Magnetospheric MultiScale (MSS) System Manager

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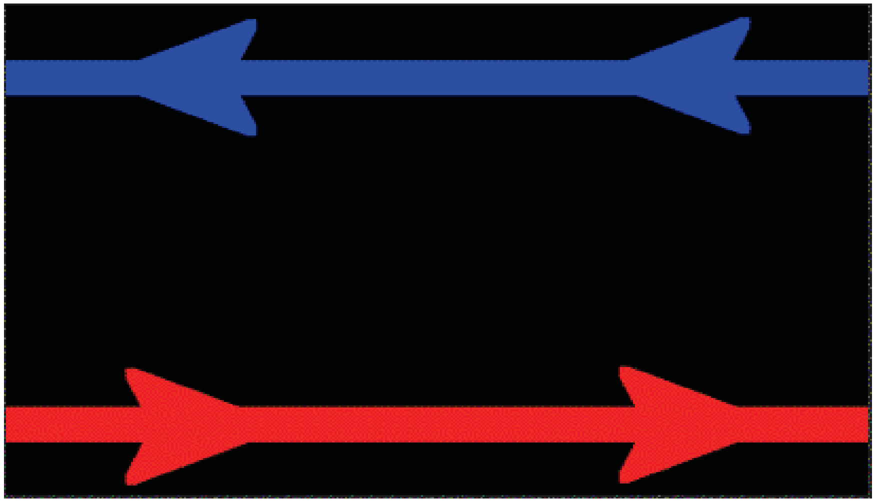
THE MISSION

Science of Magnetic Reconnection

- Study magnetic reconnection in the Earth's magnetosphere
- Magnetic reconnection converts magnetic energy into kinetic energy
  - Oppositely directed parallel field lines are pinched
  - They join and snap apart like a breaking rubber band

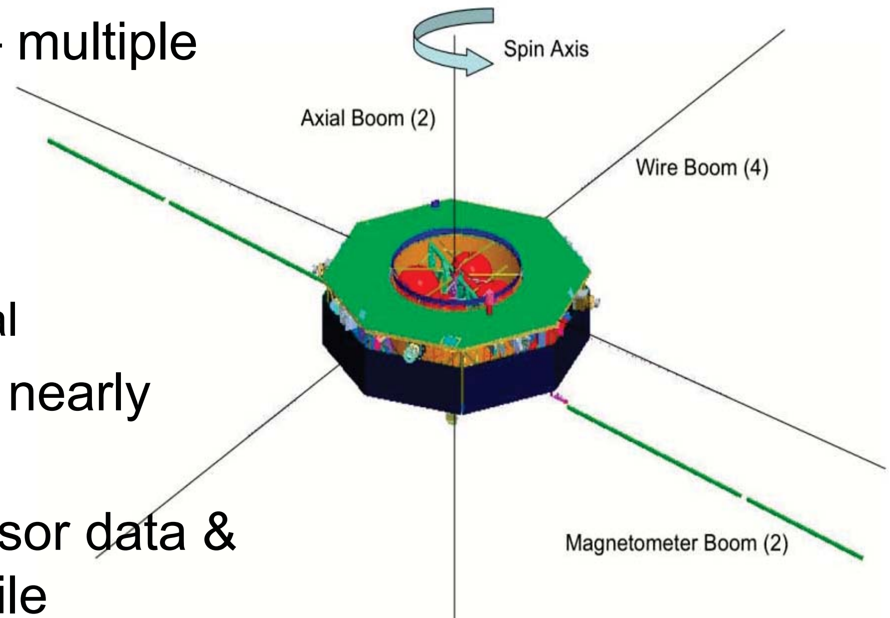


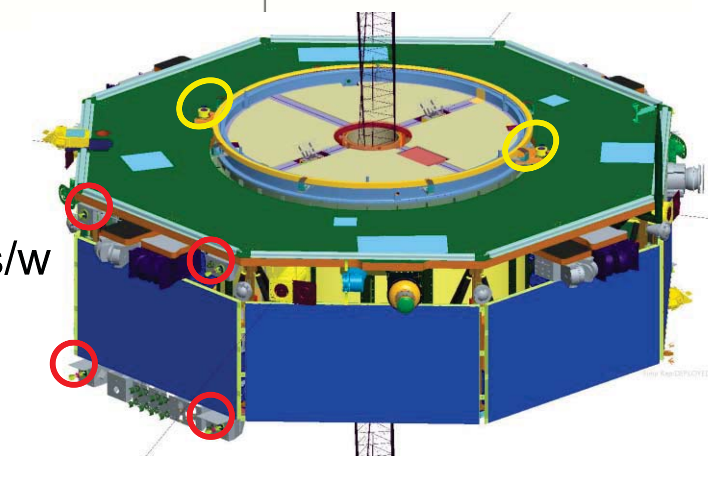
Credit: European Space Agency

- Benefit: understanding of how the Earth lives with the Sun (e.g. Class X Flash 0156 GMT Tuesday, Feb. 15, 2011)
  - Power grid problems
  - Communications disruption
  - Aurora formation

