Photometric performances of GAIA

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Abstract

The expected photometric standard errors for GAIA photometry with the Astro-1 and -2 and the Spectro telescopes are given in diagrammes as obtained according to the proposed specifications of the GAIA photometric systems in SAG-CUO-58 of 11 Feb. 1999. This is an update of the plots produced in June 1998, reproduced in CUO-53. Plots for three values of the interstellar absorption, A_V, are given in an Annex. Many changes of design result in important change of the standard errors, explained here. Most significant is that the errors of broad-band photometry (BBP) for faint stars have increased, and that the errors of narrow-band photometry (NBP) have much improved, especially in the ultraviolet.

1 Introduction

1.1 Michael's plan of 12 Jan 1999

For red report, 3 pages planned, 1 page=800 words

Photometric objectives: classification, reddening etc should be covered in section by Fabio 2-3 pages + 4 subsections:
Stromvil system (Straizys, 2 pages)
Alternative system (Munari, 2 pages)
LRS (Favata, 2 pages)
automated classification (Bailer-Jones, 2 pages)

Then: Photometric accuracy, 3 pages planned

1.2 Our revised plan

Photometric accuracy, 5 pages: The following Section 2 (1 page) and the four Figures 1, 2, 3, 4.

Section 2 is intended for the red report. Section 3 discusses the changes of standard errors from the previous ones of June 1998. The figures are based on technical details given in CUO-59 and this report is available in:

`http://www.astro.ku.dk/~erik/gaia/59.photometry.technical`

The six figures in the text are taken from the Annex which contains 21 plots for different values of A_V and for different abscissae, Ic, G and V.

2 Photometric accuracy

Photometric observations in many colour bands are obtained for all stars detected by GAIA. We shall give precision estimates of these observations, assuming that data for 100 field crossings are collected during the mission of 4 years effective observing time.

A field crossing gives a number of CCD samples in each colour band which are transmitted to ground. A quick photometric reduction will be carried out for each field crossing, a so-called epoch photometry. This epoch photometry will be used for verification purposes and for science, e.g. for detection of supernovae or other sudden events.

A much better photometric reduction can be obtained when later in the mission accurate satellite attitude and CCD calibration data become available, and also astrometric information for each star, i.e., position, proper motion and parallax. Since no on-board processing is carried out, except data compression, it is possible to reduce all photometric data for each star in an optimal way, using all available information. At this stage also the highest angular resolution of double stars is obtained, including close companions fainter than the originally detected star.

The two Astro telescopes obtain photometry in a very wide spectral band defined by the CCD sensitivity. Such G band photometry is performed by the Astro sky mapper (ASM) and by 16 CCDs in the astrometric field. The epoch photometry as average from one field crossing, has a standard error of e.g. 0.01 mag for $V \sim 18.5$ (see Fig. 1.) The epoch photometry is more accurate in G than in other bands and therefore better suited for detection of variability. [The signal is about 5.0 times higher than that in the g band for the same integration time, and the standard error per CCD is about 2.2 times smaller.] Altogether, a given error in G per field crossing is obtained for nearly 5 mag fainter stars than in the g band.

The two Astro telescopes also obtain broad-band photometry (BBP) in five bands $fgriz$ of about 100 nm width located between 390 and 900 nm. [described in above section by ???] The magnitudes resulting from averaging 100 observations obtained during a mission time of 4 years will have a precision of, e.g., 0.04 mag in the g band at $I \sim 20.0$ mag for all spectral types, according to present estimates (see Figs. 1 and 2). In Astro-1 a sample is assumed to consist of 1×8 pixels and in Astro-2 of 6×8 pixels. This results in smaller standard errors for faint stars with Astro-2 than with Astro-1 due to the smaller total readnoise.

The advantage of using Astro-2 is more pronounced for measuring surface brightnesses of galaxies and other nebulosities. Since such objects bright enough to be detected in the ASM and then measured cover only a small fraction of the whole sky, less than a few percent, the Astro-2 can be used for stellar photometry most of the time. This implies that an average star obtains $67 + 67 \simeq 133$ observations in each band of the BBP, and thus a somewhat smaller standard error than given in Fig. 1 or 2.

