NASA/GSFC Onboard Autonomy And Automation

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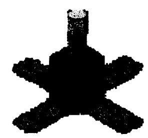
Why Have Onboard Autonomy

- FSW Autonomy Has Been An Evolutionary Process Over the Past ~30 Years
- FSW Autonomy Evolutionary Process Driven By Individual Mission Needs
  - Meet top level science data volume requirements
  - Meet mission-unique, time-sensitive science requirements
  - Provide for spacecraft safety
  - Minimize mission operations costs

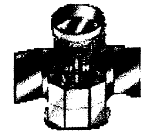
GSFC In-House FSW Autonomy Evolution

SAMPEX
(launched 8/92)

SWAS
(12/98)

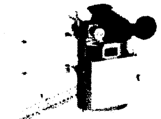


TRACE
(3/98)



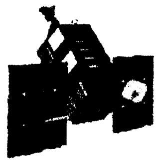
WIRE
(2/99)

SMEX-Lite



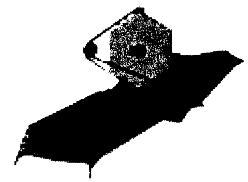
Triana
(mission cancelled)

Swift BAT
(12/04)



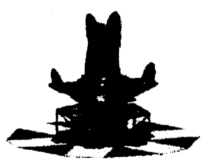
RXTE *(12/95)*

TRMM *(11/97)*



JWST ISIM
(2013)

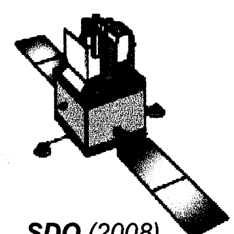
IceSat GLAS *(01/03)*



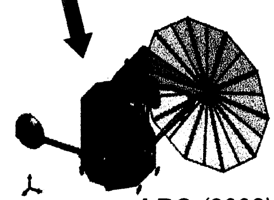
WMAP *(06/01)*

Core FSW Executive (2005)
Core FSW System (2007)

ST-5 *(2/06)*



SDO *(2008)*



LRO *(2008)*

Future EI Spacecraft and Instruments

Challenges Associated With Onboard Autonomy

- **Verification requires extensive & expensive testing**
- **Must be able to create simulated, realistic on-orbit scenarios AND then**
  - **what if .... ?**
- **Autonomy results must be predictable & repeatable in order to remotely troubleshoot & fix post-launch anomalies**

FSW Autonomy Infrastructure at GSFC

- FSW Enablers of Autonomous Science
- FSW Autonomous Management of Onboard Resources
- FSW Autonomous Management of Health & Safety

FSW Enablers of Autonomous Science

- Autonomous Science Execution
  - Execute uplinked science observing programs without ground intervention
    - 1 – 7 days of contiguous science target maneuvers, reconfigurations, observing
    - 'Lights-out' Ground Operations (8x5. no evenings/weekends)
    - Types of stored commanding
      - Absolute timed
      - Relative timed
      - Conditional
  - Insert realtime ground requests amidst autonomous onboard activity
- Science Target Acquisition
  - Attitude slews by spacecraft
  - Science target identification, acquisition & configuration by SI
- Autonomous Target Pointing Control
  - Maintenance of fixed pointing
  - Angular momentum management
  - Ephemeris measurement/propagation
- Science Data Packaging
  - Data compression
  - Interleaving science and engineering data

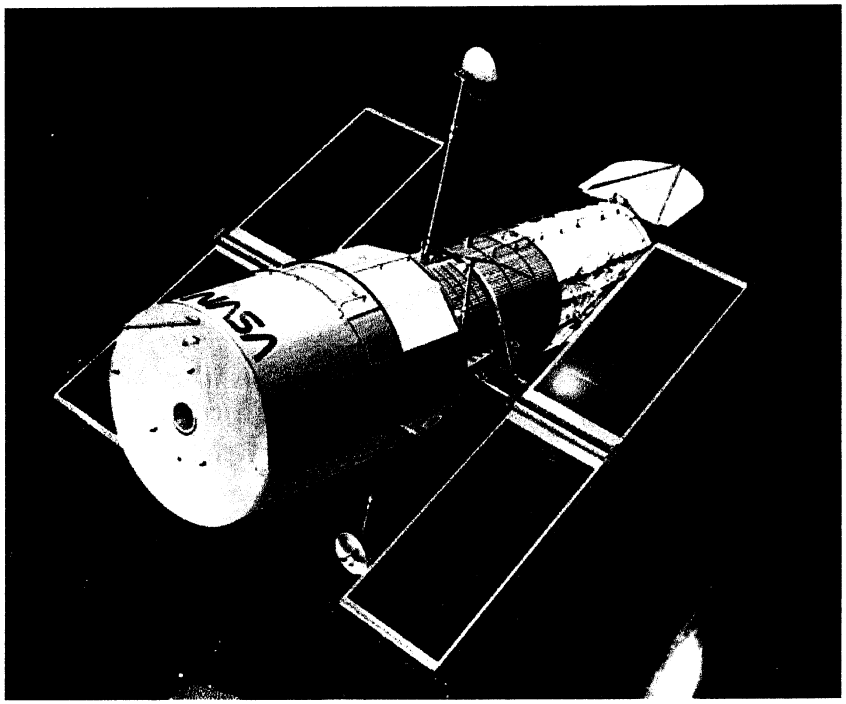
FSW Autonomous Management of Critical Onboard Resources

