NTT and the quality of the food in the La Silla cafeteria.

Entering the 90's, we started to fear that the driving core of the team was softening with increasing age, that motivations were on the low side, that new arrivals did not integrate in the possibly obsolete working schemes: in short that we might not be up to the new challenges that ESO is facing.

On a hot Saturday in July, on the Max Planck field in Garching, an ESO team with a shaken self-confidence and an average age dangerously approaching 40, entered the ASTRO CUP, a one-day competition with the teams of our neighbours and friends of the Max Planck Institutes für Astrophysik and für Extraterrestrische Physik and of the Observatory of the University of Munich.

At the end of the day, after four strenuous games where we scored 5 goals and suffered 2, we stood as battered but clear winners with the cup at our feet and glasses of excellent Bavarian beer in our hands (both courtesy of the sponsor CONVEX). We might well lose the Cup next year to one of our excellent contenders, but we are satisfied to have proved this time that we are not at our wit's end and that we still have energies to spend when needed.

We are too realistic to claim that this victory is a good omen for other activities of the Organization, but it does not hurt to secretly play with this feeling. Long live ESO! *S. D'ODORICO, ESO*

The ESO team who successfully competed in the 92 Astro-Cup, from the left, top: M. Klaus, C. Gouiffes, a visitor to ESO, E. Zolti (a friend from NET), A. Wallander, F. Koch, J. Quebatte; bottom: L. Noethe, F. Zigmann, B. Delabre, S. D'Odorico, M. Quattri, M. Basbilir (other team members not included in this picture: B. Buzzoni, D. Chittim, A. van Dijsseldonk, G. Fisher, P. François, B. Jørgensen, P. Møller, T. Oosterloo and R. Warmels).

Astrometry with ESO Telescopes

A Contribution to the Construction of the New Extragalactic Reference Frame

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Astronomical research is strongly dependent on the availability of a unique all-sky reference frame though most astrophysicists do not explicitly take notice of this complex astrometric problem.

However, the necessity of very precise pointing of new generation large telescopes from ground or space and the unambiguous identification of very faint objects in all spectral regions accessible from ground and space, in particular in the radio and infrared region, has sensitized the astronomical community to this problem.

During the IAU General Assembly in Buenos Aires a resolution by the Working Group on Reference Systems has been adopted (IAU 1992) which describes the properties of a new, inertial, extragalactic reference frame and a new intercommission working group has been established to provide a practical solution within the coming three years to be presented to the IAU during the 1994 General Assembly in The Hague.

1. Main Properties of the New Reference Frame

Contrary to the present fundamental system which is based on the positions and proper motions of bright stars – the basic FK5 contains 1535 bright stars –, the future extragalactic system will be based primarily on the positions of a carefully selected small number of compact extragalactic radio sources; almost all of these sources will display optical counterparts, mainly quasars and BL Lac's but also some compact galaxies.

This choice is based on the generally agreed assumption of cosmic distances of these objects with the consequence of negligible proper motions and therefore fixed space directions for a long period. This idea already has a long history, but only in the last decade the practical realization of this concept became feasible through the mature technique of VLBI radio astrometry.

Using a global net of suitably distributed radio telescopes, positions of these primary radio sources can now be determined in a routine way to milliarcsecond (mas) precision and an absolute global reference frame can be established and maintained for the future.

At the same time the high angular resolution of VLBI provides comprehensive information on source structure and their temporal changes with sub-mas resolution.

A second group of objects is of equal importance for solving this problem; namely selected radio stars, the cm radio emission of which has to be strong and steady enough to be measured with mas precision by VLBI, the VLA and future VLBA-net on a routine basis.

