Asteroid data mining and precoveries in the Gaia area

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Abstract

Asteroids are components of a very large family of the Solar System. We denote more than 590 000 such objects at the present date. As soon as there is a discovery of an asteroid, a preliminary orbit can be calculated and the improvement of this orbit can be performed thanks to new observations to be done starting from their discovery. But ancient observations can also be retrieved in the past. The data mining allows us to find these old observations in archives. We present general considerations on the asteroid orbital precision in this article and the very important impact of the future Gaia catalogue. We show the expected consequences for the study of Near-Earth Asteroids, in particular for 99942 Apophis.

Introduction

The advent of a so accurate stellar catalogue than the Gaia catalogue (at the level of tens of microarcsec for stellar objects) will yield many improvements in different domains. For the asteroid science, it will be a very important step toward not only a better knowledge of the orbital characterization but of the physical one as well. In this article, after some considerations upon the status in terms of numbering and astrometric precision, we present some consequences of the Gaia measurements for the Near-Earth Asteroids (NEAs) orbital characterization, in particular through the study of the specific case of the Potentially Hazardous Asteroid (PHA) 99942 Apophis. But more generally we can also expect several improvements such as an easier identification of new objects by chaining ancient and new observations, a more efficient prediction of stellar occultations and the improvement of the risk assessment for the PHAs.

1- The asteroid number and astrometric accuracy

Asteroids are intensively observed by a wide astronomical community. Nowadays many professionals and amateurs provide observational data to databases. The astrometric measurements can come from different techniques and instrumentation. Several space missions have also recently provided important data leading to a substantial improvement of our vision of this numerous group of Solar System Objects. One main international center collects the astrometric data under the umbrella of the International Astronomical Union, the Minor Planet Center (http: //www.minorplanetcenter.org/iau/mpc.html). We can particularly found there a huge collection of observational data and of orbital elements. Besides, in another place, at Lowell Observatory, a complementary analysis is performed and we can access there another big database, labeled “Astorb” including several parameters related to the uncertainties on the orbital elements. At the Pisa university, complementary information is also provided concerning the asteroids (ASTDyS service at http://hamilton.dm.unipi.it/astdys/) or especially the Near-Earth Asteroids (NEODyS service at http://newton.dm.unipi.it/neodys/).

Table 1. List of the various kinds of astrometric measurements and related accuracy issued from the MPC database.

type	name	number of measurement	percentage of accepted measurement	accuracy	
C	CCD	73 938 542	99.48%	0.401	arcsec
S	Wise	1 497 360	99.89%	0.579	arcsec
S	Hubble Space Telesc.	867	96.54%	0.577	arcsec
S	Spitzer	48	33.33%	1.672	arcsec
A	B1950 to J2000	631 982	81.68%	1.175	arcsec
c	Corrected CCD obs.	419 070	99.68%	0.509	arcsec
P	Photographic	345 698	93.17%	1.088	arcsec
T	Meridian/transit circle	26 968	99.74%	0.288	arcsec
M	Micrometer	12 081	90.65%	1.896	arcsec
H	Hipparcos obs.	5494	100.00%	0.201	arcsec
E	Occultations	1570	100.00%	0.126	arcsec
R	Ranging	546	95.79%	5.695	km
R	Doppler	401	99.00%	7.128	km/s
V	Roving observer	356	49.72%	0.829	arcsec
e	Encoder	16	100.00%	0.557	arcsec

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Table 1 gives the distribution of the observations of the MPC database with respect to the different kinds of techniques. Obviously, the CCD technique, which shows the best quantum efficiency, provided the main part of the data. Table 2 gives the spanning period of the observations as issued from the ASTDyS database.

Table 2. List of the various astrometric measurements and related spanning period issued from AstDyS-2 (http://hamilton.dm.unipi.it/astdys/)

code	type	number	percentage	timespan
C	CCD	82 849 054	93.74%	1986-2012
S/s	Satellite observation	4 006 902	4.53%	1994-2011
	HST	3 544	0.09%	1994-2010
	Spitzer	114	0.00%	2004-2004
	WISE	4 003 244	99.91%	2010-2011
A	Observations from B1950.0 converted to J2000.0	647 649	0.73%	1802-1999
c	Corrected without republication CCD observation	462 065	0.52%	1991-2007
P	Photographic	352 113	0.40%	1898-2011
T	Meridian or transit circle	26 968	0.03%	1984-2005
X/x	Discovery observation	16 706	0.02%	1891-2010
M	Micrometer	12 081	0.01%	1845-1954
H	Hipparcos geocentric observation	5 494	0.01%	1989-1993
R/r	Radar observation	1 602	0.00%	1968-2006
E	Occultations derived observation	1 571	0.00%	1961-2011
V	"Roving observer" observation	372	0.00%	2000-2010
n	Mini-normal place derived from averaging observations from video frames	93	0.00%	2009-2011
e	Encoder	16	0.00%	1993-1995