The Spectro telescope will collect narrow-band photometry (NBP) [or medium-band ???] in 10 bands. The seven Strömvil bands of about 20 nm width are located between 345 and 655 nm, and three bands at about 875 nm measuring the Paschen jump [described in above section by ???] . Each stars will be observed on average at 100 field crossings. The resulting average magnitudes will have a precision of, e.g., 0.012 mag in the y band at $V = 18$ mag, and 0.012 mag in the u band at $V = 18$ mag for an unreddened G2V star (see Fig. 3.) For a G2V star of $V = 18.0$ and reddened by $A_V = 4$ mag, the precision of the three Paschen bands is 0.005, 0.007, 0.008 mag (see Fig. 4).

The standard errors in the plots contain only photon noise and readnoise from the star and background observations. Simple aperture photometry has been assumed, but proper use of the point-spread function (PSF photometry) is known to give smaller errors. Loss-free compression of the transmitted data has been assumed. Other error sources exist, e.g. cosmic hits, calibration errors, disturbance from stars or galaxies, non-ideal performance of the CCDs, all of which have been tentatively taken into account by multipliing the directly calculated standard errors by a factor 1.20. We assume that a further asymptotic standard error of about 0.01 mag should be added to the plots to obtain realistic values for the absolute accuracy of the photometry. This will mainly affect stars brighter than $V = 18$ mag. Additional errors will be encountered for narrow double stars and stars in dense regions, which accounts for only a small fraction of all stars, but which may be astrophysically important.

The standard error of a single BBP observation, epoch observation, is obtained as 10 times the error from the plots. That is for instance 0.01 mag for the g band for $I = 13$ mag. When epoch observations are considered for the detection of variability, realistic standard errors for isolated, sufficiently bright, single stars may well be smaller than the above mentioned asymptotic error of 0.01 mag.

3 Discussion

Figures 1, 2, 3 and 4 may be sufficient for the red report, the others are included here for SAG discussion. Figures 5 and 6 show Astro-1 with respectively Ic and G as abscissa. The G might be useful as abscissa because it is used for detection in the Astro telescopes, and the Ic was used in CUO-53. But we have now preferred V for the sake of comparing with the Strömvil photometry where V is the natural abscissa since the detection before measuring the Strömvil bands in the Spectro telescope is carried out in a wide V band (see CUO-58). The errors in the Paschen bands should perhaps be plotted as function of Ic since the detection in these bands and for the radial velocity measurement is carried out in a wide I band, according to CUO-58.

A comparison with the standard errors given in Figures 3 and 4 of CUO-53 is of interest.

For the BBP the standard errors (in Fig. 5) are larger now because of the smaller bandwidth of 100 nm instead of 150, the CCD is less sensitive in the red, the readnoise is now $r \simeq 6$ e- instead of 4.5 e-. The factor of increase for a star of $Ic = 20.0$, G2V, $A_V = 0$ in Astro-2 is, e.g., 1.6 for g compared with g' and 2.7 for i compared with i'.

For the NBP it appears that the standard errors at $V = 18.0$ for a G2V star are, e.g. for the bands $uPvb$ improved by the factors 0.3, 0.5, 0.5, and 0.5, respectively. This is due to a combination of reasons, e.g. for u, P the transmission, bandwidth, and total integration time were increased (cf. CUO-58, Table 4). The factors are smaller but still significant for ZyS: 0.60, 0.67, 0.60.