Absolute positions, proper motions

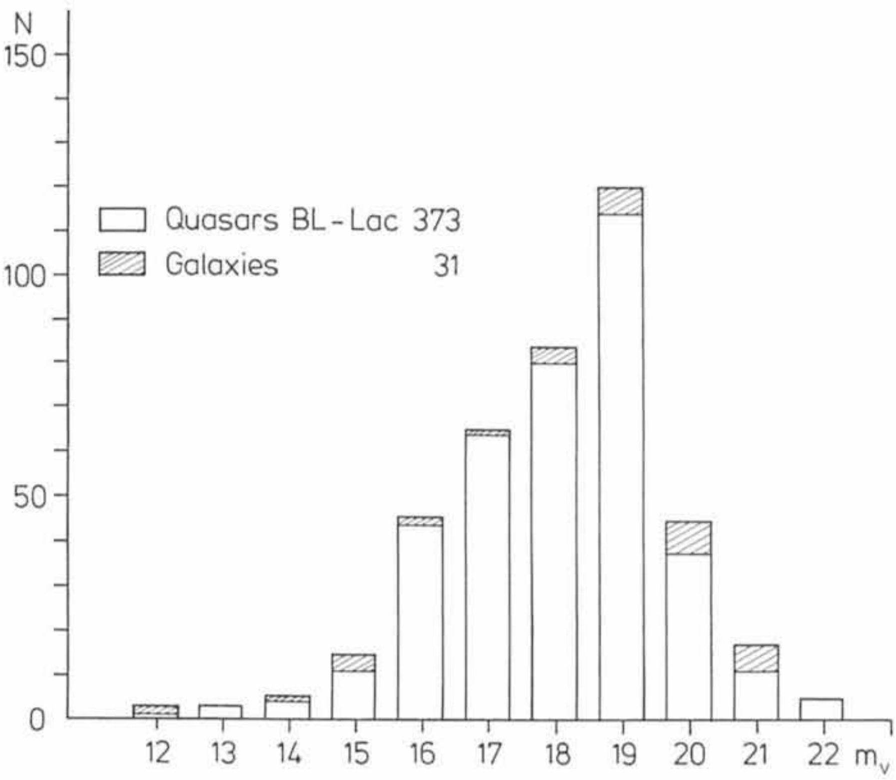

Figure 1: *Magnitude distribution of 404 radio sources for the Extragalactic Reference Frame.*

and parallaxes of those stars are obtained then in the primary extragalactic frame. At the same time these galactic objects can be easily accessed by optical astrometry because of their brightness thus providing a natural link to the optical spectral region.

While being optimal candidates in the radio domain, the primary sources are not very suitable to work with in the optical spectral range directly. The reasons are obvious: firstly, the faintness of their optical counterparts (mostly beyond 18th magnitude, see Fig. 1), which requires large telescopes for observation, the astrometrically usable field of which is ≪ 1 degree, with an additional dramatic decrease of usable field size when CCDs are used instead of the photographic plate. Therefore the object of interest and the reference frame sources have to be very close in the sky, a situation which will allow only very occasionally to link any other object directly to the primary reference frame.

Secondly, there is no realistic measuring technique presently available in the optical domain to determine object positions relative to these very faint primary sources over large arcs, contrary to the radio. Therefore a practical realization of the new reference frame must be based in addition on a dense, global net of fairly bright stars. At the same time this net should be of comparable precision with the radio positions. The anticipated HIPPARCOS stellar net will be the natural choice and will be superior to any previous fundamental catalogue, provided it can be linked in a unique way to the VLBI based primary reference frame.

Thus a multi-step approach is necessary for the construction of this new reference frame, on the other hand, dealing again with stars which will reflect kinematically their galactic origin and the earth's and solar system's motion, precise proper motions (p.m.) and parallaxes have to be determined. Because of unavoidable systematic and random errors in this process, the stellar net will deteriorate substantially as a function of changing epoch. To maintain the initial high precision of the HIPPARCOS net and to improve the precision (2 mas/yr) of the HIPPARCOS proper motions, future astrometry satellite missions are indispensable. Furthermore, a continuous improvement of the main astronomical constants as for example precession and nutation are of crucial importance to maintain a high-precision reference frame.

