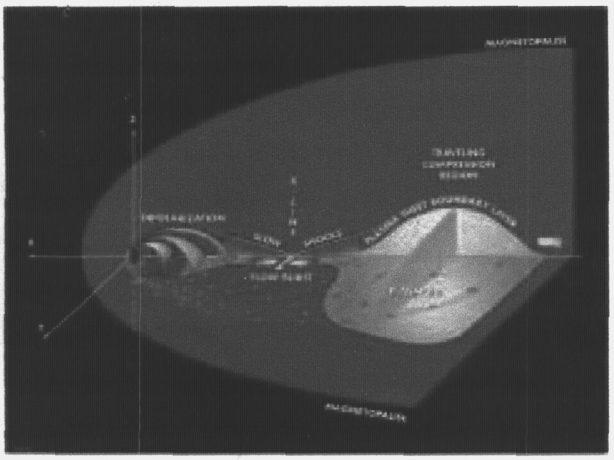


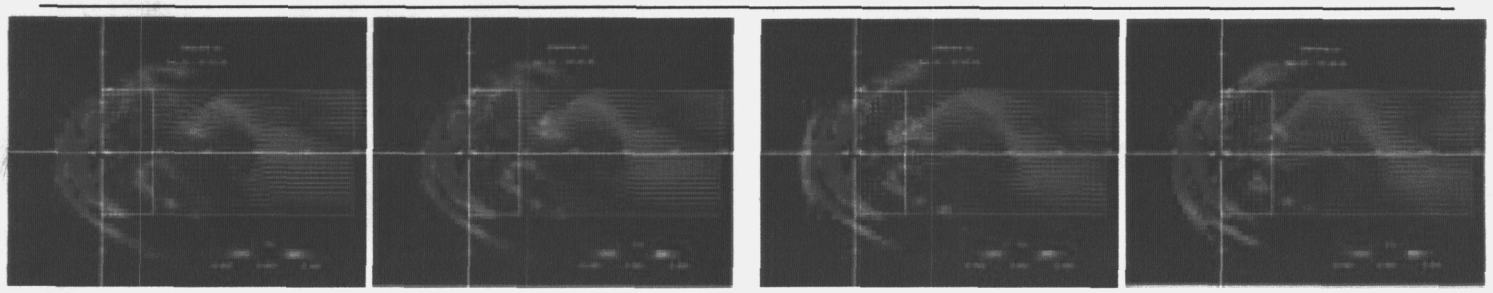
Cartoon of global consequences of tail reconnection near Earth during substorm. Fast flows propagate Sunward accompanied by rapid dipolarization. New plasmoid travels downstream, creating traveling compression region in magnetic lobes. DRACO nanosatellites shown schematically throughout plasma sheet. (Courtesy J. Slavin, NASA/GSFC.)

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.

NASA Goddard Space Flight Center http://stp.gsfc.nasa.gov

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-/macroscope" 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.

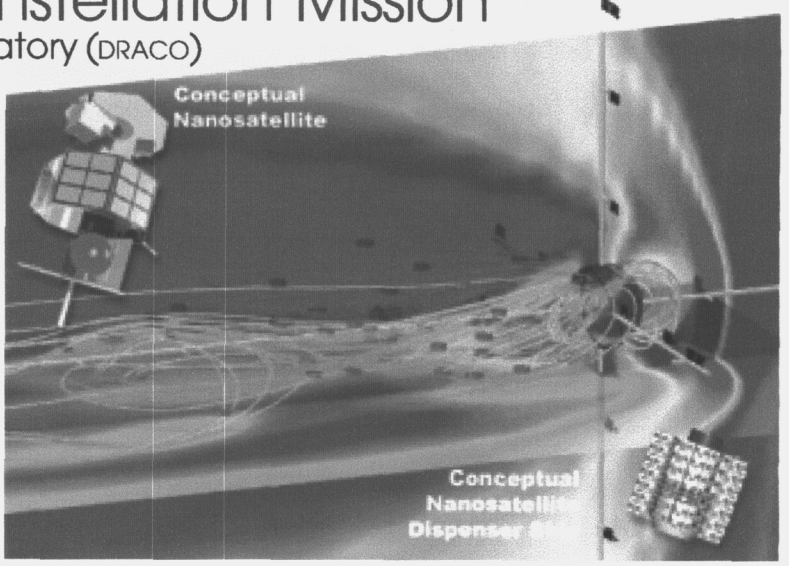
***Most important phenomena involve simultaneous variations in space and time. In some cases cases measurements at two locations will provide unambiguous results. . . [I]t may be necessary to make simultaneous measurements at several hundred locations.*—C.E. McIlwain**



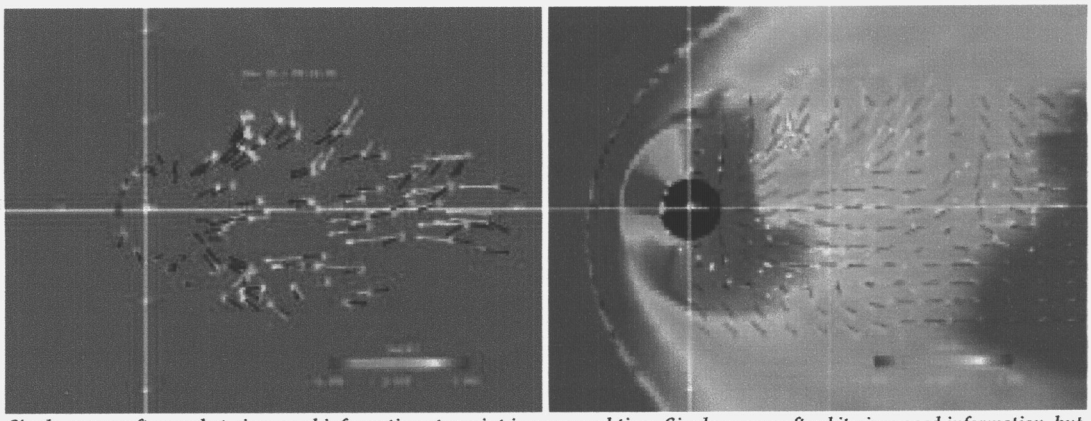
The Magnetospheric Constellation Mission

Dynamic Response and Coupling Observatory (DRACO)

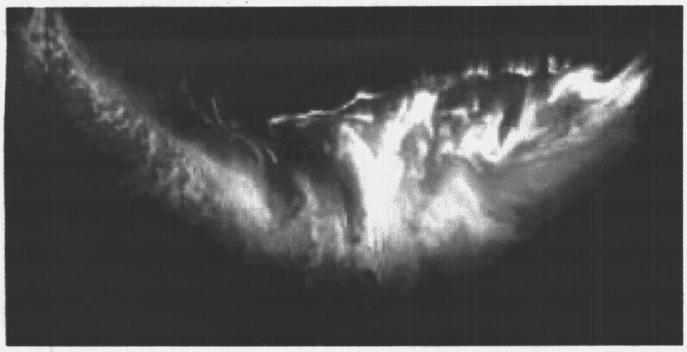
- *How does the magnetotail control energy flow?*
- *What processes control magnetotail structure and dynamics?*
- *How do the physical processes and regions couple over the hierarchy of scales?*



MAGNETOSPHERIC 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.

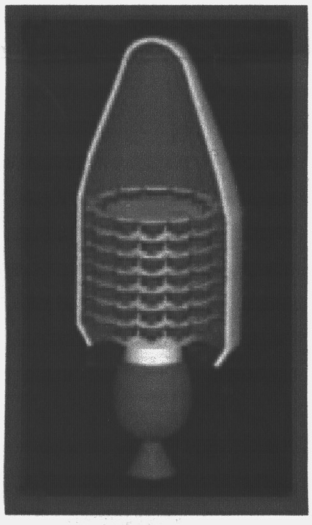


Single-spacecraft snapshot gives good information at a point in space and time. Single-spacecraft orbit gives good information, but over a 3-day orbit that evolves through space over time. Constellation gives a dense set of data with time and spatial resolution adequate to resolve main global features of simulation (right). (Courtesy C.C. Goodrich.)



