Goddard Space Flight Center

HST/GSFC Project Report

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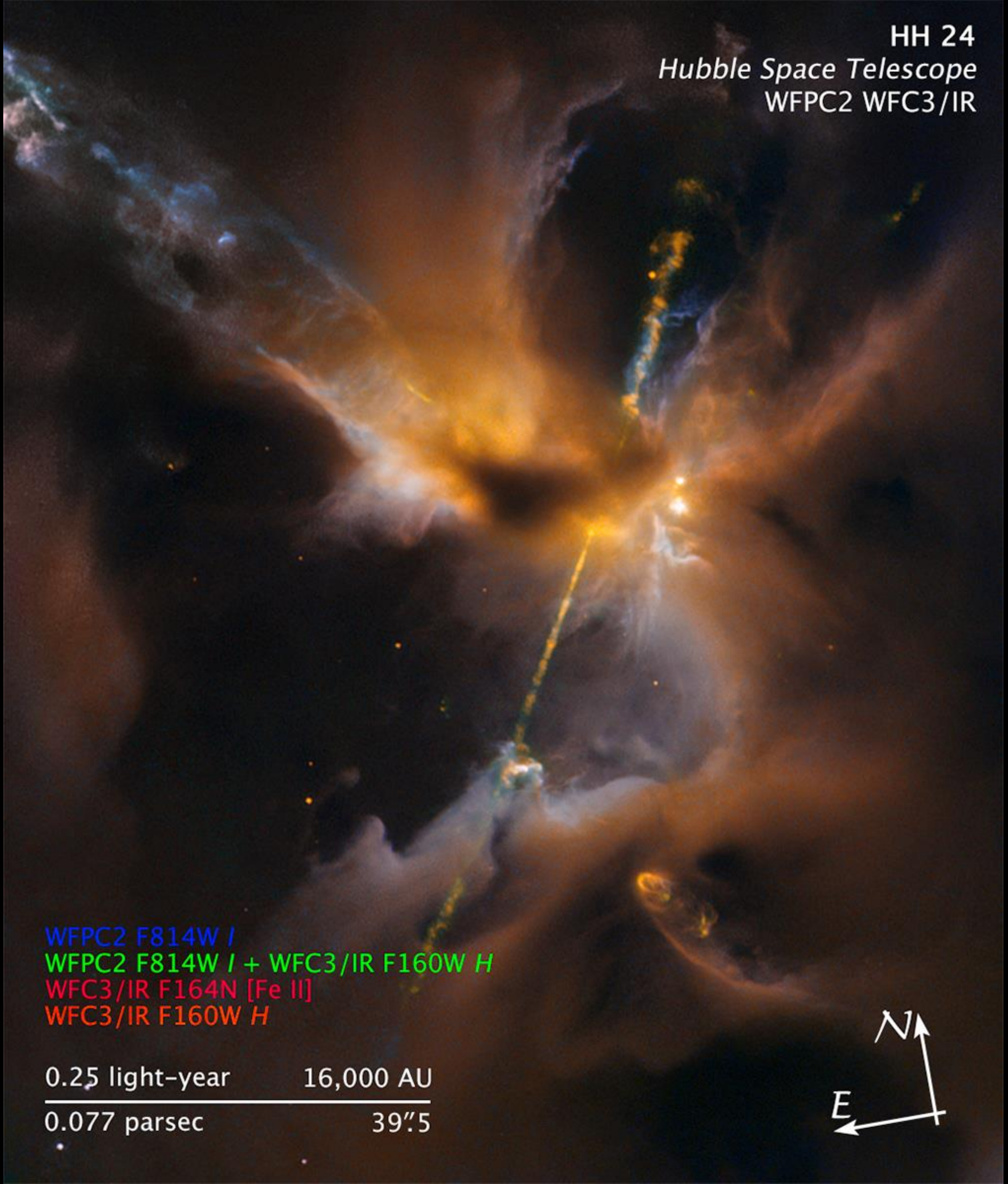
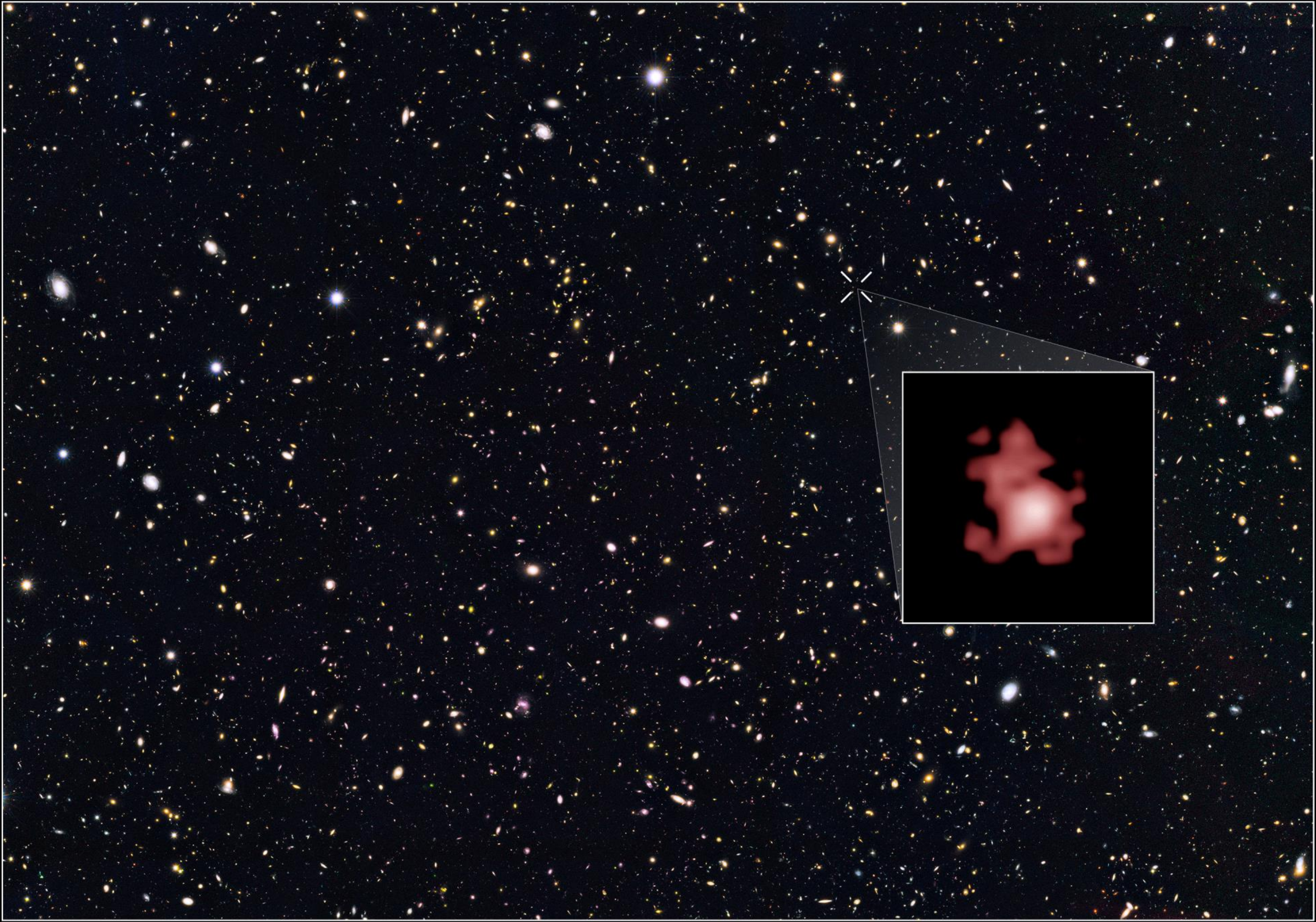
Space Telescope Users Committee Meeting May 12, 2016