Although the selection of the about 120,000 HIPPARCOS programme stars was based primarily on astrophysical proposals, the scanning principle used by the satellite and the requirement to monitor continuously the satellite orientation by a large set of so-called starmapper stars fortunately had the consequence that the selection of the programme stars had to be made as uniformly as possible on the sphere. A large body of stars with well-known astrometric history is therefore included in the programme stars; for a recent overview see (*A & A*, 1992).

Thus the HIPPARCOS mission will provide automatically a homogeneous and fairly dense stellar net of about 2.7 stars/sq.deg., mainly in the magnitude interval 7–10 (see Fig. 3).

Furthermore, the Tycho Mission will add some 500,000 fainter stars with precise photometry although reduced astrometric accuracy. However, if we recall for example that already the AGK3 on the northern hemisphere and the CPC2 on the southern hemisphere provide stellar densities of ≥ 10 stars/sq.deg. it is obvious that the HIPPARCOS net should soon be made denser and extended to much fainter limiting magnitudes by further catalogue projects to keep up with the needs of large telescopes with their small-field, highly sensitive area detectors.

2. Linking HIPPARCOS to the VLBI System

The rigidly constructed HIPPARCOS stellar net still may contain a small unknown rotation of some mas/year which will be reflected in the HIPPARCOS proper motions. After this residual motion has been taken out, the HIPPARCOS net will be adjusted to a fixed origin, close to that of the FK5/J2000 system. Because none of the VLBI primary sources is observed by HIPPARCOS directly, a number of indirect approaches has been worked out to provide the link to the inertial (rotation-free) extragalactic system (see Table 1). With a view to the ongoing problems with HST, several ground-based, large observing programmes are underway to provide this link. (Froeschle and Kovalevsky, 1982; *A & A*, 1992; de Vegt et al., 1991).

However, whereas the extragalactic VLBI net does not display a net rotation because of the inertial nature of its target objects, the zero point of the R.A. system has to be adjusted, because VLBI provides only R.A. differences, although absolute declinations. According to the quoted IAU resolution, the R.A. zero point shall be adjusted to the FK5/J2000 zero point at epoch J2000. To achieve this goal, precise optical positions of a suitable subset of the radio sources have to be determined in the FK5 system. Furthermore, the physical nature of the radio and optical emission and the morphology of the sources have to be studied in detail to ensure that the optical and radio emission centres will coincide to the precision of the VLBI measurements, i.e. within mas. At present, knowledge is lacking in this respect, therefore the number of objects and object types (quasars, BL Lac's,

