EXTENSION OF THE OPTICAL REFERENCE FRAME: GROUND BASED

N. ZACHARIAS
U.S. Naval Observatory, nz@pyxis.usno.navy.mil
3450 Mass.Av.NW, Washington DC 20392, USA

1. Introduction

The International Celestial Reference Frame (ICRF) is realized by the positions of 608 compact extragalactic radio sources (Ma & Feissel 1997) with milliarcsecond (mas) and sub–mas accuracy, all being on the same system, the International Celestial Reference System (ICRS). The Hipparcos Catalogue (ESA 1997) is the practical realization of the ICRF at optical wavelengths, giving accurate positions ($\approx$ 1 mas) at the mean epoch of 1991.25 and proper motions ($\approx$ 1 mas/yr) for 117 995 stars. This is about 2.5 stars per square degree, most being in the 7 to 9 magnitude range and a few as faint as 12. However, for many astronomical applications the Hipparcos Catalogue is not dense enough and does not reach faint enough magnitudes.

The Tycho Catalogue (ESA 1997) provides accurate positions ($\approx$ 25 mas) for about one million stars to magnitude 11, but lacks precise proper motions. Ground–based observations are an efficient way to complement the Hipparcos mission and to extend the optical reference frame to fainter magnitudes and yield a denser grid of astrometric standard stars. New reductions of early epoch photographic data will be used to provide highly accurate proper motions for stars to about magnitude 12. Current and new observational projects will extend the optical reference frame to even fainter magnitudes.

2. AC reductions, proper motions for Tycho stars

One major step for a densification of the optical reference frame is the reduction of the Astrographic Catalogue (AC) data to the Hipparcos system. For a general overview of the AC and Carte du Ciel (CdC) data, which were taken with the AC data to provide an atlas of the sky, see Eichhorn (1974). The AC covers the entire sphere and provides over 4.6 million positions of stars to about 12th magnitude. The AC 2000 (Urban *et al.* 1998) is the result of a complete re–reduction of the AC data performed at the U.S. Naval Observatory. The ACT contains accurate proper motions derived from the combination of AC 2000 and Tycho data. The ACT is now available on CD–ROM (send a request to seu@sicon.usno.navy.mil). The Tycho Reference Catalog (TRC) is a similar project with contributions from institutes in Moscow, Heidelberg, Copenhagen and Lund (see Høg 1997, this JD), which is expected to be completed by the end of 1997. These AC reductions allow the derivation of proper motions for almost all of the million Tycho stars with an accuracy of 2–4 mas/yr. Currently there is no recent epoch, high precision astrometric catalog available to fully utilize the over 3 million other AC positions. The Tycho 2 project (see Høg 1997, this JD) aims at deriving positions on the 50 mas and 100 mas level for 2 million stars of magnitude 11 and 12, respectively, by a re–analysis of the Tycho space mission data.

3. Re–measuring of old epoch photographic plates

Many zones of the AC project would benefit from a re–measurement. The IAU has set up a working group to explore the options. Of high priority is the Vatican zone ($55° \leq \delta \leq 64°$), with poor published measurements and early plates (around 1900) that are still in good shape. Bordeaux Observatory (Requième 1997, *priv.com.*) has started to measure the Bordeaux Zone CdC plates.

J. Andersen (ed.), Highlights of Astronomy, Volume 11A, 300–303.

Hamburg Observatory plans to re-measure the AGK2 plates (epoch ≈1930) which are kept there under excellent conditions (de Vegt 1988). Only one of the two exposures of about 186 000 stars were originally measured. The new measurements would give results for at least 10 times as many stars, to the limiting magnitude of about 12, with an estimated accuracy for the final catalog positions of 100 mas, resulting in a proper motion accuracy of at least 1.7 mas/yr.

4. Current and near future observational programs

TABLE 1. Current and near future observational programs. The star selection column indicates star list observing (L), selected regions (S) and all stars (A) within the given area and magnitude limits. The approximate standard error of a catalog position, σ_{cat}, is given for *well exposed stars*, which usually means stars of 2 or more magnitudes brighter than the limiting magnitude of the project indicated in the mag.range column.

