3. EXPECTED DEVELOPMENTS IN HIGH PRECISION ASTROMETRY

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A NEW ERA OF GLOBAL ASTROMETRY. II: A 10 MICROARCSECOND MISSION[1]

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Abstract. A ground-based project for a small telescope about 20 cm aperture is proposed. It would be able to obtain 500 million astrometric observations per year of all stars between V=7 and 18 mag, based on the Hipparcos-Tycho reference net of one million stars. In addition, V and I magnitudes for all stars from V=7 to 17 mag would be obtained. — A new space mission is proposed, capable of obtaining 10 microarcsecond (μas) precision for parallaxes and proper motions of stars of $V = 11$ mag, and a precision of 0.5 millimagnitude (mmag) for intermediate-band photometry. The mission is here called Roemer Plus (or Roemer+) and the design is derived from Hipparcos and Roemer, but a larger telescope aperture and high-precision metrology is applied. At magnitude $V = 20$ a precision of 1.0 milliarcsecond (mas) would be achieved.

1. Introduction

The Hipparcos and Tycho catalogues (Lindegren 1994; Perryman 1994; Turon 1994; Høg 1994 – at this symposium) will be epoch-making for the understanding of the Galaxy and its stellar content. It is worth noting that these catalogues can also be regarded as a first, and necessary, step towards a new era of observational astronomy, where much higher astrometric accuracy can be obtained for fainter stars in even greater number, and where precision multi-colour photometry can be included. The Hipparcos mission results and the use of special CCDs are conditions for improvements by

[1]Part II of a paper. Part I was presented at a conference in Padova, Høg (1994)

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many orders of magnitude, as discussed here for two proposed instruments, one on the ground and one in space.

The ground-based project can be implemented on an existing meridian circle. A reflector system is preferred instead of a refractor in order to increase the spectral band in good focus. The design of a reflecting telescope and of a CCD mosaic is given by Høg (1994), including performance data, assuming a 16 cm aperture. Fig. 1 shows a detail of the special CCD which might be manufactured piggyback on a wafer with other CCDs in order to lower the development cost. A meridian circle reflector with such CCDs would become a hundred times more efficient than if a standard meridian circle refractor were equipped with standard CCDs with square pixels. It would be able to obtain 500 million astrometric observations per year of all stars between V=7 and 18 mag. In addition, V and I magnitudes for all stars from V=7 to 17 mag would be obtained.

This ground-based survey could serve many purposes, one of them would be to produce an input catalogue for the following space project, Roemer+.

The design of a new astrometric satellite, called Roemer+, is discussed in Sect. 2. A precision of 10 microarcseconds (μas) for parallaxes and annual proper motions will be achieved for stars of V=11 mag from a 2.5 year mission, i.e. about six times smaller errors than for the basic Roemer satellite proposed for the M3 mission of ESA by Lindegren et al. (1993). The limiting magnitude will be fainter than V=20, and all stars to the limit can in principle be measured.

Precision intermediate-band photometry, i.e., standard errors about 0.003 mag or less, will be obtained for all stars in the interval $V = 6 - 16$ mag.

Sources of global astrometric data, including a possible future, are characterized in Table 2.

2. Ten microarcsecond astrometry by Roemer+

The proposed satellite is shown schematically in Fig.2. Two reflective telescopes of 70 cm aperture observe two separate fields on the sky. Due to the large size of the mirrors it will not be possible to use a beam-combiner technique, like in Hipparcos. The beam-combiner of that satellite joined two fields on the sky into a single focal plane image where the measurements were carried out. A beam-combiner much larger than the one of 29 cm diameter in Hipparcos would be very difficult to manufacture whereas the telescopes in Roemer+ could be manufactured to almost any size. Another advantage of having separate telescopes is that 'parasitic' stars and sky background from the other field of view will be absent. Each focal plane holds a mosaic of CCDs as shown in Fig. 3, similar to that in the basic Roemer satellite, as it is described by Høg (1994).

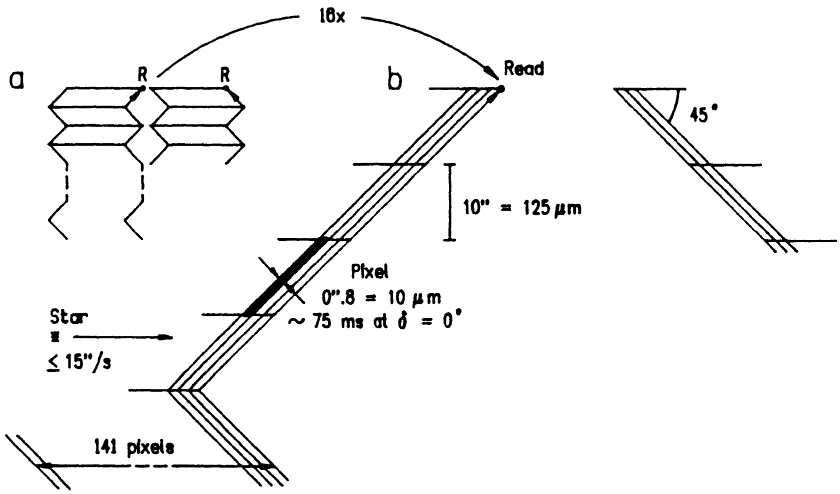

Figure 1. Special CCD for a ground-based telescope. The stars cross the CCDs horizontally from left to right. (a) Detail of two CCDs, further magnified in (b). Readout takes place at R each 75 ms for a star at equator, after 10 s integration time on each CCD.