4 Annex

The Annex is available in:

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http://www.astro.ku.dk/~erik/gaia/60.figA0-20.ps.gz

It contains 7x3=21 figures from which the above six are taken.
#A0-2:   Astro-1 vs Ic for the 3 values A_V=0, 2, 4
#A3-5:   Astro-2 vs Ic for the 3 values A_V=0, 2, 4
#A6-8:   Astro-1 vs G for the 3 values A_V=0, 2, 4
#A9-11:  Astro-2 vs G for the 3 values A_V=0, 2, 4
#A12-14: Astro-1 vs V for the 3 values A_V=0, 2, 4
#A15-17: Astro-2 vs V for the 3 values A_V=0, 2, 4
#A18-20: Spectro vs V for the 3 values A_V=0, 2, 4
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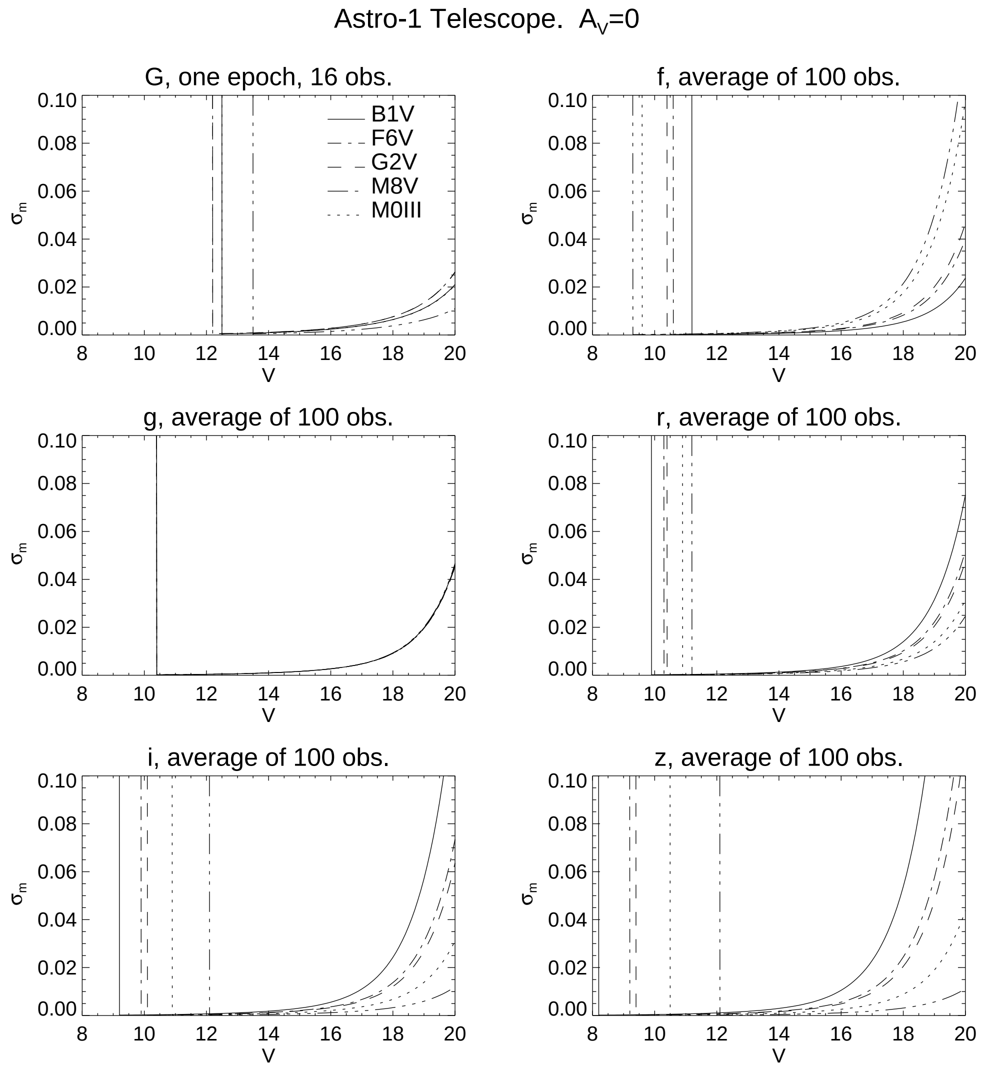

