Earth Science Technology Office (ESTO) New Observing Strategies (NOS) and NOS-Testbed (NOS-T)

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Advanced Information Systems Technology (AIST) Program

ESTO/AIST Objectives

- **AIST**
  - Advanced Information Systems Technology Program
  - Part of the Earth Science Technology Office (ESTO) in NASA Science Mission Directorate (SMD)

- **AIST Goals**
  - Reduce the risk, cost, size, and development time of Earth Science Division (ESD) space-based and ground-based information systems;
  - Increase the accessibility and utility of science data; and
  - Enable new observation measurements and information products.

FY18 Primary Technology Thrusts

- New Observing Strategy
  - Constellations of sensors from different vantage points
  - Designing a complete architecture to create a unified picture of a phenomenon
    - Forecast models as a measure of quality of understanding
    - Non-NASA sources of data or relevant services
- Analytic Center Framework to determine needs for tool integration
  - Focus on supporting Science Investigations
    - Allow maximum discretion on part of Science PI in using data and tools
    - Reduce the repetitive work in data access and
  - What tools are needed and how to accelerate development through AIST18
- Related Science support questions
  - How do we make an objective and quantitative comparison of multi-dimensional data
  - How do we measure science value?

NOS Testbed Goals

- Technologies to be deployed should be first integrated into a working ***breadboard*** where the components can be debugged and performance and behavior characterized and tuned-up.
- A system of this complexity should not be expected to work without full integration and experimental characterization

Testbed Main Goals:

1. Validate new NOS technologies, independently and as a system
2. Demonstrate novel distributed operations concepts
3. Socialize new DSM technologies and concepts to the science community by significantly retiring the risk of integrating these new technologies.

NOS Testbed – Concept of Operations

The NOS Testbed consists of multiple *sensing nodes,* simulated or actual, representing space, air and/or ground measurements, that are interconnected by a *communications fabric* (infrastructure that permits nodes to transmit and receive data between one another and interact with each other). Each node is supported by hardware capabilities required to perform nodes monitoring and command & control, as well as intelligent “onboard” computing. The nodes work together in a collaborative manner to demonstrate optimal science capabilities.

The testbed is built in a modular fashion with well-defined interfaces so that each of its components (e.g., sensors; inter-node communication model, technique and protocols; inter-node coordination; real-time data fusion and understanding; planning; sensor re-targeting; etc.) can be replaced, tested and validated without modifying the rest of the testbed.

The testbed has the capability to interact with various mission design tools, OSSEs and one or several forecast models. It will demonstrate the science value of a concept, what we could do with it and what we could not do otherwise.

NOS Testbed Phased Execution

The NOS Testbed is built in such a way that it can be incrementally augmented and improved with additional sensors and capabilities. It will have multiple phases, e.g.:

- Phase 1 with only multiple satellite-simulators, i.e., actual or simulated data from ground stations Level 0 data and/or software simulated satellite data
- Phase 2 integrating in-situ sensors with satellite simulators
- Phase 3 integrating in-situ sensors and satellite simulators with UAV's and balloons
- Phase 4 integrating actual CubeSat(s) with the previous sensors
- Phase 5 could include international collaborations and coordination.

DSM/SWOS/NOS technologies and operation concepts would then be ready to transition and actually be infused into actual Science missions.

Experiment Lifecycle (for a given phase of the testbed):

1. Experiments are proposed under various mechanisms
2. For a given proposed *Experiment*:
   a. Governance Board tentatively approves *Experiment*
   b. Primary requester works with the Testbed Support Contractor to produce test plan, test script and cost estimate, including in-kind contributions, if any
   c. Primary Requester negotiates cost estimate with Governance Board
   d. Governance Board approves the *Experiment* and its funding
   e. *Experiment i*s run and results are published
   f. The Primary Requester presents the results and any lessons learned to the Governance Board
   g. Based on (f), Governance Board decides to update the testbed accordingly, if needed

Experiment Considerations

- Inputs from all relevant stakeholders
  - Anticipate conflicting objectives
- **Good Experiment Design**
- Combine experiments into a single set of experiments
- Permit separation of proprietary from public experiments
- Ensure all testbed data is collected and authenticated
- Ensure key data are evaluated in real-time to ensure any variations/corrections are collected
- Ensure Science stakeholders are satisfied of the value of an NOS Strategy

NOS Testbed – Framework Components

Sensing Nodes can be represented at different remote locations and by:

- Level 0 data received at ground stations
- Simulated data derived from actual Level 0 data
- In situ sensors
- UAV's equipped with one or several sensors
- Balloons equipped with one or several sensors
- High Altitude Pseudo-Satellites (HAPS), high flying UAV's
- CubeSats carrying one or several sensors

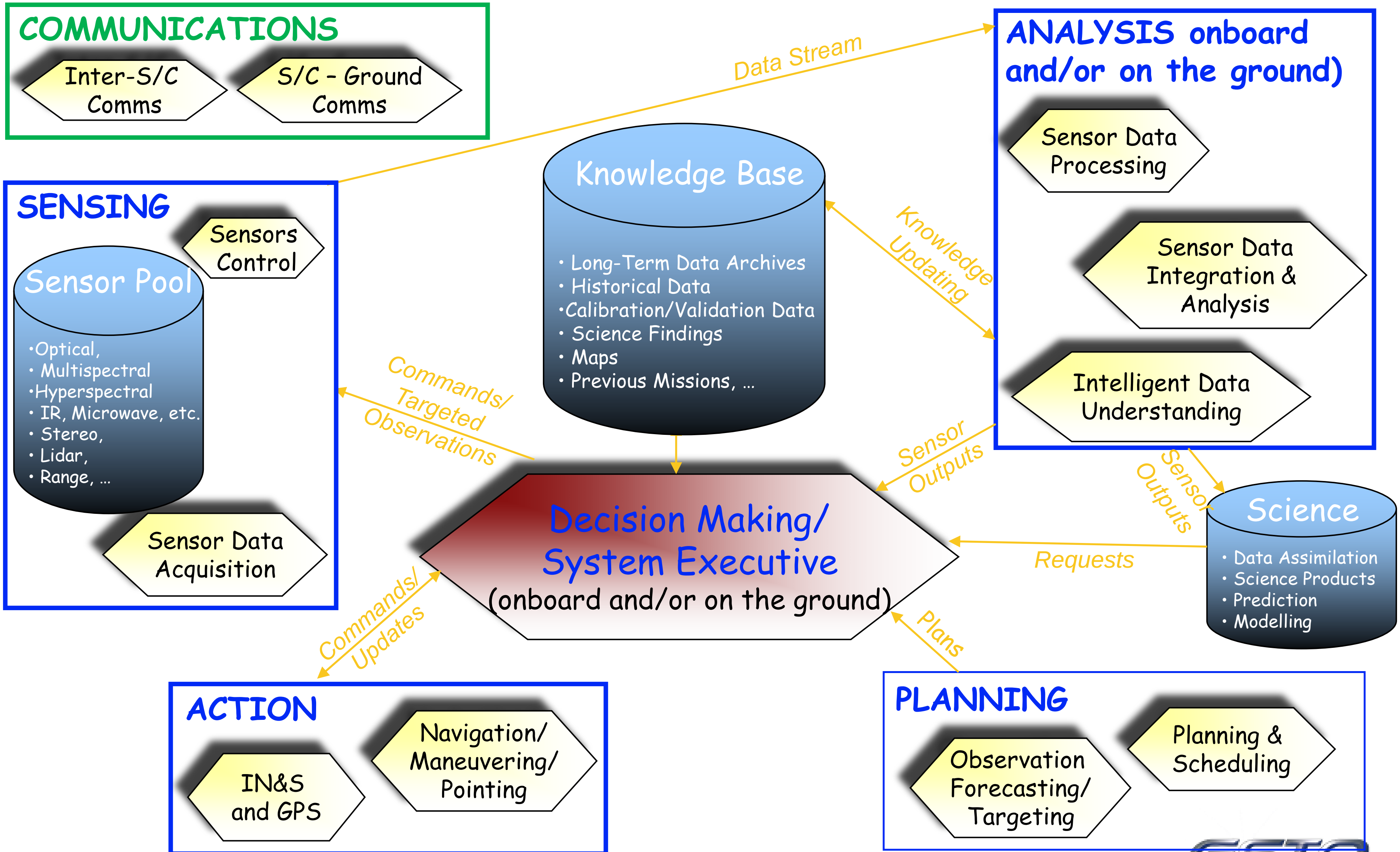
Computing Hardware will be available at each node, e.g.:

- AIST-14 and -16/French Simulator
- AND/OR Actual Hardware:
  - Raspberry PI (RPI)
  - CHREC CubeSat Space Processor (CSP)
  - SpaceCube 2.0, etc.
- Neuromorphic Chips: SBIR/RBD (Palo Alto) or Intel Loihi or IBM TrueNorth (actual if available or simulators)

Software Framework, e.g.:

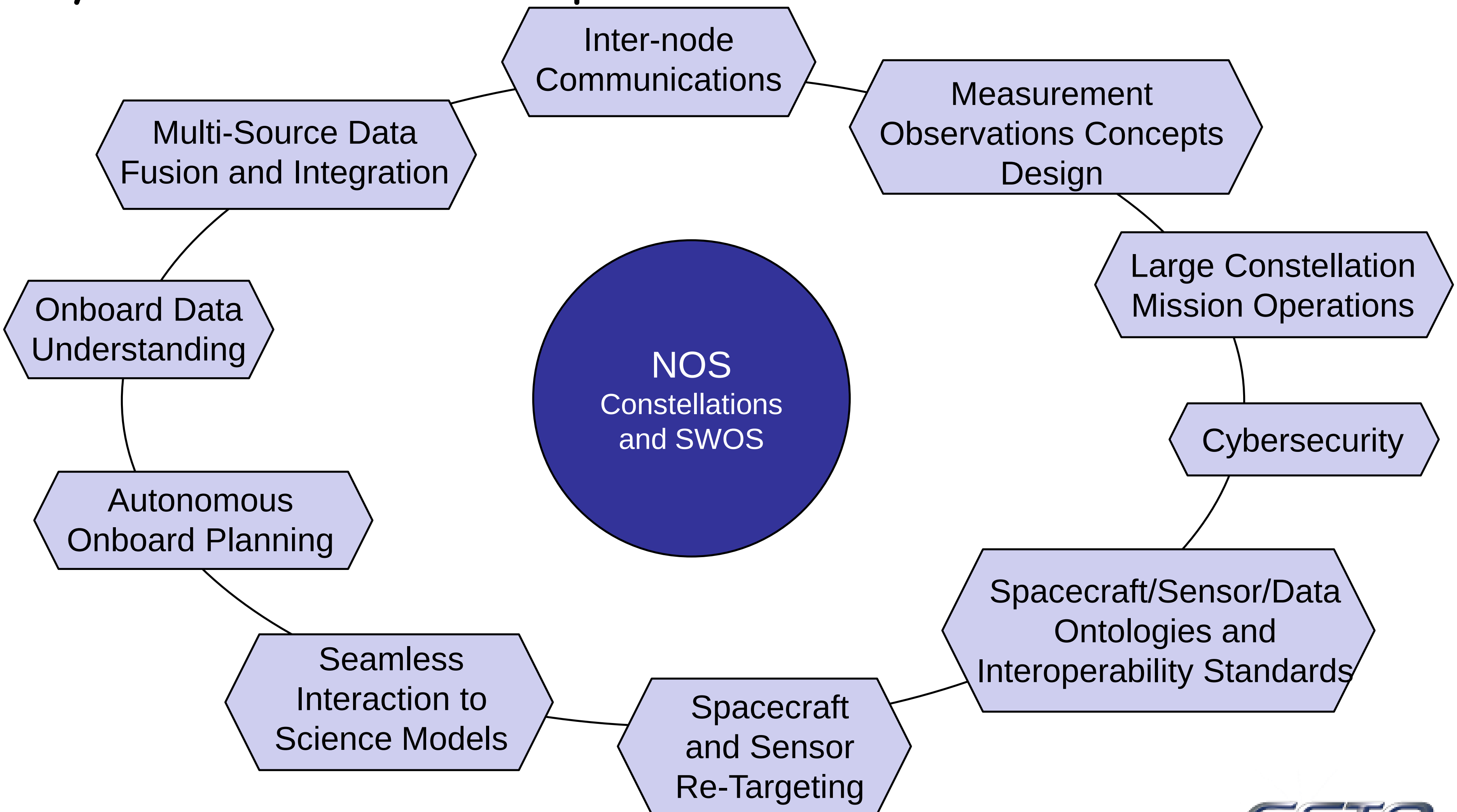
- Flight Software: core Flight System (cFS) running at each node
- Distributed Messaging System – middleware for communicating between nodes, e.g., combination of SBN, DTN, 0MQ, SpaceWire
- Data System – RTAP
- Command and Telemetry System – COSMOS

NOS Testbed – System Architecture



Some Specific NOS Required IS Capabilities

Developing Information Systems Technologies to Create a Unified and Dynamic Pictures of Science phenomena with NOS Architectures