2- The impact of the data mining

The Astorb database includes in particular a specific parameter named CEU (Current Ephemeris Uncertainty expressed in arcsec.) which is the absolute value of the current 1-sigma ephemeris uncertainty. The date of CEU is also provided in the records. A brief description of the uncertainty analysis technique is presented in Yeomans et al. (1987) and all the details can be found in Muinonen and Bowell (1993). This CEU parameter allowed us to get a global visualization of the improvement of the orbital precision along with the time interval of the observation. Depending on the length of arc where astrometric data exist and can be used to fit an orbital model, we get more or less precision. The figure 1 gives the relationship between this precision, as measured with the CEU parameter, the number of observations, and the length of orbital arc. Generally, the longer is the arc length, the more precise is the orbit.

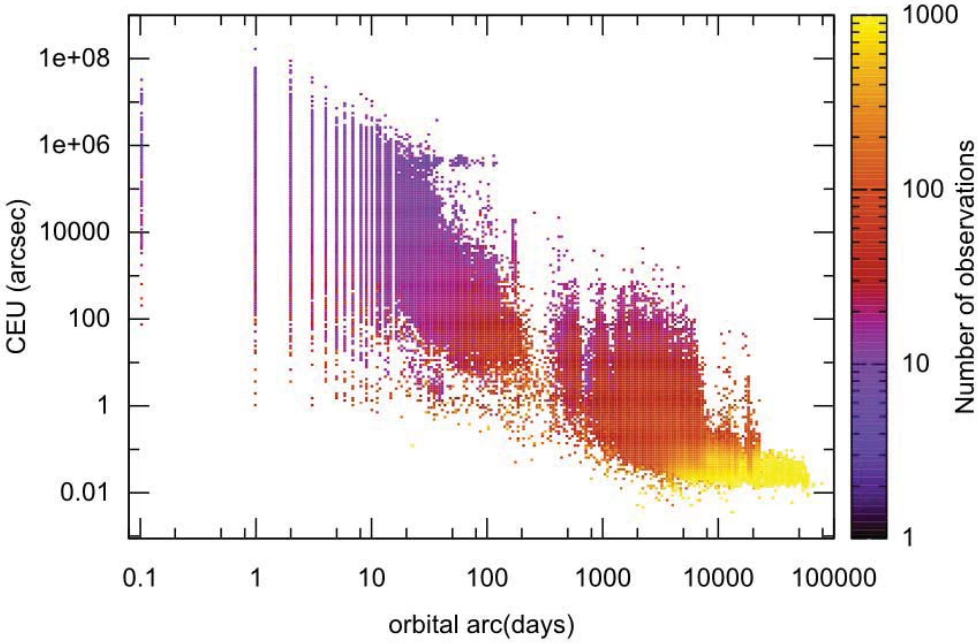

Figure 1. Relationship between the uncertainty parameter CEU, the length of orbital arc usable to fit a model and the number of observations of the asteroids.

In this figure we can determine three parts. The short arc part for arc length of less than 250 days corresponds to bad CEU parameters from 1 to 10^7 arcsec, the medium part for arc lengths included between 250 and 8000 days corresponds to CEU from 0.1 to 100 arcsec, the third part for arc lengths greater than 8000 days corresponds to CEU between 0.01 and 1 arcsec.

Once a new asteroid is discovered, a preliminary orbit is computed but its improvement requires new observations. The precovery of this asteroid, when possible, in image archives allows us to extend the orbital arc used for the fit of the model and an improved orbit can then be determined. How many asteroid orbits have been improved thanks to data mining? By analyzing the Astorb database, it is possible to estimate the number of asteroids for which such data mining has been performed. The figure 2 gives the relationship between the year of discovery and the year of the first observation. We see that the major part of the asteroid orbits (71% of the asteroids, 29% of the NEAs) have been improved thanks to the retrieving of observations previously performed.

