Navigating to the Moon

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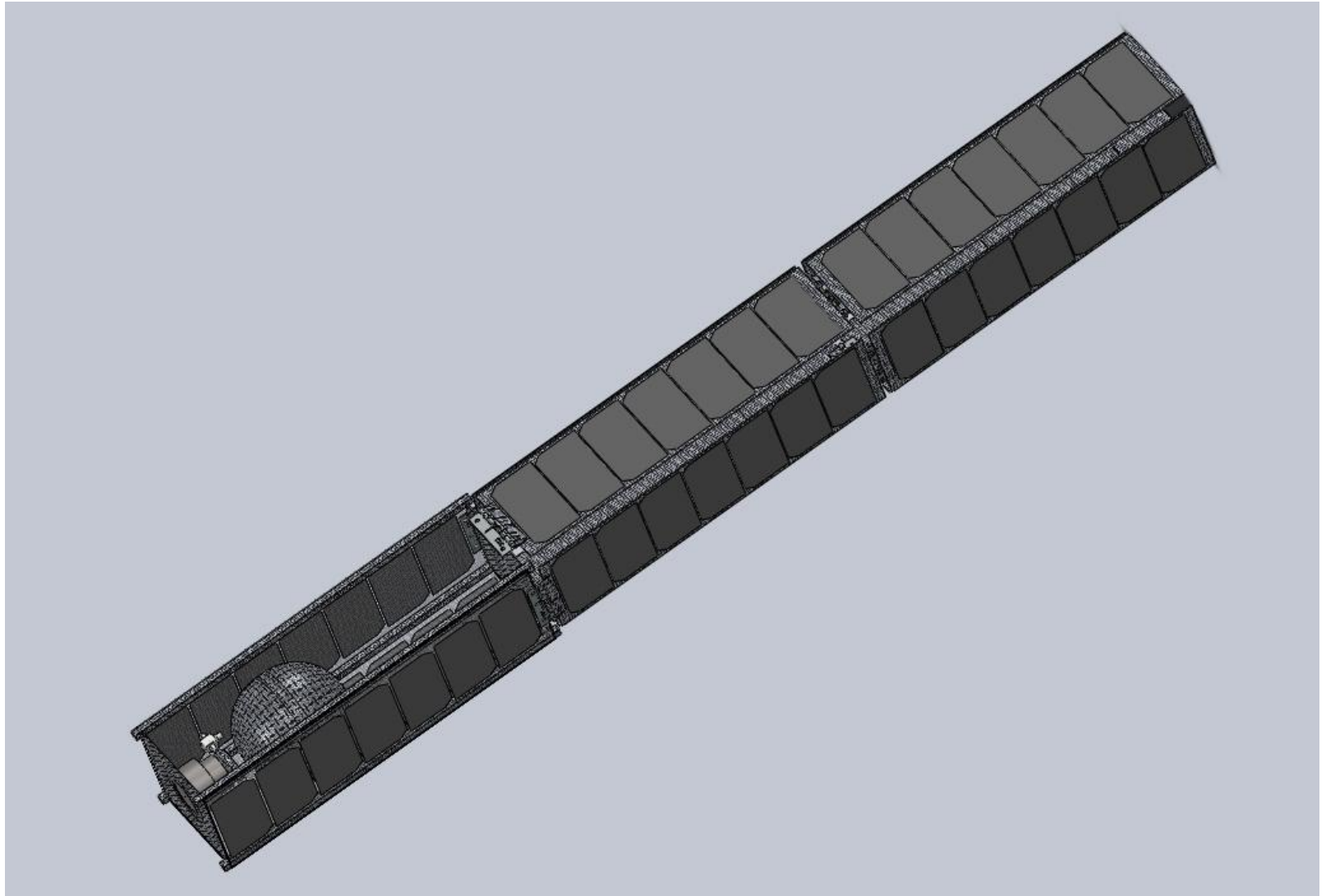
http://www.cubesatlab.org

Ion Propulsion CubeSat

- Triple CubeSat Lunar orbiter will have one MiXI 1 mN thruster, Specific Impulse about 2,500 – 3,000 seconds

