NEW ADDITIONS TO THE ASTRONOMICAL ALMANAC: ALMANAC DATA FOR DWARF PLANETS

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ABSTRACT *The Astronomical Almanac* (AsA) is regarded as a standard publication, therefore any changes to it must reflect current astronomical understanding. Following IAU resolution B5, (1) Ceres, (13340) Pluto, (136108) Haumea, (136199) Eris and (136472) Makemake have been designated dwarf planets. Beginning with the 2013 edition, the AsA will reflect this new classification scheme. New additions with regard to dwarf planets and calculations used to obtain them are discussed in this paper. We also present new definitions and their application for dwarf planets.

1. INTRODUCTION

Section G of the AsA has been restructured to cover "Dwarf Planets and Small Solar System Bodies". We follow the new IAU classification scheme (see IAU Resolution B5 and B6) for solar system bodies throughout this section (and also Section E which deals with planets). This scheme distinguishes between three main types of bodies:

1. Planets: a "planet" is in orbit around the Sun, has sufficient mass for its self-gravity to assume a hydrostatic equilibrium (nearly round) shape, and has cleared the neighbourhood around its orbit.
2. Dwarf Planets: a "dwarf planet" is in orbit around the Sun, and assumes a hydrostatic equilibrium (nearly round) shape, but it has not cleared the neighbourhood around its orbit (and is not a satellite).
3. Small Solar System Bodies: all other bodies, except satellites, in orbit around the Sun.

Data for comets and bright minor planets continue to be given within Section G in the format of previous editions of the AsA. This paper explains the new data which have been added to Section G for dwarf planets. The current list of dwarf planets considered in the AsA follows the list published on the IAU website which includes the following objects: Ceres, Pluto, Haumea, Eris and Makemake. Given that dwarf planets are a new category in solar system nomenclature, new discoveries and reclassifications of known objects are likely. Additionally, ephemerides and estimates of physical properties are subject to change. Thus, the contents and data for these objects are likely to change in the foreseeable future. Table 1 lists the physical properties of the five dwarf planets as published in the 2013 edition of the AsA.

2. CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS

In order to calculate ephemerides for physical observations of the dwarf planets, we use information provided in the 2009 report of the Working Group for Cartographic Coordinates and Rotational Elements (WGCCRE, Archinal et al., 2011a). At the moment, WGCCRE data are available for Pluto and Ceres. The main change for Pluto in the 2009 WGCCRE report was a change in the definition of poles due to its reclassification. An error was discovered in the 2009 WGCCRE data for Pluto during the preparation of the material for the 2013 AsA. Hence, an erratum was issued for the 2009 WGCCRE (Archinal et al. 2011b). We use these corrected values for Pluto. Dwarf planets and small solar system bodies (minor planets, comets) differ in the scheme used to describe cartographic coordinates and rotational elements

Name	Equ. Radius	Mass	Minimum Geo-centric Distance	Sidereal Period of Rotation	Maximum Angular Diameter	Geometric Albedo	Year of Dis-covery
	km	kg	au	d	′		
Ceres	479.7	9.39 x 10^{20}	1.5833	0.3781	0.840	0.073	1801
Pluto	1195.0	130.41 x 10^{20}	28.6031	6.3872	0.110	0.30	1930
Haumea	1000.0	42.00 x 10^{20}	33.5620	0.1631	0.092	0.73	2004
Eris	1200.0	166.95 x 10^{20}	37.5984	1.0800	0.088	0.86	2005
Makemake	850.0	–	37.0193	7.7710	0.053	0.78	2005

Table 1: Physical properties of dwarf planets (see AsA (2013))

	Dwarf Planets	Planets
Poles (defined differently for planets and dwarf planets)	Positive or negative pole: the direction follows the right hand rule.	North or south pole, depending on the position (above or below) in regard to the invariable plane of solar system
Cartographic Position of Prime Meridian (Definition is the same for both planets and dwarf planets): Where possible, this is defined by a surface feature, e.g.: • Ceres: (Unnamed) bright spot • Pluto: Sub-Charon point • Mars: Crater Airy-0		

Table 2: Some definitions for dwarf planets and planets from the 2009 WGCCRE report

compared to planets. Pluto's rotation which was described as retrograde while it was listed with the planets, is now a positive value. Table 2 gives the definition of some relevant data in detail.

3. ORBITAL DATA

For Ceres, Pluto and Eris we publish the following data (these objects have been chosen due to historical reasons - Ceres and Pluto are both well known objects, while the discovery of Eris has started the discussion on how a planet/dwarf planet should be defined. In the future, data of more dwarf planets are most likely going to be included in the AsA):

- Osculating elements for Ceres, Pluto and Eris: osculating elements are tabulated for three days per year. The chosen dates are 100 day dates (Table 3 shows an example of this).
- Heliocentric coordinates for Ceres, Pluto and Eris: like the osculating elements, the table is for three 100 day dates per year.
- Astrometric coordinates: are given for Ceres, Pluto and Eris if they have an opposition during the year of the AsA. A daily ephemeris 60 days either side of the opposition date is printed in such a case. Along with the ephemeris data, star charts showing the path of the dwarf planet are provided. The first chart shows an overview of the whole year (plus some overlap), the second chart is a detailed map of the path 60 days either side of the opposition date. Figure 1 shows the charts for Eris for the year 2013.

For Ceres and Pluto, enough observational data are available to also reliably provide the following information:

- Ephemerides for physical observations: are given in an interval of 10 days, and the data are tabulated over the whole year (see Table 4).

