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SOME COMMENTS ON THE ASTROMETRIC PROPERTIES OF THE GUIDE STAR CATALOG[1]

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ABSTRACT

The first version of the Hubble Space Telescope Guide Star Catalog has been completed and released. Although primarily designed to serve as an engineering adjunct to the spacecraft's Pointing Control System, its all-sky coverage, its deepness (~14.5 mag in *V*), and its availability in machine-readable form all make it applicable for many different astrophysical uses. In this *Letter* we briefly examine the principal aspects of the Guide Star Catalog positional system, its systematic errors (which occur relative to a plate-based coordinate system), its north-south discontinuity, and its steep magnitude dependence for stars brighter than $V \lesssim 9$ mag. Positional errors (i.e., accuracy) from plate center to edge vary from 0".5 to 1".1 in the northern celestial hemisphere and from 1".0 to 1".6 in the southern celestial hemisphere. Between $V = 6$ mag and $V = 10$ mag the positional errors decrease from 1".2 (1".9) in the north (south) to 0".6 (1".1). Relative errors for a single star are also important for the Guide Star Catalog; they range (at 30′ separation) from 0".33 to 0".76 depending upon hemisphere and magnitude. The desired goal was 0".25 for $V \in [9, 14.5$ mag].

Subject headings: astrometry — stars: catalogs

I. INTRODUCTION

The Hubble Space Telescope Guide Star Catalog (Lasker, Jenkner, and Russell 1988) was created to assist in the precision pointing of the spacecraft and the ultimate acquisition of scientific targets for Hubble Space Telescope (HST) instrumentation. The Guide Star Catalog (GSC) will exist in several versions, the first being a no proper motion, no color index, current epoch catalog planned for a 1984 launch and released in 1989. The basis for the GSC positions is a set of large-scale, 6°.4 × 6°.4, Schmidt plates; they are principally 20 minute *V* plates taken with the Oschin telescope at Palomar and 50–75 minute *J* plates taken with the UK Schmidt at Siding Spring. It is the reduction of material from these two instruments which we shall discuss. Significant improvements in the astrometric reduction of large-scale Schmidt plates has been accomplished only recently (Taff 1989; Taff, Lattanzi, and Bucciarelli 1990; Taff, Bucciarelli, and Lattanzi 1989). Therefore, the current GSC necessarily suffers from all the systematic effects that dominate earlier Schmidt plate reduction procedures.

II. ERROR ANALYSIS

Because Schmidt plate reductions have been dominated by systematics, neither internal examination of residuals from a model nor formal error estimates of precision can be reliable. Only a comparison with an independent, external standard can reveal the true nature of the GSC. For this purpose we utilize the Carlsberg Meridian Circle Catalogs, La Palma (Numbers 1, 2, 3; CAMC Consortium 1985, 1986, 1987). Although they do not yet contain independent, high-quality proper motions, the positions in these catalogs are nearly coeval with the GSC plate material, they uniformly cover most of the celestial sphere (down to $\delta \simeq -45°$), they cover an interesting magnitude range (8–12 mag), and they are of sufficient precision in position (typically 0".16 for $\delta > 0$ and 0".22 for $\delta < 0$; Helmer 1989) to allow analysis of the GSC astrometric errors. All our comparisons, such as the one shown in Figure 1, are based on the stars in these three Carlsberg catalogs. The small contribution of the imprecision of the Carlsberg Automatic Meridian Circle (CAMC) stars has not been removed from any of our curves because the GSC suffers primarily from systematic errors (inaccuracy) rather random errors (imprecision).