NOS Testbed Benefits to Earth Science

- **Reduce risk** of new technologies and/or novel integration of multiple technologies => increase TRL of each technology and SRL of the integrated system
- Thoroughly test all the implications of various mission concepts by linking the testbed to mission design tools, OSSEs and models
- Compare several competing technologies in a standardized framework
- Develop confidence in the Earth Science Community in the use of integrated observing strategies

Initial NOS-T Experiment

- **Purpose**
  - Debug the NOS-T implementation and initial Governance process
  - Evaluate basic concepts of a simple hydrology architecture
- **Initial Collaborators**
  - Systems Engineering Research Consortium (SERC) – NOS-T Design
  - NASA Ames Research Center – Demonstrate Tip & Cue capability to respond to event detections
  - NASA JPL – Plan/Schedule coordinated observations
  - NASA Goddard Spaceflight Center – hydrology observations assimilation and modeling
  - KBR-Wyle – management support

Backup

Analytic Center as a Framework

Focus on the Science User

User
- Project Definition
- Plan for Investigation

Data
- Catalog
- NASA DAAC
- Other US Govt
- Non-US
- Local or non-public

Project Work Environment

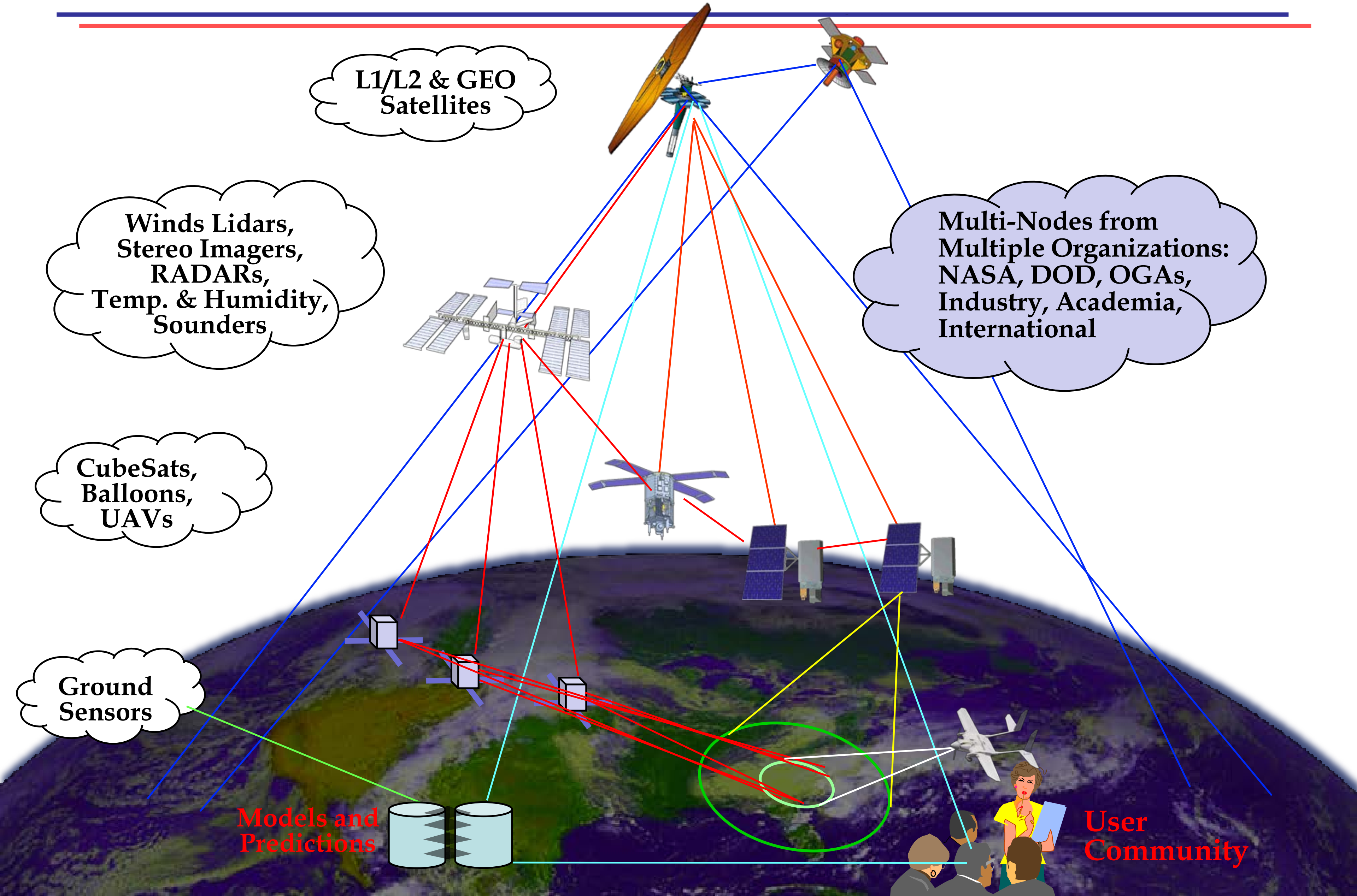
Tools
- Discovery & Catalog
- Work Management
- Data Interfaces
- Analytic Tools
- Modeling
- Collaboration
- Visualization
- Sharing/ Publication
- Local/custom

Computational Infrastructure
- Computing
  - Capacity
  - Capability
- Storage
- Communications

Storage
- Data Containers
- Thematic model
- Metadata/Ontology
- Resulting Products
- Published data
- Provenance

Computing
- Local systems
- High End Computing
- Cloud Computing Capability
- Quantum Computing
- Neuromorphic Computing

