Mem. S.A.It. Suppl. Vol. 5, 42

Memorie della
Supplementi

Apparent Motion Interpretation of Generic Orbits (AMIGO)

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Abstract. A new tool, called AMIGO ('Apparent Motion Interpretation of Generic Orbits'), is presented. It provides a first kinematical classification of moving objects in a given direction of sky at any date, generating representative populations of asteroids of all classes (Near-Earth Objects, Main Belts, Trojans of the outer planets, Kuiper Belt Objects etc.), and imposing simple constraints on line of sight direction, date and orbital parameters in order for them to fall in the imaged field. The code calculates the apparent velocities of each population, and displays the generated objects as points projected into a RA-DEC velocity plane. The different groups (Main Belt asteroids, Jupiter Trojans, and so on) occupy well defined (and usually well separated, especially at opposition) regions in this plane. Plotting on the same plane the detected real objects, such plots permit to discriminate between interesting detections and non interesting ones. AMIGO is therefore of immediate help to observers. Moreover, in some cases AMIGO can also constrain the orbital parameters of the detected objects. Some applications to images obtained with the 2.2m WFI and the Asiago-Schmidt telescope will be presented. In all cases analysed so far (over more than 1000 new detections), AMIGO has always provided a reliable kinematical classification.

Key words. asteroids, dynamics

1. Introduction

In this paper, we shall illustrate a new software tool, called *AMIGO*. The name stands for 'Apparent Motion Interpretation of Generic Orbits'. *AMIGO* has been developed to interpret the motion, and hence the nature, of the bodies of our Solar System, by studying their velocity with respect to the Earth.
It is an useful support during observations devoted to the discovery of minor bodies. It provides an indication of detections nature, by suggesting which candidates could be Main Belt asteroids, Outer Trojans (of Jupiter, Saturn, ...), Trans Neptunian Objects, or Near Earth asteroids. In this way, the researcher can decide in real time which objects are worth to be followed up.

In the following sections, we shall explain how the software has been developed (section 2), and how it works. In particular, we shall illustrate some applications of *AMIGO* in analyzing the nature of detections on images, taken with the ESO-2.2m telescope and the Asiago-Schmidt camera.

2. Software development

AMIGO is a fortran code, which can be used on UNIX-LINUX workstations.
It uses an ASCII input file, where the user can specify the desired date and the equa-

torial coordinates (RA_0, Dec_0) of the line of sight. *AMIGO* calculates, for the observational constraints, the orbits of a number of objects belonging to different classes: Main Belt (MB), Jupiter Trojans, Saturn Trojans, Uranus Trojans, Neptune Trojans, by producing their orbital elements, that is semimajor axis a, eccentricity e, inclination i, perihelion argument Ω, ascending node longitude ω, mean anomaly f.
Ω, ω, e and i are generated randomly: Ω and ω between 0° and 360°, e between 0 and 1, and i between 0° and 90°. Orbits which present high values for i are not likely to be real, and in the following we will show what changes are produced when restricting the range for i.

Once the above orbital elements are chosen, the other two, namely f and a, are univocally determined. As a matter of fact, the orbits cannot be generated totally random, owing to the specific line of sight (RA_0, Dec_0) one is interested to. Hence, f and a can be reckoned from the previous orbital elements and from (RA_0, Dec_0). At this stage, the generated orbits are divided on the basis of their nature. The typical considered classes are Near Earth Objects (NEOs), Main Belt Asteroids (MBAs), Jupiter Trojans, Saturn Trojans, Uranus Trojans and Neptune Trojans. These classes are also defined in the input file. NEO class is defined by $q < 1.3$ AU (q is the perihelion distance, defined as $q = a(1 - e)$); Main Belt and Jupiter Trojan classes are defined by considering the real distributions of their members, while the others are defined by considering the theoretical works by Marzari et al. (2002), Marzari et al. (2003). For MBAs we used: $q > 1.7$ AU and $Q < 4.2$ AU (Q is the aphelion distance, defined as $Q = a(1 + e)$); for Jupiter Trojans: $q > 3.9$ AU and $Q < 6.1$ AU; for Saturn Trojans: $q > 7.5$ AU and $Q < 11.5$ AU; for Uranus Trojans: $q > 16.5$ AU and $Q <$ 21.5 AU; and for Neptune Trojans: $q > 25.5$ AU and $Q < 34.5$ AU.

The patterns generated by *AMIGO* strongly depend on the viewing geometry. To show this, Fig. 1 (a, b, c, d) displays different plots, all computed for January 1st, 2000, for ecliptic latitude =0° and ecliptic longitudes $=0°, 30°, 60°, 90°$ respectively. The clouds corresponding to each family are well separated at quadrature a) and opposition d). For intermediate values of solar elongation, we see a progressive superposition of the different clouds. This can be explained by the fact that objects velocities are composed with Earth's velocity, whose effect depends on the reciprocal position of the Earth and asteroid, and hence on the line of sight (RA_0, Dec_0).

The orbits in Fig.1 (a, b, c, d) are generated randomly in the range $0 < i < 90°$, and this is the reason why the clouds (in particular those of Main Belt) are so widespread. To show the inclination effects we generated, for the same configuration of Fig.1 a), orbits with inclination restriction of 0°- 30° (see Fig.1 f), and 0°-60° (see Fig.1 e). When the inclination range decreases, the distribution of asteroids classes on the velocity plane becomes sharper.