Example of global auroral structure during significant magnetospheric disturbance. Image acquired by Defense Meteorological Spacecraft Program spacecraft moving along relatively low Earth orbit, and is, therefore, time-aliased. (Courtesy Air Force Research Laboratories.)

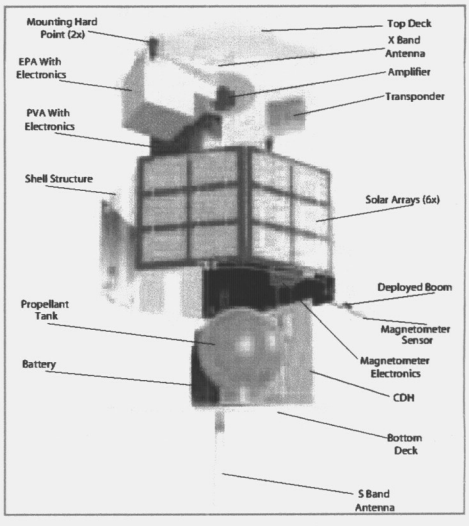
IN THE MAGNETOTAIL, global circulation of magnetic fields and plasmas responds to changing solar wind conditions. Impulsive localized flow bursts launch and dissipate, powerful electrical currents form and evolve abruptly, and magnetic energy is explosively converted to particle energy. The fundamental 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.



Conceptual dispenser ship.

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 occur 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.



Conceptual view of ST–5 satellite for Magnetotail Constellation.

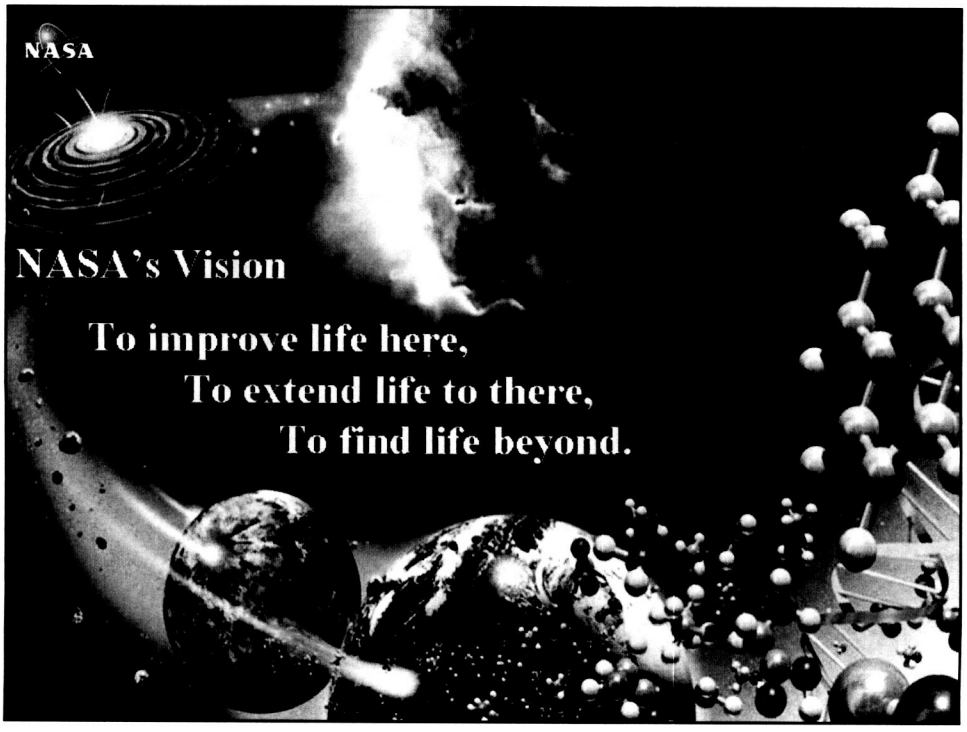
National Aeronautics and Space Administration

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

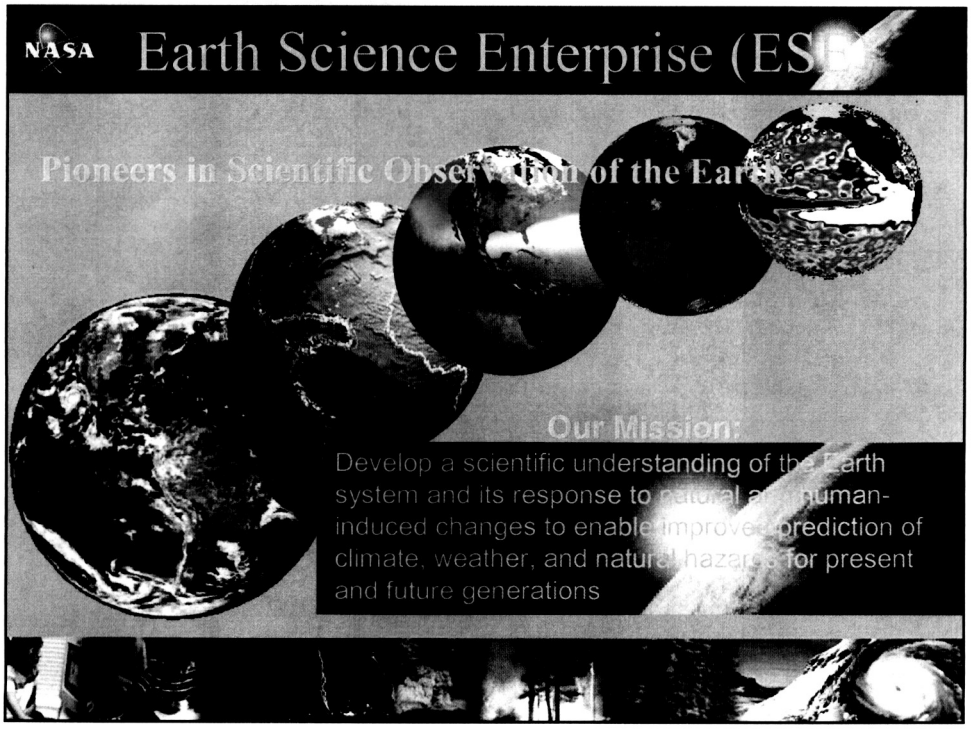
Dr. Aprille Joy Ericsson

NASA GSFC AETD

Aerospace Engineer

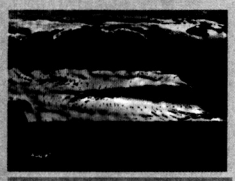
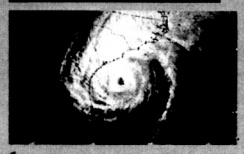
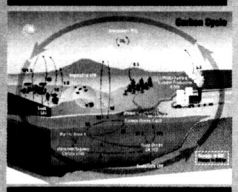



NASA
NASA Mission
To understand and protect our home planet
To explore the universe and search for life
To inspire the next generation of explorers
...as only NASA can.


NASA
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 human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations

