



Magnetospheric MultiScale (MMS) System Manager

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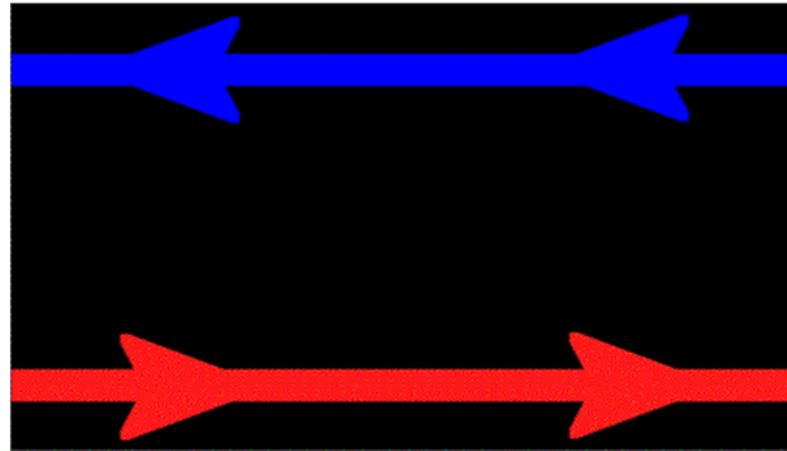
THE MISSION



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

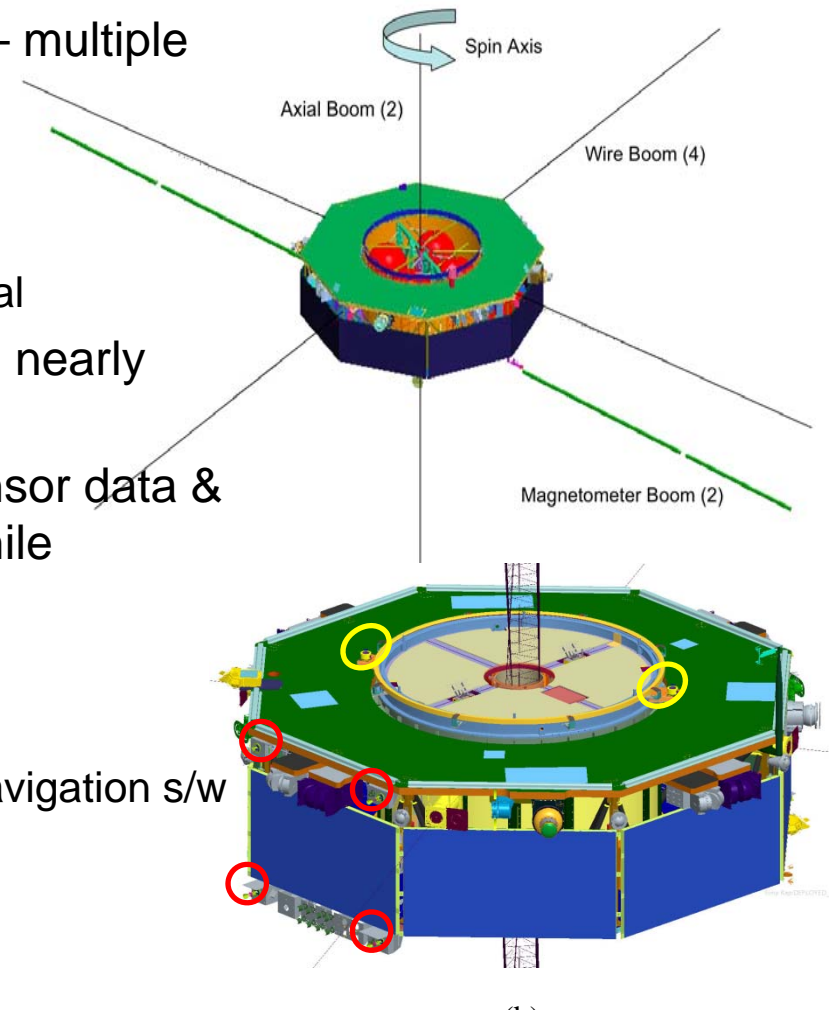
- Benefit: understanding of how the Earth lives with the Sun (e.g. Class X Flash 0156 GMT Tuesday, Feb. 15, 2011)
 - Power grid problems
 - Communications disruption
 - Aurora formation