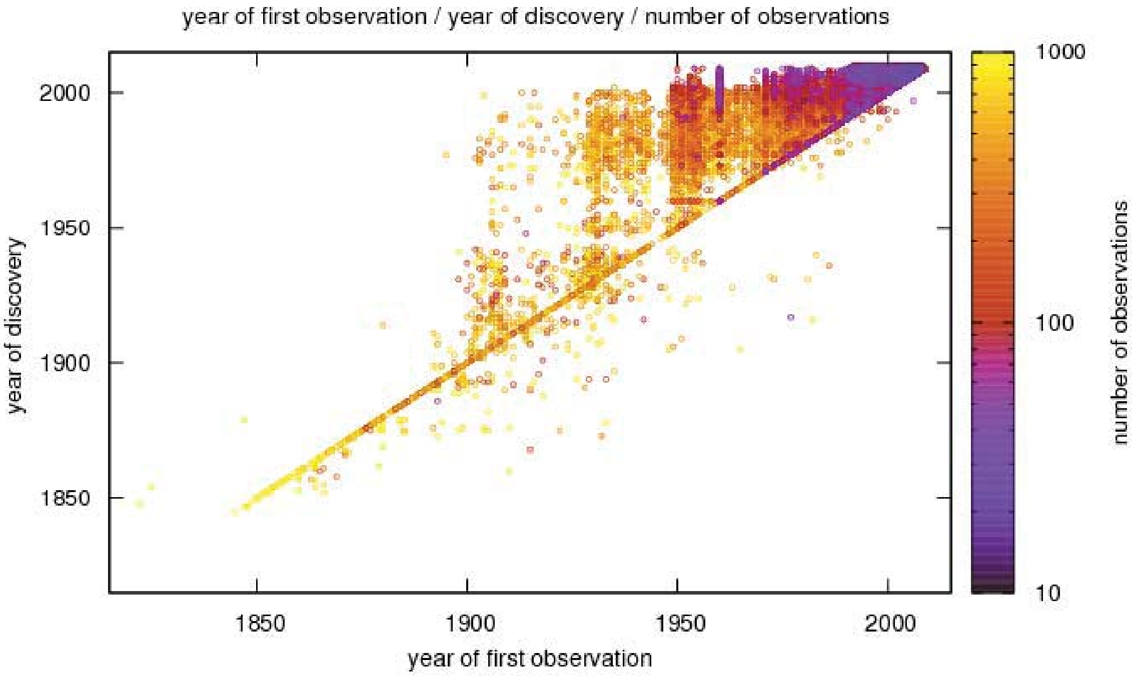

Figure 2. Relationship between the year of discovery of the asteroids and the year of first observation.

How to proceed for mining an archive? For exemple by using the specific tool, named SkyBoT (Sky Body Tracker) which has been developed, in the Virtual Observatory framework, at IMCCE (Berthier et al., 2006). A huge database of pre-computed ephemerides, periodically updated, covering more than 150 years, has been developed for all the asteroids and a web service has been developed for accessing these data and getting a fast answer on request. This web service has been implemented in the Aladin Sky Atlas and can also be implemented in any software thanks to the interoperable VO protocols. The conditions for efficiency in data mining are firstly to be able to access to images and to accurate timing, secondly to access an accurate stellar catalogue for operating stellar astrometry.

3- The case of 99942 Apophis

In the case of a PHA, the improvement of the orbit is necessary to better estimate the risk of impact. The risk assessment requires the analysis of probable trajectories crossing the b-plan (perpendicular to the relative velocity of the PHA during a close approach and containing the Earth center). An ellipse of uncertainty can be determined as well as specific zone of impact trajectories, named keyholes (Fig. 3). Data mining can then be of primordial interest in particular using the future Gaia catalogue. Such an analysis has been performed using recent observations of Apophis by Bancelin et al. (2012). What is the impact of the use of the future Gaia catalogue in that kind of analysis? A simulation of a reduction of astrometric measurements by using the Gaia catalogue, applied to ground-based observations on the 2004-2011 period, can lead to a precision better than 50 mas. Assuming this improvement, the ellipse of uncertainty for the 2029 close approach of Apophis is reduced by a factor

10. Furthermore, a simulation including a set of Gaia direct observations of the asteroid at the 5 mas level leads to an uncertainty ellipse reduce by a factor 150 (see fig. 3).

