Visualizing and understanding these processes will require observations made by a network of satellites distributed within this domain. MC-DRACO will reveal simultaneously for the first time both the global spatial structures and the time variations of the magnetotail. It will determine which phenomena are responses to solar wind inputs and which occur as a result of internal instabilities. In particular, it will reveal the locations and extents of the instabilities that trigger the explosive release of solar wind energy, mass, and momentum stored within the magnetotail, how these entities are transported, and the means by which magnetotail phenomena are propagated between regions and to the auroral ionosphere.

**MC-DRACO**, the logical outgrowth of a sequence of STP missions, will explore plasma transport and energy conversion processes over a broad range of spatial sizes. Designed to be a "meso-/macroscopic" for the magnetotail, it will resolve persistent controversies and yield a new understanding on which to build a predictive science of next-generation magnetospheric meteorology.

*Most important phenomena involve simultaneous variations in space and time. In some cases measurements at two locations will provide unambiguous results... It may be necessary to make simultaneous measurements at several hundred locations.—C.E. McIlwain*

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**The Magnetospheric Constellation Mission**

**Dynamic Response and Coupling Observatory (DRACO)**

- How does the magnetotail control energy flow?
- What processes control magnetotail structure and dynamics?
- How do the physical processes and regions couple over the hierarchy of scales?
Magnetostric Constellation Draco hopes to answer these questions. It is the Solar Terrestrial Probe designed to understand the nonlinear dynamics, responses, and connections within Earth's structured magnetotail, using a constellation of as many as 100 distributed vector measurement spacecraft. MC–Draco will reveal magnetotail processes operating within a specified domain, on spatial and time scales accessible to global circulation models.

In the magnetotail, global circulation of magnetic fields and plasmas responds to changing solar wind conditions. Impulsive localized flow bursts launch and dissipate, powerful electrical currents form and evolve abruptly, and magnetic energy is explosively converted to particle energy. The fundamental plasma process known as magnetic reconnection is thought to occur during substorms and is more frequent during magnetospheric storms. Because of the magnetotail's dynamic and turbulent evolution, globally coherent pictures of the system dynamics become lost in the “noise” of individual measurements. Despite over 30 years of research with ever more sophisticated instrumentation on ever-evolving spacecraft, fundamental questions concerning the dynamic response of the magnetotail remain unanswerable due to a lack of relevant measurements.

MC–Draco will use rapidly developing technologies to deploy a “constellation” of nanospacecraft. With resources of -10-20 kg and 10 W apiece, 50-100 nanosatellites will be deployed in highly elliptical, equatorial orbits with com-mon perigees of 3 R_E and apogees distributed from 7-40 R_E, yielding mean interspacecraft separation of ~1-2 R_E. The primary science will be accomplished annually when the constellation sweeps through the magnetotail. Ancillary magnetospheric/magnetosheath/solar wind science occurs during the balance of each year.

With a design lifetime of 2 years, MC–Draco is scheduled for launch in 2012 or earlier, depending on the progress of miniaturization and mass manufacturability of nanosatellites and their instrument payloads, while preserving functionality.
National Aeronautics and Space Administration

Guidance, Navigation and Control Innovations at the NASA Goddard Space Flight Center

Dr. Aprille Joy Ericsson

NASA GSFC AETD
Aerospace Engineer

NASA’s Vision
To improve life here,
To extend life to there,
To find life beyond.
NASA Mission

To understand and protect our home planet

To explore the universe and search for life

To inspire the next generation of explorers

...as only NASA can.