a) Plate-based Systematics

Figure 1 was constructed by taking a large sample of plates from the north (168) and the south (182), finding all CAMC stars thereon, computing the difference between the GSC and CAMC position for each of the ≃40 CAMC stars per plate, and the second moments thereof. We then binned the results according to the star's distance from the center, in 0°.8 bins, and finally averaged over all the stars in the annulus. One hypothesis for the poorer results in the south is that the GSC northern hemisphere reference catalog, the AGK3 (Dritter Katalog der Astronomischen Gesellschaft), is significantly better than its southern hemisphere reference catalog, the SAOC (Smithsonian Astrophysical Observatory Star Catalog; in the far south, below $\delta = -65°$, the GSC uses the CPC [Cape Photographic Catalogue for 1950.0]). While it is true that at the mean epoch of the GSC plate material, which is the epoch of our comparison, the AGK3 is 3 times better than is the SAOC (0".6 vs. 1".7), this hypothesis is incorrect (see Taff, Lattanzi, and Bucciarelli 1990). The most likely cause of the jump is the factor of 3 difference in plate exposure time, the difference in sensitivity between the two sets of plates, the consequently larger images, and the use of the same plate measurement process and centroiding algorithms.

There is another way in which we can see the variations across a typical GSC plate and the small-scale variations in the

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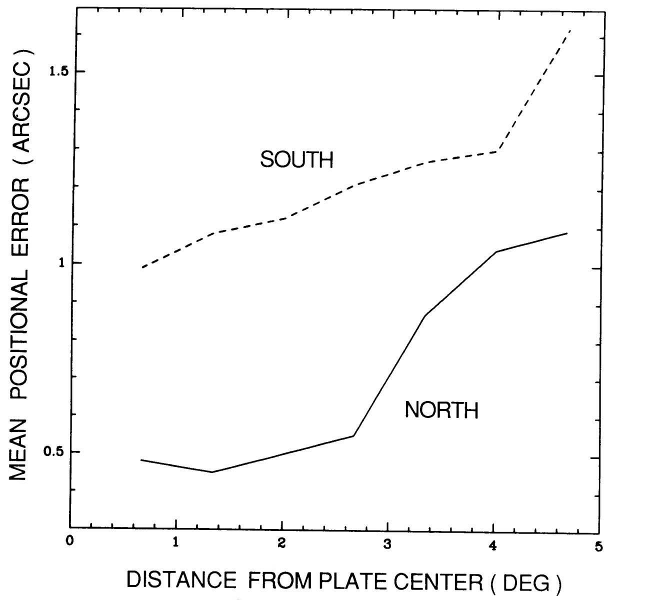

FIG. 1.—Absolute (total) positional error vs. distance from the center of the Schmidt plate.

GSC systematic errors. For the two large samples of plates we used above, we can compute CAMC residuals, $\Delta\alpha \cos \delta$ and $\Delta\delta$, as a function of position on the plate. If, in a plate-based coordinate system, we establish a grid and place each vector residual in its appropriate box, then after averaging over all the plates in our two samples we can obtain detailed maps of the GSC systematic departures from the GSC plate model. Such maps or pictorial tables of differences, are shown in Figure 2. The bins are 13′ square and each symbol represents the average vector total error at that place in the grid.

The northern residual map is smoother than the southern one, both because of the superiority of the AGK3 over the SAOC (so the plate constants are more precisely determined leading to more stable residuals) and because of the smaller image sizes on the shorter exposure northern plates. In both hemispheres we can see two types of behavior in the maps. Either a small area of the residual map shows very similar systematic trends, in which case relative astrometry can be precise, or it shows abrupt, large ($\geq 0\farcs5$) variations. While some of these jumps are a consequence of small number statistics in our bins, many are not. Hence, for these regions of plates in the GSC, precision is not achieved and good accuracy is not obtainable.

b) Magnitude-related Systematics

The GSC magnitude effect, Figure 3, is pronounced. One may inquire whether or not for the typical star in the GSC ($V \in$ [9, 14.5 mag]), as opposed to the typical reference star used to construct the GSC ($V \in$ [8, 10 mag]), the magnitude effect is much diminished. In the absence of a high-quality, dense, faint, independent reference catalog, this issue cannot be resolved. We can, however, split our CAMC sample into two mutually exclusive groups at $V = 10$ mag and repeat our earlier analysis. The results of doing so are shown in Figure 4. The reader must understand that this separation reflects the image processing (i.e., measurement error, image size, the centroiding algorithms, and so on). We can make no comment on either the traditional astrometric magnitude term (because of poor statistics beyond $V = 10$ mag in Fig. 3) or any color index effects (because of lack of information).

