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Close Approaches of Potentially Hazardous Asteroids during Two Centuries

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Abstract Asteroids are the most important small bodies in the solar system and the near-earth asteroids (NEAs) are of especial concern to the world. The reason is that they will make close approaches to the earth in the near future. We use a reasonable dynamical model and an efficient computing method to calculate the orbits of over 160 Potentially Hazardous Asteroids (PHAs) for two centuries.

Key words: celestial mechanics — asteroids — Earth

1 INTRODUCTION

Near-earth asteroids (NEAs) can move very near the earth or intrude into the earth orbit, hence they are of particular concern to the world. Even more so are the so-called Potentially Hazardous Asteroids (PHAs). PHAs (JPL, http://neo.jpl.nasa.gov/neo/pha.html) are currently defined by parameters that measure the asteroid's potential of making threateningly close approaches to the earth. Specifically, all asteroids with an earth Minimum Orbit Intersection Distance (MOID) of 0.05 AU or less and an absolute V-magnitude (H) of 22.0 or brighter are considered as PHAs. We should carefully watch and track these unexpected and dangerous "earth visitors", keeping a detailed record of their close-approaching status, such as the MOID and the encounter time. A lot of research work has been done in this field in recent years: Minor Planet Center (MPC, http://cfa-www.harvard.edu/iau/mpc.html) maintains the daily list of PHAs; Chesley et al. (Chesley & Milani 1999) have contributed an online website of NEODyS to provide asteroid information; Bowell et al.(Bowell 1999; http://www.lowell.edu/users/elgb/current_moid.html) have also presented asteroid ephemerides services via their website, etc. Another important motivation that drives us to the present work is that late last year a group of Hawaiian astronomers announced that an asteroid (2000 SG344) will collide with the earth in 2030, but one day later they corrected their statement and that the

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impact possibility would be down to a little more than one in thousand in 2071. Consequently, in this paper, after an introduction we shall report on our computation of 160 PHAs' orbits and show their encounter status during a period of two centuries.

As far as the tracking and observing of PHAs is concerned, many space-watching programs, such as LINEAR, NEAT, SPACEWATCH etc., have been set up; in addition, the project of 1.0 m/1.2 m Schmidt telescope in search of NEOs, sponsored by Purple Mountain Observatory of Chinese Academy of Sciences will be completed in 2002. International collaboration is so important to provide the new observations by monitoring PHAs in time, so that PHAs' orbits can be better determined and their future earth-impact threat will be well predicted.

This paper is organized as follows: Section 2 describes the dynamical model in the computation; Section 3 introduces the computation method we adopted; Section 4 presents our results and a brief discussion.

2 DYNAMICAL MODEL

In the dynamical model, the eleven large bodies are the sun, the nine major planets from Mercury to Pluto and the moon. In addition, the three biggest asteroids (the "Big 3", i.e., Ceres, Pallas and Vesta) in the main belt are also taken into account. As several NEAs such as (1566) Icarus can move so close to the sun, the relativity effect is also considered in the model. The orbits of the major planets, the moon and the Big 3 are calculated as well as the NEA's. In the heliocentric ecliptic coordinate system referred to J2000.0, the equations of motion can be uniformly written as

$$\begin{aligned} \ddot{\vec{r}}_i &= -(1+\mu_i)\frac{\vec{r}_i}{r_i^3} - \sum_{j=1,\, j\neq i}^{14} \mu_j \left(\frac{\vec{\Delta}_{ji}}{\Delta_{ji}^3} + \frac{\vec{r}_j}{r_j^3}\right) \\ &\quad + \left(\vec{A}_{\rm PN}\right)_i + \left(\vec{A}_{\rm Fig}\right)_e, \quad i = 1, ..., 14 \end{aligned} \tag{1}$$

where $\vec{r}_i$, $\vec{r}_j$ denote position vectors of the major planets ($i = 1 \sim 9$), the moon ($i = 10$), the Big3 ($i = 11 \sim 13$) and the NEA ($i = 14$), with $\vec{\Delta}_{ji} = \vec{r}_i - \vec{r}_j$, μ_i and μ_j are these bodies' masses with respect to the sun. The mass of the NEA can be neglected, so in the right-sided expression of Equation (1) for the other bodies, the gravitational terms from the NEA will not appear. $(\vec{A}_{\rm PN})_i$ stands for Post-Newtonian terms, which stem from the gravitational effect of the sun. $(\vec{A}_{\rm Fig})_e$ represents the effect of the figuration of the earth, which becomes important when the NEA moves very close to the earth.