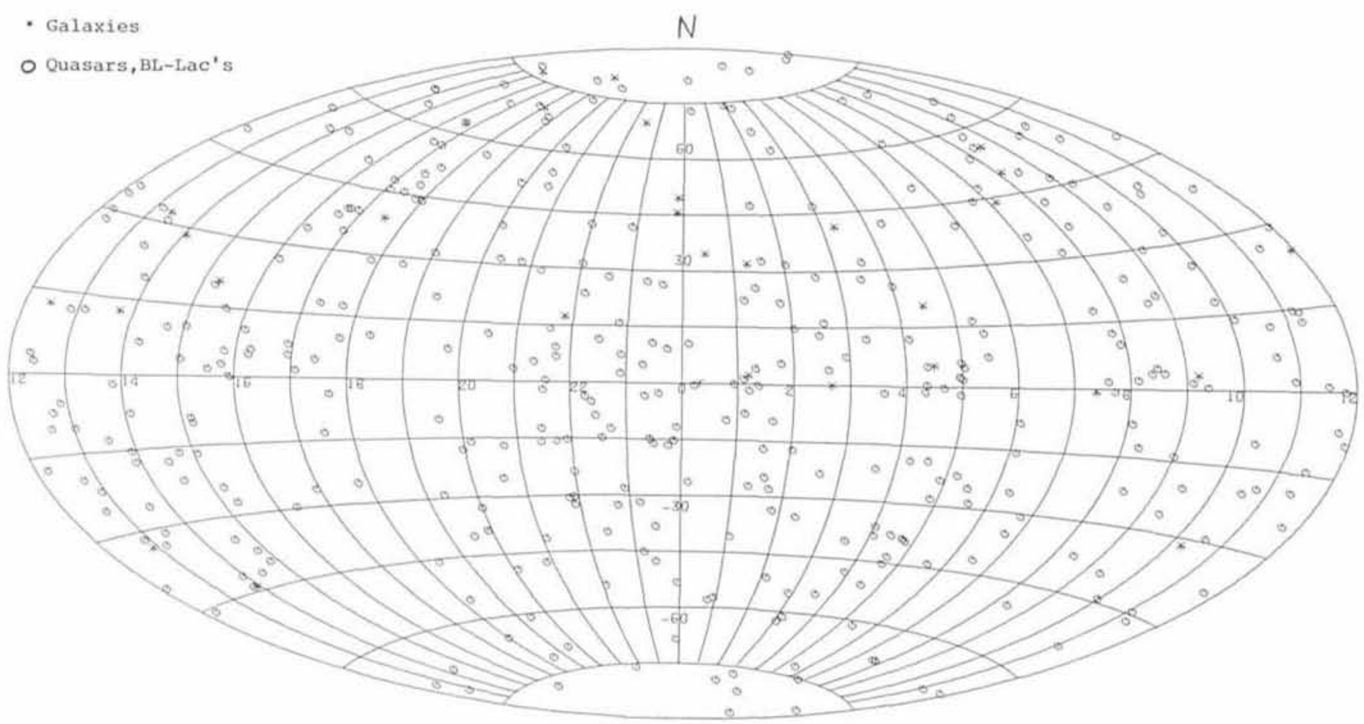

Figure 2: *Distribution of 413 radio sources for the new Extragalactic Reference Frame.*

AGN's . . .) should be as large as possible with the result that possible differences of the emission centres in the various wavelengths will hopefully average out. The same situation obviously will be met with radio stars, although here the source geometry is easier to evaluate.

Any successful link method therefore must be a statistical approach, because no ideal objects do exist with point source properties in all wavelength regions.

In our long-term programme to establish a VLBI-based reference frame (Johnston et al., 1991; de Vegt et al., 1991) we have been using long exposure plates to determine positions of compact radio sources from this primary VLBI net in the FK5 optical fundamental system. Figure 2 shows the source distribution as presently selected for this reference frame. A subset of these objects has already been used successfully for the orientation of a first high-precision VLBI reference frame catalogue. (Ma et al., 1990). Although the optical positions are less precise by about a factor 10 (some 0.01 arcsec) than the corresponding radio positions, the large number of sources available (some 100) will allow to determine the R.A. zero point, also with mas precision.

As Figure 1 clearly demonstrates, most optical counterparts are fainter than 18th magnitude. To link these objects directly to the FK5 system is impossible because almost all FK5 stars are brighter than 6th magnitude and the low catalogue density of about 1 star/30 sq. deg. will provide only a vanishing probability to find a fundamental star in the telescope field (≪ 1 deg. diam.) together with the target object and in addition no detector can handle the enormous magnitude differences. A multi-step approach therefore has to be used. In the first step we are using high precision wide field astrographs in both hemispheres to provide a dense system of secondary reference stars in the magnitude $m_v = 12-14$. The primary reference stars to be used for the astrograph plates solutions are taken from the AGK3RN and SRS catalogues in the northern and southern hemispheres respectively.

These transit circle based catalogues form the main body of the global IRS reference system and are transformed to the IAU FK5/J2000 system.