c) Relative Errors

As the principal role of the Guide Star Catalog is to guide the Hubble Space Telescope, the positional quality specifi-

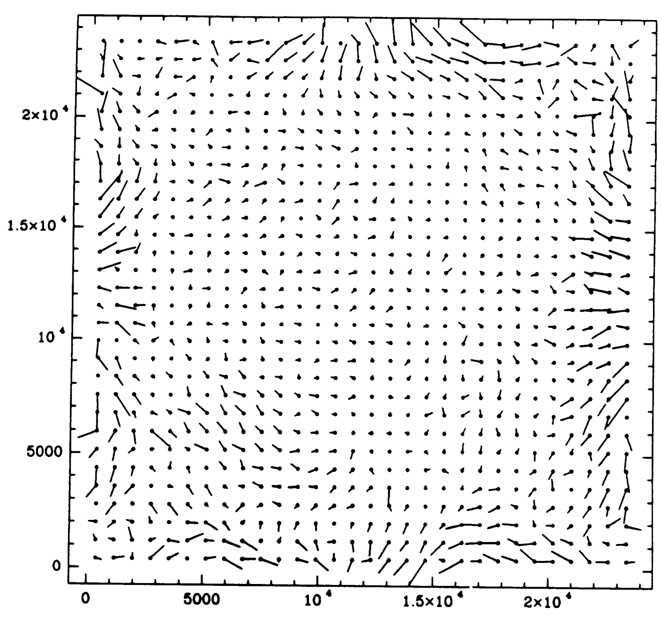

FIG. 2*a*

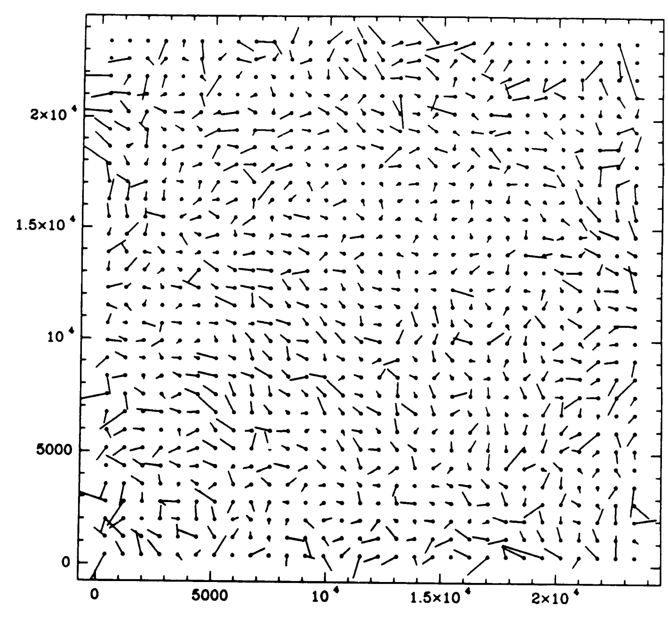

FIG. 2*b*

FIG. 2.—(*a*) Mean vector residual map for the northern celestial hemisphere. The axes are labeled by pixels. (*b*) Same as (*a*) for the southern celestial hemisphere.