- Xenon propellant of 0.5-0.75 kg

- Power for the xenon ion drive will come from photovoltaic cells on the spacecraft body and eight fold out 30 cm x 10 cm panels
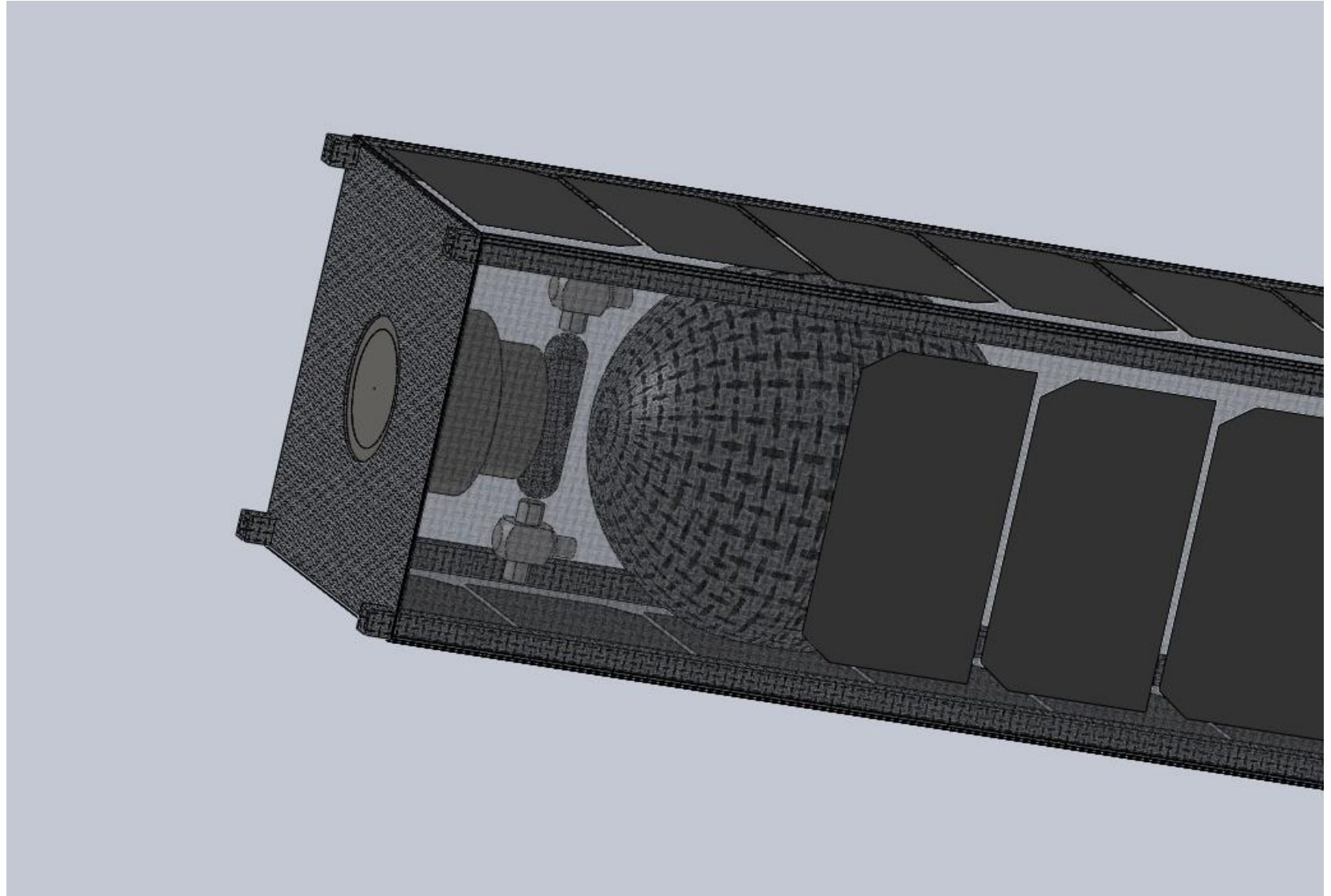
Ion Propulsion System