- Electrical Power
- Thermal State
- Computing Power
- Internal Data Transfer
- Data Storage
- Telemetry Bandwidth
- Guidance, Navigation & Controls Sensors/Actuators
- Propulsion Fuel

FSW Autonomous Management of Health & Safety

- **Monitor Spacecraft Functions**
- **Detect Flight Hardware/Software Anomalies and Failures**
- **Identify Flight Hardware/Software Anomalies and Failures**
  - Onboard diagnostics to determine "why" of anomaly
- **Institute Corrective Action**
  - Realtime execution of pre-planned command sequences and reconfigurations
  - Reinitialize in real-time following SEUs and continue pre-planned science program
  - If all else fails, autonomous entry into Safehold providing power and thermal safe conditions
- **Provide Ground Insight into S/C Systems**
  - Optimized telemetry formats
  - Multiple telemetry formats
  - Telemetry filter tables
- **Provide Ground Access to S/C Systems**
  - Commanding infrastructure (validation and prioritization)
  - Model parameter modification
  - FSW code modification/maintenance

Hubble Space Telescope (HST) ('90)



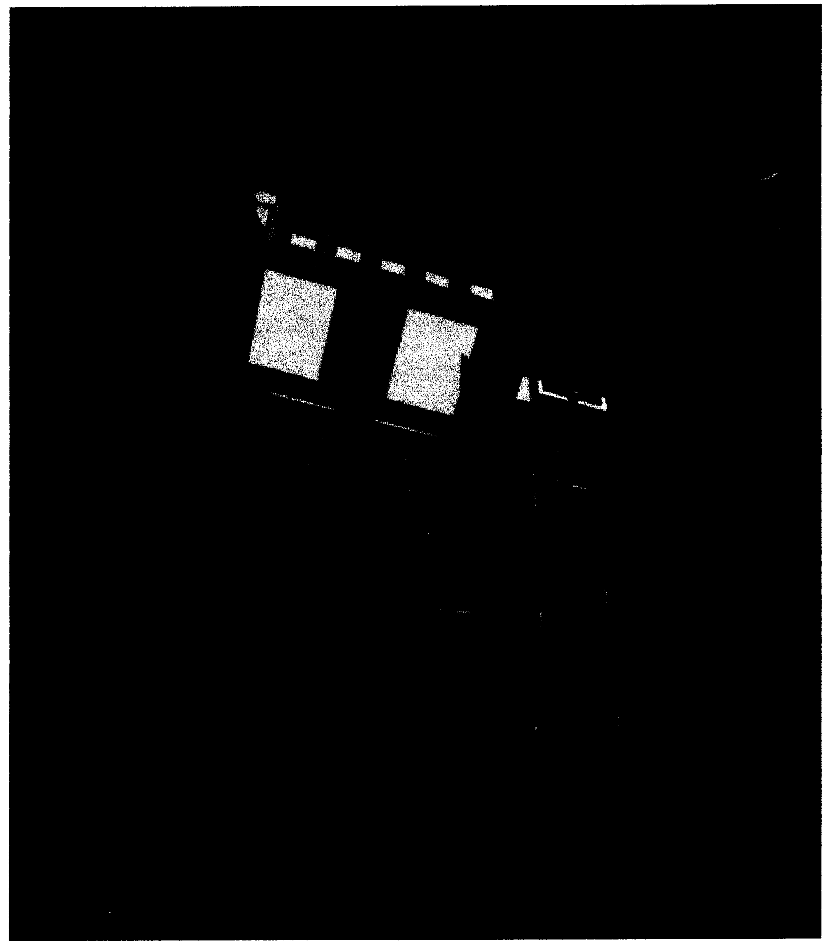
LEO, Stellar Pointer
<u>Mission FSW Requirements</u>