Spacecraft Description

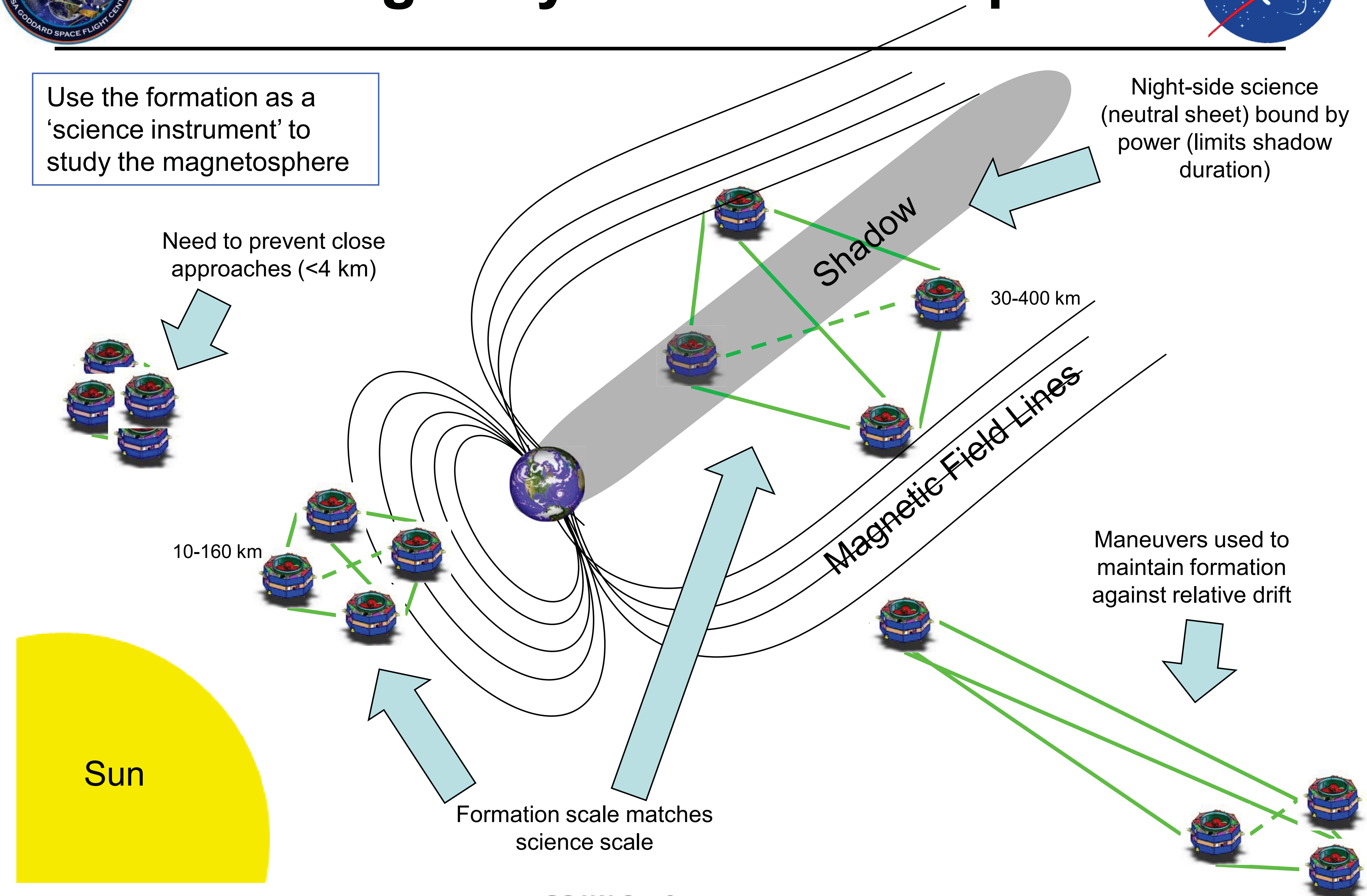
- The 4 MMS Spacecraft are
  - Equipped with the standard 'particles and fields' instrument suit (7 types of instruments – multiple copies per spacecraft)
  - Equipped with 8 science booms
    - 2 Axial (E-field)
    - 4 Wire (E-field) & 2 Magnetometer Radial
  - Spin-stabilized at 3.0 rpm with spin-axis nearly parallel to ecliptic north
  - Onboard controllers process GN&C sensor data & fire thrusters to achieve accurate ΔV while keeping the booms safe
    - Digital Sun Sensor & Star Camera
    - Accelerometer
    - Navigator GPS receiver with GEONS navigation s/w
  - Equipped with 12 thrusters
    - 4 Axial 1-lbf (yellow)
    - 8 Radial 4-lbf (red)