It is worth noting that in the above model the perturbation of the moon is well separated from that of the earth. The reason is very obvious: when an asteroid comes near the earth, it will also come near the moon, necessitating a more detailed evaluation of the gravitational perturbation of the moon.

We take the initial elements of all the asteroids from the asteroid orbital elements database given by Bowell (Bowell, ftp://ftp.lowell.edu/pub/elgb/astorb.dat.gz) on Dec. 22, 2000. The starting positions and velocities of the planets and moon, as well as their masses, come from the JPL planetary and Lunar Ephemerides DE405/LE405, in which the slight difference between ICRF and J2000.0 is neglected.

3 COMPUTATIONAL METHOD

For the qualitative study of asteroid orbits, the symplectic algorithm (Feng 1984, 1986; Forest et al. 1990; Wisdom et al. 1991), which has many advantages such as holding the symplectic structure of the Hamiltonian system, is preferably used in the dynamical evolution of the asteroids. Liu et al. (Liu 1998, 1999a, 1999b) have come to the conclusion that the algorithm is fairly efficient and the computations are credible as long as the asteroid does not move too close to some of the major planets. However, when the asteroid is close to one or several major planets, the stepsize has to be frequently changed in the course of the integration because of the accumulating gravitation, then the merit of the symplectic algorithm is completely lost and it becomes not as good as the automated stepsize-adjusted non-symplectic algorithm, such as the RKF7(8) integrator (Fehlberg 1968), RADAU integrator (Everhart 1985) and Bulirsch-Stoer (Stoer & Bulirsch 1980) integrator.

As for the numerical method, though it is convenient to change the stepsize by using variable-stepsize integrators, yet the orbital period of the moon is so short with respect to those of the planets and other asteroids, that the total integration stepsize cannot but be kept smaller, which will lead to loss of computational efficiency. However, we have got a solution of the problem, that is, in the integration the geocentric orbital elements of the moon are adopted as the integration variables, which are further transformed into heliocentric positions and velocities with the help of the heliocentric vector of the earth (Ji & Liu 2000), while for the other bodies we still use the position and velocity vectors. Using this method the stepsize in the integration can be adjusted to much larger values, so greatly improving the computational efficiency.

4 RESULTS AND DISCUSSIONS

All of the numerical integration was carried out on Alpha workstations. The results are given for 100 years for the limited size of this paper, but the full results are available. In Table 1 the name (and the number) of the asteroids, the encountering time and the MOID (less than 0.05 AU) are listed, sorted by the distances. And we have also compared our results with those of MPC, and found most of them are in good agreement; but the dynamical model in this paper is based on more detailed considerations. We can draw the conclusion that the dynamical model is reasonable for the computation of close approaches of the PHAs and that the algorithm used is effective.

Table 1 160 PHAs Close Encounters with the Earth during the Next Century (JD=2451900.5, 2000.12.22)

Object	Name	Date of Encounter (TT) Calendar	Distance (AU)	Object	Name	Date of Encounter (TT) Calendar	Distance (AU)
	1999 AN10	2027 Aug. 7.26	0.002651	4660	Nereus	2060 Feb. 14.38	0.008033
	1999 RQ36	2060 Sept.23.21	0.004047		1998 SC15	2095 Apr. 9.31	0.008497
	2000 QK130	2036 Mar. 14.94	0.004634		1997 WQ23	2068 Nov. 4.42	0.009871
	1997 XF11	2028 Oct. 26.25	0.006168		1999 JU3	2076 Dec. 6.05	0.01048
2340	Hathor	2086 Oct. 21.82	0.006184	4179	Toutatis	2004 Sept.29.18	0.01064
	2340 Hathor	2069 Oct. 21.31	0.006606		2000 UG11	2051 Nov. 10.23	0.01068
	1998 HH49	2023 Oct. 16.81	0.007692		2000 QK130	2083 Mar. 14.57	0.01153
	1999 DB7	2048 Feb. 28.09	0.007925		1999 AQ10	2009 Feb. 18.76	0.01179