- **Science Target Acquisition**
  - Conditional commanding to support guide star acquisition
    - Highly complex algorithm to determine acceptable guide star pair
  - Realtime autonomous target acquisition via interface between "smart" Science Instrument (SI) and Flight Computer
    - Rasters HST to locate target within guide stars
    - Repoint HST to target after raster to center target in SI field-of-view
  - Maintenance of 7 milli-arcsecond pointing stability
- **5 modes of onboard power management for extended battery/solar array life**
- **Onboard Management of 5 Distinct Processing Rates in the Same Onboard Computer**
- **Extensive Health & Safety Checking with 6 Separate FSW Controlled Safemode Options**
  - Diagnoses with FSW controlled safing enables quicker recovery

Rossi X-Ray Timing Explorer ('95)

LEO, Stellar Pointer
Mission FSW Requirements

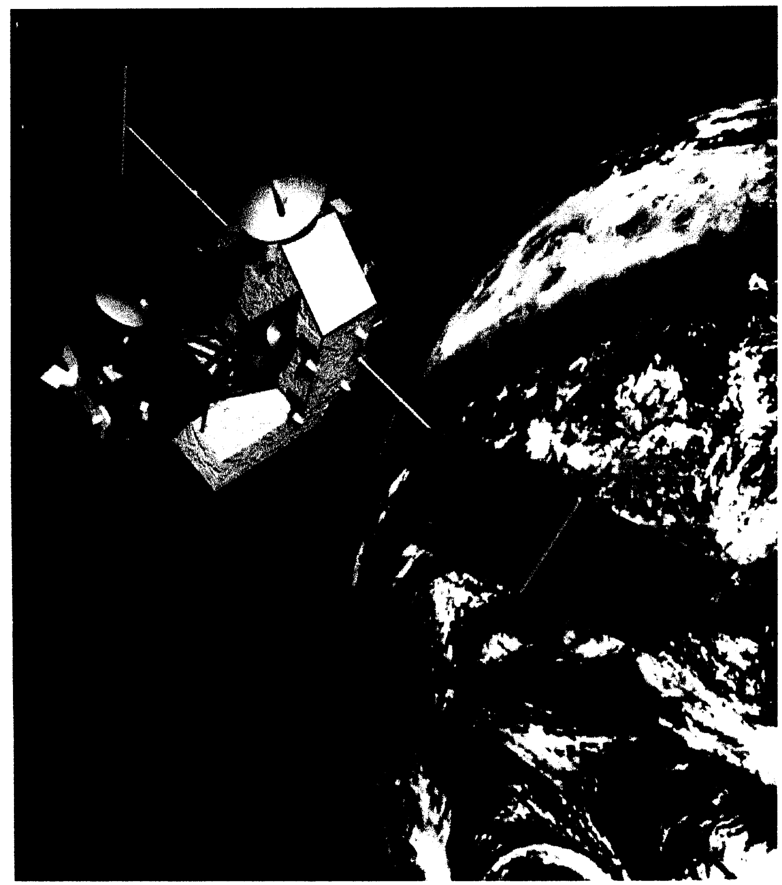
- Continue science in the event of any single onboard anomaly (e.g., h/w, control mode or system)
  - Warm restarts on SEU
  - Autonomous reconfiguration to redundant component (e.g., ST, RWA)
- Autonomously manage High Gain Antennas (HGAs) to TDRSS pointing for continuous ground communications *without ground planning* --
  - Select the HGA with the best pointing visibility to scheduled TDRS
  - Transition HGAs as TDRS visibility changes
  - Continue HGA pointing during every S/C maneuver
  - Don't lose any science data while transitioning