Figure 1: *Standard errors of GAIA photometry with the Astro-1 telescope. The G band (upper left), epoch photometry from one field crossing, i.e. average magnitude from observation on 16 CCDs. The other diagrammes correspond to average of 100 crossings of the field for five bands of about 100 nm width located between 390 and 900 nm. A factor 1.2 has been applied to standard errors calculated from photon noise and readnoise for simple aperture photometry. Integration time per CCD is 0.9 s. The vertical lines indicate saturation of the CCD at bright stars, which is assumed at* 500 000 *e- for all light from a star.*

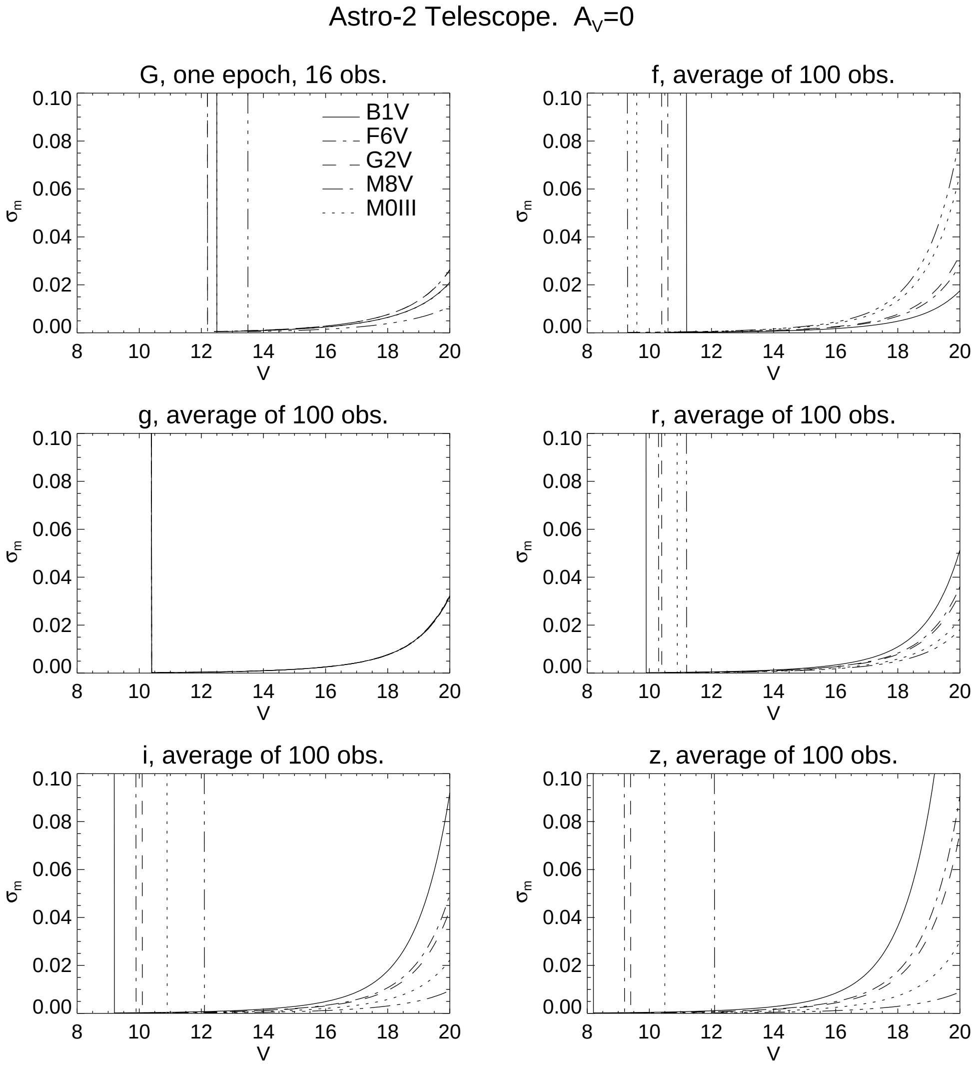

Figure 2: *Standard errors of GAIA photometry with the Astro-2 telescope. The difference compared with photometry with Astro-1 (Fig. 1) is that the sample consists of* 1×8 *pixels in Astro-1 and* 6×8 *in Astro-2 resulting in smaller standard errors.*