Table 1 Continued

Object	Name	Date of Encounter (TT) Calendar	Distance (AU)
	1998 OR2	2079 Apr. 16.69	0.01185
4581	Asclepius	2051 Mar. 24.55	0.01205
	1998 WT24	2001 Dec. 16.18	0.01249
	1988 TA	2053 Oct. 1.51	0.01253
	1998 WT24	2099 Dec. 18.16	0.01266
	1999 VP11	2017 Oct. 22.78	0.01267
	1998 SF36	2004 June 26.67	0.01291
	2000 AA6	2060 Jan. 13.09	0.01296
7482	1994 PC1	2022 Jan. 18.98	0.01326
	1994 WR12	2046 Nov. 25.91	0.01360
	1999 MN	2036 June 1.87	0.01406
	1998 WT24	2054 Dec. 19.26	0.01435
	1997 WQ23	2052 Nov. 3.28	0.01442
4660	Nereus	2071 Feb. 4.29	0.01547
	1999 KW4	2036 May 25.57	0.01554
	1989 UQ	2093 Aug. 13.08	0.01592
	2000 DO1	2094 Mar. 10.52	0.01627
	1997 QK1	2039 July 14.35	0.01682
	1994 CC	2009 June 10.44	0.01702
	1997 NC1	2026 June 27.29	0.01713
	2000 TU28	2051 Apr. 12.66	0.01726
	1999 SO5	2086 Apr. 7.05	0.01782
	1999 KW4	2071 May 26.26	0.01787
	1999 MN	2004 July 11.62	0.01805
	1995 CR	2014 Feb. 20.79	0.01833
	1998 WB2	2037 Dec. 4.69	0.01856
	1999 AN10	2081 Aug. 5.95	0.01903
3200	Phaethon	2093 Dec. 14.46	0.01981
	1999 FA	2046 Mar. 4.82	0.01984
4179	Toutatis	2069 Nov. 5.72	0.01985
	2000 EW70	2059 Mar. 25.33	0.01987
	1997 QK1	2025 Aug. 20.78	0.02003
	2000 SP43	2076 Sept.19.14	0.02050
	2000 PN9	2006 Mar. 6.43	0.02083
	2000 AA6	2086 July 29.25	0.02083
	1999 MM	2088 July 14.13	0.02089
3361	Orpheus	2091 Apr. 18.80	0.02114
3362	Khufu	2045 Aug. 22.23	0.02120
	1997 XF11	2095 Oct. 26.20	0.02210
	1999 MN	2076 July 11.44	0.02222
	1997 NC1	2088 June 26.23	0.02239
	1994 CN2	2042 Aug. 6.66	0.02244
	1998 BB10	2033 July 21.30	0.02300
	2000 AF6	2081 Dec. 13.70	0.02302
4953	1990 MU	2058 June 5.39	0.02314
	1999 MN	2030 July 11.11	0.02319
	1998 HE3	2073 May 10.79	0.02345
	1999 AN10	2076 Feb. 2.68	0.02372
	1999 RM45	2021 Mar. 3.09	0.02402
	1989 UQ	2087 Dec. 2.50	0.02403
	1997 WQ23	2084 Nov. 7.38	0.02412
	1998 BB10	2076 July 22.02	0.02422
2340	Hathor	2045 Oct. 21.68	0.02430
	1999 UR	2033 Oct. 27.22	0.02430
	1998 CS1	2080 Jan. 20.78	0.02441
	1999 KW4	2089 May 26.30	0.02447
6037	1988 EG	2041 Feb. 28.16	0.02449
	1998 HE3	2059 May 11.05	0.02472
	1998 DV9	2095 Feb. 7.32	0.02480
7822	1991 CS	2065 Aug. 31.16	0.02498
4769	Castalia	2046 Aug. 26.65	0.02512
	2000 CO101	2057 Sept.17.19	0.02523
	1996 RG3	2096 Feb. 27.75	0.02524
8566	1996 EN	2070 Sept. 8.71	0.02528
	1999 MN	2010 June 3.63	0.02532
	1999 FA	2095 Mar. 7.65	0.02560
	1994 PM	2003 Aug. 16.24	0.02562
	1998 VD35	2042 May 12.05	0.02580
	2000 RS11	2014 Mar. 12.30	0.02584
	1999 GS6	2071 Sept.10.95	0.02585
	2000 GJ147	2099 May 17.68	0.02586
	1994 CC	2074 June 15.62	0.02607
	2000 RD53	2043 Sept.19.73	0.02614
	1999 JT6	2076 Dec. 14.81	0.02615
4660	Nereus	2021 Dec. 11.73	0.02632
	1989 UP	2050 Dec. 8.06	0.02675
7335	1989 JA	2022 May 27.75	0.02693
	1998 WT24	2040 Dec. 20.73	0.02738
	1998 WT24	2015 Dec. 11.65	0.02798
3671	Dionysus	2085 June 18.29	0.02802
	2000 HA24	2079 Mar. 17.83	0.02810
	1998 QP	2053 Aug. 25.93	0.02856
	2000 RW37	2047 Feb. 23.98	0.02888
4660	Nereus	2002 Jan. 22.35	0.02903
13651	1997 BR	2051 July 23.73	0.02908
	1998 BY7	2018 June 28.40	0.02912
12538	1998 OH	2042 May 3.24	0.02921
	1998 CS1	2009 Jan. 17.59	0.02927
	2000 RD53	2074 Sept.25.16	0.02930
	2000 EW70	2069 Mar. 25.15	0.02933
	1997 WQ23	2013 Nov. 7.37	0.02959
8566	1996 EN	2033 Sept. 8.43	0.03042
9856	1991 EE	2065 Sept. 6.29	0.03056
	1999 MN	2041 June 3.91	0.03068
4953	1990 MU	2027 June 7.01	0.03083
	2000 PD3	2097 Jan. 10.25	0.03106
	1998 FW4	2046 Feb. 13.77	0.03114
	2000 EJ26	2070 Apr. 2.38	0.03120
	1999 MN	2082 June 4.21	0.03137
	1998 VO	2046 Apr. 30.80	0.03148
	2000 CO101	2096 Sept.17.19	0.03148
	1999 JV6	2098 Jan. 6.18	0.03195
	2000 AZ93	2050 Dec. 31.53	0.03197
	1999 YR14	2069 Oct. 22.62	0.03211