Agenda

- Recent Science
- 2016 Senior Review Perspective
- Observatory Status
- Gyro Performance and Tiger Team Status
- Reliability/Life Expectancy Assessment
- Contract/Budget Status


HH 24
Hubble Space Telescope
WFPC2 WFC3/IR
WFPC2 F814W I
WFPC2 F814W I + WFC3/IR F160W H
WFC3/IR F164N [Fe II]
WFC3/IR F160W H
0.25 light-year
16,000 AU
0.077 parsec
39″.5
N
E

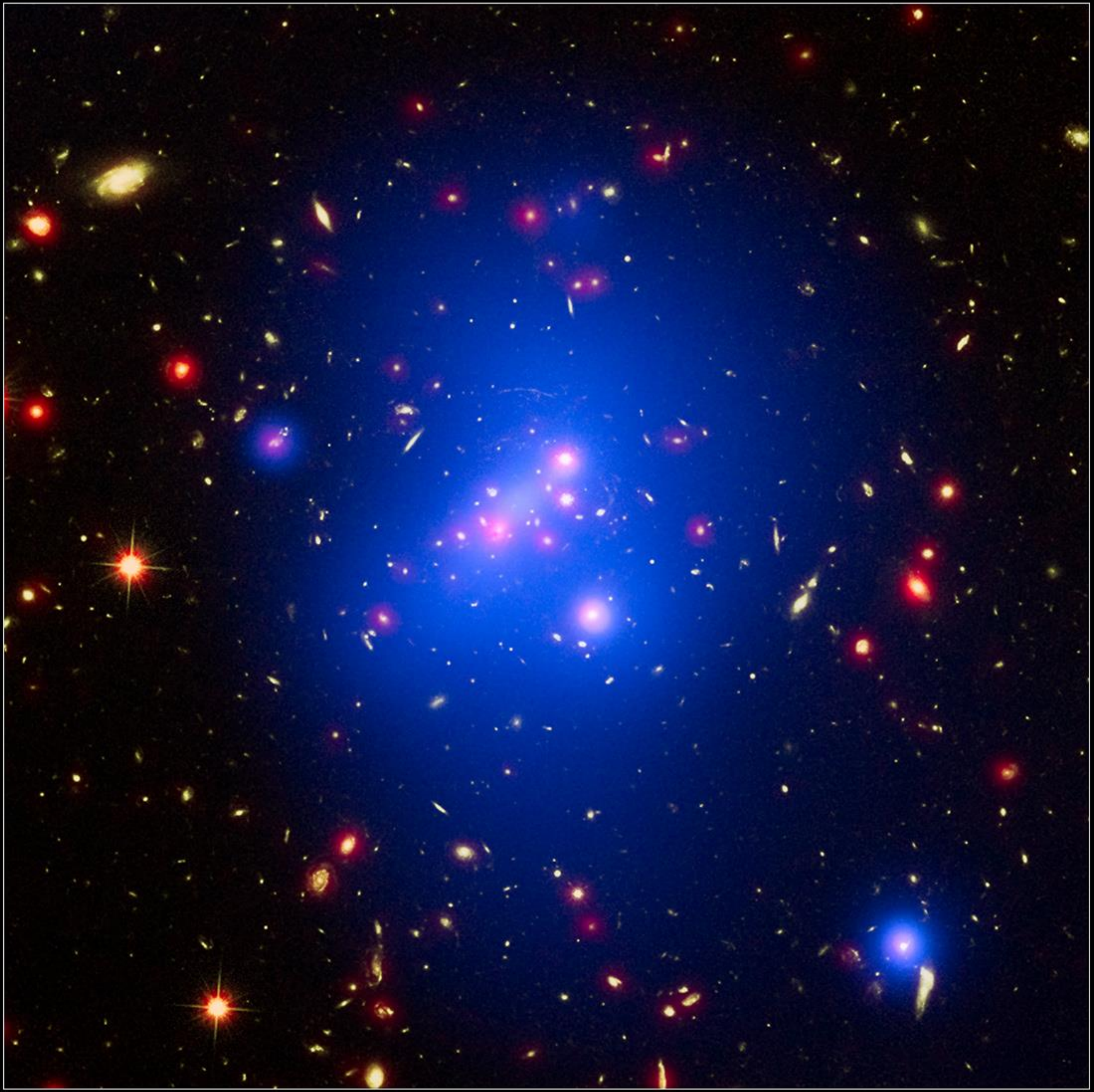
Distant Galaxy GN-z11 • Redshift 11.1 • GOODS North Survey *HST* • ACS/WFC WFC3/IR



