Deep Space 1 Flight Experience: Adventures on an Ion Drive

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New Millennium Program Deep Space 1
Successful Validation of 12 Breakthrough Technologies

- Ion Propulsion System: enables rapid access to deep space
- AutoNav: first totally autonomous on-board navigation system; first deep-space low-thrust Nav
- Total mission cost including launch vehicle and operations = $160 M
- 39 months from pre-phase-A to launch, 38 months flight operations
DS1 Guidance & Control Configuration

- SCARLET II SOLAR ARRAY 2.5 kW
- HIGH GAIN ANTENNA
- MICAS CAMERA
- SUN SENSOR
- Stellar Ref. Unit
- LN200 IMU
- IPS GIMBAL
- RCS THRUSTERS (2 CLUSTERS)
- 30 cm ION THRUSTER

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Ion Propulsion System

**Description**

- 30 cm engine provided by NASA NSTAR Program
- Throttleable
  - 20 to 90 mili-Newton thrust
  - 500 to 2500 W input power
- Typical DS1 operating parameters
  - Input power 1600 W
  - Isp 3000 sec
  - Thrust 60 mili-Newton
  - Accel voltage 1100 V
  - Exhaust vel ~40 km/sec
  - Xe flow rate 2 mg/sec
  - Spacecraft accel 11.5 m/sec per day

**Flight Experience**

- 16265 hours (677 days!) trouble-free operation
- 70 kg Xe expended to achieve 4.2 km/sec
- Equiv. mission would require 1200kg bi-prop
TVC vs. RCS Control Errors

A-1637 (bbc_CtrlErr0) vs SCET

Turning for OPNAV

RCS MODE

TVC MODE

Files 1 Start time: 01-255/00:1:00:558
Files 1 End time: 01-255/00:1:00:558
Primary Mission Trajectory

Launch 10/24/98

Asteroid Braille

Earth

Braille encounter 7/29/99

9/18/99
The Road to Borrelly

- **Launch**: 10/24/98
- **11/11/99**: SRU Failure
- **9/22/01**: Borrelly encounter
- **7/29/99**: Braille encounter
- **9/18/99**: Beginning of extended mission
- **Earth**
- **Borrelly**
- **Braille**
Downlink Power During Earth Coning

- HGA pattern crosses Earth
- Stop-Coning command
SRU vs. MURKY/MICAS

**SRU**
- 8.8 X 8.8 deg FOV
- Mag 7.5 sensitivity
- 0.25 sec update period
- Provides full attitude quaternion

**MURKY using MICAS Camera**
- 0.8 X 0.5 deg usable FOV
- Mag 6.5 sensitivity
- 30 sec update period
- Provides image file to MURKY software
- Requires sun sensor data to compute full 3-axis attitude
ACS Encounter Challenges

**Gyro Performance**
- Scale factor errors undetectable
- Developed gyro stochastic model for testing
- NAV included attitude states in flyby estimator
- “Rolled the dice” on ~monthly IMU reset

**RCS Control Gains**
- Tight timing of encounter seq called for high confidence in gains, turn settle times
- Pulse-mode thrust estimated directly from deadband motion, testbed updated to match
- Produced good agreement between flight encounter rehearsal and testbed runs.

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Debris Predict @ 2000 Km, 16.6 Km/sec
SOB9 Co-Add Image of Borrelly
Borrelly Jet Details