The CASSIOPE Satellite Ionospheric Profiling Experiment

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CASSIOPE

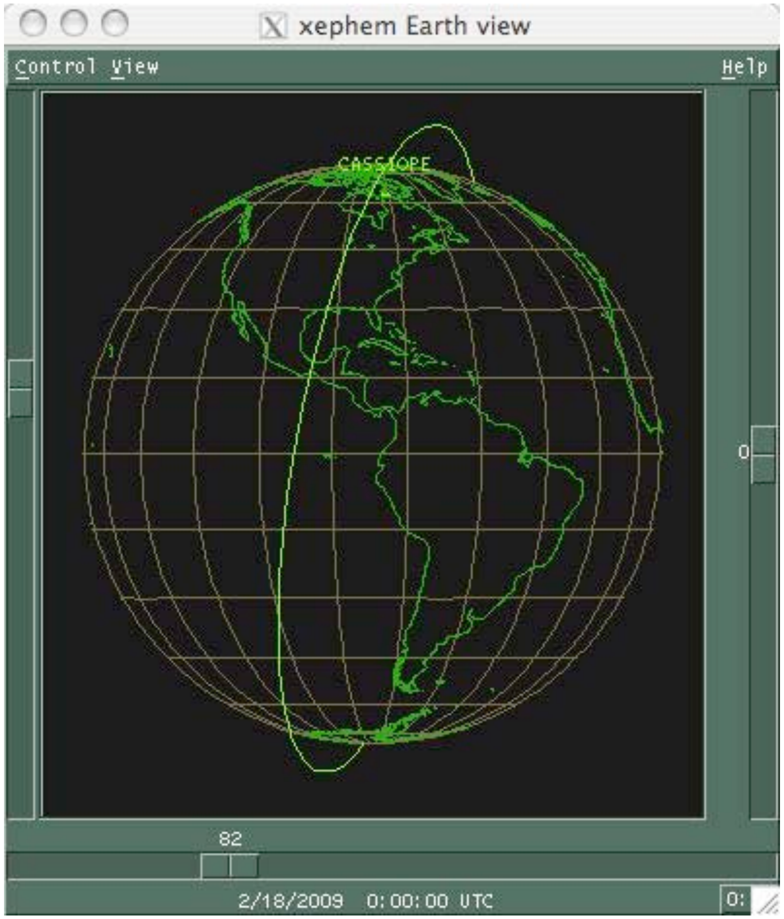
- CASSIOPE = CAScade Smallsat and IOnospheric Polar Explorer

  (also low tufted evergreen shrubs of colder parts of north temperate regions having mosslike foliage and nodding white or pink flowers; a.k.a. heather)

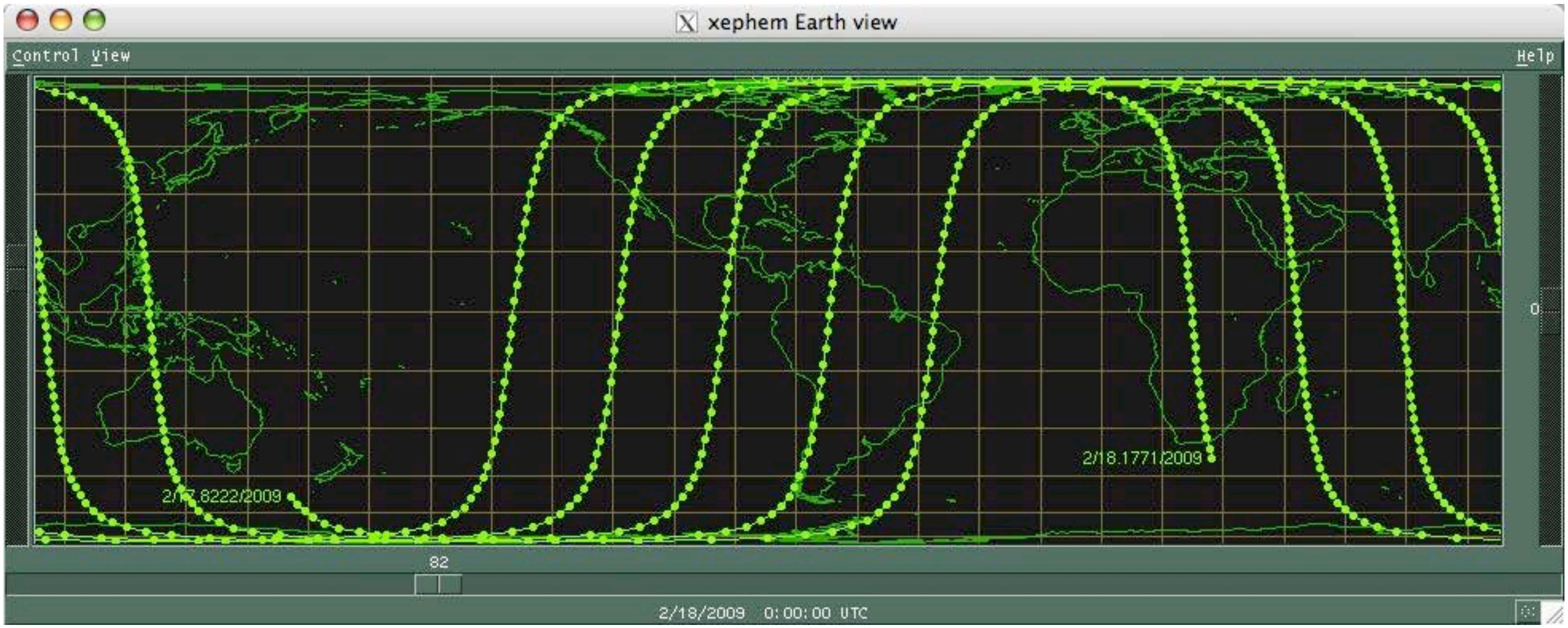
- Canada's first multipurpose satellite
- Merger of CASCADE (very wide bandwidth store-and-forward data delivery platform) with e-POP (enhanced - Polar Outflow Probe)
- Planned late 2008 launch

CASSIOPE Orbit - 1

Semi-major axis	7280 km
Period	103 minutes
Eccentricity	0.08
Apogee	1500 km
Perigee	325 km
Inclination	80°



CASSIOPE Orbit - 2



e-POP Mission Objectives

- Investigate atmospheric and plasma flows and related wave-particle interaction and radio wave propagation in the topside ionosphere
- Quantify the micro-scale characteristics of plasma outflow and related micro- and meso-scale plasma processes in the polar ionosphere
- Explore the occurrence morphology of neutral escape in the upper atmosphere
- Study the effects of auroral currents on plasma outflow.