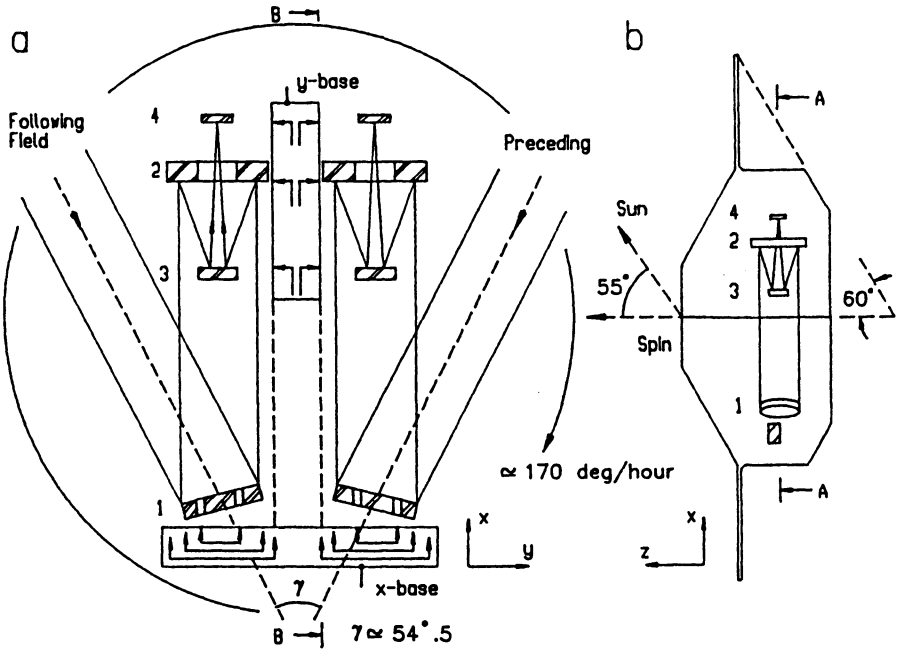

Figure 2. The Roemer+ satellite design. (a) Two Baker-Schmidt telescopes with tilted reflective corrector plates are pointed at the scanning great circle. The optical components are monitored by interferometric distance gauges with picometer precision, thus obtaining the variations of the basic angle as function of time. (b) Section of the rotationally symmetric satellite.

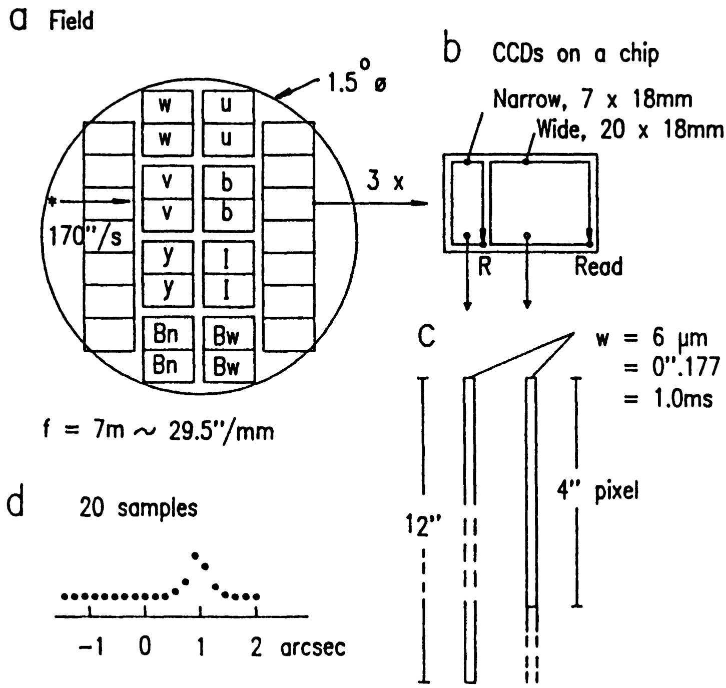

Figure 3. The CCD mosaic at the focal plane of the Roemer+ satellite. (a) The mosaic of identical CCD chips, those in the middle have colour filters as specified in Table 1. (b) A chip with a narrow and a wide CCD. (c) A pixel from each of these. (d) A sequence of observed samples of a star.

A Baker-Schmidt telescope as proposed here was studied for Hipparcos by Iorio Fili and Scandone (1979). The authors found that diffraction limited performance in a field of 1.5 degree or more could be achieved by a system with F-ratio=10.

