2000 NASA Software of the Year Award Nomination

GPS Enhanced Orbit Determination (GEODE) Software

Submitted by GSFC, Code 570

Team Members:

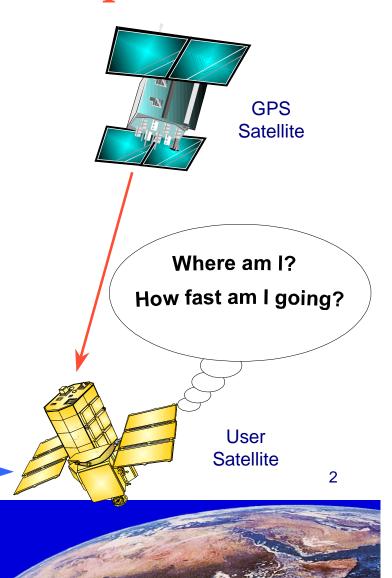|	
Mark Beckman	**Dr. J. Russell Carpenter**
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Dr. Dipak Oza	

Our Challenge: Move Satellite Navigation from Earth to Space

◆ **Satellite navigation is now performed on the ground**

◆ **Our challenge is to build a navigation system for civilian satellites using GPS that**

  – **Computes satellite position and velocity <u>onboard</u>, <u>instantaneously</u>, with <u>high accuracy</u>**

  – **Operates <u>reliably</u> without human intervention**

  – **Fits within very <u>limited</u> computing resources**

GPS Satellite

Where am I?

How fast am I going?

User Satellite

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Our Solution: GEODE

State-of-the-art navigation algorithms and operating-environment-independent, object-oriented software implementation

Unprecedented accuracy, reliability, and autonomy

$$\frac{d^2 X}{dt^2} = a_x$$
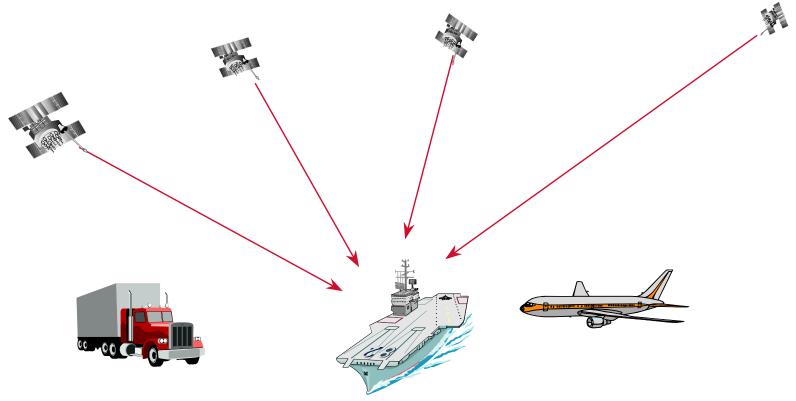
In use by NASA and commercial projects

Open-architecture, licensed GSFC product

$$K = P(-)H^T[HP(-)H^T + R]^{-1}$$

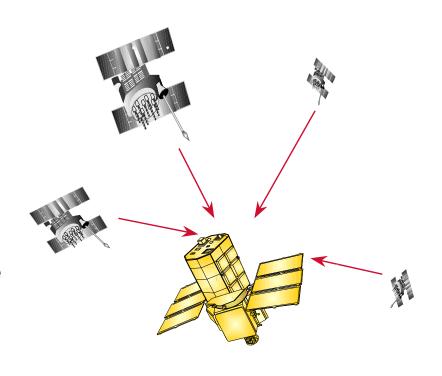**Enables advanced autonomous satellite operations**

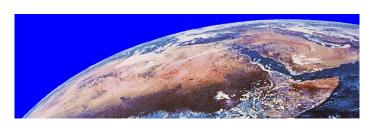# *GPS Receiver Solution Using Standard Method*

- Designed primarily for near-Earth use

- Requires continuous visibility of <u>at least four</u> GPS satellites to compute position (receiver solution)

- Accurate use of GPS signals in civil domain is eight times harder than in the military domain

Unique Challenges of Using GPS for Satellite Navigation

- **High accuracy velocity required for accurate position prediction**

- **GPS receiver outages due to hostile space environment (solar particle radiation or high velocities)**

- **GPS visibility limited by antenna placement and changing satellite orientation**