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)





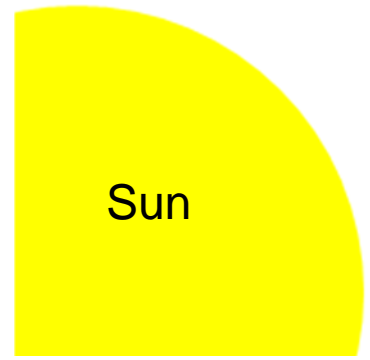
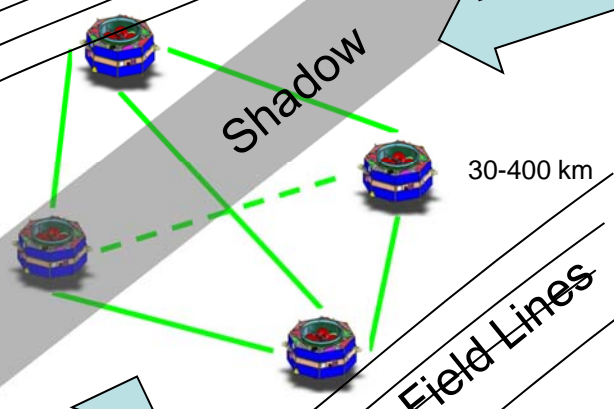
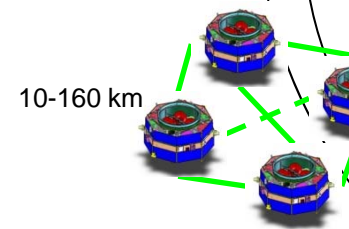
Flight Dynamics Concept



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

Night-side science (neutral sheet) bound by power (limits shadow duration)

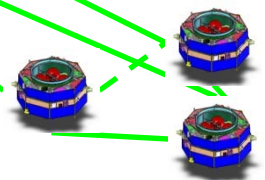
Need to prevent close approaches (<4 km)



