*International Workshop on Collaboration and Coordination
Among NEO Observers and Orbital Computers*

Present and future of the Spaceguard Survey

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Abstract. The Spaceguard Survey concept is now more than a decade old; it is therefore appropriate to review the achievements of this international program and to look forwards to its possible developments in the coming years. The major drawbacks and failures of the program are considered, and solutions suggested.

1. The Spaceguard Survey

About ten years ago, when the Spaceguard Survey Report was published (Morrison, 1992), there were only a few pioneering projects making regular searches for asteroids and comets, with special emphasis on near-Earth objects (NEO). These programs, and their leaders, where: PACS and PCAS (Helin and Shoemaker, USA), Spacewatch (Gehrels, USA), and AANEAS (Steel, Australia). Only one of these programs, Spacewatch, was using a CCD camera.

The follow-up of new NEO discoveries was not well organized, mainly because the discovery rate was rather low, and only one center in the world was dedicated to orbit determination and analysis (the Minor Planet Center of the IAU, MPC).

Following the Morrison report, the international activity related to NEO discovery and tracking has globally received the name of the Spaceguard Survey. Most of its activity, especially concerning discovery, has been done in the USA, but the contribution from other countries, both observational and theoretical, has continuously increased, to the point that we can now speak about a "Spaceguard System" being in place; it is composed by different elements that address specific functions. However, notwithstanding several efforts devoted to establish a close cooperation among the various elements, a really common project, based upon clear duties and share of competences, has not yet been promoted.

There are two basic segments in the Spaceguard System: the observatories and the computing centers. The first segment, on its turn, may be divided into two sub-segments: observatories devoted to discovery and observatories devoted to follow-up. Usually, the discovery centers do not follow their discoveries, apart from the confirming observations, because this activity would conflict with the scanning schedules. On the other hand, the follow-up centers are in general not well equipped to observe objects that may become rapidly very dim. The result, from an observational viewpoint, is that we have a very heterogeneous ensemble of instruments, sensors, software tools, competences and capabilities. This system is certainly not optimized both in terms of global efficiency and of human resources.

The computing centers have also different characters, depending on the purpose for which they have been established. The Minor Planet Center, as the clearing house of the IAU for minor bodies observations, is committed to collect and organize the observations, relate them to already known objects (identifications), compute preliminary orbits for new objects, prepare and disseminate ephemerides for immediate observations. In addition, the MPC also makes a first orbit analysis aimed at determining important parameters of the new orbits, such as close encounters in the near future.

A complete orbit analysis of NEOs is made at the moment by the NEODyS service in Pisa (Italy) and will shortly be done also by the NEO Program Office of JPL (USA). Other individuals and institutions contribute to this analysis, especially when a possible impact in the near future is detected.

In the USA, following a precise indication of the Congress, all the NEO researches are addressed towards the so-called "Spaceguard Goal", i.e. to discover at least 90% of NEOs supposedly larger than 1 km (visual absolute magnitude about 18) within 2008.

As said before, the status of the system is by no means optimal. I will try to briefly underline the major drawbacks of the scheme, without aiming to be complete; in some cases a possible solution is straightforward, although not easy, in other cases only a major change in the present situation would allow a definite step forward.

1.1. Discovery.

There has been a continuous increase in the number of discoveries, as shown in figure 1. A first jump, in 1988-89, was produced by the regular operations of the Spacewatch telescope, followed by a second jump in 1997 due to the start of the LINEAR program. NEAT and LONEOS, and then the Catalina Sky Survey, have also substantially contributed to this increase.

However, there are problems connected with this scenario; first, all the big surveys are located in a single country, almost at the same longitude and in a restricted latitude belt. This geographical distribution affects the rate at which objects are discovered. Furthermore, there is still little coordination among the survey programs and they depend mostly on the financial support of a single organization (NASA).

An additional problem is represented by the survey strategies. None of these programs searches regularly the sky at small solar elongations, where it would be easier to find Atens and the still unsampled population of IEOs (Interior to Earth's Orbit objects), and the regions at high ecliptic latitudes are definitely undersampled.