Sensor Webs for Tracking Events of Interest



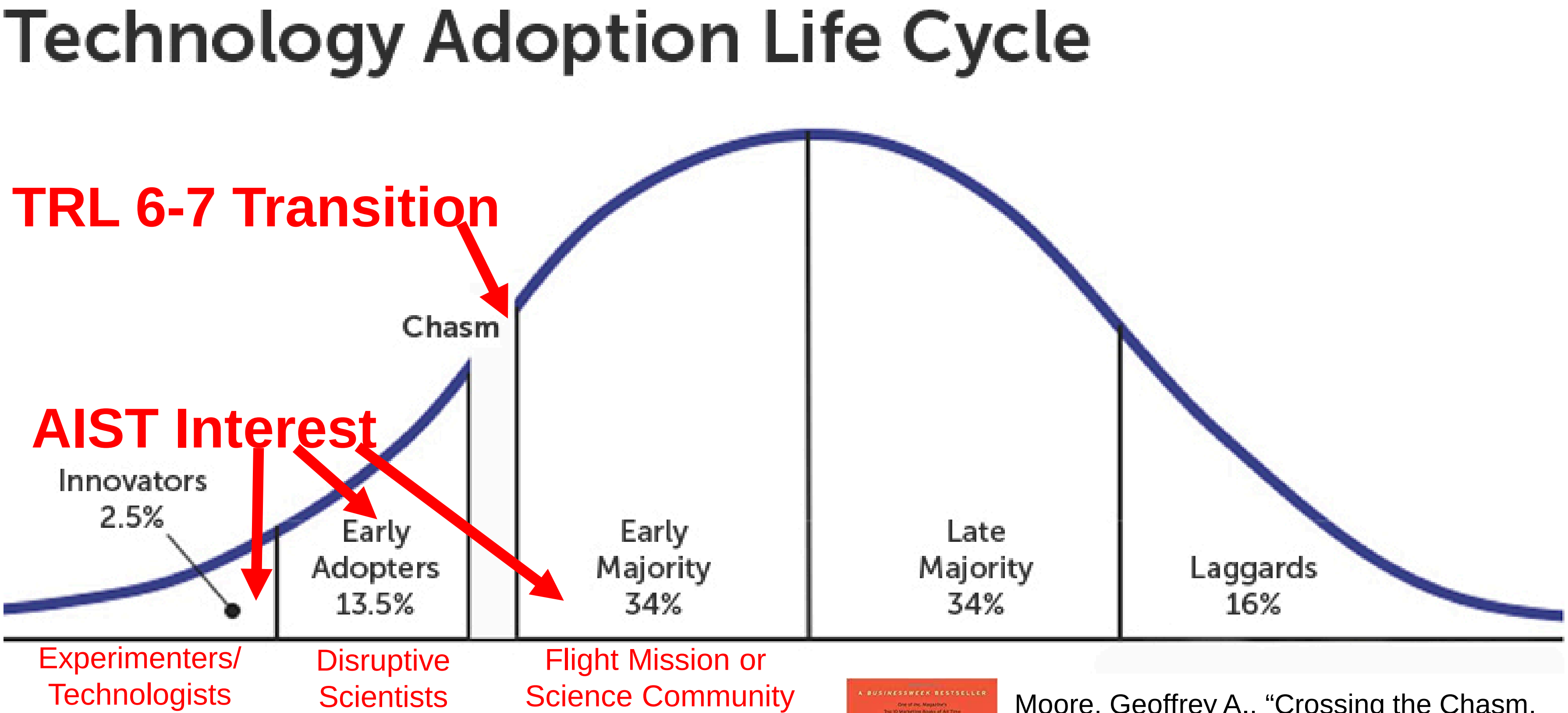
Fostering Technology Infusion

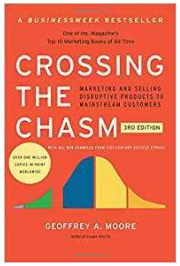
- Focus technology projects on solving science problems
  - Solicitation provisions
  - Augmentations to demonstrate proof of concept to science adopters
  - Machine Learning (Analytic Center) Workshops
  - Sensor Web (New Observing Strategy) Workshops
  - Regular conversation with HQ Program Scientists and Applied Sciences PM's
  - What science problems are out of reach?
- Increase awareness/acceptance by science community
  - Public Cloud Computing (AMCE)
  - Geographic Information System (GIS)
  - Machine Learning tools for analyzing data
  - Commercial Analysis Services (i.e., Descartes Labs, Radiant.Earth)

Cultural Change is Needed

- Technology Community Resistance
  - Lack of familiarity in changing to a new direction
  - Leisurely pace of technology development in Government environments
- Science Community Resistance
  - Perceived risk of new measurement techniques and unproven technologies
  - Process for developing community acceptance of someone else's tools
- Flight Community Resistance
  - Consider a mission to be an entire suite of observations of a phenomenon
  - New Mission Ops Model with autonomy and management
- Confidence must be built within the Science and Flight Communities
  - Conduct well designed experiments early and get a science team buy-in
  - Demonstrate components at earliest possible date and keep using them
  - Communications plan to reduce the lack of familiarity
  - InVEST experiments and demonstrations
  - Open conversation, not isolated experiments

AIST Crossing the Chasm





Moore, Geoffrey A., “Crossing the Chasm, 3rd Edition: Marketing and Selling Disruptive Products to Mainstream Customers” Collins Business Essentials, 2014

General DSM Required Capabilities

We Start with Science …

… and End with Science

Conceive and Design, Design and Development Tools
- Pre-Phase A/Phase A DSM mission design tools
- Prototyping & Validation testbeds
- Model-based engineering tools

Build and Test Manufacturing, I&T and Assembly
- Develop/extend standards
- Integration and Testing (I&T) frameworks

Launch and Deployment
- Low-thrust propulsion
- Low-cost deployment multi-spacecraft systems

Operate Communications
- High-speed S/C to S/C comms
- Low-cost & fast SmallSats uplink/downlink

Operate GN&C
HW & SW for:
- Autonomous sensing & control
- Absolute & relative navigation
- Coordinated pointing

Operate Ground Data Processing
- Multi-spacecraft mission ops Centers and ground data systems
- Solutions for DSM “big data” operations challenge

Analyze Onboard Intelligence
- Onboard recognition of events of interest
- Onboard goal-oriented planning & scheduling
- Autonomous re-targeting and reconfigurability

Analyze and Share Science Data Processing
- Scalable data management for large DSM
- High accuracy multi-platform calibration, registration & fusion