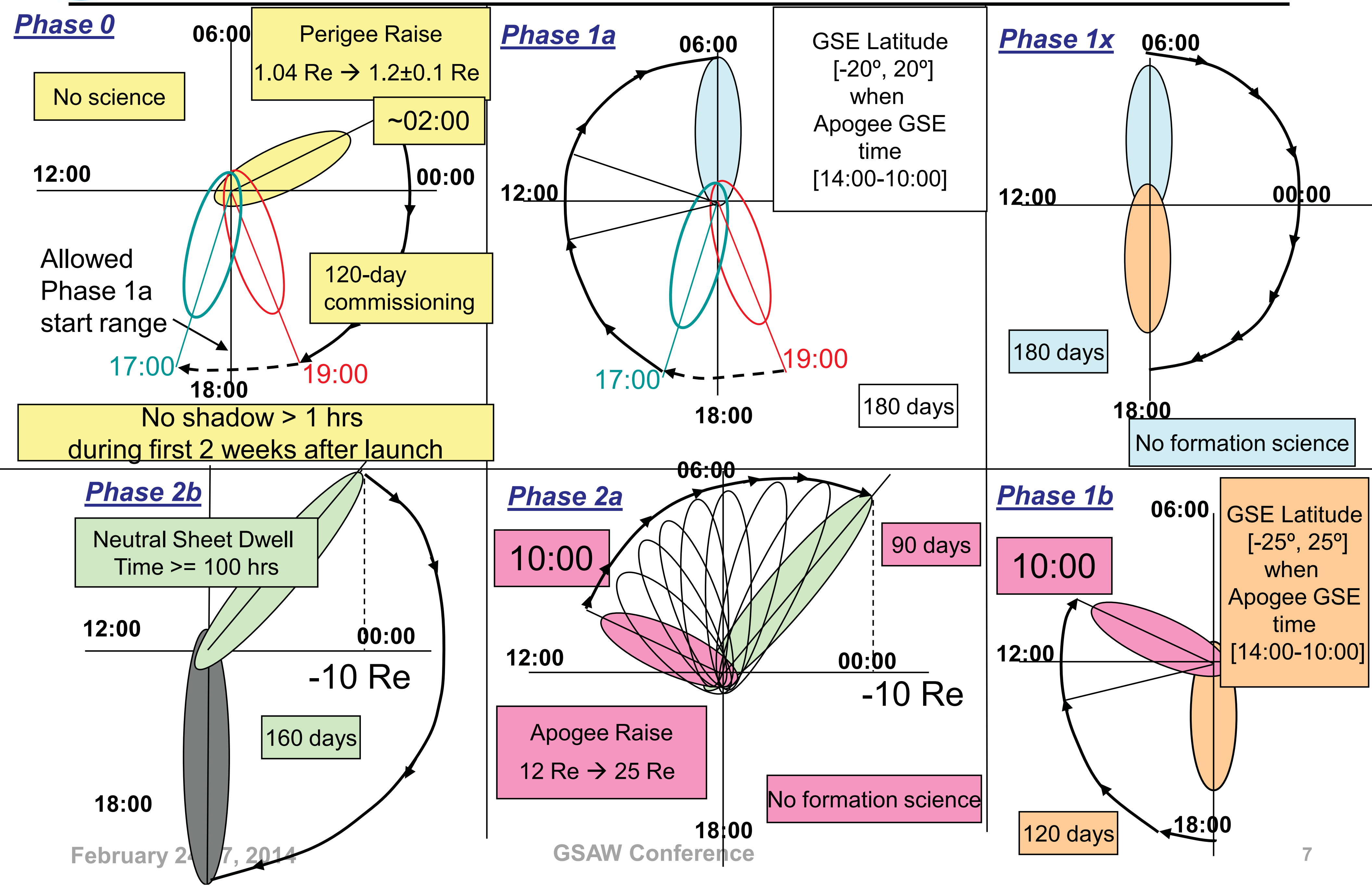
Flight Dynamics Concept

Use the formation as a 'science instrument' to study the magnetosphere

