THE HIPPARCOS MISSION: WILL IT BE A SCIENTIFIC SUCCESS?

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Abstract. The Hipparcos astrometry satellite was launched on 8 August 1989, and after spacecraft and payload commissioning, commenced the routine data acquisition phase on 26 November 1989. Having failed to reach its planned geostationary orbit, major revisions in the mission operations were made, and the post-launch expectations of the mission were strongly degraded with respect to the original goals – principally due to the greatly reduced observational efficiency (caused by the lack of ground station coverage) and the anticipated degraded mission lifetime (as a result of the high-energy particle degradation of the solar arrays in the geostationary transfer orbit).

The final astrometric accuracies attainable by the Hipparcos mission will be influenced by the spacecraft and payload performances on the one hand, and by fraction of useful data and mission lifetime on the other. It will be shown that the elemental observational measurements correspond very closely to the predictions, and the data recovery fraction now stands at around 60–70 per cent, so that the ultimate scientific value of the Hipparcos results will be tied directly to the satellite lifetime. A measurement duration of at least 18 months is mandatory if the astrometric parameters (parallaxes and proper motions) are to be decoupled through the data reductions procedures. A somewhat longer lifetime (2.5–3 years) is necessary in order to reduce the errors on the astrometric parameters to the astrophysically-significant accuracies of around 2 milli-arcsec.

It will be shown that the present indications of the satellite performances, and the significant progress already made in the data reductions, indicate that the difficulties of the 'revised' Hipparcos mission have been largely overcome, and that these target accuracies could still be achievable.

1. Introduction

The goals of the ESA Hipparcos space astrometry mission are to acquire the astrometric parameters (positions, parallaxes and proper motions) of about 120 000 pre-defined ('programme') stars to an accuracy of about 2 milli-arcsec to a limiting magnitude of about 9–12 mag (for the main experiment), as well as positions and BV photometry, to a lower precision, for the 400 000 or so stars down to a limiting magnitude of about 10–11 mag.

Following a nominal launch by Ariane 4 on 8 August 1989, the satellite's apogee boost motor failed to ignite, and the satellite was left, not in its intended 24-hr geostationary orbit, but in a 10-hr elliptical transfer orbit, with apogee 36 000 km and a perigee of 200 km. Early estimates of the satellite's useful lifetime were considered to be limited to an approximately 6-month lifetime of the solar arrays, dictated by the high radiation background in the given orbit. The satellite operations were further complicated by numerous other considerations, new to the revised orbit, and therefore, in the early days of the mission, poorly understood.

Y. Kondo (ed.), Observatories in Earth Orbit and Beyond, 27–33.

TABLE I
Instrument parameters

Optics:	Telescope configuration	All-reflective Schmidt
	Field of view	$0^\circ.9 \times 0^\circ.9$
	Separation between fields	58°
	Diameter of primary mirror	290 mm
	Focal length	1400 mm
	Scale at focal surface	6.8μm per arcsec
	Mirror surface accuracy	$\lambda/60$ rms (at $\lambda = 550$ nm)
Primary Detection System:	Modulating grid	2688 slits
	Slit period	1.208 arcsec (8.2μm)
	Detector	Image dissector tube
	Photocathode	S20
	Scale at photocathode	3.0μm per arcsec
	Sensitive field of view	38 arcsec diameter
	Spectral range	375–750 nm
	Sampling frequency	1200 Hz
Star Mapper (Tycho) System:	Modulating grid	4 slits perpendicular to scan 4 slits at ±45° inclination
	Detectors	Photomultiplier tubes
	Photocathode	Bi-alkali
	Spectral range (B_T)	$\lambda_{\rm eff} = 430$ nm, $\Delta\lambda = 90$ nm
	Spectral range (V_T)	$\lambda_{\rm eff} = 530$ nm, $\Delta\lambda = 100$ nm
	Sampling frequency	600 Hz

2. Problems Posed by the Revised Orbit

The major problems encountered in the operation of the Hipparcos satellite in its revised elliptical orbit were the following:

(1) Final orbital configuration: an early decision was required to utilise the on-board hydrazine propulsion system (originally foreseen for nutation correction and station acquisition) for a possible perigee raising manoeuvre. To minimise perturbing torques at perigee, the available hydrazine was used to raise the perigee to approximately 600 km, and a corresponding orbital period of 10h 40m. The final orbit achievable nevertheless suffers from the disadvantages of poor station coverage from a single ground station as well as the continuous interception of the Van Allen radiation belts each orbit.