1.2. Follow-up.

Also in this case there has been a continuous improvement of efficiency, although the follow-up activity still represents a difficult problem to solve. The reasons of the increased efficiency may be found in a greater coordination among observers, facilitated by the set up of the Spaceguard Central Node in 1999. There is still a long way to raise the follow-up activity at the same level of the discovery, mainly because of the difficulty in having available in a timely fashion powerful tele-

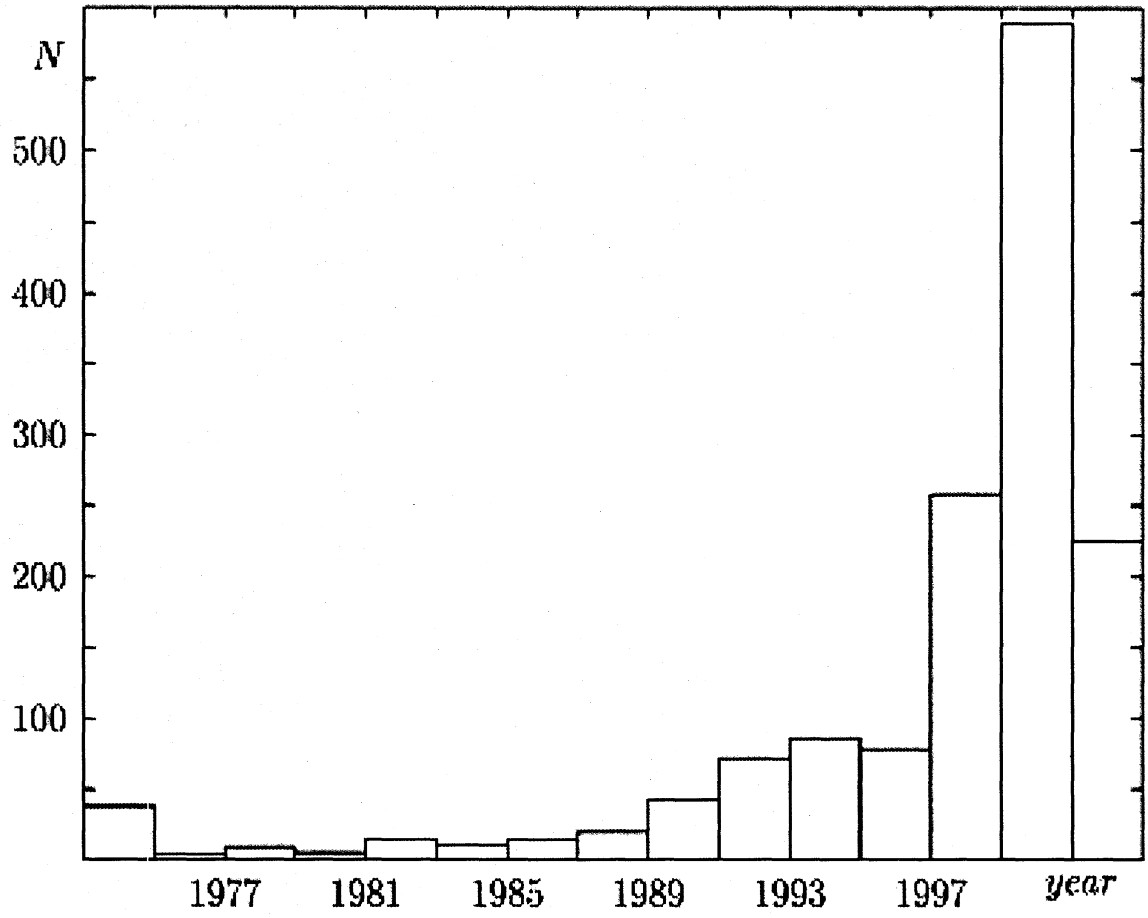

Figure 1. Time distribution of NEO discoveries binned in 2-year intervals. The first bin on le left groups all discoveries prior to 1975. Data relative to Sept. 13, 2001.

scopes, whose use is fundamental in securing observations of very faint objects in danger to become lost.

Another problem is posed by the need to have a great number of observing stations continuously operational, typically ten times the number of search programs. This is not a necessary requirement, however, and is dictated basically by the fact that many observations are needed, for every object, to secure a precise orbit determination. In addition, there are not so many instruments with the appropriate characteristics available full time, and the follow-up of about two thousand objects takes a lot of time.