- **Many potential science missions are above the GPS constellation**

- **Limited computer processing power in space**

Key Accomplishments vs Evaluation Criteria

Innovation

Science and Technology Significance and Impact
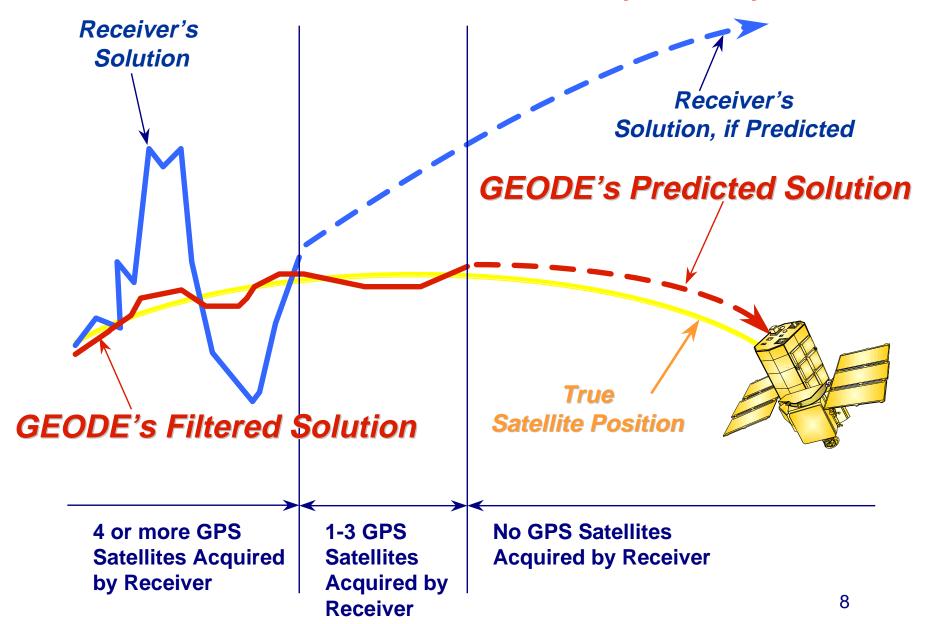
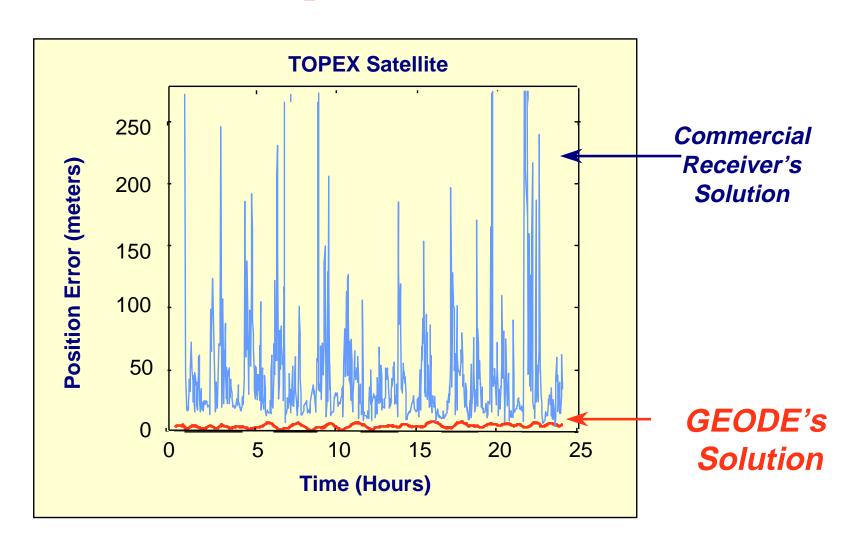**Extent of Current and Potential Use**

Usability of Software

Quality Factors

Innovation: State-of-the-Art Algorithms for the Space Environment

Innovative Algorithms	Benefits
Accurate model for satellite motion (gravity, Earth's atmosphere, etc.)	Can coast through receiver outages for more than 24 hours
Kalman filter for computation of corrected position and velocity	Computes real-time corrections Computes high-accuracy velocity solutions Requires measurements from only 1 visible GPS satellite
Combination of accurate model and Kalman filter	Eliminates impact of GPS signal corruption