Table 1 Continued

Object	Name	Date of Encounter (TT) Calendar	Distance (AU)
	2000 GE2	2024 Oct. 3.70	0.03225
	1998 SC15	2042 Apr. 7.14	0.03226
	1999 KW4	2001 May 26.12	0.03237
	1999 JV6	2016 Jan. 6.45	0.03248
	1989 UP	2078 Dec. 13.50	0.03257
	1999 SG10	2078 Oct. 10.40	0.03285
	1999 RQ36	2005 Sept.20.41	0.03305
1862	Apollo	2082 May 12.27	0.03336
	1998 HE3	2012 May 10.40	0.03356
5604	1992 FE	2017 Feb. 24.28	0.03361
	1997 XF11	2090 May 19.40	0.03365
	2000 ED14	2090 Mar. 17.15	0.03416
6037	1988 EG	2079 Aug. 22.76	0.03427
	1999 KW4	2019 May 25.99	0.03463
	2000 JG5	2045 Apr. 25.67	0.03488
	1998 WT24	2085 Dec. 6.85	0.03501
	2000 HA24	2038 Sept.27.82	0.03506
11500	1989 UR	2053 Nov. 26.90	0.03514
	1999 LX1	2068 June 5.52	0.03514
	1988 TA	2080 May 14.62	0.03518
	2000 QW7	2019 Sept.14.91	0.03520
	1999 RM45	2095 Sept. 5.64	0.03525
1862	Apollo	2046 Nov. 13.12	0.03530
	1999 BJ8	2054 Feb. 24.50	0.03533
2101	Adonis	2036 Feb. 7.32	0.03570
	2000 AA6	2051 July 28.05	0.03573
	1991 GO	2089 Oct. 27.69	0.03580
	1994 XL1	2088 Dec. 5.74	0.03605
	1998 FW4	2009 Oct. 1.07	0.03614
	2000 AZ93	2071 Jan. 3.31	0.03623
	1998 VO	2056 May 3.47	0.03665
	1994 XD	2052 June 10.52	0.03670
	2000 GJ147	2094 May 16.14	0.03689
	2000 ET70	2059 Feb. 19.59	0.03696
4450	Pan	2060 Feb. 17.60	0.03700
	1998 SH36	2091 Oct. 12.20	0.03746
	1994 XL1	2077 Dec. 4.60	0.03756
	2000 EE104	2030 Nov. 11.10	0.03764
	1994 CN2	2038 Oct. 20.10	0.03764
	1998 FG2	2003 Oct. 21.58	0.03781
3361	Orpheus	2025 Nov. 19.03	0.03792
3757	1982 XB	2074 Dec. 18.17	0.03793
	1994 XL1	2099 Dec. 7.13	0.03800
	1991 GO	2081 Oct. 25.78	0.03815
	1998 VF32	2090 Nov. 22.83	0.03818
	1998 SF36	2001 Mar. 29.49	0.03831
	2000 AZ93	2031 Jan. 4.52	0.03834
	1999 MN	2097 July 9.65	0.03835
	2000 QS7	2093 Sept. 8.72	0.03835
	2000 LB16	2051 Dec. 14.65	0.03839
	1998 QC1	2052 Jan. 20.58	0.03841
	1999 RQ36	2054 Sept.29.76	0.03843