The reference stars are mostly from the magnitude interval $m_v = 6-9$ with an average density of 1 star/sq. deg. Both astrographs are used with a 6-mag objective grating, therefore we can measure first-order diffraction images of all reference stars together with their central images and also diffraction images of the 1–3 FK5 stars which often will be in the astrograph field also. The plate constants obtained therefore allow to determine the positions of the secondary reference stars very precisely in the FK5 system. As a very important additional step we are measuring all HIPPARCOS programme stars in the astrograph field (about 80–100) for a final HIPPARCOS-based plate solution. It should be recalled here that most of the IRS stars are already among the HIPPARCOS programme stars.

3. Astrometry of Source Plates Using ESO Telescopes

To obtain high-precision astrometric plates for the radio sources, we have used the 3.6-m telescope in the prime focus mode very successfully and currently are using the ESO-Schmidt telescope, because the 3.6-m telescope unfortunately is no more available for direct photography. Although both telescopes provide the necessary limiting magnitude and plate field size to guarantee a sufficient number of secondary reference stars for the determination of precise positions of the target source, the much larger scale of the 3.6-m and the plane image field are more favourable for precise astrometry than the Schmidt, although some accuracy can be regained by averaging a larger number of Schmidt plates. However, concerning possible object structure and problems with crowded fields there is no compensation for the favourable scale of the 3.6-m telescope.

3.1 3.6-m Prime Focus Astrometric Model

The 3.6-m was used with the 3-lens red-triplet corrector which provides a usable field of about 50 arcmin diameter and a flat image plane, 24 × 24 cm,

Table 1. *Main Programmes to link the HIPPARCOS Net to the Extragalactic System.*

Object class	Technique	N	M	Orientation	Rotation
Radio stars	VLBI VLA	<20 <100	D D	yes yes	yes yes
Extragal. radio sources with opt. counterparts	VLBI Opt. astrometry	<400	I	yes	partly
H*-quasar-pairs	VLBI Opt. astrometry HST-FGS	<100	I	partly	yes
Lick p.m. stars (mainly N. Hem.)	Opt. astrometry	<20,000	D	no	yes

N = approximate number of objects available.
M = Mode D = direct link (objects observable in both systems).
I = indirect link (objects are not HIPPARCOS programme stars).

1.5-mm thick Kodak 098-04 plates have been used. However, the corrector introduces a strong third-order regular geometric distortion term which has to be taken into account in the plate model.

Furthermore, there is no possibility to calibrate the intersection of the optical axis on the plate, therefore two additional terms for the zero point of the distortion have to be included. Because of the limited field size and the position of the target object very close to the plate centre, a 6-constant affine plate model (de Vegt, 1991) will be sufficient for modelling differential refraction and aberration and the usual projection onto the tangential plane.

The linearized plate model therefore is:

$$XI = ax + by + c + Lx(x^2 + y^2) - U(3x^2 + y^2) - V(2xy)$$
$$ETA = a'x + b'y + c' + Ly(x^2 + y^2) - U(2xy) - V(x^2 + 3y^2)$$

(standard coordinates XI, ETA; plate measurements x, y: unknown plate constants a, b, c, a, b, c, L, U, V; L = 3rd-order distortion term, U, V = compensation for zero point of distortion).

A successful application of this model is only possible because of the large number of reference stars (50–100) available in the plate field. Furthermore we are only interested in obtaining the target position which is at the plate centre. The complete astrometric modelling of the whole plate field turned out to be much more complex, because of additional 5th order regular distortion and irregular field distortions increasing to the field edge. In addition the distortion terms depend on the position and optical quality of the filter also.