Name	Magnitude Parameters		Mean Diameter	Julian Date	Inclination	Long. of Asc. Node	Arg. of Perihelion	Semi-major Axis	Daily Motion	Eccentricity	Mean Anomaly
	H	G			i	Ω	ω	a	n	e	M
			km	245	○	○	○	au	○/d	○	
Ceres	3.34	0.12	952	6400.5	10.594	80.330	72.167	2.768	0.2140	0.076	327.8540426
				6500.5	10.594	80.329	72.259	2.767	0.2141	0.075	349.1710915
				6600.5	10.594	80.328	72.292	2.766	0.2141	0.075	10.5575049

Table 3: Osculating elements, given for the ecliptic and equinox of J2000.0 (Ceres, AsA (2013))

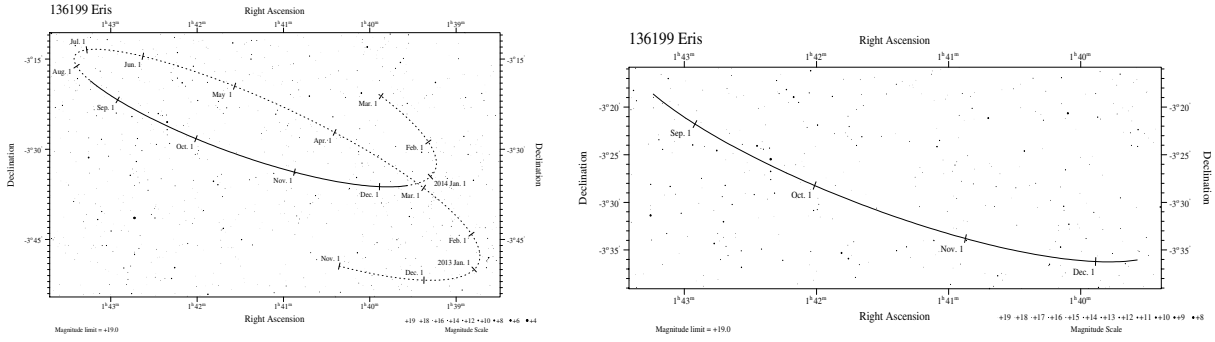

Figure 1: Star charts showing astrometric coordinates for a dwarf planet (in this case, Eris) : the first chart shows the path of the dwarf planet over the whole year, while the second chart is a detailed view of the path 60 days either side of opposition.

Date		Light Time	Visual Magnitude	Phase Angle	L_S	Sub-Earth Point Longitude	Sub-Earth Point Latitude	Positive Pole P.A.
		m		○	○	○	○	○
Jan	-12	277.07	14.2	0.4	59.00	259.40	+ 47.8	235.34
	-2	277.28	14.2	0.1	59.06	139.31	+ 48.1	235.00
	8	277.24	14.2	0.3	59.12	343.23	+ 48.4	234.65

Table 4: Excerpt of the ephemeris for physical observations, for 0^h terrestrial time (Pluto, AsA (2013))

4. CALCULATIONS

Different methods were used to calculate the published data. In detail these included:

- Osculating elements:

  Ceres: the same method and calculations as used for minor planets are applied. The data for Ceres therefore continue seamless from earlier editions, where Ceres is still tabulated with the minor planets.

  Pluto and Eris: the osculating elements for those two objects are calculated using methods as applied by USNO to produce the osculating elements for planets in Section E of the AsA. The mass of all the planets which are inside the orbit of Pluto or Eris is included in the calculations.

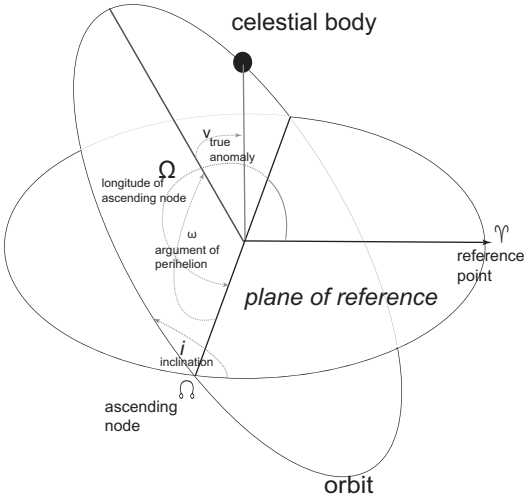

Figure 2: Osculating elements as they are tabulated in the AsA. The value of the true anomaly ν relates to the tabulated mean anomaly M: $\nu = M + (2e - e^3/4)\sin M + (5e^2/4)\sin 2M + (13e^3/12)\sin 3M + ...$

For Pluto we can therefore seamlessly go from the 2012 to the 2013 edition. Figure 2 shows the tabulated elements, Table 3 provides an example for the data as it is tabulated in the AsA.

- Heliocentric coordinates: this table is calculated using HMNAO routines; it is corrected for frame bias.
- Astrometric coordinates: this table is calculated the same way as the astrometric coordinates for minor planets.
- Ephemerides for physical observations: here, we follow the procedures used in Section E for planets to calculate these data for Pluto and Ceres. When looking at overlapping days between 2012 (e.g. from AsA 2012) and 2013 (see Table 4), the table for Pluto very clearly shows the difference which is due to different definitions between planets and dwarf planets - e.g. the position of the pole is 180 degrees shifted, since for dwarf planets the positive pole is tabulated as opposed to the north pole for planets.

5. REFERENCES

Archinal, B.A. et al., 2011a, "Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements: 2009", Celestial Mechanics and Dynamical Astronomy, Volume 109, Issue 2, pp.101-135

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