Astron. Astrophys. 323, L49–L52 (1997)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

The Hipparcos Catalogue*

M.A.C. Perryman[1], L. Lindegren[2], J. Kovalevsky[3], E. Høg[4], U. Bastian[5], P.L. Bernacca[6], M. Crézé[7], F. Donati[8], M. Grenon[9], M. Grewing[10], F. van Leeuwen[11], H. van der Marel[12], F. Mignard[3], C.A. Murray[13], R.S. Le Poole[14], H. Schrijver[15], C. Turon[16], F. Arenou[16], M. Froeschlé[3], and C.S. Petersen[4]

[1] Astrophysics Division, European Space Agency, ESTEC, Noordwijk 2200AG, The Netherlands
[2] Lund Observatory, Box 43, S-22100 Lund, Sweden
[3] Observatoire de la Côte d'Azur, CERGA, Avenue Copernic, F-06130 Grasse, France
[4] Copenhagen University Observatory, Juliane Maries Vej 30, DK-2100 Copenhagen OE, Denmark
[5] Astronomisches Rechen-Institut, Mönchhofstrasse 12–14, D-69120 Heidelberg, Germany
[6] Astrophysical Observatory, via dell'Osservatorio, I-36012 Asiago, Italy
[7] 18 rue Nicolazic, F-56400 Sainte Anne d'Auray, France
[8] Centro di Studi Sui Sistemi, Via Vincenzo Vela 27, I-10128 Torino, Italy
[9] Observatoire de Genève, CH-1290 Sauverny, Switzerland
[10] Astronomisches Institut, Waldhäuserstrasse 64, D-72076 Tübingen, Germany
[11] Royal Greenwich Observatory, Madingley Road, Cambridge CB3 0EZ, UK
[12] Department of Geodesy, Delft University of Technology, Thijsseweg 11, 2629JA Delft, The Netherlands
[13] Derwent Cottage, 12 Derwent Road, Eastbourne, Sussex BN20 7PH, UK
[14] Sterrewacht Leiden, Postbus 9513, 2300RA Leiden, The Netherlands
[15] SRON, Sorbonnelaan 2, 3584CA Utrecht, The Netherlands
[16] Section d'Astrophysique, Observatoire de Paris, F-92195 Meudon Cedex, France

Received 29 April 1997 / Accepted 1 May 1997

Abstract. The principal observational characteristics of the Hipparcos Catalogue, and a summary of its main astrometric and photometric properties, are presented. Median astrometric standard errors (in position, parallax, and annual proper motion) are in the range 0.7–0.9 milliarcsec (mas) for stars brighter than 9 mag at the catalogue epoch (J1991.25). The catalogue is a materialisation of the ICRS reference system, coinciding with its principal axes at the level of ± 0.6 mas, and with proper motions consistent with an inertial system at the level of ± 0.25 mas/yr. The 118 218 constituent stars provide a mean sky density of $\sim$ 3 stars deg^{-2}. The catalogue is available in printed and machine-readable forms.

Key words: Hipparcos – astrometry – parallaxes – proper motions – catalogues

1. Introduction

The scientific goal of ESA's Hipparcos space astrometry project was to provide positions, proper motions, and direct distance estimates for more than 100 000 stars in the solar neighbourhood, in order to determine their physical properties, and to place theoretical studies of stellar structure and evolution, and studies of galactic structure and kinematics, on a more secure observational footing. The Hipparcos Catalogue, one of the two major stellar catalogues resulting from the project, was completed in August 1996, and published in June 1997 (ESA 1997). This paper summarises the key attributes of the Hipparcos Catalogue, complete details of which are provided in the documentation accompanying the catalogue. A summary of the Tycho Catalogue, derived from an analysis of the satellite's star mapper observations, is presented in an accompanying paper by Høg et al. (1997).

