RELATIVE ASTROMETRY WITH IMAGING TRANSIT TELESCOPES

G. F. BENEDICT
McDonald Observatory
University of Texas
Austin, TX 78712

AND

J. T. MCGRAW AND T. R. HESS
Institute for Astrophysics
University of New Mexico
Albuquerque, NM 87131

Abstract. A CCD/Transit Instrument (CTI) has produced relative astrometry with standard errors less than 2.6% of a 1.55 arcsecond pixel for stars with $V \leq 17$. Additional astrometric studies with existing data are required to better understand the ultimate contribution these devices can make to our science.

The CTI is presently dismantled, awaiting a move to a new site. We briefly discuss the potential astrometric scientific returns from the exisiting data set, from a refurbished CTI, and from a similar device emplaced on the Moon.

1. Introduction

It may be that an Imaging Transit Telescope that patiently collects data night after night can, through brute force $\sqrt{n}$, approach the lofty goals of our symposium title. While van Altena (1994) discusses possible roles for CCD drift-mode devices dedicated to astrometry, few have been built specifically for astrometry. Generally, the astrometrist must make do with devices built to satisfy other scientific goals (*e.g.*, McGraw and Benedict, 1990). We contend that astrometry can and should come from any such device built for whatever astronomical purpose. We shall explore the astro-

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metric scientific returns from existing CTI data, from a refurbished CTI, and from a Lunar-based Imaging Transit Telescope.

2. The Steward Observatory CCD/Transit Instrument (CTI)

The CTI (1.8 m f/2.2) is an example of an Imaging Transit Telescope and its operation. The principal motivation for the CTI (McGraw *et al.*1986) is to monitor a strip of the sky nightly in an imaging survey to detect and characterize objects variable on time scales of days to years. The goal is to measure the light curves of a variety of objects, including variable stars, supernovae, and QSOs, and to provide high S/N time-averaged magnitudes, colors and positions for these objects. Because CTI measures variability, brightness cannot be used as a matching criterion when comparing objects from night to night. Matching must be done by positional coincidence. Sub-arcsecond accuracy astrometry is required for the proper function of the CTI system.

3. Present and Future Astrometric Capabilities of the CTI

Though not built specifically for astrometry, several attributes of the CTI make it astrometrically attractive. These include use of stable, thermally-controlled CCD detectors, observations which are always made within a few degrees of the zenith, measurement to faint limiting magnitudes, and the structural integrity of the telescope/detector combination. Benedict *et al.* (1991) presented a preliminary assessment of the CTI as an astrometric device. Our primary conclusion was that overlapping plate astrometry with data from ten nights of CTI operation yielded relative positions with formal standard errors of less than 40 mas (2.6% of a 1.55 arcsec CTI pixel) for stars $V \leq 17.0$.

The stars at the top and bottom of the CCD drift across at different rates, due to declination differences. Monet (1994) singles this out as a primary concern for CCD-based drift mode devices. CTI smearing amounts to 0.3 arcsec at the top of the field, compared to the center. We saw no patterns in the residuals indicating poorer results for the smeared stars. Evidently, when used for differential astrometry within a fixed declination strip each night, our simple first moment centering algorithm provides repeatable centroids.

Having only explored 10 nights out of hundreds available, additional astrometric studies with existing data are required to better understand the ultimate contribution these devices can make to our science. These include running models with "plates" constructed from over 50 data sets, to determine the level at which we no longer obtain a $\sqrt{n}$ decrease in positional error. This study is currently underway in support of a project to identify (Wetterer *et al.*1994) many new RR Lyrae stars from colors and magnitudes and to confirm those identifications through spectroscopy and proper motions.

The test area represents 0.056% of the total CTI surveyed strip. Since this random piece of the sky netted us three stars out of 61 whose motions were in excess of 2 arcsec/century, continuing the exploration of the entire strip might result in the discovery of more than 3500 stars with similar proper motions in the range $12.5 < V < 19$.

The CTI is presently shut down. Once it is moved to a site in New Mexico and recommissioned, we would like to upgrade the CTI with modern CCD technology, providing smaller pixel size and far lower read-out noise. For example, using CCDs with 15 micron pixels would allow centroiding individual objects to approximately 15 mas, assuming we can continue to achieve 2% pixel precision. The smaller pixels would more adequately sample the seeing disk, and allow experimentation with point spread function fitting algorithms to more accurately estimate centroids. Lowering the read-out noise provides sky noise limited photometry over all bandpasses. This would in turn allow higher precision centroids to be determined, independently of the details of the centering algorithm. Sampling the point spread function more densely might allow us to better centroid the smeared images at the declination extremes of the CCD. Finally, the CTI provides a test-bed for alternative area detectors (Baron and Priedhorsky, 1993) that could electronically compensate for varying drift rates across the field of view.

Finally, a once again operational CTI would, after a year of data collection, have a data base with a time span approaching 9 years. This would allow precise proper motion determinations for stars at V=17 with proper motions $> 6\ mas\ yr^{-1}$. The Tychocatalog will provide a wealth of high-precision local astrometric reference stars against which to measure these motions. The Tycho catalog density on the sky will reduce the along-track size of the sample required to obtain a suitable reference frame.

4. The Lunar Ultraviolet Transit Experiment (LUTE)

The Moon is a gravity-gradient stabilized satellite from which to accomplish a wide variety of astrophysical observations. It presently lacks instrumentation. For many compelling reasons (McGraw, 1994) the first telescope on the Moon could be an Imaging Transit Telescope, not necessarily using a CCD detector. Paramount among them is simplicity. Space is a harsh environment. Simple often survives. No moving parts is the epitome of simplicity. Simplicity means relatively low cost.

The scientific return from a lunar-based UV-sensitive Imaging Transit Instrument can include (McGraw and Benedict, 1990); discovery and statistics of stars with active chromospheres, studies of interstellar dust and reflection nebulae, statistics of flaring on dwarf M and related stars, and stellar necrology (white dwarfs).

Obtaining proper motions and distances from astrometry of any objects found peculiar or otherwise interesting from a LUTE mission with a 2 year or longer duration is an obvious major increase in the scientific return.

The technology to produce a Lunar Transit Telescope has been investigated (McBrayer *et al.*, 1994). Research is currently underway (Baron and Priedhorsky, 1993) to provide area-format detectors capable of meeting the astrophysical constraints of accurate and precise astrometry and photometry, while being robust enough to withstand the high-energy particle flux on the lunar surface. This is the last remaining technological hurdle to implementing the next version of an imaging transit telescope.

In conclusion Imaging Transit Telescopes are relatively cheap to build and operate. Someday there may be many more. Astrometrists should know of their existence and limitations and be prepared to exploit them.

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