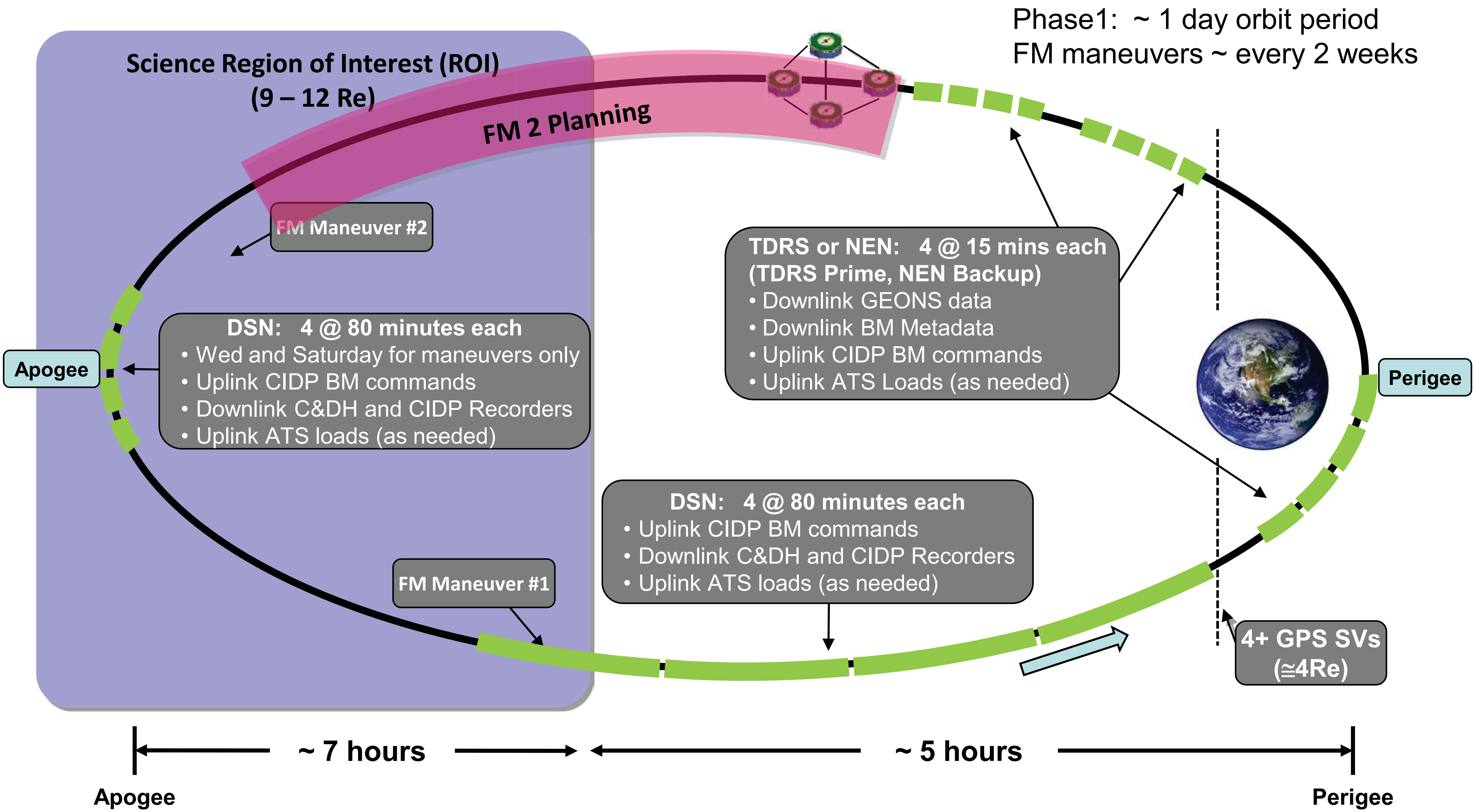


MMS Mission Summary

(approximately 2.5 years in duration)



