New Observing Strategies (NOS)
Introduction to the Workshop

February 25, 2020

One of the 2 Current AIST Thrusts – *New Observing Strategies (NOS)*

New Observing Strategies (NOS)

Optimize measurement acquisition using many diverse observing capabilities, collaborating across multiple dimensions and creating a unified architecture

- Using Distributed Spacecraft Missions (DSM) or SensorWebs at various vantage points
- In response to Decadal Survey mission design needs, forecast or science model-driven, or event-driven
- Using NASA- as well as non-NASA data sources or relevant services

New Observing Strategies (NOS):

- 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

Science Applications

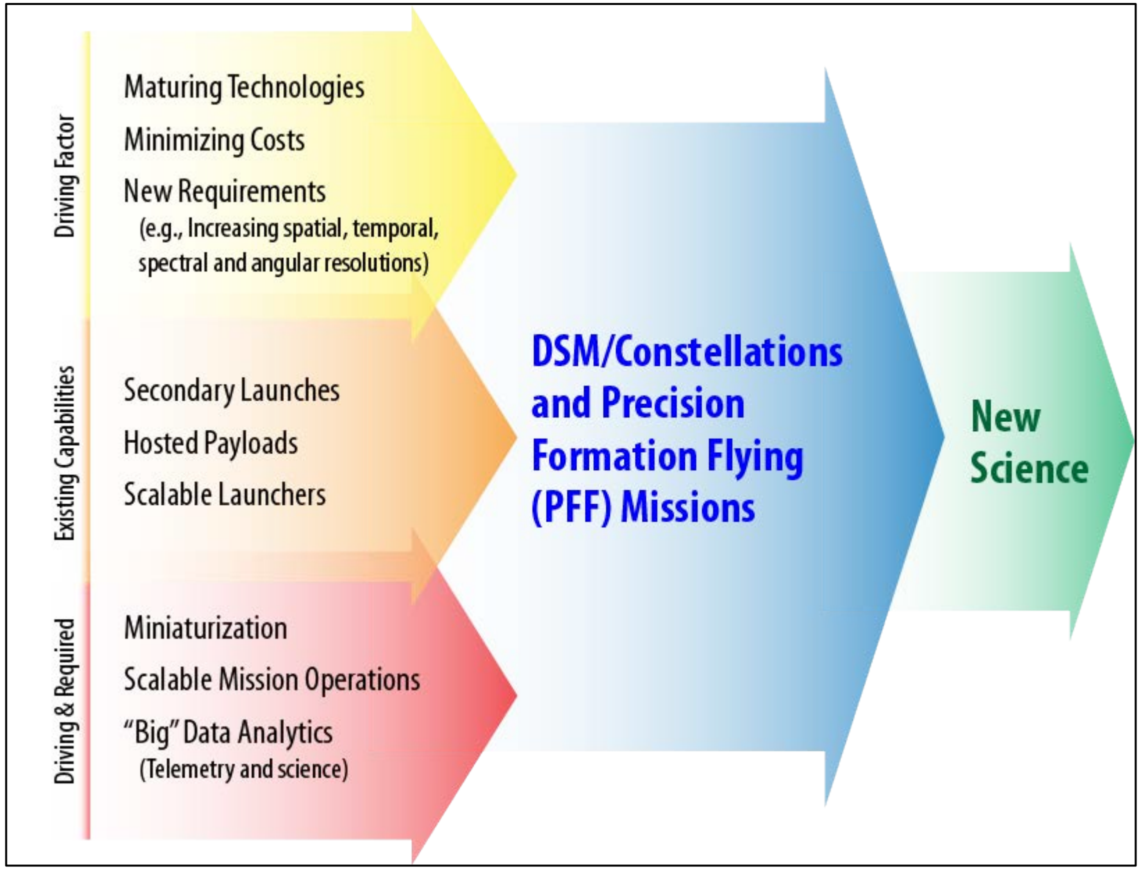
- **Hydrology**, e.g., River flow and Flooding; Snow fall in 3D; Aquifer degradation
- **Precipitation**, e.g., Extreme precipitation events
- **Cryosphere**, e.g., Glaciers changes; Sea Ice changes
- **Urban Air Quality Events**, e.g., At vartious resolutions (vertical and horizontal)
- **Biodiversity**, e.g., Migrations ; Invasive species; Transient spring phenomena
- **Solid Earth and Interior**, e.g., Landslides; Plate movement; Volcanic activity; Interior magma movement
- **Disaster Management**, e.g., Floods; Earthquakes; Volcanic Eruptions

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 interoperability-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.)

