1. Numerical Simulations

The LSST Image Simulator (ImSim) has been used to study two key areas of astrometric performance. The first is the astrometric error for a single measure of a single coordinate for a single star. A sequence of 6 steps of elevation (30, 42, 53, 65, 76, 84 degrees) was chosen on a single night, and 143 stars of various magnitudes were simulated in each of 5 bands (g, r, i, z, y). Figure 1 shows the RA (red) and Dec (blue) components of the differential chromatic refraction (DCR), and Figure 2 shows the astrometric error (mas) for the RA (red) and Dec solutions as a function of g-band magnitude. The plateau in error at the faint magnitudes comes from the small sample size.

Another important astrometric study is whether DCR coefficients can be used to identify objects with non-stellar spectra. A simulation of several stars and QSOs was done. The QSO spectral energy distributions were taken from the SDSS DR9 server. Figure 4 shows the DCR coefficients computed from (u,g,r,i) simulations. It is obvious that the refraction in u- and g-band is quite different, but this is predicted from the broadband colors. A future study will pursue this concept with stars and QSOs of similar broadband color.

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2. Short Exposure Observations With the Dark Energy Camera

A legacy of astrometric experience gained at the USNO Flagstaff Station and other sites demonstrates that the astrometric error measured in large field, short exposure images can be dominated by effects arising from seeing. For its parallax program, USNO uses a minimum of 5 minute exposures for a 10 arcminute field of view. LSST’s observations will be a pair of 15 second exposures covering 9.6 square degrees. During the preparation of the LSST Science Requirements Document (SRD), astrometric studies of data were taken with a variety of telescopes (Subaru, CTIO 4-m, Gemini South) to provide support for the values presented in the SRD. The recent commissioning of the Dark Energy Camera (DECam) provided a new opportunity to collect wide field, short exposure observations under circumstances remarkably similar to those expected for LSST.

The DECam data were sequences of 5 exposures in each of 4 times (1, 3, 10, 30 seconds) on a field near NGC 288. SExtractor was used to compute centroids for all images in each of the 62 CCDs in the DECam. For each CCD in each exposure, three astrometric fits were done using (constant, linear, cubic) models for the transformation between the individual images and the mean coordinate system. In the mean system, all pairs of stars observed on each CCD were identified, and the mean and standard deviation of the separation between the stars in each pair were computed from the 5 exposures in each sequence. The result is the growth of the astrometric error as a function of the distance between stars as a function of the distance and of the exposure time. Figure 5 shows such a plot for a night of “good” seeing (about 1.2 arcsec FWHM) and Figure 6 for a night of “bad” seeing (about 1.8 arcsec FWHM). In each, the constant solution is shown with triangles, the linear solution with squares, and the cubic solution with circles.

3. Conclusions and Acknowledgements

The results from the ImSim are encouraging, but the astrometric accuracy seems better than what was expected. In particular, the size of the astrometric error continues to decrease for stars brighter than those included in this sample, and there is little ground-based legacy to support single-measure errors much smaller than about 3mas. More numerical experiments are needed to understand this issue, and changes to the ImSim seeing masks may be needed.

The results from the DECam are quite encouraging. Real data from a real sensor at a comparable site carry large weight, and it is encouraging to see that the quality of the astrometry is correlated with the quality of the data as measured by the image FWHM and the comments of the observers. The astrometric solutions based on only a constant transformation might include an error term arising from the size of the dithers between exposures, and in any case it is unreasonable to adopt such a primitive model for the LSST pipeline. The important result is that on nights of both “good” and “bad” seeing that a cubic transformation provides an adequate model of the residual refractive effects of the atmosphere over the spatial scales needed for a single astrometric solution per LSST CCD. If confirmed by more observations, this can be used to add robustness to the LSST astrometric pipeline processing.

This research makes use of data provided by Cerro Tololo Inter-American Observatory, as distributed by the NOAO Science Archive. NOAO is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation. Observations were taken with DECam, built by FNAL under auspices of the Dark Energy Survey collaboration.

1http://dr9.sdss3.org/advancedSearch
2http://www.astromatic.net/software/sExtractor