ESTO Distributed Testbed

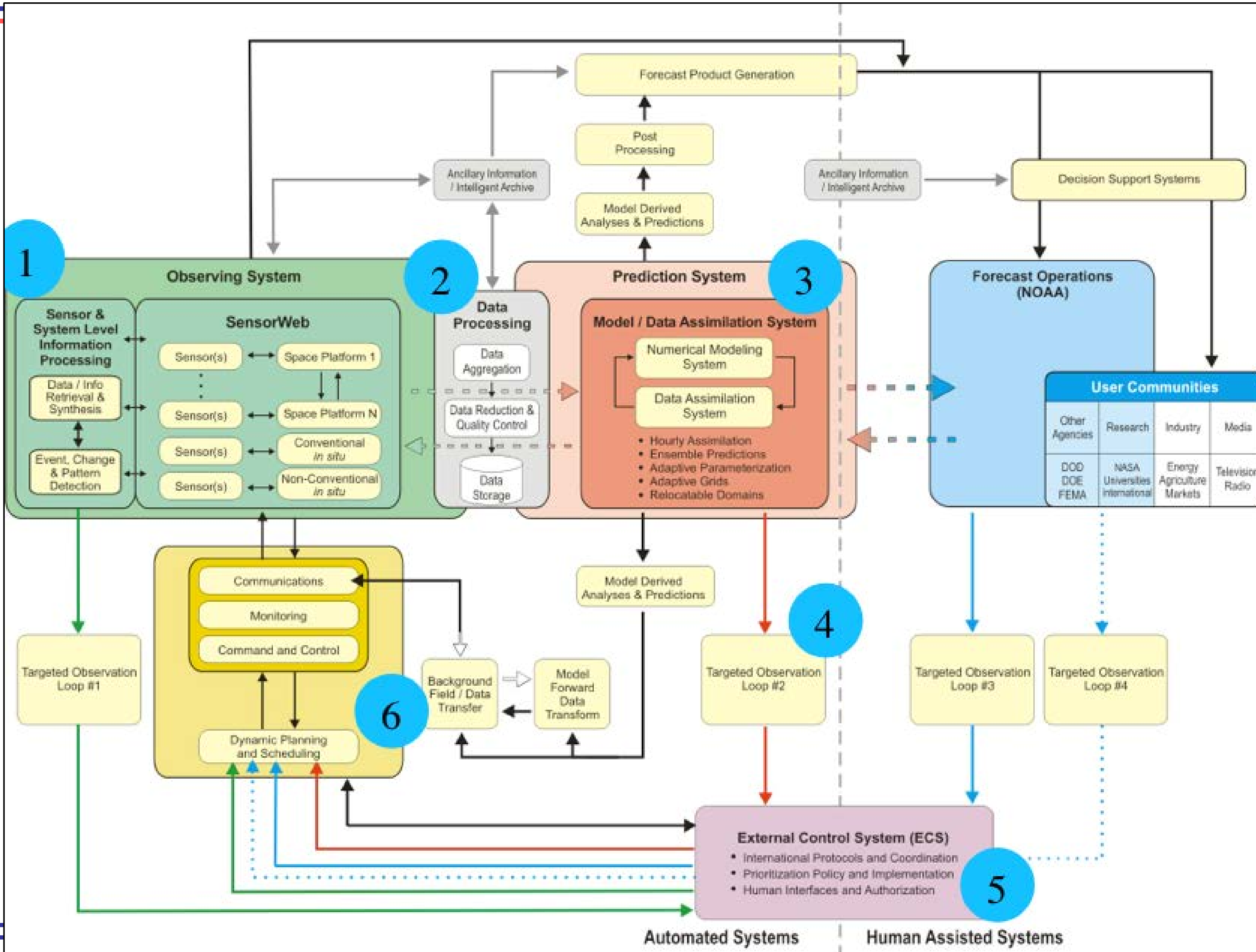
- Not a single facility, rather a collaboration among a wide range of participants
  - Each has something to contribute
  - Each could benefit by experimenting in the open (non-proprietary)
  - Emulated in situ, airborne and orbital assets
- Funded to conduct early-stage experiments and demonstrations
  - Competitively selected
  - Agree to commitment to making contribution available
- Governance
  - Self-managed, prioritized and coordinated
  - Lifetime expected 5 years
  - Annual Review
- Types of testing initially
  - Remote operation of instruments among different parties at different sites
  - Deconflict commands and schedules
  - Block-chain distributed ledger applications
  - Protocol for quick reaction agreement to share facilities (think seconds instead of months)
  - Control and Monitor system needs
- Demonstrate some specific science use cases
  - Emulate several science missions with different science communities
- Elevate at least two nodes into space (Compete in INVeST Program)
  - Impact of latency, international agreements, etc.,
  - Perform experiments to debug, revise, estimate performance and demonstrate integration

References

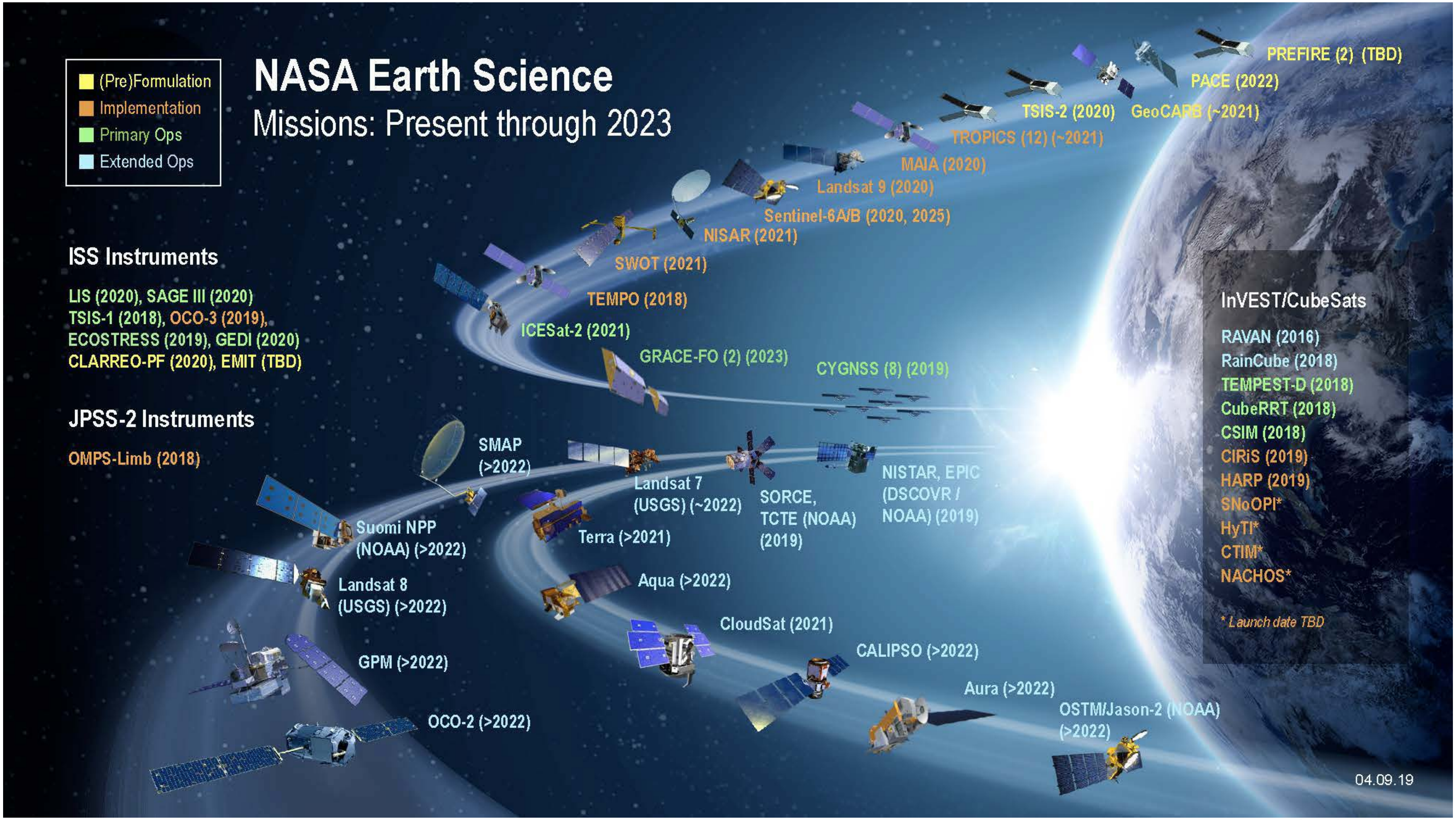
- CubeSat Space Processor (CSP), https://www.spacemicro.com/assets/datasheets/digital/slices/CSP.pdf
- Real-Time Application Platform (RTAP), http://www.tnbrqats.com.my/rtap/ and http://www.tnbrqats.com.my/wp-content/uploads/2017/09/TNBR-Tech-Profile-021-Real-Time-Application-Platform.pdf
- Core Flight System (cFS), https://cfs.gsfc.nasa.gov/
- SpaceCube 2.0, https://spacecube.nasa.gov/
- Zero-M-Queue, 0MQ, Distributed Messaging, http://zeromq.org/intro:read-the-manual
- Delay/Disruption Tolerant Networking (DTN), https://www.nasa.gov/content/dtn
- Software Bus Network (SBN), https://software.nasa.gov/software/GSC-16917-1
- COMSOL MultiPhysics Software, https://www.comsol.com/

