SOFIA Non-Sidereal Pointing and Tracking (an update)

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Executive Summary

- Last briefed the SUG in November prior to full implementation of TA changes and V&V
- MCCS and the TA systems were successfully updated in late 2013 to provide an initial non-sidereal capability.
- Verification Results:
  - Not yet achieving tight *computational* accuracy requirements for absolute/blind pointing (but still relatively high accuracy)
  - Robust design appears able to easily adjust pointing
- Has been used in-flight

Acknowledgments

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- Dr. Elizabeth Moore, USRA –ISD Manager
- Dr. Holger Jakob, DSI – TA Lead
- Doug Hoffman, Orbital – Data Analysis
- John Rasmussen, Critical Realm Corp, algorithm development, Scenario/algorithm lead
- Chris Luk, Wes Patterson, Todd Jenkins, L3 Communications – Software Development Team

Non-Sidereal Tracking Use Cases Analysis

Track vs. Target Type	Track Object is Sidereal	Track Object is Non-Sidereal
Target is Sidereal	"Typical" – e.g. observe stellar nebula using nearby track star	Is there a case here? Seems *contrived* (i.e. not necessary) …*but, contrived case may help in verification since target location (track point) is well known…*
Target is Non-Sidereal	Lowell Observatory method – use track ***stars*** to guide observations of a non-sidereal target	Observe an asteroid/comet/ planet that could be used to guide as well

Design Approach

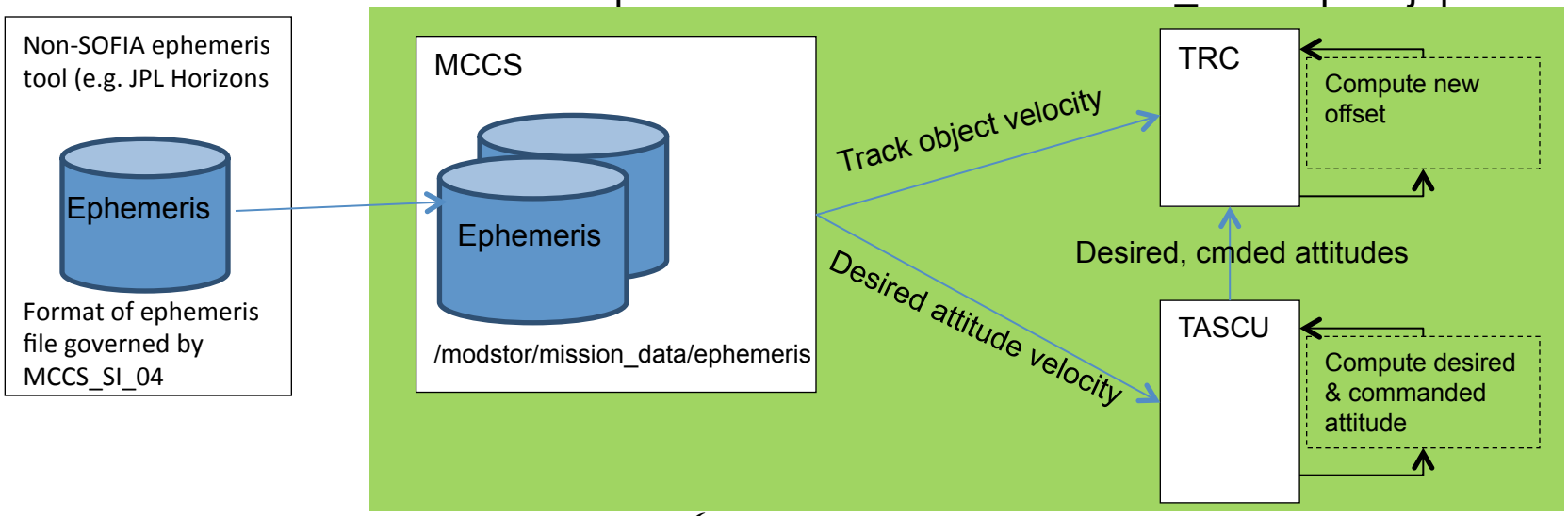
1. Non-sidereal observing utilizes geocentric ephemeris files in JPL format (first phase --- osculating elements will be prioritized for a later phase)
2. MCCS interpolates ephemeris for the given time and converts geocentric ephemeris to topocentric coordinates using current SOFIA longitude, latitude and altitude
3. MCCS will compute TA velocities of Tracker Area of Interests (AOIs) and Fine Drive controller and provide velocities to the TA Tracker and TASCU
4. TA will propagate velocities and change guide object-to-target offset as needed during tracking
5. Subsequent nods, dithers, tweaks, or pointing in SI coordinates leave velocity in place