NASA, ESA, and P. Oesch (Yale University) STScI-PRC16-07a

Galaxy Cluster IDCS J1426.5+3508

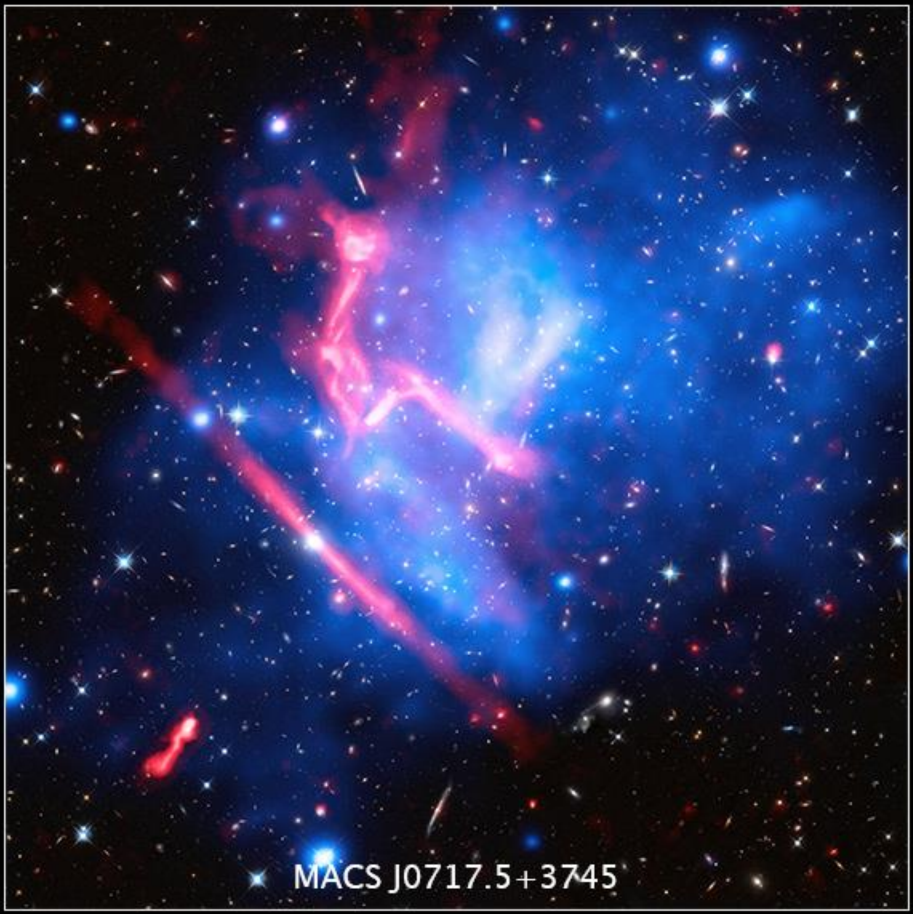
CXO ▪ HST ▪ SST

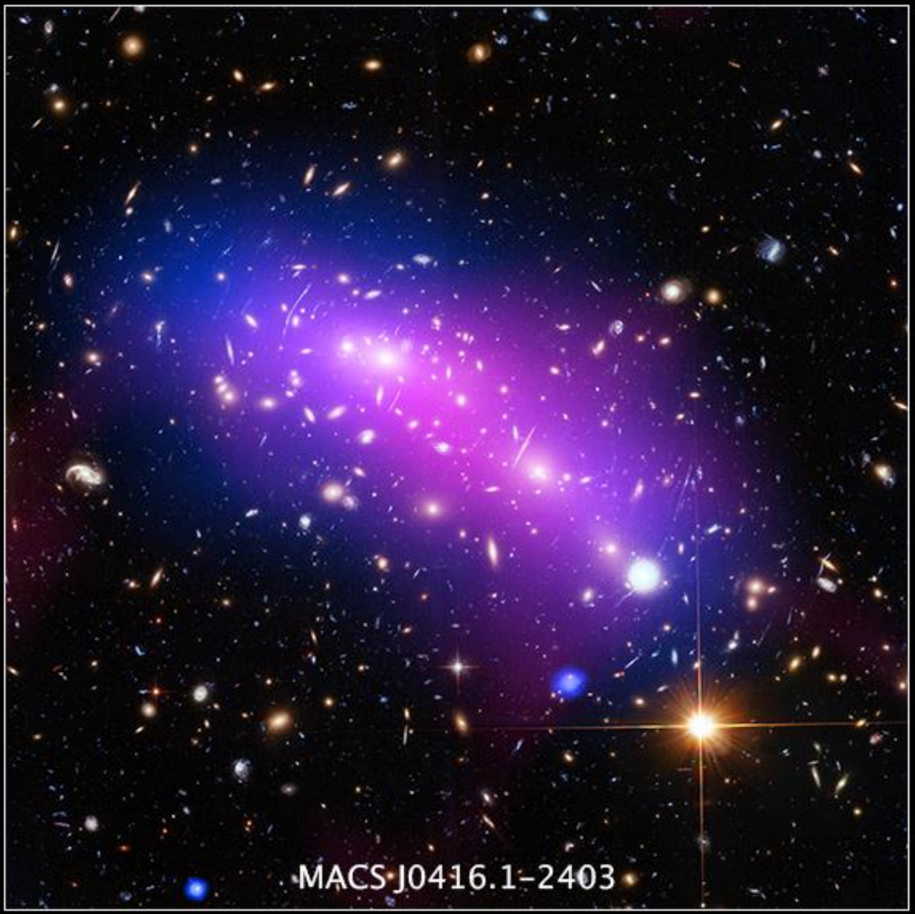


NASA, ESA, and M. Brodwin (University of Missouri)

STScI-PRC16-02

Hubble Frontier Fields ▪ *Chandra X-ray Observatory, Hubble Space Telescope, Jansky Very Large Array*