Sun

Formation scale matches science scale

Maneuvers used to maintain formation against relative drift



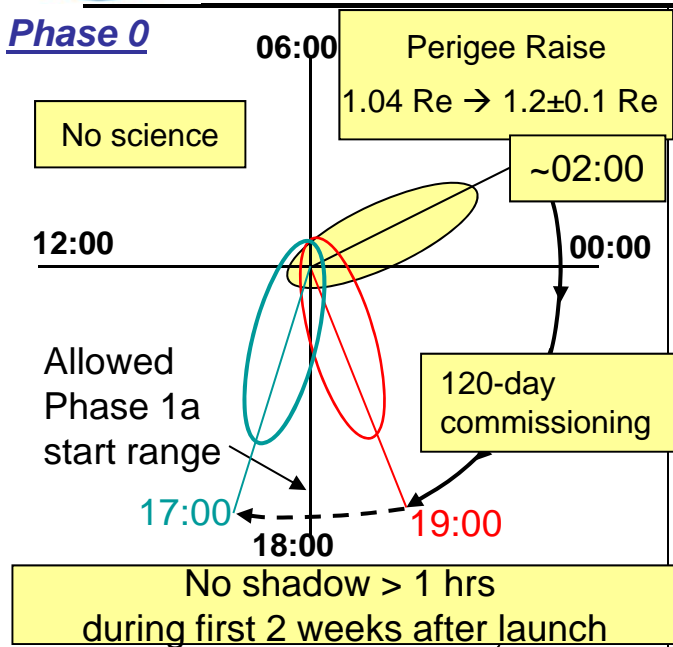


MMS Mission Summary

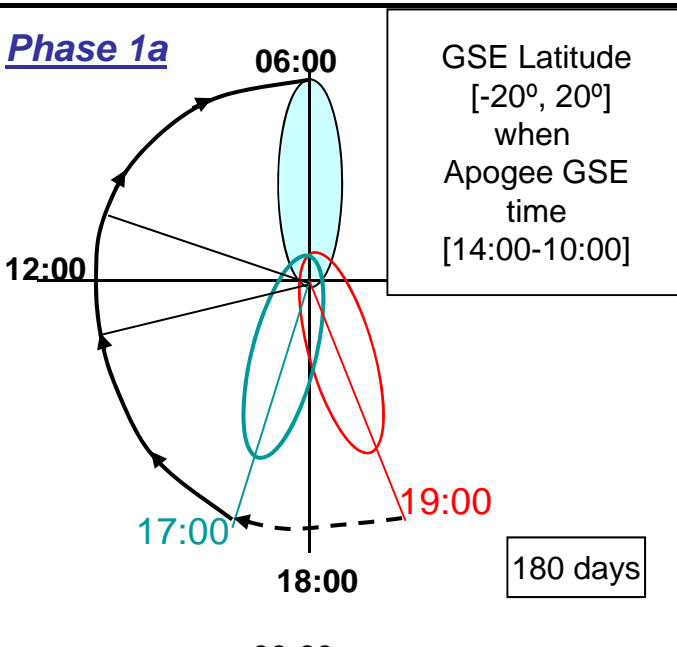
(approximately 2.5 years in duration)