Data Flow

- From some external source (e.g. JPL Horizons)
  - Create ephemeris file for object to observe and track object (if non-sidereal)
  - Use stepsize per required accuracy (i.e. moons will change velocity)
    - Recommend 15min to avoid significant error in apparent velocity determination
- Transfer to SOFIA
- Create positions and go

PDR

  - coord.position name=jupiter (ephemeris={xyz file})
  - ta_pos.goto pos=jupiter
  - New command to associate ephemeris with an AOI coord.aoi_create pos=jupiter



Performance

High-level SOFIA Requirements:

3.2.30 The SOFIA System shall maintain, by *FOC+4* years, a Science Instrument boresight pointing of a sidereal target, over a time duration of at least 60 minutes to within *0.40* arcseconds (radial rms).

Derived software performance requirement

3.2.34 3.2.34 The PIS software shall adjust a geocentric ephemeris to produce a topocentric apparent right ascension and declination interpolated to the current time that is within *0.01* arcseconds of the JPL Horizons topocentric-adjusted RA/Dec, for a given location and assuming an ephemeris time step of 60 seconds.

The Platform Interface Subsystem (PIS) requirement was aggressively chosen to preserve pointing budget for TA, opto-mechanical error

Verification in Lab

- Ran in Lab with 1-min ephemerides from JPL Horizons for: sol, venus, mars, jupiter, saturn, uranus, neptune, moon
- Positioned simulated aircraft both stationary at Palmdale and flying from Christchurch
- Took samples of published, topocentric-adjusted coordinates from MCCS, along with long, lat, altitude
- Ran a MATLAB script to obtain topocentric-adjusted coordinates directly from JPL for comparison
- Results: failure to meet tight-pointing requirement
  - No problem for distant planets
  - Worst case Mars/Venus: ~0.02” error
  - Worst case Sol: ~0.05 error
  - Worst case Moon: ~.9”