2. Observational Principles

The observational capabilities and operational principles of the Hipparcos satellite have been presented in the literature on numerous occasions. The key features of the observations (see also Table 1) were as follows:

(a) through observations from space, the effects of atmospheric seeing, instrumental gravitational flexure and thermal distortions could be obviated;

* Based on observations made with the ESA Hipparcos astrometry satellite

Table 1. Principal observational characteristics of the Hipparcos Catalogue. ICRS is the International Celestial Reference System.

Measurement period	1989.85–1993.21
Catalogue epoch	J1991.25
Reference system	ICRS
coincidence with ICRS[1]	±0.6 mas
deviation from inertial[1]	±0.25 mas/yr
Number of entries	118 218
with associated astrometry	117 955
with associated photometry	118 204
Mean sky density	~ 3 stars deg^{-2}
Limiting magnitude	$V \sim 12.4$
Magnitude completeness[2]	$V = 7.3 - 9.0$

[1] about all 3 axes
[2] depending on galactic latitude and spectral type

Table 2. Astrometric characteristics of the Hipparcos Catalogue.

Median σ_α at J1991.25[1]	0.77 mas
Median σ_δ at J1991.25[1]	0.64 mas
Median σ_π[1]	0.97 mas
Median $\sigma_{\mu_\alpha \cos\delta}$[1]	0.88 mas/yr
Median σ_{μ_δ}[1]	0.74 mas/yr
10 per cent better than[2]	0.47–0.66 mas
Smallest errors[2]	0.27–0.38 mas
Distance $< 10\%$ ($\sigma_\pi/\pi < 0.1$)	20 853
Distance $< 20\%$ ($\sigma_\pi/\pi < 0.2$)	49 399
External errors/standard errors[3]	$\sim 1.0 - 1.2$
Systematic errors in astrometry[3]	< 0.1 mas

[1] for $Hp \leq 9$ mag
[2] on each of the five astrometric parameters
[3] estimated from various investigations

Table 3. Statistics of solved or suspected double/multiple systems contained in the Double and Multiple Systems Annex.

Total	23 882
Systems with component data (annex C)	12 195
of which 2 996 newly-determined	
Orbital systems (annex O)	235
Astrometric binaries (annexes G and V)	2 910
Suspected non-single (including annex X)	8 542

(b) all-sky visibility permitted a direct linking of the stars observed all over the celestial sphere;

(c) the two viewing directions of the satellite, separated by a large and suitable angle, resulted in a 'rigid' connection between quasi-instantaneous one-dimensional observations in different parts of the sky, and in parallax determinations which are absolute;

(d) the continuous ecliptic-based scanning of the satellite resulted in an optimum use of the available observing time, with a resulting catalogue of reasonably homogeneous sky density and uniform astrometric accuracy;

(e) the various geometrical scan configurations for each star, at multiple epochs throughout the 3-year observation programme, resulted in a dense network of one-dimensional positions from which the barycentric coordinate direction (α, δ), the parallax (π), and the object's proper motion ($\mu_\alpha \cos\delta$, μ_δ) could be solved for in what was effectively a least-squares reduction of the global observations. The astrometric parameters as well as their standard errors and correlation coefficients were derived in the process;

(f) since the number of independent geometrical observations per object was large (typically of order 30) compared with the number of unknowns for the standard model (5 astrometric unknowns per star) astrometric solutions not complying with this simple 'five-parameter' model, could be expanded to take into account the effects of double or multiple stars, or non-linear photocentric motions ascribed to unresolved 'astrometric binaries';

(g) a somewhat larger number of actual observations per object, of order 110, provided accurate and homogeneous photometric information for each star, from which mean magnitudes, variability amplitudes, and in many cases period and variability type classification could be undertaken.

