Science Implications of Operating HST in Reduced Gyro Mode

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Summary

The entry of HST into a Reduced Gyro Mode (RGM) will reduce the scientific productivity of HST by ~25 percent, preclude several existing science observing strategies, reduce synergies with other observatories, and decrease the likelihood of responding to time critical events. This memo explores the science implications of running HST in RGM including observing efficiency, target availability, and the impacts on specific types of science observations.

1.0 Introduction

HST currently operates using three gyros for attitude control and target acquisition. After their replacement during SM4, the spacecraft had six gyros. Since then, one has failed (G5) and others have shown varying degrees of aging. Although three gyros (G3, G4, and G6) are constructed with an improved technology that provides hope for significantly longer life than prior units, it is reasonable to expect that HST will have fewer than three working gyros at some time in the future. HST was previously operated with fewer than three gyros during 2007-2009 using a two-gyro mode. Subsequently a one-gyro mode was developed and briefly tested. All indications are that scientific performance and scheduling considerations are essentially the same in two- and one-gyro modes so operation in one-gyro mode will be assumed for this study. For convenience we hereafter will refer to two-gyro and one-gyro modes as reduced gyro mode (RGM).

HST's control system obtains attitude knowledge from multiple sources, including the Fine Guidance Sensors (FGS), Fixed Head Star Trackers (FHST), Gyros, and Sun and geo-magnetic field sensors. During routine operations (*i.e.* this discussion does not consider the various safe mode situations), HST is (1) guiding on a target, (2) acquiring a target, or (3) not performing science operations (*e.g.* during slews and/or occultation by the Earth). When guiding on a target in three-gyro mode, the FGS instruments work with the gyros to maintain precise pointing while in RGM the FGS directly provide the necessary inputs to the pointing control law. This results in a minor degradation in the spacecraft's jitter performance, but was found to be scientifically insignificant during the two-gyro operations period prior to SM4. Thus as long as HST has three operational FGS instruments, we may consider the impact of RGM on guiding performance insignificant. We do note that guiding on a single guide star (which might become more common following the loss of an FGS) will be impacted when in RGM. The implications for target acquisition are considered in the following two sections.

2.0 Observing Efficiency

The largest science impact of operating in RGM is a reduction in the number of orbits that can be scheduled for science and external calibration observations. Currently, three-gyro mode scheduling yields ~84 orbits per week (plus ~5+ snapshot observations). Past experience and experiments with the current scheduling system lead us to expect to be able to schedule ~73 orbits per week in RGM for the current mix of science and calibration observations. This corresponds to a reduction of 550-600 science observations per year (assuming that the calibration requirements remain essentially static). Given a GO plus DD allocation of somewhat under 4000 orbits per year, this represents a 15 percent reduction in science output from the observatory.

The largest impacts in RGM arise from the reduction in knowledge of spacecraft attitude when FGS inputs are not available (*i.e.* during Earth occultation or other periods of non-guided operation). This reduces the field of regard (see Section 3), requires longer acquisition times, and increases the number of failed acquisitions. Target acquisition is impacted in RGM as the entry conditions are less well defined, necessitating a somewhat longer search time for both initial and re-acquisitions. This reduces the available science observing time during visibility periods by ~2 minutes or about 4%. The scientific impact of this varies from fairly unimportant for programs taking simple orbit-long integrations to major for tightly constructed visits where, for example, short visits with multi-filter observations and where one fewer filter can be accommodated due to RGM. A reasonable assessment of the aggregate impact of RGM due to shortened visibility periods is probably ~4% or 160 orbits per year.

We also expect some increase in the numbers of failed acquisitions – prior experience suggests that the absolute fraction will increase by 1% or about 40 orbits per year.

3.0 Field of Regard

In RGM the gyros are unable to provide sufficient information for target acquisition following an Earth occultation. Thus a position update via the FHST is required prior to <u>every</u> FGS acquisition and re-acquisition. As the FHST are mounted facing towards the –V1 and –V3 axes of HST (*i.e.* facing anti-Sun outwards and aft), this requires a view of the sky not blocked by the Earth and thus greatly limits the fraction of the sky observable at any particular time. In addition, to ensure spacecraft safety, the solar exclusion zone is increased from 50 degrees in three-gyro operations to 60 degrees for two-gyro and 62.5 degrees for one-gyro operations.

The net result is a large reduction in the instantaneous field of regard for HST from 82% to 40-50% of the sky (see Figure 1). The available field changes with both the position of the Sun and the precession of HST's orbit. This has at least five major science implications.