Mitigation for Absolute Pointing Error

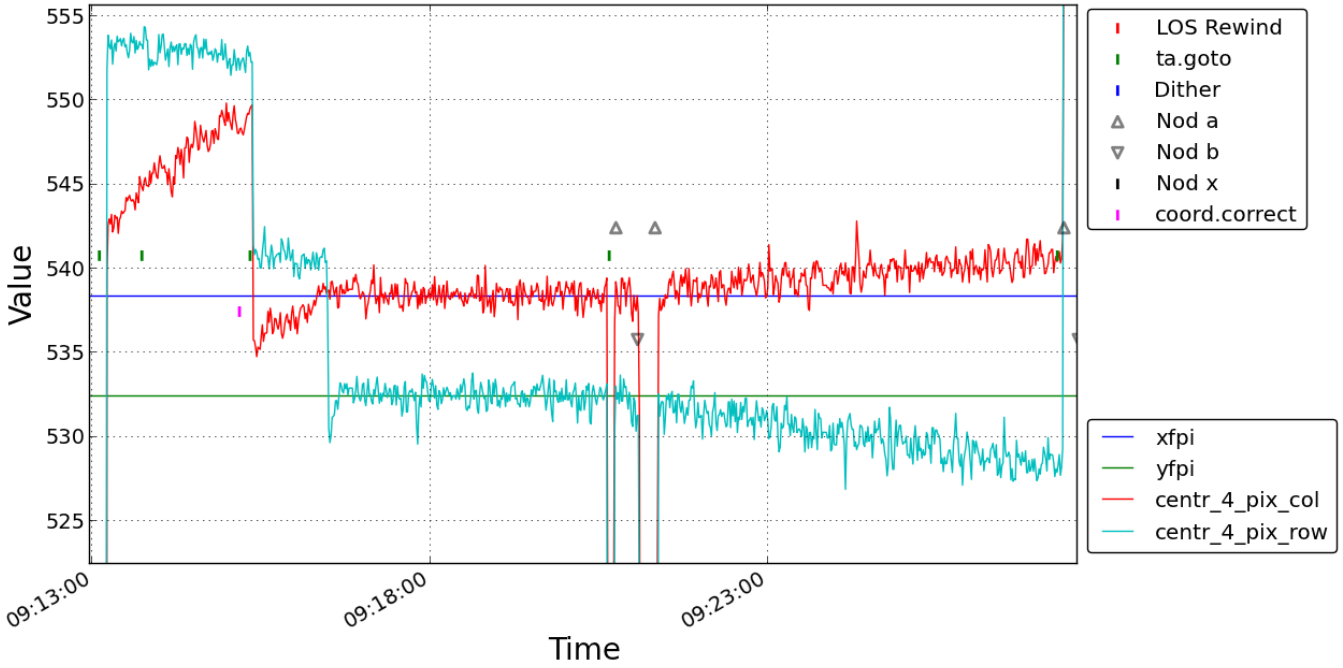
- Topocentric algorithms need review and update
  - perhaps with JPL Horizons subject matter experts
  - perhaps taking a back seat to other pointing improvement items
- Apply adjustment during As Necessary
  - Adjust pointing in SI coordinates (or imager coordinates)
    - This will not remove velocity updates sent to the telescope
    - Operator or observer can tweak or adjust pointing by a few pixels and the telescope will continue to integrate velocity on an ongoing basis
    - This is the same mitigation for an inaccurate ephemeris
  - Pointing the telescope with *absolute* Equatorial, Galactic, or Ecliptic coordinates will reset the TA velocity to zero.

01/14/14 Aten Asteroid Observatory V&V Line Ops

- Some Unexplained Problems evident in FPI movie
- Pointing at *Aten* and staring shows steady divergence between SI boresight and actual asteroid
  - Suggests incorrect velocity estimation or application
- Tracking on *Aten* shows good results
  - Velocity error would be cancelled and hidden in gyro drift
  - We do see small gyro drift evident by error in other trackable stars which could indicate some error in velocity
- Tracking on *Star* while observing Aten shows good results
  - To reconcile with no tracking case, should have seen steady growing offset between SI boresight and actual asteroid since velocity error would not cancel
  - But we didn't….suggesting gyro drift rate was swamping velocity error
    - D. Hoffman – movie of Aten