project name	place	number of stars	mag. range	star sel.	Dec.zone (area)	σ_{cat} (mas)	status remark
automated transit circles:							
CAMC	La Palma	0.1 M	7...14	L	$-40 \le \delta \le 90$	50	active, CMC 9
CMASF	El Leoncito		7...14	L	$-90 \le \delta \le 30$		1997 →
scanning telescopes:							
AMC	Nicolaev		...15	S	North		start 1998
FASTT	Flagstaff	0.7 M	10...18	S	$-1.7 \le \delta \le 1.7$	40	1996 for SDSS
MERIDIAN2000	Bordeaux		9...16	A	$11 \le \delta \le 17$		1997–2000
	Sao Paulo		9...15		$-90 \le \delta \le 30$		just started
NAOJ	Tokyo	1 M	12...16	S	$-30 \le \delta \le 45$		1997–2001
SDSS	Apache Point	100 M	10...23	A	North gal.cap	≈100	start 1998
photographic astrograph:							
FON	Kiev	30 M	...16	(A)	$-23 \le \delta \le 90$	200	start 1982
NPM	Lick, Flagstaff		8...18	A	$-23 \le \delta \le 90$	150	re-meas. 1997 →
SPM	San Juan, Yale		...18	A	$-90 \le \delta \le -23$		2nd epoch ?
CCD astrograph:							
UCA test	Washington	0.3 M	7...16	S	$29 \le \delta \le 33$	20	1997
UCAC-S	CTIO, Wash.	40 M	7...16	A	$-90 \le \delta \le 2$	20	1998–1999
Schmidt surveys		≥500 M	11...20	A	$-90 \le \delta \le 90$	≤250	1950–2000

The Carlsberg Automatic Meridian Circle (CAMC) is the most productive instrument in its class, with the 9th catalog in press (CMC9 1997). Due to the list-mode observing technique, only a relatively small number of stars can be observed each year. However, in selected areas, e.g. around extragalactic reference frame sources, a dense grid of stars to about 14th magnitude has been established. A similar instrument has started test observations on the Southern Hemisphere in El Leoncito, Argentinia (Muinos 1997, *priv.com.*).

Scanning transit telescopes utilize a CCD-camera and integrate light as the sky drifts by due to the diurnal motion of the Earth. The USNO Flagstaff Astrometric Scanning Transit Telescope (FASTT) (Stone *et al.* 1996) did a pioneering job, producing a catalog of star positions along equatorial regions. The Bordeaux meridian circle (Requième 1997, *priv.com.*) and the National Astronomical Observatory of Japan (NOAJ) transit circle (Yoshizawa 1997, *priv.com.*) have recently been upgraded with a CCD-camera and observations are made in scanning mode. A similar instrument is being set up in Sao Paulo, Brazil.

The precision of individual wide-angle observations with modern automated transit circles is about 100 mas for well exposed stars near the zenith, and a catalog accuracy of about 50 mas is reached with multiple observations. For scanning transit circles the wide-angle positional accuracy has been about 150 mas but will be about 40 mas in differential observing with the use of Tycho reference stars. The scanning telescope curved-stellar-path-problem at higher declinations can be overcome; however, active driving along the sky and a rotation of the detector are then required, thus introducing other problems. The Sloan Digital Sky Survey (SDSS) instrument (Richmond 1993) will operate this way, and estimates of its astrometric capabilities range from 50 to 200 mas.

The following photographic astrometric surveys are ongoing or have been recently finished. First data (single overlap) of the FON project (Yatskiv 1997, *priv.com.*) will soon be published. Observations have been made with astrographs on blue sensitive plates by various institutes in the former Soviet Union. The Lick Northern Proper Motion (NPM) survey (Klemola *et al.* 1987) is complete, however only a fraction of the imaged stars have been measured so far (Klemola *et al.* 1993). The Southern Proper Motion (SPM) survey (Girard *et al.* 1997) is lacking the second epoch plates for a large fraction of the sky. Although modern astrographs are capable of an accuracy of under 100 mas for a single observation using photographic plates (Zacharias *et al.* 1994), there are currently no new such surveys in preparation.

The USNO CCD Astrograph Catalog South (UCAC-S) project (Gauss *et al.* 1996) will start in early 1998 to observe the entire Southern Hemisphere with a 4k CCD camera on a 2-meter focal length state-of-the-art astrograph. A positional accuracy of 15 mas has been achieved from guided exposures in test observations with that telescope (Zacharias *et al.* 1997). A 1.3-meter telescope for wide-field CCD imaging is being constructed at USNO, Flagstaff, which will have a wide-field, astrometric capability for faint stars ($\approx 13...22^m$). Similarly, mosaic imaging cameras at major observatories are now planned or already in test operation, which are capable of mapping a significant fraction of the sky to very faint magnitudes ($\geq 22^m$).