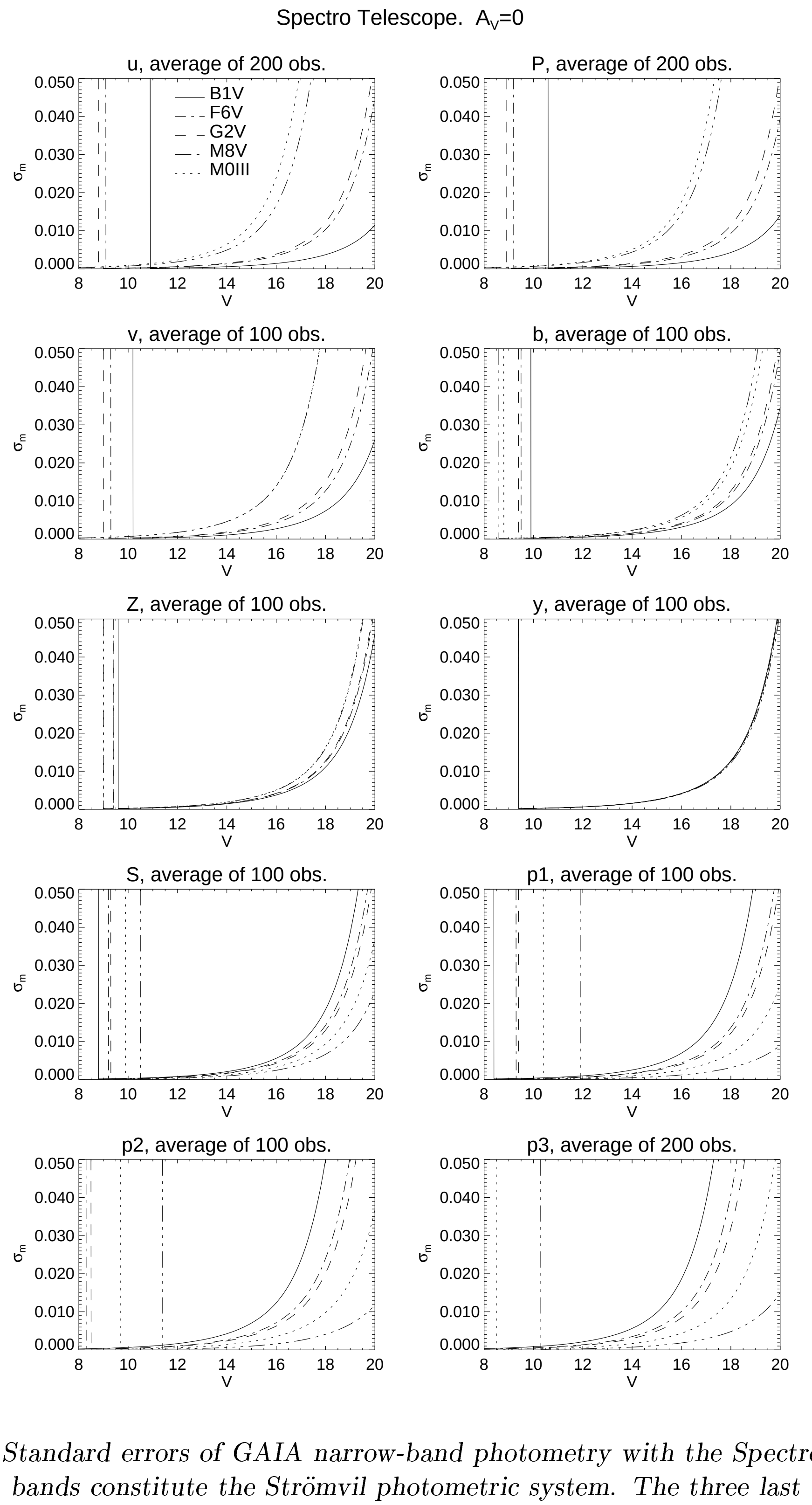

Figure 3: *Standard errors of GAIA narrow-band photometry with the Spectro telescope. The seven first bands constitute the Strömvil photometric system. The three last bands in the red measure the Paschen jump. Average of 100 or 200 observations, integration time 4.8 s per observation. The vertical lines indicate saturation of the CCD at bright stars, which is assumed at 500 000 e- for all light from a star.*