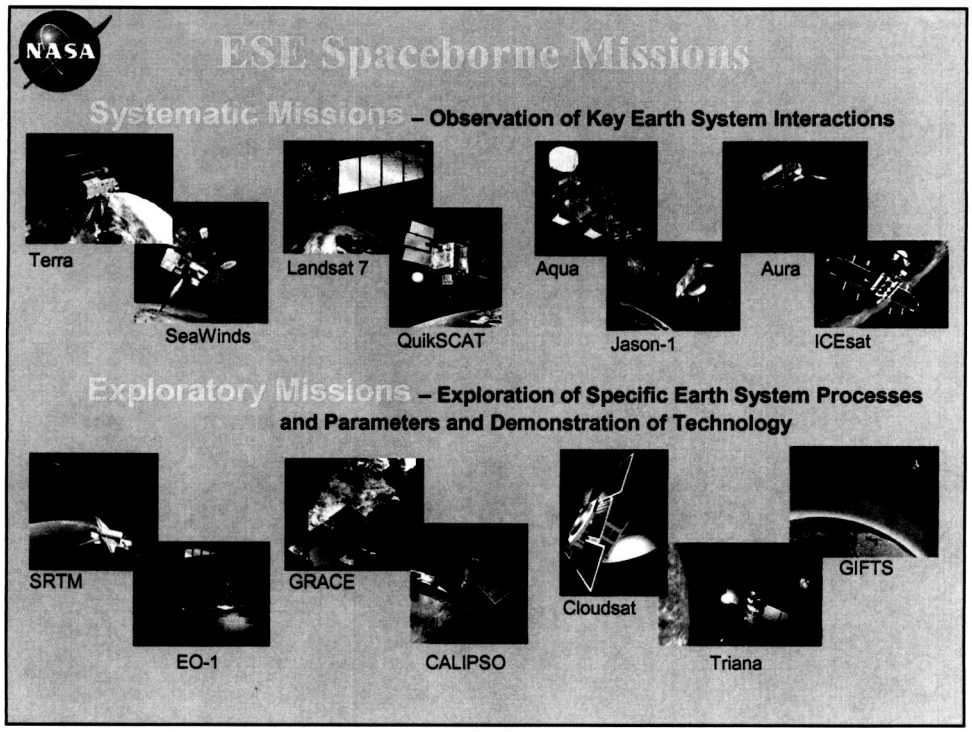
Earth Science Research Focus Areas

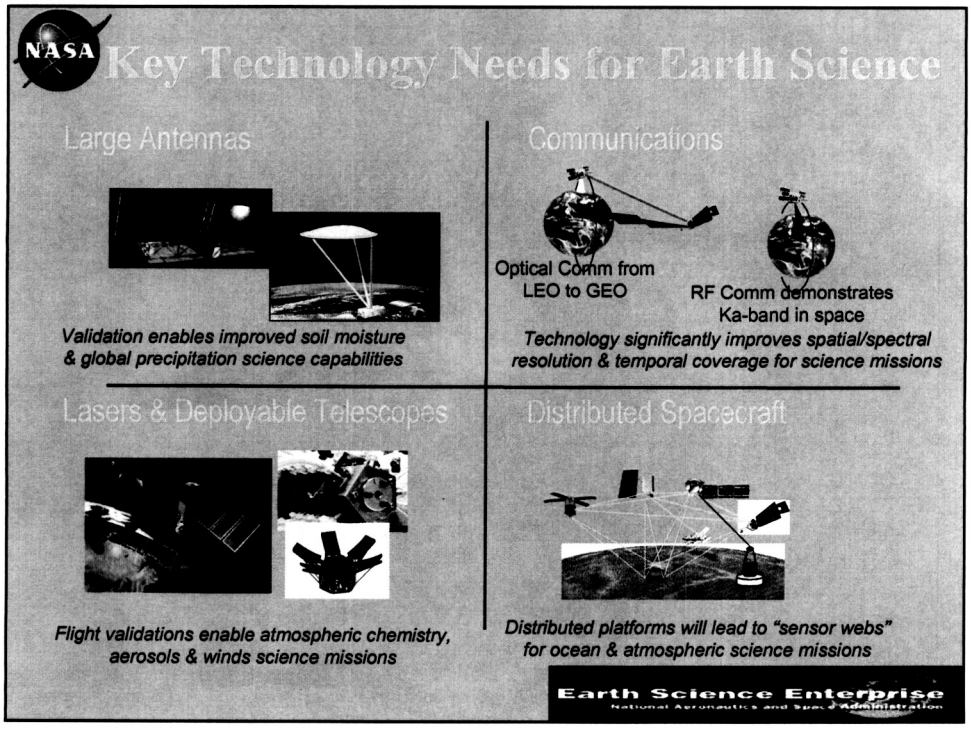
- Long Term Climate
- Medium Term Climate
- Extreme Weather
- Ecosystems & Carbon Cycle
- Solid Earth & Natural Hazards
- Sun/Earth Interaction

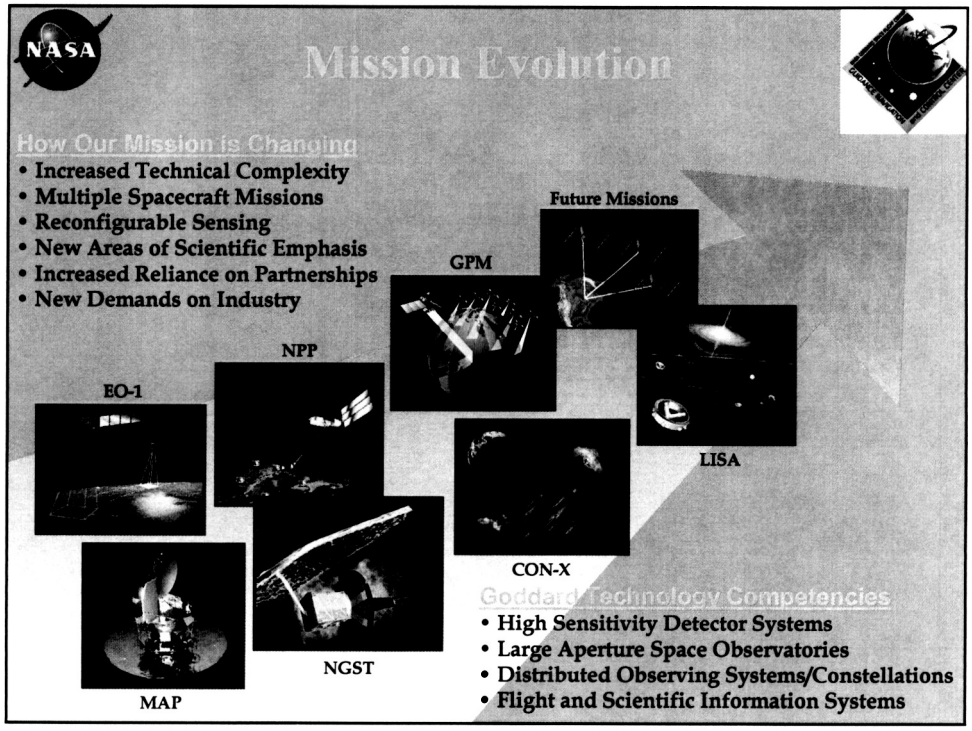





Partnerships Are Essential

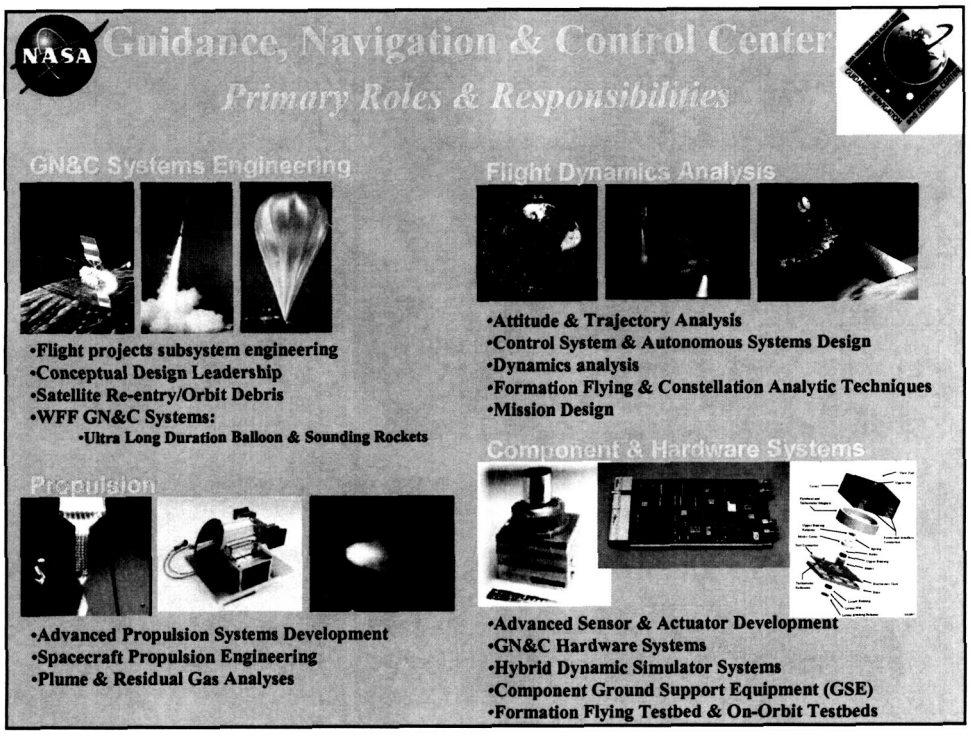
- International
  - Over 290 agreements with approx. 60 different countries
  - International research programs with multilateral organizations such as FAO, UNEP, WMO, WHO and CCAD
- Interagency
  - Joint weather satellite programs with NOAA & DoD
  - Landsat with DOI/USGS
  - Research and applications 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