Innovation: A Better Way to Fly

Receiver's Solution

Receiver's Solution, if Predicted

GEODE's Predicted Solution

GEODE's Filtered Solution

True Satellite Position

4 or more GPS Satellites Acquired by Receiver

1-3 GPS Satellites Acquired by Receiver

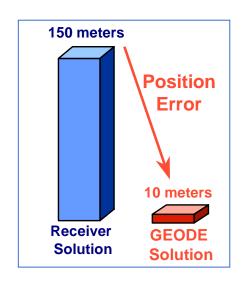**No GPS Satellites Acquired by Receiver**

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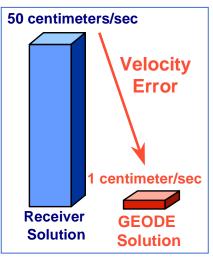# *Innovation: Demonstrated Performance Improvements*

Significance: Unprecedented Accuracy and Reliability

◆ *Unprecedented Accuracy*

   – **Drives down navigation errors by a factor of 15 in position, a factor of 50 in velocity versus receiver solution**

150 meters

Position Error

10 meters

Receiver Solution   GEODE Solution

50 centimeters/sec

Velocity Error

1 centimeter/sec

Receiver Solution   GEODE Solution

◆ *Unprecedented Reliability*

   – **Maintains performance using measurements from only 1 GPS satellite**

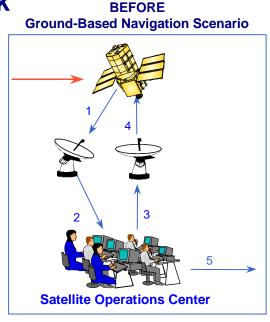   – **Predicts position for 24 hours without GPS measurements**

GEODE is the only licensed, open-architecture product available that provides this level of performance!

Significance: Supports Advanced Earth and Space Science Mission Concepts
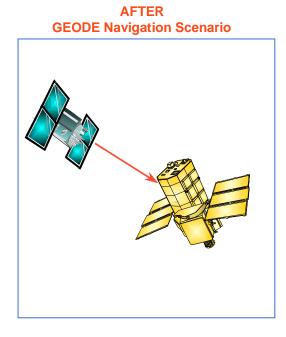
◆ **Critical technology for meeting NASA's strategic needs for increased satellite autonomy**

◆ **Essential technology for collaborative science missions**

◆ **Opens up GPS navigation to satellites with severely limited GPS visibility, e.g. high-Earth and geosynchronous missions**

◆ **Enabling technology for many proposed formation-flying/ constellation missions, e.g. Orion/Emerald**

Impact: Better, Faster, Cheaper Satellite Operations

- **High accuracy navigation products**
  - Increase accuracy of satellite orientation control
  - Provide more precise scientific measurements
  - Enable autonomous maneuver planning and control
- **High reliability reduces risk**
- **Streamlined operations provide satellite position instantaneously in science data stream**
- **Autonomous operation drives down ground operations costs**

BEFORE
Ground-Based Navigation Scenario

AFTER
GEODE Navigation Scenario

1
4
2
3
5

Satellite Operations Center

2-30 Day Delay

Instantaneous

Impact: Other Science and Technology Applications

◆ **Enroute aircraft navigation to eliminate or augment FAA's GPS/WAAS**

◆ **Improved navigation accuracy using GPS receivers for Search and Rescue**

◆ **Other commercial GPS-related applications**
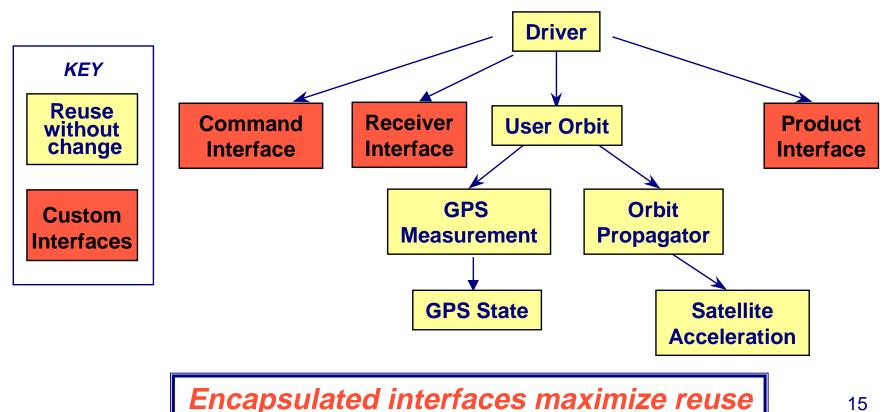
Extent of Use