NASA, ESA, CXC, NRAO/AUI/NSF, and STScI ▪ STScI-PRC16-08

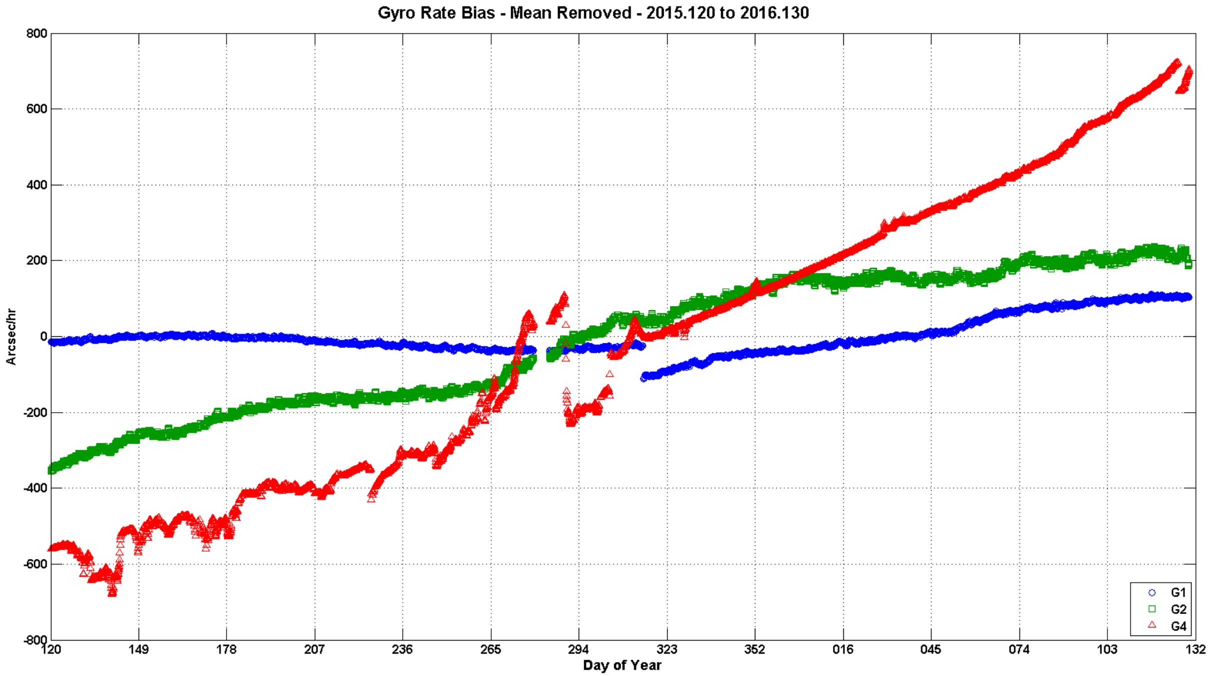
HST Observatory Status

4/30/16

Subsystem		Summary
Science Instruments (SI)	G	• WFC3 performance excellent; Channel Select Mechanism (CSM) movement and dust particles monitored − CSM movements have been significantly reduced − Most recent particle observed in December 2015 (first since July 2015; August 2013 prior to that) • COS − Moved to 3rd position on February 8, 2015; planning well underway for 4th position (expected in 2017) − FUV detector sensitivity monitoring continues following completion of sensitivity ARB closure 4/2011 • ACS and STIS repaired instruments (SM4) performing nominally • NICMOS in standby following decision to not restart following Cycle 19 proposal evaluations
Electrical Power System	G	• Performance of batteries is excellent; benchmark set to 510 Amp Hours • Solar Array 3 performance remains excellent; section 1 ~2 amp loss in June 2015 • 12/22/12 Software Sun Point (SWSP) safemode entry; first unplanned entry since 2007 • Solar Array Drive Electronics (SADE) investigation following 2/15/13 SWSP completed; no further actions
Pointing Control System	G	• Gyro 5 failed on 3/7/14; 1-2-4 gyro configuration; Gyro 6 powered off 3/13/14; Gyro 3 removed from control loop and powered off in 2011; all gyros configured to operate on secondary heater controller • Gyro 4 motor current increased from 120mA to 190mA in 9/2011, has remained stable at ~178 mA • Gyros 2 and 1 motor currents increased to 200 mA on 11/8/15 and to 165 mA on 11/11/15, respectively • Attitude Observer Anomaly (AOA) (ARB report 10/2011) mitigation completed 11/2012 • FGS-3 bearings degraded (~10% duty cycle to preserve life); FGS-2R2 Clear Filter operations began 1/2015
Data Management System	G	• SI Control and Data Handling (C&DH) has had 7 lockup recoveries since 6/15/09; most recent was 10/20/14 • SI FSW enhanced to protect detectors in event HV left on from SI C&DH lock up event • Science Data Formatter (SDF) input cycling modified to reduce thermal load • Solid State Recorders (SSRs) 1&3 have each experienced a single lock up while in the South Atlantic Anomaly (SAA); Alert monitors detect condition to minimize data loss
Communications	G	• Multiple Access Transponder 2 (MAT2) coherent mode failed (12/24/2011); Two-way tracking unavailable • Joint Space Operations Center (JSpOC) now the source for the operational ephemeris via Conjunction Avoidance Risk Assessment (CARA) team and the Flight Dynamics Facility
Thermal Protection System	G	• Condition of Multilayer Insulation (MLI) observed during SM4 was as expected • New Outer Blanket Layers (NOBLs) installed on Bays 5,7, and 8 during SM4

Mission Operations – Gyro Performance

- **Gyro performance update**
  - Gyro-4 performance had been out of family May-November 2015
  - Gyros-1 and 2 each experienced a sudden increase in motor current in November
  - Tiger Team investigated elevated motor current and provided initial briefing in February
  - All 3 gyros have performed nominally in pointing control system since mid-November
  - On May 5, Gyro-4 experienced a sudden bias shift that impacted 4 orbits



Mission Operations – Gyro Run Time Performance

4/30/16

Current Gyro Runtimes

Post SM4 RGA	Status	Flex Lead	Total Hours 2016/121
G1	On	Standard	26068
G2	On	Standard	26240
G3	Off – AOA 2011	Enhanced	22353
G4	On – Max Hrs	Enhanced	71537
G5	Failed 2014	Standard	51497
G6	Off	Enhanced	35945