- Time critical observations become much more difficult to schedule. This impacts both absolute time observations and observations requiring a cadence spanning several months.
- Simultaneous or near simultaneous observations with other observatories (most significantly JWST in a few years) may be impossible due to the reduced field of regard.
- Currently HST carries out observations separated by approximately 6 months such that the spacecraft roll angle changes by 180 degrees. This enables, amongst other things, efficient observations using ACS and WFC3 in parallel to observe the same fields.
- HST is constrained in the numbers of observations that can be planned for a given region of the sky during a year. Even in three-gyro mode this has been a problem necessitating restrictions on the TAC for allocating orbits on popular regions of the sky.
- The requirement for FHST visibility constrains the possible spacecraft orientations (*i.e.* roll angles) that are important for certain science observations.

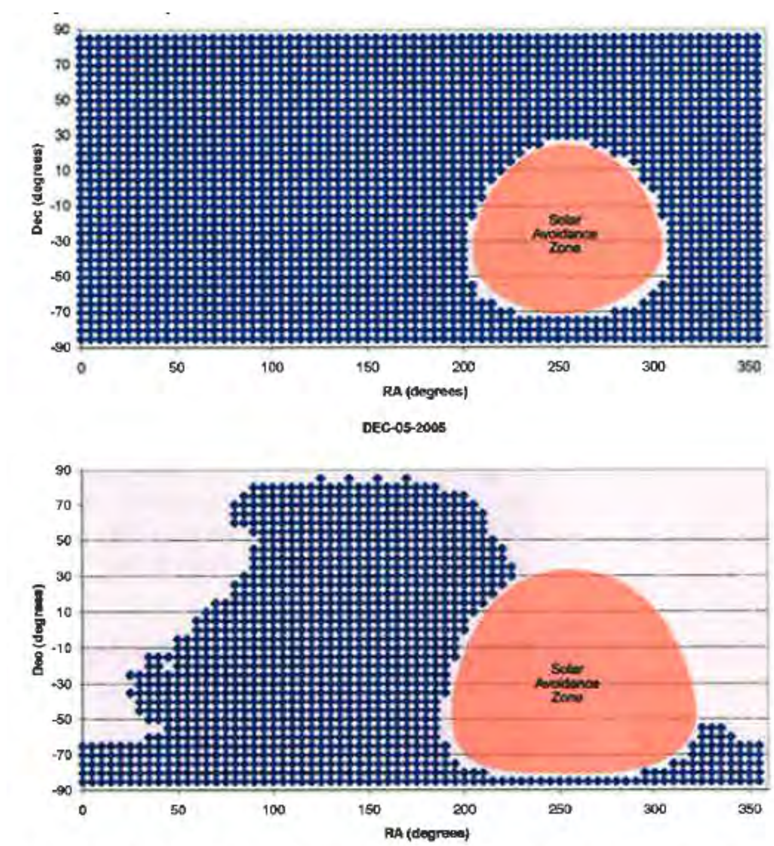

Figure 1: Sky availability on 5 December 2005 for 3-gyro and 2-gyro mode observations (from the Cycle 14 Two Gyro Handbook).

4.0 <u>Science Impacts</u>

In this section we consider a range of science impacts organized roughly by distance – not importance. This is certainly not an exhaustive list. We attempt to distinguish between impacts that make observations entirely infeasible, those where the population of potential targets is reduced, and those which become significantly more expensive to carry out.

4.1 Solar System Objects

The increased solar angle constraint in RGM effectively rules out any further observations of Venus, while the absence of gyro pointing mode precludes observations of the Moon. Time constraints reduce scheduling opportunities and, in particular, the probability of observing transient phenomena (*e.g.* comet passages or impacts; coordination with interplanetary spacecraft) is significantly reduced. For example, the best opportunity to observe a comet at its most active is often when it is near the solar exclusion zone thus expanding that zone will have a major impact, especially for the very scientifically important Sun-grazing comets. Furthermore, observations at desirable viewing angles (*e.g.* opposition) will become more difficult to schedule. Lastly, the rarely used capability to perform guide star handoffs is not available in RGM, which will make observations of very fast moving targets less efficient.

4.2 Exoplanet Observations

HST continues to lead in the characterization of exoplanet atmospheres via transit observations mainly with WFC3/IR spatial scans but also with STIS or COS observations in the ultraviolet. These will be more difficult to schedule for repeated transit observations (especially for longer period targets). As gyro guiding with spatial scans permits moving at 8 arc seconds per second versus 5 arc seconds per second under FGS control, Grism observations of the very brightest targets ($H_{AB} < \sim 4$) become impossible. For serpentine scans, the rate restriction is 1 arc second per second thus limiting observations further by ~2 magnitudes. In addition, roll angle constraints make the avoidance of nearby bright confusing stars for WFC3/IR spectroscopy more difficult to schedule.