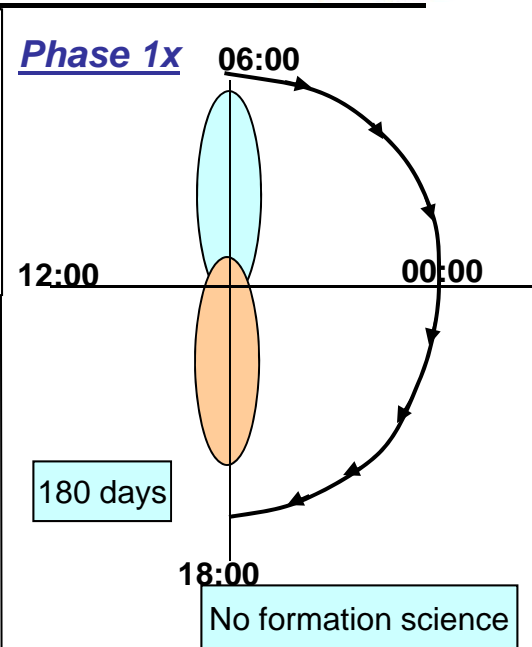
Phase 0



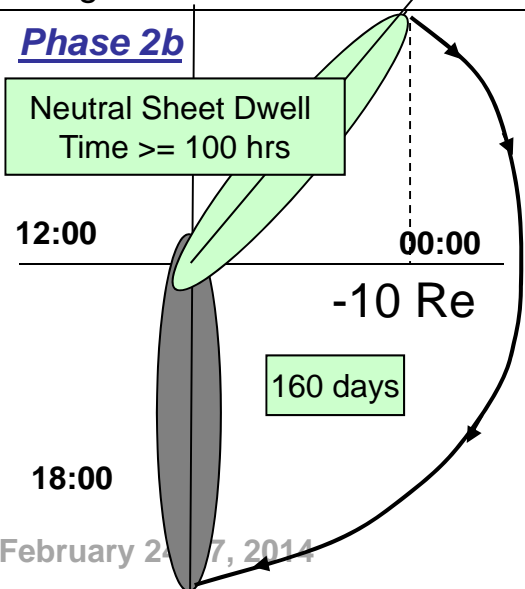
Phase 1a



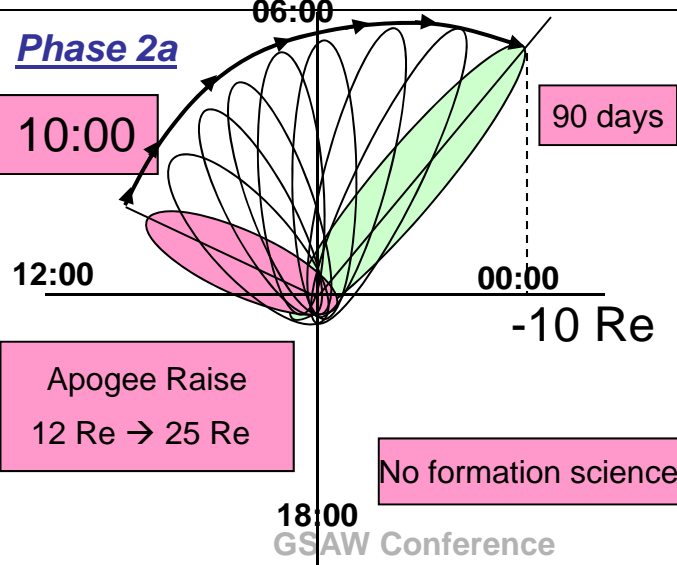