Following the perigee raise, the solar panels and telescope baffle covers were deployed, and the spacecraft and payload subsequently commissioned. Commissioning proceeded without major difficulties, although on a longer timescale than that originally foreseen, due to the extended periods of satellite non-visibility im-

TABLE II
The members of the ESA Hipparcos Science Team

Name	Institute	Main Responsibilities
Prof. P.L. Bernacca	Asiago (I)	Data reductions (FAST)
Dr. M. Crézé	Besançon (F)	Input Catalogue (FAST)
Prof. F. Donati	Torino (I)	Data reductions (FAST)
Dr. M. Grenon	Genève (CH)	Input Catalogue, photometry
Prof. M. Grewing	Tübingen (D)	Tycho
Prof. E. Høg	Copenhagen (DK)	NDAC and TDAC Consortia Leader
Prof. J. Kovalevsky	Grasse (F)	FAST Consortium Leader
Dr. F. van Leeuwen	Cambridge (UK)	Data reductions (NDAC)
Dr. L. Lindegren	Lund (S)	Data reductions (NDAC)
Dr. H. van der Marel	Delft (NL)	Data reductions (FAST)
Mr. C.A. Murray	RGO (UK)	Data reductions (NDAC)
Dr. M.A.C. Perryman	ESA	Project scientist, ESA
Mr. R.S. Le Poole	Leiden (NL)	Instrument performances
Dr. C. Turon	Meudon (F)	INCA Consortium Leader

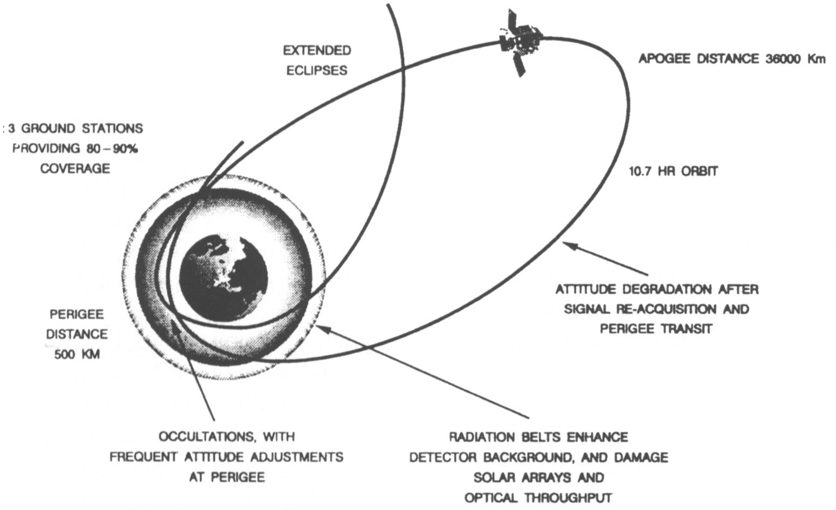

Fig. 1. The present Hipparcos orbit, and the problems associated with it.

plied by the single ground station coverage. The satellite and payload performances closely reflect the nominal, pre-launch predictions, which have been extensively reported (Perryman *et al.* 1989, *The Hipparcos Pre-Launch Status*, ESA SP-1111). In particular, the throughput of the entire optical/detection was within 10 per cent (actually better than) the budget prediction, and the instrumental chromaticity (the geometrical shift between stellar images of extreme star colours) is below 1 milli-arcsec. Signal modulation, geometrical distortion, and payload stability, were all within their respective specifications.