Distributed Spacecraft Missions and Future Missions 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.*



New Mission Designs that:

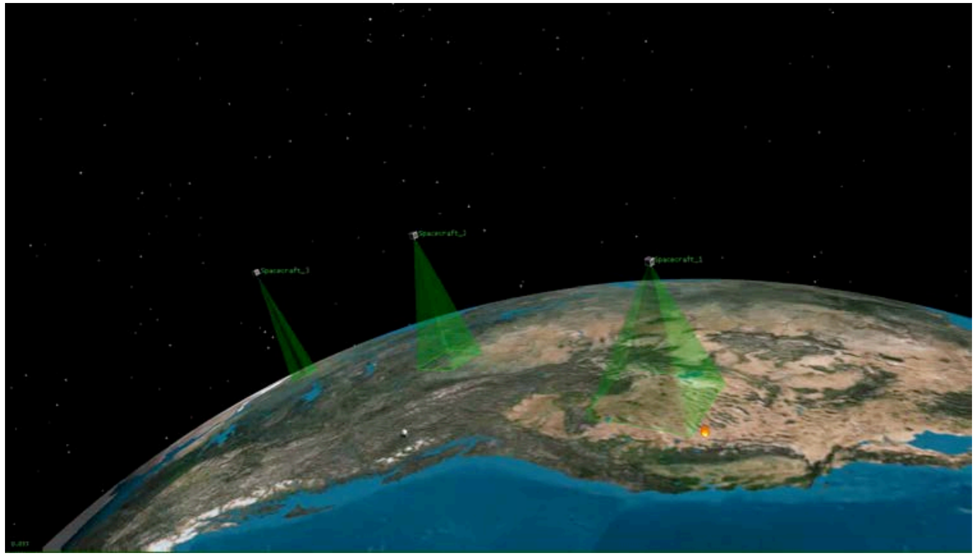
- **Utilize Distributed Spacecraft Missions (DSM),** i.e., missions that involve multiple spacecraft to achieve one or more common goals.
- **Coordinate Space Measurements with Other Measurements (e.g., in-situ).**

New Observing Strategies (NOS) for Earth Science

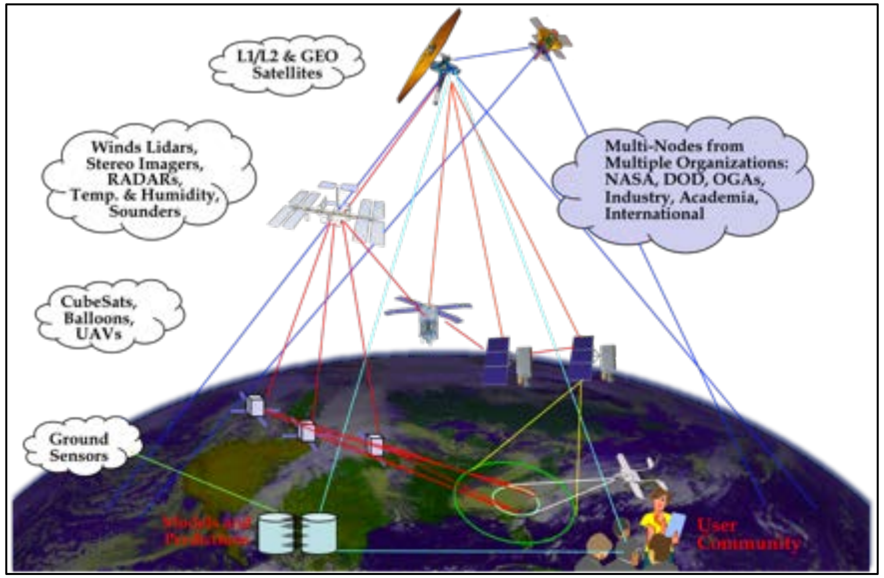
A **Distributed Spacecraft Mission (DSM)** can be a general Constellation, Formation Flying, Fractionated, etc.