Phase 1x



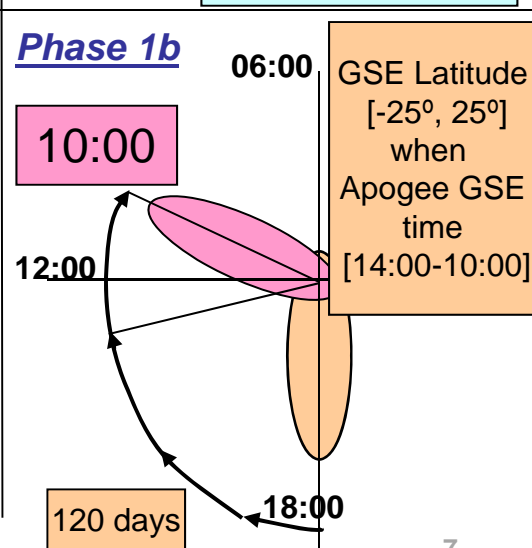
Phase 2b



Phase 2a

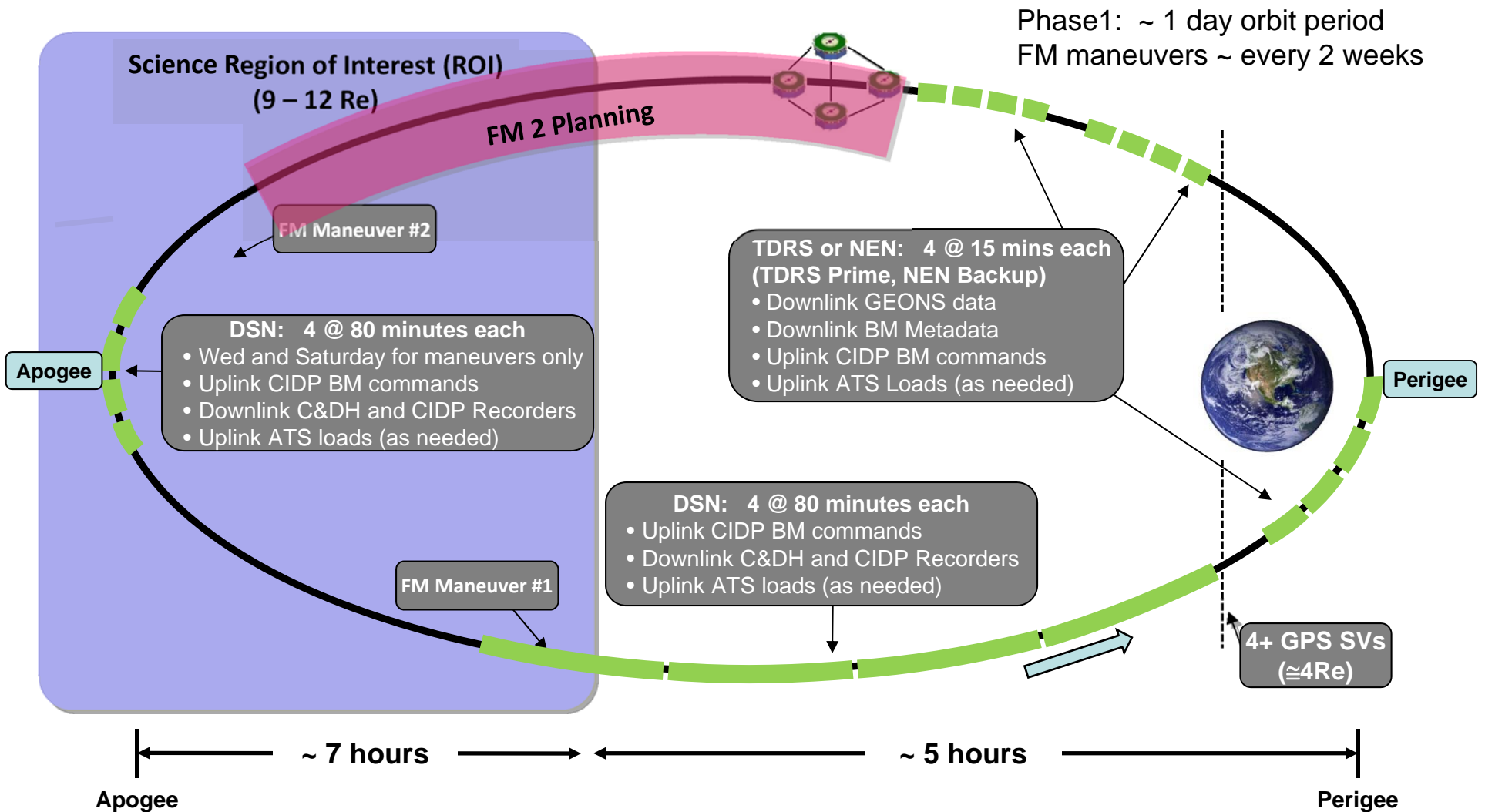


Phase 1b