(2) Solar array performance: after the early pessimistic lifetime predictions, the on-board systems were configured to provide in-orbit measurements of the solar array voltage and current characteristics, and the orbital characteristics were used to estimate high-energy proton and electron fluencies responsible for the degradation of the solar arrays. In-orbit measurements and theoretical prediction are now in good agreement, and an estimated lifetime of approximately 3 years is now considered to be realistic. The probability of catastrophic component failure through radiation damage is less easy to quantify, and may ultimately limit the achievable lifetime.

(3) Particle background radiation: as well as degrading the performance of the solar arrays, systematically as a function of time, the $\sim$ 1 MeV electron fluence within the Van Allen belts also contributes to the instantaneous detector background, as a result of Cerenkov emission within the payload diotropic elements. At the level of the primary image dissector tube, the relatively small (30 arcsec diameter) instantaneous field of view limits the impact of this effect to a small loss (about 0.4 mag) in the limiting magnitude of the observations during the passage of the satellite through the radiation belts. For most purposes, this is a small effect. However, the larger field of the star mapper detector, used for the real-time attitude determination as well as for the Tycho experiment, significantly reduces the amount of data that can be used by the Tycho experiment, as well as that available for the real-time estimates of the satellite attitude (see below).

(4) Perigee transits: grouped into the category of problems arising during the periods around perigee transits are the higher radiation background (affecting in particular the real-time attitude determination), the extended earth occultation (when one or other of the telescope's two fields of view are occulted by the earth), the gaps in the ground station visibility, and the higher perturbing torques, resulting in modification to the precise attitude control strategy required to keep the satellite following its pre-defined scanning law.

(5) Ground station coverage: in the nominal mission, ground station coverage (telecommanding and telemetry) was to have been provided by a single ground station (at Odenwald, FRG) resulting in continuous satellite visibility for the ground station, and an overall useful observing time (after accounting for calibration, earth and moon occultations, and all other operational overheads) of between 90–95 per cent. In the revised orbit, the Odenwald station alone would have provided some 30 per cent useful data acquisition. Fortunately, it was possible to incorporate the ESA station at Perth, Australia, and the CNES station at Kourou, French Guiana, within weeks of the apogee motor failure. This brought the satellite observability to about 80 per cent, and the useful data fraction to about 55 per cent. Further assistance by NASA has brought the Goldstone station, in Californis, into the network. As of mid-April 1990 the Goldstone station will bring the average satellite observability to about 93 per cent, the useful achievable data fraction to about 60–70 per cent. Very importantly, it will also reduce the present ground station coverage 'gaps' to a maximum of about 1.5 hours. This is expected to improve the preservation of the satellite real-time attitude estimation.

(6) Eclipse passages: unlike the geostationary orbit configuration, where maximum eclipse durations of about 5 per cent of the orbital period would habe been experienced, the present orbit results in eclipse durations of up to 15 per cent of the orbital period. This placed very severe constraints on the battery charging cycles, designed for the geostationary case. Fortunately, the largest eclipse duration expected over the first 3 years of the satellite lifetime, 105 min, was passed in mid-March with a margin of about 5 min on the battery power. This meant that no power saving procedures were necessary, and the scientific observations were able to proceed without interruption.

(7) Real-time attitude determination: the high detector background, the high perturbing torques at perigee and the long signal outages due to a combination of earth occultations and ground station 'gaps', have resulted in considerable difficulties in running and optimising the continuously evolving real-time attitude determination tasks. This now runs more-or-less routinely, with limited ground intervention. The cold gas propulsion system which, along with the star mapper, gyros, and on-board computer systems, is responsible for maintaining the satellite attitude, is slightly more inefficient than that foreseen for the nominal mission (due to the larger perturbing torques at perigee), although it is likely to sustain satellite operation for up to 5 years.

3. The Scientific Observations

Due to the global nature of the Hipparcos observations and reductions it has been neither desirable nor fortunately, necessary, to modify the observing programme. It is a great tribute to the work of the Input Catalogue Consortium to note that the observations have proceeded entirely nominally; not only for the 120 000 or so programme stars, but also for the 50 or so minor planets, planetary satellites (Titan and Europa) and the large amplitude variable stars. The broadband (H), Tycho bands (B and V) photometric measurements, and the astrometric residuals at the preliminary great-circle reduction level are entirely consistent with the ground-based compilation of their *a priori* values.