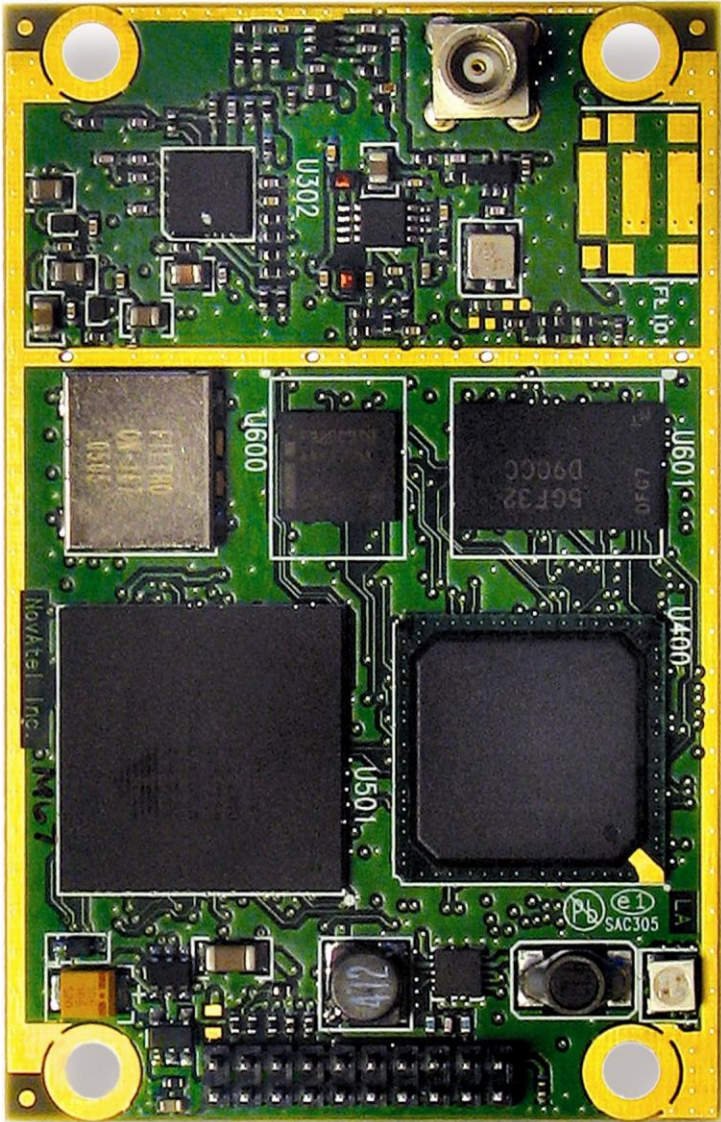JPL Miniature Xenon Ion (MiXI) Thruster

Spacecraft

Triple CubeSat Ion Lunar Orbiter with fold outs

Spacecraft Detail

Triple CubeSat Ion Lunar Orbiter Engine & Tanks

NovAtel OEMV-1 GPS Board

16 mm Lens for
1 megapixel
Star Tracker

NovAtel *OEMV-1* GPS Board

- Currently supplying GPS data for the RAX CubeSat

- The CoCom speed and altitude limits are removed

- The API for the Arm processor is enabled

- We have 4 MB each of RAM & ROM for running the GEONS navigation software on the board