Phase-1 Orbit in the Life with Formation Maintenance Maneuvers





SYSTEM MANAGER



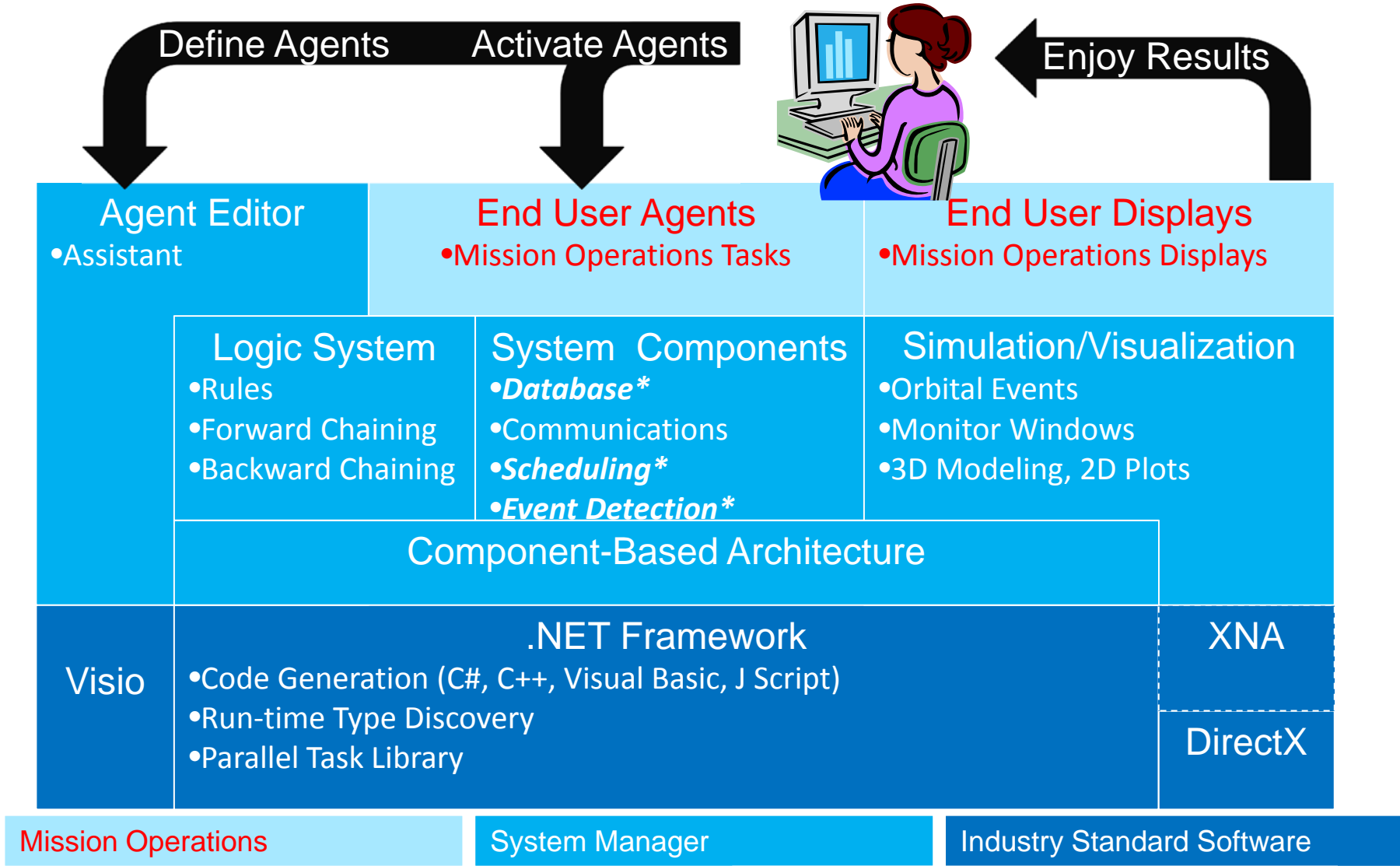
Why Automate? And How To?



