ASTROMETRIC AND PHOTOMETRIC PERFORMANCE OF THE SMALL ASTROMETRIC INTERFEROMETER SATELLITE DIVA

U. Bastian[1], **R.-D. Scholz**[2]

[1]Astronomisches Rechen-Institut, D-69120 Heidelberg, Germany
[2]Astrophysikalisches Institut Potsdam, D-14482 Potsdam, Germany

ABSTRACT

The expected performance of the small astrometric interferometer satellite DIVA is investigated. Using simulated detector signals, we discuss the dependence of the achievable precision in astrometry and photometry on various technological and mission-specific parameters. Such considerations, which are analogously applicable to other mission concepts (like FAME and GAIA95), lead to a proper recognition of the critical aspects in the mission design. For DIVA, in particular, it is shown that the expected performance significantly exceeds that of Hipparcos, and that the CCD read-out noise is the most critical mission parameter for faint stars.

Key words: space astrometry; DIVA.

1. INTRODUCTION

DIVA is the smallest and least expensive of several space astrometry missions proposed to go beyond the success of Hipparcos. Its design goal is to perform astrometric and photometric observations of a least 1 million stars, see the paper by Röser et al. in this volume. DIVA essentially is a 1:10 model of GAIA95 (Høg et al. 1997). This drastic reduction in size produces a correspondingly large difference in the technical requirements, mission costs and, of course, in the scientific performance as compared to GAIA. According to rule-of-thumb formulae derived by Høg et al. (1997), both the brightness limit for such a scaled mission and the mean errors of astrometric results at any given magnitude are proportional to the inverse square of the scaling factor. Thus, while having a factor of 100 higher limiting magnitude and measuring uncertainty than GAIA, such a small instrument could still be expected to rival or even surpass Hipparcos. This simple consideration led to the idea of DIVA. More careful performance estimates are given in the present paper.

2. THE SIMULATIONS

Simulated raw detector signals of the DIVA instrument (see the paper by Scholz & Bastian in this volume) were transformed to performance figures by formal error calculus. The necessary formulae are essentially given by Høg et al. (1997). The only difference to Høg et al. (1997) is the inclusion of CCD read-out noise into the calculations.

For the numerical values given in Figures 1 to 6, a mission duration of 24 months, square instrument apertures of 5 cm, realistic CCD sensitivities (see the paper by Scholz and Bastian in this volume) and a realistic focal-plane coverage with CCD mosaics was assumed (see the paper by Röser et al. in this volume). For different choices of the mission/instrument parameters, the resulting values scale approximately as follows: Limiting brightness proportional to the inverse square of the aperture size. Mean errors inversely proportional to the square root of the mission duration (positions, parallaxes) or to the 1.5th power of the mission duration (proper motions), and to the inverse square of the aperture size. All other parameters except the read-out noise have essentially fixed values for realistic missions. Thus the performance figures are given as functions of source brightness and CCD read-out noise only.

3. RESULTS

The results of the computations are shown in Figures 1 to 6. For details we refer to the extensive figure captions.

4. DISCUSSION

The figures clearly show that even with the binocular-sized optics of DIVA the astrometric performance of Hipparcos can be significantly exceeded. Due to the improved limiting magnitude, DIVA can observe many more stars than Hipparcos. Combination of Hipparcos and DIVA positions will improve the proper motions for Hipparcos stars by about a factor of 10.