NASA Goddard Spaceflight Center Developed GPS Enhanced Onboard Navigation System (GEONS) Software
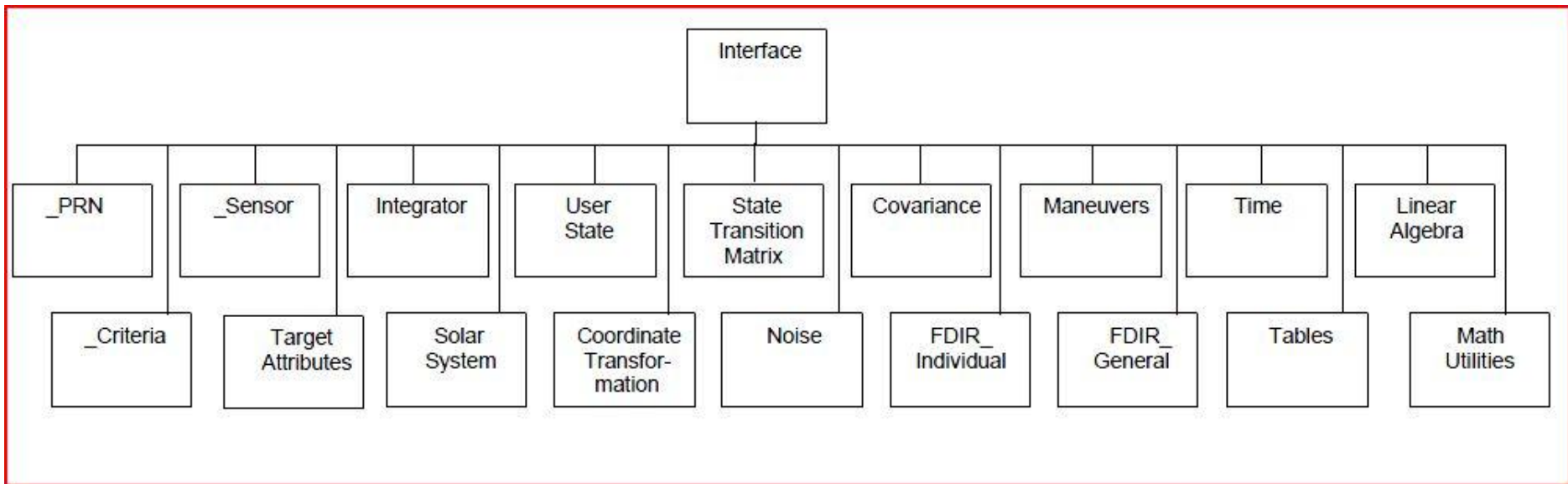
- Autonomous navigation
- High performance GPS out to 50 Earth radii
- Celestial navigation for greater distances
- Earth ground transponders (we are not using)
- 20,000 lines of C code
- 60 kB compiled
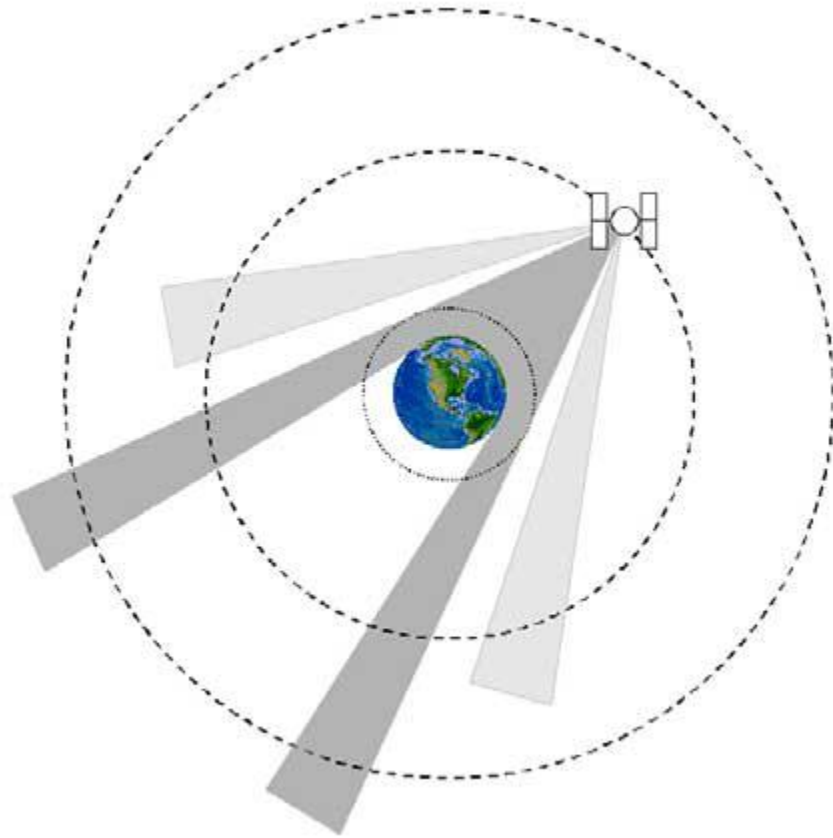
GPS Enhanced Onboard Navigation System

- Hi fidelity model for satellite navigation (gravity, Earth's atmosphere, etc.) – can coast through data outages for more than 24 hours