The satellite observations were based on the Hipparcos Input Catalogue, compiled by the INCA Consortium and representing the synthesis of scientific observing proposals submitted in 1982, and a stellar reference network consistent with observational and data analysis requirements (Turon et al. 1995). The data reductions were carried out in parallel by two data analysis consortia (FAST and NDAC) – recent descriptions of the data reduction processes have been given by Kovalevsky et al. (1995), with details of the properties of the preliminary catalogue in comparison with ground-based stellar positions and proper motions given by Lindegren et al. (1995). The analyses, proceeding from nearly 1000 Gbit of satellite data, incorporated a comprehensive system of cross-checking and validation of the entire data reduction and catalogue construction process. Final results of the two independent analyses were rigorously combined into the single final Hipparcos Catalogue and associated annexes.

Transformations from coordinate to natural directions were carried out in space-time coordinates characterised by a spherically symmetric, heliocentric General Relativistic metric in which light-bending by the Sun (and, in NDAC only, the Earth) was taken into account. Deviations from this assumed metric were parameterised in a PPN-type formalism, from which values of $\gamma = 1.000 \pm 0.004$ (in FAST) and $\gamma = 0.992 \pm 0.005$ (in NDAC) gave further confidence in the metric formalism and global reductions.

Proper directions were computed using the Earth ephemeris VSOP 82/ELP 2000 (consistent with DE200), combined with the satellite ephemeris provided by the operations centre (ESOC), the latter accurate to some 1.5 km in position and 0.2 m s^{-1} in velocity. Otherwise, the former IAU (1976) system of constants was used for the reductions. Terrestrial Time (TT) was adopted for both astrometric and photometric results, the latter published as arrival times at the solar system barycentre.

The adopted catalogue epoch is J1991.25, close to the mean central epoch of the observations for each star. The provision of

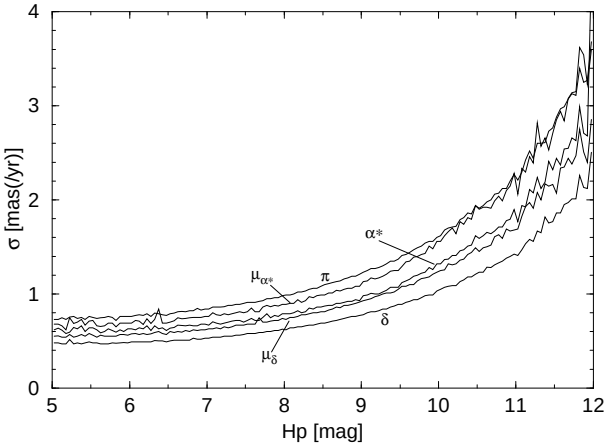

Fig. 1. Median standard errors of the five astrometric parameters as a function of Hp magnitude. The unit of the standard error is milliarcsec (mas) for the positional components (α, δ) and parallax (π), and mas/yr for the proper motion components ($\mu_{\alpha*} = \mu_\alpha \cos\delta$, μ_δ).

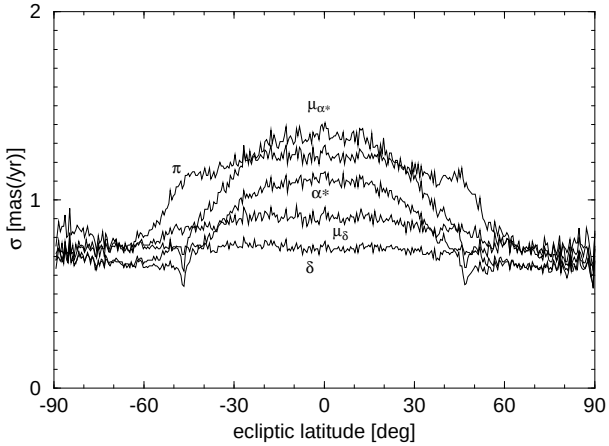

Fig. 2. Median standard errors of the astrometric parameters as a function of ecliptic latitude (units as for Fig. 1). The dependency on ecliptic latitude is a consequence of the ecliptic-based scanning law. The errors are given at the catalogue epoch, J1991.25.

the correlation coefficients for each astrometric solution allows the standard errors of transformed quantities to be determined at an arbitrary epoch including, for example, the epoch at which the standard error is minimised for each individual star.