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.



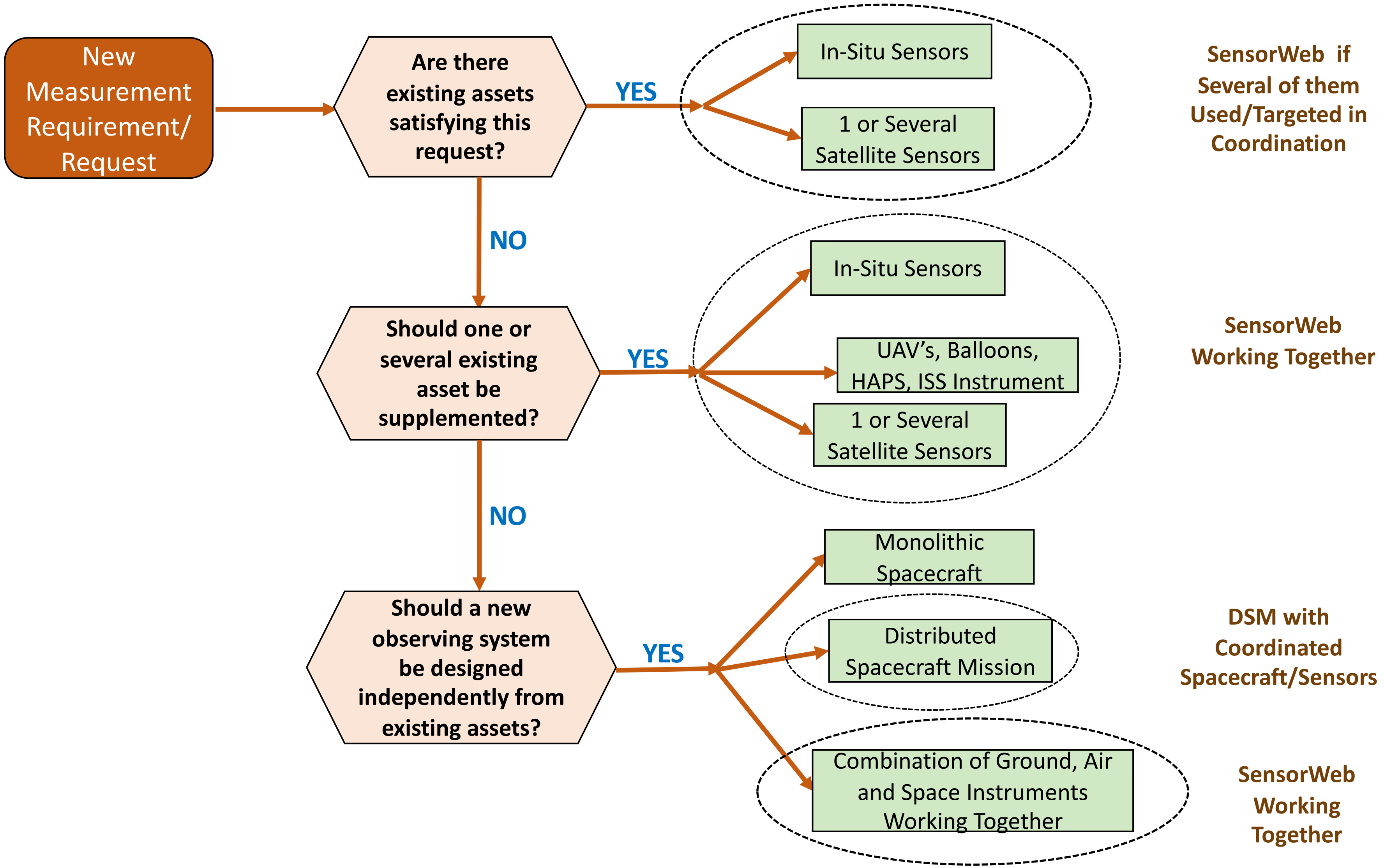
A **SensorWeb** is a distributed system of *sensing nodes* (space, air or ground) that are interconnected by a *communications fabric* and that functions as a single, highly coordinated, virtual instrument. It semi- or - autonomously detects and dynamically reacts to events, measurements, and other information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