- Kalman filter for computation of corrected position and velocity

- Can process GPS signals from the far side of the Earth

- We will run it on the Novatel OEMV-1 Arm processor

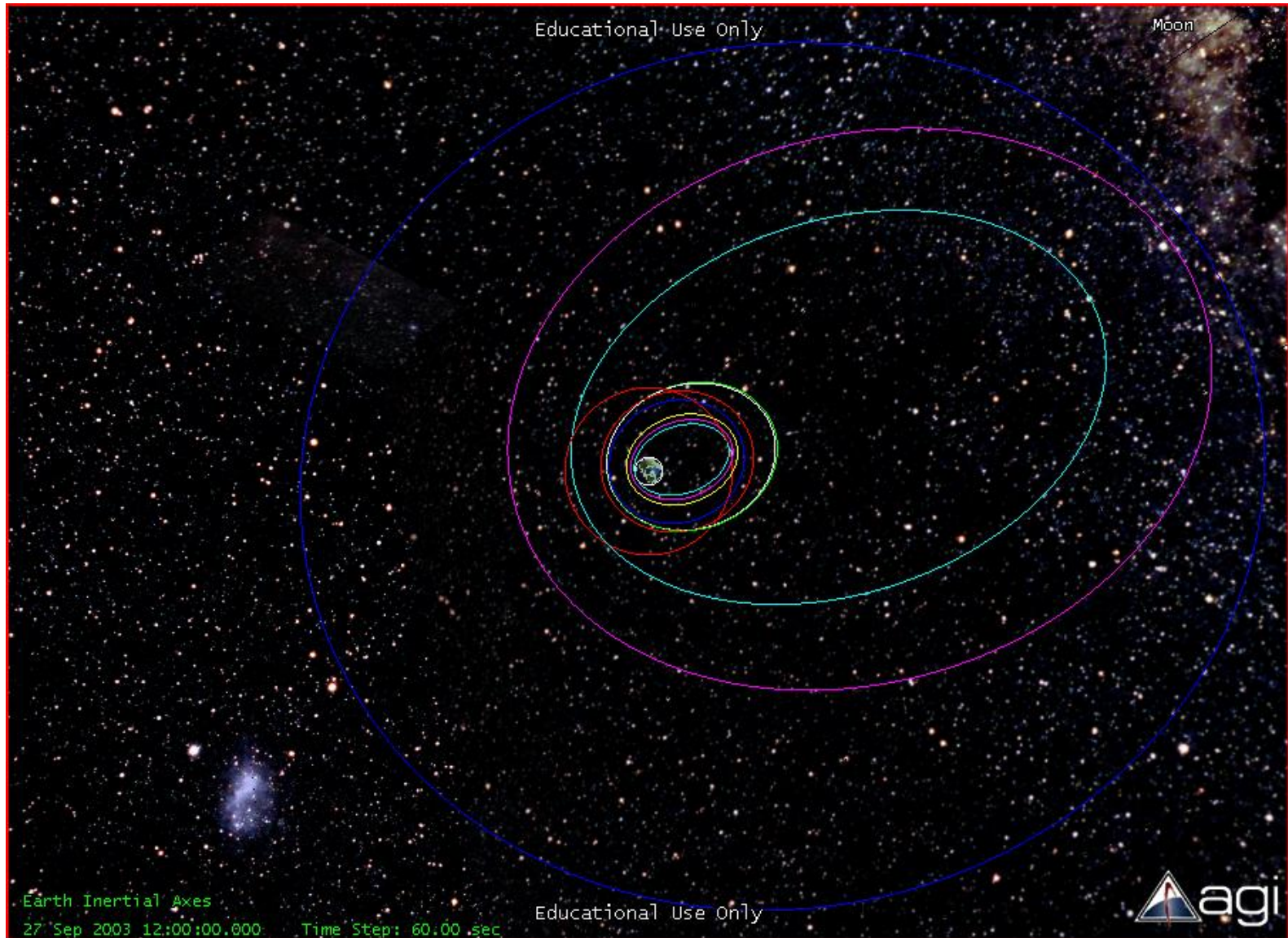# GPS Enhanced Onboard Navigation System
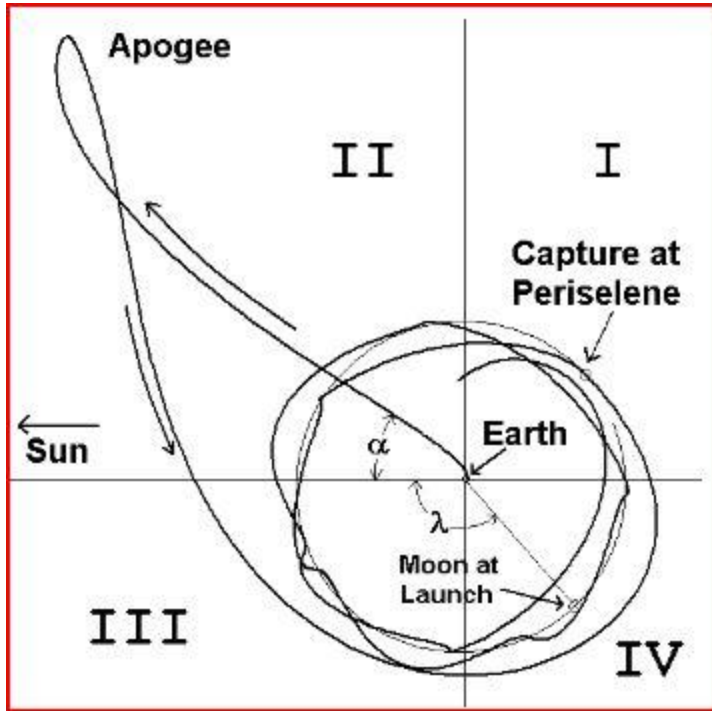
Software Classes