Object	Name	Date of Encounter (TT) Calendar	Distance (AU)
3361	Orpheus	2021 Nov. 21.72	0.03856
	2000 AZ93	2070 Dec. 31.36	0.03872
	1997 QK1	2067 Aug. 26.09	0.03890
7822	1991 CS	2090 Sept. 1.16	0.03907
	1996 JG	2049 Nov. 25.26	0.03919
8014	1990 MF	2080 Sept.12.29	0.03933
	1998 WT	2040 Mar. 4.44	0.03938
	1998 FH12	2047 Feb. 15.41	0.03972
	1998 XN2	2032 Aug. 28.90	0.03979
	1991 GO	2073 Oct. 25.08	0.03987
	1994 XD	2012 Dec. 1.29	0.03995
	2000 JG5	2090 Apr. 27.16	0.04000
	2000 EE104	2031 Nov. 12.32	0.04007
	1994 WR12	2090 Nov. 22.86	0.04016
	2000 EV70	2055 Aug. 9.44	0.04023
	1992 UY4	2005 Aug. 8.63	0.04041
	2000 EJ26	2083 Apr. 2.11	0.04068
6037	1988 EG	2023 Aug. 23.16	0.04070
	2000 HA24	2034 Mar. 18.79	0.04090
4450	Pan	2008 Feb. 19.67	0.04091
	2000 QW7	2087 Sept.19.73	0.04095
	1998 HE3	2096 May 10.71	0.04095
	1999 MN	2071 July 10.15	0.04097
	1997 BQ	2020 May 21.77	0.04117
	1998 HL1	2019 Oct. 25.45	0.04163
	2000 AZ93	2030 Dec. 31.98	0.04202
	2000 EE104	2029 Nov. 10.81	0.04204
	1998 OR2	2020 Apr. 29.68	0.04205
	1994 WR12	2069 Nov. 29.65	0.04209
	2000 EV70	2069 Mar. 6.18	0.04220
	1999 YR14	2016 Sept. 4.36	0.04234
	1998 XN2	2094 Nov. 30.04	0.04235
	1999 FA	2027 Mar. 4.33	0.04248
	1998 FG2	2032 Mar. 1.99	0.04249
	1998 WT24	2068 Dec. 22.07	0.04254
	2000 ET70	2047 Feb. 19.65	0.04267
	1994 XL1	2005 Dec. 6.88	0.04279
	2000 DP107	2067 Sept.20.56	0.04280
	2000 EH26	2053 May 12.39	0.04295
	1999 JV6	2015 Dec. 31.91	0.04306
	2000 GE2	2022 Sept.29.27	0.04306
	2000 UL11	2038 Mar. 26.51	0.04317
	1994 XL1	2066 Dec. 4.47	0.04360
1566	Icarus	2090 June 14.45	0.04362
	1988 TA	2013 May 9.29	0.04380
	1998 VF32	2079 Nov. 22.91	0.04394
2102	Tantalus	2038 Dec. 27.20	0.04446
	1991 VH	2065 Aug. 6.52	0.04450
	1999 JV6	2097 Dec. 31.64	0.04452
	1998 FW4	2029 Sept.28.61	0.04471
	1998 SH36	2010 June 7.80	0.04487
	1991 VH	2088 Aug. 15.47	0.04533