NOS Similar to SensorWeb Concept where each Node can be Individual Sensor or DSM

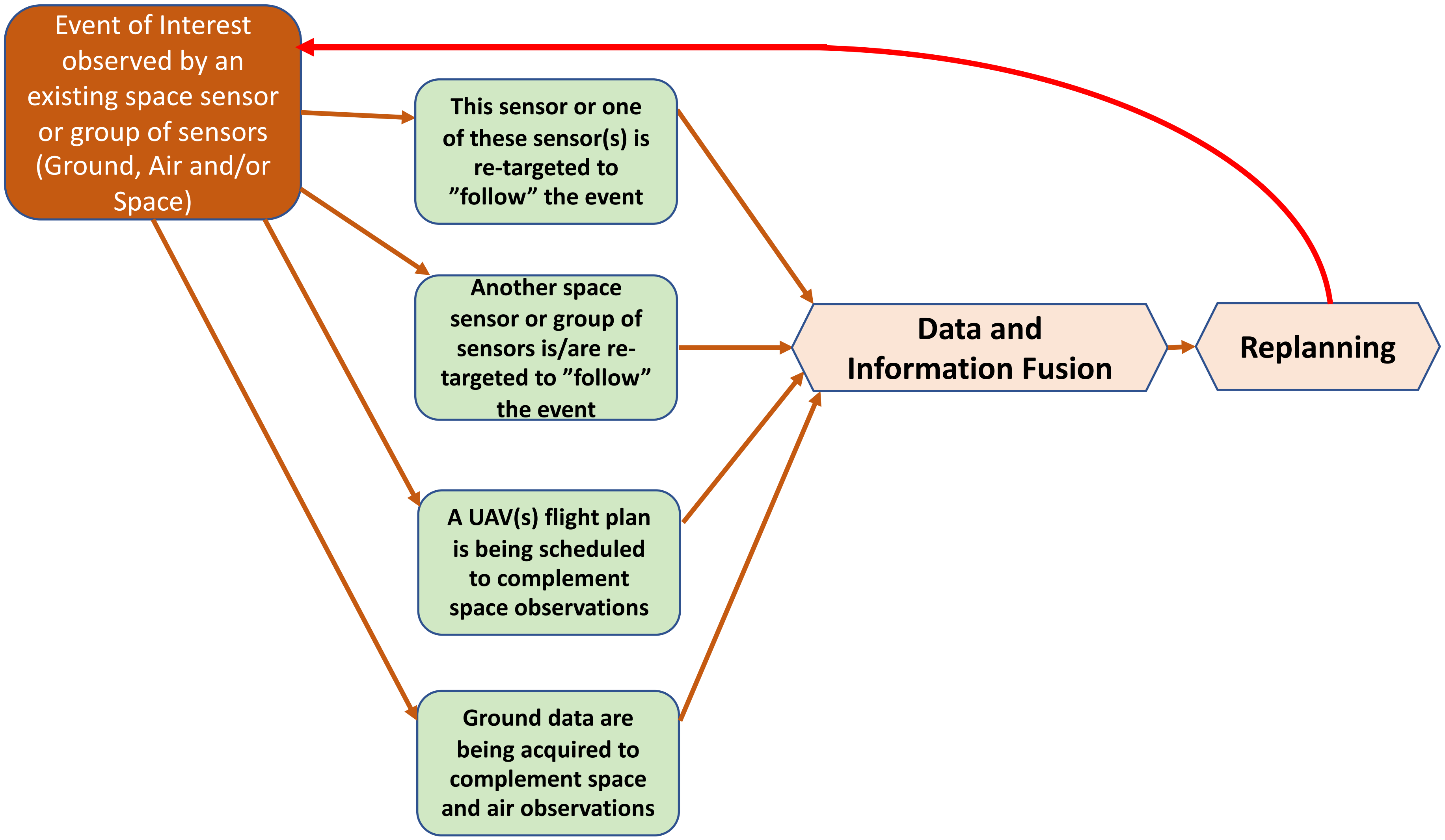
New Observing Strategies (NOS)