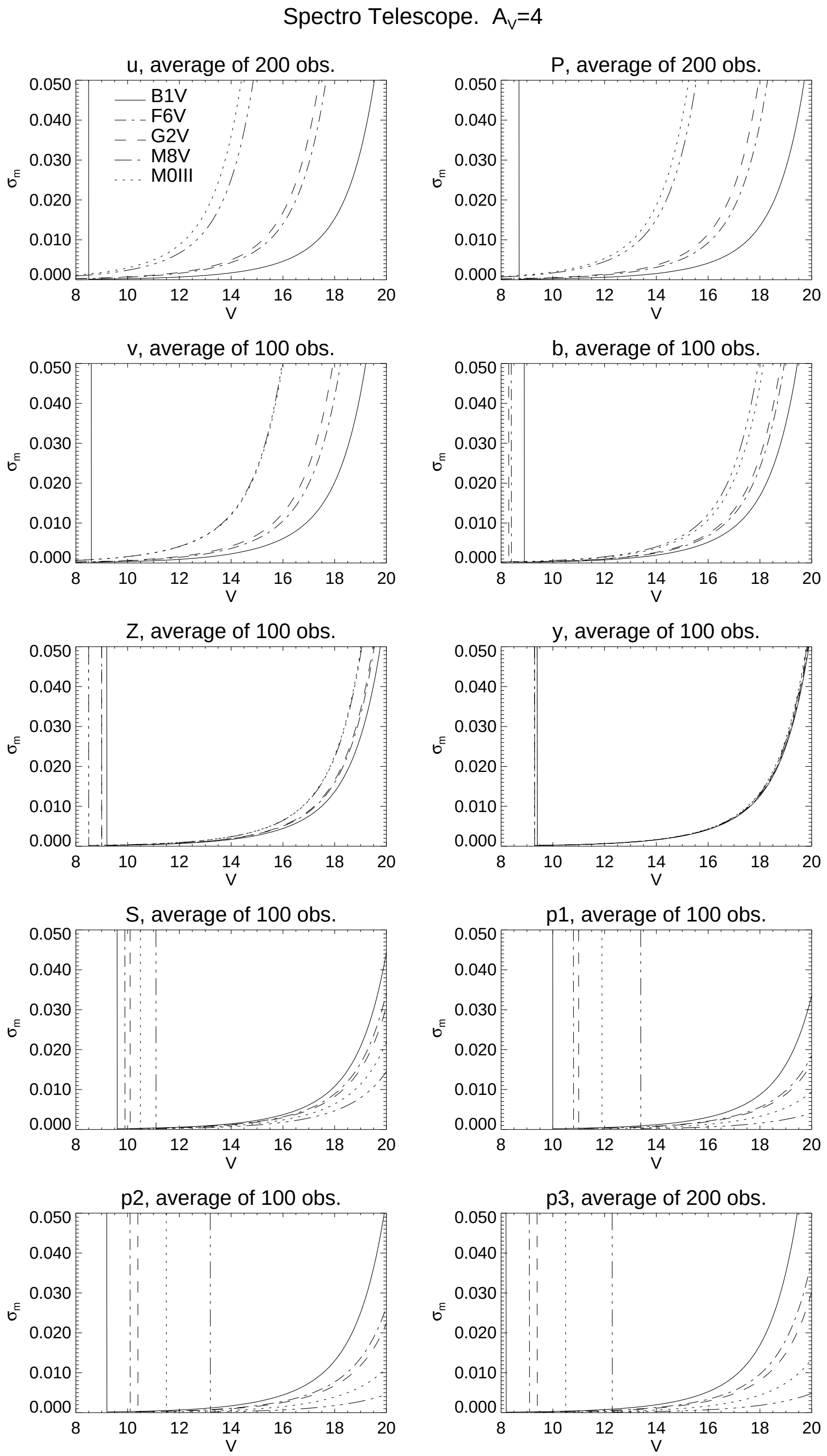

Figure 4: *Standard errors as in Fig. 3, but for* $A_V = 4$ *mag.*

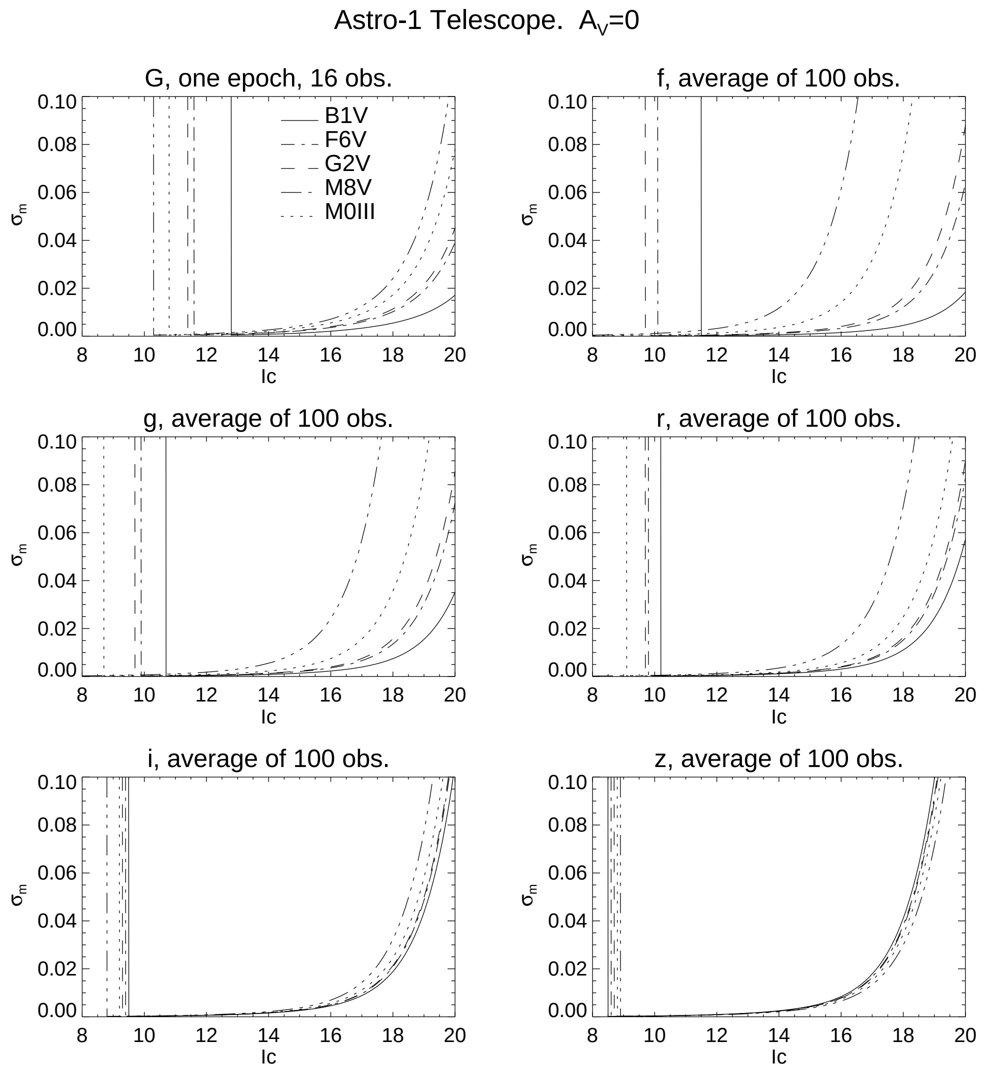

Figure 5: *Standard errors of GAIA photometry with the Astro-1 telescope as in Fig. 1, but versus Ic magnitude.*