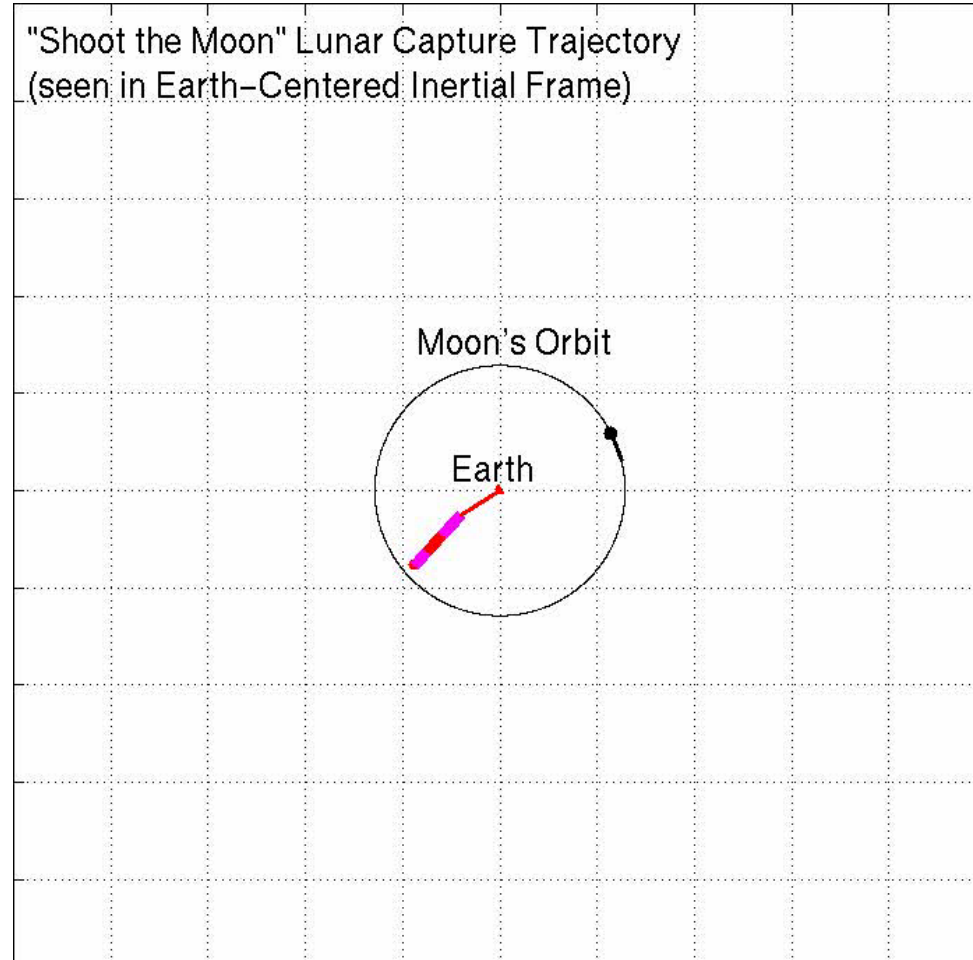# GPS Enhanced Onboard Navigation System

Ion Drive Orbits ala SMART-1