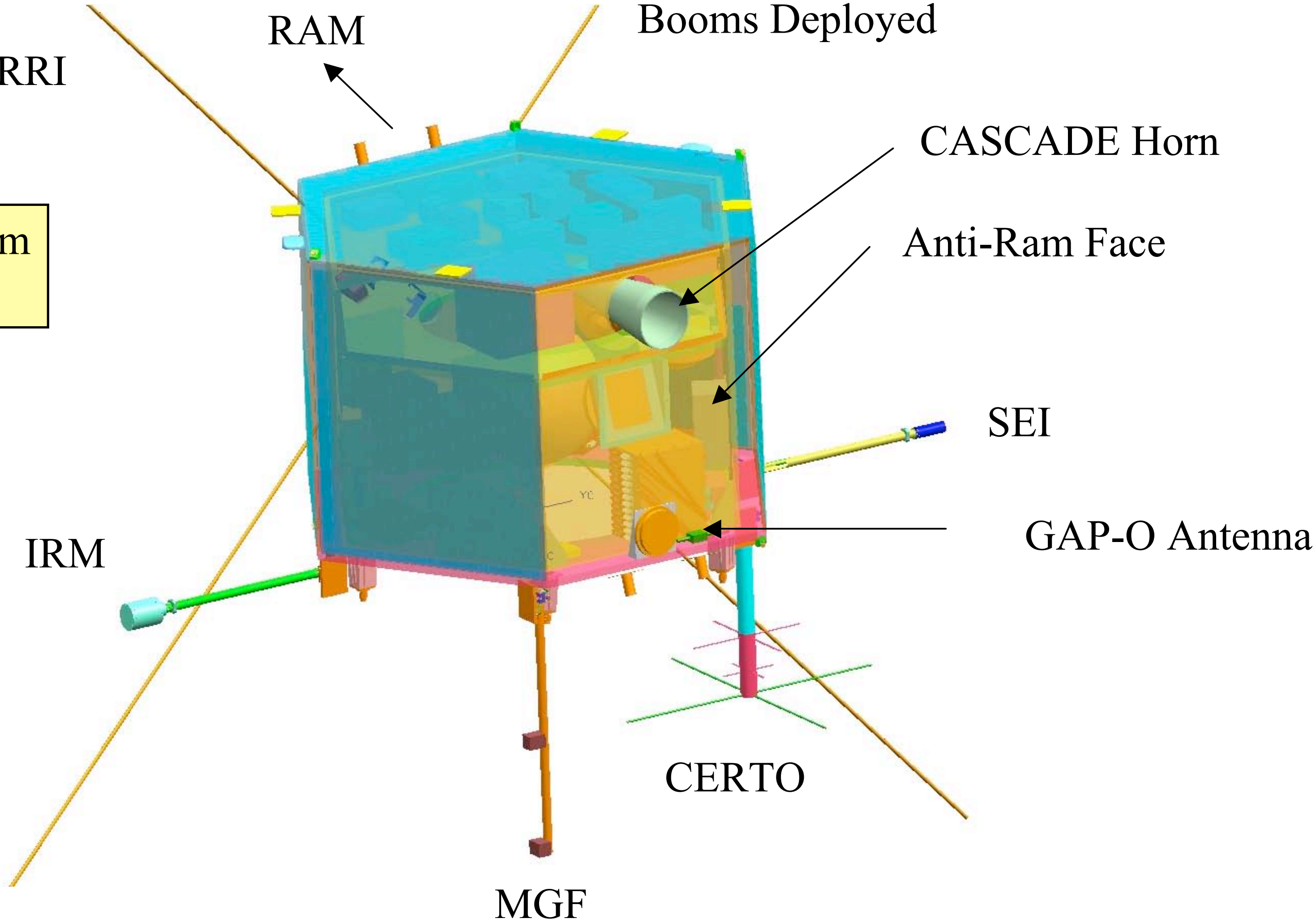
Players

- Funded by the Canadian Space Agency and the Natural Sciences and Engineering Research Council of Canada
- e-POP team includes researchers at 10 Canadian universities plus government agencies in Canada, the U.S.A., and Japan
- Chief e-POP scientist: Andrew Yau, U. of C.
- Deputy mission scientist: Gordon James, C.R.C.
- CASSIOPE spacecraft prime: MDA
- Spacecraft bus and some instrument development: Bristol Aerospace

e-POP Instruments

- Imaging Rapid-scanning Ion Mass Spectrometer (IRM)
- Suprathermal Electron Imager (SEI)
- Magnetic Field Instrument (MGF)
- Fast Auroral Imager (FAI)
- Radio Receiver Instrument (RRI)
- Neutral Mass and Velocity Spectrometer (NMS)
- Coherent Electromagnetic Radiation (CER)
- GPS Attitude, (Positioning) and Profiling Experiment (GAP)

CASSIOPE



1.8 m × 1.2 m
≈ 500 kg

Background image courtesy of Bristol. S/C is for illustrative purposed only.