Operational Use

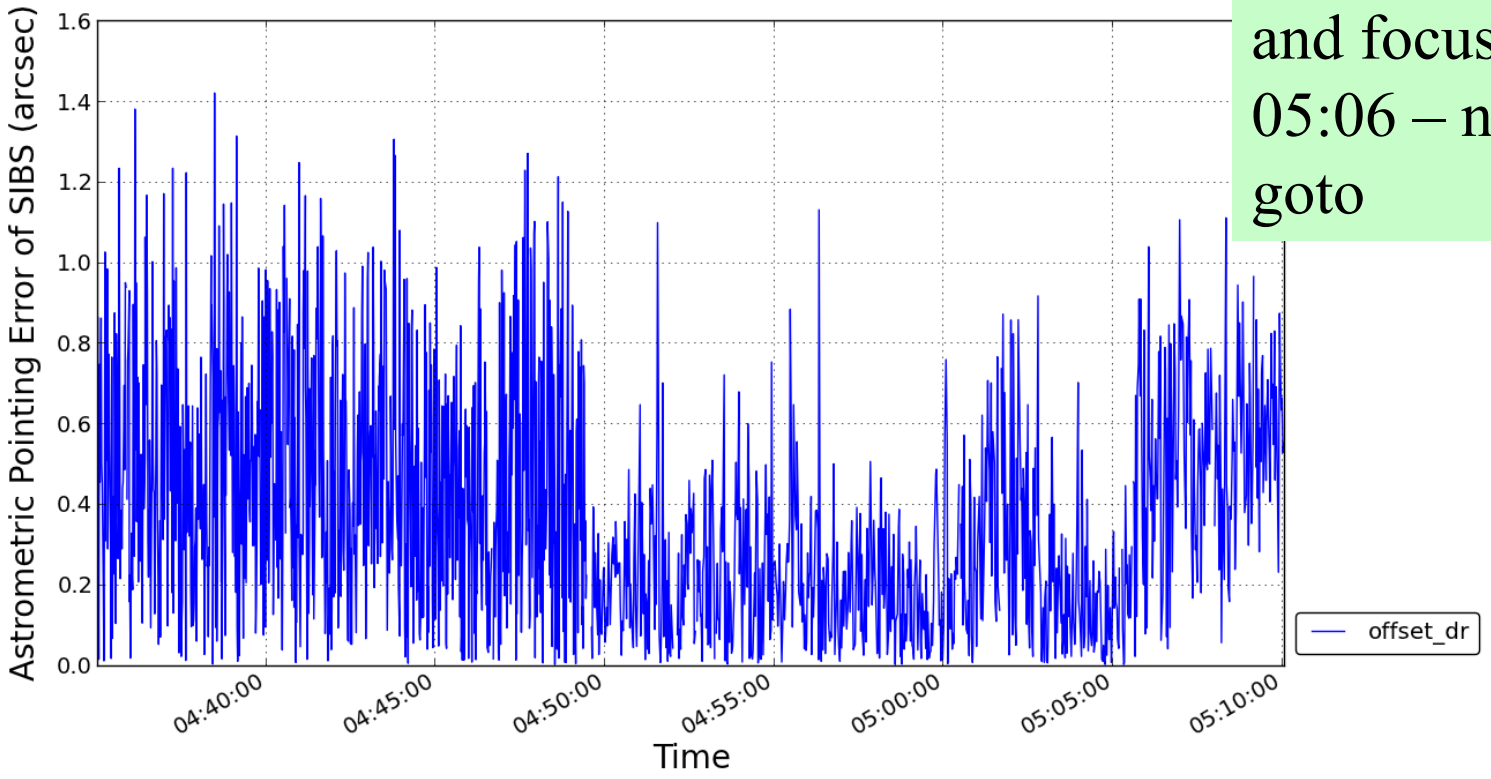
- Some hiccups in understanding
- For instance, instruments and operators learned that pointing using sidereal coordinates stops/zeroes TASCU velocity



- D. Hoffman - plot of Line Ops showing drift of asteroid Vesta from SIBS after pointing to a sidereal object during Line Ops

Operational Use

04:50 – referenced AOI and focus
05:06 – new goto



- D. Hoffman - plot of astrometric pointing error while tracking on asteroid Pallas during flight 148.

Next Non-Sidereal Steps

- Continue operational use
  - Utilize data analysis team who perform astrometric analysis of images to establish pointing, separate from SI team
  - Gather more data on use of tracking with mixed use of sidereal and non-sidereal objects
  - Work with existing SI teams to enable wider use of MCCS/TA non-sidereal functionality
- Analyze/improve topocentric adjustment algorithm
  - Improve absolute pointing performance
  - Collaborate with/request comment from JPL Horizons team
- Complete un-addressed requirements
  - Perhaps first address as yet un-implemented requirements for accounting for SI and tracking imager differential refraction
  - Address osculating elements interface to give user's an alternative to ephemeris