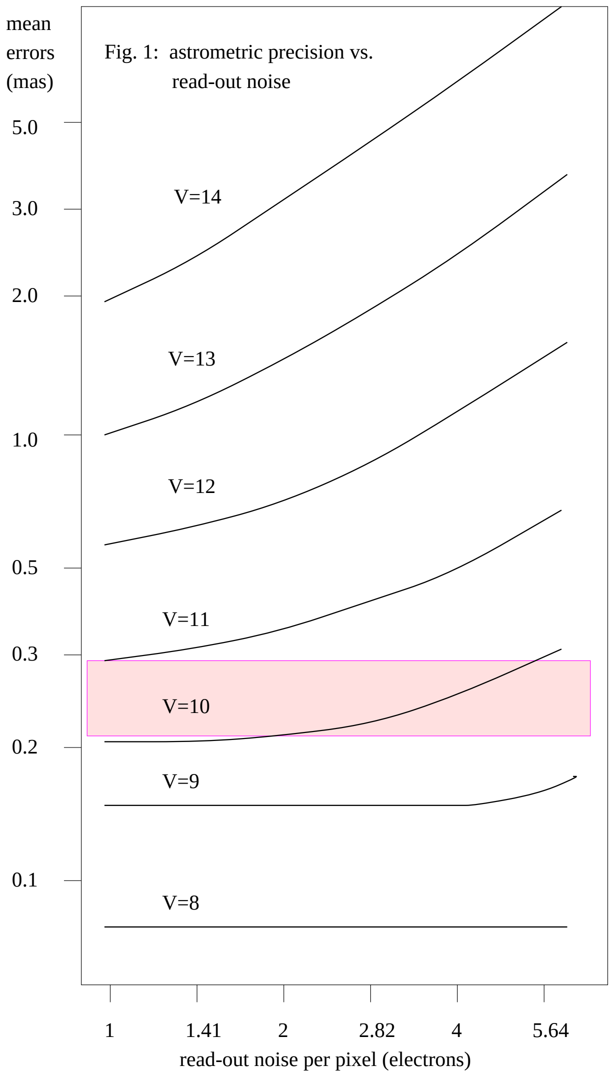

Figure 1. Performance of DIVA: Typical mean errors (in milliarcsec) of the positions and parallaxes for K3 stars of different magnitudes versus the CCD read-out noise per binned pixel (in units of photo-electron equivalents; a binned pixel consists of 6 physical CCD pixels; see the paper by Röser et al. in this volume). For a two-year mission, the mean errors of annual proper motions are larger by about a factor of 1.7. The curves include only photon and read-out noise. Realistic values for the dark current and sky background have been included into the photon noise. Other noise sources (such as satellite jitter and calibration uncertainties) will limit the achievable precision for brighter stars. No precise model calculations for these noise sources in a DIVA satellite are yet available. Rough estimates put the limit at a few hundred microarcsec (indicated by the broad shade).

All astrometric values presented in the figures are based on the assumption that the DIVA data reduction will almost reach the ultimate performance given by the theoretical Cramér-Rao limit (Yoshizawa et al. 1985) set by photon and detector noise. This will not be true for very bright stars (because other error sources, like calibration errors and the attitude uncertainty, dominate over the photon and detector noise), nor for the very faintest ones (due to source confusion and partial loss of data in the noise). But in a broad range of intermediate magnitudes, including the bulk of the observed stars, a close approach to that limit can be expected. The Tycho experiment of the Hipparcos satellite is in many respects similar to DIVA. It approached the Cramér-Rao limit to within 10 percent.

The photometric performance (Figure 6) also exceeds that of the Tycho experiment on board Hipparcos in all important aspects. DIVA provides a quasi-continuous sampling of the optical spectrum between 400 and 1000 nm, from which up to 15 independent photometric channels with freely choosable central wavelengths can be extracted (compared to only 2 fixed ones for Tycho). The precision of DIVA photometry is more than an order of magnitude higher than that of Tycho if stars of equal brightness and photometric passbands of comparable width are considered. Compared to the broad-band photometry of the Hipparcos main instrument, the millimag precision (which was achieved in large numbers by Hipparcos for the first time) is carried to about 20 times as many stars by DIVA.

It should be noted that no ultraviolet passbands are shown in Figure 6 because the presently envisaged DIVA baseline instrument is not transparent below 400 nm. However, UV photometry can possibly be achieved by a small auxiliary UV telescope on board DIVA.