GAP Objectives-1

The GPS Attitude and Profiling instrument is multipurposed. It is both a spacecraft sensor and a science instrument. It will determine:

- spacecraft three-dimensional position, velocity, and attitude
- time referenced to UTC
- ionospheric electron density profiles

Functions divided into GAP-A and GAP-O

GAP Objectives-2

GAP-A

- Position, velocity, attitude, and time can be determined in *real time* and made available to other spacecraft systems (1 Hz):
  - position to 100 metres
  - velocity to 10 metres per second
  - attitude to 5 degrees
  - time to 1 microsecond

- More accurate results will be achievable from down-linked data including attitude to 0.5 degrees and position to a few dm or better.

- Ionospheric science also possible with GAP-A.

GAP Objectives-3

GAP-O

- Electron density profiling using antenna pointed in anti-ram direction
- High-rate (20, possibly 50 Hz) measurements on setting (occulted) GPS satellites together with measurements from non-occulted satellites down linked to ground for analysis
- Analysis will provide high resolution profiles of electron density in the ionosphere and plasmasphere
- Not mandated to profile neutral atmosphere (likely insufficient antenna gain)

GPS Observation Equations

Pseudorange:

$$P(t) = \rho(t) + c[dt_r(t) - dt^s(t-\tau)] + I(t) + T(t) + \varepsilon_P(t)$$

Carrier phase:

$$\begin{aligned}\Phi(t) &= \lambda\,\phi(t) \\ &= \rho(t) + c[dt_r(t) - dt^s(t-\tau)] - I(t) + T(t) + \lambda N + \varepsilon_\Phi(t)\end{aligned}$$

t - signal reception time
λ - wavelength
c - speed of light
ρ - geometric range
τ - signal transit time
dt_r - receiver clock offset

dt^s - satellite clock offset
I - ionospheric delay
T - tropospheric delay
N - integer ambiguity
ε_P - pseudorange noise
ε_Φ - carrier phase noise

Ionospheric Propagation Delay

$$I_{L1(P)} = \frac{f_2^2}{f_2^2 - f_1^2}\left[P_{L1} - P_{L2}\right] + \varepsilon_{P(L1+L2)}$$

For absolute TEC, satellite and receiver inter-frequency biases must be accounted for

$$I_{L1(\Phi)} = \frac{f_2^2}{f_2^2 - f_1^2}\left[\left(\lambda_1 N_1 - \lambda_2 N_2\right) - \left(\Phi_1 - \Phi_2\right)\right] + \varepsilon_{\Phi(L1+L2)}$$

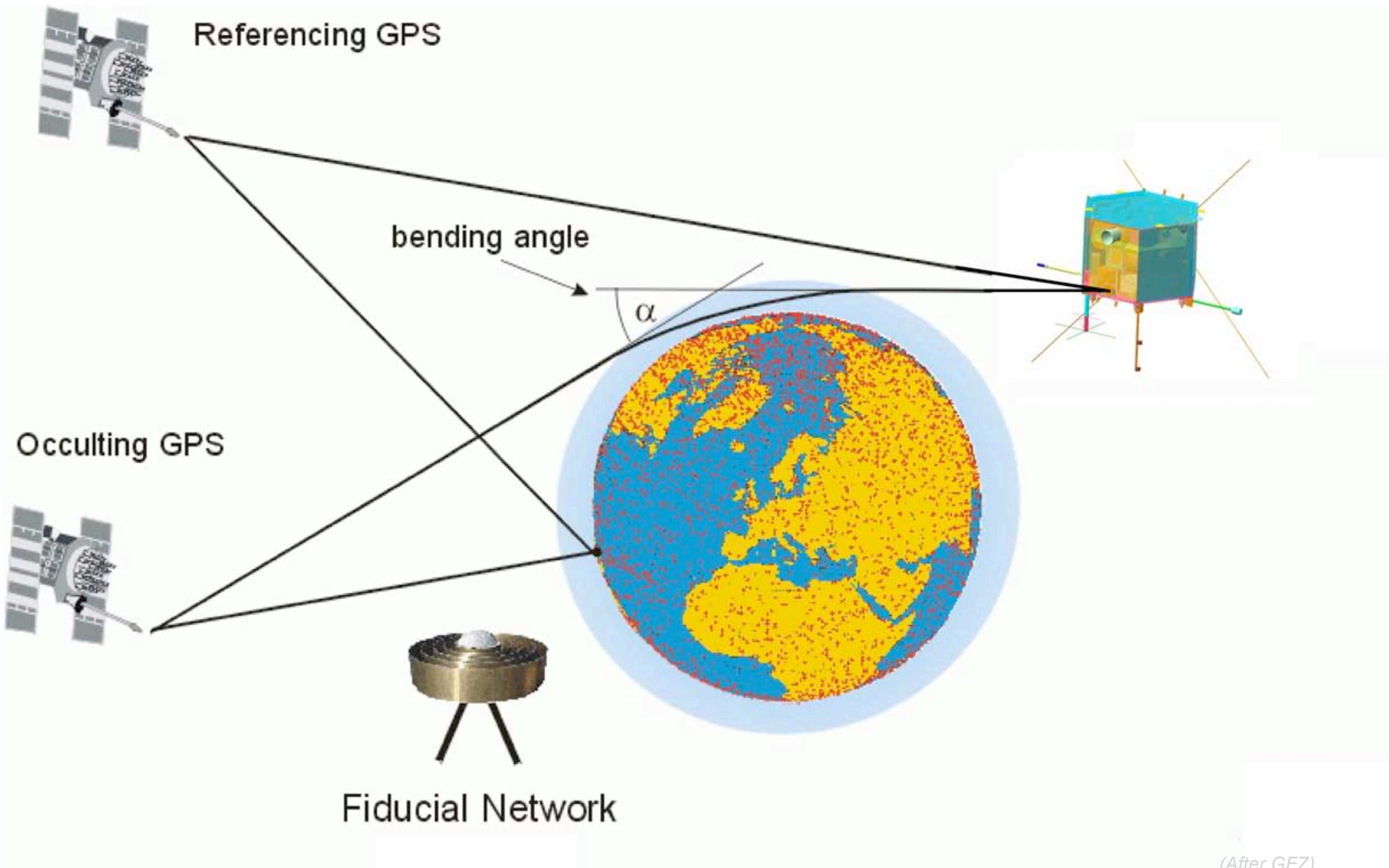
Phase levelling:

$$I = I_\Phi - \frac{\sum_{j=-\frac{n}{2}}^{\frac{n}{2}} w_j\left[I_{\Phi,j} - I_{P,j}\right]}{\sum_{j=-\frac{n}{2}}^{\frac{n}{2}} w_j}$$

$$TEC = \frac{1}{40.3} f_1^2\, I_{L1}$$

1 TECU ≈
16 cm of L1 delay

Spaceborne GPS Limb Sounding



Abel Transform

TEC $\rightarrow$ Bending angle $\rightarrow$ Refractive index $\rightarrow$ Electron density

Bending angle $\longrightarrow$ $\alpha \approx \frac{40.3}{f_1^2}\frac{dI}{da}$ $\longleftarrow$ Satellite – satellite TEC; $\longleftarrow$ Impact parameter

$$\ln[n(a)] = \frac{1}{\pi}\int_a^\infty \frac{\alpha(\xi)d\xi}{\sqrt{\xi^2 - a^2}}$$

$$n(a) \rightarrow N_e(a)$$

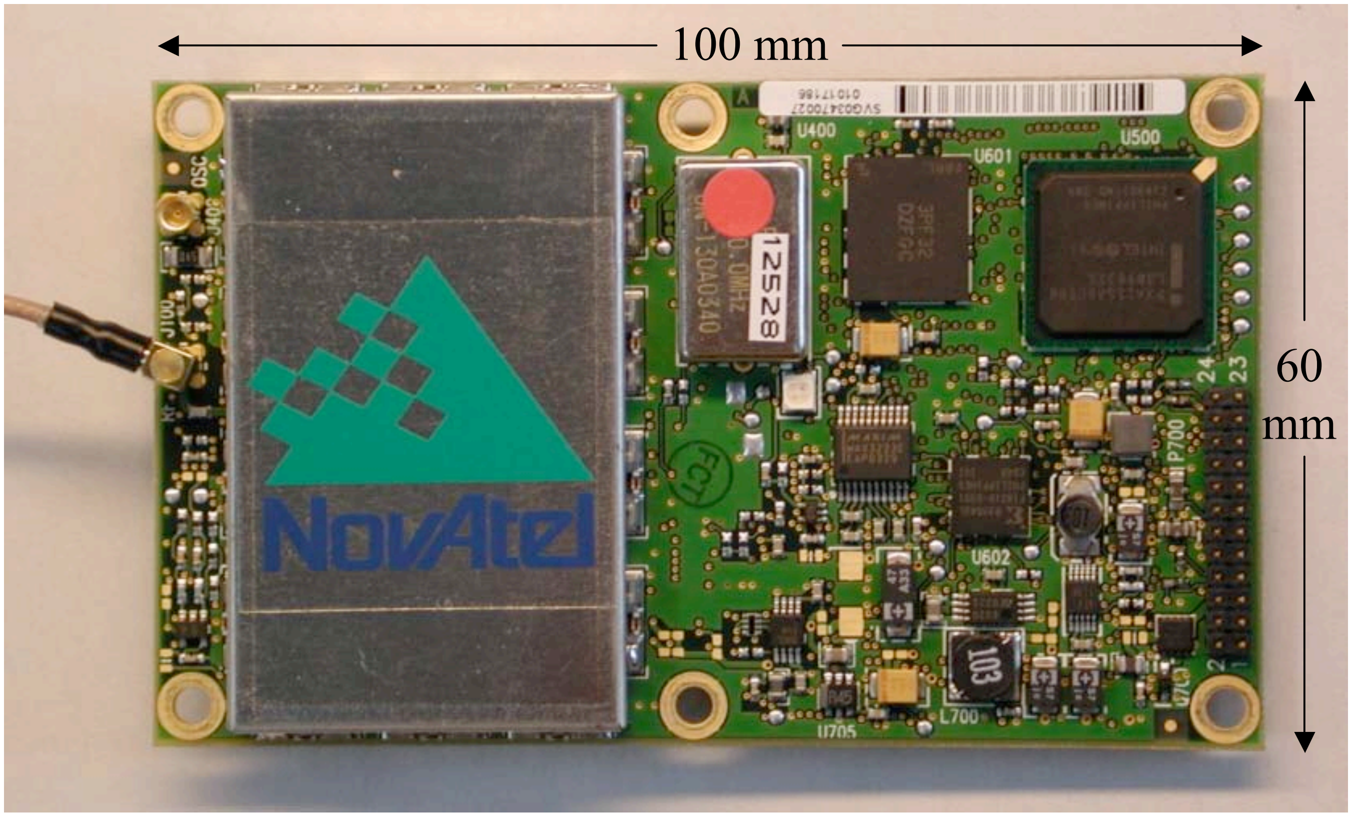
Resolution: $a \approx 3$ km (1 Hz data)