5. Reduction of Schmidt plate surveys

A re-reduction of the Space Telescope Science Institute (STScI) Guide Star Catalogue (GSC), version 1.2, has improved its positional accuracy to 250 mas at the plate centers and 500 mas at the plate edge (Röser *et al.* 1997). The version 1.3, with the same data on the Hipparcos system, will become available soon. Although not an astrometric catalog, the GSC has been and will be used for astrometry of faint stars (to 16^m) until it is superseded by e.g. the UCAC.

A complete digitization of Schmidt plate surveys (to $\approx 20^m$) is underway at the Royal Greenwich Observatory, Univ. of Minnesota, Royal Observatory Edinburgh, STScI, and the USNO Flagstaff. A recent review of the Schmidt plate surveys and scans can be found elsewhere (Lasker 1993). USNO, Flagstaff was first in finishing a global catalog (Monet 1996) from the Schmidt plate survey scans. A similar project, the GSC II is in progress with participation from STScI, Torino Observatory, ESA, and the GEMINI consortium. Reference stars fainter than 12^m have proven to be indispensable for astrometric Schmidt plate reductions. A positional accuracy of at least 150 mas seems feasible for well exposed stars from Schmidt plates, provided enough faint reference stars are available and the plates are measured to a linear accuracy of at least a micrometer (Murray & Corben 1979).

References

Carlsberg Meridian Catalogue La Palma Number 9 (1997)

de Vegt, C. (1988) in *Mapping the Sky*, IAU Sympos.133, Eds. S.Debarbat, J.A.Eddy, H.K.Eichhorn & A.R.Upgren, Kluwer Acad.Publ., Dordrecht, p.211

Eichhorn, H. (1974) *Astronomy of Star Positions*. Fred.Ungar Publ.Co., New York

ESA (1997) *The Hipparcos and Tycho Catalogues*. European Space Agency, SP-1200

Gauss, F.S., Zacharias, N., Rafferty, T.J., Germain, M.E., Holdenried, E.R., Pohlman, J.W. & Zacharias, M.I. (1997) A new astrometric survey of the southern hemisphere, BAAS 28, No.4, 1282

Girard, T.M., Platais, I., Kozhurina-Platais, V., van Altena, W.F., & Lopez, C. E. (1997) The Southern Proper Motion Program I, *submitted* to AJ

Klemola, A.R., Jones, B.F., & Hanson, R.B. (1987) AJ 94, 501

Klemola, A.R., Jones, B.F., & Hanson, R.B. (1993) National Space Science Data Center/ADC Catalog No.A1199

Lasker, B.M. (1993) Photographic Surveys and their Digitization, in *Workshop on Databases for Galactic Structure*, eds. A.G.D.Philip, B.Hauck, & A.R.Upgren, L.Davis Press, Schenectady, NY, p.77

Ma, C. & Feissel, M. (1997) Definition and Realization of the International Celestial Reference System by VLBI Astrometry of Extragalactic Objects, *IERS Technical Note* 23

Monet, D. 1996, The A1.0 and SA1.0 catalogs on CD-ROM, U.S. Naval Observatory

Murray, C.A. & Corben, P.M. (1979) MNRAS 187, 723

Richmod, M. (1993) The Sloan Digital Sky Survey, in *Workshop on Databases for Galactic Structure*, eds. A.G.D.Philip, B.Hauck, & A.R.Upgren, L.Davis Press, Schenectady, NY, p.207

Röser, S., Morrison, J., Bucciarelli, B., Lasker, B. & McLean, B. (1997) Contents, test results, and data availability for GSC 1.2, in proceedings IAU Symposium No.179, Baltimore, USA, *in press*

Stone, R.C., Monet, D.G., Monet, A.K.B., Walker, R.L., Ables, H.D., Bird, A.R., & Harris, F.H. (1996) AJ, 111, 1721

Urban, S.E., Corbin, T.E., Wycoff, G.L., Martin, J.C., Jackson, E.S., Zacharias, M.I., & Hall, D.M. (1998) The AC 2000: The astrographic Catalogue on the System Defined by the Hipparcos Catalogue, *in preparation*

Zacharias, N., de Vegt, C., Winter, L., & Weneit, W. (1994) Some results of CCD-camera based astrometric plate measurements, Proceedings of the IAU Sympos. 161, p.285 Eds.: MacGillivray et al., Kluwer, Dordrecht
Zacharias, N. (1997) Astrometric Quality of the USNO CCD Astrograph (UCA), AJ, **113**, 1925