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The New GSC-II and its Use for HST

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Abstract. The second generation HST Guide Star Catalog (GSC-II) provides a significant improvement over the original GSC-I. It provides ICRS-based positions (International Celestial Reference System) with improved accuracy for almost a billion objects as faint as J=21. This will become the default reference frame for HST observations starting in cycle 15 and will reduce the absolute errors of the astrometry in the observation headers from 1-2" down to 0.3-0.5". In addition, the new astrometry is being incorporated into the Digitized Sky Survey (DSS) images and can also be used to improve the astrometric accuracy of archival HST data.

1. Introduction

The current Guide Star Catalog (GSC-I) used for HST pointing is becoming less and less accurate as the effects of proper motion continue to increase the relative position errors between the stars. These motions have gradually increased the guide star (GS) acquisition failure rate as the positions 'age' since the epoch of the original measurement. In addition, HST proposals required that the target coordinates were in the same GS reference frame which increased the complexity of preparing phase 2 submissions. Recognizing that these issues (and others) would eventually have to be addressed, STScI in collaboration with other institutions (McLean et al 2004), embarked on a project to produce a 2nd generation GSC that would improve the coordinates and provide additional observation planning capabilities.

2. GSC-I Limitations

The GSC-I was constructed in the 1980's using photographic Sky Survey plates from the Palomar and UK Schmidt telescopes. A complete description of the project is published in Lasker at al 1990 (Paper 1), Russell et al 1990 (Paper 2) and Jenkner et al 1990 (Paper 3). At that time, there was was no single homogeneous all-sky astrometric reference catalog with the required accuracy so three different reference catalogs were used (the AGK3 for plates $0°$to $+90°$, SAOC $-60°$to $0°$, CPC $-90°$to $-60°$). Since there are significant discontinuities between the catalogs this requires GOs to ensure that supplied target coordinates are in the reference frame defined by the GSC-I. In order to simplify the task of observation planning and measuring coordinates, STScI arranged the distribution of the GSC-I and the all-sky Digitized Sky Survey (DSS) images to the community on CDROM and later on-line access via the world wide web.

The sky survey plates were taken between 1975 and 1987 and the GSC-I objects have measured coordinates between these epochs. The expected increase in relative position errors due to proper motions were factored into the GS error budget based on the HST pointing accuracy and the size of the (original) science instrument (SI) apertures. Over the last few years, we have noted an increase in the number of failed observations for small apertures due to proper motions in the GS and the targets. This was temporarily alleviated when STIS failed (since there was no longer an SI with a small aperture), however if COS is installed in a future servicing mission then we would be unable to meet the requirements for placing targets in its small apertures.

The GSC-I was originally designed to have GS in the range 9-15 over the entire sky that could be used by the FGS to point HST. This was to efficiently select GS in a highly automated way. Once STIS (and later ACS) was selected as a replacement instrument, it was recognized that it would be necessary to check the FOV for each pointing to ensure that no UV-bright star ($V \leq 20m$) would be in the aperture of the MAMA detectors. A 'bright' star would result in detector damage. This became a 'Health and Safety' issue requiring a visual inspection of the field using the DSS for each pointing. It was quickly realized that a deeper object catalog would allow similar efficiency improvements to this "Bright Object Protection' task.

3. GSC-II Overview

Even though the concept of a second-generation catalog was developed soon after the original GSC-I was completed it took many years to get all the necessary components in place. The most fundamental item was to scan more recent epoch plates. This was accomplished by obtaining access to the POSS-II surveys in the northern hemisphere and in collaboration with the AAO, arranging for a new southern hemisphere survey. The STScI scanning machines were significantly upgraded to complete digitization of all the plates at the required resolution (Laidler et al 1996). In order to proceed with the construction, digitization and distribution of the new DSS and the development and production of the GSC-II (McLean et al 1998), STScI partnered with a large number of institutions to cost-share and distribute the work in return for early access to the datasets for telescope operations.

One of the early design decisions was to scan and process all the available Palomar and UKSTU surveys in order to give both multi-passband and multi-epoch observations to allow the measurement of proper motions and colors of the objects wherever possible. This provides at least 3 passbands and 2 epochs (including a recent epoch) everywhere on the sky. The images were processed to the plate limits to get the maximum amount of information for observation planning. All of these observations are stored in a 3TB object-oriented database (Greene 1998) which is mined to produce an export catalog with the derived parameters for almost a billion objects.

