STScI | SPACE TELESCOPE SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

Improving HST/JWST Astrometry

MAST User Group Meeting

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The Problem

The astrometric errors of HST observations are ~ 0.2-0.7” due to :

- Errors in the Guide Star Catalogue coordinates
  - Originally derived from photographic plate measurements since the sky survey plates were the only all-sky optical material with epochs between 1976 - 2001
  - Highly distorted detector, astrometric reference stars are brighter and poorly measured
  - Accumulated proper motions errors between plate epoch and HST use are now significant
- Motion of science instrument apertures in the focal plane relative to the FGS
  - Cause not completely understood – thermal effects, breathing etc.
  - Relative errors ~ 0.1”

These errors can make comparison of observations from different telescopes problematic when dealing with motions and/or small-scale object structure particularly with multi-wavelength data

The Solution

The biggest part of the solution is the availability of GAIA

- MAST/STScI is an official affiliated GAIA datacenter and will host all GAIA data releases
  - DR1 provided a modern epoch catalogue with milli-arcsecond precision down to ~19th magnitude in the optical wavelengths
  - Only a small percentage of stars have proper motion but the modern epoch (2015) makes this a small error.
- There are 2 types of astrometric correction we can make
  - A priori correction – update coordinates of HST guide stars to GAIA coordinates
    - Applicable to all observations and reduces GS error so that remaining dominant error is the focal plane motion ~0.1”
  - A posteriori correction – use measurement of stars on images that have GAIA reference frame coordinates to derived a local astrometric solution for each image
    - Only use for observations that have sufficient reference stars in the image, but it does remove the focal plane errors so errors will be ~ 0.001-0.010”

Improve Guide Star Catalogue Astrometry

The Implementation : GSC 2.4.0 update for HST Operations

- GSC 2.3 was matched to GAIA DR1 to create GSC 2.4.0
  - The GAIA coordinates, and where available, proper motions were transferred to a new GSC
  - The UCAC5 was published soon after GAIA with GAIA identifiers, coordinates and proper motions for stars fainter the GAIA provided down to the UCAC5 limits ~15th mag.
  - No new objects were added to this version – just position updates
- This version of GSC was put in HST operations around 1st September 2017 and observations planned since then will have GAIA-based astrometry.

- Earlier observations based on GSC1 or GSC2 guide star positions can be updated to move the image to the GAIA reference frame (see later slide)

The Implementation : GSC 2.4.1 update for JWST Operations

- GSC 2.4.0 was matched to multiple catalogues to create GSC 2.4.1
  - As applicable the best positions, proper motions, photometry, classifications were transferred
  - New unmatched objects from each catalogue were added to this version
  - GSC 2.4.1.1 : GAIA dr1, APASS dr9, 2MASS, SDSS dr13, VISTA VHS dr4, VISTA VIKING dr2, VST ATLAS dr3, VST KIDS dr3
  - GSC 2.4.1.2 : PanSTARRS dr1, AllWISE, (SkyMapper dr1 in process)

- GSC 2.4.1.1 was put in JWST operations around November 2017 to support GTO observation planning

The Implementation : GSC 2.4.x update for all missions

- Each subsequent GAIA drX will have it's astrometry transferred to the GSC 2.4.X
- With GAIA dr1/2 and PanSTARRS a significant area of the sky will have GAIA-based astrometry for telescope pointing
- Preliminary plans are to deliver GSC 2.4.2 to HST operations around summer 2019
- Future versions will have additional (TBD) catalogues or updated releases of those already included
- The GSC 2.4.x could potentially be used as the all-sky reference catalog for astrometric corrections to image wcs to remove focal plane errors (see later slide)

- Status and documentation available at https://outerspace.stsci.edu/display/GC/GSC2+Catalogue+Home


Observation Database with Astrometric Solutions

The Implementation : Astrometric database

- The astrometric WCS for an observation can be saved in a self-contained headerlet file
- An updated astrometric solution for an image can be based on either a guide star offset or a reference catalogue solution – and saved as headerlet files.
- A database that contains the basic astrometric information and all available headerlet files for each HST observation has been constructed with a *restful web service* for accessing it.
- Python modules have been provided to apply computed offsets, rotation and scale changes to a headerlet based on a new solution.
    - Over the next few months headerlets will be created for all HST observations that used GSC1/GSC2 and added to this database.
    - Headerlets will also be created for all observation used to create the HLA/HSC with the HSC coordinates used as the reference catalogue.

The Implementation : Pipeline tools

- HST Reprocessing
  - Pipeline workflows have been created to retrieve available headerlets and apply them to the images as part of the reprocessing of active instruments so that updated wcs are in the HST archive
  - FITS file will contain multiple headerlets so a GO can choose one used if they don't like the default one we consider '*best*'
  - Legacy instrument observations will later get a custom 'reprocessing workflow' just to update the wcs without recalibration of the data.
- JWST processing
  - We have proposed that an object detection, catalogue matching step be added to the standard JWST pipeline so that an '*a posteriori*' astrometric solution be determined when possible
  - Best available *uber-catalogue?*
    - GSC 2.4.x?
    - USNO bestCat?

Schedule for Improved HST Astrometry

The Schedule : Updating Astrometry in HST Archive

- Pipeline task to update active instruments being reprocessed delivered as part of HST DMS build 2018.1
- Astrometric database & webservices in development/testing.
  - Operational delivery around March 2018
- Creation of HST headerlets from default DMS processing in progress
  - Backfill expected to be complete around March/April 2018
- Creation of GSC-GAIA corrected headerlets for all pre-GSC2.4.0 observations in development/test
  - Operational delivery around April 2018
  - After testing by instrument teams, pipeline task to make astrometric corrections in reprocessing will be enabled.
- Creation of HLA/HSC corrected headerlets will start development in April
  - Operational delivery TBD
- Pipeline task to update astrometry only is in planning stages
  - Enables updates to observations not being reprocessed (legacy instruments & backfill active)
- Goal is to have all HST images with improved astrometry by the end of 2018