ACKNOWLEDGMENTS

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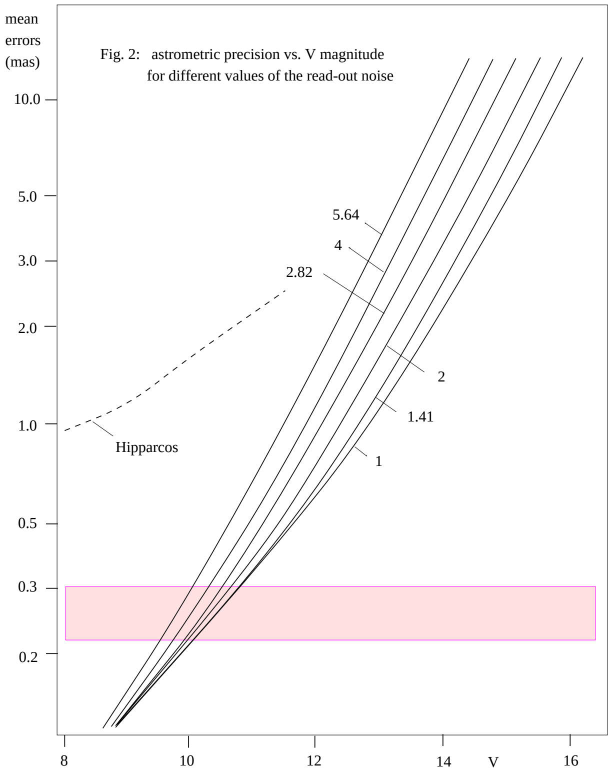

Figure 2. Typical mean errors (in milliarcsec) of the positions and parallaxes versus V magnitude for a K3 star, for different values of the read-out noise (in electrons) per binned pixel. Again, the broad shade roughly indicates the precision limit set by error sources other than photon and read-out noise. The dashed line indicates the median of the mean errors in parallax actually achieved by Hipparcos (taken from Figure 17.7 in Vol. 3 of ESA 1997).

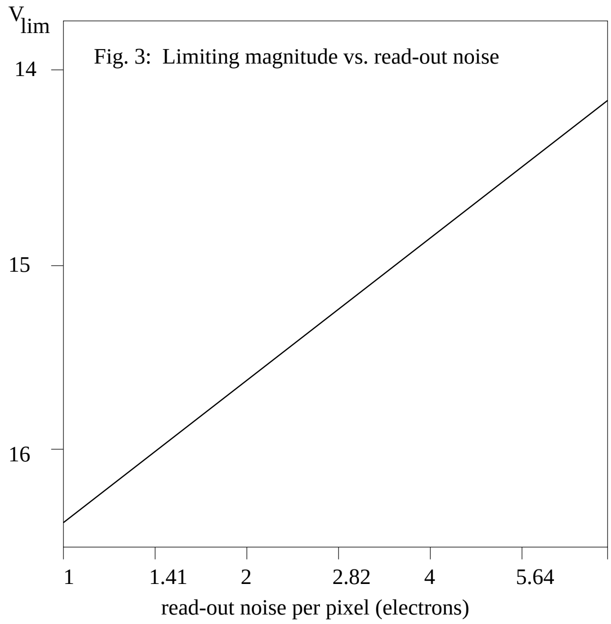

Figure 3. Limiting V magnitude (defined by a signal-to-noise ratio 1.5 of the individual observation produced by a single CCD transit, in accordance with experience from the Tycho project) for a K3 star, versus CCD read-out noise.

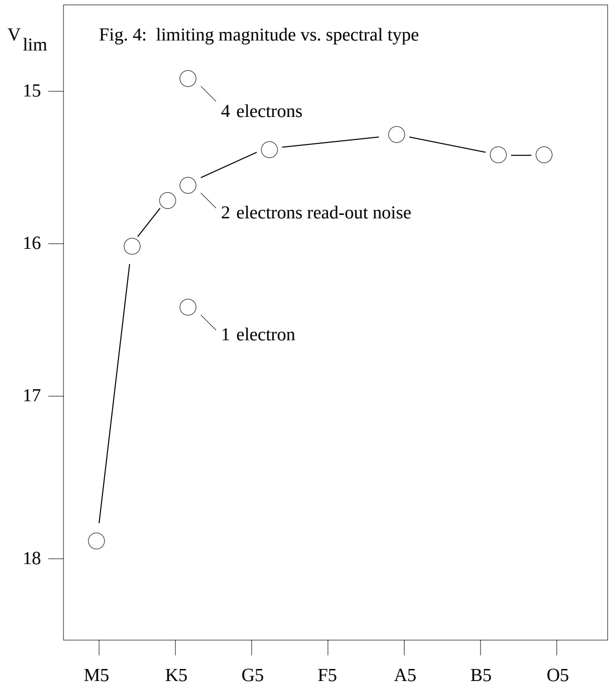

Figure 4. Limiting V magnitude (defined as for Figure 3) for different spectral types, for a fixed read-out noise of 2 electrons. At K3, two additional points indicate the effect of different values for the read-out noise: 1 electron (bottom) and 4 electrons (top). The surprisingly low brightness limit at M5 is due to the inability of the photometric V band to record the bulk of stellar photons from such very red stars.

