CONDITIONS OF POSSIBLE PROGRAMS USING SMALL AND MEDIUM SIZE GROUND-BASED ASTROMETRIC INSTRUMENTS

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ABSTRACT. The post-Hipparcos era has brought some uncertainty on the future of ground based astrometry. However, the discussions that were initiated by the IAU Working Group on future development of ground-based astrometry, showed that there are a number of fields that will not be satisfactorily covered by space astrometry. The instruments that could be used are shortly described. Then the complementarity of ground-based and space astrometry is discussed. The papers presented at this very session confirm the point of view that, with minor modifications and improvement of existing instruments, many sound scientific programs can be undertaken. The principal domains in which major scientific inputs are expected from ground-based astrometry concern the dynamics of minor planets and satellites, the shape of the Sun, double stars, kinematics within stellar clusters, and radiosource optical counterparts. In addition, the use of some small telescopes for monitoring long period irregular variable stars could be a useful reconversion of astrometric activity. Most of these programs require international cooperation to ensure sky coverage and extension in time. Some possible projects in these fields have been presented, but the Working Group cannot manage such programs. Its objective is to help organizing them and to encourage people to join them. An important point concerning these programs is that all the participants should have a reward in their work in terms of publications.

1. WHAT IS THE PROBLEM ?

In face of the remarkable progress already achieved and even more fantastic progress in astrometry that is expected, what is it reasonable to anticipate in terms of useful contributions of ground-based astrometry in the next ten-twenty years? More generally, what contribution to astronomy can still bring small and medium-size instruments in collecting fundamental data and providing new observational results? What techniques will remain competitive? These questions arose many years ago, when it became certain that astrometry from space will be carried out. At that time, there were worries in some people's minds and diverging views (Tucker and Teleki, 1978). Later, when the achievements of Hipparcos and the Hubble Space Telescope were well established, it appeared that there was still room for Earth-based astrometry in many domains of research (Kovalevsky, 1991).

But now that an additional jump of two or three orders of magnitude in accuracy is expected from SIM and GAIA (see Mignard and Kovalevsky in this volume), the same questions are again in the minds of many directors of observatories who want to participate to the scientific adventure but cannot afford installing new expensive instruments. But, as this will be shown, there is a large amount of observations that will not be done by large telescopes or space missions, and that are very important, provided that some simple not expensive arrangements are made. First answers were given recently by Stavinschi (2001) giving several reasons for continuing work on ground. In this context, the IAU, during its XXI-st General Assembly in 2000, created a Working Group to consider this problem and propose programs and any other action to help observatories to enter efficiently in the new environment. This paper describes the present state of the thoughts in the Working Group.

2. THE IAU WORKING GROUP

The IAU Working Group on future developments in ground-based astrometry was established by the IAU under the co-chairmanship of M. Stavinschi and J. Kovalevsky with the three following main objectives

1. To identify scientifically important observations that can be made with astrometric or other astronomical instruments, and that can provide data of interest to the study of the Solar System, stars, or the Galaxy, and that cannot be performed as well by space techniques.

2. To suggest possible modifications, upgrading, or additions to these instruments that would allow them to perform such observations and provide useful information with adequate accuracy, keeping in mind what future space missions will contribute to.

3. To promote the organization of international cooperative undertakings with the objective to perform observing programs, that would correspond to the above description.

The Working Group exchanged views by correspondence, and some of its members met twice. There was also an open joint discussion at the JENAM 2001 meeting in Dresden. Although the conclusions will be finalized for the 2003 IAU General Assembly in Sydney, it is already possible to give the main features of what will be presented there.

3. THE INSTRUMENTS

Let us first see what techniques are now available for ground-based observations and could be used in order to play its part in the general progress of astronomy.

The most striking advance in astrometric techniques is the outbreak of CCDs into all branches of astronomy. The dimensions of CCD chips, which were for a long time limited to 800×800, have raised to much larger dimensions. Systems with 4096×4096 pixels are now available. The read-out capabilities are also being extended with the availability of very fast compact data processors and computers. This trend is extended by arranging CCDs in mosaics. They have a very high sensitivity, so they are, in practice, the closest to a perfect detector in astronomy. In addition, the possibility to control the speed of charge transfer adds a new flexibility to their use (scan mode).