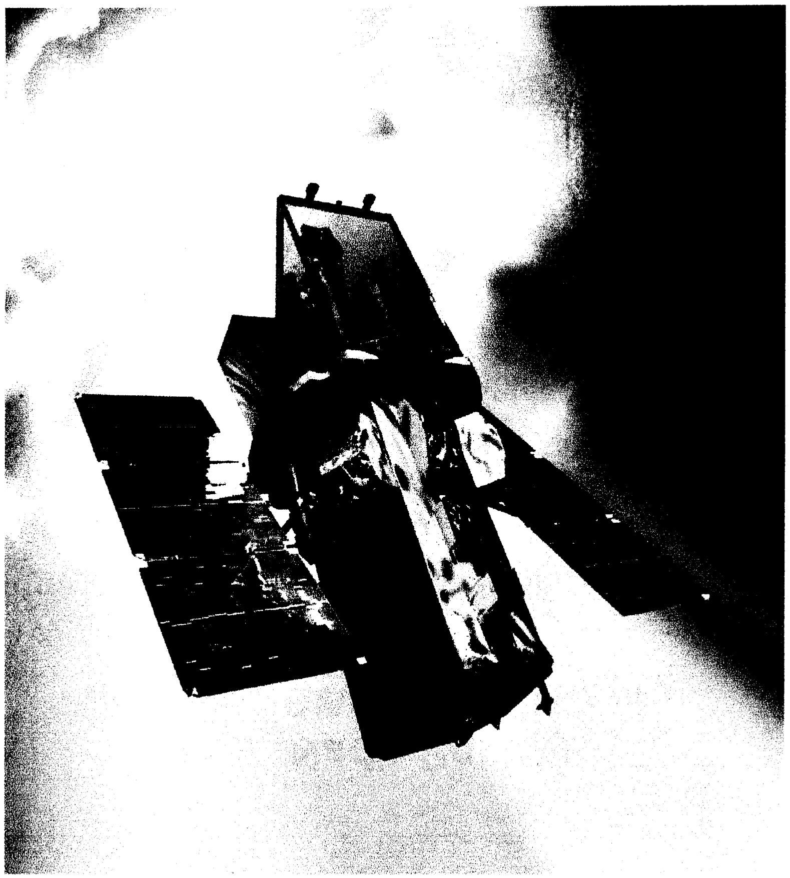
Tropical Rainfall Measuring Mission (TRMM) ('97)

LEO, Nadir Pointer
Mission FSW Requirements

- Autonomous ACS mode management to automatically transition back to mission mode
  - Table-driven design approach to configure ACS control mode monitoring and transition
  - Three primary control mode tables
    - Control mode action
    - Control mode transition validation
    - Control mode transition action
- Autonomous failure detection & correction (FDC)
  - Failure detection is distributed among ACS software subsystems
  - Failure correction is centralized in FDC Manager
  - Table-driven design to configure predefined failure detection logics and corrective actions



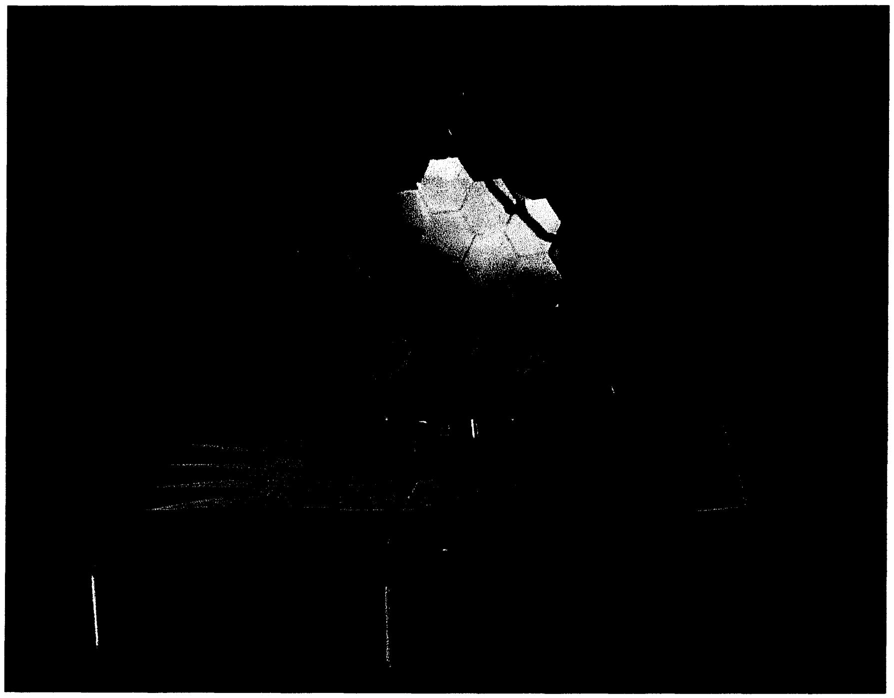
Swift ('04)



LEO, Stellar Pointer
<u>Mission FSW Reqm'ts</u>

- Execute pre-planned science observing program
- Detect & slew to Gamma Ray Bursts (GRBs)
  - Slew S/C to point to GRB (if merit is higher than pre-planned target)
  - Downlink GRB position to ground within 20 seconds
  - Observe GRB for a pre-defined time period
- Intercept pre-planned science observation program

James Webb Space Telescope ('13)