The details of the connection of the observations to the extragalactic reference frame have been presented by Kovalevsky et al. (1997). The resulting Hipparcos Reference Frame is a materialisation of the International Celestial Reference System (ICRS), which replaces the FK5 system as the practical definition of celestial coordinates in the optical region. The construction of the ICRS (Folkner et al. 1994; Arias et al. 1995) ensures that no discontinuity larger than the uncertainty of the FK5 system occurs in the transition from FK5 (mean equinox and equator J2000) to ICRS. Thus, from the viewpoint of optical astrometry, the Hipparcos Catalogue can be regarded as an extension and improvement of the J2000(FK5) system, retaining approximately the global orientation of that system but without its regional errors.

Details of the data, their reductions, the merging of the two independent astrometric solutions, and the properties of the final catalogue, are given as part of the published Hipparcos and Tycho Catalogues (ESA 1997).

3. Presentation of Results

The standard astrometric model adopted for single stars assumes uniform rectilinear space motion relative to the solar system barycentre. At some reference epoch, T_0, the stellar motion is then described by the following five astrometric parameters (the third component of the space velocity, the radial velocity, being undetermined from the Hipparcos observations): the barycentric coordinate direction (α, δ); annual parallax, π, from which the coordinate distance is $(\sin\pi)^{-1}$ AU or, with sufficient approximation, π^{-1} pc if π is expressed in arcsec; and the rate of change of the barycentric coordinate direction expressed as proper motion components $\mu_{\alpha*} = \mu_\alpha \cos\delta$ and μ_δ, in angular measure per unit time (the $\cos\delta$ factor, signified by the asterisk in $\mu_{\alpha*}$, relates the rate of change of position in right ascension to great-circle measure).

These five astrometric parameters (see Table 2) are given for almost all stars in the catalogue. Systems which could not be described by these five parameters were classified into five parts of the Double and Multiple Systems Annex (see Table 3): (C) component solutions, in which two or more components were resolved and their absolute and relative astrometry (and photometry) were reconstructed; (G) 'acceleration' solutions, in which the photocentric motion contains non-linear time-dependent terms; (O) orbital systems, for which (partial) orbital solutions could be derived, possibly in combination with ground-based observations; (V) 'variability-induced mover' solutions, in which binarity was inferred from a time-dependent photocentric displacement; and (X) 'stochastic' solutions, in which multiplicity was evident yet uncharacterised. Further details are given by Lindegren et al. (1997).

The Hipparcos Catalogue includes a variety of accurate and homogeneous photometric information for each star, in particular: the Johnson V magnitude, accurate to typically 0.01 mag, and derived from a combination of satellite and ground-based photometry; broad-band Hipparcos, or Hp, magnitudes, in an instrument specific passband, providing the most accurate multi-epoch photometric data most suitable for variability studies (the median photometric precision for $Hp < 9$ mag is approximately 0.0015 mag); two-colour B_T and V_T magnitudes derived from the Tycho (star mapper) observations; and Johnson B–V and Cousins' V–I colour-indices, again derived from a combination of satellite and ground-based measurements. The mean number of photometric observations per star over the three-year observational period is 110, providing data for detailed variability classification and characterisation. The principal photometric characteristics and variability statistics are given by van Leeuwen et al. (1997).