In Roemer+ the basic angle is calibrated every few hours by means of a 360 degrees closure of the star observations. But variations at shorter time scales than a few hours must be monitored in order to determine the basic angle as function of time. An edge-to-edge tilt of a mirror by one picometer (pm = 10^{-12} m) results in a change of the basic angle by one microarcsecond. The tilts of the six mirrors are monitored by six differential distance gauges mounted on an optical table, the x-base in Fig. 2. The arrows point in the direction of distance measurement. The distance of the four curved mirrors and the two CCD assemblies are monitored in the direction perpendicular to the optical axis by six distance gauges on the y-base, where ten times larger errors can be tolerated than for the tilts.

Distance gauges with a precision of a few picometer and stability over a few hours are required for tilt measurement. Such devices using inter-

TABLE 1. Predicted standard errors due to photon noise in astrometry and photometry for a G0-star from a 2.5 year Roemer+ mission, having two telescopes of 70 cm aperture. *Note:* The standard errors given here are $\sqrt{2}$ times smaller than those in the widely distributed preprint, where they were affected by a calculation error. Filter- and CCD characteristics are given at the bottom. A minus (-) at bright stars means non-linear response of the CCD, i.e. $> 3000e^{-}\mu m^{-2}$ in a pixel. At faint stars a minus means a signal-to-noise ratio ≤ 2.0 on a single CCD crossing. Unit: mas = milliarcsec.

	Astrometry		Photometry [millimagnitude]								
V mag	par. mas	p.m. mas/year	W	w	u	v	b	Bn	Bw	y	I
2	0.007	0.008	-	0.1	0.0	-	-	0.0	-	-	-
4	0.004	0.005	-	0.1	0.1	0.0	0.0	0.0	0.0	0.0	-
6	0.005	0.006	-	0.2	0.1	0.1	0.0	0.1	0.0	0.0	0.0
8	0.004	0.005	0.0	0.5	0.3	0.1	0.1	0.3	0.1	0.1	0.0
10	0.006	0.007	0.0	1.4	0.8	0.3	0.3	0.7	0.3	0.3	0.1
12	0.014	0.016	0.1	3.5	2.0	0.9	0.6	1.9	0.6	0.7	0.3
14	0.035	0.041	0.1	9.0	5.2	2.2	1.6	4.8	1.6	1.6	0.7
16	0.091	0.107	0.3	26.8	14.0	5.7	4.2	12.9	4.2	4.2	1.8
18	0.261	0.305	0.9	-	55.0	16.8	12.0	49.3	12.0	12.1	5.1
20	0.998	1.165	3.3	-	-	-	49.9	-	49.9	50.3	18.3
Central wavelength [nm]			-	320	350	411	467	486	486	547	800
Filter FWHM [nm]			-	20	30	25	25	3	25	25	140
Peak transmission			-	0.30	0.40	0.60	0.70	0.70	0.70	0.70	0.96
QE of CCD			-	0.80	0.85	0.93	0.97	0.97	0.97	0.95	0.77

ferometric techniques have been developed for the POINTS instrument by Noecker et al. (1993) as one step towards a space-qualifiable picometer distance gauge.

Values of the expected astrometric and photometric precision, defined as the standard error (s.e.) due to photon noise, are given in Table 1. The errors are six (6.0) times smaller than for the basic Roemer mission, given by Høg (1994). This is explained as follows. The s.e. should be inversely proportional to the square of the telescope diameter, D. One factor D comes from the number of photons collected and a second factor D from the improved optical resolution. The smaller F-ratio, compared to Roemer has also been taken into account, and CCD pixels of 6 μm width have been assumed, instead of 4 μm in Roemer. The total light collecting area is 8.0 times larger since there are two telescopes in Roemer+, each with 2.0 times larger D than Roemer.

Other sources of error than photon noise are expected to contribute

TABLE 2. Precision of global astrometric data, present and possible future. Typical *V* mag for which the precision is given. *Notes*: [1] The Tycho proper motions are obtained by means of first epoch positions from the Astrographic Catalogue, cf. Röser & Høg (1993). [2] Result of two years observations with the proposed reflective meridian circle. [3] A 2.5 years Roemer+ mission about 2010 has been assumed.

Source	N	Position at epochs: 1990 mas	2000 mas	2010 mas	2020 mas	Motion mas/yr	Parallax mas
PPM North	200 000 stars	270	300	-	-	4	-
PPM South	200 000 stars	110	130	-	-	3	-
Hipparcos	120 000 stars	1.5	15	30	45	1.5	1.5
Tycho	1 million V~10.5	30	40	70	100	3 [1]	30
MC [2]	200 million V~17	-	50	50			
Roemer+ [3]	1 million V~11	-	-	0.01	0.1	0.01	0.01
	200 million V~17	-	-	0.20	2.0	0.20	0.20

relatively little, as shown by the theory and experience of Hipparcos, and in a study by Makarov, Høg and Lindegren (1994).

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