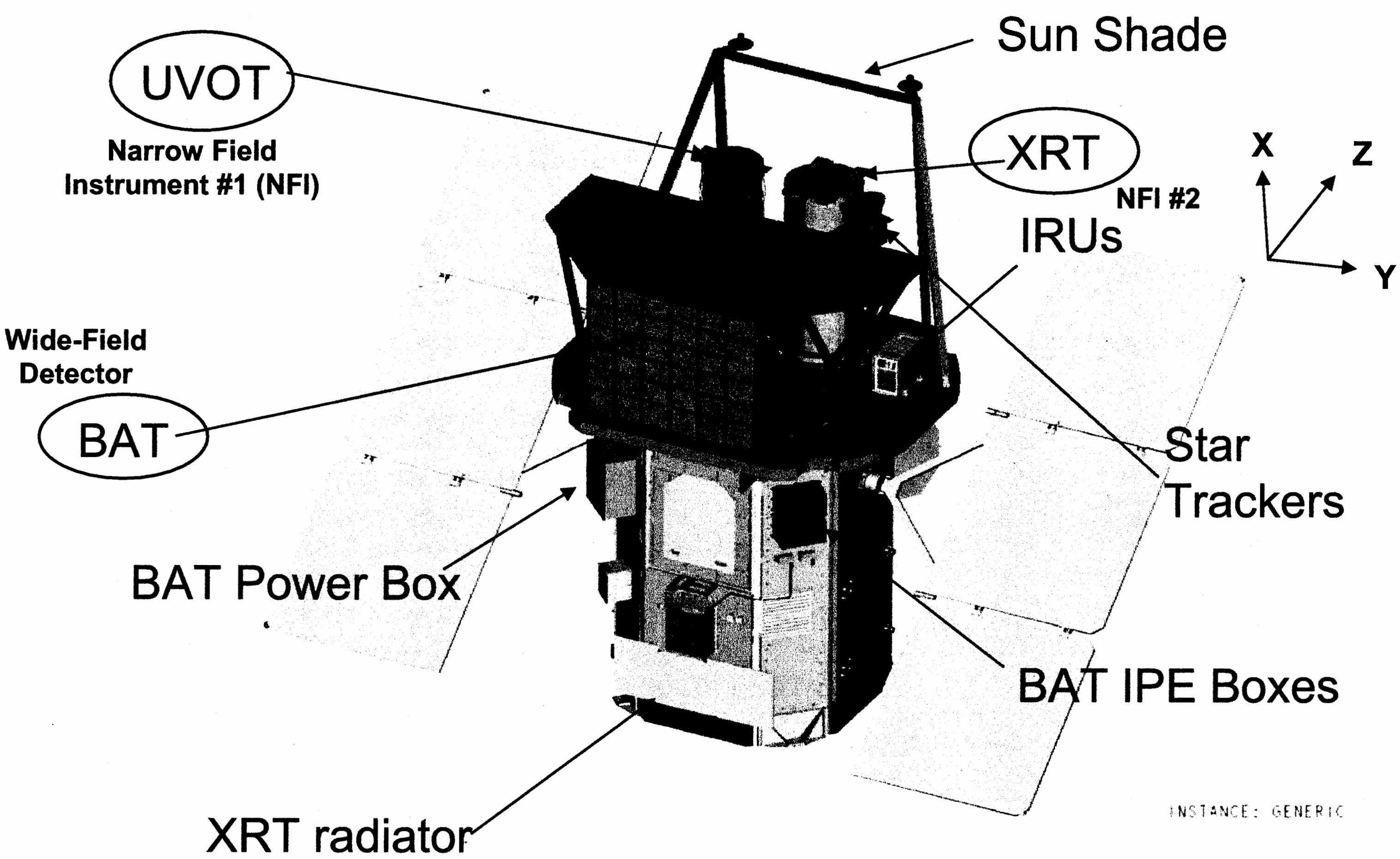


L2 Orbit, Stellar Pointer
Mission FSW Reqm'ts

- HST heritage autonomy PLUS
- Perform event-driven science observing programs
  - Execute 7day full featured science scripts - commands, logic, computations, event detection
    - High level observation program
  - Manage Onboard Instrument Activity Descriptions
    - Detailed instrument configuration/ observation activities
  - Skip Science Activities If Problems Occur
    - Reconfigure, intercept onboard science plan at a later point, continue science.

