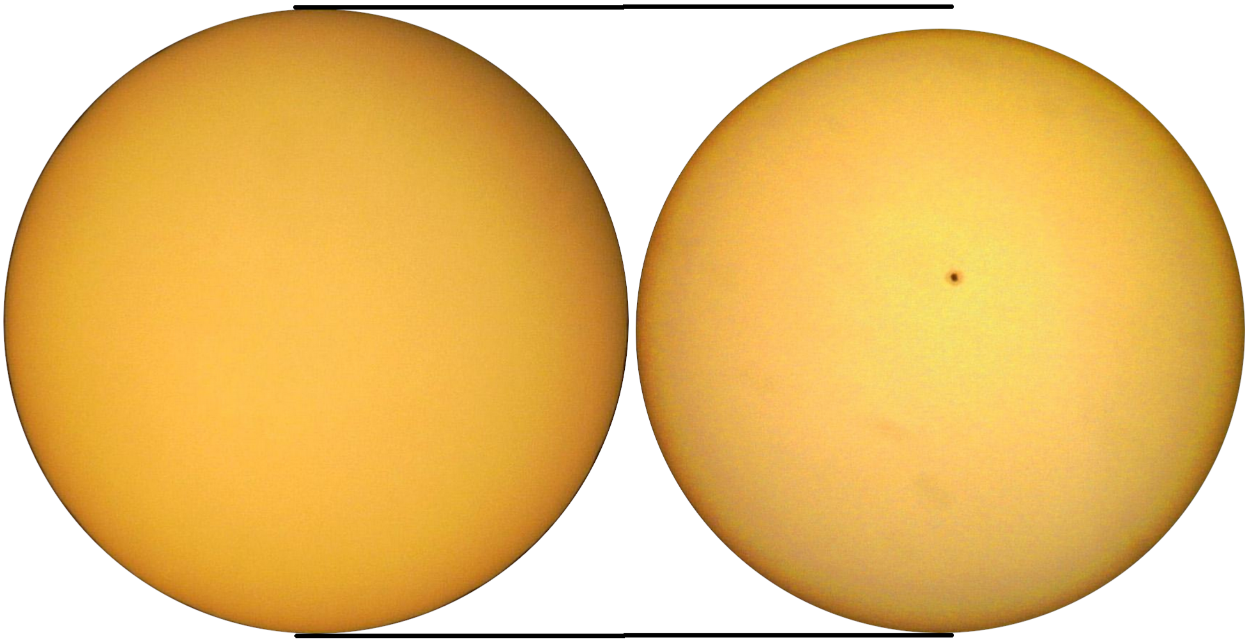
1 b)

