Balloon demonstrator Imaging Fourier Transform Spectrometer for the measurement of methane and carbon dioxide in the atmosphere

Objectives

• Development and testing of a new technology to demonstrate measurement of atmospheric composition, aerosols and air quality and measurement of cloud and albedo from a satellite platform ➔ demonstration from a balloon platform.
• Proposed IFTS instrument based on core functionalities and critical sub-systems of the space based instrument
• Development of autonomous systems to achieve these measurements from space as well as from a balloon.
• Execution of test flights on a stratospheric research balloon.
• Evaluation of system performance.
• Data analysis.
• Recommendations for future progress.
PHEOS-WCA IFTS Demonstrator

Polar Communication and Weather mission (PCW)
- Two polar HEO satellites
- Provide weather, communication and atmospheric composition over the arctic
- Continuous observations over the northern latitudes. (Temporal Resolution of 15min)

Science Payload : PHEOS-WCA
- Polar Highly Elliptical Orbit Science-Weather Climate and Air quality
- Complimentary to the meteorological suit of PCW
- Vertical sounding measurements of Green house gases and other atmospheric species.
- Composed of
  - Imaging IR Fourier transform Spectrometer (IFTS)
  - UV-VIS spectrometer
Why the Arctic?

Climate Change
- Rapid disappearance of multi-year ice.
- Global temperature change.
- GHGs
- Ozone

Weather and Air Quality
- Contribute to global forecast models.
- Critical in the development of winter storms in boreal latitudes.
- Volcanic eruption (Iceland)
Highly Elliptical Orbit (HEO)

- 12-24 hour orbital period.
- Quasi-stationary for ± 3 to 8 hours about the apogee.
- Apogee at approximately 42,000 km.
- Two satellites gives us the continuous observation we need.

TAP (Three Apogee Orbit):

- 16 hr period,
- ± 4 to 6 hour at apogee,
- Apogee ~43,500 km,
- Perigee ~8100 km,
- Reduced radiation hazard
Balloon-Based Demonstrator

- Part of FAST (Flights for the Advancement of Science and Technology)
- Vertical profile measurements of atmospheric temperature and water vapor as well as column amounts of atmospheric species
- Using a high altitude stratospheric balloon platform (~35-40 km flight altitude)

- Part of the gondola and payload developed through the PARABLE (PAyload for Remote sounding of the Atmosphere using Balloon Limb Experiments) training project.
- PARABLE provides a platform for profile measurements of trace gases and aerosols, mainly by solar occultation
- Flights from Timmins, Ontario
Gondola

- CARMEN provided by CNES
- 4 removable trays, which can support a weight of 100 kg
- Gondola structure is approximately 1.5 m by 1.5 m and 2.5 m in height.
- Gondola weight: 280 kg
  - Gondola frame
  - Pointing system
  - Azimuth joint
  - Telemetry and Tele command interface
  - Power control system
  - Batteries
  - Ballast
• At least one sunrise or sunset for the occultation instrument
• At least 4 hours of daylight for making measurements of scattered sunlight using the IFTS instrument
• Stabilization altitude: 35-42km
• Flight duration: 18-20 hr
FAST Project Payload

**Nadir-viewing IFTS**
- 50kg
- Forward model development
- Retrieval software
- Pointing System development and control
- Mechanical, Optical and Electronic aspects
- Measurements of CO2 and CH4

**Nadir-viewing UV-VIS Spectrometer**
- 15 kg
- MAESTRO-B modified for O2 measurements
- Change grating to achieve higher resolution for A and B band of O2
- Yields CO2 and CH4 measurements

**Solar Occultation IR-FTS**
- 110 kg
- Measurements of CO2 and CH4 in solar occultation mode onboard balloon
- Ground based FTS at site of balloon test flight to produce column amounts of CO2 and CH4
Imaging Fourier Transform Spectrometer (IFTS)

- Input optics (pointing system) to select the location for measurements and direct the collected light into the interferometer
- Output optics and detector system
- Control electronics
- Computer and on-board data storage

Interferometer

- Standard commercial off the shelf from ABB Bomen,
- Modified to match PHEOS-WCA scanning speed
- Thermo-electrically cooled 320x256 pixels **Single** array detector (1.6 μm)

PHEOS-WCA IFTS Optical Layout:

- Target species: CO2 and CH4
- SNR: 500
- Scan time: 100 s
- Spectral resolution: 0.25 cm⁻¹
- FOV: 10 m (PHEOS:10km)
- 70-80 m footprint
Technical aspects to be tested on the balloon flight:

- Spectral Resolution
- SNR
- Spatial Resolution
- Pointing Stability
- Image processing for pointing system
- Effects of clouds, aerosol and albedo on measurements
Pointing System

• Provide a 100s dwell time on an 80 m spatial element for the detector.
• Contributing factors to move the scene of measurement:
  – Wind Speed
  – Gondola Rotation (0.1-1 degree)
  – Gondola Pendulum Oscillation
    • Conical rotation of flight chain around suspension point (~0.1Hz)
    • Uniaxial swing mode around connection point (~1 Hz)
  – Payload induced vibrations
    • High frequency pointing jitters

Specifications

• Pointing mirror moving speed: 0.004 degrees/s (accounts for a 10 km/h wind speed)
• Gondola orientation must stay fixed wrt sun direction (no rotation) ➔ azimuth pointing system for the gondola (better than 1 degree after locking on the sun)
Tilt Mirror Scanning Pointing system

• 2-axis precise pointing system
• 4 voice-coil motors
• Pivot points made of stainless steel sheets
• ± 2.5° Travel range angle

• A camera placed next to the instrument aperture will act as the feedback to the software
Pointing System Mechanism

- Volume:
  - 13.1 0x 15.24 x 15.24 cm

- Mass without mirror:
  - Motors: 540 g
  - Structure: 300g
  - Bolts: 81g
  - Pivot: 10 g
  - Total: 931 g
Implementation on Instrument

Example:
SunPhotoSpectrometer (SPS-B)
Future Work:

- Improve to ± 5° from ± 2.5° travel range angle (FAST)
  - Design a new curved voice coil motor to be custom made
- At the moment: from ± 1.5° to ± 2.5° travel range angle (PARABLE)
  - Move motors towards the center to allow more coil clearance, or
  - Mill out more clearance on two sides of the magnet casing → effects magnet field and lowers power
- Software for the pointing system control System is being developed
- Working with ABB on Mechanical and Optical design of IFTS
Thank you.

MAESTRO and SPS