Phase-1 Orbit in the Life
with Formation Maintenance Maneuvers

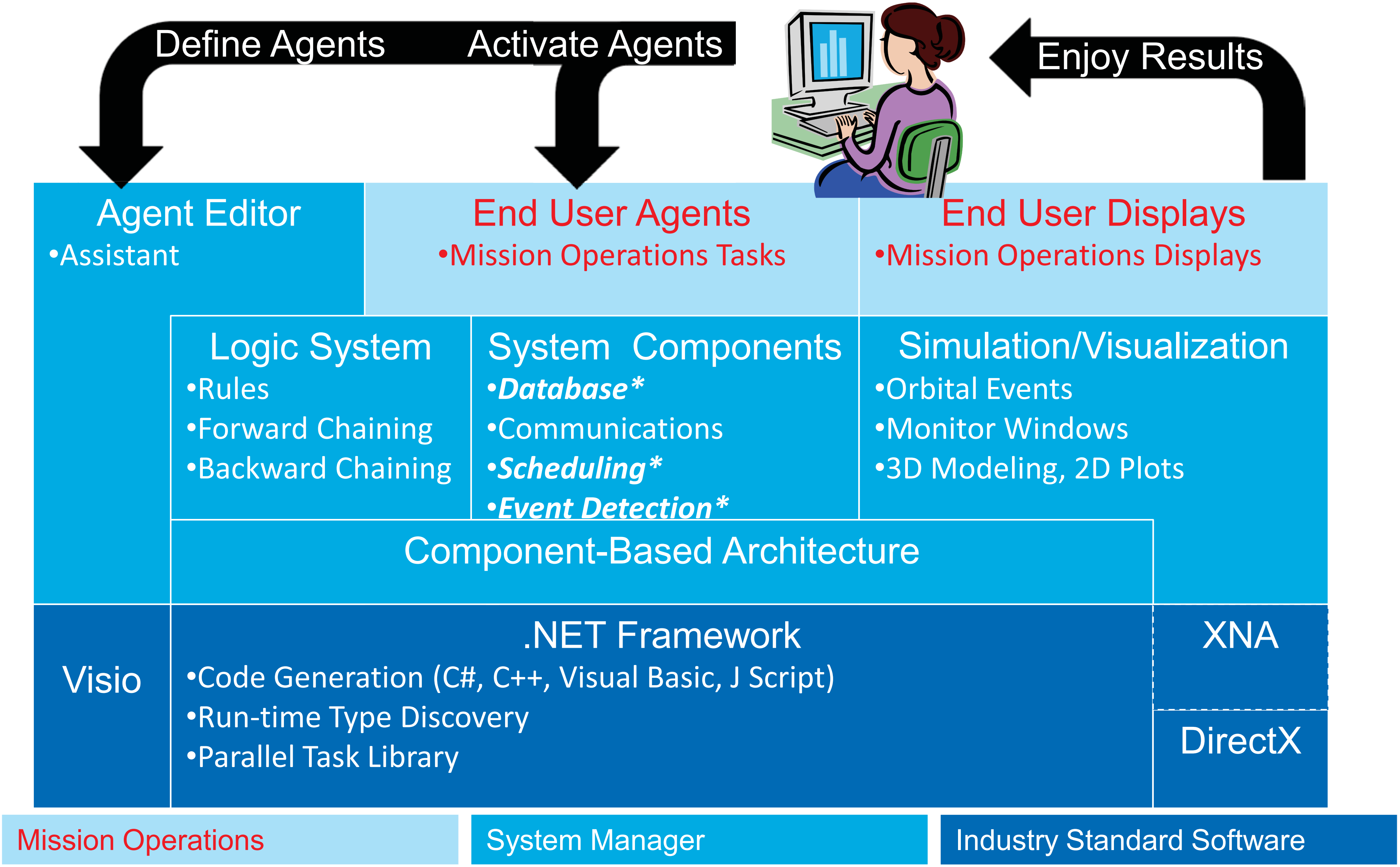


SYSTEM MANAGER

Why Automate? And How To?