Onboard Autonomy For The Swift Mission

Observatory Overview



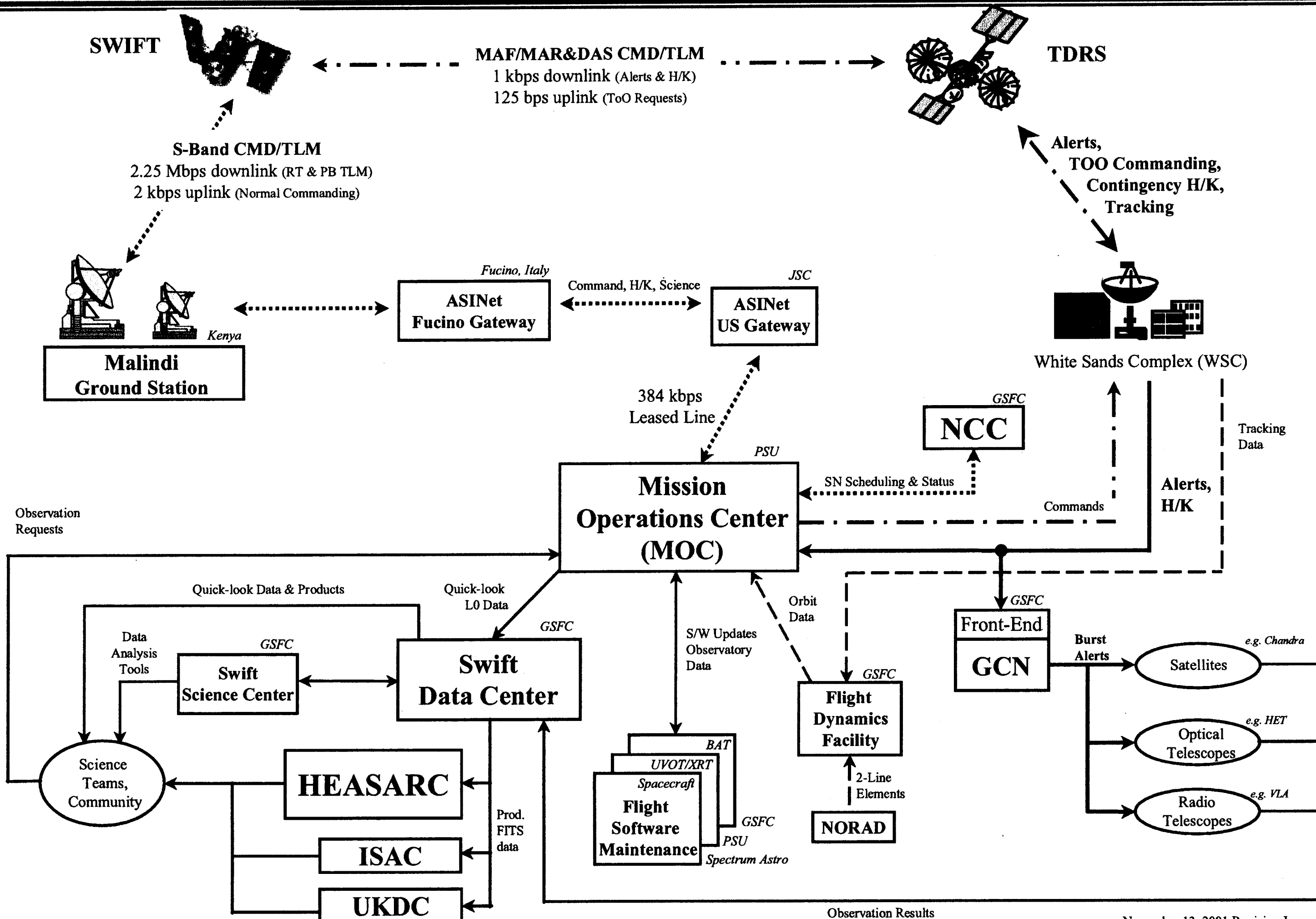
Swift Mission Unique Autonomy Drivers

(In Addition to Generic Onboard Autonomy Capabilities)

- **Science**
  - Autonomously Detect Gamma-Ray Bursts (GRBs)
    - Sophisticated BAT instrument software
  - Autonomously Chase GRBs by Slewing S/C to Center NFIs to GRB (w/o Ground Intervention)
    - Interface between S/C & instrument system
    - Fast Slews: 50° in <75 seconds
  - Observe GRB for extended period
    - Includes slewing S/C away from GRB & to pre-planned target when occulted by earth & slewing S/C back to GRB when no longer occulted
    - Ability to change onboard science observing sequence based on GRB characteristics
  - Quickly Distribute Newly Detected GRB Information To The Global Astronomy Science Community
    - Autonomously raise TDRSS Demand Access Service & forward GRB position & basic characteristics to ground within 20 seconds
    - Messages Relayed to GRB Coordinates Network (GCN) For Distribution to the Science Community in Near Real-Time
    - Link Also Used For "911" Emergency Messaging to Operations Team in the Mission Operations Center (MOC)
  - Perform Hard-X-Ray Survey
    - Pre-planned scheduled/time-based observation plan
- **Operations**
  - Supporting "Dynamic", Autonomously Slewing S/C With An 8x5 Ops Staff