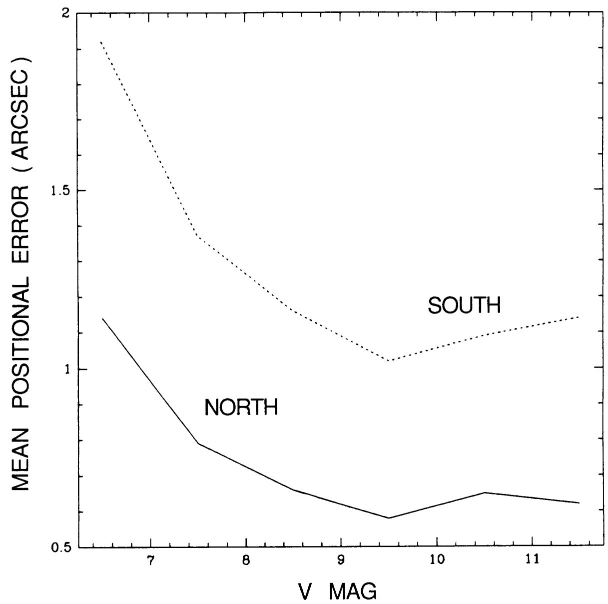

FIG. 3.—Absolute (total) positional error, averaged across a plate vs. CAMC-V magnitude.

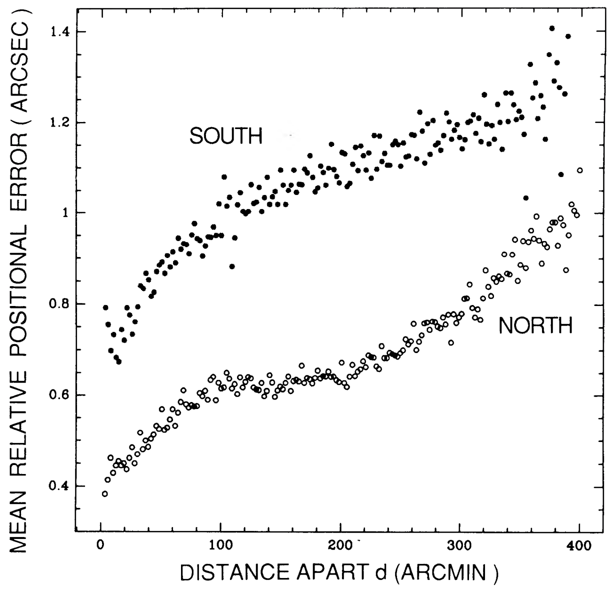

FIG. 5.—(Total) positional error for a single star based on the relative errors for pairs of stars (on the same plate) as a function of separation. Points for the south are filled circles; points for the north are open circles.

cations derive from this task. The desired goal, at the epoch of the plate, was 0".25 over the aperture of the HST ($\sim 30'$ and for $V \in [9, 14.5$ mag]); see, for instance, Russell, White, and Lasker (1982), Russell and Williams (1986), or Russell, Lasker, and Jenkner (1988). The 0".25 criterion is driven by the presumption of a normal distribution for GSC positional errors, degradation over time owing to a lack of proper motions, and a probability argument based on $3\sigma = 1''$ being one-half the smallest acquisition aperture. To determine the state of the GSC in this relative accuracy mode, we calculated the difference in distance between pairs of CAMC stars (always on the same Schmidt plate) as given by their GSC and CAMC coordinates. Binning the results as a function of separation and plotting the results yields the curves in Figure 5. The north-south discontinuity is manifest as is the rapid deterioration of the conventional Schmidt plate reduction process. (The GSC plate model was a full cubic with neither magnitude nor color terms.) The situation in the southern sky can perhaps be improved by considering anew the image processing of (at least) the bright stellar images.