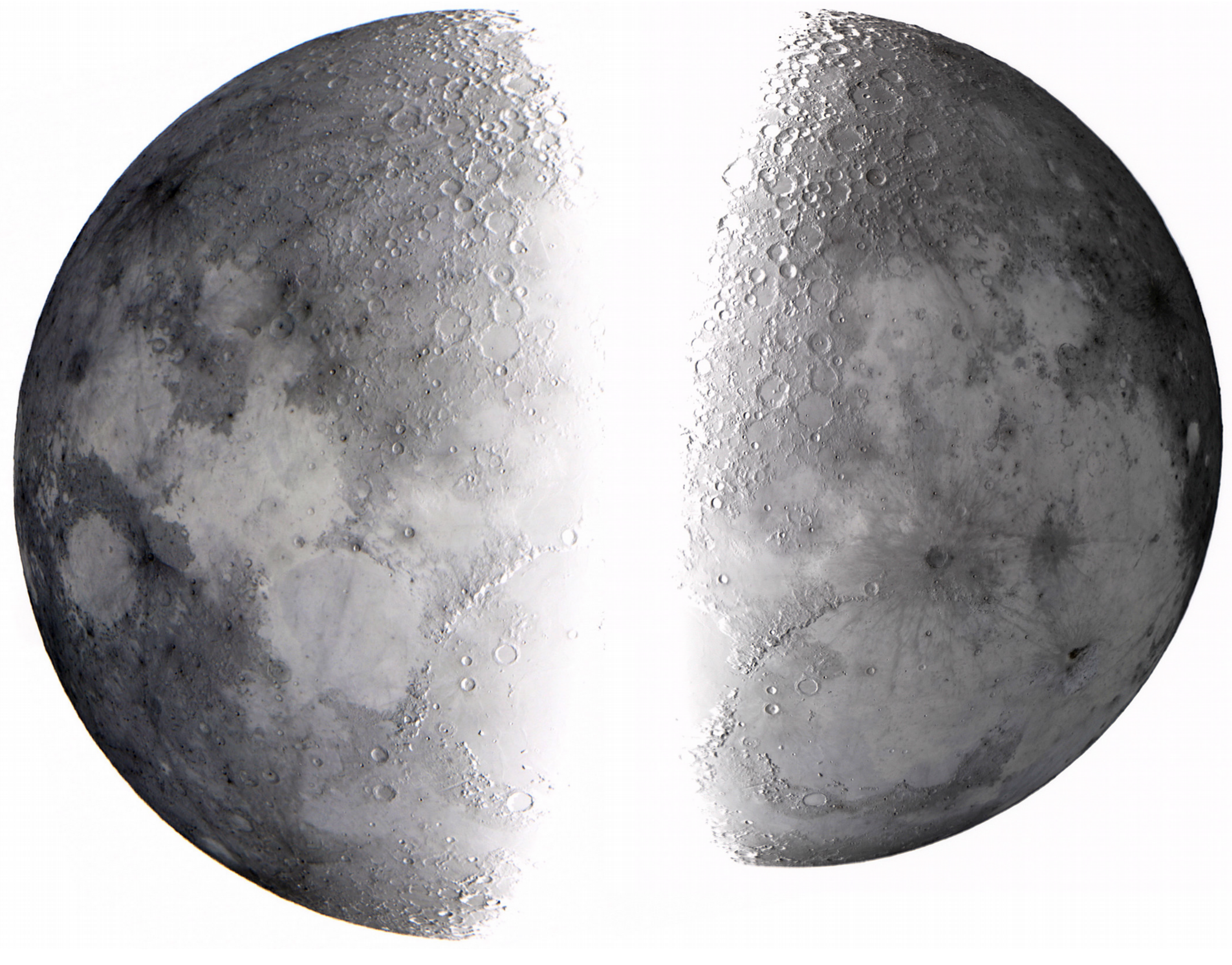


1 b)