$N_e \approx 10^{11}\ m^{-3}$

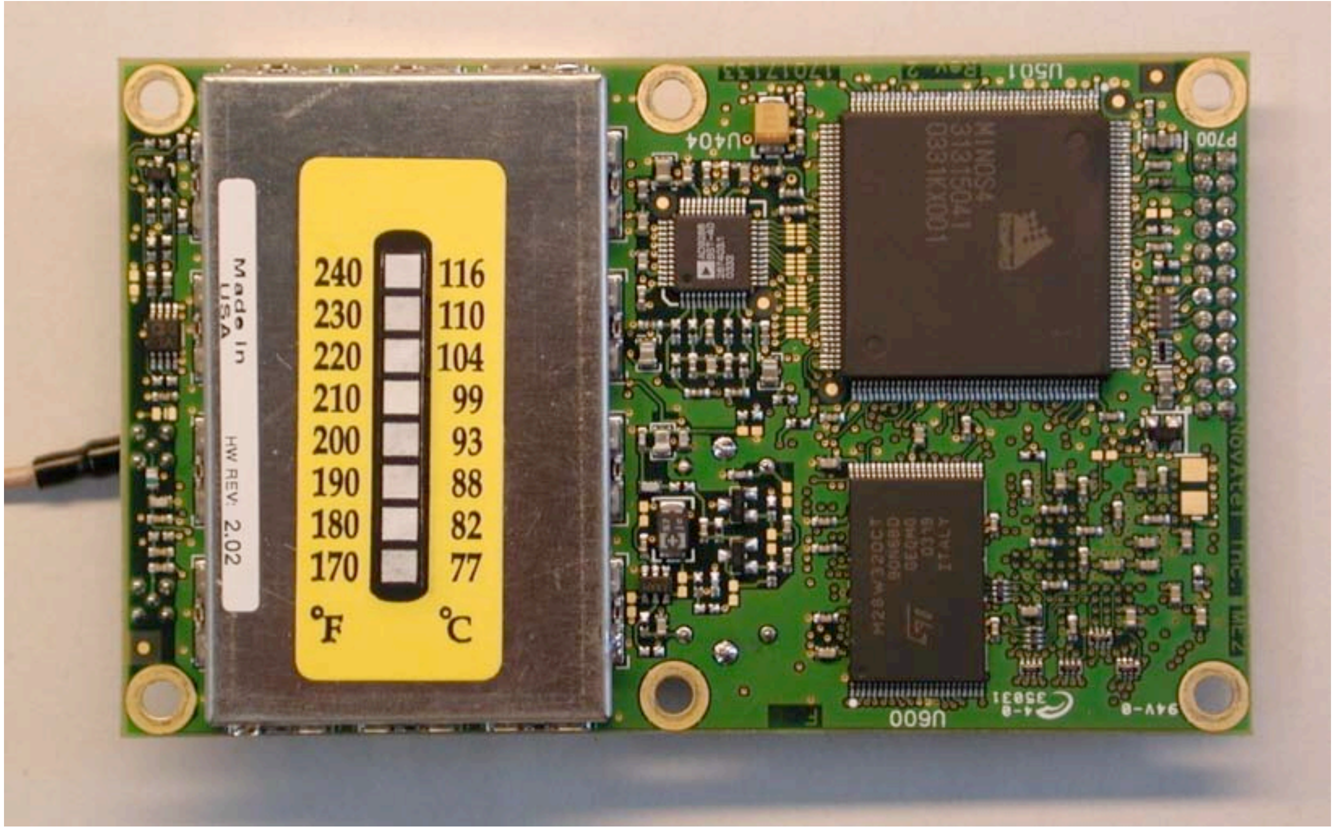
Receiver Selection

- Early in mission design, decision made to base GAP instrument on multiple COTS dual-frequency receivers
- Decision based on economics
- NovAtel OEM4-G2L selected

NovAtel OEM4-G2L



NovAtel OEM4-G2L



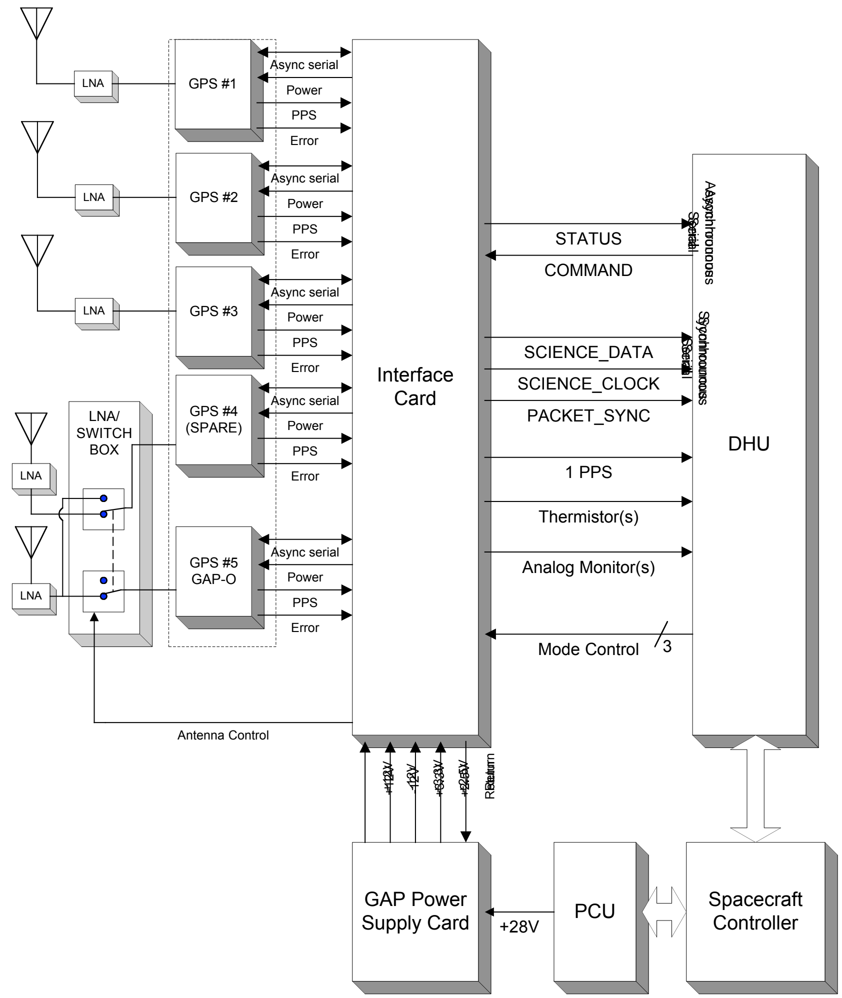
Antennas

- Positioning/attitude antennas: space-qualified Sensor Systems S67-1575-14M dual-frequency passive patch antenna
- Occultation antenna: modified NovAtel GPS-702 “Pinwheel” antenna