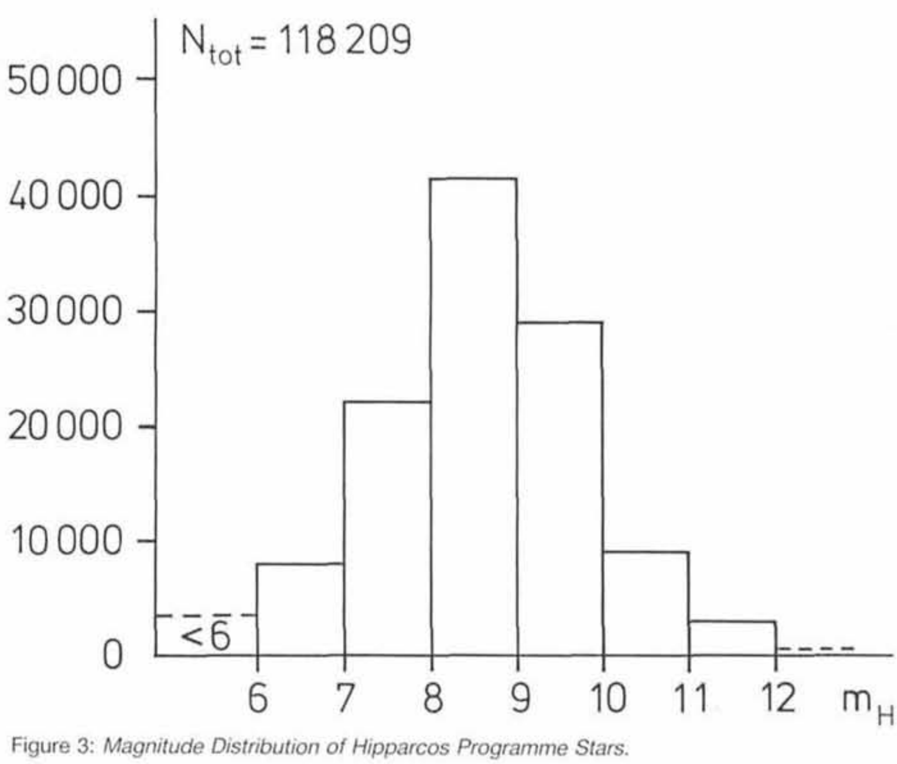

Figure 3: *Magnitude Distribution of Hipparcos Programme Stars.*

3.2 Schmidt Plates

Global astrometric modelling of Schmidt plate geometry is a major problem and in addition different solutions may be required for the different optical configurations of various Schmidt telescopes. At least one fact is obvious: any successful solution requires a dense net of very accurate reference stars which in addition have to be chosen from a magnitude range where the diffraction spikes of Schmidt plate images are negligible which means that these reference stars should be at least >12th magnitude for practical exposure conditions. Unfortunately a precise global reference star catalogue in this magnitude range is still lacking, although definite plans are available but on hold because of recent financial problems (de Vegt, 1989, 1991).

In our application we are only interested in modelling the central plate area of about 1 × 1 deg. As in the case of the 3.6-m, our system of secondary reference stars is perfectly suited for this purpose. Because of the small size of the 3rd-order term and the restricted field size, a statistically significant determination of the distortion zero point terms is not possible. Furthermore, as practical experience has shown, even the third-order term can be pre-corrected without affecting the position of the central target object significantly, provided the origin of the rectangular plate measurements x, y is carefully adjusted to the plate centre a priori.

The appropriate choice of the plate model can be limited therefore to a 6-constant affine model, with a possible extension to the 3rd-order term, if the geometry of the particular Schmidt telescope is not well known at the beginning, or the adopted plate-filter combination changes (see above-quoted model, without the U, V terms).

In the current Schmidt observing programme high quality plates for 29 sources have already been obtained. Normally 3 plates/object are taken using a 098–04+OG550 emulsion-filter combination. Plates are unhypered, exposure times are ≤40 minutes each. All plates are measured on our modernized 422F-MANN comparator which uses a CCD camera for direct image digitization (for details see Winter et al., 1992). A measuring accuracy of 0.5 microns is obtained in routine operation. In addition, a new type of astrometric measuring machine is under development which will allow to digitize a complete Schmidt plate in less than 1 hour with submicron accuracy.