In the favourable cases, different groups of moving objects are well separated in the RA-Dec velocity plane, and we immediately see which class they could belong to. Of course we cannot be sure of the classification, since, for instance, NEOs can be more or less everywhere in these plots. In other words, if an object is outside the region corresponding to a class, surely it is not a member of that class; but if an object stays inside it, we cannot conclude for sure that it belongs to that class. A proper orbit will always be needed, and *AMIGO* signals which objects are worth further observations.

The usefulness and validity of *AMIGO* has been widely confirmed by examining the nature of all previously known objects, detected on several images: they *all* lie in the corresponding classes identified in the *AMIGO* plots.

3. Some applications

Given a list of positions of detected objects, it is possible to calculate their velocity both in RA and Dec, from:

$$\frac{dr_{RA}}{dt} = \frac{RA_f - RA_i}{dt}$$

$$\frac{dr_{Dec}}{dt} = \frac{Dec_f - Dec_i}{dt}$$

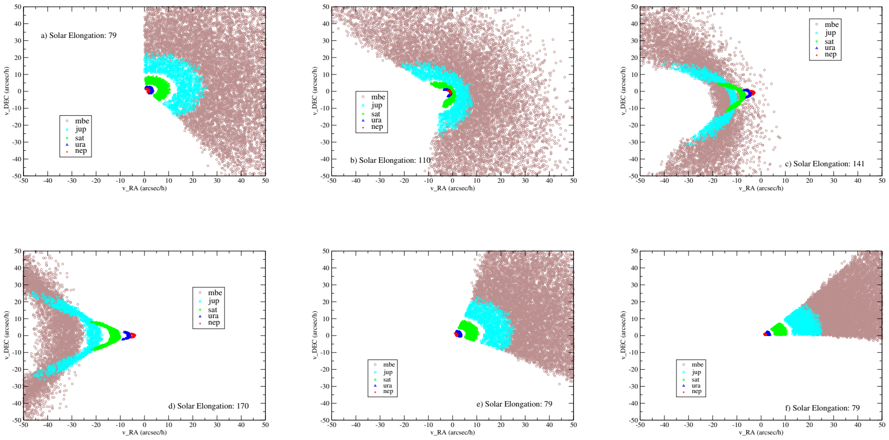

Fig. 1. Distributions in velocities generated by *AMIGO* for ecliptic lalitude 0° and ecliptic longitudes of 0°, 30°, 60°, 90°, 0°, 0° respectively, at January 1st, 2000. The two plots e) and f) reproduce the same situation as in the first plot a), but using a smaller range for inclination, 0°- 60°, and 0°- 30°, respectively.

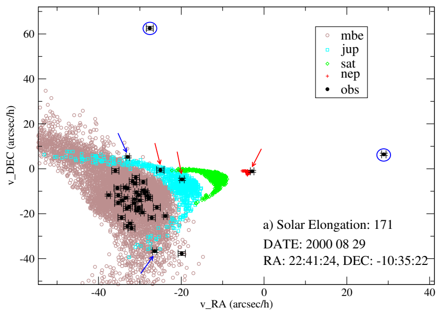

Fig. 2. An example of *AMIGO* plots, with superimposed the velocities of the detected objects. Interesting objects are marked with arrows and circles. The objects marked with circles are likely to be NEOs. On the left panel there are two possible Jupiter Trojans, and one TNO.

where *dt* is the time span between the last position and the first one. Such velocities are calculated in a geocentric reference frame, so they are not the intrinsic velocities of the objects, but that calculated with respect to the Earth. Therefore, we can superimpose detections velocities to the *AMIGO* plots, and be quite sure about their nature. This approach works well when all the asteroid clouds are well separated, that is at quadrature and at opposition.

3.1. Archive images

We have applied this procedure to approximately 1000 moving objects detected on archive images taken with the ESO-2.2m telescope. Among these, about 200 were already known, so that the study of their positions on the RA-Dec plane permitted us to verify the goodness of AMIGO code. A more detailed presentation of our work on archive images can be retrieved on Barbieri et al. (2004).

In Fig.2 we show two actual examples of plots generated by *AMIGO*, with superimposed the detected objects. Here, the different clouds are well separated, even if there is a partial superimposition between the Main Belt and the Jupiter Trojans zones. Interesting objects are marked with arrows or circles.

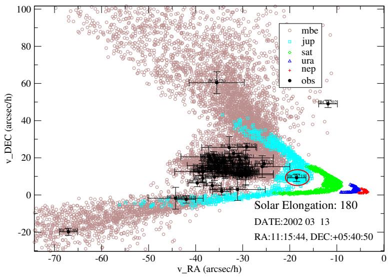

Fig. 3. An example of AMIGO plot applied to Asiago files. Notice, that the marked object is actually a Jupiter Trojan, as predicted by AMIGO.

3.2. Asiago images

The same procedure has been applied to images taken with the Schmidt 67/92 telescope of Asiago. In this case, there is the great advantage that all interesting objects can be followed up, in order to derive a precise orbit for them. This is obviously not possible for archive images.

4. Conclusions

We have presented a new, user-friendly, software tool (AMIGO), which is useful both during observations and for the subsequent analysis to derive immediate information about the nature of the detected moving objects. We have tested its goodness by applying it to several sets of objects found with different telescopes. The result is fully satisfactory, because AMIGO code has provided reliable information about the nature of all already known asteroids.

The limitation is that we cannot use AMIGO to derive orbital parameters for the detected objects; we can only have an indication about which class our detections belongs to. This limitation could be overcome, in favourable cases, for objects detected on Hubble Space Telescope images, as we shall prove in a future paper, taking advantage of the considerable orbital parallax of the telescope during the exposure time.

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