Swift System Architecture

(Architecture Required to Support Mission Autonomy)

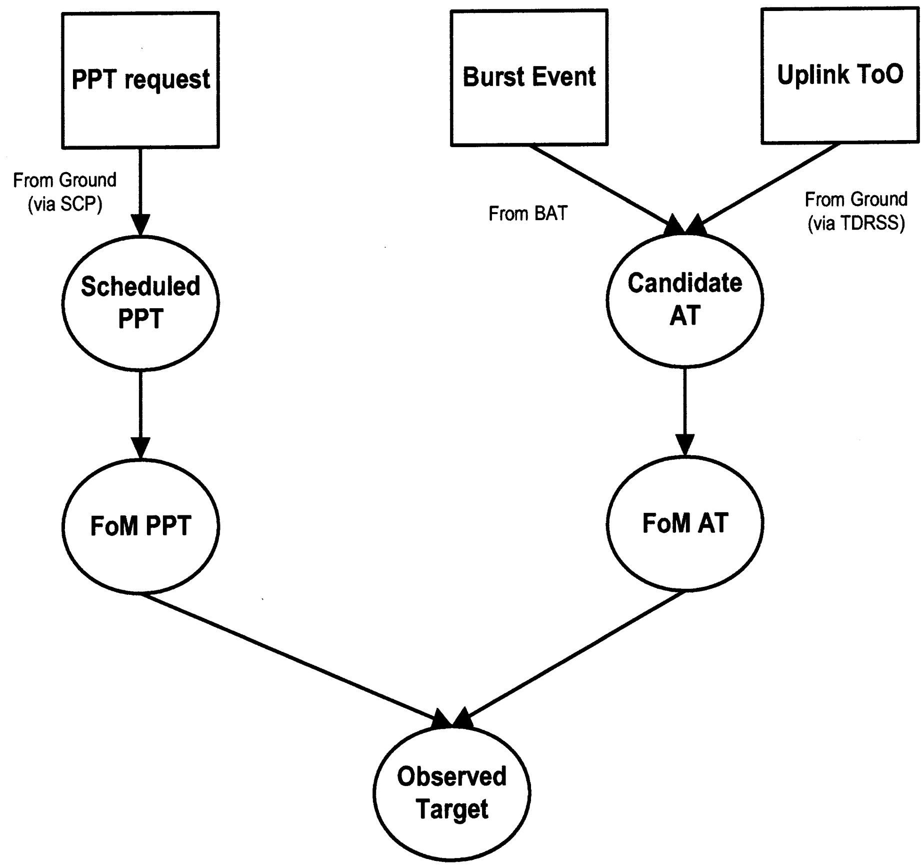


Day In the Life of Swift

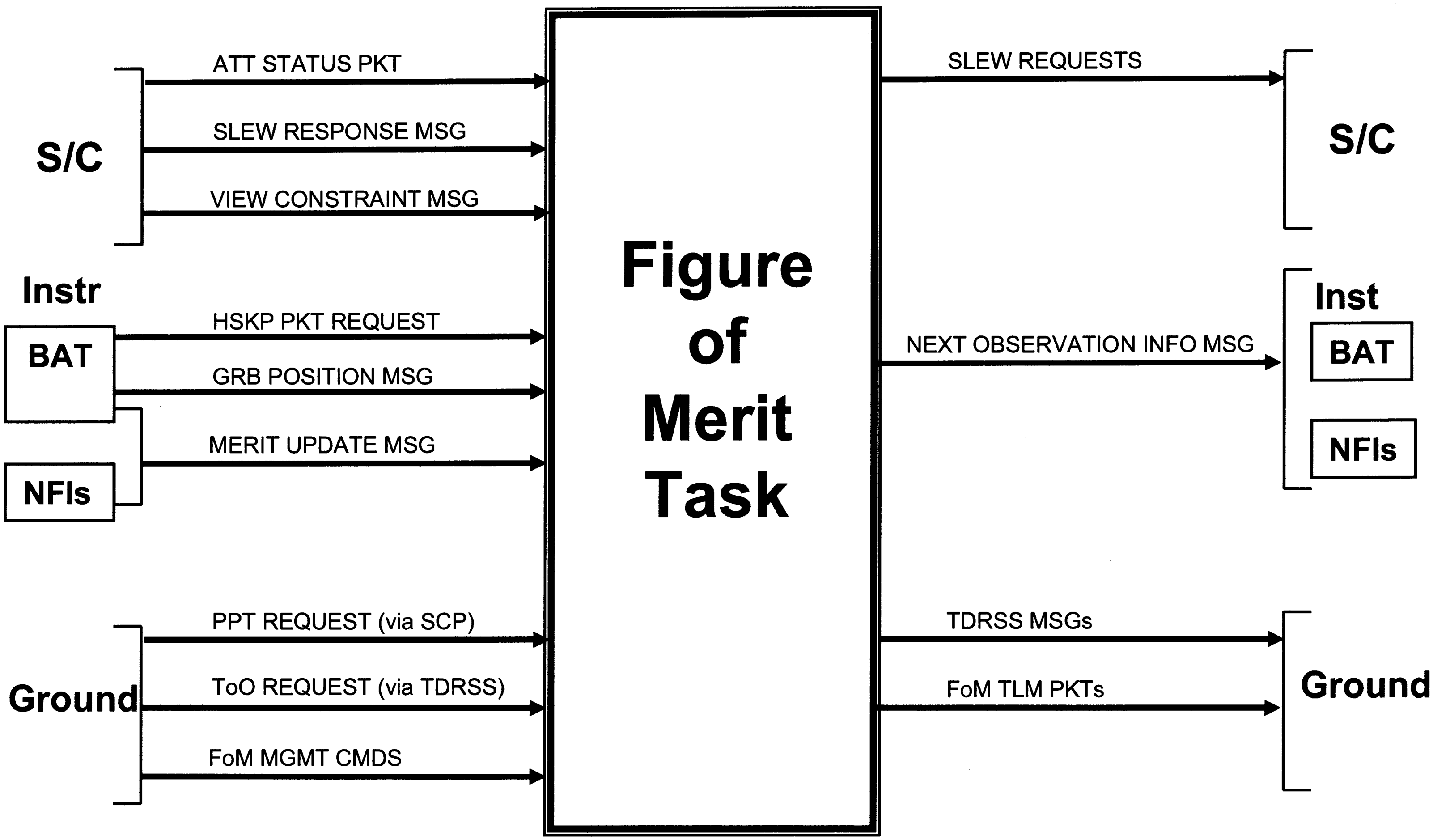
- **Swift following pre-loaded schedule**
  - 72 hours of pre-planned targets (PPTs) performing hard x-ray survey or follow-up of recently detected GRB
- **Burst Alert Telescope (BAT) wide-field detector detects GRB**
  - BAT alerts FoM FSW with associated merit value
  - (Typically,) GRB merit value higher than pre-planned target, so FoM request S/C to slew observatory to GRB
  - BAT begins observing GRB
    - Executes script based on initial GRB characteristics
    - Scripts are reconfigurable (uploadable) & highly flexible
  - BAT generates GRB alert message with GRB location/characteristic
- **S/C (if deemed safe) slews to requested GRB location**
  - Fast slew mode for GRBs to get on-targets ASAP (50° in <75 seconds)
  - S/C raises TDRSS Demand Access service & downlinks GRB alert message to GRB Coordinates Network within 20s
  - Once on-target, NFI performs science observation (based on GRB characteristics)
- **FoM manages GRB observation**
  - FoM monitor S/C ancillary data for when GRB will be occulted
  - Just prior to GRB being occulted, FoM requests S/C to slew to PPT
  - FoM requests S/C to slew back to GRB as soon as it is no longer occulted
  - FoM manages time on target & terminates GRB observation when time complete

FoM FSW Target Observation Flow

- The unique capability which distinguishes Swift from all other astrophysics missions is the requirement to slew the spacecraft to acquire the newly discovered GRBs within the field of view of the Narrow-Field Instruments
- The scientific premium on rapid acquisition is so high as to preclude ground control of the slew request, so the Swift spacecraft must include an onboard decision process to enable an entirely automated response to unplanned slew requests (hence, the Figure of Merit FSW)



FoM FSW Functional Interfaces



Summary / Conclusions

- **Swift's autonomy requirements drove system architecture**
  - Required project system engineering design early on
  - Drove overall operations concept
- **Extensive verification program**
  - High fidelity S/C simulator required
  - Extensive "day-in-the-life" & "what if's" simulations (which became core of observatory's Comprehensive Performance Test)
  - FSW systems designed to support quick determination of as-flown timeline (i.e., what actually happened) & for on-board trouble-shooting
- **Swift Represents A New Class of Missions Requiring Autonomous S/C Repointing Without Ground Intervention & Programmable Responses**
  - Not possible for FOT to be in the loop for authorizing "chasing' of GRB
  - Onboard FoM FSW, separate from S/C, manages S/C slews for GRB observations (reassess/replan)
  - Onboard Script Controller/Executors provides powerful/programmable response based on findings in-orbit