Measurement Acquisition ("Mission" Design or Model-Driven)



New Observing Strategies (NOS)

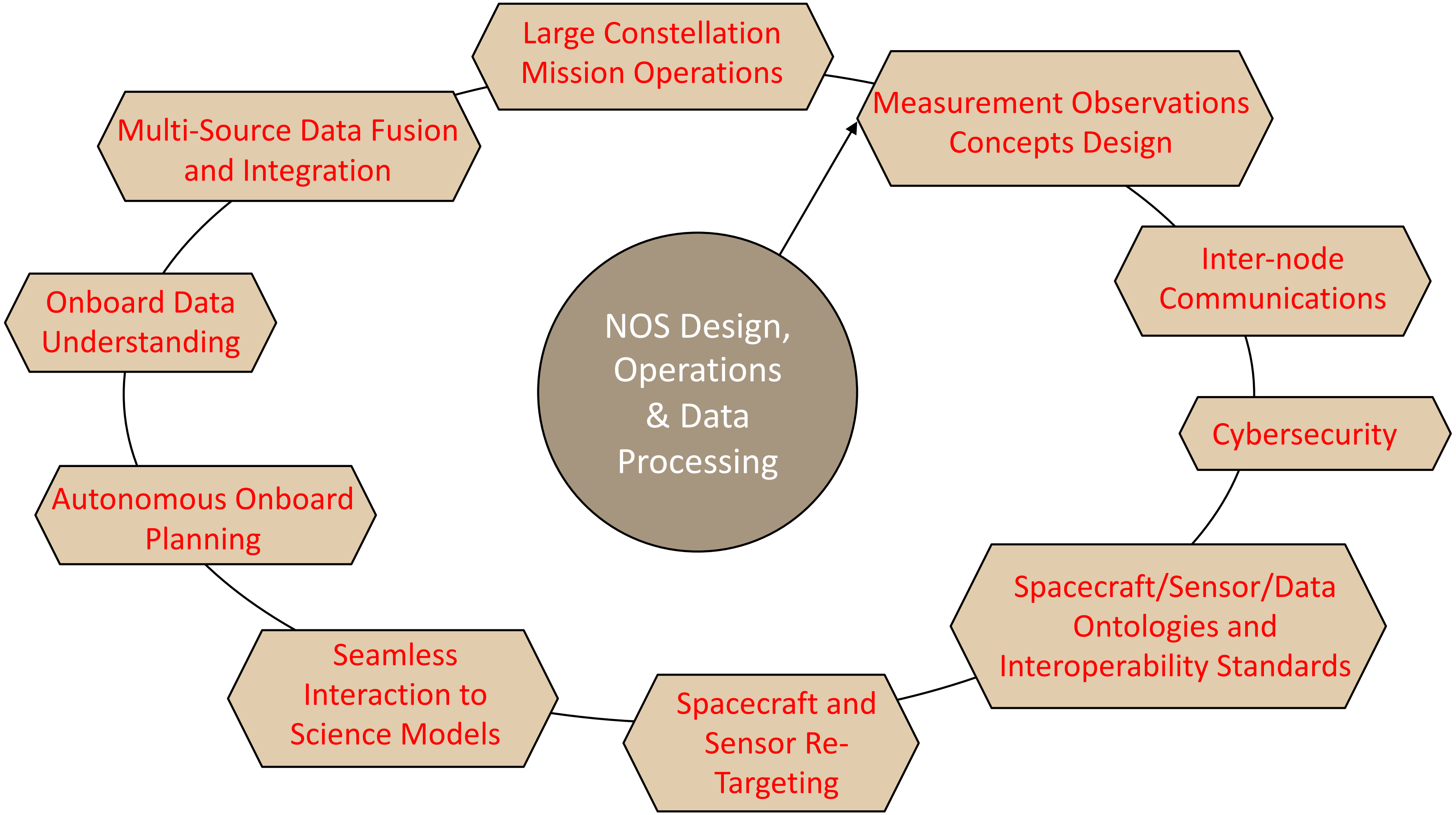
Observation Planning or Rapid Response to Event of Interest