Previous Flex Lead Failure Runtimes

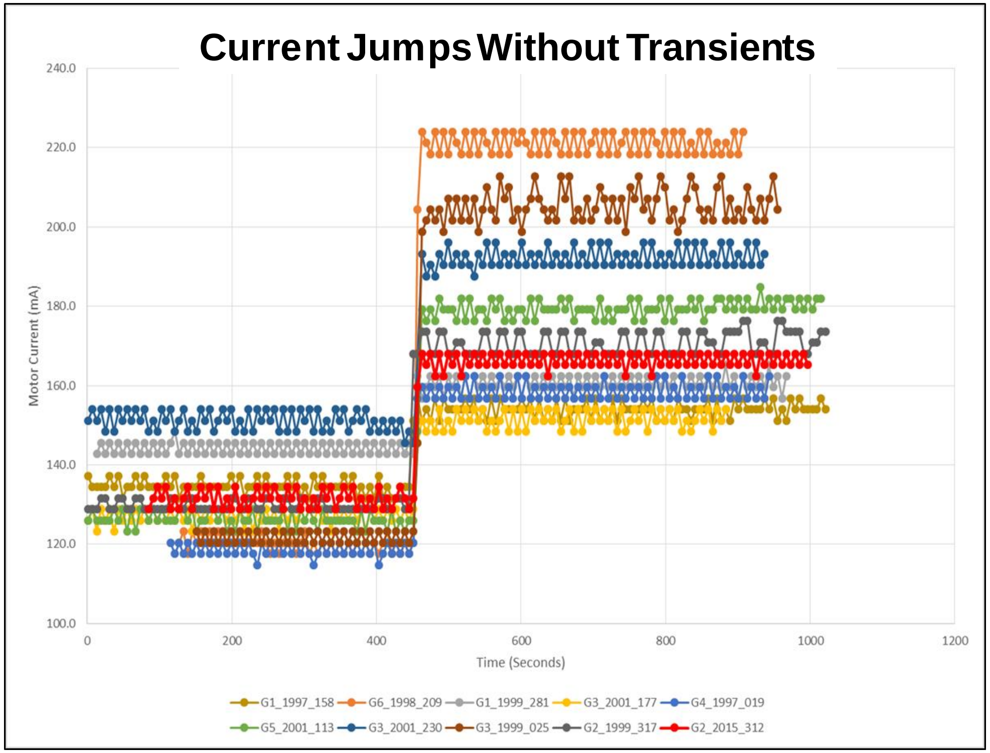
Date of Failure	Gyro	Flex Lead	Total hours at failure
1992.281	G6	Standard	34825
1997.099	G4	Standard	31525
1998.295	G6	Standard	46276
1999.110	G3	Standard	51252
1999.317	G1	Standard	38470
2007.243	G2	Standard	58039
2014.066	G5	Standard	51497

Maximum runtime hours (current G4)	71,537
Minimum runtime hours (SM3A G5, rotor restriction)	13,857
Mean runtime hours for 6 current onboard gyros	38,940
Mean runtime hours for all 22 HST operational gyros	40,707
Mean runtime hours for the 7 HST flex lead failure gyros	44,555

Gyro Elevated Motor Current Tiger Team

- **Gyro Elevated Motor Current Tiger Team Findings Briefed on February 11**
  - Most likely cause of elevated motor current:
    - G1 most likely experienced a Major Transient Rotor Restriction
    - G2 most likely experienced a Minor (duration) Rotor Restriction or Clock Discontinuity
  - No single common cause event has been identified for these two events
  - The refined understanding of the two contributions to the elevated motor current indicates motor re-poling (weaker magnetization) is a far greater factor than increased drag due to remaining debris
    - The potential risk of a failed restart of a gyro at elevated current is now considered to be less than previously assumed
    - Additionally, there is the opportunity that a restart of the motor would be a benefit since lower current produces less flex lead degradation and re-poling to the optimal magnetization would produce higher torque margin to crush future debris

Minor-Step Motor Current Increase



Minor Step Signature

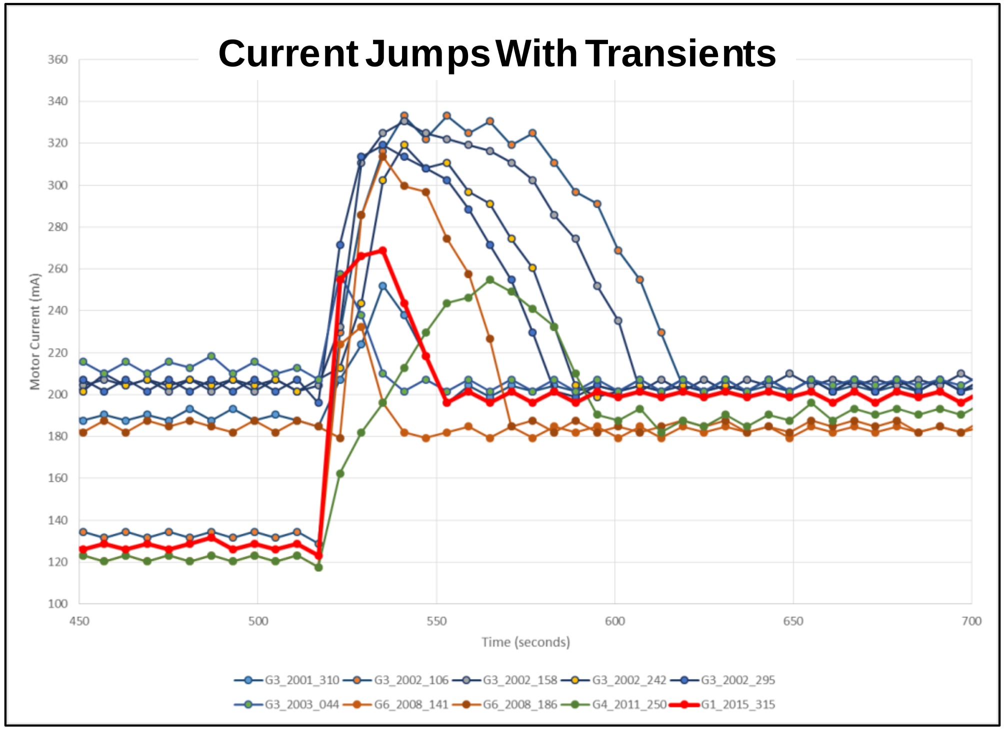
<u>This type of Current Signature can be caused by:</u>

1. **<u>Flex Lead Failure:</u>** *A mechanical breakage of one of the motor's four flex leads resulting in close to doubling[1] of the motor current in the remaining operating phase. Since the breakage changes the force applied to the float, a Flex Lead Failure is usually associated with a large change in bias.*
2. **<u>Clock Discontinuity:</u>** *A momentary disruption of the drive clock resulting in a permanent[2] motor current increase due to exceeding the maximum operational phase angle between rotor and stator magnetic fields. Observed when the ECU's Channel clock master is changed.*
3. **<u>A. Minor Rotor Restriction:</u>** *A permanent[2] increase in motor current initiated by a momentary restriction of the rotor caused by a particle(s) in the gap between the rotor and stationary motor components. The particles are passed through so fast that a transient is not observed in the motor current telemetry. This permanent[2] motor current increase is due to exceeding the maximum operational phase angle between rotor and stator magnetic fields (and potentially some small increased drag.) May result in small bias shift as a result of thermal transient caused by current increase.*

1. Intuitively, the current would double, but with the remaining winding handling the full drag torque, a more efficient phase angle is achieved.