- **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**
 - **Agent** - a computer program that acts for a user or other program
 - **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

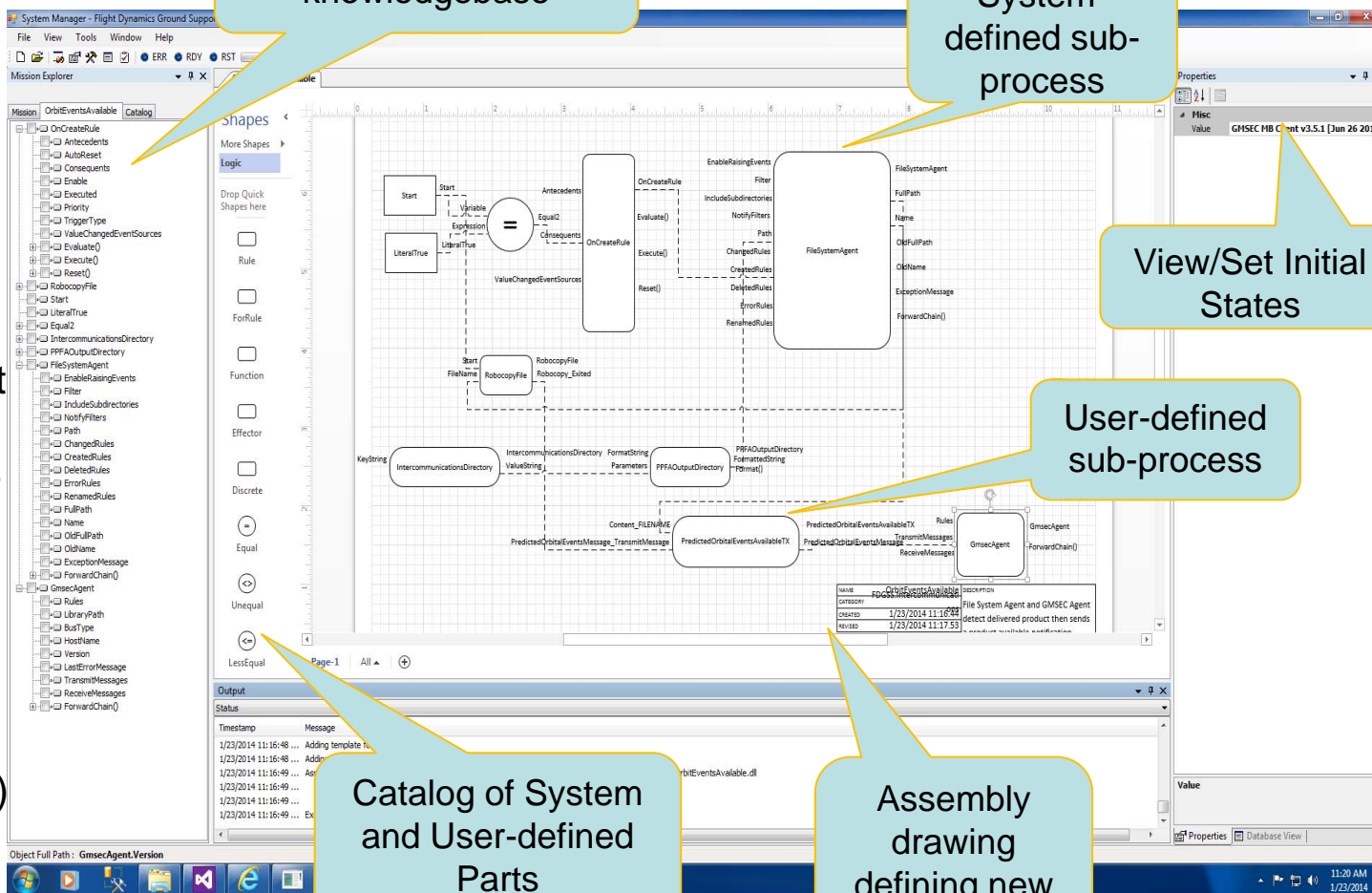


* - components discussed in following slides



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.