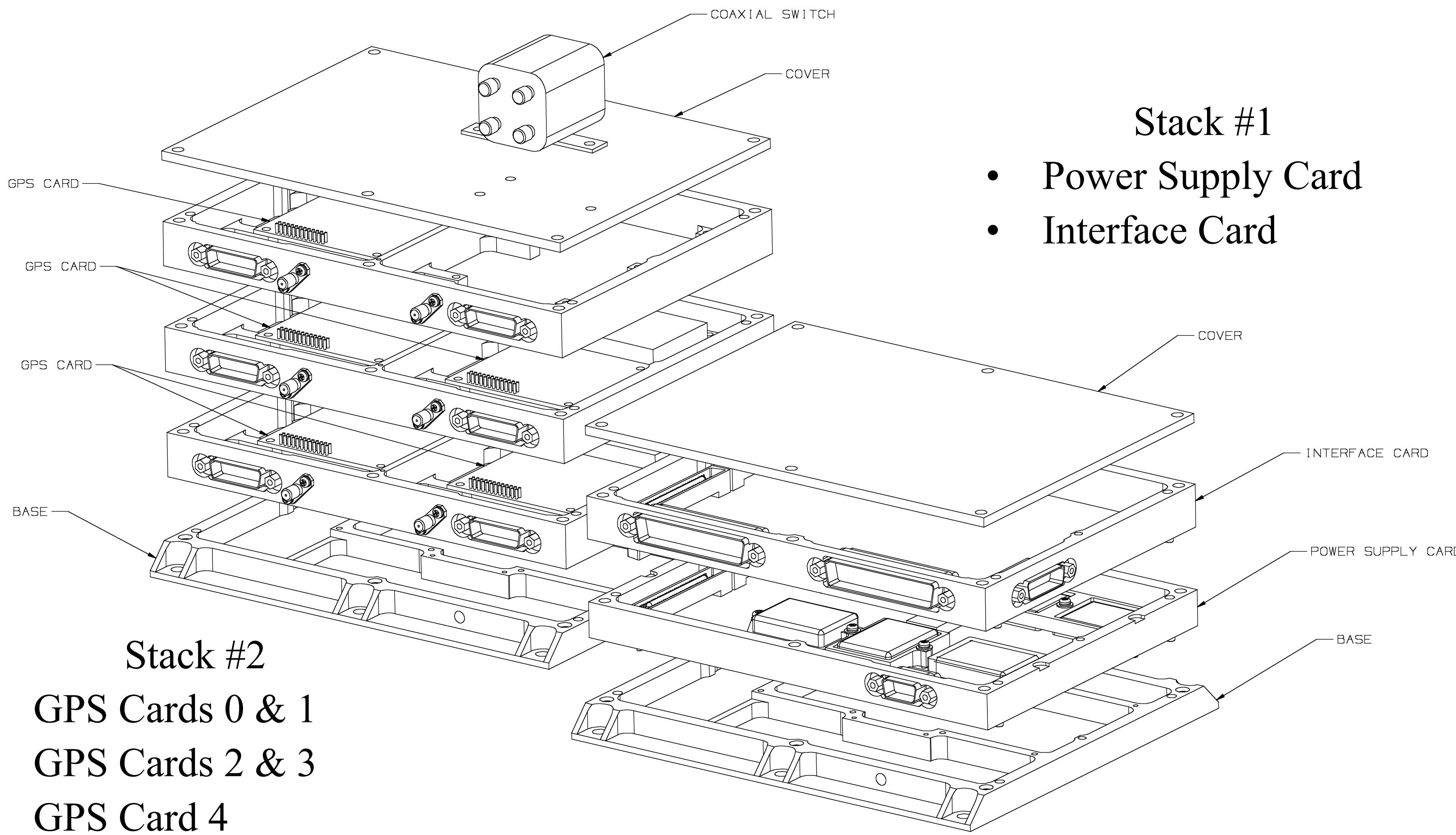
GAP Functional Description

- Instrument consists of:
  - An interface card
  - Power supply card
  - 5 GPS cards (includes one spare)
  - 5 GPS antennas and LNAs
  - Antenna/LNA switch