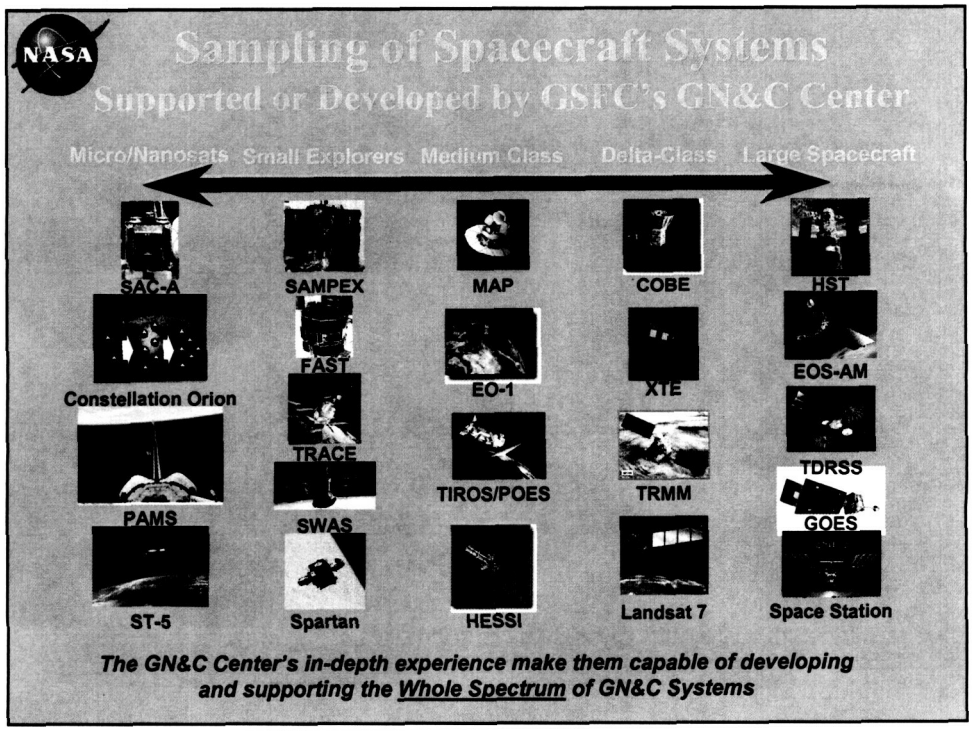

ESE Spaceborne Missions
Systematic Missions – Observation of Key Earth System Interactions
Terra
SeaWinds
Landsat 7
QuikSCAT
Aqua
Jason-1
Aura
ICEsat
Exploratory Missions – Exploration of Specific Earth System Processes and Parameters and Demonstration of Technology
SRTM
EO-1
GRACE
CALIPSO
Cloudsat
Triana
GIFTS

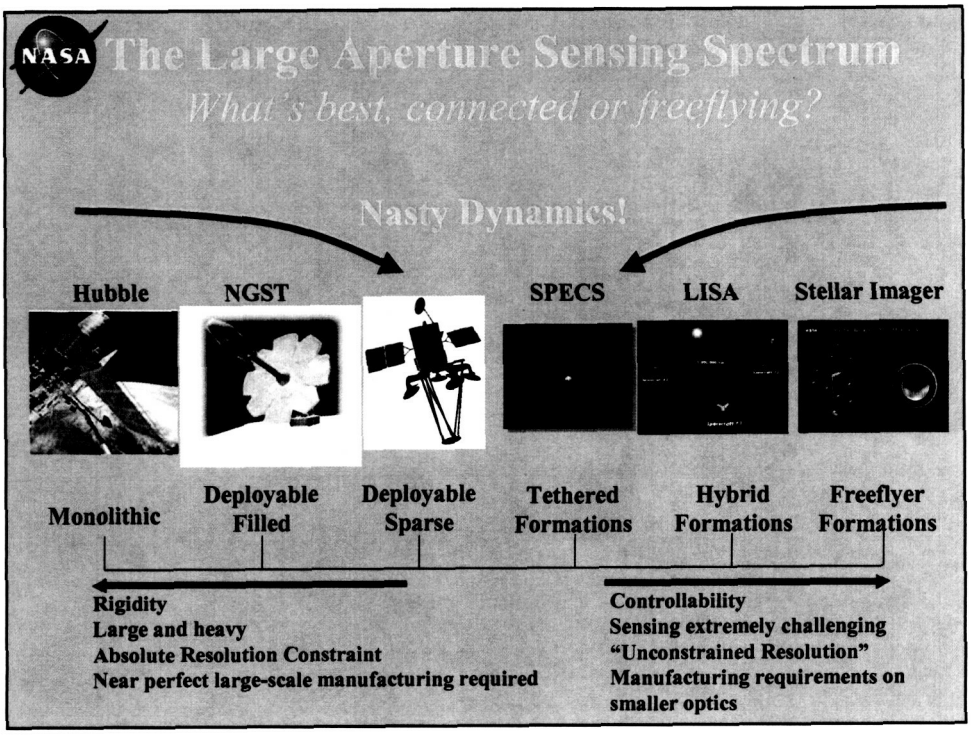

Key Technology Needs for Earth Science
Large Antennas
Validation enables improved soil moisture & global precipitation science capabilities
Communications
Optical Comm from LEO to GEO
RF Comm demonstrates Ka-band in space
Technology significantly improves spatial/spectral resolution & temporal coverage for science missions
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
Earth Science Enterprise

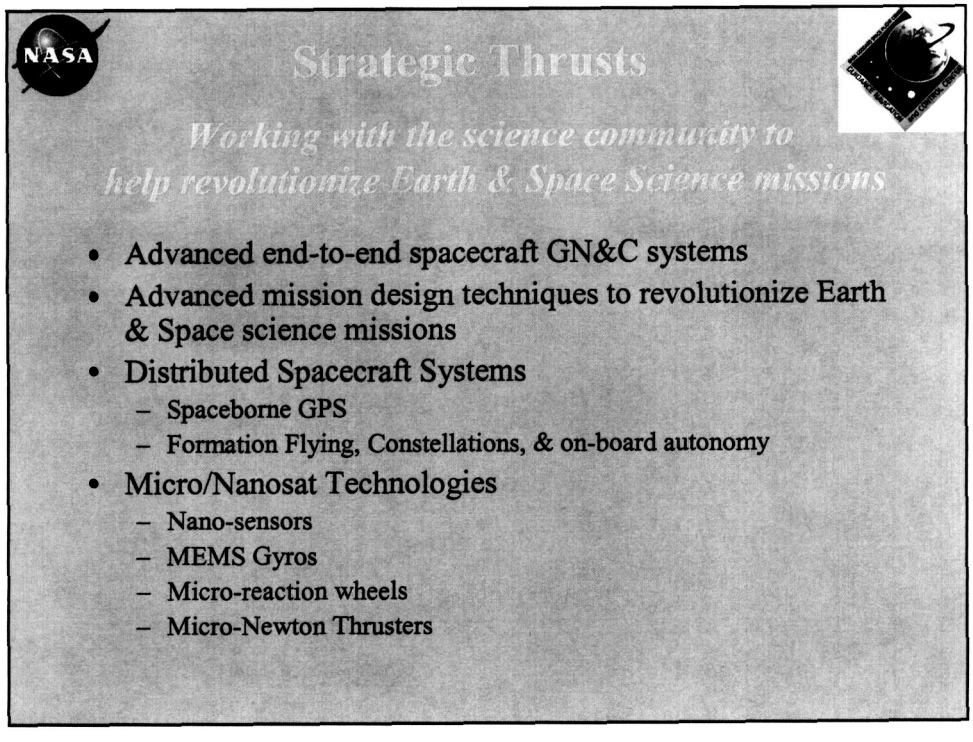

Mission Evolution
How Our Mission is Changing
• Increased Technical Complexity
• Multiple Spacecraft Missions
• Reconfigurable Sensing
• New Areas of Scientific Emphasis
• Increased Reliance on Partnerships
• New Demands on Industry
Future Missions
GPM
NPP
EO-1
LISA
CON-X
NGST
MAP
Goddard Technology 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