4. The Data Reductions

The operational configuration (changing ground stations, changing detector background levels, variations in the data quality as a function of satellite elevation, attitude perturbations after satellite signal re-acquisition, etc.) does mean that the burdens and complexity of the data interfaces (between ESOC and the data reduction teams) are increased over those foreseen. Although a source of frustration for the data reduction teams, these problems should not affect the eventual data

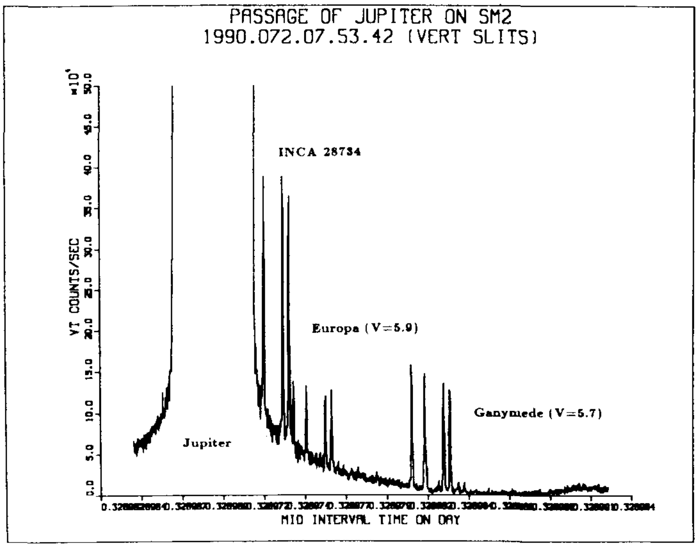

Fig. 2. Star mapper observations of Jupiter and its moons.

quality.

Although the 'mass' data treatments are not yet running routinely, the satellite data are now passing through all major elements of the data analysis chains, and dat from 12 hours of observations (approximately 1 Gbit) are now processed routinely to derive star abscissae on a reference great circle with a precision of 5–10 milli-arcsec. Instrument parameters are calibrated (as part of the ESOC real-time payload monitoring, as part of the FAST, NDAC and TDAC's routine data analysis, and within the FAST Consortium's 'first look' analysis facility) with sub-milli-arcsec precision, and are very stable. All reduction elements are in the process of becoming fully operational.

5. Final Accuracies

Simulations by the data reduction teams have shown that a mission duration of at least 18 months is necessary before the various astrometric parameters become separable. Should the satellite lifetime be less than 18 months, a significant improvement to the present astrometric reference frame will be made (individual positions will estimable to about 10 milli-arcsec) but with very limited astrophysical (parallax and proper motion) information. A progressively longer mission duration will lead to improvements in the precision of all five astrometric performance levels, the astrophysically-significant (and nominal target) accuracies of around 2 milli-arcsec should be achievable.

Present indications are therefore that the original astrometric (and hence scientific) goals could still be achievable, although there are, evidently, obvious uncertainties involved in such an extrapolation.

Acknowledgements

The rescuing of the Hipparcos mission was made possible by the skill and dedication of the many members of the operation team at ESOC, under the leadership of the Ground Segment Manager, Jozef van der Ha, and the Spacecraft Operations Manager, Dietmar Heger, as well as the project teams of ESA and the industrial prime contractor, Matra. The Agency is grateful for the continued guidance of the Hipparcos Science Team, as representatives of the scientific consortia involved in the Hipparcos project, who have worked since launch, and will continue to work, under difficult circumstances. The author acknowledges particularly the Input Catalogue Consortium and its leader, Dr. C. Turon, for providing a trouble-free operational and observing catalogue (the Input Catalogue), the FAST, NDAC and TDAC data reduction consortia, and their leaders Professors J. Kovalevsky and E. Høg, Dr. L. Lindegren for his early assessments of the accuracy implications for the revised mission, and the FAST Consortium who, through the work of Dr. J. Schrijver, established a first-look analysis facility which has greatly expedited the early understanding of the flight data.