Another striking example of the progress that is now currently available at the focus of 1 meter class telescopes is speckle interferometry. The theory of speckles (Korf, 1973) shows that each individual speckle, which is a distorted interferometric pattern contains all the angular information that tha telescope could provide if it were in a perfect environment. The pattern changes with a period of a few hundredth of a second, so that the successive views are uncorrelated. A speckle interferometer consists essentially of an electronic receiver at the focus of a telescope with a focal extension giving focal ratios of 300-500, which registers in a few milliseconds on a CCD, all the details of the image consisting of speckles. The successive images are combined by a computer. Then, the autocorrelation function is determined or, if one works in the Fourier space, its Fourier transform. The result is added to analogous results obtained in successive CCD frames, the final analysis being done on the mean of the computed functions. Images of double stars are obtained with sub-milliarcsecond accuracies. See also, Kovalevsky (2002).

Although photometers are essentially used for the determination of the apparent brightness of stars, they have also important astrometric applications for instance for the observation of eclipses and occultations. It could be a good use of small telescopes to be dedicated to single or, better, multi-channel photometry because, in addition to astrometric applications, there are plenty of important programs related to variable stars. And, for completeness, let us mention specific instruments for special objectives like the solar astrolabe or CORAVEL-type spectroscopic instruments. However, they are rather expensive and difficult to calibrate.

4. SPACE AND GROUND-BASED ASTROMETRY COMPLEMENTARITY

The role of the ground-based astrometry in the future must be considered in the light of the expected results of the space astrometry missions. Potential accuracies and high magnitudes that will be reached are such that there is no way to compete with them from the ground. Hence, the role of ground-based astrometry is to complement these observations in those domains where they do not contribute at all, or at least insufficiently.

One may list the main deficiencies of space astrometry missions as follows:

1. *They are not flexible.* In the case of Hipparcos and GAIA, once the scanning law is initialized, one may know in advance when a given spot on the sky will be observed. At any other time, this spot will not be observed. In the case of SIM or the HST, there are possibilities to observe a phenomenon at any time, but the flexibility is still very limited.

2. *They are not designed for monitoring.* Even for a steerable instrument like HST or SIM, the large number of users does not permit systematic continuous observations of a given body.

3. *They have a limited lifetime.* Even if a variable feature has a sufficiently dense observation record, other means must be deployed to continue the observations after the end of the mission.

4. *They cannot observe every type of object.* The Sun is an example (though the projected satellite COROT will determine its shape and diameter), but it is also the case of very crowded portions of the sky in which even GAIA will not be able to separate or identify stars. Astrometric positions of comets, large planets and their faint satellites are also out of the reach of the projected space astrometry missions.

On the contrary, ground-based astrometry programs may be set to monitor, if necessary indefinitely, an evolving feature at any given periodicity. They have the flexibility to observe transient phenomena and all types of suddenly appearing objects such as novæ, bursts, comets, etc... These considerations lead to the following open list of objectives for ground-based astrometry. Let us consider them in the next sections.

5. THE SOLAR SYSTEM

The main objective of astrometric observations of bodies in the Solar system is to provide data for the improvement of our knowledge and understanding of the dynamical behavior of its components. Several types of programs contribute to this goal, all of which cannot be properly accomplished by space missions.

5.1. *Minor planets*

The most important objectives for astrometric position determination are the following:

- Observations of minor planets used to determine planetary masses. This requires the observation of both the perturbing and the perturbed planets during long intervals of time, so that the effect on the orbits become sizeable. The largest is the time interval, the better are the uncertainties of the determination.
- Observations of identified minor planets whose orbits have interesting features for Celestial Mechanics such as chaotic behavior, resonant orbits, etc...
- Systematic observations of Earth's grazing objects for which it is necessary to update frequently the orbits.
- Observation of objects of special interest such as comets or objectives of space probes.
- Bulk observation of newly discovered objects in order to determine a sufficiently good orbit so as to recognize them at further oppositions.
- If a sufficiently large telescope is available, the positions of objects in the Kuiper belt are necessary to determine or improve their orbits.

The common characteristics of these observations is that they have either to be carried out during a long time, or in special occasions. Both requirements do not fit in space astrometric programs, even if, occasionally, they may produce useful data.

Another important activity is the observation of the occultation of stars by a minor planet. One needs several photometers spread in latitude and coupled with accurate time determinations. The goal is to determine the length of several planetary arcs from the duration of the occultation. Very accurate ephemerides of the planet are required to forecast the geographic position of the photometers, and this means preliminary accurate astrometric observations of the planet.