Guidance, Navigation & Control Center
Primary Roles & Responsibilities
GN&C Systems Engineering
•Flight projects subsystem engineering
•Conceptual Design Leadership
•Satellite Re-entry/Orbit Debris
•WFF GN&C Systems:
•Ultra Long Duration Balloon & Sounding Rockets
Flight Dynamics Analysis
•Attitude & Trajectory Analysis
•Control System & Autonomous Systems Design
•Dynamics analysis
•Formation Flying & Constellation Analytic Techniques
•Mission Design
Propulsion
•Advanced Propulsion Systems Development
•Spacecraft Propulsion Engineering
•Plume & Residual Gas Analyses
Component & Hardware Systems
•Advanced Sensor & Actuator Development
•GN&C Hardware Systems
•Hybrid Dynamic Simulator Systems
•Component Ground Support Equipment (GSE)
•Formation Flying Testbed & On-Orbit Testbeds

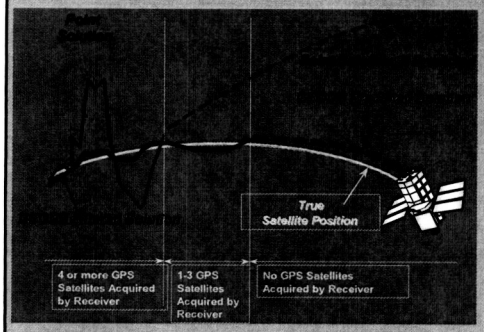

Sampling of Spacecraft Systems
Supported or Developed by GSFC's GN&C Center
Micro/Nanosats
Small Explorers
Medium Class
Delta-Class
Large Spacecraft
SAC-A
SAMPEX
MAP
COBE
HST
Constellation Orion
FAST
EO-1
XTE
EOS-AM
TRACE
PAMS
SWAS
TIROS/POES
TRMM
TDRSS
GOES
ST-5
Spartan
HESSI
Landsat 7
Space Station
The GN&C Center's in-depth experience make them capable of developing and supporting the Whole Spectrum of GN&C Systems


The Large Aperture Sensing Spectrum
What's best, connected or freeflying?
Nasty Dynamics!
Hubble
NGST
SPECS
LISA
Stellar Imager
Monolithic
Deployable Filled
Deployable Sparse
Tethered Formations
Hybrid Formations
Freeflyer Formations
Rigidity
Large and heavy
Absolute Resolution Constraint
Near perfect large-scale manufacturing required
Controllability
Sensing extremely challenging
"Unconstrained Resolution"
Manufacturing requirements on smaller optics


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

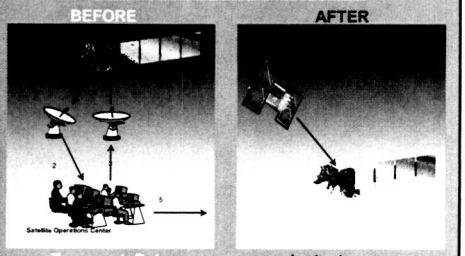
Global Positioning System (GPS) Navigation

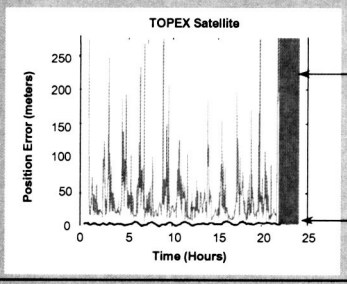
GPS satellite navigation is a proven technology that provides potential for low-cost autonomous satellite navigation.



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

Ground-Based Navigation Scenario

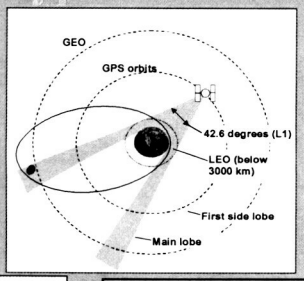


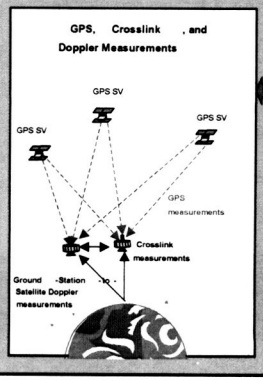


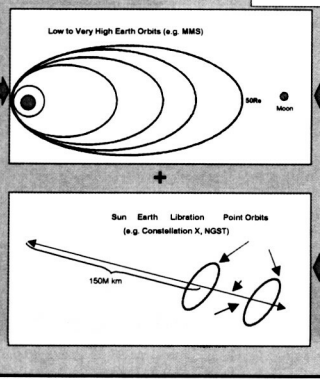
GEODE improves position accuracy by a factor of 15

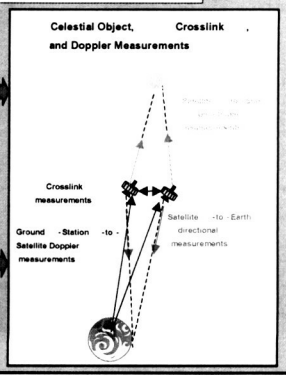
Mission Orbit Types

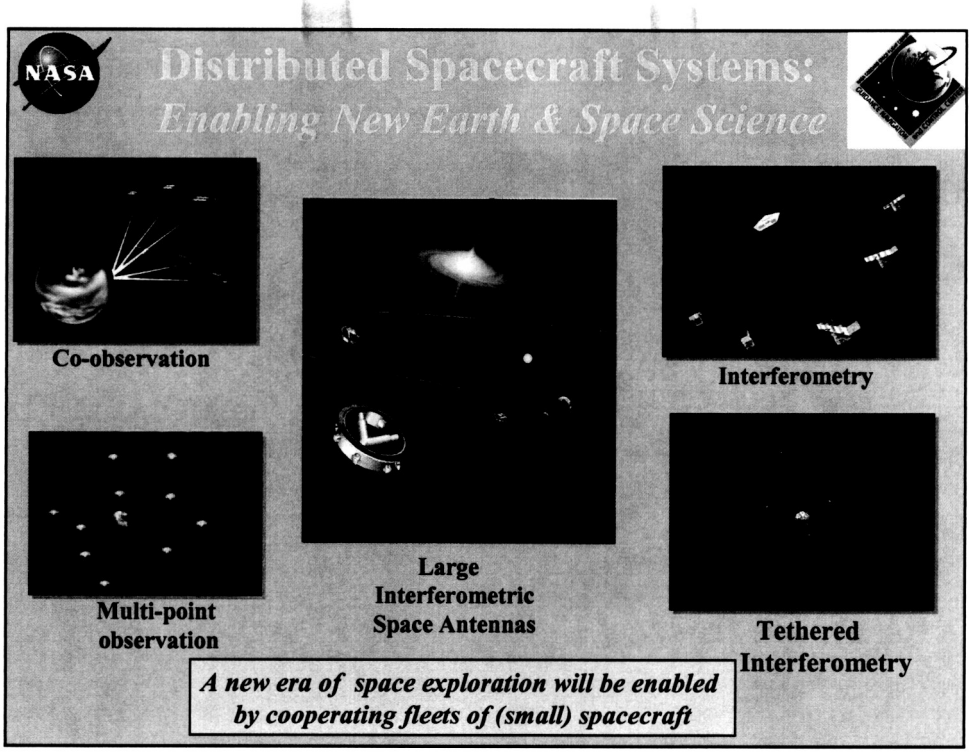
GPS algorithms, software, receiver hardware, and simulators must be enhanced to broaden the mission scope to include all near-Earth missions, such as highly elliptical orbits (HEO) and geosynchronous Earth orbits (GEO), and to support relative navigation for formation flying applications.