Capabilities Needed for NOS

Some Examples of Capabilities Needed Onboard:

- Recognizing science events of interest
- Exchanging data inter-spacecraft
- Analyzing data for optimal science return
- Reconfiguring the spacecraft based on coordinated observations



Some Technologies Required for Intelligent and Collaborative Constellations (ICCs)

- **Onboard Processing**
  - High Performance Spaceflight Computing
  - Radiation-Hardened vs. Radiation Mitigation by Software (e.g., SpaceCube)
  - Neuromorphic Computing
- **Enabling and Supporting Technologies**
  - Multi-Spacecraft Flight Software
  - Real-Time and Onboard Image Processing and Analysis
  - Sensor Protocols and Secure Access
  - Semantic Representation (Bridge) of Disparate Observation Data
  - Precision Attitude Control Systems
- **Collaborative Systems Technology**
  - Dynamical and Fast Sensor/Inter-Spacecraft Communications
  - Sensor Fleet Management; Automated Tools for Mission Planning, Risk Analysis and Value Assessment
- **Knowledge Management for Decision Making**
  - Onboard Machine Learning and AI Technologies
  - Data/Information Fusion and Decision Systems

New Observing Strategies Testbed

- 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 as a "system of systems"

Testbed Main Goals:

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

Goals of the Workshop

1. Update on current AIST NOS development
2. Develop NOS reference concepts (or Science Use Cases), both:
   a. Model- or measurement-driven
   b. Event-driven
3. Identify corresponding capabilities and technologies required to develop NOS concepts
   a. Identify existing technologies of interest (same or different domains)
   b. Identify technology gaps
4. Map science concepts and capabilities/technologies
   a. Identify cross-cutting technologies (several Earth Science domains, and potentially other Science domains, e.g., Planetary or Heliophysics)
   b. Prioritize technologies' development
5. Inform the design of the NOS-Testbed architecture

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<u>Think 10 years ahead</u>
Identify concepts and technologies to be included in the next Decadal Survey

Any Questions?

Appendix

When does it make sense For a Constellation to be Fully Autonomous?

- Observe events that are unpredictable in terms of :
  - Location
  - Start Time
  - Duration Time
  - Movement/Change throughout Duration Time

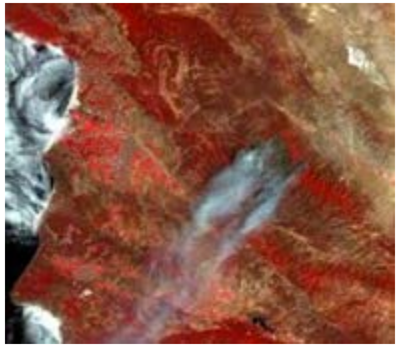
- Communication time to the ground vs. between spacecraft does not allow to optimally observe the event (time varies as a function of distance to the ground; “event” definition different for LEO or Deep Space or Planetary missions)

- Information obtained from multiple distributed sensors about the event is much smaller in terms of data rate compared to sending the full datasets

- Some Basic Conditions:
  - Area of interest observable by at least 1 SC in the constellation at all times of the event duration
  - {Onboard Processing + inter-SC communication} time small compared to event changes