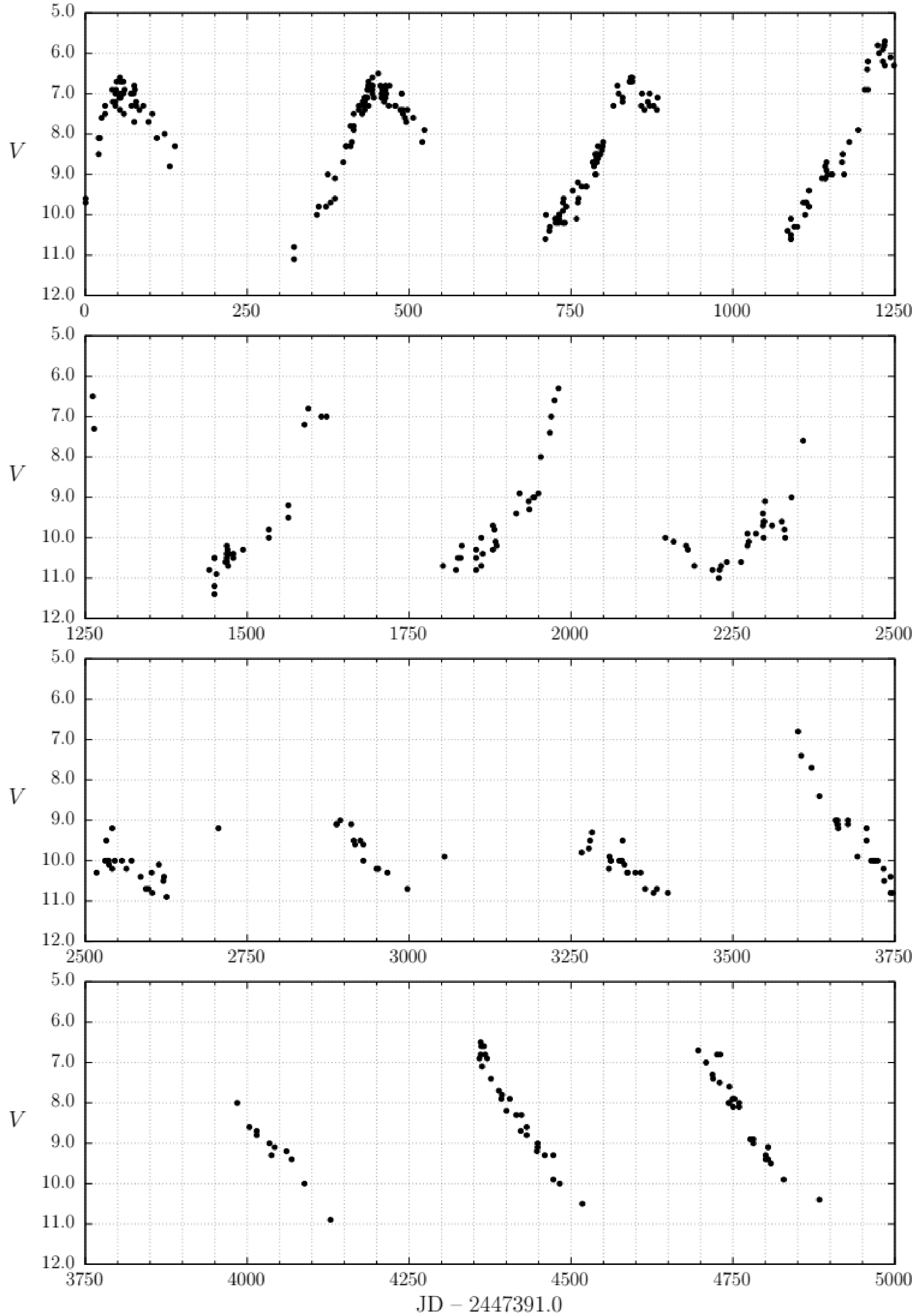


1 c)