NASA
Distributed Spacecraft Systems:
Enabling New Earth & Space Science
Co-observation
Interferometry
Multi-point observation
Large Interferometric Space Antennas
Tethered Interferometry
A new era of space exploration will be enabled by cooperating fleets of (small) spacecraft


NASA
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 (450km along-track separation)

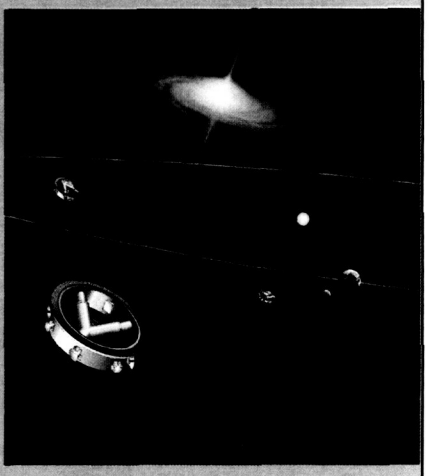
Laser Interferometer Space Antenna (LISA)

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



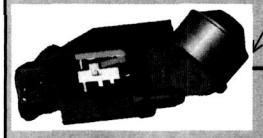
Results:

- Performance improvement of 100,000,000

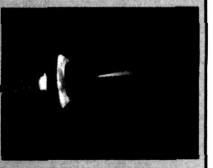
ST7 Disturbance Reduction System (DRS)

Proof Mass position/rotation outputs

Thruster Commands



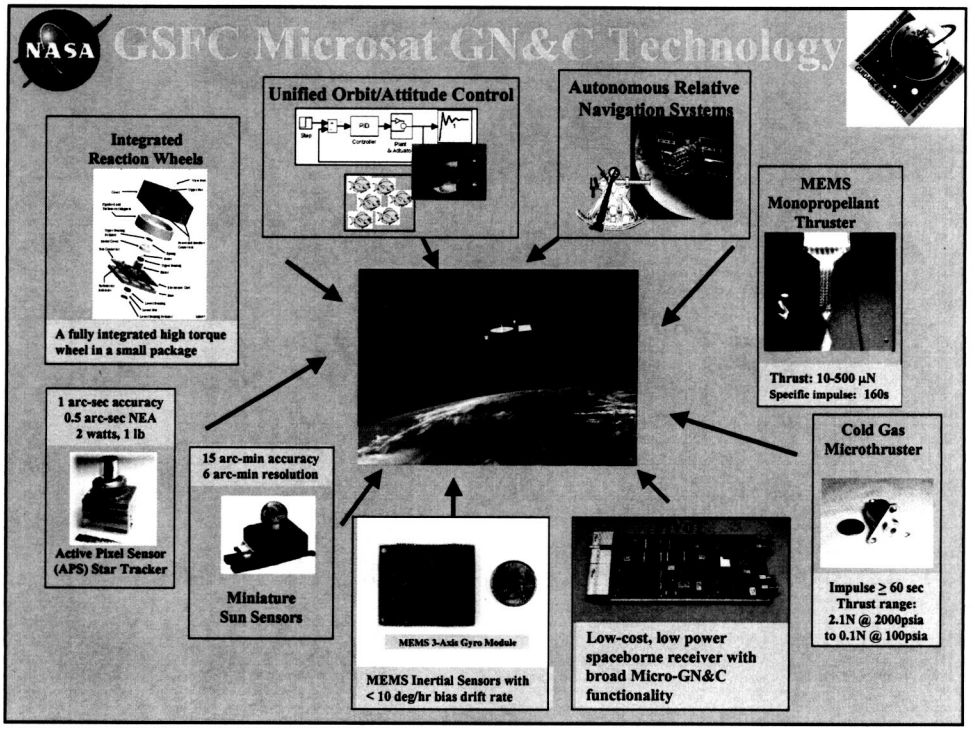
Spacecraft Attitude and Translational Control Flight Software

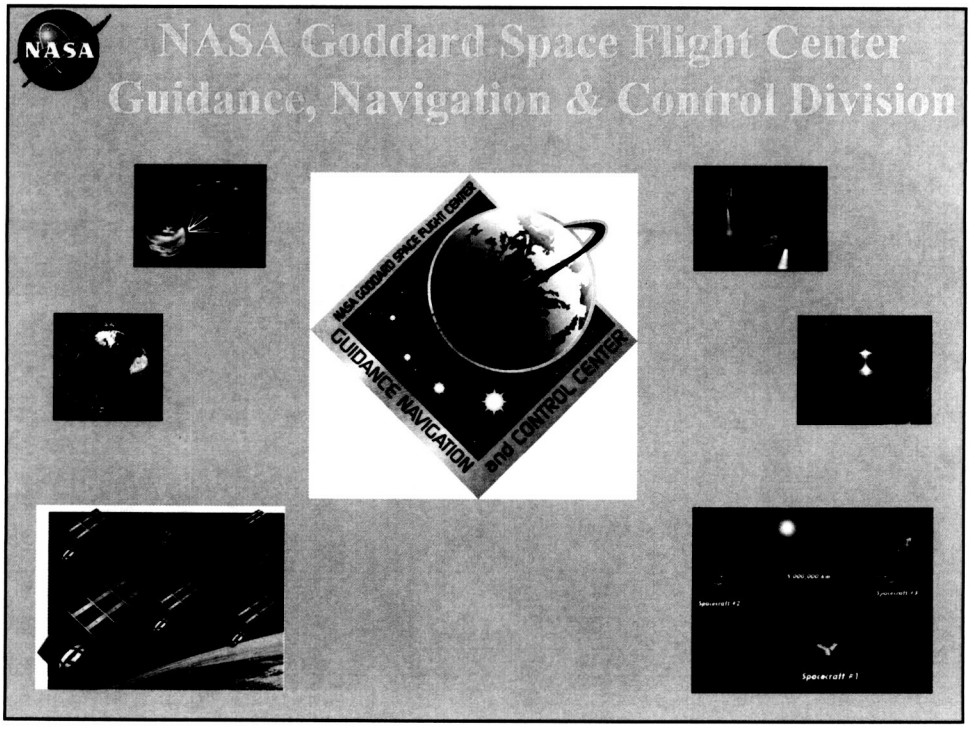


Gravitational Reference Sensor **(Stanford University)**

ST7 DRS Processor **(GSFC)**

Micro-Newton Micro-Colloidal Thrusters **(Busek Technology)**


GSFC Microsat GN&C Technology
Unified Orbit/Attitude Control
Autonomous Relative Navigation Systems
Integrated Reaction Wheels
A fully integrated high torque wheel in a small package
MEMS Monopropellant Thruster
Thrust: 10-500 μN
Specific impulse: 160s
1 arc-sec accuracy
0.5 arc-sec NEA
2 watts, 1 lb
Active Pixel Sensor (APS) Star Tracker
15 arc-min accuracy
6 arc-min resolution
Miniature Sun Sensors
Cold Gas Microthruster
Impulse ≥ 60 sec
Thrust range:
2.1N @ 2000psia
to 0.1N @ 100psia
MEMS 3-Axis Gyro Module
MEMS Inertial Sensors with < 10 deg/hr bias drift rate
Low-cost, low power spaceborne receiver with broad Micro-GN&C functionality