- **Automation needed handling the complexity**
  - Large number of interactions
  - Goal to reduce human error and operations cost
  - Want dependable agent – must act like an ‘ideal operator’ that is never sick, always on time, able to handle multiple processes once taught
  - Want smart agent – must adapt to changing situations and know when to ask for help
- **System Manager Automation framework using agents**
  - ***User-defined Agents*** – core automation objects that respond to events or defined schedules by triggering forward-chain or backward-chain processes.
  - ***Process Control*** – collaborative set of agents that achieve objectives based on the state of the process flow via user-defined rules.
  - ***Adaptive Scheduling*** – existing schedules are altered based on incoming events
  - ***Operations Planning/Automated Recovery*** – target operational state is used to plan a proper course of action via backward-chaining (inferring the cause that gives a desired effect)

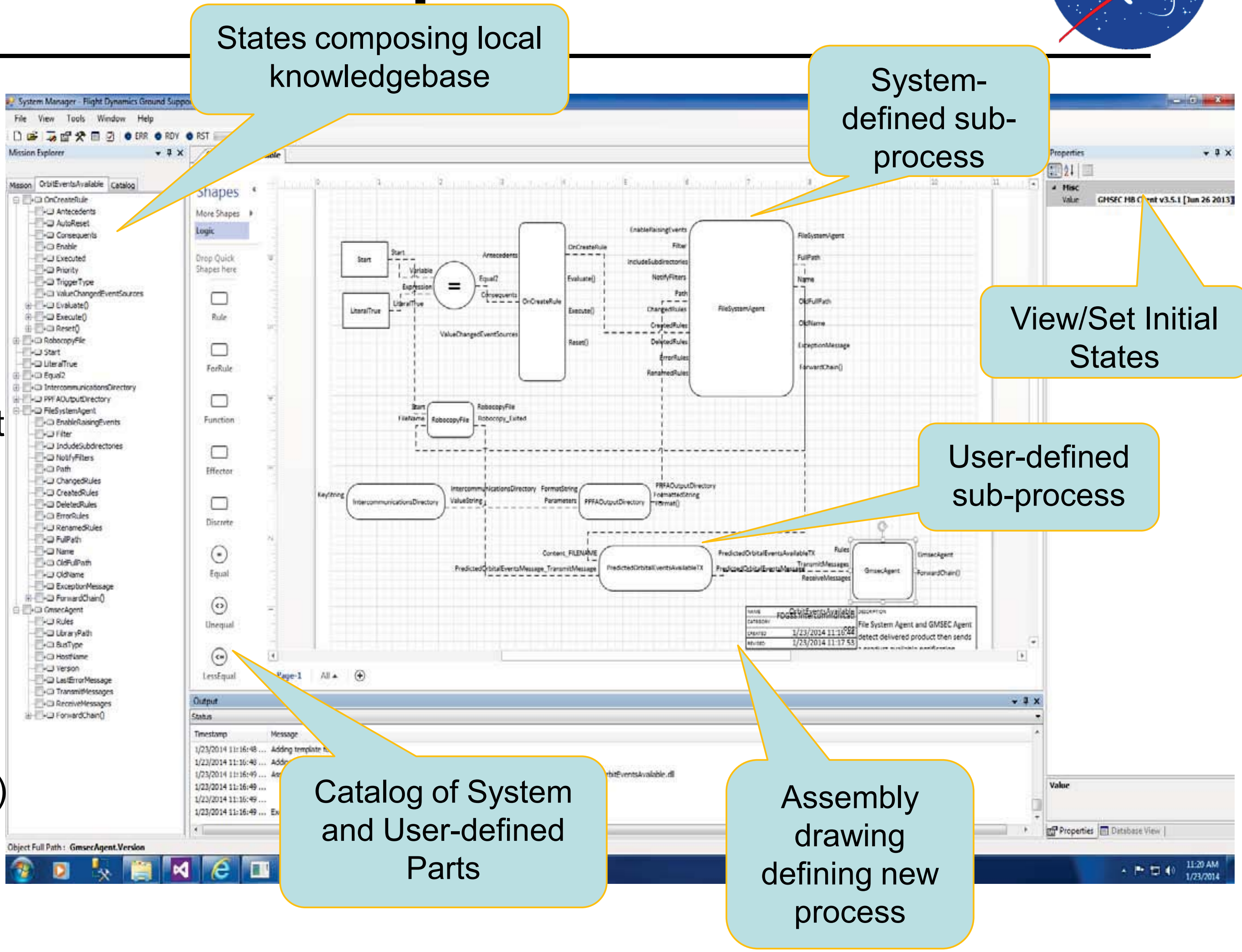
System Manager – Component Based Architecture