The availability of homogeneous all-sky astrometric reference catalogs (ACT, TYCHO-2) based on the ICRS reference frame was a major factor in the astrometric improvements along with improved plate modeling and reduction techniques. The result is that GSC-II has an absolute astrometric error of 0.25" (1-sigma) over the entire sky. In order to obtain a photometric calibration fainter than 15th magnitude a major observing campaign was begun to obtain CCD frames for every survey field to create a network of secondary reference stars for calibrating the plates. Despite using photographic material we typically have a photometric error of 0.3mag (1-sigma) and a classification rate (star/non-star) of 95%.

4. HST Observing

Whilst the fundamental goal of this change is to improve the precision of HST pointing, the GO will see some simplification of the procedures used to provide target coordinates.

4.1. Phase 2 Changes

A new keyword (ICRS) has been added to the phase 2 proposal preparation options for the coordinate reference frame. The existing keywords are still present for cycle 15 whilst this transition takes place, but ICRS is the default selection and recommended whenever possible. Many of the recent major surveys and catalogs are ICRS-based (2MASS, SDSS, USNO-B, FIRST etc), so coordinates may be taken directly from these sources without transferring them into the GSC reference frame.

4.2. Measuring DSS Images

If your target is an extended non-stellar source such that it's catalogued coordinate in GSC-II (or any other catalogue) is not where you wish to place the SI aperture, and yet is bright enough to appear on the DSS images you can measure the coordinates as before. The GSC-II coordinates are primarily based on the IIIaF (red) surveys. This is the most recent epoch so we strongly recommend using these images to minimize the errors. The DSS images headers have also been updated to include the ICRS astrometry. Whilst the old GSC-I calibration keywords are still in the headers (for backward compatibility), a new set of GSC-II calibration keywords and FITS extensions are also included. This calibration however, is a 3-step non-linear transformation that most FITS readers do not yet implement. To provide the ICRS information we have modified the code running on the DSS server at STScI to dynamically compute a simple FITS WCS (World Coordinate System) calibration that all packages should be able to utilize. This uses the local GSC-II solution at the position of each image extraction to compute the WCS keywords which it then inserts into the returned FITS image. You can measure the positions using any analysis tool that utilizes the FITS WCS. Once your measured position is entered into your proposal, please select the ICRS reference frame option.

4.3. Measuring CCD images

If your target is not visible directly on the DSS images or otherwise catalogued, you are expected to provide coordinates by transferring the GSC reference frame to your images (this includes HST images). Instead of using GSC-I, one can now use the much deeper GSC-II, *or any other ICRS-based catalogue* which makes finding reference stars easier.

4.4. Tools

Access to the GSC-II and DSS images will be built into the cycle 15 release of the Astronomers Proposal Tool (APT) which provides a convenient interface using the Visual Target Tuner (VTT). Alternatively, one will be able to find links to web forms available from the STScI website. If a GO has successfully observed a target with HST in a previous cycle and is confident that the target has zero proper motion, we also provide a web form that can convert your GSC-I based coordinate to the GSC-II ICRS coordinate. This tool measures the *average* coordinate shift for the GSC-I objects over the HST field of view and corrects the supplied coordinate accordingly.

5. Status

At the time of submitting this manuscript, HST has successfully used the GSC-II for a first on-orbit test. Assuming that the remaining tests are successful, then the ICRS/GSC-II will become the *default* reference system for HST observing in cycle 15 and beyond.

We have successfully completed a feasibility study (Koekemoer et al 2005) of using the GSC-II to recalibrate HST ACS images, and looking ahead, STScI is considering a project to do this for as many images in the HST archive as possible. This would significantly improve the scientific usefulness of HST images when comparing them to observations at different wavelengths. In the case of images without sufficient GSC-II stars to recalibrate, then updating the coordinates using the GSC-I to GSC-II offset will still improve the astrometry and put it on the standard ICRS.

Even further in the future, it is planned to use the GSC-II (with improvements and cross-matching to 2MASS for IR magnitudes) as the basis for JWST operations. Studies have established that it is deep enough to provide sufficient GS (even at near-IR wavelengths) to point JWST.

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