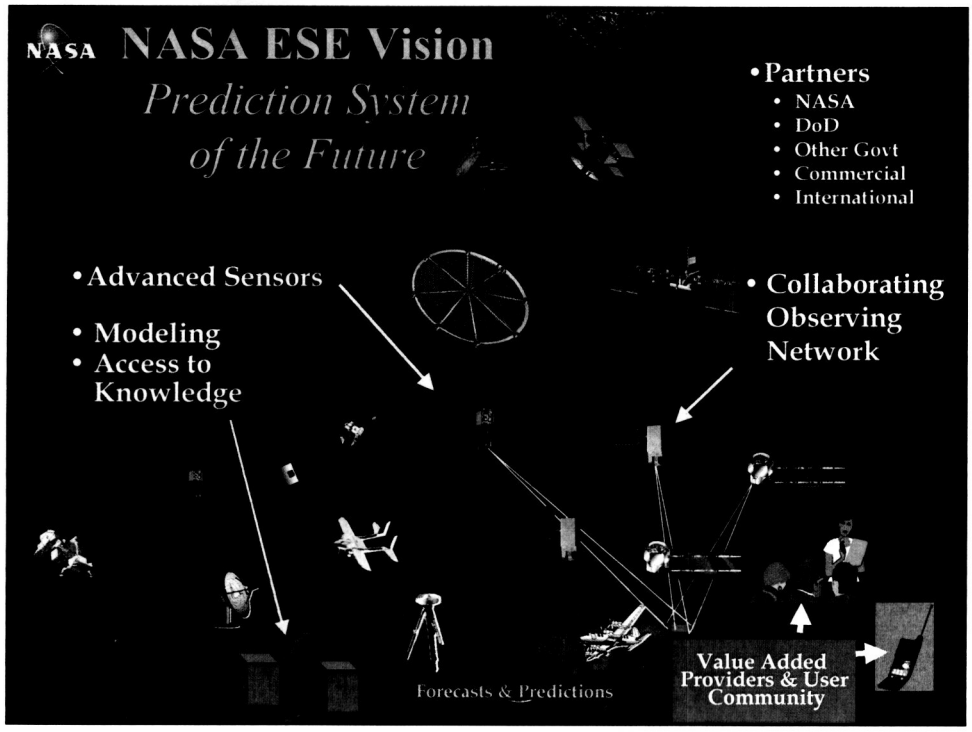

NASA Goddard Space Flight Center
Guidance, Navigation & Control Division
NASA GODDARD SPACE FLIGHT CENTER
GUIDANCE NAVIGATION and CONTROL CENTER

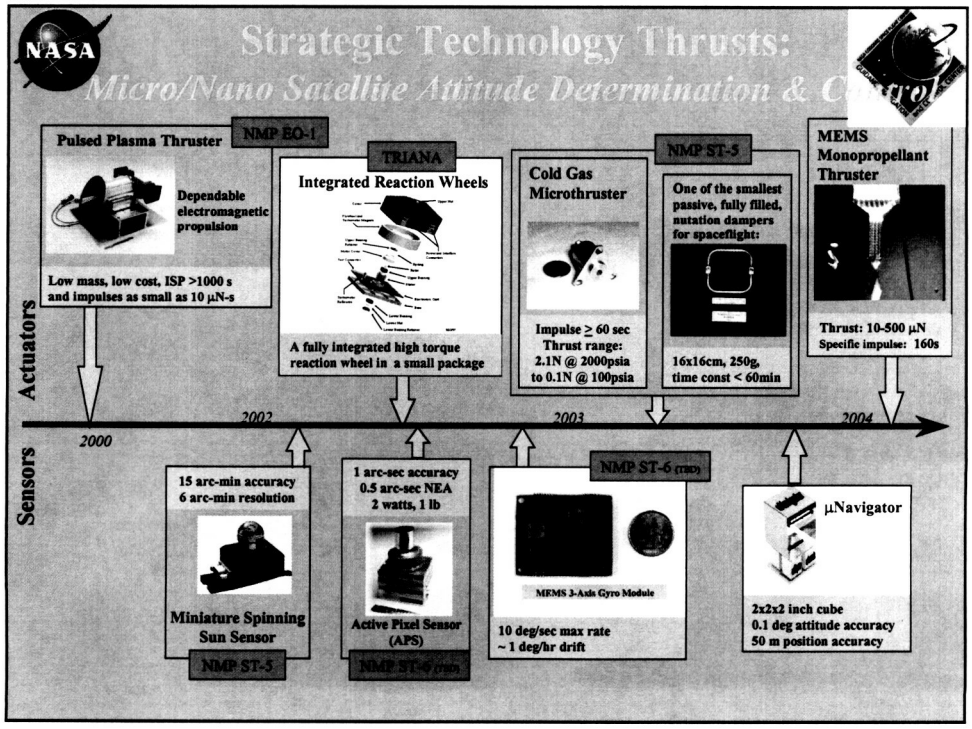
Summary

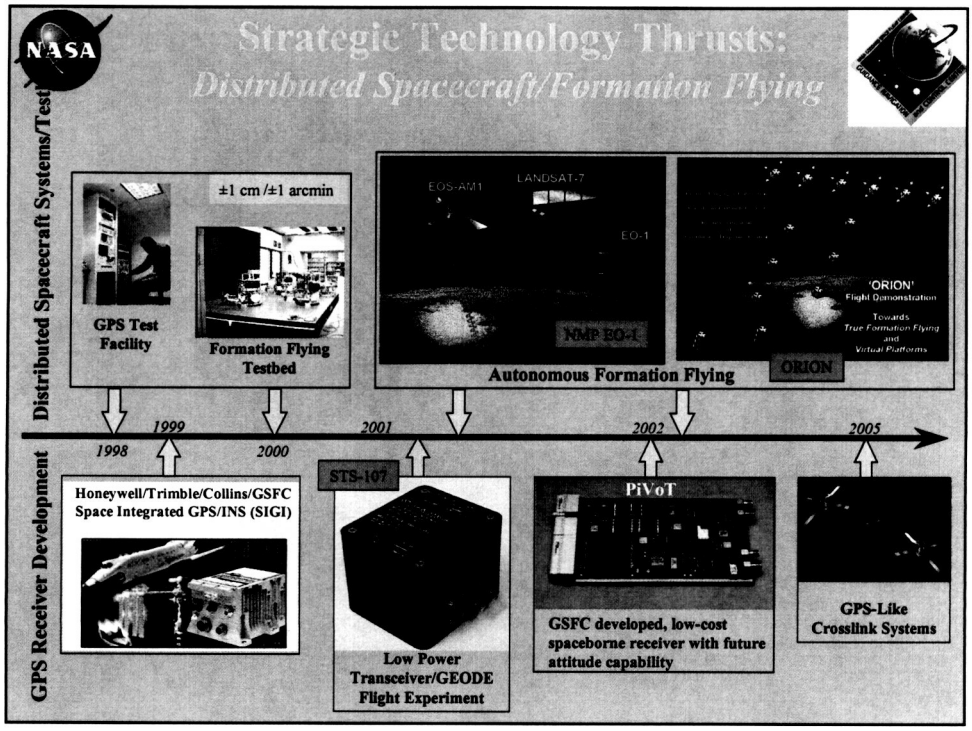
- Future Earth and Space Science missions pose significant science-driven and cost-driven GN&C challenges
- Innovative GN&C technologies are being developed at GSFC to meet these challenges :
  - Precision pointing and stabilization
  - Relative navigation and control for formation flying
  - Advanced 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

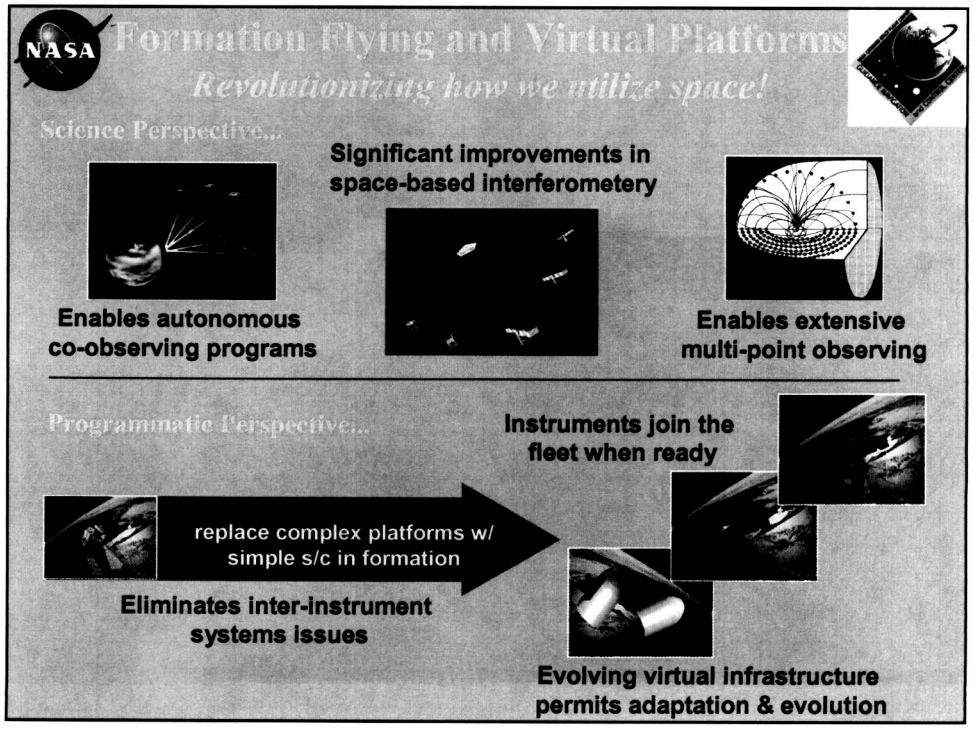
GN&C Technology is Our Future!