- GAP-A and GAP-O functions combined into a single instrument



Instrument Overview



Stack #1

- Power Supply Card
- Interface Card

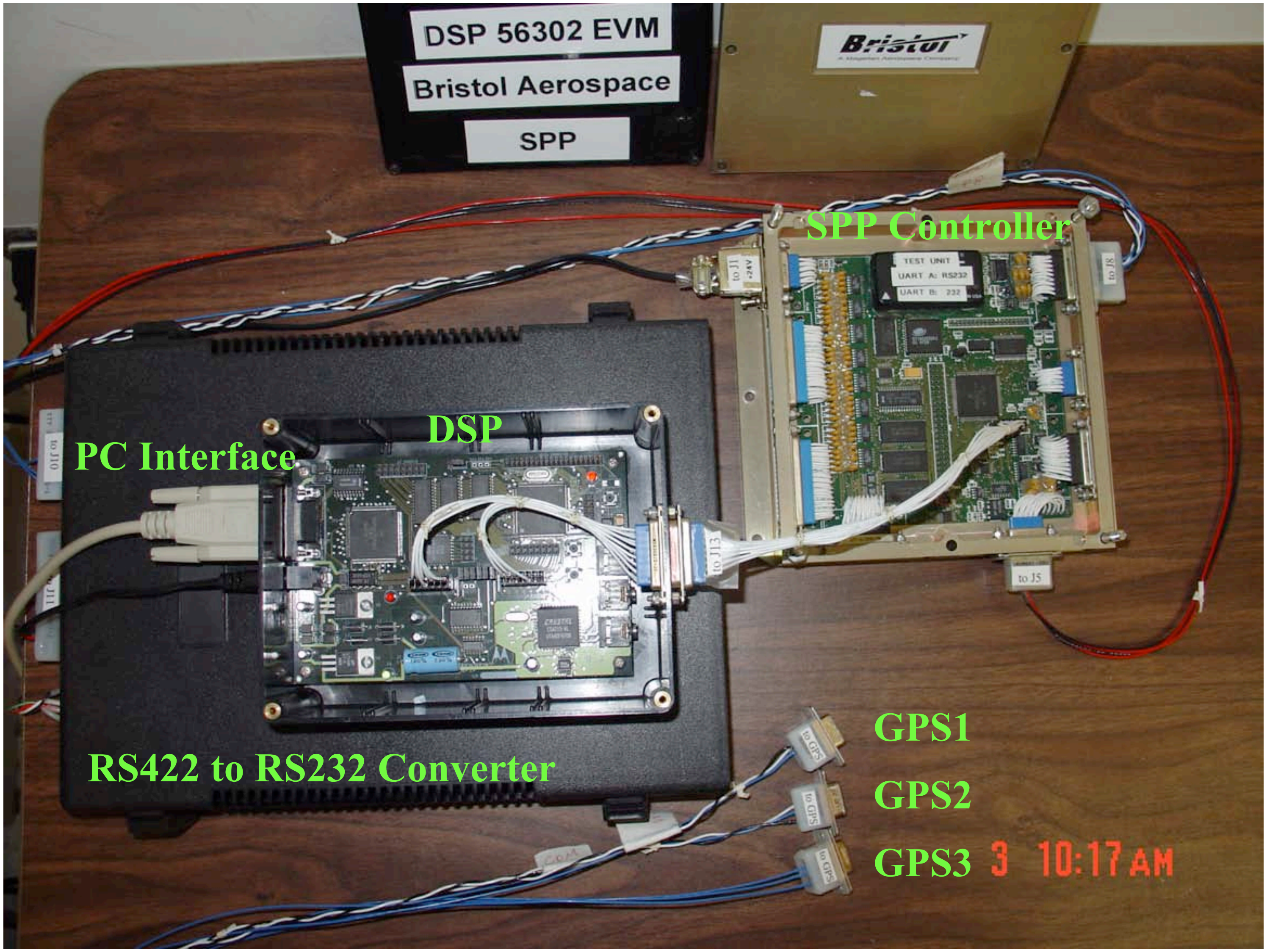
Stack #2

- GPS Cards 0 & 1
- GPS Cards 2 & 3
- GPS Card 4
- Coaxial switch

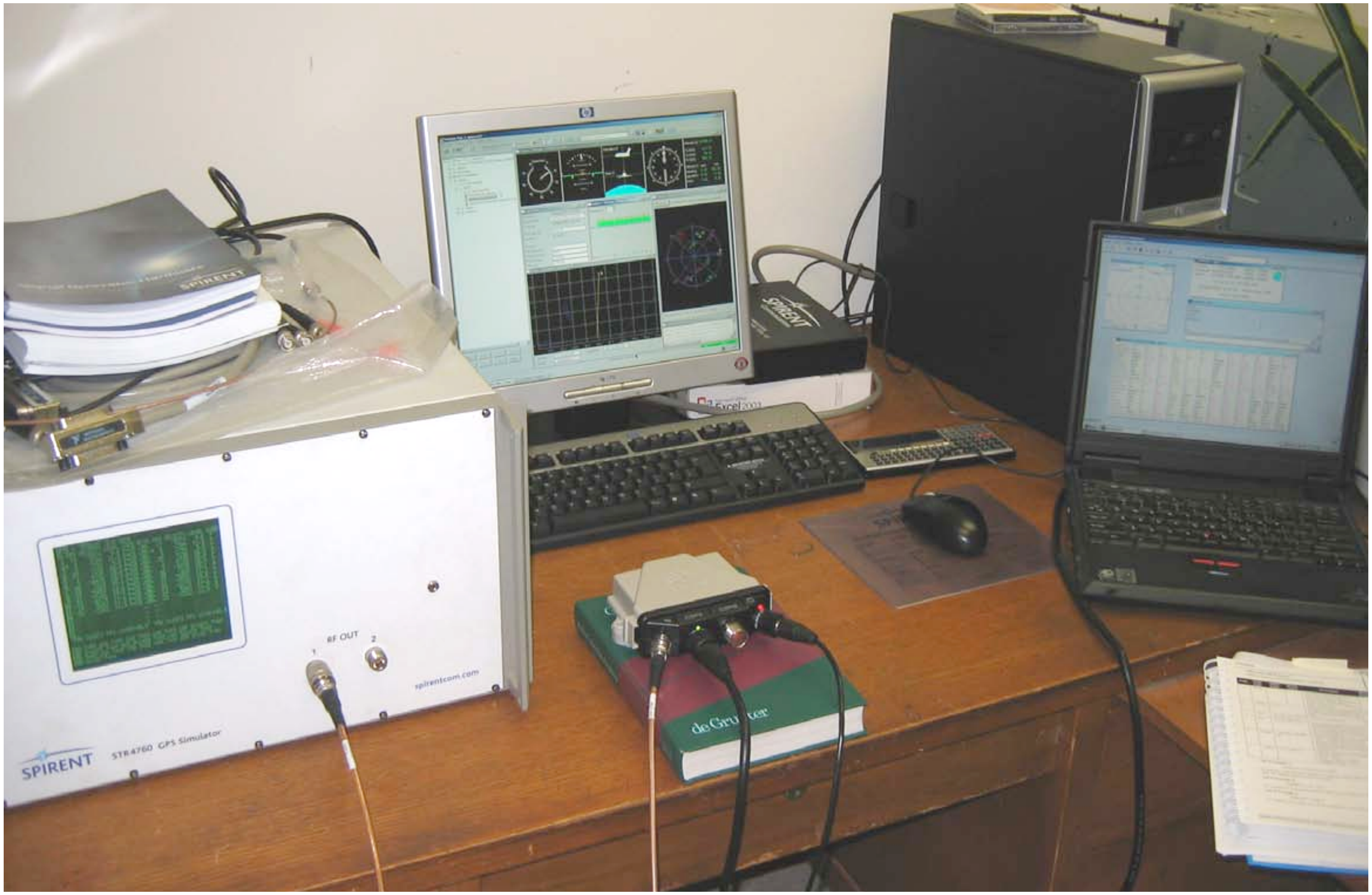
GAP Development and Testing

- A series of tests were carried out to see if the OEM4-G2L could withstand the rigors of spaceflight:
  - Tracking (at ESTEC and UNB)
  - Radiation (by DLR)
  - Thermal vacuum (at Bristol Aerospace)
- Real-time attitude software development and testing at UNB