Low Energy Lunar Transfer

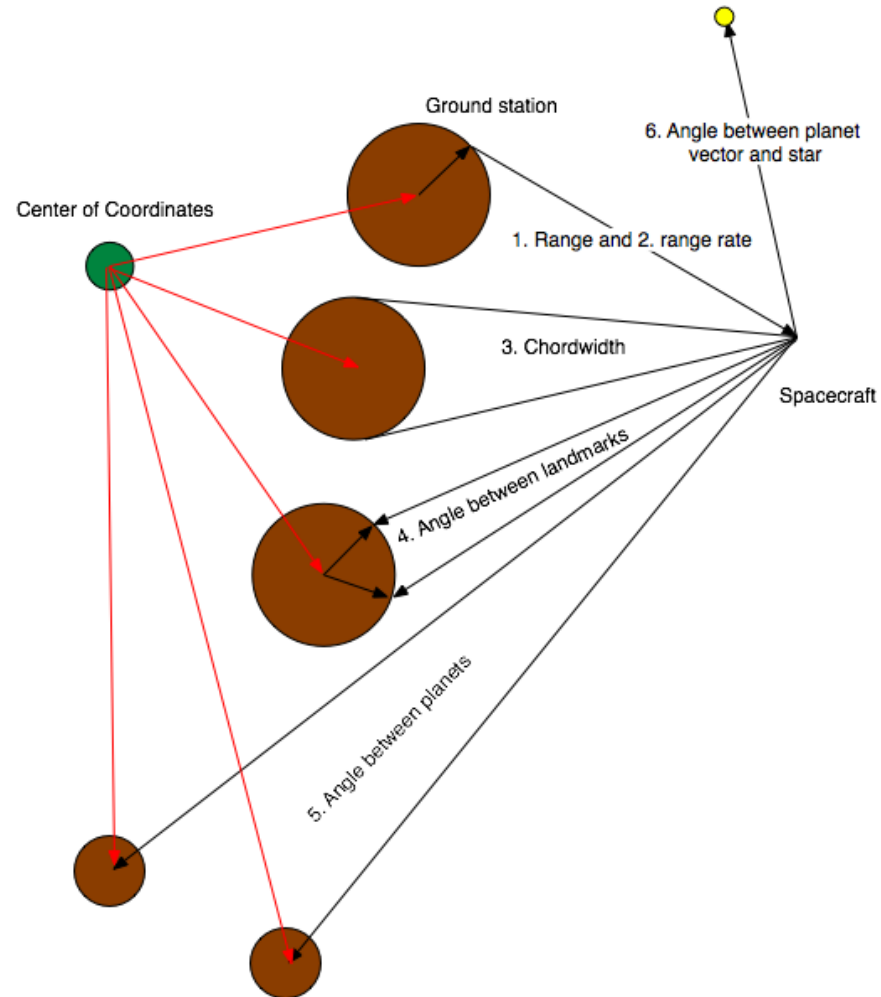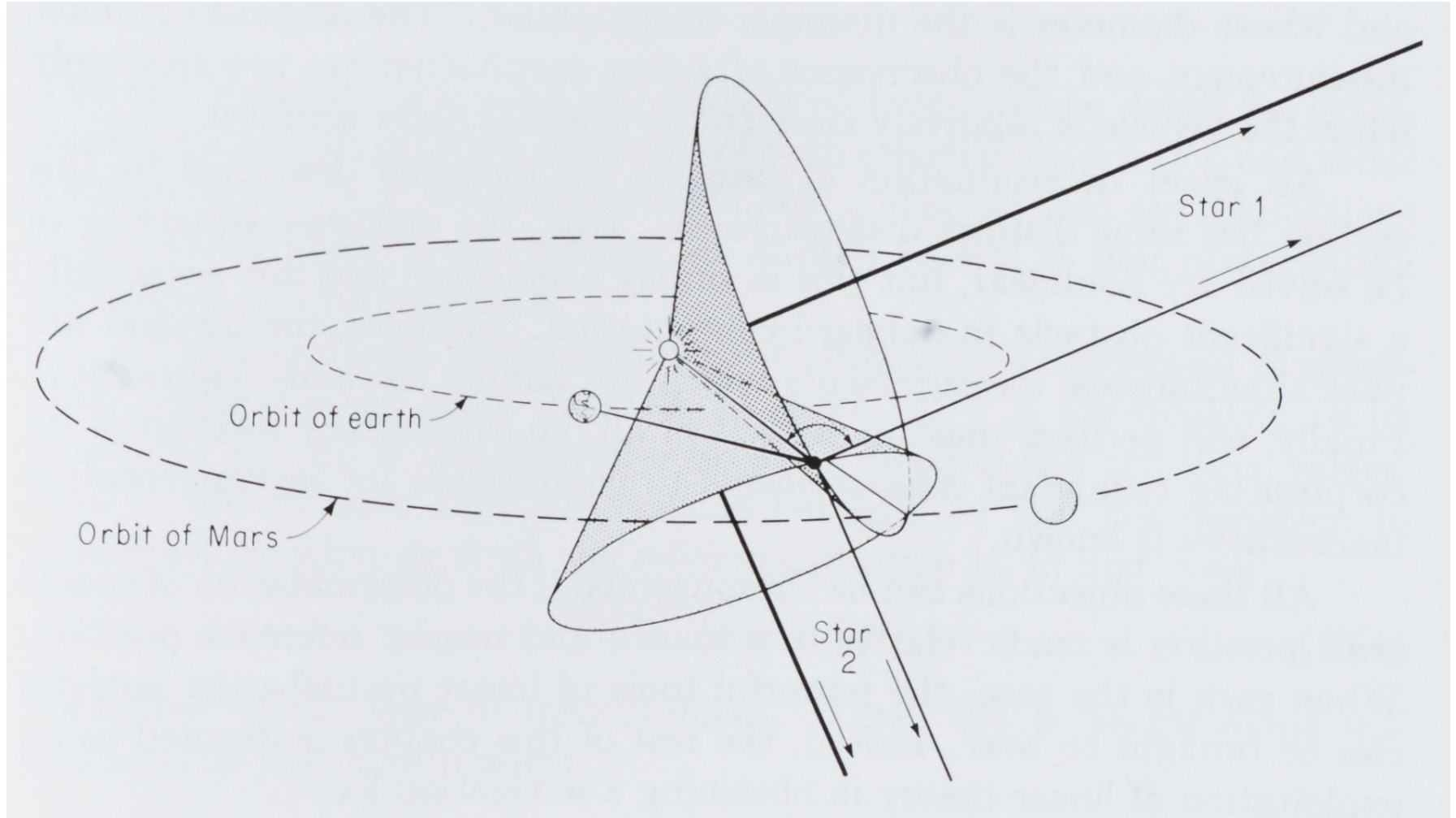Weak Stability Boundary