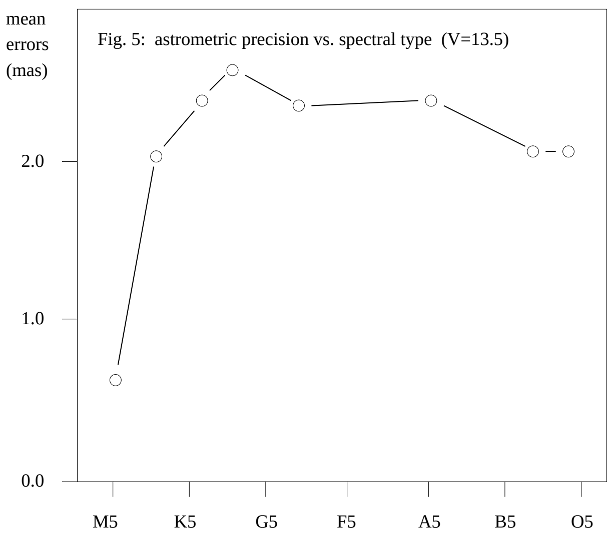

Figure 5. Typical mean errors (in milliarcsec) of positions and parallaxes for stars of different spectral types but identical magnitude $V = 13.5$. For this figure, a read-out noise of 2 electrons per binned pixel was assumed.

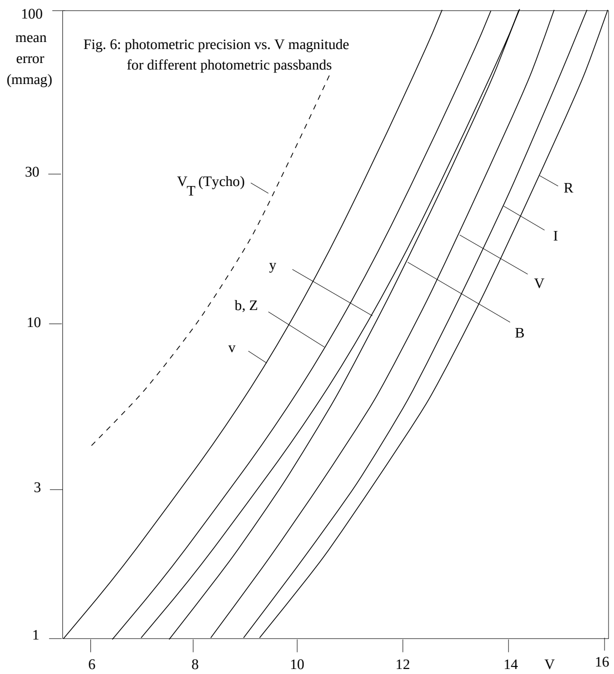

Figure 6. Typical mean errors in different photometric passbands (in units of millimag = 10^{-3} mag) of the mean magnitudes for a K3 star. A read-out noise of 2 electrons per binned pixel was assumed. The bands shown belong to the standard UBVRI and Strömgren uvby systems; the Z band belongs to the Stromvil system (see Straizys & Høg 1995). As before, only detector and photon noise (including sky background) were taken into account in the computations. Below 1 millimag it can be expected that other noise sources will dominate. It should be noted that the curves for the intermediate-width ($\simeq$ 20 nm) bands vbyZ shown here were computed as if DIVA had a spectral resolution of 20 nm. More realistically, DIVA will provide bands at similar wavelengths with about 40 nm width, but at $\sqrt{2}$ better precision. The dashed line shows the precision actually achieved by the Tycho experiment in the V_T band.