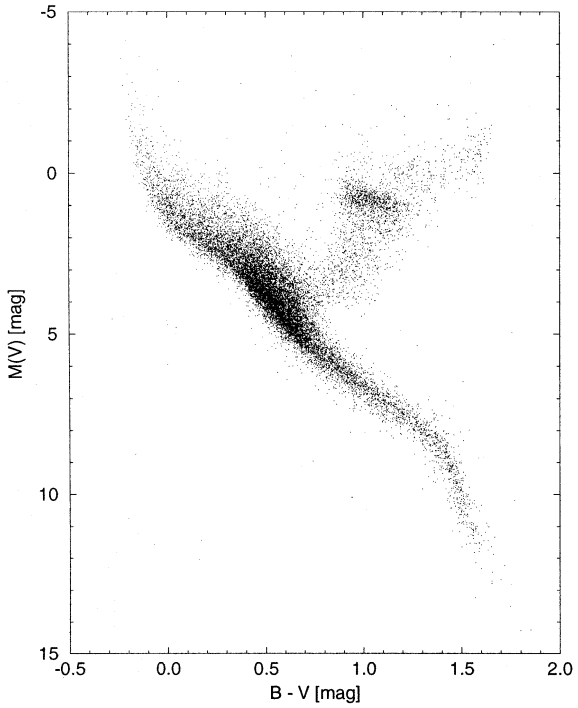

Fig. 3. The observational Hertzsprung-Russell diagram, M_V versus $B-V$, for the 20 853 stars with $\sigma_\pi/\pi < 0.1$, and with the additional constraint $\sigma_{B-V} < 0.025$ mag.

4. Final astrometric accuracies

Figs 1 and 2 illustrate the median precision of each of the astrometric parameters as a function of Hp magnitude and ecliptic latitude, respectively. Detailed sky charts and histograms giving the astrometric and photometric accuracies as a function of position and magnitude are included in the Hipparcos Catalogue. As an illustration of the astrometric and photometric quality of the catalogue, Fig. 3 gives the observational Hertzsprung-Russell Diagram, M_V versus B–V, for the 20 853 stars for which distant determinations are better than 10% (i.e. $\sigma_\pi/\pi < 0.1$), and with the additional constraint $\sigma_{B-V} < 0.025$ mag. The general features of this diagram, based on the preliminary catalogue, have been discussed by Perryman et al. (1995).

5. Catalogue Products

The Hipparcos Catalogue is available as a 17-volume publication, ESA SP–1200. This includes the main Hipparcos Catalogue, the Double and Multiple Systems Annex, the Variability Annex, identification charts for faint objects or objects in crowded regions, light curves for periodic and unsolved variables, and a full sky star atlas with nearby, variable, high proper motion, and multiple systems indicated. All products of the mission, including intermediate astrometric data and the catalogues of epoch photometry, are also provided on 6 ASCII CD-ROMs included within the 17-volume publication.

Acknowledgements. The Hipparcos Catalogue is the primary result of the Hipparcos space astrometry mission, undertaken by the European Space Agency, with the scientific aspects undertaken by nearly two hundred scientists within the NDAC, FAST, TDAC and INCA Consortia, of whom the present authors – either as members of the ESA Hipparcos Science Team, or with major involvement in the main catalogue finalisation tasks (FA, MF, CSP) – are representatives. The efforts of the many individuals and organisations participating in the Hipparcos project over many years have been an essential component of the project's successful completion.

References

Arias, E.F., Charlot, P., Feissel, M. Lestrade, J.-F., 1995, A&A, 303, 604
ESA 1997, The Hipparcos and Tycho Catalogues, ESA SP–1200
Folkner, W.M., Charlot, P., Finger, M.H., et al., 1994, A&A, 287, 279
Høg, E., et al., 1997, A&A, this volume
Kovalevsky, J., Lindegren, Froeschlé, M., et al., 1995, A&A, 304, 34
Kovalevsky, J., Lindegren, L., Perryman, M.A.C., et al., 1997, A&A, in press
van Leeuwen, F., et al., 1997, A&A, this volume
Lindegren, L., Röser, S., Schrijver, H., et al., 1995, A&A, 304, 44
Lindegren, L., et al., 1997, A&A, this volume
Perryman, M.A.C., Lindegren, L., Kovalevsky, J., et al., 1995, A&A, 304, 69
Turon, C. Réquième, Y., Grenon, M., et al., 1996, A&A, 304, 82

This article was processed by the author using Springer-Verlag TEX A&A macro package 1992.