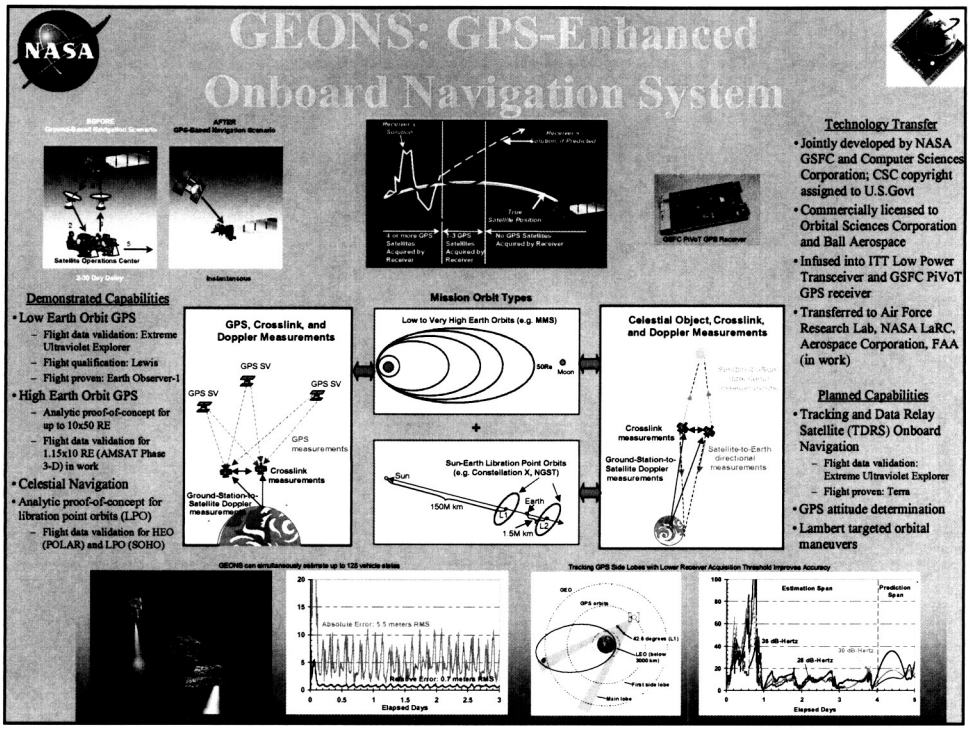
Backup Slides


NASA ESE Vision
Prediction System of the Future
• Partners
• NASA
• DoD
• Other Govt
• Commercial
• International
• Advanced Sensors
• Modeling
• Access to Knowledge
• Collaborating Observing Network
Forecasts & Predictions
Value Added Providers & User Community


Strategic Technology Thrusts:
Micro/Nano Satellite Attitude Determination & Control
Actuators
Sensors
Pulsed Plasma Thruster
NMP EO-1
Dependable electromagnetic propulsion
Low mass, low cost, ISP >1000 s and impulses as small as 10 μN-s
TRIANA
Integrated Reaction Wheels
A fully integrated high torque reaction wheel in a small package
Cold Gas Microthruster
NMP ST-5
One of the smallest passive, fully filled, nutation dampers for spaceflight:
Impulse ≥ 60 sec
Thrust range:
2.1N @ 2000psia
to 0.1N @ 100psia
16x16cm, 250g,
time const < 60min
MEMS Monopropellant Thruster
Thrust: 10-500 μN
Specific impulse: 160s
2000
2002
2003
2004
15 arc-min accuracy
6 arc-min resolution
Miniature Spinning Sun Sensor
NMP ST-5
1 arc-sec accuracy
0.5 arc-sec NEA
2 watts, 1 lb
Active Pixel Sensor (APS)
NMP ST-6 (TBD)
NMP ST-6 (TBD)
MEMS 3-Axis Gyro Module
10 deg/sec max rate
~ 1 deg/hr drift
μNavigator
2x2x2 inch cube
0.1 deg attitude accuracy
50 m position accuracy


Strategic Technology Thrusts:
Distributed Spacecraft/Formation Flying
Distributed Spacecraft Systems/Test
±1 cm /±1 arcmin
GPS Test Facility
Formation Flying Testbed
EOS-AM1
LANDSAT-7
EO-1
NMP EO-1
'ORION'
Flight Demonstration
Towards
True Formation Flying
and
Virtual Platforms
ORION
Autonomous Formation Flying
1998
1999
2000
2001
2002
2005
GPS Receiver Development
Honeywell/Trimble/Collins/GSFC
Space Integrated GPS/INS (SIGI)
STS-107
Low Power
Transceiver/GEODE
Flight Experiment
PiVoT
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 interferometery
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
NASA
BEFORE
Ground-Based Navigation Scenario
AFTER
GPS-Based Navigation Scenario
Satellite Operations Center
3-30 Day Delay
Instantaneous
Maneuver Initiation
Maneuver Completion (Predicted)
True Satellite Position
Five more GPS Satellites Acquired by Receiver
3 GPS Satellites Acquired by Receiver
No GPS Satellites Acquired by Receiver
GSFC PiVoT GPS Receiver
Technology Transfer
• Jointly developed by NASA GSFC and Computer Sciences Corporation; CSC copyright assigned to U.S.Govt
• Commercially licensed to Orbital Sciences Corporation and Ball Aerospace
• Infused into ITT Low Power Transceiver and GSFC PiVoT GPS receiver
• Transferred to Air Force Research Lab, NASA LaRC, Aerospace Corporation, FAA (in work)
Demonstrated Capabilities
• Low Earth Orbit GPS
– Flight data validation: Extreme Ultraviolet Explorer
– Flight qualification: Lewis
– Flight proven: Earth Observer-1
• High Earth Orbit GPS
– Analytic proof-of-concept for up to 10x50 RE
– Flight data validation for 1.15x10 RE (AMSAT Phase 3-D) in work
• Celestial Navigation
• Analytic proof-of-concept for libration point orbits (LPO)
– Flight data validation for HEO (POLAR) and LPO (SOHO)
Mission Orbit Types
GPS, Crosslink, and Doppler Measurements
GPS SV
GPS SV
GPS SV
GPS measurements
Crosslink measurements
Ground-Station-to-Satellite Doppler measurements
Low to Very High Earth Orbits (e.g. MMS)
50Re
Moon
Sun-Earth Libration Point Orbits (e.g. Constellation X, NGST)
Sun
150M km
L1
Earth
L2
1.5M km
Celestial Object, Crosslink, and Doppler Measurements
Crosslink measurements
Ground-Station-to-Satellite Doppler measurements
Satellite-to-Earth directional measurements
Planned Capabilities
• Tracking and Data Relay Satellite (TDRS) Onboard Navigation
– Flight data validation: Extreme Ultraviolet Explorer
– Flight proven: Terra
• GPS attitude determination
• Lambert targeted orbital maneuvers
GEONS can simultaneously estimate up to 128 vehicle states
Absolute Error: 5.5 meters RMS
Relative Error: 0.7 meters RMS
Elapsed Days
Tracking GPS Side Lobes with Lower Receiver Acquisition Threshold Improves Accuracy
GEO
GPS orbits
42.6 degrees (L1)
LEO (below 3000 km)
First side lobe
Main lobe
Estimation Span
Prediction Span
35 dB-Hertz
30 dB-Hertz
28 dB-Hertz
Elapsed Days