5.2. *Satellites*

The main objective of the observations of natural satellites is to improve their orbits. In addition to the specific interest for Celestial Mechanics (resonances, high inclinations or eccentricities), many are objectives of planetary space probes, which require very accurate ephemerides. There are two types of observations:

1. Photometric observations of occultations, eclipses and mutual events of the quasi-equatorial satellites of Jupiter and Saturn.
2. CCD observations of the relative positions of satellites with a mask to dim the high luminosity of the planet.

None of these observations is expected to be performed from space.

5.3. *Solar diameter and shape*

The observations of solar diameter by solar astrolabes have shown variations that are not well understood and are unpredictable. It is therefore essential to continue to have an organized net of instruments in both northern and southern hemispheres to monitor them throughout the years.

6. STARS

Space astrometry missions are optimized for the determination of positions, proper motions, and parllaxes of stars. Now that SIM, and especially GAIA are approved missions, there is no sense to have ground-based observing programs to obtain these parameters. The exception may be using a very large specialized instruments like the 61-inch Flagstaff astrometric telescope for faint stars, but even there, the Hipparcos accuracy is very difficult to reach. So, one should forget about such ground-based stellar astrometry programs. On the other hand, GAIA also collects photometric and double star data, but these observations are limited to the life-time of the mission, and this may not be sufficient. In this case, ground-based observations are necessary to complement them.

1. *Double stars.* For separated double stars, the determination of the orbital elements is, in general, impossible using only four or five years of observations. During the mission, Hipparcos and GAIA provide very good values of the separation, of the position angle, and of the magnitudes for large classes of binaries. But whenever the time span is too short, it is necessary to complete them with observations made over a longer time. Even if they are not as precise, the time factor plays such a role, that the contribution of the latter is comparable in weight and provides the necessary diversity of equations of condition.

   For close binaries, speckle interferometry is the ideal technique, as shown by the excellent results obtained by several groups (Mason et al., 2002). However, the large number of such stars and their potential for mass determination call for more instruments devoted to speckle interferometry.

   It is to be noted that astrometric observations alone do not permit the actual determination of the masses, but only some conditions on masses. In addition, one must determine the absolute motion of each component together with the parallax. For such a program, a long focus telescope is necessary. Another issue is to measure the radial velocity of each component. In this case, one needs a high dispersion spectrograph, but not necessarily a large telescope: there are still very many bright double stars with good orbits, but with unknown masses.

2. *Stellar diameters.* The apparent dimension of stars is another parameter that is known for a very limited number of stars. If the most efficient technique is stellar interferometry, either fromthe ground, or with SIM, one may also use speckle interferometry. But the most accessible method to small telescopes is the photometric observation of occultations by the dark limb of the Moon. It is to be noted that to get astrophysically significant results, it is advisable to observe them in three different colors, including near infra-red.

3. *Variable stars.* The GAIA mission will provide individual multi-color data for variable stars. As i was the case for Hipparcos, this is sufficient to describe fully the periodic variables (Cepheids, eclipsing binaries, RR Lyræ, etc..). But long periodic, semi-periodic, and irregular variables, novæ, burst stars must be observed either systematically or when they are active. This is again a perfect objective or ground-based small or medium-size instruments.

4. *Stellar systems.* As said above, it is a domain in which space astrometry cannot be challenged. There is, however, one exception: in very densely crowded fields, the GAIA

images will overlap, and will not be properly separated. Confusion will arise when the same field is projected on different reference great circles. So, using CCD speckle images on long focus instruments, it may be possible to recognize individual stars and determine proper motions within globular clusters or other highly populated areas of the Galaxy.

5. *Miscellaneous*. Identification of the optical counterparts of objects that are observed in other wavelengths: radio, microwave, and infra-red sources.

7. ORGANIZATION OF PROGRAMS

Most of the programs sketched above have in common the property that they can be performed with a part- time use of small or medium size telescopes that exist in many observatories, and are not very actively operated. They should be supplied with one or a mosaic of CCDs and/or a photometer with a few filters. This rather light and cheap equipment is sufficient to participate in several such programs.

Some of them could be undertaken in a single observatory, but in other cases, cooperation between several teams in different observatories will considerably increase their efficiency. This is already the case of the observation of the mutual events of Jupiter and Saturn satellites. Organized by J.-E. Arlot and his team, this program lasts since more than twelve years and is very successful. It is a model hat could be followed in many other instances. The IAU working Group encourages such cooperations and will support as much as possible atronomers who would wish to organize them.

An important point, however, is that all participants to a cooperative program should be rewarded by being associated to publications and, whenever feasible, to publish personalized papers. These programs, making use of small or medium size instrument, provide in addition a very good opportunity to introduce students and young astronomers to astronomical observations.

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