Earth Science Enterprise (ES)

Pioneers in Scientific Observation of the Earth

Our Mission:
Develop a scientific understanding of the Earth system and its response to natural and humaninduced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations.
Earth Science Research Focus Areas

- Long Term Climate
- Medium Term Climate
- Extreme Weather
- Ecosystems & Carbon Cycle
- Solid Earth & Natural Hazards
- Sun/Earth Interaction

Partnerships Are Essential

- International
  - Over 290 agreements with approx. 60 different countries
  - International research programs with multilateral organizations such as FAO, UNEP, WMO, WHO and CCAD
- Interagency
  - Joint weather satellite programs with NOAA & DoD
  - Landsat with DOI/USGS
  - Research and applications with USDA, DOT, NSF, FEMA, USFS
  - US Global Change Research Program
- Regional, State & Local
  - Associations of states, counties and cities
  - Consortia of local governments and universities
- Commercial
  - Traditional industrial partnerships
  - Purchases of commercial data
  - Targeted advanced technology collaborations
**ESE Spaceborne Missions**

**Systematic Missions** - Observation of Key Earth System Interactions

- Terra
- LandSat 7
- Aqua
- Aura
- SeaWinds
- QuikSCAT
- Jason-1
- ICEsat

**Exploratory Missions** - Exploration of Specific Earth System Processes and Parameters and Demonstration of Technology

- SRTM
- GRACE
- CALIPSO
- Cloudsat
- GIFTS
- EO-1
- Triana

**Key Technology Needs for Earth Science**

**Large Antennas**

- Validation enables improved soil moisture & global precipitation science capabilities

**Communications**

- Optical Comm from LEO to GEO
- RF Comm demonstrates Ka-band in space

**Lasers & Deployable Telescopes**

- Flight validations enable atmospheric chemistry, aerosols & winds science missions

**Distributed Spacecraft**

- Distributed platforms will lead to "sensor webs" for ocean & atmospheric science missions
Mission Evolution

How Our Mission is Changing:
- Increased Technical Complexity
- Multiple Spacecraft Missions
- Reconfigurable Sensing
- New Areas of Scientific Emphasis
- Increased Reliance on Partnerships
- New Demands on Industry

Future Missions:
- GPM
- LISA
- CON-X

Goddard Technology Competencies:
- High Sensitivity Detector Systems
- Large Aperture Space Observatories
- Distributed Observing Systems/Constellations
- Flight and Scientific Information Systems

Guidance, Navigation & Control Division (GN&C)

Vision
We are the premier GN&C organization providing innovative solutions that help revolutionize Earth and Space science missions.

Mission
Enable Earth and Space Science Missions by:
- Providing GN&C Applied Engineering
- Leading GN&C Technology Development
The GN&C Center's in-depth experience make them capable of developing and supporting the Whole Spectrum of GN&C Systems.
Advanced end-to-end spacecraft GN&C systems

Advanced mission design techniques to revolutionize Earth & Space science missions

Distributed Spacecraft Systems
- Spaceborne GPS
- Formation Flying, Constellations, & on-board autonomy

Micro/Nanosat Technologies
- Nano-sensors
- MEMS Gyros
- Micro-reaction wheels
- Micro-Newton Thrusters

Strategic Thrusts

Working with the science community to help revolutionize Earth & Space Science missions

- Advanced end-to-end spacecraft GN&C systems
- Advanced mission design techniques to revolutionize Earth & Space science missions
- Distributed Spacecraft Systems
  - Spaceborne GPS
  - Formation Flying, Constellations, & on-board autonomy
- Micro/Nanosat Technologies
  - Nano-sensors
  - MEMS Gyros
  - Micro-reaction wheels
  - Micro-Newton Thrusters
GPS satellite navigation is a proven technology that provides potential for low-cost autonomous satellite navigation.

GPS Enhanced Orbit Navigation System (GEONS) flight software provides a factor of 15 improvement in position accuracy over point solution.