The most important factor affecting the efficiency of follow-up is certainly a very good coordination. Important steps forwards have been made in the past few years, but there is still room for substantial improvements. It may be noted, in the end, that most of the follow-up is being done outside the USA, and that the teams devoted to this important piece of work are generally understaffed and with little funds available.

1.3. Physical characterization.

It is clear that understanding the distribution of NEOs, and even computing accurate orbits for them so that a possible impact is predicted decades in advance (a very important requirement, see Carusi et al., 2002), does not solve the problem of the identification of suitable countermeasures, apart from the possibility to evacuate the target area. What we need to know is a definition of important physical parameters such as the mass, the density, the internal structure and strength, the rotation state. The collection of this type of information is particularly difficult and requires the use of very powerful instruments located in suitable sites, where the screening influence of the atmosphere can be minimized. As an alternative, this information can be obtained with space observatories.

The current status of the knowledge of physical parameters for NEOs is very poor, notwithstanding the many efforts that several groups are devoting to the subject. Access to large facilities is problematic because of the strong competition in obtaining observing time, and a space observatory is certainly much more expensive than a ground-based instrumentation with the same power. However, due to the difficulty in getting funds for building a dedicated, large telescope for physical observations, it may well turn out that the space option will become viable, as I will discuss in a moment.

1.4. Data collection and distribution.

The International Astronomical Union, at its XXIVth General Assembly in Manchester (2000), has approved Terms of Reference for its Minor Planet Center. It is the first time that such a document is compiled and its approval has not taken place without controversies. It is however useful to discuss a little the role of the MPC in the changed situation due to the strong push for NEO search, which has produced a more than 10-fold increase in the number of asteroid observations received by the MPC.

The main purpose to collect data in a single place is to guarantee the homogeneity of data sets and the verification of their validity. Data are collected and used to compute orbits and, ultimately, to predict possible impacts. However, the MPC deals with all minor bodies observations, including also mainbelters, trojans, centaurs and transneptunian objects. The NEOs represent only a tiny fraction of the volume of data received daily, but the NEOs cannot be separated a priori from the other asteroids until a preliminary orbit is computed: all observations must be received and processed by a single center.

In principle, the MPC could have only the function of collecting and verifying data. All other functions, from the identification of objects to the computation of preliminary orbits and ephemerides, could be delegated to other centers. The advantage of such a scheme would be to divide the workload among several centers and to allow an internal check of all computational processes.

1.5. Orbit analysis.

As mentioned before, a complete orbit analysis of all potentially hazardous asteroids (in fact, not only PHAs) is performed by NEODyS (Italy) and in the near future by JPL (USA). This analysis includes the determination of the "region of uncertainty" in the phase space of orbital elements and the projection of the orbital evolution of a cloud of "virtual asteroids" filling this region for many decades in the future. In such a way it is possible to identify "virtual impactors", which are then posted on a web page.

We must note that the analytical and computational techniques that lay behind this work have been tremendously improved in the last five years, after the 1997 XF11 "affair". Several new terms are now commonly used and the reader is referred to Valsecchi et al. (2001), Milani et al. (2002) and Chesley et al. (2002) for a complete review. The recent improvements have allowed to perform these computations in real time, but the amount of work is large: the major problem here is manpower. Moreover, the determination of the uncertainty region requires that all data relative to observations of asteroids be available as soon as they are taken, thus requiring a good correlation among the functions of these centers and of the MPC. This connection is, at this time, not well established and should be improved.

1.6. Interface with funding institutions, international organizations, and the public.

The research on NEOs is not only a scientific endeavor. It has been recognized by several international organizations as of relevance for the world population because impacts represent a threat with potentially devastating consequences for the life on earth and for the human society.

As I have already mentioned, the US Congress has been the first political body to acknowledge the importance of studies on NEOs, by directing NASA to form the two working groups led by D. Morrison (detection) and J. Rahe and J. Rather (interception, J. Rahe and J. Rather, 1992) in 1991. The next relevant initiative has been the approval by the Council of Europe of the Resolution 1080 "on the detection of asteroids and comets potentially dangerous to humankind" (1996), in which a strong support was provided to the Spaceguard Foundation (SGF). This Resolution was also explicitly mentioning the role of ESA.