Autonomy Application: *Transient Event Observation*

- Intelligent and collaborative sensing initiated by autonomous recognition of a science event of interest
- Earth Science or Heliophysics Constellation Example:
  - All spacecraft have a Wide Field of View (WFOV) sensor and one Narrow Field of View (NFOV) sensor with higher spatial resolution than the WFOV sensors
  - Desired area of observation viewed at good enough resolution and with short enough revisit time intervals such that transient events of interest (e.g. fires, floods, eruptions) can be detected quickly.
  - Onboard processing and inter-satellite communications capabilities
- Key Capabilities:
  - Recognize quickly and onboard science events of interest
  - Exchange data inter-spacecraft
  - Optimize data acquisition by targeting NFOV based on WFOV observations analysis to optimize science data return
- Benefits:
  - Follow fast-evolving events in real-time
  - No or minimal ground intervention
- Questions:
  - What should be the "speed" of events for an autonomous constellation to be beneficial?
  - Which computing capabilities needed onboard?



EO-1 California Forest Fires

STEREO spots a Coronal Mass Ejection (CME) soaring into space

Landsat Mt St Helens Before and After Eruption

Current NASA DSM Tech Development
Distributed Spacecraft Autonomy (DSA)

Game Changing Development (GCD) Technology – POC: Mark Micire/ARC:

- Objective: Demonstrate Autonomous Decision Making
  - For deep-space multi-spacecraft missions due to latency, bandwidth constraints, and mission complexity.
  - To increase the effectiveness of multi-spacecraft missions by operating them as a collective rather than individually.
- DSA Goals:
  - Advance command and control methodologies for controlling a swarm of spacecraft as a single entity.
  - Develop, mature, and demonstrate autonomous coordination between multiple spacecraft in the swarm.
  - Develop, mature, and demonstrate approaches for adaptive reconfiguration and distributed decision-making across a swarm of spacecraft.
- DSA will demonstrate autonomy with up to four spacecraft in conjunction with the Starling flight mission in the first 2 years, and independently from Starling on ground hardware with 100 spacecraft in the 3rd year.
- DSA will exclusively focus on the following technical areas related to scalable spacecraft autonomy:
  - **Reactive Operations**
  - **Distributed Resource and Task Management**
  - **Verification and Validation Techniques**

- DSA will partner with Starling flight mission on the following technical areas related to scalable spacecraft:
  - **Human-Swarm Interaction**
  - **Ad hoc Network Communications**
  - **System Modeling and Simulation**

AIST & ESIP
New Observing Strategies (NOS)

Current NASA NOS Tech Development
Planning & Scheduling for Coordinated Observations

ESTO
Earth Science Technology Office

Earth Science and Technology Office (ESTO) – POC: Steve Chien/JPL

- Autonomous planning and scheduling framework to coordinate multiple observing assets (e.g. space, air, land) to perform coordinated and continuous measurements at varying scales (e.g. spatial, temporal).
- Relevant planning and scheduling capabilities include automated or autonomous:
  - Scheduling/resource management
  - Data interpretation
  - Multi-modal observations, and
  - Assimilation of information from other models, services, and nodes in the Constellation/Sensorweb.
- Builds on:
  - CASPER (Continuous Activity Scheduling Planning Execution and Replanning) which uses iterative repair to support continuous modification and updating of a current working plan in light of changing operating context.
  - ASPEN (Automated Scheduling and Planning ENvironment), based on AI techniques, which is a modular, reconfigurable application framework for complex planning/scheduling systems and to develop a sequence of commands for a system that achieves the user's objectives.

