ASTEROID EPHEMERIDES FINAL REPORT (March 3, 2011)

EXECUTIVE SUMMARY OF THE STUDY PERFORMED BY IMCCE

A study on Asteroid ephemerides has been performed by IMCCE. The statement of work described by the contract 22885/09/F/MOS has been investigated on the basis of five work packages (coordination and management WP excluded).

The asteroid ephemerides state of the art has been first studied through the analysis of the two main databases (MPCORB from the Minor Planet Center and ASTORB from Lowell Observatory). The CEU parameter, provided by ASTORB to characterize the predictability and accuracy, appears to be the most relevant parameter. With this CEU criterion, we have highlighted a relation between predictability, absolute magnitude and orbital arc. Considering their classification in nine groups according to their orbital arc, their dynamical classes and their CEU, asteroids can be selected by their sensitivity to non gravitational forces (Yarkovsky, YORP...). We show that the CEU can be expressed as a logarithmic function of the orbital arc. The main factors to reduce the ephemeris uncertainty are precision of the single observation, observations distribution, and length of the orbital arc. Finally, we have estimated the contribution of radar measurements for a typical NEA (Apophis). Considering its current observations or assuming future realistic measurements, the radar observations allow a better determination of orbit both in target plane and in distance. Concerning space-based measurement campaign, we focused our study on the Gaia mission. For a known object, Gaia observations will provide unprecedented accuracy both in target plane and in distance.

We have provided a compilation of radio science techniques and a list of space missions already performed for asteroids. Long-term mission based on the NEAR experience, providing pseudo-ranging data, has been considered. In contrast to a ponctual single rendez-vous this is the best case for a long term orbit improvement. In this case the ranging is of the highest value. Moreover, because of long-term very accurate data, optical observations data become marginally useful in as much as, with only tracking data, the uncertainty on the orbital elements is quickly reduced.

A Radio Frequency space mission to an asteroid can increase the ephemerides precision. A bound orbit tracking is preferable to a single flyby tracking, it can surpass all optical and radar observations on short time scale. Eventually direct tracking to the asteroid target could be done. Determination of the initial conditions should be foreseen as well as validation of the dynamical model. The accuracy requirement can be governed or prescribed by the size of a given keyhole for a given PHA Near-Earth object. A mission to a target equipped with ad-hoc instrumentation would provide many physical parameters with high confidence such as the spin, shape/size/volume, thermal inertia, mass and subsequently bulk density. Combined with the most precise in-orbit tracking, or ground-based direct tracking, it would provide the best facility to study with scrutiny the orbit evolution and understand the limitations in the dynamical model used. This could be performed by a space single mission but, depending on operational constraints, it can also benefit of ground-space synergy.

We have studied types of measurement providing physical and dynamical measurement. Thanks to the MPC database, we have compiled information (frequency, duration, accuracy) for each type of measurement used in astrometry. More accurate measurements are provided by radar (doppler and ranging) but their number are and will be still limited in the future. CCD cameras provide the large part of measurements (94%) and remain accurate (0.6 arcsec). Due to their cost, space missions to asteroids remain marginal (only 11 asteroids). The data mining can be useful for a few observed asteroids in order to improve their orbit but it presents several limitations such as limited access to metadata or limiting magnitude. The stellar occultation allows to determine the size, the shape or the duplicity of an asteroid. It can also provide an astrometric position of the asteroid however, this method remains difficult to be applied for the improvement of asteroid ephemerides (precision of

stellar catalogue, number of observing sites, site mobility). Most of the stellar catalogues used to determine asteroid position are biased. Using a reference star catalogue, it is possible to debias current observations. The Gaia mission will provide high accurate observations of asteroids then an unbiased and very accurate star catalogue. Thanks to this catalogue, future observations will provide accurate measurements of asteroid positions but also, it would be possible to reduce former observations with this new catalogue making these observations more accurate.

According to the study done, very different parameters, perturbing effects, events, are involved and the establishment of a roadmap for the improvement of the asteroid ephemerides appears as an ideal goal to reach but is a non trivial work. Nevertheless, taking into account the limiting factors, the problems involved, we give a list of prioritary points to study related to the observing technique and the object class. On the basis of these priorities, we propose a scheme as roadmap in which several important dates could drastically change the frame where asteroid ephemerides can be developed. In this scheme we have underlined several activities which can be carried out sequentially for some of them:

• improving the access to data thanks to setting up or expanding of standards, Virtual Observatory may be an interesting solution;

• encouraging the use of standards for data reduction and modeling;

• supporting the data centres for the considerable increase of data due to the next generation of surveys and their use for ephemerides;

• facilitating data mining on archives and re-reduction based on the use of improved stellar catalogues;

• supporting the research activities for Yarkovsky effect and the physical characterization of asteroids. This could be also performed by guaranteed telescope time from ground or space;

We also suggested proposals for space missions and programs which could be interesting for the asteroid science and ephemerides. This could be organized in three directions:

• enhancing radar capabilities, in particular in Europe, with the goal to increase the amount of data related to Solar System objects, NEAs in particular;

• developing the use of two-ways RF combined with VLBI as well as the Laser Ranging for Solar system objects; the close encounter of (99942) Apophis in 2029 would be a nice opportunity to apply direct RF or Laser ranging and to get high accurate astrometric measurements and physical characterization of this PHA;

• studying of space astrometry either local astrometry through a ”Sentinelle” space observatory, or global astrometry through a ”Super Gaia” space probe.