Once again the results are better for the fainter stars and mostly for the closer pairs, $d < 100'$. Figure 6 shows the faint

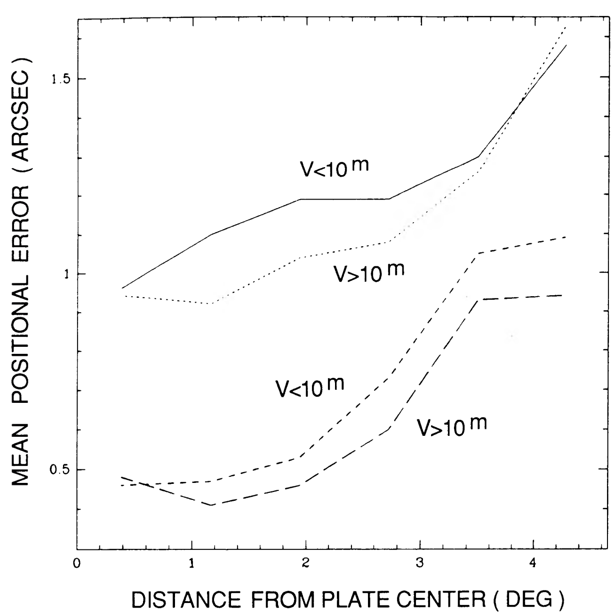

FIG. 4.—As in Fig. 1 but each hemisphere has been split into two mutually exclusive magnitude groups at $V = 10$ mag. For each of the two pairs of curves, the fainter sample is the lower one.

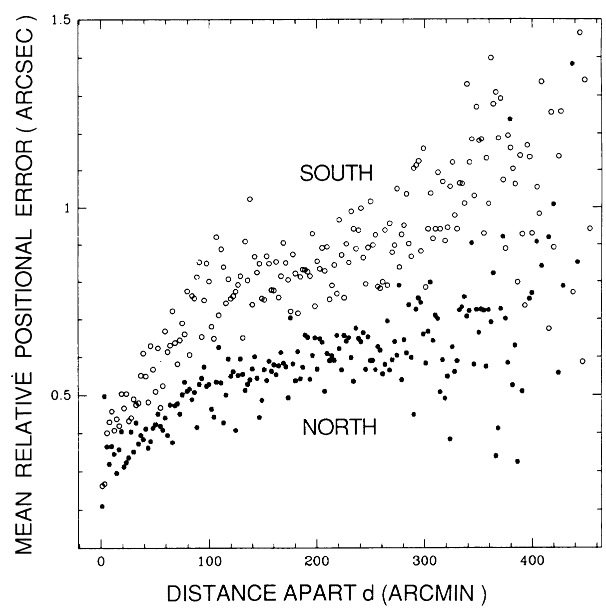

FIG. 6.—As in Fig. 5 but only the $V \geq 10$ mag samples for each hemisphere (north is filled circles; south is open circles).

TABLE 1

GSC Relative Errors at 30′ Separation

	North		South	
	CAMC Errors Included?		CAMC Errors Included?	
Magnitude Range	Yes	No	Yes	No
Bright ($V < 10$ mag)	0″.51	0″.48	0″.79	0″.76
Faint ($V \geq 10$ mag)	0.37	0.33	0.48	0.43
All	0.47	0.44	0.79	0.76

($V > 10$ mag) curves for each hemisphere. Since both stars in these pairs are faint, the results will be worse for a bright/faint combination.

Table 1 shows the GSC relative errors at 30′. Although we reiterate that the random CAMC errors cannot be disentangled from the systematic GSC errors, Table 1 also shows the results of doing so as if the GSC errors were random too.

III. SUMMARY

We have presented a quick look at the astrometric quality of the Hubble Space Telescope Guide Star Catalog. We have examined its systematics, positions, and magnitude dependence as Newcomb (1906) would have treated a star catalog. Guide Star Catalog positions are dominated by systematics in a plate-based fashion. It is discontinuous, by a significant amount, at the celestial equator. Finally, it has a strong magnitude effect for its brighter ($V \lesssim 9$ mag) stars. The implications of these results for HST operations are being actively reviewed. Many of the systematic errors discussed herein will be reduced in a future version of the GSC using the precepts given in Taff, Lattanzi, and Bucciarelli (1990).

We wish to thank the Carlsberg Consortium for advance copies, in machine-readable form, of their excellent catalogs.

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