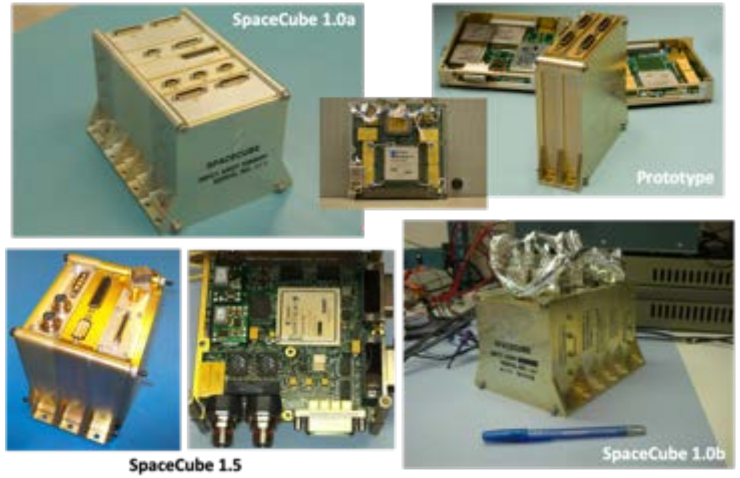
SensorWeb Experiments, POCs: Dan Mandl (GSFC, now Aerospace) and Steve Chien/JPL

- Namibian Early Flood Warning SensorWeb Pilot Project (NASA, UN-Spider, Namibia Department of Hydrology, Canadian Space Agency, Ukraine Space Research Institute, DLR (Germany) and others)
- Volcano SensorWeb Pilot Project
- Fire SensorWeb Pilot Project (with NRO, DIA, CEOS, Forest Service and NASA ARC)

Current NASA Tech Development for *Onboard Processing*

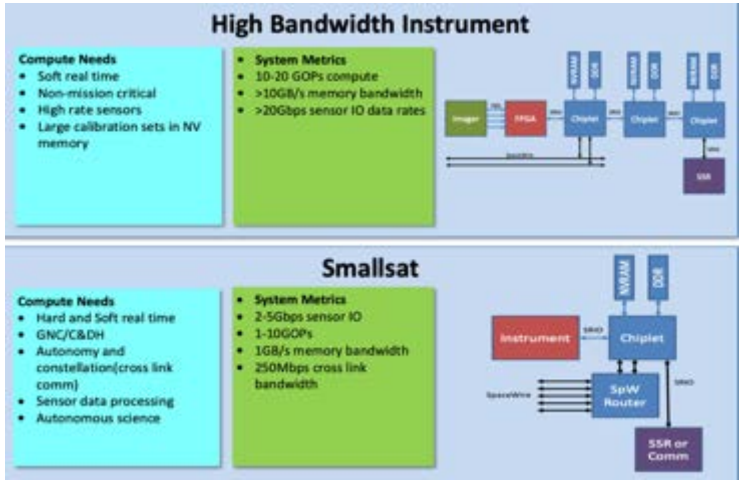
SpaceCube Family, POC: Gary Crum/NASA GSFC

- SpaceCube: Field Programmable Gate Array (FPGA) based on-board hybrid science data processing system.
- Provides 10× to 100× improvements in on-board computing power while lowering relative power consumption and cost.
- “Order of magnitude" increase in processing power + Ability to "reconfigure on the fly" => Implement algorithms to detect and react to events, and produce data products on-board => Enable multi-platform collaboration.



High Performance Spaceflight Computing (HPSC), POC: Rich Doyle/JPL and Wes Powell/GSFC

- Joint project between NASA and United States Air Force (USAF), which includes both AFRL and SMC.
- Goal: Develop a high-performance multi-core radiation hardened flight processor
- HPSC offers a new flight computing architecture to meet the needs of NASA missions through 2030 and beyond.
- Will provide on the order of 100X the computational capacity of current flight processors for the same amount of power, the multicore architecture of the HPSC processor, or "Chiplet" provides unprecedented flexibility in a flight computing system.



HPSC Chiplet Architecture Applications

New 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.

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 will be proposed under various mechanisms
2. Experiments will be approved and reviewed by a governance board
3. Lessons learned will be used to:
   a. Identify technology gaps
   b. Improve testbed
   c. Define additional experiments
4. Experiments will be published appropriately

New 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 Current Concept