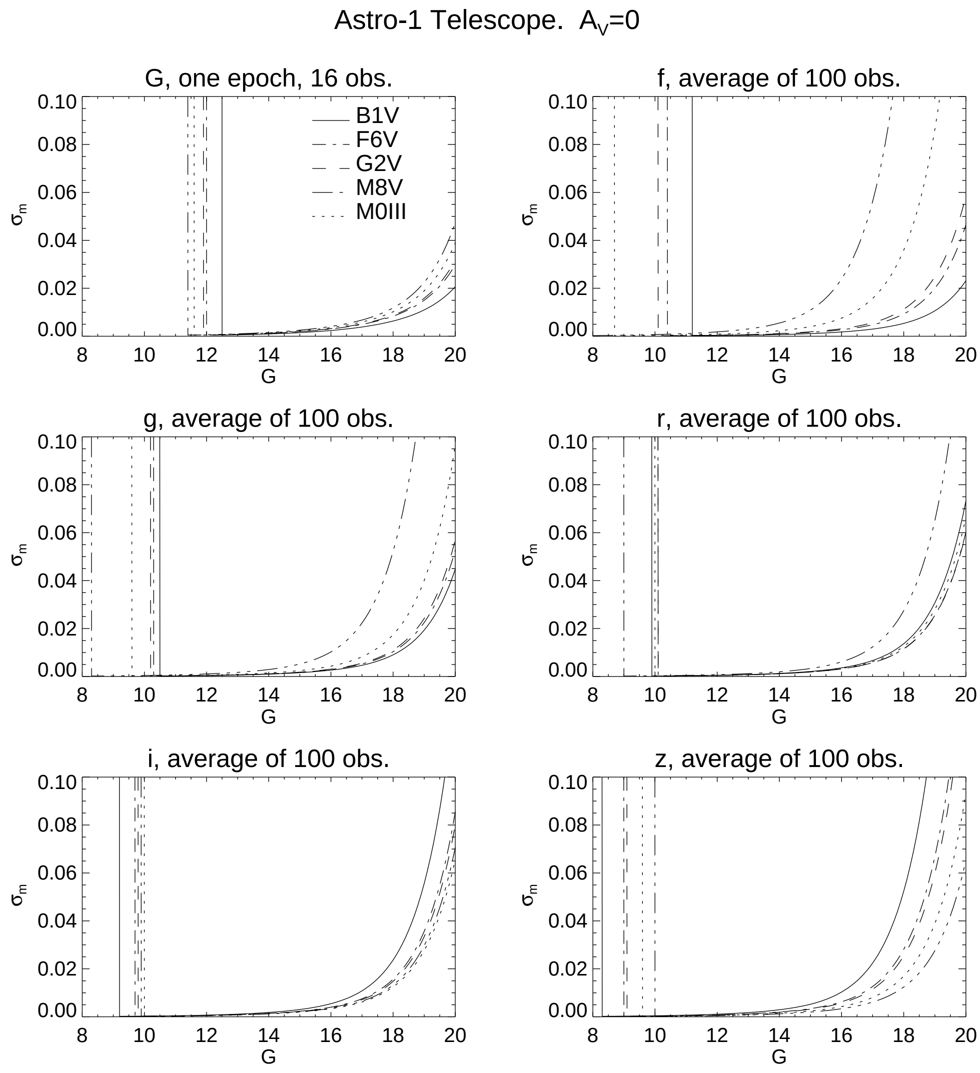

Figure 6: *Standard errors of GAIA photometry with the Astro-1 telescope as in Fig. 1, but versus G band magnitude.*