* - components discussed below

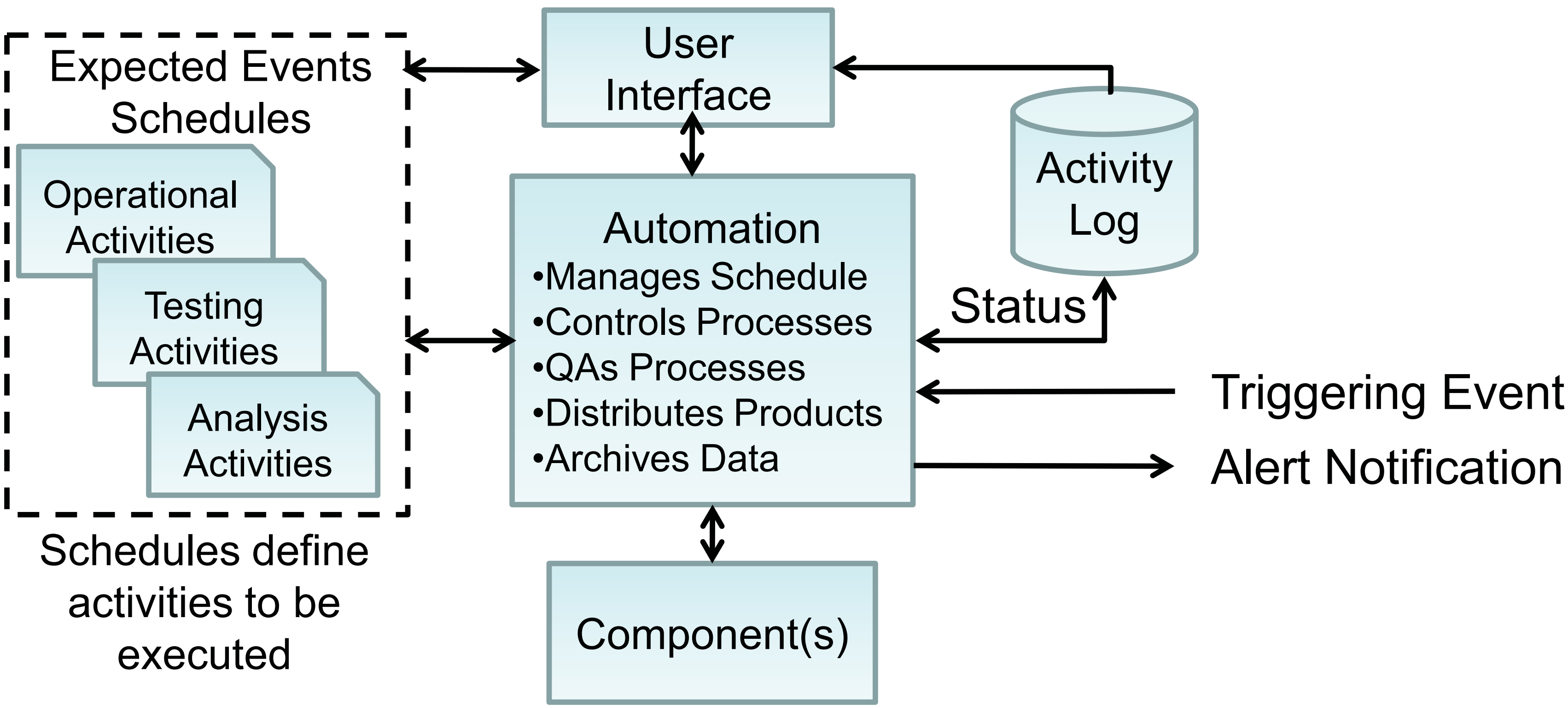
Process Representation

- *Microsoft Visio* is used to represent processes via assembly drawings.
- Shapes represent system- and user-defined sub-processes, called parts.
- Connectors specify the data and control (logic) linkages between parts.



Scheduling Concepts: Processes, Activities, & Events

- Response Schedule is a list of ***expected activities*** to be performed, using defined processes, as a response to an event
- Response Schedule is ***dynamic*** – based on external special requests (i.e. from MOC) and automated response to events, user/agents can add or remove activities
- Automation uses the schedule in two ways:
  1. Perform activities currently on schedule (schedule-driven)
  2. Add an activity to the schedule as a response to a detected event (event-driven)



Database

- Database functionality using the Entity Framework forms the backbone for the automation