Current Uses

- **Autonomous navigation capability for the New Millennium EO-1/ Landsat 7 formation-flying experiment**

- **Critical element in GSFC's development of low-cost GPS receivers for high-Earth and formation flying missions**

- **License agreements in place/under negotiation:**
  - **OSC**
  - **ITT**
  - **United Space Alliance**
  - **MIT Lincoln Laboratory**
  - **LaRC**
  - **Ball Aerospace**
  - **UCLA**
  - **University of Colorado**
  - **Aerospace Corp.**

Potential Uses

- **Advanced Earth Science formation-flying missions such as MMS and Auroral lites**

- **Provided to LaRc for potential use by Picasso/CENA**

- **OSC may integrate GEODE into a space-qualified version of their Astech GPS receiver**

- **Development of advanced autonomous satellite systems by universities and industry**

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Usability: Highly Reusable System

- **Portable: ANSI standard C, environment-independent implementation**

- **Modular: Object-based architecture, with encapsulated interfaces**

- **Reuse of GEODE by GSFC for EO-1 and SPARTAN and OSC for ORBVIEW has saved more than $1million per project**

KEY
- Reuse without change
- Custom Interfaces

Driver → Command Interface, Receiver Interface, User Orbit, Product Interface

User Orbit → GPS Measurement, Orbit Propagator

GPS Measurement → GPS State

Orbit Propagator → Satellite Acceleration

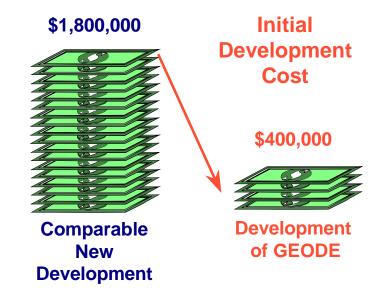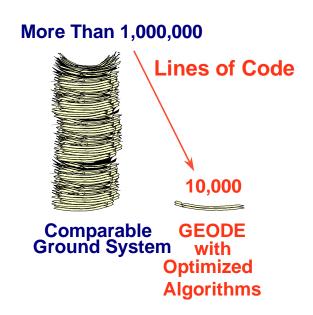*Encapsulated interfaces maximize reuse*
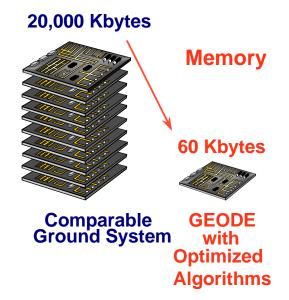
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Quality Factors

◆ **Object-oriented architecture selected to build in flexibility to support a wide range of mission types**

◆ **ANSI C language selected to reduce code size and for ease of portability**

◆ **Designed to be operating-environment independent**

◆ **Successfully executed in the following environments:**

  – **PC/Windows**

  – **Sun/HP/ Unix**

  – **Dec Alpha/Linux**

◆ **TRL 8, flight-qualified against operational standards**

◆ **Recently adapted for high-Earth missions and formation-flying applications with relative ease**

Quality Factors: Engineered to Satisfy Cost and Resource Constraints

- ◆ **Reused GSFC-developed TONS components to save more than $1,400,000 in initial development**

- ◆ **Engineered to fit within the constraints of an onboard processor without compromising accuracy**

$1,800,000

Initial Development Cost

$400,000

Comparable New Development

Development of GEODE

More Than 1,000,000

Lines of Code

10,000

Comparable Ground System

GEODE with Optimized Algorithms

20,000 Kbytes

Memory

60 Kbytes

Comparable Ground System

GEODE with Optimized Algorithms

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Bottom Line

- *Significance and Impact*

   GEODE is more accurate and more reliable than any commercial GPS navigation system. GEODE is enabling technology for NASA's future formation-flying missions.

- *Extent of Use*

   Licensed GSFC product. Currently active in NASA and commercial sectors.

- *Usability*

   Used successfully on several projects to support wide-range of missions.

- *Quality Factors*

   Meets or exceeds all original performance objectives.

- *Innovation*

   GEODE is the only licensed, open-architecture product suitable for satellites with limited, intermittent GPS visibility.

Autonomous satellite navigation using GPS is still a developing technology

Our team is a pioneer and leader in this technology