Mission Orbit Types

GPS algorithms, software, receiver hardware, and simulators must be enhanced to broaden the mission scope to include all near-Earth missions, such as highly elliptical orbits (HEO) and geosynchronous Earth orbits (GEO), and to support relative navigation for formation flying applications.
**Distributed Spacecraft Systems: Enabling New Earth & Space Science**

- **Co-observation**
- **Interferometry**
- **Multi-point observation**
- **Large Interferometric Space Antennas**
- **Tethered Interferometry**

*New era of space exploration will be enabled by cooperating fleets of (small) spacecraft*

**Landsat-7 / Earth Observer-1 Co-observing Program**

- Demonstrates a cross-calibration of Earth observing instruments and GN&C formation flying techniques

Landsat-7 launch, July 1999
Earth Observer-1 launch, November 2000
Two satellites fly in along-track formation
Earth Observer-1 flies over same ground track as Landsat-7
Nominal 1-minute +/- 6-second spacecraft separation (450 km along-track separation)
Laser Interferometer Space Antenna (LISA)

**Mission:**
- 3 spacecraft separated by 5,000,000 km form a three-arm 'Michelson Interferometer' to observe gravitational waves in a $10^{-4}$ to $10^{-1}$ Hz bandwidth

**Approach:**
- Each spacecraft payload includes two freely falling proof masses which serve as arm 'end mirror' optical references
- Test masses must be free of Earth gravitational forces (geodesically pure)
- Gravitational waves cause change in optical path in one arm of interferometer relative to other arm
- Distance changes measured with picometer precision to detect gravitational wave strains down to $10^{-23}$
- Disturbance Reduction System (DRS) uses proof mass displacement sensor outputs to drive low-noise micro-Newton thrusters for 'drag-free' system operation

**Results:**
- Performance improvement of 100,000,000
Future Earth and Space Science missions pose significant science-driven and cost-driven GN&C challenges.

Innovative GN&C technologies are being developed at GSFC to meet these challenges:

- Precision pointing and stabilization
- Relative navigation and control for formation flying
- Advanced mission (trajectory & attitude) design
- Drag-free control systems (DRS)
- GPS in “above-the-constellation” flight regimes
- Autonomous navigation beyond the reach of GPS
- Miniature, low power, low mass Micro/Nanosat GN&C components

**GN&C Technology is Our Future!**
Strategic Technology Thrusts: Distributed Spacecraft/Formation Flying

GPS Receiver Development
- Honeywell/Trimble/Cellnet/GSFC Space Integrated GPS/INS (SIG)
- Low Power Transceiver/GEODE Flight Experiment
- GSFC developed, low-cost spaceborne receiver with future attitude capability
- GPS Like Crosslink Systems

Formation Flying and Virtual Platforms
Revolutionizing how we utilize space!

Science Perspective:
- Significant improvements in space-based interferometry
- Enables autonomous co-observing programs
- Enables extensive multi-point observing

Programmatic Perspective:
- Instruments join the fleet when ready
- Replace complex platforms w/ simple s/c in formation
- Eliminates inter-instrument systems issues
- Evolving virtual infrastructure permits adaptation & evolution
GEONS: GPS-Enhanced Onboard Navigation System

Demonstrated Capabilities
- Low Earth Orbit GPS
  - Flight data validation: Defense
  - Flight qualification: Loral
  - Flight proven: Earth Observer
- High Earth Orbit GPS
  - Analytic proof-of-concept for up to 1500 kg
  - Flight data validation for 1500 kg (3300 lb) in work
- Celestial Navigation
  - Analytic proof-of-concept for elevation point orbit (EPO)
  - Flight data validation for 1500 kg (3300 lb) (NEAL) and 3500 kg (7700 lb)

Mission Orbit Types

Celestial Object, Crosslink, and Doppler Measurements

Transmit/Receive Transponder Transponded Responses

Transmit/Receive Transponder Transponded Responses

Transmit/Receive Transponder Transponded Responses

Transmit/Receive Transponder Transponded Responses

Technology Transfer
- Jointly developed by NASA GSFC and Computer Sciences Corporation, CSC copyright assigned to U.S. Gov't
- Commercially licensed to Orbital Sciences Corporation and Ball Aerospace
- Inferred into ITT Low Power Transmitter and GSFC PVMT GPS receiver

Flighted Capabilities
- Tracking and Data Relay Satellite (TDRS) Onboard Navigation
  - Flight data validation: Defense
  - Flight proven: Terahertz
  - GPS attitude determination
  - Low Earth orbit celestial maneuvers

N. C.

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