4.3 Debris Disks and other Coronagraphic observations

Although the pointing performance is essentially identical under RGM there is slightly more power in the wings of the PSF due to jitter excursions. It is difficult to determine at this point if this will have any meaningful impact. However, the constraints on roll angles posed by RGM are significant for coronagraphic observations. Multiple roll angles during a single orbit are not possible (decreasing observing efficiency) and subsequent observations where scientific drivers require re-visit intervals of months may not be schedulable.

4.4 Parallax measurements and ultra-high precision astrometry

The use of spatial scans with the WFC3/UVIS channel has achieved relative astrometric measurements at the 20 micro-arc second level via averaging thousands of samples. This enables several types of science that will be adversely impacted or made impossible in RGM. Because this technique provided separation measurements in only one dimension, spacecraft orientation is important. Ideally measurements are made with scans in the column direction to minimize the effects of charge transfer inefficiencies in the CCD detector combined with the necessity of arranging sources in the field to avoid overlapping the scans. Thus opportunities for such measurements will be considerably limited in RGM. One important use of this technique has been the measurement of source distances using parallax due to the Earth's motion around the Sun. This requires observations spaced approximately six months apart to realize the maximum baseline and with the same (or 180 degree rotated) orientation. This will be difficult to impossible for many targets in RGM.

4.5 Target of Opportunity and Simultaneous Observations

The major reduction in the instantaneous field of regard of HST has a correspondingly large impact on target of opportunity observations. Furthermore, the ability to schedule simultaneous (or nearly simultaneous) observations with other observatories (*e.g.* JWST) with limited fields of regard is significantly reduced.

4.6 Imaging Surveys using ACS+WFC3

A particularly efficient use of HST time since SM4 has been the parallel operation of the ACS/WFC with the WFC3. This has resulted in doubling the efficiency of the multi-cycle treasury programs CANDLES and PHAT and added flanking fields to the CLASH and Frontier Fields programs. Collectively these parallel operations have in effect added nearly one year of HST observations since SM4. Central to these programs is the ability to control roll angle for efficient tiling over long periods of time and, in some cases – most notably Frontier Fields – to return to a field after six months when the relative positions of ACS and WFC3 on the sky are reversed. For future deep imaging surveys that use both ACS and WFC3 wavelength coverage and rely upon 180-degree flips, this represents a 50% increase in the required number of orbits to achieve similar observations in RGM.

4.7 Tiling Mode observations with WFC3/IR

Tiling Mode (a.k.a. Drift and Shift – DASH) permits up to eight WFC3/IR images per orbit using gyro pointing control. This enables wide-shallow surveys and was introduced in Cycle 23. This mode of operation will not be possible in RGM.

4.8 COS orient constraints due to dual apertures

The COS FUV and NUV detectors can be damaged by exposure to bright sources and thus each target observed by COS as well as the field around it needs to pass a bright object protection (BOP) check. COS has two 2.5 arc second apertures. Whenever COS is used and the primary aperture is observing a specific target, the secondary aperture is open and views an offset region on the sky. To avoid placing bright sources in this secondary aperture, spacecraft orientation constraints may be required. This will make observations of some targets more difficult, or in the worst case impossible, in RGM.

4.9 Very long term (6 months) observing campaigns

HST has carried out long-term synoptic campaigns in the past that will be shortened or made impossible in RGM. For example, the reverberation mapping observations with COS of a supermassive black hole (Program 13330; P.I. Peterson) required daily one orbit visits for six months. The science applications are very sensitive to both the density and duration of the temporal sampling achieved. Likewise, HST has followed the evolution of supernovae for long periods and such observations will become increasingly difficult and infrequent in RGM.

5.0 Other Impacts and Considerations

5.1 Calibration Target Availability

The instrument calibrations depend upon regular monitoring programs to constrain variability in fundamental calibrations and to assure science observers that their data are calibrated to a known accuracy. The instrument teams are currently assessing the need for establishing additional calibration targets but it is expected that some calibration orbits in three-gyro mode will need to be applied to the calibration of secondary calibrators to continue the current frequency of the monitor programs.

5.2 Interactions with other aspects of HST life limiting systems

While beyond the scope of this study, we raise the concern that RGM in combination with other lifetime considerations (*e.g.* FGS star selectors) may result in additional constraints on the scientific productivity of HST.

5.3 Return to 3 gyro for special circumstances

One issue raised in our discussions was the possibility of rapidly returning to three-gyro operations in the event that entry into RGM was voluntary. The situation envisioned was a once-in-a-lifetime event such as a galactic or local group supernova which would otherwise lie outside of HST's current field of regard. A past example might be the 1994 comet impacts on Jupiter.

6.0 Conclusions

Entry into RGM will reduce the scientific productivity of HST by ~25 percent, preclude several existing science observing strategies, reduce synergies with other observatories, and decrease the likelihood of responding to time critical events.