2. Permanent until a restart of the motor at the higher start voltage provides maximal magnetization of the motor rotor. When exceeding the maximum operational phase angle, re-poling (weaker magnetization) of the rotor occurs, but at a weaker magnetization due to the running voltage being lower than the start voltage. Multiple rotor restrictions over time can result in multiple current steps, until a weakest rotor magnetization is reached.

Major-Transient Step Motor Increase



Major Transient Step Signature

<u>This type of Current Signature can be caused by:</u>

3. <u>B. Major Transient Rotor Restriction:</u>

A permanent[2] increase in motor current initiated by a restriction of the rotor caused by a particle(s) in the gap between the rotor and stationary motor components. The transient[3] in motor current is the result of increased drag as the foreign particles is ground into smaller pieces (~100mA+ for <100 seconds). After the transient the increase in motor current is a combination of permanent[2] increase in motor current due to re-poling (weaker magnetization) and in some cases small increases in drag (~6mA) for an extended period (<year) as the smaller particles are redistributed. May result in small bias shift as a result of thermal transient caused by current increase.

2. Permanent until a restart of the motor at the higher start voltage provides maximal magnetization of the motor rotor. When exceeding the maximum operational phase angle, re-poling (weaker magnetization) of the rotor occurs, but at a weaker magnetization due to the running voltage being lower than the start voltage. Multiple rotor restrictions over time can result in multiple current steps, until a weakest rotor magnetization is reached.

3. During the transient, the increased current is the result of increased drag torque.

Gyro Elevated Motor Current Tiger Team

Vehicle Electrical System Test (VEST) Testing

Objectives

- Demonstrate that increased gyro current behavior can be made to occur by reducing rotor magnetization
- Demonstrate that nominal gyro current can be restored by increasing the rotor magnetization
- Show that we can duplicate the range of currents seen on orbit in a properly functioning gyro such that we know that drag torque is nominal
- Characterize the motor parameters

Results

- Observed a well behaved relationship of increased current and magnetization at lower voltage
- When suppressing the elevated motor voltage (simulating a rotor restriction re-magnetization at 28V), the ~200mA run current observed on orbit was duplicated
- In addition, a running restart did restore the current to nominal levels
- It was also observed, similar to on-orbit behavior, that the motor can re-magnetize its winding when there are slight disturbances in the phasing between the rotor and the drive signal, and step to a lower steady state motor current, correcting the conclusion that only a change in drag can result in a motor current decrease. Drag AND a re-magnetization due to a rotor disturbance can both create a decrease in steady state current. The re-magnetization would be a sharp step completed in the microsecond range. The change in drag would be a function of the debris movement.
- Characterization of the motor torque parameters is still underway

Gyro Elevated Motor Current Tiger Team

Recommendation 1

- Create a macro to perform an autonomous running restart of G1, G2, or G4 when its motor current approaches stall level
    - Under a pending stall condition a stall failure is imminent and the increased torque may mitigate the pending stall failure
- ***Status*:**
    - Requirements defined & design review has been completed
    - Operations Acceptance Test and Flight Readiness Review are scheduled for June 15th & 29th

Gyro Elevated Motor Current Tiger Team

Recommendation 2

- Proactively execute a running restart of both G1 & G2 to support life extension of these SFL gyros
  - A running restart has the advantage of re-magnetizing the poles at the power on voltage (55v) and avoids the risk of debris generation by preventing surface contact
- ***Status*:**
  - Requirements defined & macros developed
  - Work is currently on-hold
    - Latest analysis indicates marginal flex lead life expectancy improvements by lowering the motor current
    - Benefit of increased torque margin is available only momentarily