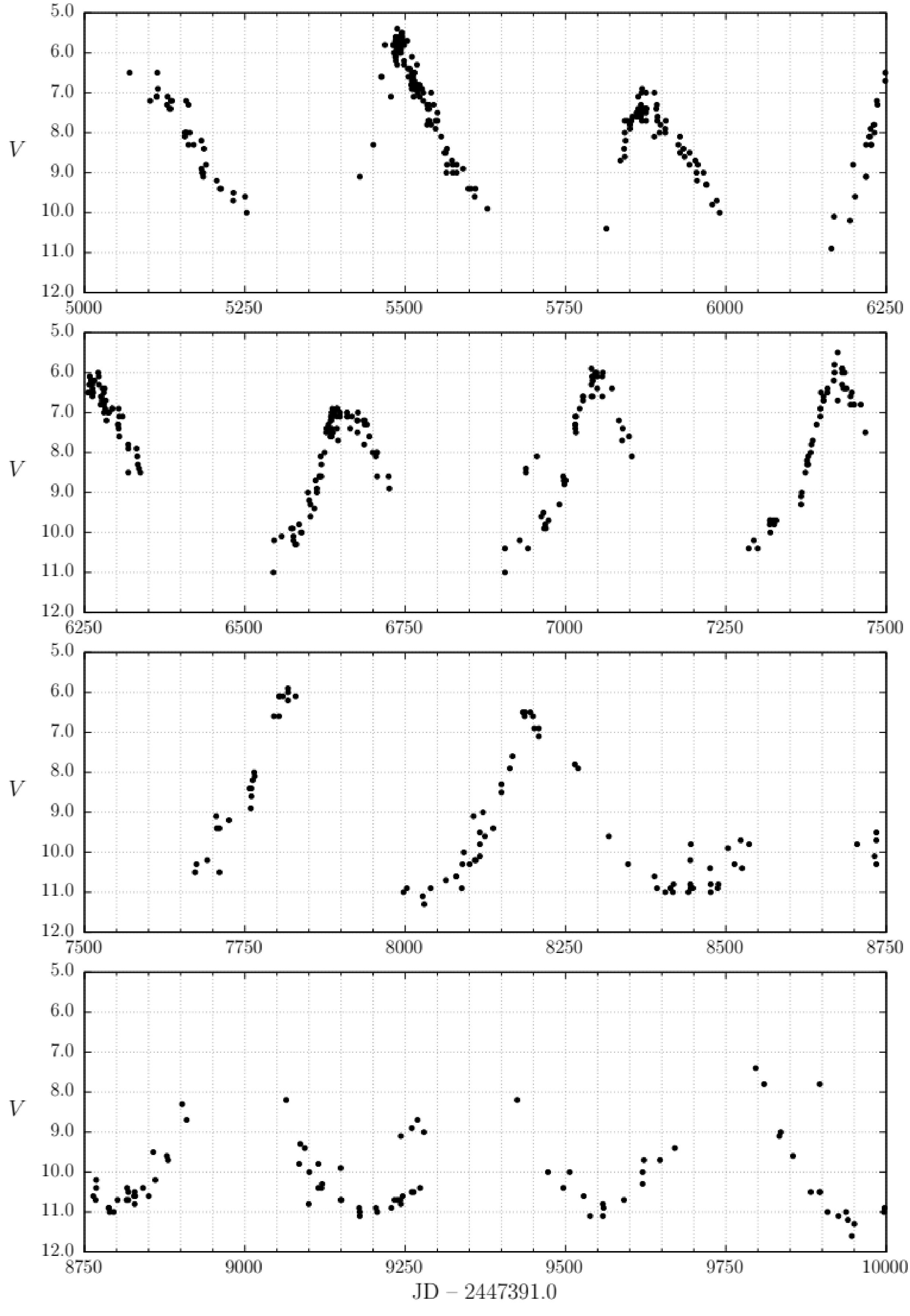


2.



5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
V
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
4750
5000
JD − 2447391.0

2.



V
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
5000
5250
5500
5750
6000
6250
6500
6750
7000
7250
7500
7750
8000
8250
8500
8750
9000
9250
9500
9750
10000
JD − 2447391.0