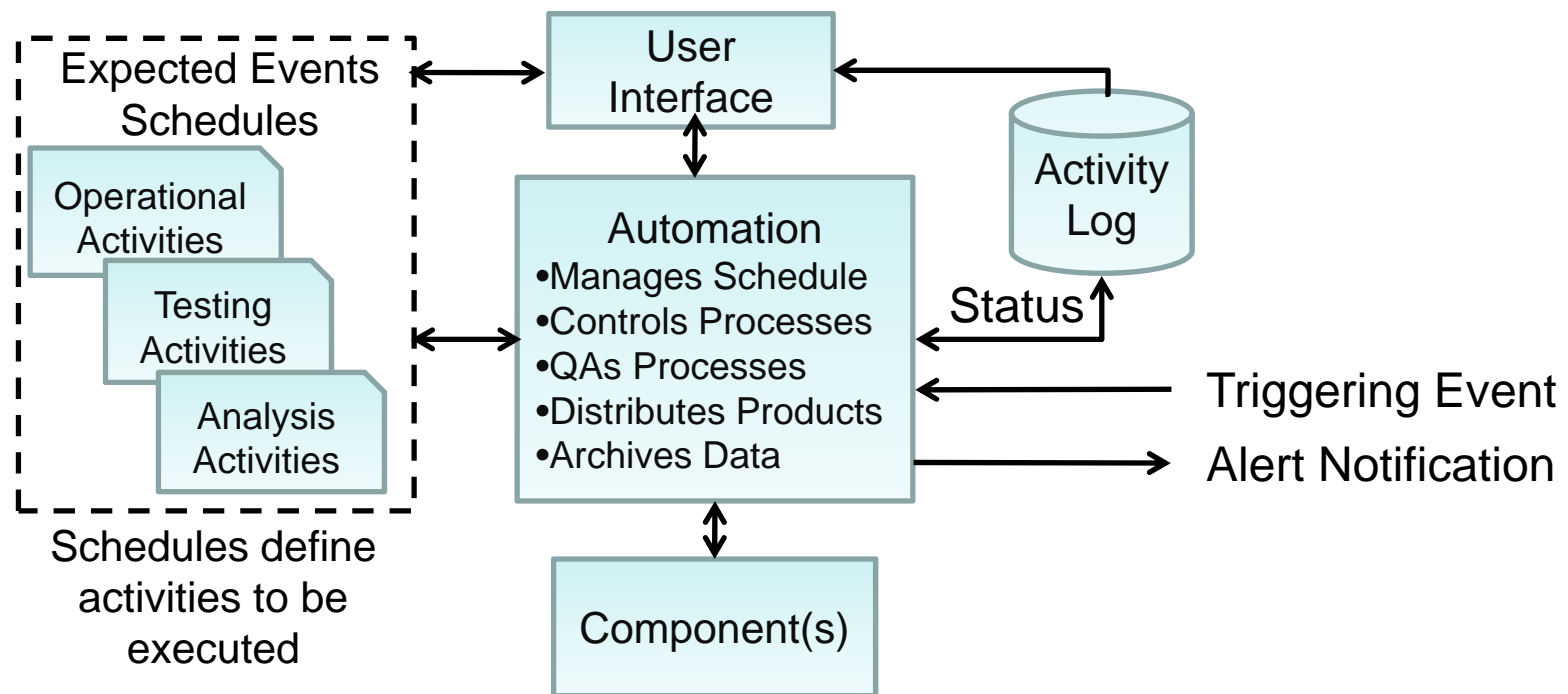




Scheduling Concepts: Processes, Activities, & Events



- 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



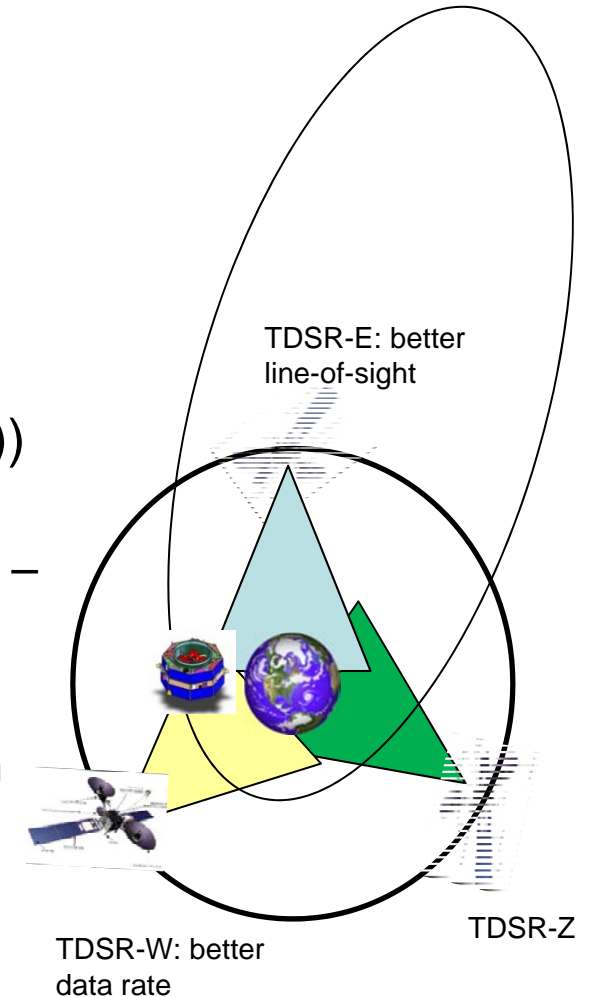
CONTACT ANALYSIS IMPLEMENTATION



Contact Analysis: Problem Definition



- Contact between the MMS spacecraft and the TDRS fleet is needed every perigee (see slide 8)
 - 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 data 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



CONCLUSION



Conclusion

- System Manager provides the degree of flexibility and autonomy needed for the MMS mission
 - System Manager running MMS software tools directly by following a local operating procedure (local process)
 - System Manager running System Manager (meta process)
- Different instantiations of the System Manager currently are running
 - Ground processing of the onboard orbit determination solutions and generation of associated products
 - Generation and delivery of contact analysis products
 - Requests for attitude telemetry data and delivery of resulting products
- Final operational release in May of 2014 will feature meta-processing that support (including up to 72-hours of 'lights-out')
 - All of routine operations (approximately 95% of the time)
 - Maneuver operations (remaining 5%)