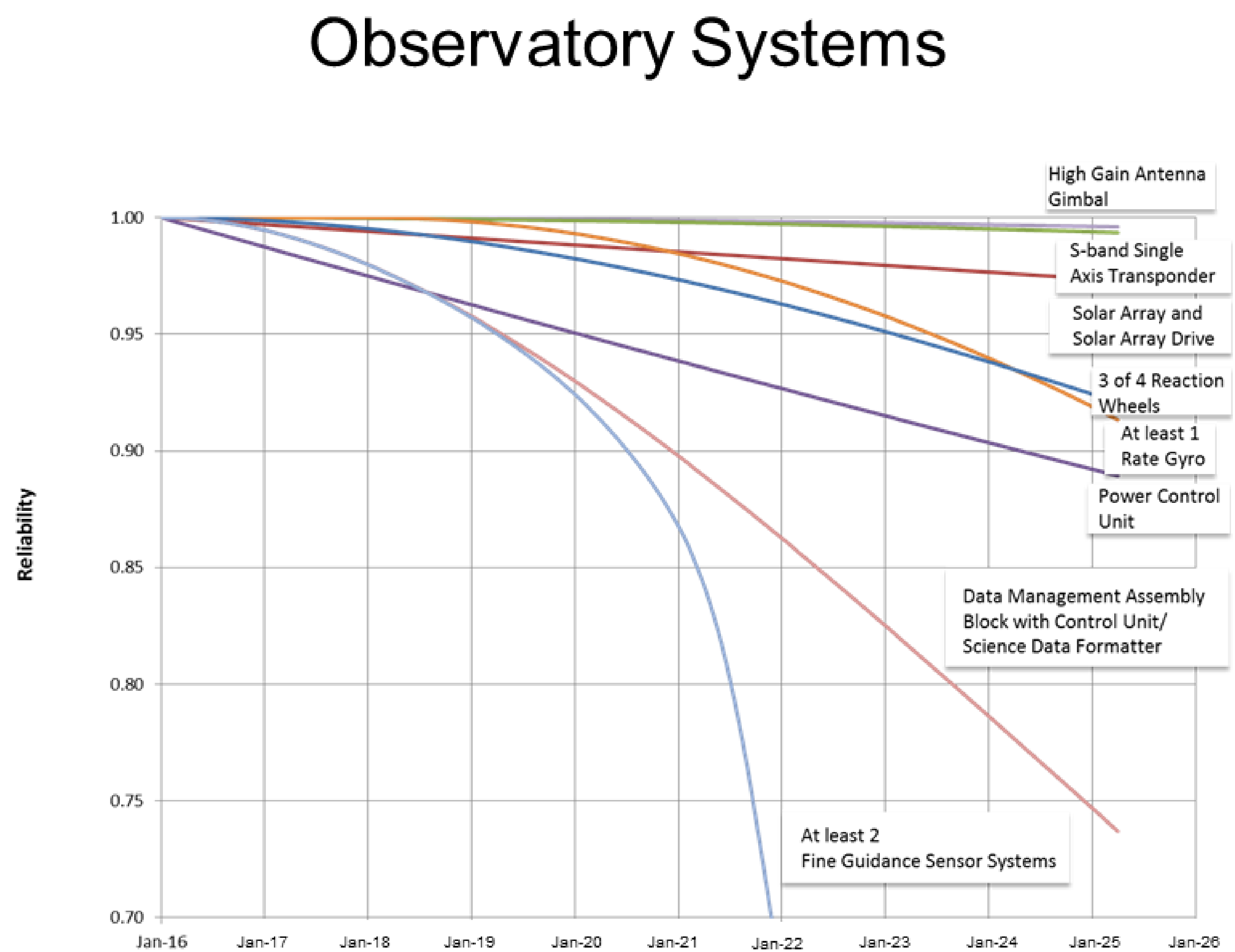
Recommendation 3

- Perform VEST testing to assess motor characteristics
- ***Status:***
  - Testing was completed
  - Awaiting final completion of motor torque analysis

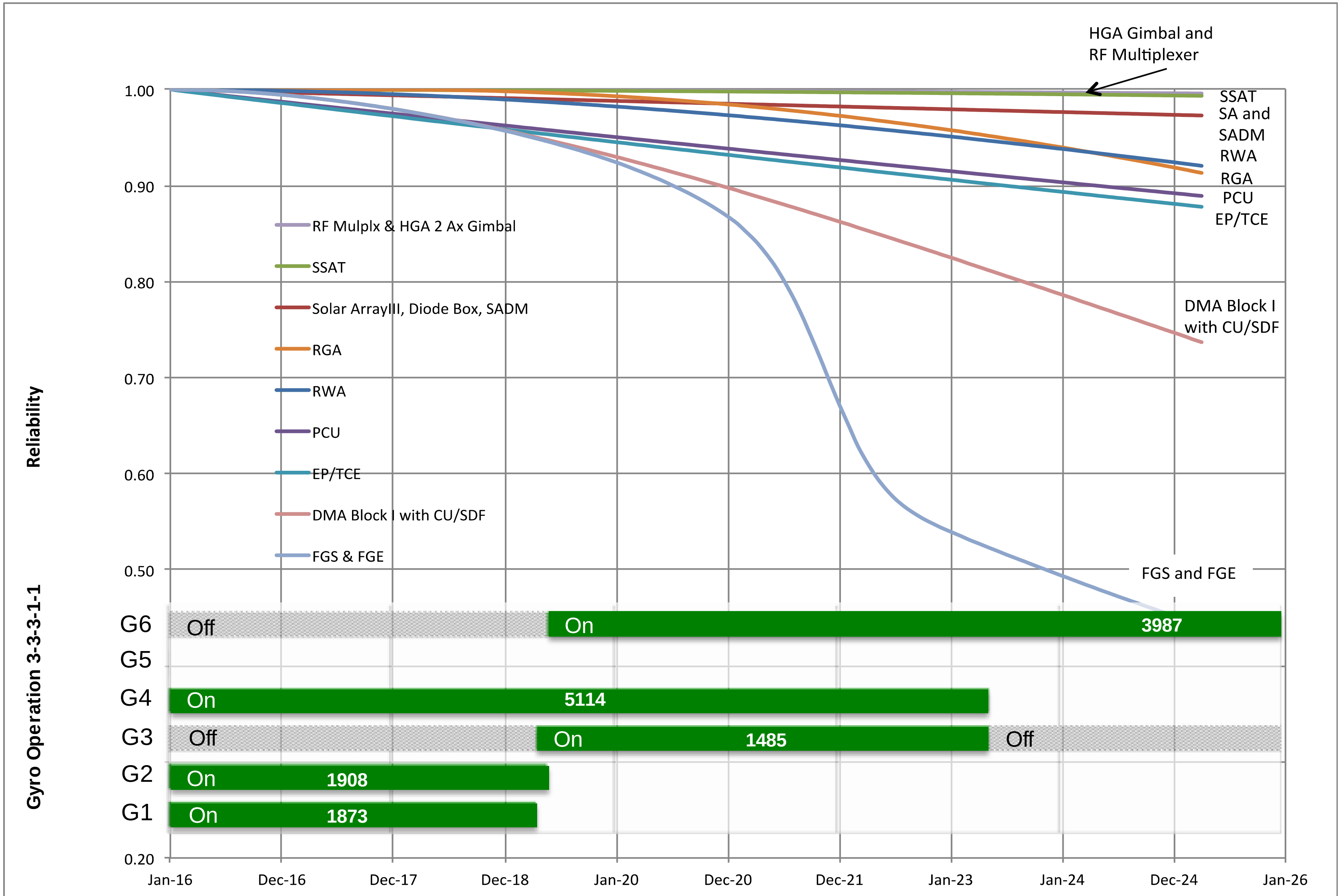
Gyro Reliability Assessment

- **NASA Engineering and Safety Center provided modeling updated 1/1/2016**
  - 10 million Monte Carlo runs for each scenario
  - Model updated to reflect G5 failure in 2014
  - Assumed Enhanced Flex Leads have 5 times life of Standard Flex Leads
  - Used current mean time to failure rate of 14 years
  - **95% probability** of reaching **2023** with 1 working gyro (52% chance of 2 Fine Guidance Sensors in 2023)
  - **80% probability** of getting to **2029** with 1 gyro
  - G1 and G2 are expected to have ~3 years of life remaining; G4 ~6 years, G6 ~10 years, and G3 ~ 11 years
- **Current Gyro Management Strategy (maximizes time in 3 gyro mode)**
  - Operating on 3-gyros (G1, G2, and G4) – G3 and G6 in reserve
  - Upon next gyro failure, activate G6 (leaving G3 in reserve)
  - Upon 2nd failure, activate G3 and continue in 3-axis mode
  - Upon 3rd failure, power off one of the remaining gyros and continue in 1-gyro mode
  - Upon 4th failure, power on last gyro and continue in 1-gyro mode