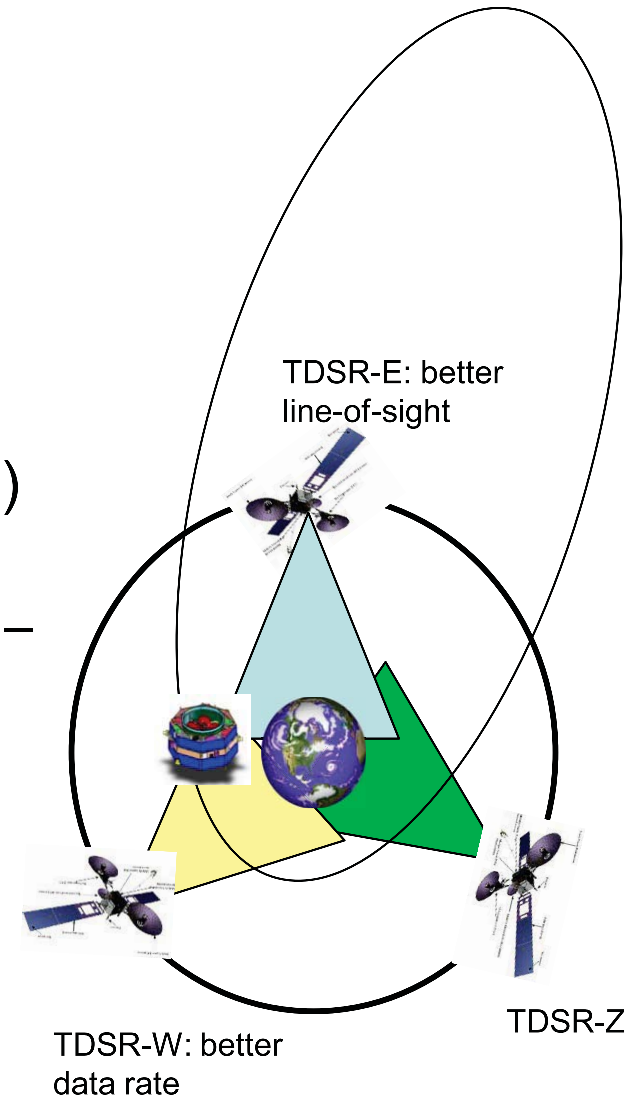
- Serves as the intermediary for inter-process communications
  - Used as media to transfer data between processes.

- Enables data mining and querying
  - User queries using transformations and operators defined by entities.
  - Metadata-based model allows for queries specifying multiple physical, dimensions, engineering units, coordinates systems, etc.
  - ‘Snapshot’ functionality allows for GUI data monitors and visualization to show internal state of process being executed
    - User entry point for debugging
    - Automated fault detection and (where possible) correction

CONTACT ANALYSIS IMPLEMENTATION

Contact Analysis: Problem Definition

- Contact between the MMS spacecraft and the TDRS fleet is needed every perigee (see slide 7)
  - Important for science retrieval
  - Critical for formation maneuvers
- Motion model (line-of-sight & distance vs. time)
  - TDRS in correct geostationary boxes
  - MMS following its elliptical trajectory
- Antenna model (gain pattern & field-of-view (FOV))
  - TDRS-E/W S-band Single Access (SSA) antennas with 4 FOVs (simple, primary, elliptical extended x2 – ordered approximately from most to least available)
  - TDRS-Z SSA with simple FOV
  - MMS has upper & lower deck s-band omni ('garden weasel') antennas
- Objective
  - Find the simplest operational scenario (number of handoffs) that maximizes data rate (link margin)



Contact Analysis: System Manager Approach

- System Manager generated a set of predicted events
  - Logical yes/no for link between MMS and TDRS at a given data-rate (typical operations approach)
  - Constraint transitions (yes-to-no or no-to-yes) placed in a decision tree (not so-typical in operations)
    - Decision tree hierarchy based on the importance of mission rules/constraints (e.g. occultation has higher precedence than FOV)

- System Manager used an A* search algorithm to generate the optimal contact schedule
  - A* search works by finding the ‘shortest path’ across a ‘set of nodes’
  - The decision tree provides the nodes based on the constraint transitions
  - Link margin, antenna availability, data rates, etc. automatically built-in

Contact Analysis: Results

- System Manager analyzed a typical 2.5-year mission scenario
  - Able to find the best schedule (smallest number of hand-offs for the maximum date rate)
  - Statistically characterized the mission probability of successful contacts – e.g. 87% percent meet requirements, remaining 13% needs a workaround
  - Results consistent with official results from Space Network Loading and Modeling
- Performance
  - Analysis took several seconds on a typical Windows-based workstation
  - Results successfully vetted against hand-computations of all permutations (days of work)
- Operational benefit
  - Provides a robust way to find optimal results for given mission scenario
  - Gives a sense of how often MMS will have to work around network constraints
  - Makes a rapid response possible should base assumptions change