The United Nations had already contributed with several workshops (on Basic Space Science) that mentioned the NEO issue, and with a Conference in New York in 1995. But the major involvement of the UN in this field was the inclusion of the topic in the agenda of the UNISPACE III Conference in Vienna (1999): the "Declaration of Vienna" stated explicitly the relevance of the problem, based on the recommendations provided by a side workshop on NEOs (UN, 1999).

So the NEO issue, also because of many reports in the international press and of the distribution of movies and fictions, has slowly become known to the general public, to governments and to international bodies. The major space agencies have started to study, and to support financially, the activity at various levels: NASA collected in a single Program Office all NEO initiatives, providing grants to the major discovery programs in the US. ESA, on its turn, signed two contracts with the SGF in 1997 and 1999 (Carusi et al., 1997 and 2000); the first led to the creation of the Spaceguard Central Node, already mentioned, as an important coordination center especially for follow-up, and the second (the study SISyPHOS) represented the first attempt at designing an integrated, international system including a substantial space segment.

More recently (2000), also the European Science Foundation (ESF), the European Southern Observatory (ESO), and the Organization for Economic Cooperation and Development (OECD) have been addressing the impact threat, with initiatives that are still under way, as we will see in the next section.

At governmental level only the USA, and recently Japan, have taken serious initiatives involving financial support. The United Kingdom formed a Task Force in 1999 with the purpose to examine the problem and to recommend to the UK government actions to be taken (Atkinson, 2000). No other European country has taken any explicit commitment in support of these researches and, even more important, no country in the Southern hemisphere has promoted or funded any specific program.

1.7. Where are we standing now?

The situation briefly depicted in the above paragraphs can be summarized as follows:

- No discovery programs in Europe and the Southern hemisphere
- Follow-up centers understaffed and still poorly coordinated and funded
- Physical characterization very deficient
- Lack of studies in the social and civil defense domains
- International coordination far from satisfactory

These are all major issues that need to be addressed for the continuation and improvement of the Spaceguard Survey, and even for reaching NASA's "Spaceguard Goal", the rate of discovery being probably a bit lower than required to meet that goal. However, the ultimate purpose of Spaceguard is to catalog all objects that may represent a threat, down to the size of Tunguska's. To extend the search and orbit analysis to hundreds of thousand objects with the current systems, even if optimized, is definitely impossible.

However, given the resources available, both from a financial and a human viewpoint, the Spaceguard effort has been very successful to date. It is now commonly accepted that only a well coordinated international program may help to cope with the problem, and all scientific teams working on this subject are interconnected. A further major improvement can only marginally be obtained by a better coordination and cooperation based on the good will of individuals and on the current level of funding: if we want to extend the "goal" to the discovery and tracking of objects much smaller than 1 km we need a "quantum leap", and this can be achieved only by a much greater support from political bodies.

2. A look at the future

In the previous section I have indicated initiatives under way in the international context. It is worth mentioning that the OECD, through its Global Science Forum, has formed a Working Group that will be active in the second half of

2002. The charter of this WG is to further analyze the problem, not only from a scientific point of view, but also for its implications for the governments. A real and deep study of the scenarios following even a minor impact, and of the actions that local governments should take to minimize the consequences, has never been done, and this will be one of the major tasks for the OECD WG. At the same time, the UN have also formed a Working Group, with basically the same purposes of that of the OECD but more addressed to the international aspects of the problem. Hopefully, the outcomes of these working groups will finally reach the individual governments and will produce some effects.

As already mentioned above, ESA is very much involved in NEO studies, having been explicitly asked in this sense by the Council of Europe. In January 2002 ESA has issued an Invitation To Tender entitled "Near Earth Objects Space Mission". The purpose of this call is to promote a small number of studies of innovative missions of three broad types: i) NEO rendez-vous missions, ii) NEO space based discovery and follow-up missions, iii) Space based systems for NEO-atmosphere related studies. No "real" mission is anticipated to originate from these pre-phase A studies, but it is important that new concepts and solutions be identified for a possible actual development.

It is also worth mentioning that new technologies and projects based on ground are going to be studied in the coming years, some of which may have a great relevance for the study of NEOs. The most interesting among these are the LSST project (see `http://www.lssto.org/lssto/index.htm`) and the Virtual Observatory project (see `http://www.us-vo.org` and `http://www.eso.org/projects/avo`).

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