- Performance tests at U. of C. with spacecraft bus simulator and GPS signal re-radiator

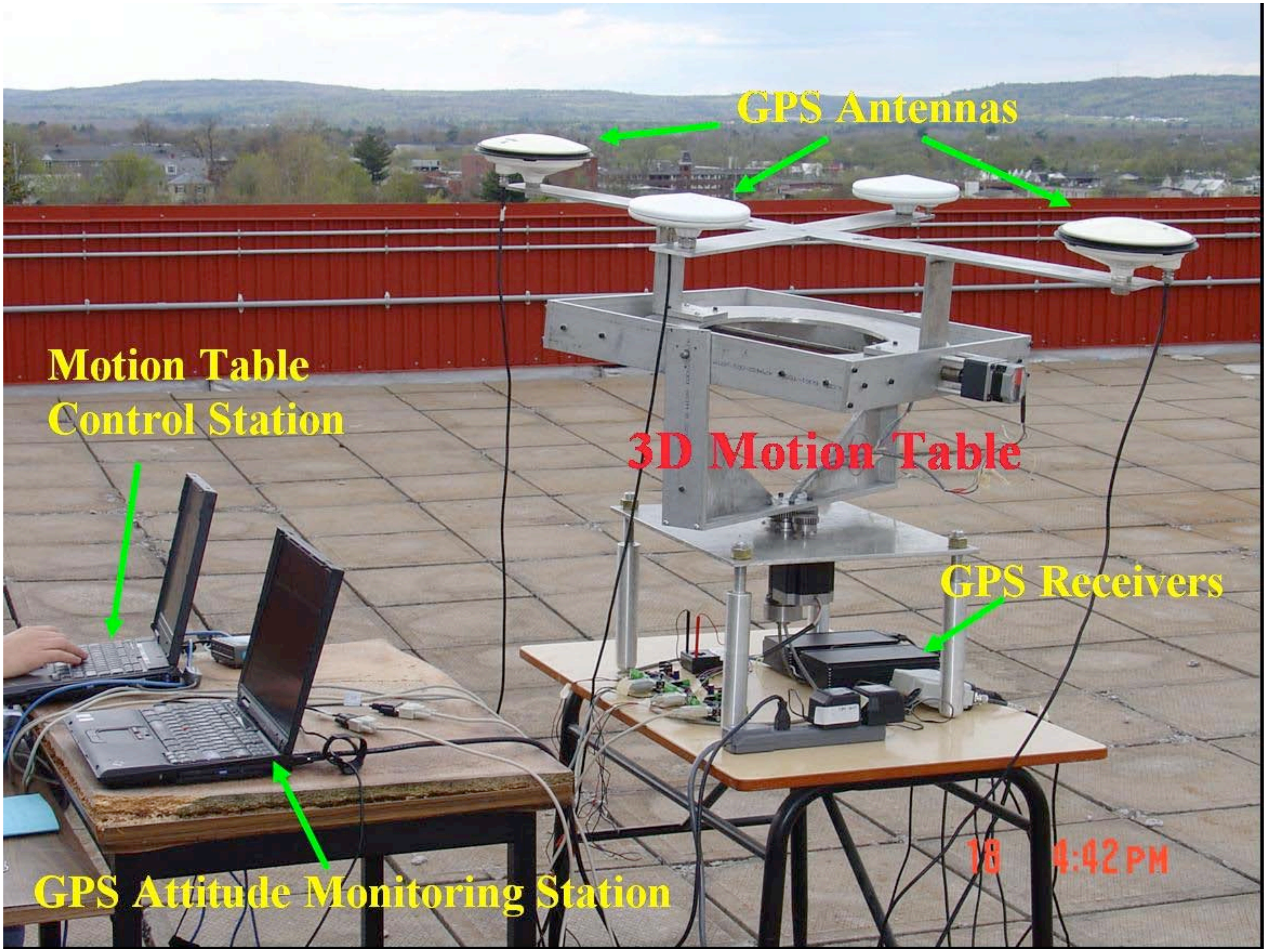
DSP and SPP Controller



NovAtel OEM4 Flexpack-G2L, Connected to a Spirent STR4760



Attitude Test Platform - 3D Motion Table



Future Work

• Complete instrument tests, including further performance tests with live GPS signals

• Complete quick-look data validation software

• Develop automated data processing and archiving facility

Acknowledgements

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- University of Calgary