Critical System Reliability

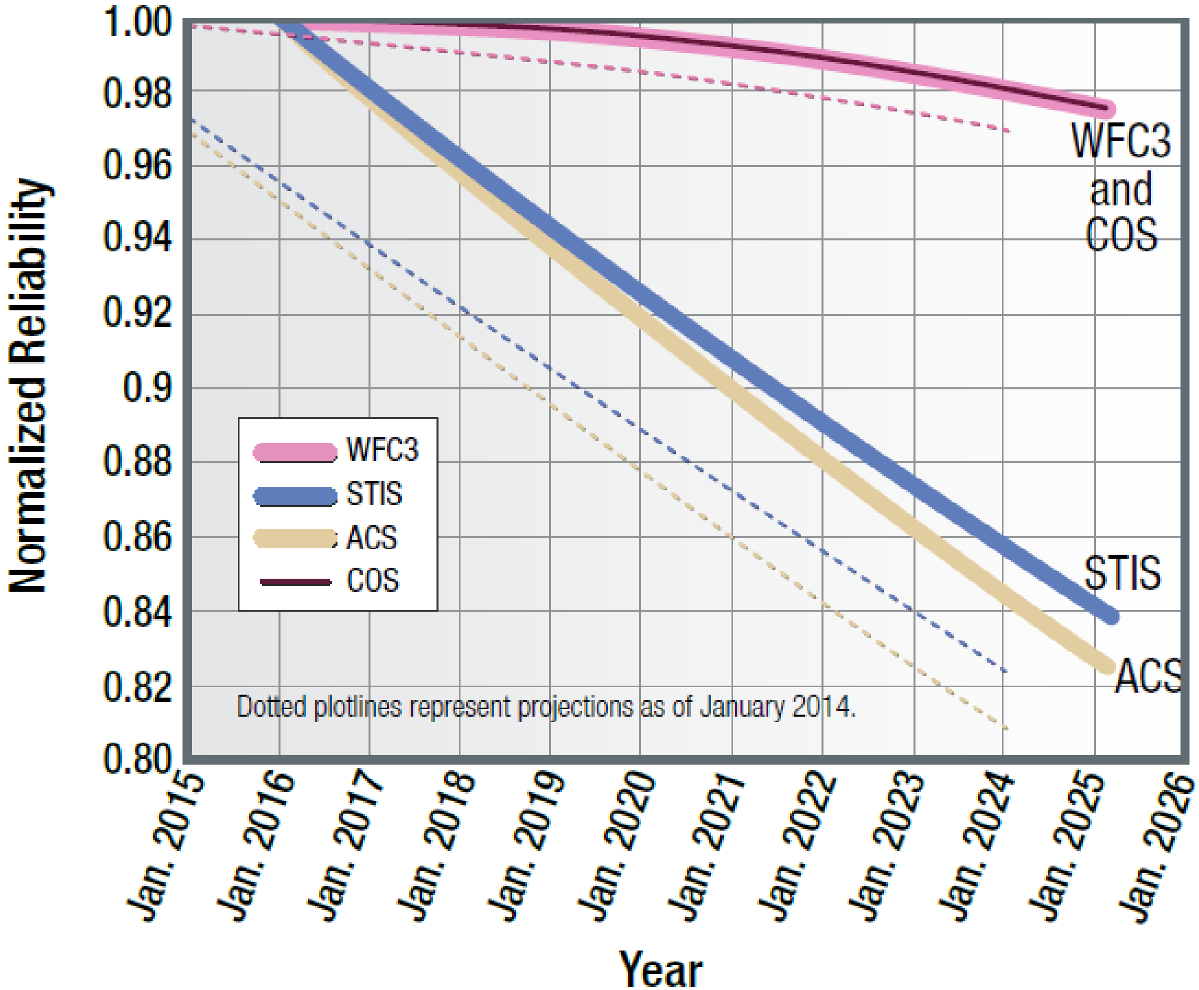


Critical System Reliability



Critical System Reliability

Science Instruments



Life Expectancy Summary

- **Orbit life – most likely reentry in 2036; worst case 2028**
- **Instruments – COS FUV detector is being consumed due to usage**
  - Current pace suggests moving to 4th position in 2017 and 5th position for ~2020-2022
  - May revisit previously used positions with lower signal to noise
- **Critical Subsystems**
  - Random failure is determined from historical performance of components flown on Hubble as well as on other known programs
  - FGS 3 “wear out” is estimated based on linear extrapolation of usage
  - Standard flex lead gyros are based on both random failure and corrosion rate of the flex lead due to temperature – corrosion is the dominant term
  - Enhanced flex leads are estimated, based on chemical properties, to last perhaps 5 times longer than standard flex leads – random failure becomes the dominant term
  - Radiation dosage has been examined, and where total dosage is predicted to exceed the design specification, the expectation is for “graceful degradation”

Hubble is expected to be productive beyond the current 2022 budget horizon

Budget/Contract Status

- **Budget Outlook**
  - Executing FY16-FY21 at $98.3M per year (reviewed annually)
  - Committed to operating HST as a Great Observatory through 2020 and beyond
- **Science Operations Contract Status**
  - Contract negotiations are complete
  - Executing in May under a no cost extension
  - Expect final review and execution of the contract extension mod later this month
- **General Observer / Archival Research**
  - Cycle 22 and 23 awarded value was $28.9M; Cycle 23 included ~200 orbits for Mid-Cycle programs
  - Cycle 24 – based on recent experiences, expect to be able to increase > $28.9M
  - Cycles 25/26 – examining options ranging from nominal one year cycles to a single 2-year cycle; working closely with STScI to identify potential issues; no major obstacles identified at this time

Discussion

- **Questions?**