Ballistic Capture

Spacecraft Celestial Navigation

Star Sight Geometry

Control Software

- Control Software written in SPARK/Ada using Adacore's GNAT Programming Studio & GNAT compiler

- Praxis' SPARK Toolset used to prove the correctness of the code

- Sofcheck's AdaMagic compiles it to produce ANSI C intermediate code

- Software run on CubeSat Kit MSP430 CPU

SPARK/Ada Example

```
procedure Matrix_2 (J : in Natural)
    --# global in out Upper_Matrix; in In_Matrix, Diagonal;
    --# derives Upper_Matrix from Upper_Matrix, J, In_Matrix, Diagonal;
    --# pre J >= Diagonal'First and J < Diagonal'Last and
    --#     Upper_Matrix'First(1) = Upper_Matrix'First(2) and
    --#     Upper_Matrix'Last (1) = Upper_Matrix'Last (2) and
    --#     Diagonal'First     = Upper_Matrix'First(1) and
    --#     Diagonal'Last      = Upper_Matrix'Last (1);
    is
    begin
      Upper_Matrix (J, J) := 1.0;
      for I in reverse Natural range Diagonal'First .. J - 1 loop
        Upper_Matrix (I, J) := 0.0;
        for K in Natural range J + 1 .. Diagonal'Last loop
          Upper_Matrix (I, J) := Upper_Matrix (I, J) +
                      (Diagonal (K) * (Upper_Matrix (I, K) * Upper_Matrix (J, K)));
        end loop;
        Upper_Matrix (I, J) := (In_Matrix (I, J) - Upper_Matrix (I, J)) / Diagonal (J);
      end loop;
    end Matrix_2;
```

Navigation Components

- Converting the NASA Goddard GEONS navigation system to SPARK/Ada (about half done) yields about 1% of the error rate of C software

- This process has already found a number of errors in the NASA GEONS software

- Star tracker camera in development at Norwich University

- Attitude control system for a stable platform for the star tracker in development

Remaining Tasks

- Analyze the various low energy transfer paths for delta-v and transit times at University of Vermont

- Choose a flight path

- Model the Van Allen radiation exposure at University of Vermont

- Develop the flight plan

NASA Launch Opportunity

- NASA's 2010 CubeSat Launch Initiative

- Our project was selected for launch

- A single-unit CubeSat will be launched as part of NASA's ELaNa IV Falcon 9 flight in March 2012

- It will test the Lunar navigation system in Low Earth Orbit

- Follow our project at www.cubesatlab.org

Our 3m GENSO 2.4GHz Dish

Acknowledgements

- NASA Vermont Space Grant Consortium

- NASA

- Vermont Technical College
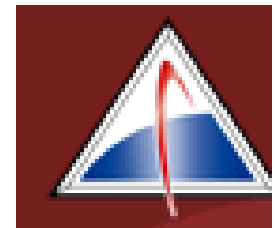
- AdaCore, Inc. (GNAT Pro)

- Praxis High Integrity Systems (SPARK)

- SofCheck (AdaMagic)

- Applied Graphics, Inc. (STK)

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