Table 1 Continued

Object	Name	Date of Encounter (TT) Calendar	Distance (AU)
	2000 ET70	2012 Feb. 19.63	0.04546
	1998 DV9	2058 Feb. 12.35	0.04550
	1998 SF36	2036 June 8.04	0.04555
	1999 KW4	2054 May 25.67	0.04573
	2000 CO101	2009 Sept.17.75	0.04575
	1991 VH	2008 Aug. 15.27	0.04579
	1998 FW4	2095 Feb. 14.67	0.04588
	1998 FH12	2088 Feb. 17.02	0.04595
	2000 DP107	2075 Sept.13.37	0.04597
	1999 UR	2046 Dec. 18.60	0.04600
	2000 AZ93	2091 Jan. 9.93	0.04622
	2000 AZ93	2099 Dec. 17.62	0.04632
	1998 FH12	2052 June 30.35	0.04637
4179	Toutatis	2012 Dec. 12.57	0.04637
	2000 QK130	2066 Mar. 20.78	0.04646
	2000 AZ93	2011 Jan. 10.58	0.04671
	1999 JD6	2054 July 25.60	0.04703
	2000 BF19	2055 Aug. 26.36	0.04712
4581	Asclepius	2099 Aug. 23.53	0.04715
	1993 BX3	2021 Jan. 17.56	0.04734
	1993 VB	2023 Feb. 22.33	0.04736
	1999 VP11	2077 Oct. 20.85	0.04739
	1999 YG3	2067 Jan. 14.77	0.04739
	1999 JU3	2033 Dec. 21.03	0.04742
	1998 HH49	2097 Oct. 12.42	0.04762
1620	Geographos	2051 Aug. 22.97	0.04789
	1998 HD14	2050 Apr. 5.93	0.04791
	1996 GT	2003 Nov. 12.52	0.04805
	1998 WT	2079 Mar. 7.89	0.04823
2340	Hathor	2014 Oct. 21.70	0.04827
	1999 GS6	2058 Sept.11.45	0.04838
	1998 SH36	2015 Oct. 14.60	0.04841
	1999 MN	2077 June 1.67	0.04855
	2000 CE59	2057 Aug. 16.91	0.04946
13651	1997 BR	2068 July 24.81	0.04948
	1998 WT24	2029 Nov. 25.85	0.04958
	1996 GT	2062 Oct. 19.47	0.04986

As more and more PHAs are being or will be discovered and their orbits will be further refined and better determined with more observations, it is clear that precise orbits of the PHAs are important for their future orbital motion. The predictions of the PHAs' close approaches are sensitive to the initial conditions, so we will construct an online website on this topic to update the results everyday. In our future papers, we will introduce our work on the dynamics of the orbital evolution of the NEAs.

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References

Bowell E. A, DPS meeting #31, #28.03, 1999
Chresley S. R., Minali A., DPS meeting #31, #28.06, 1999
Feng K., Proc. 1984, In: Feng K. ed., Beijing Symposium on Differential Geometry and Differential Equations, Beijing: Science Press, 1985, p.42
Feng K., 1986, J. Comp. Math., 4, 279
Fehlberg E., Classical Fifth-, Sixth, Seventh-and Eight-order Runge-Kutta formulas with stepsize control., NASA TR R-287, 1968
Forest E., Ruth R. D., 1990, Physica D, 43, 105
Everhart E., In: A. Carusi, G. B. Valsecchi, eds., Dynamics of Comtes: Their Origin and Evolution, Reidel: Dordrecht, 1985, p.185
Liu L., Ji J. H., 1998, Chin. Astron. Astrophys., 22, 218
Liu L., Ji J. H., Liao X. H., 1999a, Chin. Astron. Astrophys, 23, 108
Liu L., Ji J. H., 1999b, Chin. Astron. Astrophys., 23, 273
Ji J. H., Liu L., 2000, Science in China (A), 43, 1114
Wisdom J., Holman M., 1991, AJ, 102, 1528