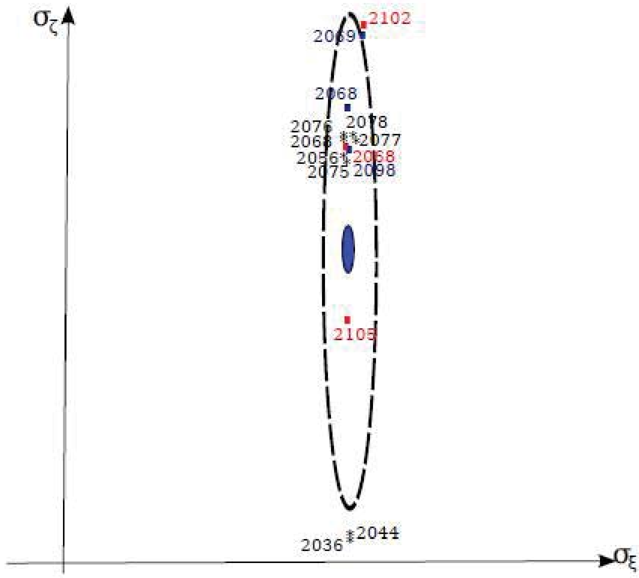

Figure 3. Ellipse of uncertainty in the Bessel plan during the close approach of Apophis in 2029. The keyholes are noted with the year of possible impacts. The central zone is the uncertainty ellipse using a Gaia observation.

Direct observations of the asteroid by the probe will also have a very important impact on our knowledge of its orbit. The figure 4 shows different simulations, based on the propagation of error by means of covariance matrix, using new observations in 2013 and after: radar observations and Gaia observations. Gaia observations at the 5 mas level, combined with the already known observations, leads to the knowledge of the Apophis position at the km level on the 2013-2029 period (Desmars et al, 2013).

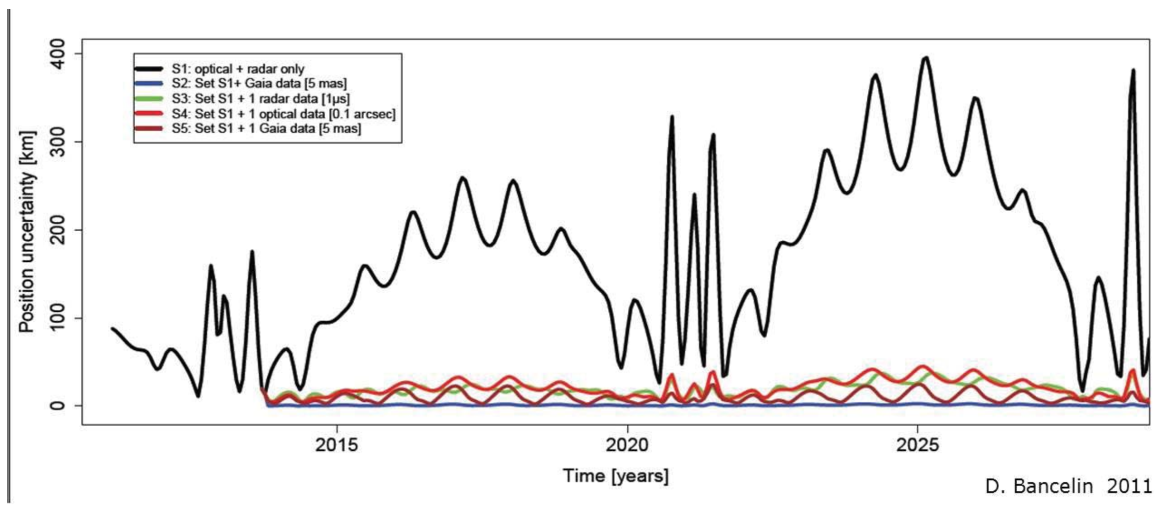

Figure 4. Propagation of error in the orbit of Apophis in several cases.

Conclusion

The precision of the orbit of asteroids is strongly related to the length of arc where astrometric observations are available for fitting a dynamical model. Therefore in case of the discovery of a new object, data mining can allow the improvement of the preliminary orbit. The Gaia catalogue, providing stellar positions and proper motions of high accuracy, will have important consequences for this process concerning new objects, or for already known objects when the re-reduction is possible. In other cases, when direct observations of the asteroids by Gaia are possible, our simulations show a very important impact on the accuracy of the orbital model. In case of a Potentially Hazardous Asteroid, such as Apophis, this improvement can be fundamental since it allows a precise impact risk assessment.

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