2003-2013 / SensorWeb Model

Higgins, G., Kalb, M., Lutz, R., Mahoney, R., Mauck, R., Seablom, M., Talabac, S., 2003:
"Advanced Weather Prediction technologies: Two-Way Interactive Sensor Web & Modeling System"



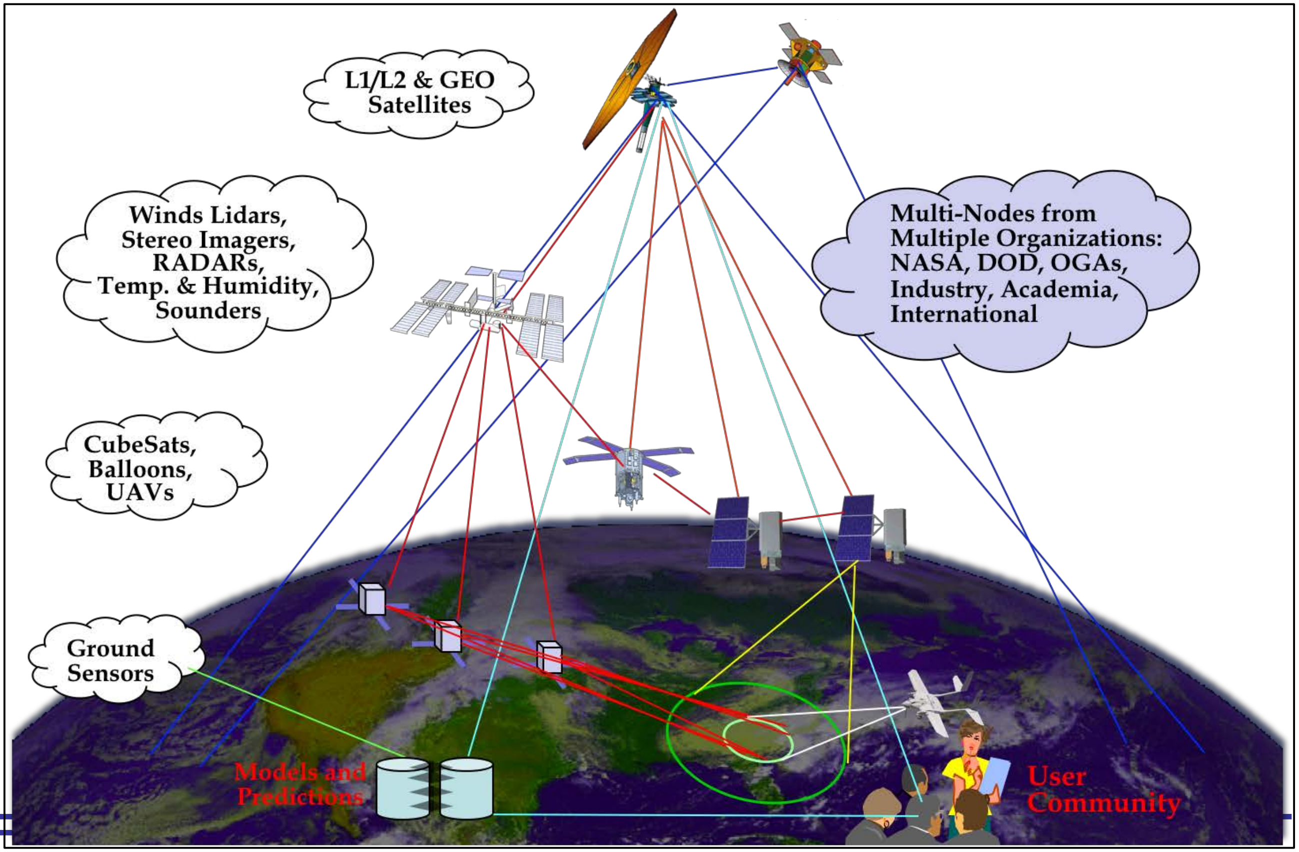
Current Observing Strategy



New Observing Strategies (NOS)

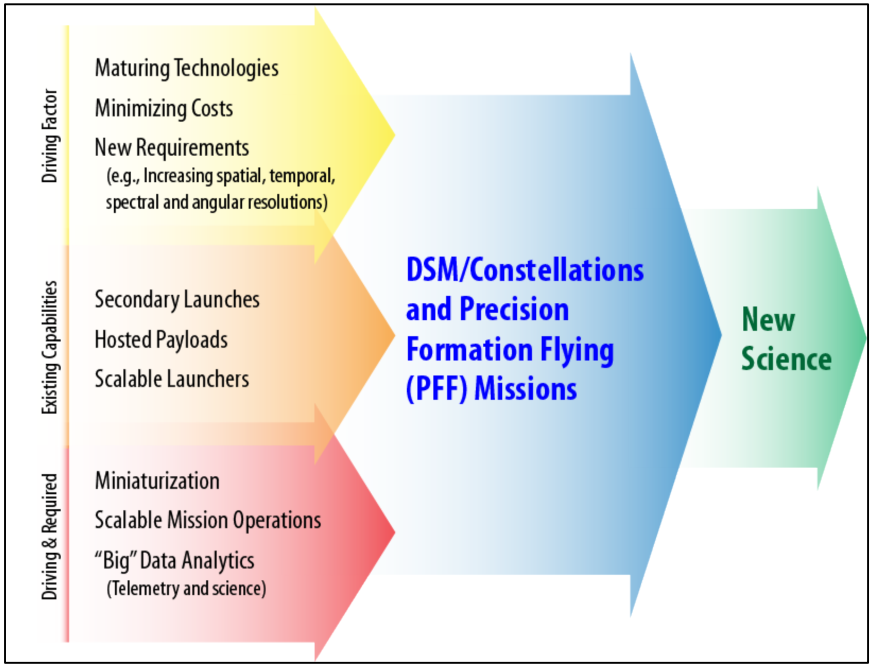
New Observing Strategies:

- Multiple collaborative sensor nodes producing measurements integrated from multiple vantage points and in multiple dimensions (spatial, spectral, temporal, radiometric)
- Provide a dynamic and more complete picture of physical processes or natural phenomena



NOS Environment

***Technology advances** have created an opportunity to make new measurements and to continue others less costly, e.g., **Smallsats** equipped with science-quality instruments and **Machine Learning** techniques permit handling large volumes of data*



NOS will:

- **Utilize Distributed Spacecraft Missions (DSM),** i.e., missions that involve multiple spacecraft to achieve one or more common goals.
- **Coordinate Space Measurements with Aerial and Ground Measurements.**

NOS Goals:

- Enable new science measurements
- Improve existing science measurements
- Reduce cost of future NASA missions

DSM/ICC and Sensor Webs

A special case of DSM is **an Intelligent and Collaborative Constellation (ICC)** which involves the combination of:

- Real-time data understanding
- Situational awareness
- Problem solving
- Planning and learning from experience
- Communications and cooperation between multiple S/C.

A Sensor Web is a distributed system of *sensing nodes* (space, air or ground) that are interconnected by a *communications fabric* and that functions as a single, highly coordinated, virtual instrument. It semi- or - autonomously detects and dynamically reacts to events, measurements, and other information from constituent sensing nodes and from external nodes (e.g., predictive models) by modifying its observing state so as to *optimize mission information return.* (Note: a "communications fabric" is a communications infrastructure that permits nodes to transmit and receive data between one another) (e.g., EO-1 SensorWeb 3G). (Ref: Steve Talabac et al, 2003)

NOS Drivers

- **Respond to new Earth Science Decadal Survey – Measurement-based:**
  - Utilize multiple modes (wavelengths, spatial, temporal res), multiple vantage points, etc. to create a unified picture of a physical process or natural phenomenon
  - Reduce costs: large flagship missions only when needed, leverage first existing govt and commercial assets, ground sensors, UAVs, balloons, instruments on ISS and CubeSats
- **Create an "internet" of sensor data, from models up to in-orbit assets, via all intermediate levels:**
  - Link WWW to Space-Internet
  - Link to other networks (e.g., DARPA Blackjack)
  - Provide interoperatibility-accessibility with/to large flagship missions
  - Future: link Earth SensorWeb to Helio SensorWeb to Lunar SensorWeb to Martian SensorWeb, etc.
- **Create an analog-like system to test future lunar, Mars or deep-space sensor webs and constellations**
- **Societal Applications:**
  - Respond quickly, on-demand to unexpected events (hurricanes, volcanoes, etc.)
  - Leverage "out of network" assets for emergencies (DOD-, NOAA-, Foreign-, etc.)

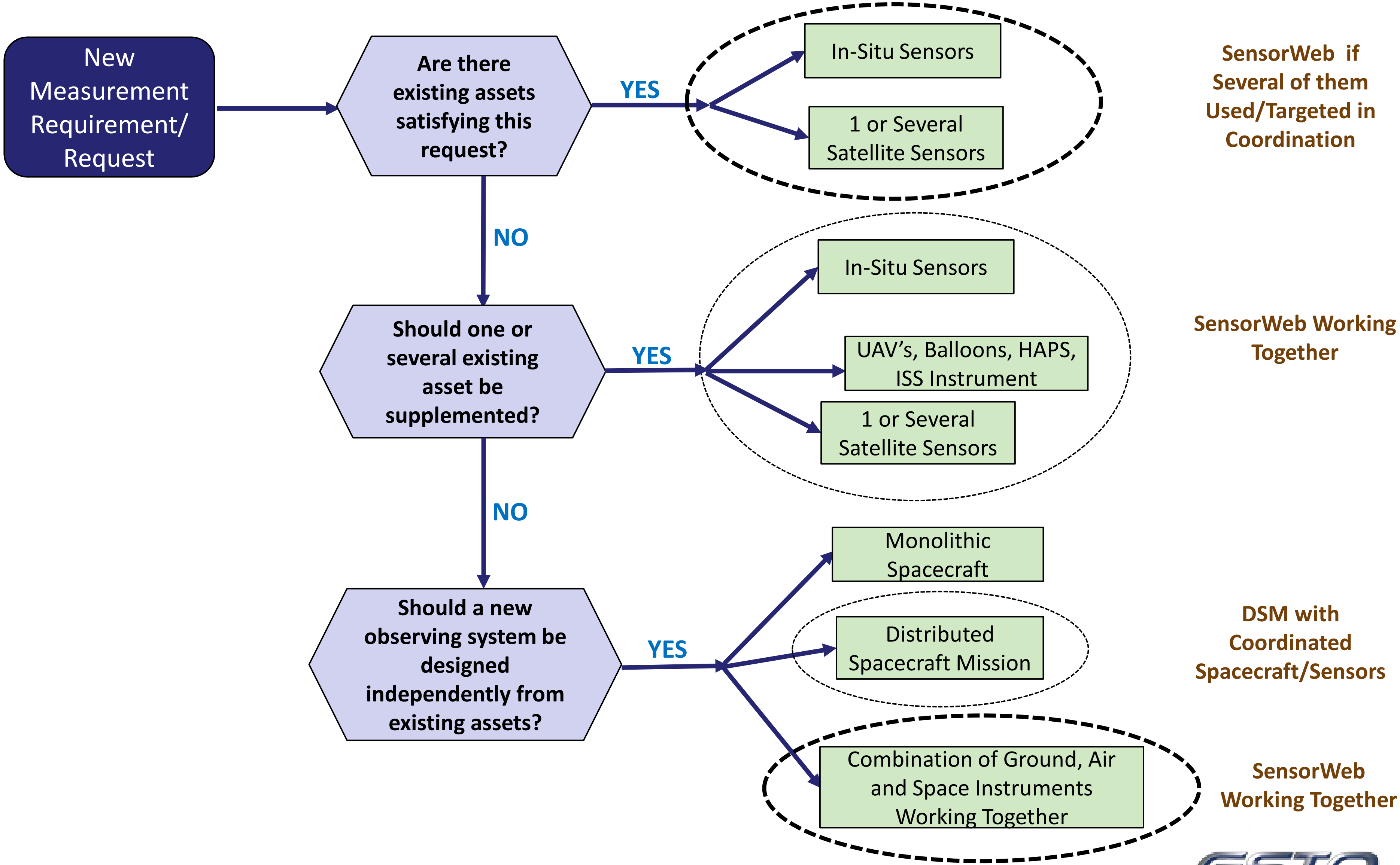
NOS Enables Earth Science

- **Improved Models that can Drive Observations**
  - Integrate models with in situ, airborne and orbital instruments
  - Continuously running models direct the observation system in collecting data