(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	1992.224	-6.4	4.6	172.0	4.7	NTT
2	1994.314	-28.5	4.8	179.0	3.4	NTT
3	1995.534	-37.3	3.8	172.1	4.3	NTT
4	1996.253	-43.4	3.6	164.4	3.6	NTT
5	1996.427	-45.9	1.9	161.5	5.3	NTT
6	1997.544	-59.0	3.4	130.4	2.8	NTT
7	1998.373	-65.3	4.7	122.1	3.5	NTT
8	1999.465	-67.5	4.4	106.0	4.1	NTT
9	2000.472	-55.3	5.0	63.9	3.1	NTT
10	2001.502	-49.3	3.8	23.8	2.1	NTT
11	2002.250	-3.1	4.0	-6.6	4.0	VLT
12	2002.335	6.6	2.7	-7.6	2.7	VLT
13	2002.393	16.3	3.8	0.0	3.8	VLT
14	2002.409	18.2	3.3	2.1	3.3	VLT
15	2002.412	17.3	3.3	2.3	3.3	VLT
16	2002.414	17.4	3.3	3.2	3.3	VLT
17	2002.488	27.8	11.5	14.9	10.4	NTT
18	2002.578	30.8	3.3	20.7	3.3	VLT
19	2002.660	33.7	3.2	27.3	3.2	VLT
20	2002.660	34.1	3.2	26.9	3.2	VLT
21	2003.214	41.1	0.3	66.6	0.4	VLT
22	2003.351	41.4	0.3	75.0	0.3	VLT
23	2003.356	40.7	0.4	74.8	0.4	VLT
24	2003.446	40.6	0.5	79.8	0.5	VLT
25	2003.451	41.3	0.4	80.4	0.4	VLT
26	2003.452	41.5	0.3	80.5	0.3	VLT
27	2003.454	40.9	0.3	80.6	0.3	VLT
28	2003.454	41.3	0.4	81.8	0.4	VLT
29	2003.550	40.9	0.3	85.3	0.3	VLT
30	2003.676	40.6	0.3	91.8	0.3	VLT
31	2003.678	41.1	0.6	91.6	0.6	VLT
32	2003.761	40.2	0.4	96.6	0.4	VLT
33	2004.240	37.2	0.9	113.2	0.9	VLT
34	2004.325	36.9	0.3	116.2	0.3	VLT
35	2004.347	36.1	0.3	117.6	0.3	VLT
36	2004.443	36.0	0.3	120.4	0.3	VLT
37	2004.513	35.3	0.3	123.1	0.3	VLT
38	2004.516	35.2	0.6	123.1	0.6	VLT
39	2004.574	34.3	0.6	123.9	0.6	VLT
40	2004.574	34.4	0.4	124.8	0.4	VLT
41	2004.664	33.6	0.3	127.2	0.3	VLT
42	2004.730	34.0	0.7	128.9	0.7	VLT
43	2005.270	28.1	0.3	143.0	0.3	VLT
44	2005.366	27.0	0.3	145.2	0.3	VLT
45	2005.467	26.3	0.4	146.9	0.4	VLT
46	2005.576	24.9	0.4	149.4	0.4	VLT
47	2006.324	17.5	0.8	161.7	0.6	VLT
48	2007.545	2.8	0.9	175.7	0.7	VLT
49	2007.550	4.1	0.4	175.2	0.4	VLT
50	2007.686	2.5	0.5	176.0	0.5	VLT
51	2007.687	1.9	0.6	176.0	0.6	VLT
52	2008.148	-4.6	0.4	179.0	0.4	VLT
53	2008.197	-5.2	0.3	179.0	0.3	VLT
54	2008.268	-6.1	0.3	180.0	0.3	VLT
55	2008.456	-8.4	0.3	180.2	0.3	VLT
56	2008.472	-8.1	0.4	180.7	0.4	VLT
57	2008.601	-10.6	0.3	180.3	0.3	VLT
58	2008.708	-11.4	0.3	181.2	0.3	VLT
59	2009.185	-17.3	0.7	181.1	0.7	VLT
60	2009.273	-18.0	0.3	181.2	0.3	VLT
61	2009.300	-18.5	0.3	181.3	0.3	VLT
62	2009.303	-18.2	0.3	181.5	0.3	VLT
63	2009.336	-18.3	0.3	181.2	0.3	VLT
64	2009.336	-18.4	0.4	181.2	0.4	VLT
65	2009.371	-18.6	0.3	181.0	0.3	VLT
66	2009.505	-20.1	0.3	181.2	0.3	VLT
67	2009.557	-20.2	0.3	181.4	0.3	VLT
68	2009.557	-20.9	0.4	181.5	0.4	VLT
69	2009.606	-21.2	0.3	181.5	0.3	VLT