As an example of our current work, results for the QSO 748+126 (m_v = 17.8, z = 0.889) are presented. This primary reference frame radio source shows a stellar appearance on the plates. Using the quoted reduction model, a m.e. of unit weight for the plate solution of < 0.1 arcsec could be obtained. The final FK5/J2000 position, based on 3 plates, is

RA(J2000) 7^h 50^m 52.051^s;

DEC(J2000) +12° 31' 04.84"

Using the corresponding VLBI position from (Ma et al., 1990), the system difference in the sense "optical minus radio" then is:

DAcos(DEC) = +0.073 arcsec;

DDEC = +0.01 arcsec

which is in good agreement with earlier results (Johnston et al., 1985) and the recently quoted first preliminary results of a HIPPARCOS-FK5 comparison in that sky region (Lindegren, 1992). However, a dense grid of some 100 comparison points, as will be provided by our reference frame programme is required for a more detailed conclusive analysis.

Acknowledgements

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The ESO Minor Planet Sky

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The European Southern Observatory was established in 1962 to operate the powerful La Silla observatory for the benefit of many fields of astronomy and astrophysics. Only a few programmes were directly concerned with the survey of the solar system and the discovery of minor bodies like comets and minor planets. In many cases, observations of these objects were made only as valuable by-products of other campaigns. It was especially the wide-field telescopes, the 1-m ESO Schmidt and the 40-cm GPO Astrograph, which yielded an enormous amount of positional data. During the last decades ESO has always maintained a leading position in the world, as far as the number of minor planet observations is concerned.

In 1988, Commission 20 of the IAU established a special study group to elucidate the meanings of minor planet names. This endeavour, which comprises a lot of data for the first 5012 minor planets numbered until the end of 1991, has now reached completion (L.D. Schmadel, *Dictionary of Minor Planet Names*, X+687 p., Springer-Verlag, 1992).

Since all information in this work has been archived in a computer-readable data base, it is very easy to extract material which directly or indirectly pertains to ESO. I have here used the data base and some recently published, additional material to illustrate the "ESO minor planet sky".

The many thousands of observations at ESO have inevitably produced quite a few discoveries. However, there is a long way from the detection of a new solar system object until it can be definitively numbered and named. The new planet has to be observed in – at least – three oppositions before it can be numbered. Therefore, the majority of new detections remain in a "dormant" stage in the Minor Planet Center's computer files. In some cases it is possible to identify new positions with planets observed earlier; this shortens the process. Nowadays, it is a rare exception when a newly discovered planet can be quickly identified with a long series of prior observations.

The statistics show that until July 1992, some 186 ESO discoveries have reached the status of "established", i.e. numbered, minor planets. Table 1 records these objects in ascending order together with the name (or preliminary designation), the year of discovery and the discoverer(s). Whereas the great majority was found by Belgian astronomer Henri Debehogne during special surveys for minor planets, most others were found by chance, mainly with the Schmidt telescope, and during the various ESO atlas projects. A total of 16 astronomers earned discoverer merits; they are shown in Table 2 together with the overall numbers of discoveries and co-discoveries (in parentheses).

It is interesting to note that in the very near future ESO is likely to rank fifth (behind Heidelberg, Crimea, Palomar and the Anderson Mesa Station of Lowell Observatory) on the list of the most successful minor-planet discovering observatories. In the ranking list of the most successful discoverers of minor planets of all times, Henri Debehogne now occupies the 13th place – one place ahead of the famous visual planet hunter A. Charlois in Nice, who detected some 99 planets between 1887 and 1904.

The right to name a minor planet essentially belongs to the discoverer. As can be seen from Table 1, only a small fraction of ESO discoveries honours ESO astronomers. This has to be done by other colleagues, and there are in fact a lot of names which together constitute a kind of "ESO minor planet sky". While it is very easy to extract all ESO successes from the data base, it is nearly impossible to find among the 4,000 existing minor planet names those which have been accorded to ESO officials, staff astronomers, etc.

The list in Table 3 gives all those which are mentioned in the book about the ESO history, recently written by Adriaan Blaauw. Still, it cannot be considered to be a complete compilation. It shows, however, that it is not very exaggerated to speak about the ESO minor planet sky!