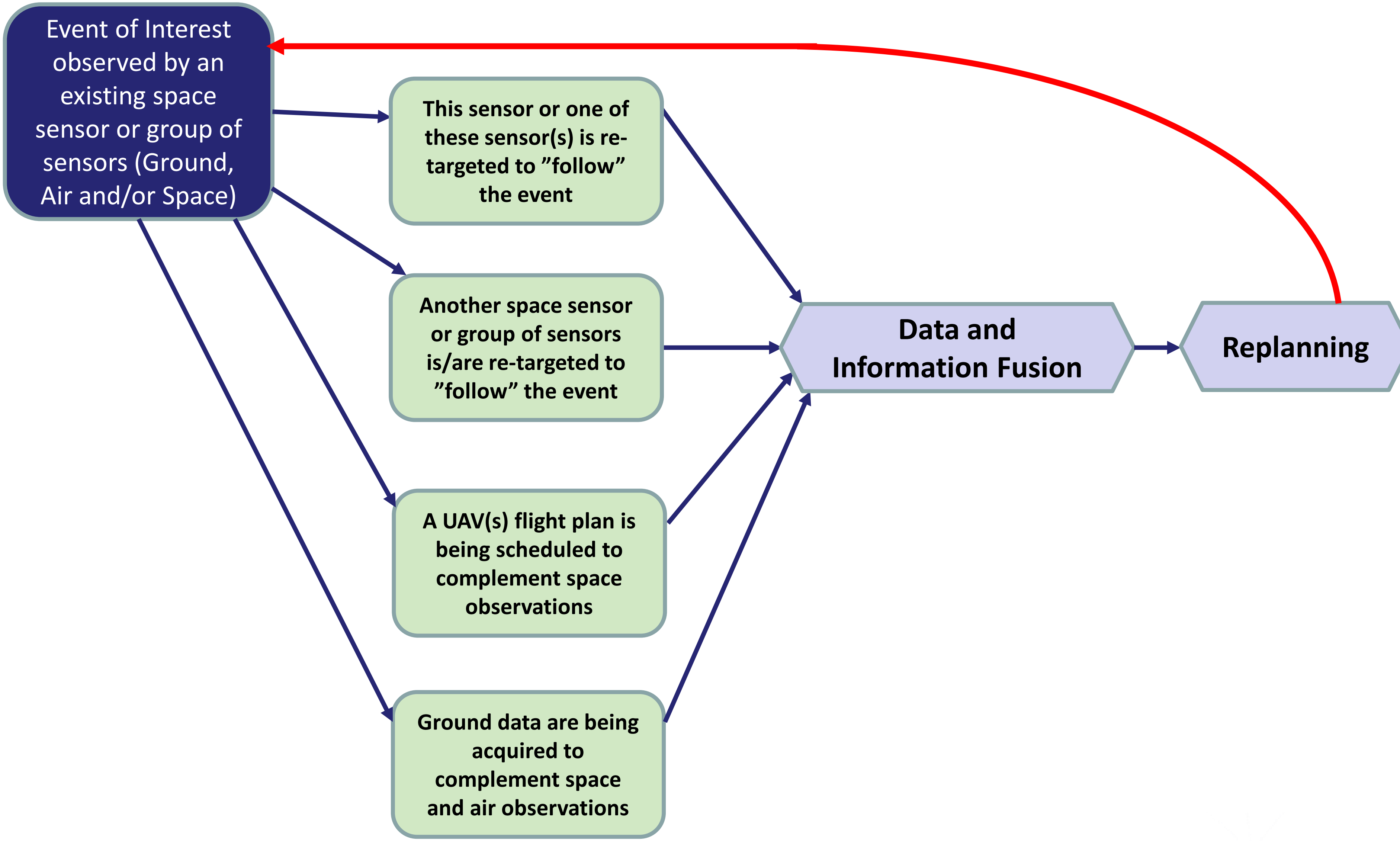
- **Real-time targeting of transient and transitional phenomena**
  - In situ triggering of observing system
  - Train configuration prolonging observation of an event
  - Viewing an event from multiple angles
  - Autonomy in focusing the observational system on the event

- **Coordinated arrays of sensors (station keeping)**
  - Reduce error with statistics
  - Improve resolution with multi-node instruments in phased arrays
  - Viewing of phenomenon from multiple angles and directions

New Observing Strategies (NOS) – *Measurement Acquisition (“Mission” Design or Model-Driven)*



New Observing Strategies (NOS) – *Observation Planning or Rapid Response to Event of Interest*



NOS for Candidate Science Needs

- **Hydrology**
  - River flow and Flooding
  - Snow fall in 3D
  - Aquifer degradation

- **Precipitation**
  - Extreme precipitation events

- **Cryosphere**
  - Glaciers changes
  - Sea Ice changes

- **Urban Air Quality Events**
  - At a resolution (vertical and horizontal)

- **Biodiversity**
  - Migrations
  - Invasive species
  - Transient spring phenomena

- **Solid Earth and Interior**
  - Landslides
  - Plate movement
  - Volcanic activity
  - Interior magma movement

- **Disaster Management**
  - Floods
  - Earthquakes
  - Volcanic Eruptions

Example of an Hydrology Use Case

Flood Monitoring with Space and Ground Sensors

1. A weather forecast or radar image indicates the potential for flood-inducing precipitation.

2. This triggers a network of ground-based sensors measuring changes in overland flow to begin telemetering data at high frequency.

3. When the ground sensors detect change in overland flow, they trigger a series of additional measurements:
   a. Space-based measurements, e.g., combination of space-based optical and radar, to determine surface water extent.
   b. In-situ measurements taken by either USGS technicians or future in-situ or UAS-mounted sensors, to measure high water level.
   c. A constellation of radar CubeSats is tasked to take targeted multi-angle measurements